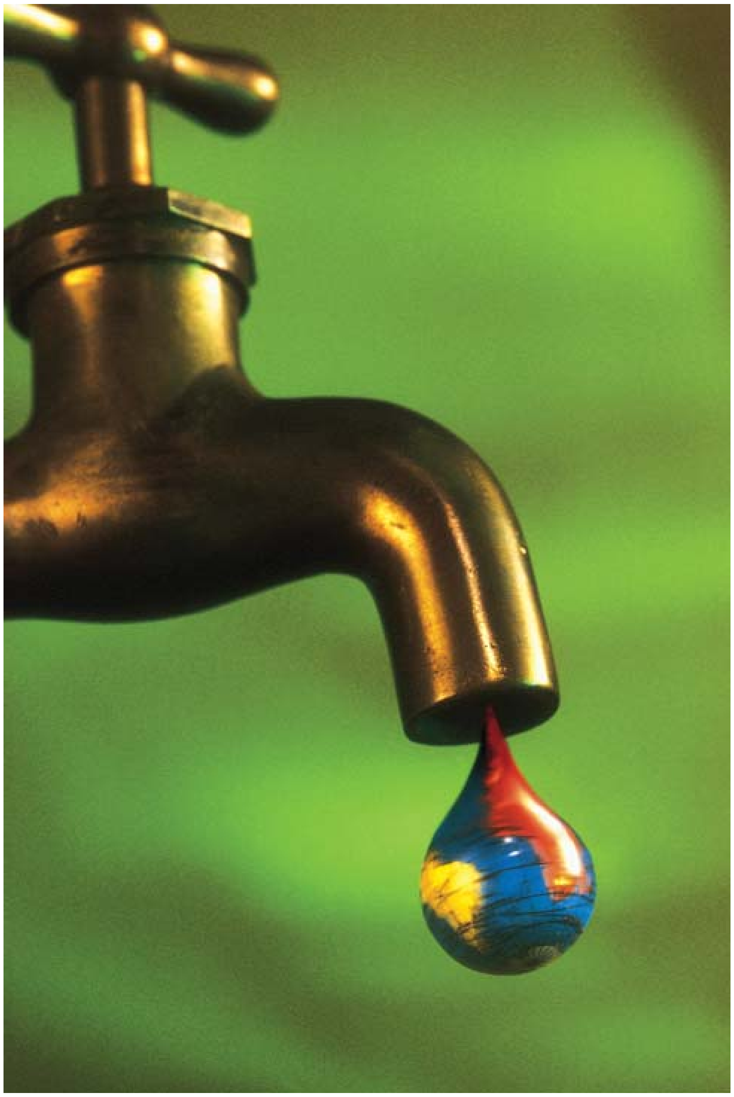
Electricity Use and Management in the Municipal Water Supply and Wastewater Industries



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Electricity Use and Management in the Municipal Water Supply and Wastewater Industries

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EXECUTIVE SUMMARY

Clean drinking water and effective wastewater treatment are vital services needed in all communities. These safeguards protect the public health, strengthen the community infrastructure, and provide a foundation for economic growth. Yet increasing concerns about the adequacy of existing services are posing serious challenges to local communities. These concerns are felt not just in the U.S., but internationally as well. The relationship between water and energy and opportunities for better managing energy use continues to be an area of great interest for electric utilities and water and wastewater treatment facilities.

The use of electricity for water and wastewater treatment is increasing due to demands for expanded service capacity and new regulations for upgraded treatment. Options available to control the electricity costs include technological changes, improved management, and participation in electric utility sponsored energy management programs. Appropriate options for a specific system will vary depending on the system characteristics, availability of electric utility programs to assist the water and wastewater utilities, and adequate funding and management skills to implement changes.

Background

In 1996, EPRI's Community Environmental Center at Washington University in St. Louis, MO published a report entitled *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*.[1] The report describes how electricity is used and can be managed efficiently in water and wastewater treatment.

At the time the 1996 report was developed, the electric power industry and the water and wastewater industries recognized that the inextricable link between energy and water was only getting stronger due to significant changes such as:

- Increasing demand for water and wastewater services
- Promulgation of more stringent environmental regulations
- Concerns about funding for upgrading aging facilities
- Growing operating costs

To address the impacts of the changing water and wastewater industries, EPRI engaged a team of experts to identify opportunities for energy management so both electric utilities and their water and wastewater customers could work together to define and implement appropriate programs. Thus, the 1996 report was designed to provide electric utility planning and marketing staff as

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[1] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. EPRI, Palo Alto, CA: September 1996. CR-106941.

well as water and wastewater treatment plant management with a practical tool to help them better understand the industry.

Since its publication, the report has been cited extensively as one of the premier resources describing the water-energy connection. It continues to be referenced today, yet the data are over 15 years old. Much of the data now requires updating, particularly in the discussion of current energy management opportunities, practices, and technologies. Further, clarification on proper use of this data needs to be addressed so that planners and engineers can use it with a proper contextual understanding.

Objectives

The primary objective of this study is to update the previous report to describe the current industry. Though much of the information in the 1996 EPRI report is still relevant, the electric utility industry and the water and wastewater industry have changed over the past 15 years. Environmental regulations have continued to become more rigorous, operating costs including labor and energy have increased, technology has advanced, and there are now greater opportunities for managing energy use. Similar to its predecessor, this report is designed to provide electric utility planning and marketing staff and water and wastewater treatment plant management with a practical tool to:

- Understand the water and wastewater industries and the challenges they face
- Understand the various operations and processes used in water and wastewater treatment and how electric energy is used in different plant configurations
- Identify and characterize opportunities for improving energy efficiency and load management, promoting demand response, recovering and generating energy, and encouraging electrotechnologies that will benefit both the water and wastewater treatment facilities and the electric utilities
- Help develop energy management plans to realize such opportunities

An additional study objective is to identify water and wastewater research, development and demonstration (RD&D) projects for joint sponsorship by both the water and wastewater industry and electric utility representatives. Given the significant electricity requirements of the water and wastewater industry, the commonalties between electric utilities and water and wastewater utilities, and the importance of solid infrastructure to economic growth, it makes good business sense for electric utilities and EPRI to participate in water and wastewater RD&D activities.

Scope

This report describes how electricity is currently used and how it can be managed more efficiently in the public water supply and municipal wastewater treatment industries. The intention is to provide energy use characteristics that represent what is actually occurring at water and wastewater treatment plants across the country, based on the study team's field experience and a comprehensive review of the literature. Therefore, the energy use data reflect electric use values as encountered in operating plants today, rather than the most efficient operation possible. Water and wastewater treatment plants typically operate at some fraction of design capacity nearly all the time, meaning that operating inefficiencies are built into the facility. The report provides daily energy use values for common water and wastewater unit processes and describes approaches for summing up pertinent unit process values to develop an “expected” total daily energy use for a facility, recognizing that the range of possible electric use values for treatment facilities is quite broad.

Complementary Work

The Water Environment Research Foundation (WERF) has been carrying out another study in parallel with the EPRI study. The WERF study is developing energy use data for a wide range of wastewater treatment facilities, with a focus on developing energy benchmarks.[2] The benchmarks provide facilities with targets for energy use, depending on a plant’s size and unit processes. The WERF study provides more detail for wastewater treatment facilities, but does not include drinking water facilities. While the WERF study is developing energy benchmarks based on engineering design calculations and Best Practices, the EPRI study provides energy intensity values for various unit processes based on calculations of what is typically seen in water and wastewater treatment facilities. The EPRI study and the WERF study complement each other through their different approaches. Both studies stand to increase the understanding of the water-energy nexus and opportunities to maximize energy efficiency and energy management.

Approach

To achieve study objectives, the team assembled information from the literature, government entities, private research groups, and other sources to characterize the water and wastewater industries in terms of number and type of facilities, processes use, electricity use and usage patterns, and changes that are occurring in regulations and technology. From this information, the team segmented each industry based upon parameters such as size, function, and key process elements to assess the relative magnitude of energy management opportunities. New processes and operations that were not included in the 1996 report, but which are now considered significant, were added to the analysis. The team used a bottom up approach based on available data to update the energy intensity (EI) values (in kWh/million gallons) for the various unit processes. The values were refined using best engineering judgment and by cross-checking with actual water and wastewater treatment plant data. The team identified those treatment unit processes offering the best opportunities for energy management measures and analyzed them in detail to identify electrotechnologies and other alternatives to better meet process objectives. Representative facilities were included as case studies, exemplifying the application of various energy management and technological solutions. Finally, the team reviewed and presented emerging and innovative technologies that promise greater energy management and improved treatment and, thus, represent good candidates for demonstration projects.

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[2] As of October 31, 2013, the WERF study had yet to be published. The WERF project is titled “Energy Balance and Reduction Opportunities, Case Studies of Energy-Neutral Wastewater Facilities and Triple Bottom Line (TBL) Research Planning Support” (WERF project number ENER1C12). The principal investigators are Steve Tarallo, P.E., and Paul Kohl, P.E.

Findings

Electricity Use in Public Water Supply and Treatment

The vast majority of the U.S. public water supply consists of community water systems. There are over 51,000 community water systems in the U.S., with most systems being relatively small. Ninety two percent of the community water systems provide drinking water to communities serving 10,000 people or less, while 8% of community water systems provide water to about 82% of the population. The two primary sources of water for public drinking water systems are groundwater and surface water. Groundwater systems exist in the greatest quantity, but they tend to be smaller than surface water systems and they serve a smaller share of the population. Surface water systems require more water treatment than groundwater systems and are thus more energy intensive. A small percentage of water is supplied from the desalination of sea water and brackish water (less than 4%), but this is a growing segment. Desalination is the most energy intensive type of water treatment. For all drinking water plants much of the energy is used for pumping.

The team developed estimates of energy intensity for raw water pumping and all unit processes associated with drinking water treatment as a function of average flow rate. The flow rates investigated are 1, 5, 10, 20, 50, 100, and 250 million gallons per day (MGD). The report provides comprehensive tables containing these values, which can be used to estimate composite energy use for hypothetical plants made up of different combinations of unit processes.

The project team used these data to develop electric energy intensity values for three types of systems: surface water, groundwater, and desalination. Then, the team mapped the resulting energy intensities to detailed inventory data for existing public water systems from the U.S. Environmental Protection Agency (EPA) and U.S. Geological Survey to approximate total electricity use by U.S public drinking water industry. Using this method, U.S. public drinking water systems use roughly 39.2 billion kWh per year, which corresponds to about 1% of total electricity use in the U.S.

Electricity Use in Municipal Wastewater Treatment

The municipal wastewater treatment industry is composed of nearly 15,000 publicly owned treatment works (POTWs) that handle a total flow of over 32,000 MGD and serve about 74% of the U.S. population. The remaining population is served by septic and other on-site systems. Larger plants treat the majority of the wastewater flow; most U.S. plants provide secondary or greater treatment. In contrast to drinking water systems where pumping accounts for most energy use, wastewater treatment is more closely related to treatment needs. Advanced wastewater treatment usually includes aeration for removing dissolved organic matter and nutrients; thus, aeration is the principal energy-using process in wastewater treatment.

Using the same approach as for drinking water systems, the team developed estimates of energy intensity for typical unit processes associated with wastewater treatment as a function of average flow rates ranging from 1 to 250 MGD. Unit processes investigated include wastewater pumping, primary treatment, secondary treatment, solids handling, treatment and disposal, filtration and disinfection, utility water, and potential energy recovery (from anaerobic digestion of solids). Several treatment options have been added since the 1996 report reflecting their widespread implementation or acceptance within the industry, including odor control, sequencing batch reactors, membrane bioreactors, UV disinfection, and various filtration methods. The resulting tables of values can be used to estimate composite energy use for hypothetical wastewater treatment plants containing different configurations of unit processes.

The team estimated electricity use for the U.S. wastewater treatment industry following the procedure in the 1996 EPRI report. The approach uses EPA's Clean Watershed Needs Survey plant flow data based on level of treatment along with the energy intensity values developed by the project team and a review of prior estimates from other organizations. The result is that municipal wastewater treatment systems in the U.S. use approximately 30.2 billion kWh per year, or about 0.8% of total electricity use in the U.S.

Comparison with 1996 Report

The use of electricity for water and wastewater treatment in the U.S. has grown during the last 20 years and will continue to grow. Table ES-1 compares the annual electricity use values developed in this study with those reported in the 1996 EPRI study. For public drinking water systems, the current estimate represents a 39% increase relative to the value given in the 1996 report, likely due principally to population growth and a small but significant increase in desalination. For the municipal wastewater industry, the current estimate corresponds to a 74% increase over the previously reported value, likely due to both population growth and the more widespread implementation of secondary treatment by U.S. wastewater treatment facilities. It is worth noting that there have been some inroads made from more energy efficient practices by water and wastewater treatment agencies that have probably decreased the magnitude of the potential increase, but substantial progress is still possible in this area.

Table ES-1
Comparison of Annual Electricity Use Between 1996 Report and Now

	Annual Electricity Use (billion kWh/yr)		Percent Increase
	1996 Report	Current Study	
Public Water Supply and Treatment	28.3	39.2	39%
Municipal Wastewater Treatment	17.4	30.2	74%

Energy Management Opportunities

This report categorizes the opportunities for improving energy management in the water and wastewater industries into three main groups, which are summarized in Table ES-2. Opportunities that involve electrotechnologies are in bold font type.

Table ES-2
Energy Management Opportunities Presented in the Study

Energy Efficiency and Demand Response	Emerging Technologies and Processes	Energy Recovery and Generation
• Strategic Energy Management • Data Monitoring and Process Control • Water Conservation • **High-Efficiency Pumps and Motors** • **Adjustable Speed Drives** • Pipeline Optimization • **Advanced Aeration** • Demand Response	• **Odor Control** • **Membrane Bioreactors** • Deammonification Sidestream Process • Water Reuse • **Residuals Processing** • Microbial Fuel Cells • **LED UV Lamps**	• Cogeneration Using Digester Biogas • Use of Renewable Energy to Pump Water • Recovery of Excess Line Pressure to Produce Electricity

The report also presents eight case studies, each of which exemplifies a facility that has successfully implemented innovative energy management strategies in practice.

Energy Efficiency Potential

EPRI sponsored an energy efficiency potential study that assessed the potential for energy efficiency and demand response in the U.S. from 2010 to 2030.[3] The study quantified a range of savings from technically feasible to realistically achievable. Given the volatility of energy prices in the past decade and the large amount of energy savings that is technically feasible in the water and wastewater industry, specific predictions of energy efficiency potential in the water and wastewater industry is beyond the scope of this report. Based on the macroscale analysis in the potential study, the team approximates that the realistic achievable potential for the water and wastewater industry by 2030 is approximately 8% of baseline. Yet, with the generation of methane through anaerobic digestion and the recovery of pumping head in drinking water distribution systems, there is tremendous opportunity for energy recovery in the water and wastewater industry. A concerted and joint effort between electric utilities and the water and wastewater facilities they serve could produce a water and wastewater industry approaching net-zero energy use.

Opportunities for Demonstration

The target areas of past EPRI RD&D initiatives in the water-energy arena remain relevant today, including the following:

- Energy Efficiency and Demand Response
- Energy Recovery
- Improved Biosolids Treatment
- Water Reuse and Desalination

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[3] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030).* EPRI, Palo Alto, CA: January 2009. Product No.1016987.

As with any complex industry, there are hundreds or even thousands of potential demonstration projects that could be proposed. The project team chose to highlight demonstration projects where the interests of electric utilities align with those of the water and wastewater industry. The demonstration opportunities are summarized in Table ES-3. Opportunities that involve electrotechnologies are in bold font type.

In addition to demonstrations of new technologies, there are numerous established technologies that simply need to be more widely implemented. In those cases, EPRI can serve as a change leader in market transformation through the publication and dissemination of fact sheets and technical summary documents. Specifically, EPRI can work with its electric utility members in collaborating with water and wastewater facilities to publicize success stories and promote under-utilized technologies.

Table ES-3
Demonstration Opportunities Identified in the Study

Energy Efficiency, Load Management, and Demand Response	Energy Recovery	Improved Biosolids Treatment	Water Reuse and Desalination
• Deammonification and Other Low Energy Alternatives to Activated Sludge • Advanced SCADA Systems • Automatic Demand Response (Auto-DR) • Distributed Power Generation • Remote Sensing • **High-Speed Gearless (Turbo) Blowers**	• Pelton Turbine for Energy Recovery from Water Distribution Systems • Francis Turbine for Energy Recovery from Desalination Plants • Distributed Power Generation • **Digester Enhancements to Improve Methane Yield**	• **Cell Lysis through Chemical or Ultrasonic Means** • **Electrodewatering** • **Microwave Drying of Sludge** • Lystek Process	• **Dual Reverse Osmosis with Chemical Precipitation** • Use of Renewable Energy

Conclusions and Recommendations

Water and wastewater customers, electric utilities, and water and wastewater utilities can use this report to gain a better understanding of the inextricable link between water and energy. It is intended to serve as a resource for water and wastewater plant characteristics, electricity requirements, and opportunities for improving energy management practices. The report contains descriptions of well-known energy efficiency and demand response measures that still offer potential for greater adoption as well as case studies and demonstration ideas for novel and emerging technologies, processes, and energy management programs. Water and energy engineers and practitioners can use the unit operation data to estimate expected electrical energy use at specific facilities, and assess the effects of selecting different types of unit operations on overall plant energy intensity. Moreover, data on the ranges of energy savings possible with the various technological and programmatic solutions, along with information on regional areas of focus, can serve as a guide to prioritize next steps.

To further advance knowledge for the industry as a whole, the study team has five primary recommendations:

- Develop a formal program directed by a mix of professionals from the water and wastewater industry along with electric utility representatives to study and demonstrate innovative energy management solutions and to disseminate knowledge
- Identify host sites for technology demonstration projects
- Design a software tool to facilitate estimation of plant level energy intensity and annual energy use by aggregation of unit operations
- Conduct a comprehensive energy efficiency and demand response potential study focused specifically on the water and wastewater industries as a follow on to EPRI's 2009 study
- Carry out an assessment of the potential for energy recovery and generation from the water and wastewater industries

Key Words

Case studies

Demand response

Demonstration

Distribution

Electrotechnologies

Energy efficiency

Energy intensity

Energy management

Energy recovery

Emerging technologies

Municipal wastewater treatment

Pumping

Public water supply

Treatment

Trends

Unit processes

Wastewater

Water

ABBREVIATIONS

AMR automatic meter reading

ASD adjustable speed drive

Auto DR automated demand response

AWWA American Water Works Association

AWWARF American Water Works Association Research Foundation

BAS Building Automation System

BEP best efficiency point

BGD billion gallons per day

bhp brake horsepower

BNR biological nutrient removal

BOD biochemical oxygen demand

BPA Bonneville Power Administration

Btu British thermal unit

C&I commercial and industrial

CEC California Energy Commission

CBP capacity bid pricing

CEE Consortium for Energy Efficiency

CFM cubic foot per minute

CHP combined heat and power

CPP critical peak pricing

CWA Clean Water Act

CWNS Clean Watershed Needs Survey

CWRF Central Water Reclamation Facility

DBP demand bid program

DG distributed generation

DLC Direct Load Control

DO dissolved oxygen

DOE Department of Energy

DR demand response

ECUA Emerald Coast Utilities Authority

EBMUD East Bay Municipal Utility District

EMS energy management systems

EMWD Eastern Municipal Water District

EPA Environmental Protection Agency

EPRI Electric Power Research Institute

EWQMS Energy and Water Quality Management System

FOE Focus on Energy

GHG greenhouse gas

GJJWTF Gloversville-Johnstown Joint Wastewater Treatment Facility

GPCD gallon per capita day

gpm gallons per minute

GWUI groundwater under the direct influence of surface water

HVAC heating, ventilation, and air conditioning

hp horsepower

IDP Innovation Development Process

ISO International Organization for Standardization or Independent System Operator

kPa kilopascal

kWh kilowatt hour

kWh/MG kilowatt hours per million gallons

LVVWD Las Vegas Valley Water District

LBNL Lawrence Berkeley National Laboratories

LED light emitting diode

MBR membrane bioreactor

MF microfiltration

MFC microbial fuel cell

mg milligrams

MG million gallons

MGD million gallons per day

mg/L milligrams per liter

MW megawatt (million watts)

MWW municipal water and wastewater

NDWRCDP National Decentralized Water Resources Capacity Development Project

NF nanofiltration

NRECA National Rural Electric Cooperative Association

NYSERDA New York State Research and Development Authority

O&M operation and maintenance

OTE oxygen transfer efficiency

PLC programmable logic controller

POTW publicly owned treatment works

psi pounds per square inch

PSAT Pumping System Assessment Tool

PV photovoltaic

RD&D research, development, and demonstration

RO reverse osmosis

RTO Regional Transmission Operator

RTU remote terminal unit

SBRs sequencing batch reactors

SCADA Supervisory Control and Data Acquisition

SFBW spent filter backwash water

TDS total dissolved solids

THM trihalomethane

TWh terawatt hour

UF ultrafiltration

USGS U.S. Geological Survey

UV ultraviolet

VFD variable frequency drive

VOCs volatile organic compounds

WAS waste activated sludge

WEF Water Environment Federation

WERF Water Environment Research Foundation

WaterRF Water Research Foundation

WQA Water Quality Act of 1987

WWTP wastewater treatment plant

WWTF wastewater treatment facility

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INTRODUCTION

Background

In 1996, EPRI's Community Environmental Center at Washington University in St. Louis, MO published a report entitled *Water and Wastewater Industries: Characteristics and Energy Management Opportunities* prepared by Burton Environmental Engineering.[4] The report describes how electricity is used and can be managed efficiently in water and wastewater treatment.

At the time the 1996 report was developed, the electric power industry and the water and wastewater industries recognized that the inextricable link between energy and water was only getting stronger due to significant changes such as:

- Increasing demand for water and wastewater services
- Promulgation of more stringent environmental regulations
- Concerns about funding for upgrading aging facilities
- Growing operating costs

To address the impacts of the changing water and wastewater industries, EPRI engaged a team of experts to identify opportunities for energy management so both electric utilities and their water and wastewater customers could work together to define and implement appropriate programs. Thus, the 1996 report was designed to provide electric utility planning and marketing staff as well as water and wastewater treatment plant management with a practical tool to:

- Understand the water and wastewater industries and the challenges they face
- Understand the various operations and processes used in water and wastewater treatment and how electric energy is used
- Identify and characterize opportunities for improving energy efficiency, promoting load management, and encouraging electrotechnologies that will benefit both the water and wastewater treatment facilities and the electric utilities that serve them
- Help develop energy management plans to realize such opportunities

The 1996 EPRI report was very well received by both electric utilities and water and wastewater treatment facilities. Since its publication, it has been used and cited extensively as one of the premier resources for the water-energy connection. Even though the data are over 15 years old, it continues to be referenced today. Much of the data now requires updating, including the

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[4] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*. EPRI, Palo Alto, CA: September 1996. CR-106941.

discussion of current information on energy management practices and technologies. In addition, clarification on proper use of this data needs to be addressed so that planners and engineers can use it with a proper contextual understanding.

Purpose of Report

The purpose of this report is to update the previous report with current information. Though much of the qualitative information in the 1996 EPRI report is still relevant, significant changes in the water and wastewater industries have continued to occur over the past 15 years. Changes relate to evolving environmental regulations, ever-increasing operating costs, technology advancements, and greater opportunities for load management. In addition, the majority of the quantitative information is in need of updating to ensure there is a new information source for others to cite that contains timely and accurate data representing the current state of the water and wastewater industries. The relationship between water and energy and opportunities for better managing energy use continues to be an area of great interest for electric utilities and water and wastewater treatment facilities.

Similar to its predecessor, this report is designed to provide electric utility planning and marketing staff and water and wastewater treatment plant management with a practical tool to:

- Understand the water and wastewater industries and the challenges they face
- Understand the various operations and processes used in water and wastewater treatment and how electric energy is used in different plant configurations
- Identify and characterize opportunities for improving energy efficiency, promoting load management, recovering and generating energy, and encouraging electrotechnologies that will benefit both the water and wastewater customers and the electric utility
- Help develop energy management plans to realize such opportunities

This report characterizes energy management opportunities through:

- Description of the key electric energy end-uses in each industry including the technologies used and their operating characteristics
- Description of energy management technologies and approaches applicable to the key electric energy end-uses
- Brief case study examples of energy management applications within each industry
- Recommended demonstration projects

The Role of Energy in the Water and Wastewater Industry

Electricity is used to power equipment such as pumps, fans and blowers, mixers, centrifuges, ozone generators, and ultraviolet (UV) disinfection equipment. The equipment usually operates around-the-clock, but peak demands occur during the peak hours.

The use of electricity for water and wastewater treatment has grown during the last 20 years and will continue to grow. Market growth (in terms of use of electricity) is accompanied by increased demand. The challenge, therefore, becomes (1) how to accommodate the requirements for increased electric service and (2) how to institute measures to promote better energy management and improved efficiency. Improved energy efficiency can be brought about by better management of operations and the incorporation of technological changes.

The electric utility structure has also changed dramatically in the last 20 years. Deregulation has affected many utility customers in different ways depending on their regional location and electric utility provider. A host of options may be available to water and wastewater operators for managing their electric costs, ranging flexible rate structures to incentive payments for energy efficient equipment upgrades. Renewable energy standards now may offer additional incentives for biogas recovery and other renewable energy options. Water and wastewater operators will continue to use a greater amount of electric-based technologies in response to more stringent treatment requirements. At the same time, pressure will mount to offer these technologies with the highest level of energy efficiency. New monitoring and control equipment will provide operators with data and information needed to make energy management decisions on a broad basis. Benefits to the water and wastewater customer include reduced electricity use, reduced demand charges, flexible rate schedules, demand response program payments, energy efficiency incentive payments, renewable energy program incentives, and lower electric bills.

To create and implement successful energy management programs for the water and wastewater treatment industries, electric utilities must understand the needs of the customer involved. These needs go well beyond just reducing energy cost and include environmental compatibility, regulatory requirements, regional growth, watershed planning, and technological improvements. By entering into an energy management "partnership," electric utilities and their water and wastewater customers can reap benefits in terms of improved energy efficiency, sustained regional growth, demand reduction, load growth, and cost savings.

Study Methodology

To achieve study objectives, the study team assembled information from many government entities, private research groups, and other sources to characterize the water and wastewater industries in terms of number and type of facilities, processes used electricity use and usage patterns, and changes that are occurring in regulations and technology. From this information, the team segmented each industry based upon parameters such as size, function, and key process elements to assess the relative magnitude of energy management opportunities. New processes and/or operations that were not included in the 1996 report, but which are now considered significant, were added to the analysis. The team used a bottom up approach based on available data to update the energy intensity (EI) values (in kWh/million gallons) for the various unit processes. In some cases, the team relied on best engineering judgment to refine EI numbers and then verified the values by cross-checking with actual water and wastewater treatment plant data. The team focused on energy end-uses offering the best opportunities for energy management measures and then analyzed them in greater detail to identify electrotechnologies and approaches suitable for each end-use. Representative facilities were included as case studies, exemplifying the application of energy management measures. Finally, the team reviewed and presented new and innovative technologies that offer opportunities for greater energy management and improved treatment and, thus, represent good candidates for demonstration projects.

2

OVERVIEW OF THE PUBLIC WATER SUPPLY INDUSTRY

This chapter presents an overview of the public water supply industry in the U.S. It begins by describing the number and types of public water systems, the populations they serve, where they are located, and water use trends over time. It then discusses the technical features of water supply systems and processes, including types of water sources and their characteristics, methods of water treatment, and systems for distributing and storing water.

Public Water Supply in the United States

According to the U.S. Geological Survey (USGS), public water supply consists of water delivered for domestic, commercial, and industrial uses and includes withdrawals by both public and private water suppliers. There are nearly 153,000 active public drinking water systems in the U.S.[5] Each system regularly serves an average of at least 25 people daily or has at least 15 service connections for at least 180 days a year. Public water supply systems can be categorized into three types, as defined by the U.S. Environmental Protection Agency (EPA):

- **Community water systems (CWS):** Serve the same population of people year-round (e.g., residents served by municipal and private water utilities, as well as trailer parks, subdivisions and apartments with their own water supply systems)
- **Non-transient non-community water systems (NTNCWS):** Serve at least 25 people in the same population for at least six months per year, but not year-round (e.g., workplaces, schools and hospitals that have their own water supply)
- **Transient non-community water systems (TNCWS)**: Serve places where people do not remain for long periods of time and are open for 60 or more days per year (e.g., campgrounds, rest areas and gas stations)

Table 2-1 shows the number of U.S. public water supply systems and the population they serve by type and size of system. The values include systems in the states as well as U.S. commonwealths, territories, and tribal regions. As shown in the table, there were more than 51,000 community water systems, more than 18,000 non-transient non-community water systems, and over 83,000 transient non-community water systems as of October, 2011.

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[5] *Fiscal Year 2011 Drinking Water and Ground Water Statistics*, U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, Washington D.C.: March 2013. EPA816-R-13-003. http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf

Table 2-1
Number of Public Water Systems and Population Served, 2011

		Very Small	Small	Medium	Large	Very Large	Totals
	Size Range by Population Served	< 501	501 – 3,300	3,301 – 10,000	10,001 – 100,000	>100,000	-
CWS	Number of Systems	28,462	13,737	4,936	3,802	419	51,356
	Population Served	4,763,672	19,661,787	28,737,564	108,770,014	137,283,104	299,216,141
	% of Systems	55%	27%	10%	7%	1%	100%
	% of Population Served	2%	7%	10%	36%	46%	100%
NTNCWS	Number of Systems	15,461	2,566	132	18	1	18,178
	Population Served	2,164,594	2,674,694	705,320	441,827	203,000	6,189,435
	% of Systems	85%	14%	1%	0%	0%	100%
	% of Population Served	35%	43%	11%	7%	3%	100%
TNCWS	Number of Systems	80,347	2,726	92	13	1	83,179
	Population Served	7,171,054	2,630,931	514,925	334,715	2,000,000	12,651,625
	% of Systems	97%	3%	0%	0%	0%	100%
	% of Population Served	57%	21%	4%	3%	16%	100%
	Total # of Systems	124,570	19,029	5,160	3,833	421	152,713

Source: *Fiscal Year 2011 Drinking Water and Ground Water Statistics*, U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, Washington D.C: March 2013, EPA 816-R-13-003, http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf.

Though there are significant numbers of transient and non-transient non-community water systems, these two categories of public water supply systems do not serve a very large percentage of the population relative to community water systems. For example, community water systems served approximately 299 million people in 2011, while transient and non-transient non-community water systems served only 19 million people. The EPA's accounting method involves some double-counting of population served, but considering that the U.S.

population was about 313 million in 2011 when the EPA water system data were compiled, community water systems serve roughly 96% of the total U.S. population.[6]

There are approximately 51,360 community water systems in the U.S., with most systems being relatively small. Ninety two percent of the community water systems provide drinking water to communities serving 10,000 people or less, while 8% of community water systems provide water to about 82% of the population. The top 10 states by population account for about 45% of all U.S. community water systems.

The two primary sources of water for public drinking water systems are groundwater and surface water. A small percentage of water is supplied from the desalination of ocean water and brackish water or from the recycling of treated wastewater to augment drinking water supplies. Table 2-2 shows the breakdown of community water systems by major source type. The majority of systems (77%) are supplied by groundwater sources, but the majority of the population (71%) is served by surface water. The smallest systems, including the non-community ones, rely on groundwater sources which generally require less treatment.

Table 2-2
Community Water Systems by Water Source, 2011

		Groundwater	Surface Water	Totals
CWS	Number of Systems	39,624	11,721	51,356
	Population Served	86,585,984	212,573,760	299,216,141
	% of Systems	77%	23%	100%
	% of Population Served	29%	71%	100%

Source: *Fiscal Year 2011 Drinking Water and Ground Water Statistics*, U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, EPA 816-R-13-003, March 2013, http://water.epa.gov/scitech/datait/databases/drink/sdwisfed/upload/epa816r13003.pdf.

According to the most recent data available from the USGS, public supply water withdrawals were 44,200 million gallons per day (MGD) in 2005,[7] of which one-third was from groundwater sources and two-thirds were from surface water sources (see Table 2-3).[8] During the same year, the population served by the public supply was 258 million. These values equate to an average of approximately 171 gallons per day per person served, which includes a combination of commercial, residential, and industrial water usage.

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[6] The U.S. Census Bureau estimates the total U.S. population including Puerto Rico was about 313 million as of December 31, 2011. As of July 1, 2012, the population is estimated to be 318 million, including Puerto Rico. See http://www.census.gov/popest/estimates.html.

[7] *Estimated Use of Water in the United States in 2005*, U.S. Department of the Interior, U.S. Geological Survey, Circular 1344, Reston, Virginia: 2009, http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf. This survey is updated every five years. Data compilation for the 2010 survey was delayed. Report completion and data availability are not expected until 2014.

[8] USGS defines public supply withdrawals as water withdrawn by public and private water suppliers that provide water to at least 25 people or have a minimum of 15 connections.

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Table 2-3
Public Supply Water Withdrawals, 2005

	Population Served by Public Supply	Water Withdrawals in Million Gallons per Day (MGD)		
		Groundwater	Surface Water	Total
Total for U.S. (Includes Puerto Rico and U.S. Virgin Islands)	258,000,000	14,600 (33%)	29,600 (67%)	44,200 (100%)

Source: *Estimated Use of Water in the United States in 2005*, U.S. Department of the Interior, U.S. Geological Survey, Circular 1344, Reston, Virginia: 2009, http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf.

Figure 2-1 illustrates public water supply withdrawals by U.S. location in 2005. Water supply withdrawals are largely a function of population and (to a lesser extent) climate, so it is not surprising the top three states are California (6,990 MGD), Texas (4,270 MGD) and Florida (2,450 MGD).9 The top 10 states with highest public supply withdrawals represented 60% of total withdrawals across the nation that year. It is also interesting to note that eight of the top 10 states also are also on the top list of withdrawals from surface water.[10]

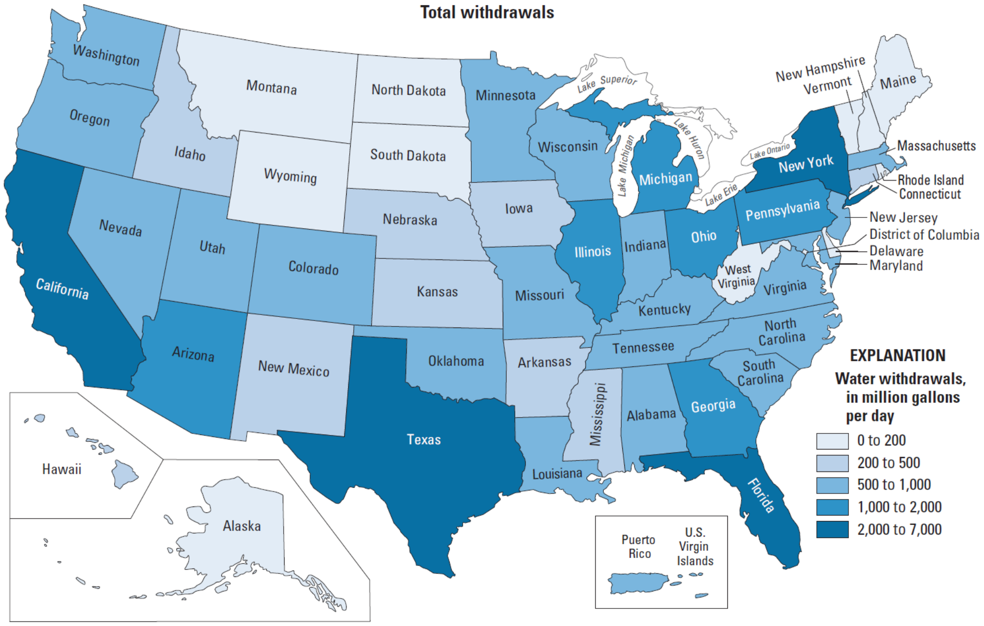

Figure 2-1
Public Water Withdrawals by U.S. State and Region, 2005

Source: *Estimated Use of Water in the United States in 2005*, U.S. Department of the Interior, U.S. Geological Survey, Circular 1344, Reston, Virginia: 2009, http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf.

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[9] Ibid. (USGS, 2005)

[10] Ibid. (USGS, 2005)

Historical data from the USGS show that public supply water use steadily increased between 1950 and 2005, growing from 14 billion gallons per day (BGD) in 1950 to 44.2 BGD in 2005 (see Figure 2-2).[11] Figure 2-2 also compares the water withdrawals with the population growth across the U.S., including territories and commonwealths. Between 1950 and 1985, public water withdrawals were increasing at a greater rate than the population. However, over the last two decades (1985-2005), average increases in withdrawals have been roughly on par with population growth, with both increasing at an average rate of 5% per five-year period between 1985 and 2005. If we assume that water withdrawals between 2005 and 2015 increased at the same average rate, we can project public water use to be about 48.7 BGD in 2015, as shown on Figure 2-2. Other factors such as conservation and recycling may reduce the rate of increase in the future.

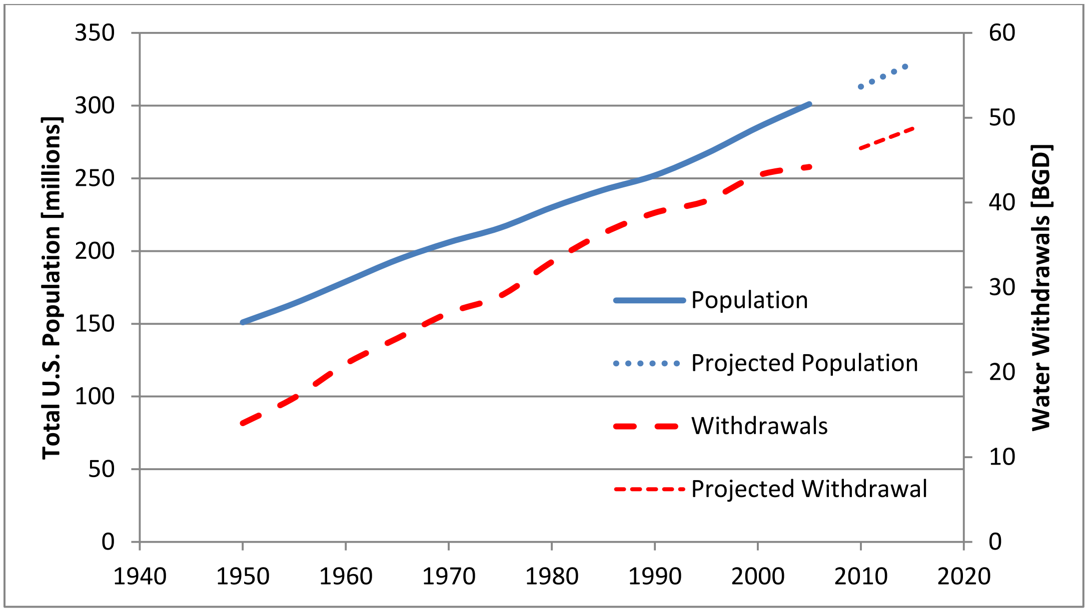

Figure 2-2
Water Use and Population, 1950-2005 with Projections to 2015

Source: Historic data from *Estimated Use of Water in the United States in 2005*, U.S. Department of the Interior, U.S. Geological Survey, Circular 1344, Reston, Virginia: 2009, http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf.

Water Supply Systems and Processes

Water supply involves the transportation of water from its source(s) to treatment plants, storage facilities, and end user. Currently, most of the electricity used is for pumping; comparatively little is used in treatment. For most surface sources, treatment is required consisting usually of chemical addition, coagulation and settling, followed by filtration and disinfection. In the case of groundwater (well) systems, the treatment may consist only of disinfection. Chlorine has been the major disinfectant for many decades. However, as drinking water regulations have increased and there is a need to continually address contaminants of emerging concern, advanced treatment technologies including membrane filtration, ozonation, and ultraviolet (UV) irradiation have gained a greater share of the treatment market since the mid-1990s, especially in light of

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[11] Ibid. (USGS, 2005)

technological advancements and reduced costs for these technologies in recent years. These more energy intensive processes are likely to continue to be installed. This is particularly true in the cases of surface water or groundwater under the influence of surface water because surface water typically requires greater treatment than groundwater.

The following subsections describe the general characteristics of public supply systems, including primary water sources, methods of water treatment, and water distribution and storage.

Water Sources

Water systems start with the source of water. The vast majority of water supplied to cities and communities is derived from surface sources (rivers and lakes) or from groundwater (wells). As noted previously, a small amount of water is supplied from the desalination of sea water and brackish water or from the recycling of treated wastewater to augment potable supplies. Water Research Foundation studies provide varying estimates of desalination's impact. Estimates of the share of population served by desalination range from 0.05% to nearly 3%.[12,13] Figure 2-3 presents schematic diagrams showing the components of surface water and groundwater systems. Subsequent chapters of this report discuss some of the energy impacts of desalination and water recycling.

Characteristics of Surface Sources

Surface water supplies require treatment and disinfection prior to distribution because of impurities. The amounts and types of impurities can change depending on the hydrologic or physical conditions in the watershed. Concentrations of impurities increase because of mineral pickup from surface runoff, farming and construction practices and other man-made activities within the watershed. In areas of slow-moving or impounded water, plants and algae grow, changing the aesthetic and microbial characteristics, which can affect taste and odor. Surface water sources may also be receiving wastewater, which has a major impact on water quality and can add greatly to the spectrum of contaminants present. Non-point source runoff and point source wastewater discharges can add microorganisms such as bacteria and viruses, and other contaminants.[14] The principal surface water quality constituents that must be controlled or removed by treatment are classified as either physical, chemical, or biological constituents and are summarized in Table 2-4. Treatment approaches for specific substances are dictated by treatment goals, which are set by federal and state regulations. The intent of this report is to define only some of the more common constituents or constituent groupings in order to

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[12] *Desalination Facility Design and Operation for Maximum Energy Efficiency,* Water Research Foundation, Denver, CO: 2010.

[13] *Desalination Product Water Recovery and Concentrate Volume Minimization*, Water Research Foundation, Denver, CO: 2009.

[14] A non-point source is any source of water pollution that does not meet the legal definition of "point source" in the Clean Water Act. The Clean Water Act defines a "point source" as any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, animal feeding operation, o vessel or other floating craft, from which pollutants are or may be discharged.

understand the purpose of general water treatment methods. As noted previously, there is a need to continually address contaminants of emerging concern.

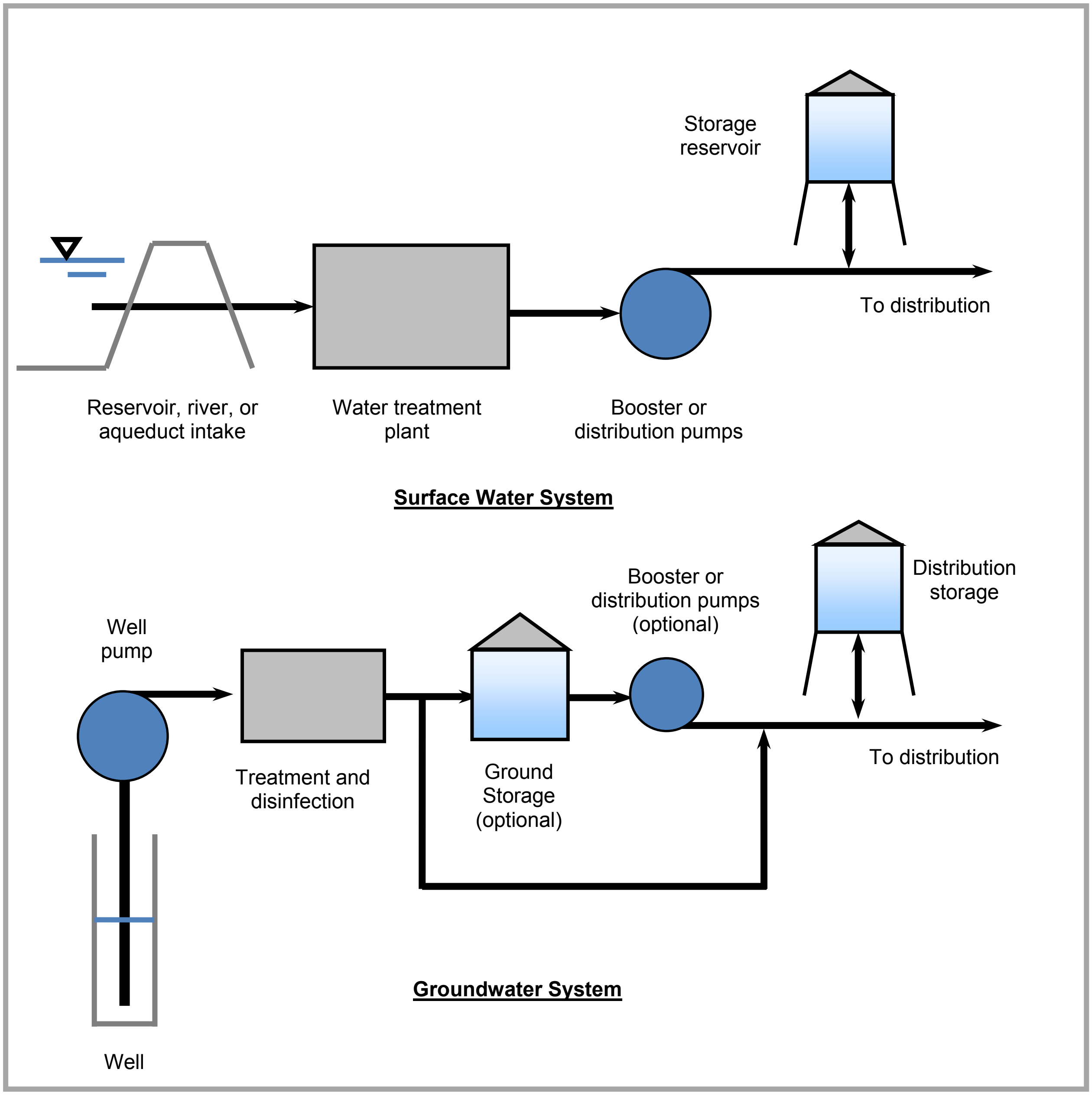

Figure 2-3
Schematic Diagrams of Typical Surface Water and Groundwater Supply Systems

Table 2-4
Summary of Major Constituents of Concern in Surface Water Supplies

Classification	Constituent
Physical	Turbidity Color Odors and tastes Gases
Chemical	Hardness and alkalinity Heavy metals (lead, mercury, copper, silver, etc.) pH (measure of acidity or basicity, which relate to corrosivity) Specific trace elements Specific organic compounds
Biological	Coliform bacteria (indicator organisms of potential pollution) Viruses Algae *Giardia lamblia* (a cyst forming organism that causes of a form of gastroenteritis) *Cryptosporidium* (a cyst-forming protozoan parasite that also causes gastroenteritis and is more resistant to disinfection than *Giardia*) Cyanobacteria (blue-green algae) and metabolites (toxins)

Characteristics of Groundwater Sources

Groundwater is generally characterized as cold and colorless but often has higher levels of hardness and total dissolved solids than surface water. Nitrates, chlorides, and sulfates may also be present in greater amounts. The principal constituents of concern in groundwater are summarized in Table 2-5. Groundwater that is under the influence of surface water (and thus must be treated as such) may have some of the constituents of concern listed in Table 2-5.

The decomposition of organic matter also removes dissolved oxygen from the water percolating through it. Such water, free from oxygen and high in carbon dioxide, dissolves iron and manganese from the soil. Hydrogen sulfide sometimes occurs in groundwater and is associated with the decomposition of organic matter.

Although bacteria and other microorganisms may be present on the surface of the ground, percolation of water into the subsoil results in the filtering out of most these microorganisms, but fissures, coarse subsoils, and faulty well construction can result in the transfer of contamination to the water table. Contamination of the groundwater with industrial toxic chemicals from leaking tanks, unlined or improperly lined ponds, and poor disposal practices has unfortunately become too common an occurrence. As a result, some groundwater supplies require extensive treatment before the water is fit for use.

At the present time, groundwater is not often treated other than for disinfection. Groundwater with excessive amounts of iron and manganese, or containing very high hardness or radon (a naturally occurring, water soluble radioactive gas), however, requires above-ground treatment (usually aeration). Groundwater that is contaminated with chemicals such as volatile organic compounds (VOCs) or heavy metals also requires special above-ground treatment. Special treatment systems for groundwater cleanup are not considered in this report.

Table 2-5
Summary of Major Constituents of Concern in Groundwater Supplies

Classification	Constituent
Physical	Total dissolved solids (TDS) Color Odor Gases
Chemical	Iron Manganese Hardness and alkalinity Nitrate Sulfate pH (measure of acidity or basicity, which relate to corrosivity) Specific trace elements Specific organic compounds Other inorganic elements, such as arsenic Radionuclides
Biological	Coliform bacteria (indicator organism of potential pollution) Viruses

Water Treatment

Surface water treatment usually employs a combination of physical and chemical treatment systems to remove the constituents of concern. Depending on the solids content in the incoming water and the type and amount of chemicals used in treatment, the volume of residuals produced in water treatment can vary widely. As mentioned previously, in groundwater treatment, physical-chemical treatment is only used when excessive concentrations of specific constituents such as hardness or iron and manganese must be reduced. For many groundwater systems, disinfection is the only treatment process used. The subsections that follow discuss the methods commonly used in water treatment and residuals management. Emerging electrotechnologies and new developments for water treatment are presented in Chapter 6.

Water Treatment Processes

The primary requirement for acceptable water for public use is that it is free of deleterious substances harmful to human health (including microorganisms). In addition, it should be colorless, odorless, and pleasant to the taste and that it should not stain, be corrosive, or form excessive scale. Treatment processes (or methods) selected to meet these requirements are based on the type of water source, raw water quality, and desired finished water quality. Table 2-6 lists typical treatment processes used for treating surface waters and groundwater.

The most common surface water treatment system used is conventional treatment, which employs physical methods such as sedimentation and filtration to remove suspended material from the water and chemical disinfection to control bacteria, viruses, and *Giardia lamblia*. Chemical processes such as coagulation are typically added to enhance the effectiveness of sedimentation and lime-soda softening to remove the dissolved salts responsible for hardness. These processes may also be effective for the removal of organics and some inorganics.

Table 2-6
Typical Treatment Processes Used for Treating Surface Water and Groundwater

Constituent of Concern	Treatment Process	Applications
Microbial/biological contamination	Disinfection (chlorination, ozone, UV, and/or other oxidants) Conventional treatment (coagulation, flocculation, sedimentation, filtration, and disinfection), membranes	Surface water and groundwater Surface water, GWUI
Turbidity & dissolved organic matter	Conventional treatment, membranes	Surface water, GWUI
Color	Conventional treatment, ozone	Surface water, GWUI
Odors	Clarification, oxidation (chlorination, potassium permanganate, chlorine dioxide, or ozone), carbon adsorption	Surface water, GWUI
Iron and manganese	Ion exchange, oxidation (aeration, chlorination, or potassium permanganate) followed by filtration Permanganate and greensand Biologically active filtration or biological filtration	Groundwater and surface water Groundwater
Hardness	Ion exchange softening, lime-soda softening, membranes	Groundwater and surface water
Dissolved minerals	Ion exchange, reverse osmosis, lime soda softening	Groundwater and surface water
Corrosivity (low pH)	pH adjustment with chemicals Carbon dioxide stripping by aeration	Groundwater and surface water Groundwater
Disinfection Byproducts	Reduce or eliminate prechlorination, remove THM precursors, ozonation, chloramination (substitute for chlorine)	Surface water, GWUI
Nitrate	Anion exchange, reverse osmosis, biological	Groundwater
Volatile organic compounds (VOCs)	Packed tower aeration Activated carbon	Groundwater Groundwater and surface water
Synthetic organics	Granular activated carbon, advanced oxidation	Surface water, GWUI
Radon	Packed tower aeration, granular activated carbon (for small systems)	Groundwater

Note: GWUI = Groundwater under the influence of surface water.

Membrane filtration may also be added as a substitute for conventional granular media filtration to greatly enhance particle removal, including turbidity and microbiological contaminants. Conventional treatment is capable of treating water having widely changing raw water characteristics. Further, it provides a "triple barrier" in the removal and inactivation of pathogenic organisms, particularly viruses, including flocculation-sedimentation followed by filtration before disinfection. When properly operated, the system is very effective and eliminating pathogens from drinking water supplies. A diagram of a typical flow pattern through a conventional treatment plant is shown in Figure 2-4.

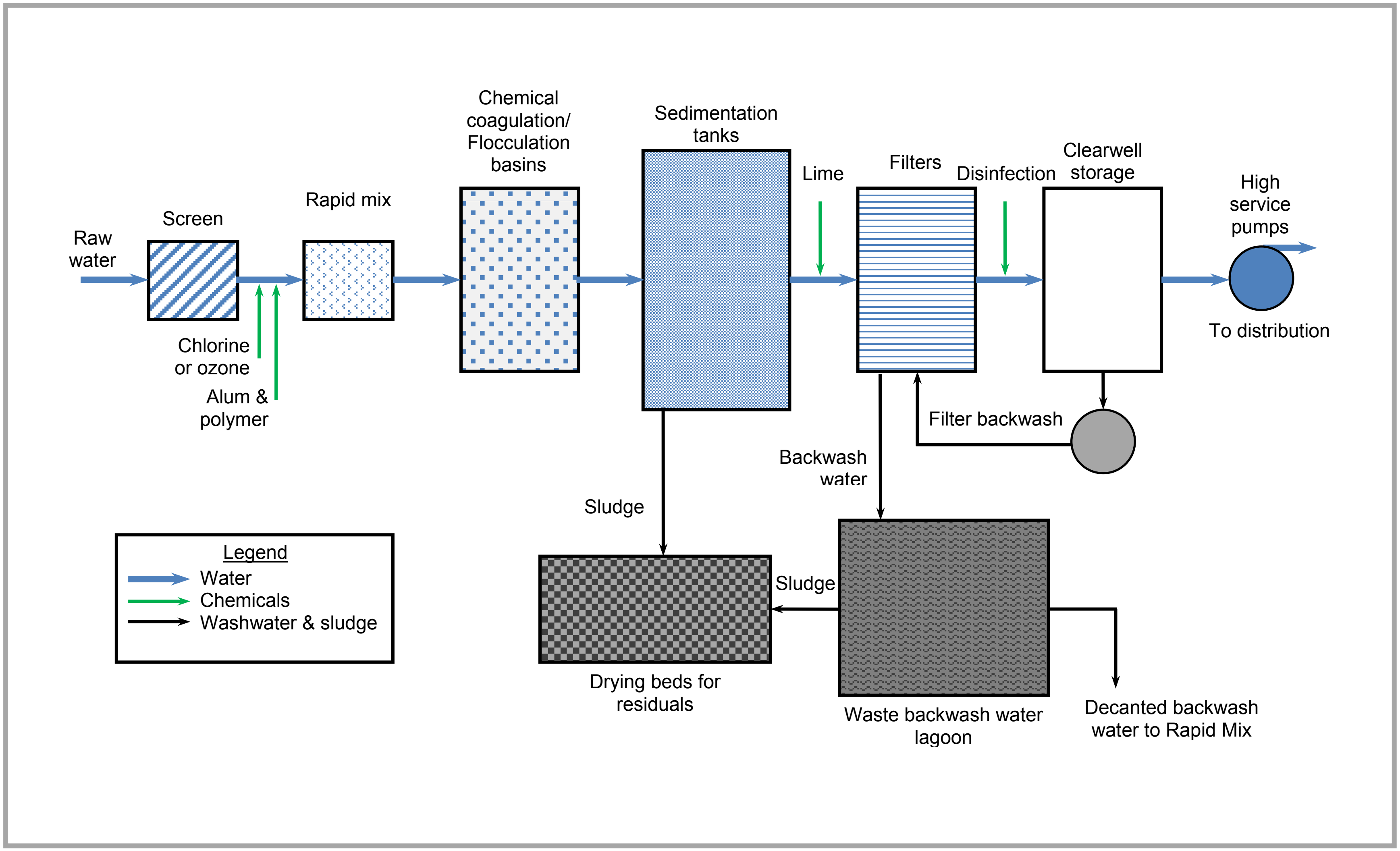

Figure 2-4
Typical Surface Water Treatment Plant Process Flow Diagram

Each treatment step serves a particular function.

- **Screens:** Remove leaves and debris
- **Preoxidation:** Kills most disease-causing organisms and oxidizes taste- and odor-causing substances. Preoxidation can involve the use of chlorine or ozone, as illustrated in Figure 2-4.
- **Flash mixing:** Mixes chemicals with raw water containing fine particles that will not readily settle or filter out
- **Chemical coagulation:** Causes colloidal particles to destabilize so that particle growth can occur during flocculation
- **Flocculation:** Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration process
- **Sedimentation:** Settles out larger suspended particles
- **Filtration:** Filters out remaining suspended particles
- **Disinfection:** Kills disease-causing organisms. Also provides a disinfectant residual for the distribution system to prevent bacterial regrowth
- **Clearwell:** Provides contact time for disinfection; stores treated water to meet system demand

Alternative approaches to conventional treatment that have been successfully employed include direct filtration, ozone pretreatment, and membrane filtration:

- **Direct Filtration:** In direct filtration, the sedimentation and sometimes the flocculation steps are eliminated and the coagulated water is sent directly to the filters. This process is used in cases where the raw water has low turbidity and color.
- **Ozone Pretreatment:** In ozone pretreatment, ozone is used (generally in conjunction with alum or ferric chloride and a polymer) prior to filtration. Ozonation is accomplished by bubbling ozone gas through the water in a contact basin. Coagulation/flocculation follows where particles of floc are formed that are removed in the subsequent filtration step.
- **Membrane Filtration:** Membrane filtration is a pressure or vacuum driven separation process in which particulate matter larger than 1 μm is rejected by an engineered barrier primarily through a size exclusion mechanism and which has a measurable removal efficiency of a target organism that can be verified through the application of a direct integrity test. [15] This definition is intended to include the common membrane technology classifications, listed in order of decreasing pore size: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO).

Residuals Management

Processes that remove contaminants in water treatment inherently produce waste byproducts, called residuals. Conventional and softening treatment facilities produce liquid waste streams

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[15] *Membrane Filtration Guidance Manual*, U.S. EPA, Washington, DC: November 2005, EPA 815-R-06-009, http://www.epa.gov/ogwdw/disinfection/lt2/pdfs/guide_lt2_membranefiltration_final.pdf

containing various concentrations of solids. The residuals produced at these plants are generated from sedimentation basins (or clarifiers) as sludge (the solids that accumulate at the bottom of the sedimentation/clarifier basin), or as spent filter backwash water (SFBW).

Of the two primary residuals streams, there are significant differences in the mass of solids contained in each stream. For most surface water plants, the majority of residual solids will be removed via the sedimentation basin sludge. Generally, the sedimentation basin sludge is a relatively low-volume, high-solids waste stream, while the SFBW is a relatively high-volume, low-solids waste stream. Minimization of residuals may be accomplished by reducing the mass of residuals produced, reducing the volume of residuals produced, or both.

Figure 2-5 shows the unit operations commonly used in residuals management in water treatment plants. The three main stages are thickening (which can include chemical addition), conditioning, and dewatering. Fewer unit operations are typically used with water plant residuals than with wastewater plant sludge because the volume produced is less and there is extensive use of lagoons or drying beds for dewatering and drying. In urban areas, where land is more expensive, mechanical thickening and dewatering units are more prevalent.

An area of growing interest in residuals management is for concentrates from membrane systems. This is a particular problem for treatment facilities where desalination or zero-liquid discharge is practiced. Desalination concentrates, in particular, present significant disposal challenges; current practices include deep well injection, sewer discharge, evaporation ponds and land application.[16] In fact, one study in 2003 suggested that high recovery and zero-liquid discharge schemes are generally not economically feasible for municipal applications.[17]

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[16] *Demonstration of Membrane Zero Liquid Discharge for Drinking Water Systems: A Literature Review*, Water Environment Research Foundation, Alexandria, VA: 2012. No. WERF5T10.

[17] *Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities*, Water Research Foundation, Denver, CO: 2008. Report No. 4073.

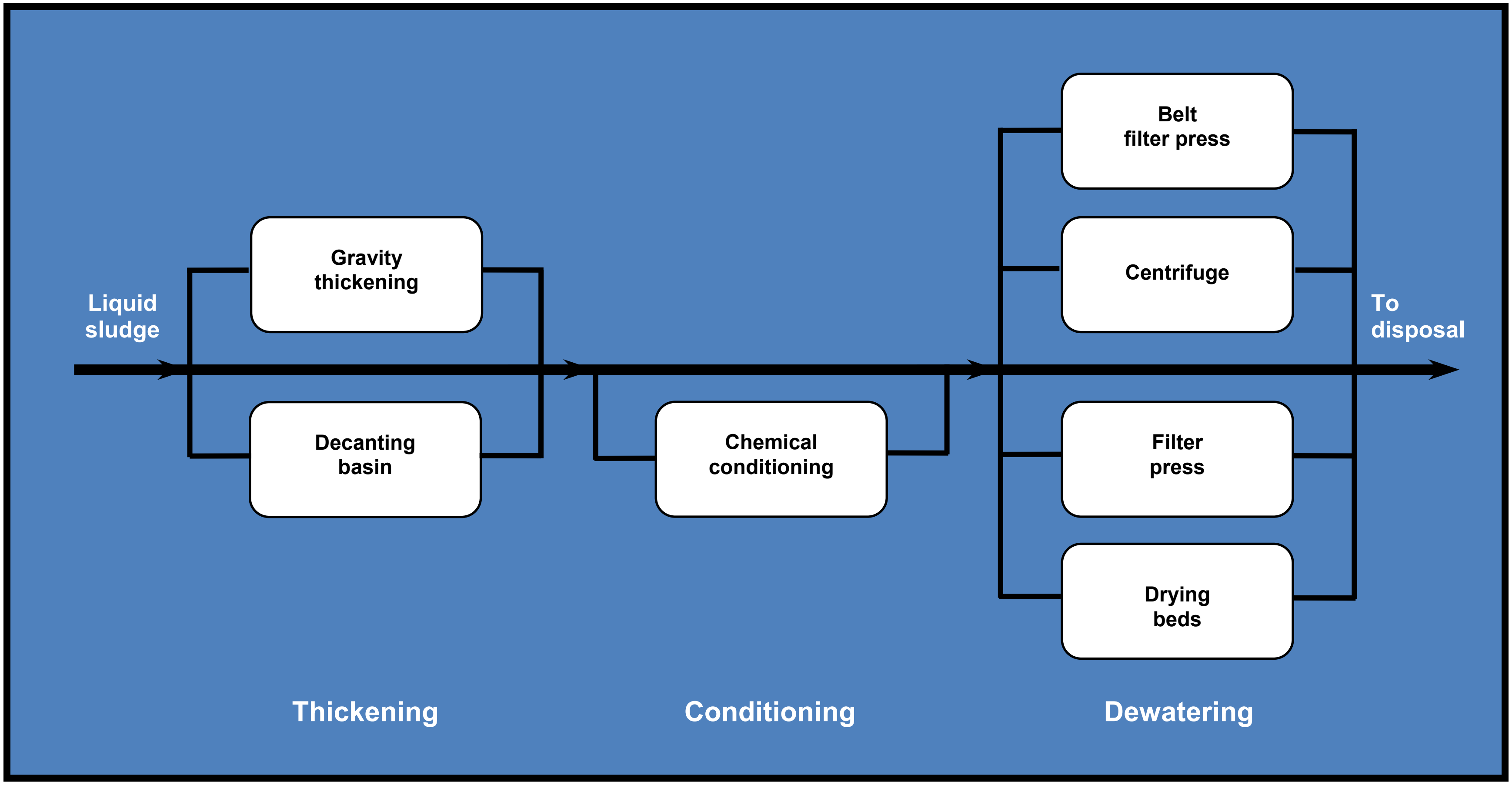

Figure 2-5
Water Treatment Plant Sludge/Residuals Processing Flow Diagram

Water Distribution and Storage

After treatment, water is usually pumped at high pressure to the distribution and storage system, which consists of storage tanks or reservoirs and, in some cases, additional pump stations to deliver water to other distribution zones.

Distribution pumping and storage serves several operational purposes including:

- Overcoming pipe friction within the distribution system
- Providing adequate pressure for the water end users
- Providing adequate storage volume and pressure for fire fighting and other emergency uses
- Providing adequate equalization storage volume to meet water demand if the water needs in a system exceed constant pumping capacities

Distribution system pumping is provided by the use of high service pumps and booster pumps to distribute water to water users under adequate pipe pressure. High service pumps are generally large horsepower pumps located at the water treatment plant that pump treated water into the service area under high head pressure conditions. Booster pumps are distributed throughout the distribution system and provide a similar function to deliver water to other distribution zones.

The term "adequate pressure" can vary widely from one system to the next, with a typical range of 40 to 100 pounds per square inch (psi) measured in the distribution mains. State health departments often specify a minimum pressure of 20 psi. With less than 40 psi, there may not be adequate pressure to serve sanitary needs in public and commercial buildings. High rise buildings usually have their own booster pumps to serve the upper stories. Water storage and system pressure are both “tools” the system operators can use to actively manage for electrical demand and electrical energy savings. Chapter 6 discusses in greater detail the use of water storage and system pressure to manage peak demand.

Trends in Public Water Supply

Technology trends in the public water supply industry may have a significant impact on increasing energy use for water treatment. From an electrical utility standpoint this is especially relevant, as peak water demand often coincides with hot and dry weather, when peak electric demand also occurs. Increasingly stringent water quality regulations are leading to an increase in the use of membrane technologies for physical removal of particulates and turbidity, including, microbial contaminants. Ozone and ultraviolet (UV) technologies may be increasingly used for disinfection due to their ability to inactivate bacteria, viruses, *Giardia*, and *Cryptosporidium* as effectively as chlorine while minimizing disinfection byproducts, which are harmful to human health. Membrane, ozone, and UV technologies are more electric-intensive than traditional clarification and disinfection methods. (Chapter 4 discusses the electric intensity of various water system unit operations in greater detail.)

Water reuse is gaining momentum in the public water supply industry. Treated wastewater is being used to meet cooling water and irrigation demands; thus reducing the need for treated drinking water required by the public water supply industry. Water reuse could increase total energy use unless large amounts of energy are used in supplying fresh water to treatment plant intakes. Locales with a high cost of energy and long raw water transmission systems often find water reuse economically attractive. However, direct reuse of treated wastewater as drinking water has not been popular to date due to negative public perceptions related to water quality, and is not expected to have a significant impact on water use trends in the next decade.

Environmental concerns, especially pertaining to greenhouse gas emissions, drive local and state governments to promote energy efficiency. As municipal functions, water treatment systems are often a focus for energy efficiency programs. For instance, both the California Energy Commission (CEC) and the New York State Energy Research Development Authority (NYSERDA) sponsor energy programs specifically tailored to water and wastewater agencies. This emphasis on energy efficiency will continue.

The emphasis on energy efficiency is likely to manifest itself in several ways. First, energy efficient operations, particularly with pumping systems, will be instituted. Second, energy recovery and alternative energy sources to grid power are likely to be evaluated and promoted. Public water supply systems often must maintain equipment spread out over large regions, so there is ample opportunity to install distributed generation (DG) equipment.

Finally, growth in water use is closely tied to population growth. Given current demographics, growth in electric energy use by the U.S. public water supply is inevitable. If water quality regulations tighten further, that growth could accelerate. Electric utilities can benefit by working closely with an industry that is very similar to their own, with common customers and concerns.

3

OVERVIEW OF THE MUNICIPAL WASTEWATER TREATMENT INDUSTRY

This chapter presents an overview of the municipal wastewater treatment industry in the U.S. It begins by describing the number and types of wastewater treatment systems, the populations they serve, where they are located, and treatment trends over time. It then discusses the technical features of wastewater systems and processes as they relate to wastewater collection, wastewater treatment, solids management, and effluent disposal and reuse. The discussion includes descriptions of specific liquid and solid treatment processes.

Municipal Wastewater Treatment in the United States

Wastewater (sewage) contains floatable, settleable, and dissolved solids. It must be collected, treated, and disposed of properly to protect the public from water-borne pathogens and odorous, dangerous gases and to prevent environmental pollution. Wastewater treatment involves processes that remove pathogens and other contaminants and alter the wastewater characteristics to meet effluent standards. Treatment processes including disinfection constitute a major aspect of wastewater treatment and with them comes a significant energy demand.

The U.S. has a large infrastructure designed to collect, treat, and dispose of wastewater. The EPA Clean Watershed Needs Survey (CWNS 2008) is a summary of current and anticipated wastewater infrastructure needs completed every four years. According to the most recent CWNS, the municipal wastewater treatment industry is composed of about 14,780 publicly owned treatment works (POTWs) that handle a total flow of about 32,345 MGD and serve a population of 226 million, or about 74% of the U.S. population.[18] (The remaining population is served by septic and other on-site systems). The EPA survey provides an overview of the number of treatment plants in use or projected to be in use when all of the treatment needs are to be met (in approximately 20 to 30 years, depending on the availability of funding).

Table 3-1 summarizes the results of the survey categorized by plant size (capacity). If all identified needs are met, the projected number of POTWs is 15,617 serving 284 million people and with a design capacity of 50,302 MGD. As with potable water systems, the vast majority of plants treat less than 1 MGD, but these smaller plants collectively represent only about 6% of the total design capacity in MGD.

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[18] *Clean Watersheds Needs Survey 2008: Report to Congress*, U.S. Environmental Protection Agency, Washington, DC: 2008. EPA-832-R-10-002, http://water.epa.gov/scitech/datait/databases/cwns/upload/cwns2008rtc.pdf. The schedule for release of the 2012 survey is late 2013.

Table 3-1
Number of Wastewater Treatment Facilities by Flow Range, 2008 and Projections

Flow Range (MGD)	In Operation in 2008[a]			In Operation if Documented Needs are Met[a]	
	Number of Facilities	Total Existing Flow (MGD)	Present Design Capacity (MGD)	Number of Facilities	Projected Design Capacity (MGD)
0.000 to 0.100	5,703 (39%)	257 (1%)	490 (1%)	4,738 (30%)	238 (0%)
0.101 to 1.000	5,863 (40%)	2,150 (7%)	3,685 (8%)	6,519 (42%)	2,590 (5%)
1.001 to 10.000	2,690 (18%)	8,538 (26%)	13,082 (29%)	3,524 (23%)	12,417 (25%)
10.001 to 100.000	480 (3%)	12,847 (40%)	17,267 (38%)	758 (5%)	19,291 (38%)
100.001 and greater	38 (0%)	8,553 (26%)	10,344 (23%)	70 (0%)	15,765 (31%)
Other[b]	6 (0%)	-	-	8 (0%)	-
Total	**14,780**	**32,345**	**44,868**	**15,617**	**50,302**

[a] Alaska, North Dakota, Rhode Island, American Samoa, and Virgin Islands did not participate in CWNS 2008. Percentage values may not add up to 100% due to rounding.
[b] Flow data for these facilities were unavailable.

Source: *Clean Watersheds Needs Survey 2008: Report to Congress*, U.S. EPA, Washington, DC: 2008. EPA-832-R-10-002. http://water.epa.gov/scitech/datait/databases/cwns/upload/cwns2008rtc.pdf.

Data from the survey also categorized the number of treatment facilities by the level of treatment. Table 3-2 summarizes these data for 2008 and reports the design capacities of the various levels of treatment when the needs are met. As shown in Table 3-2, in 2008 only 0.2% of the treatment facilities had less than secondary treatment, 84% had secondary treatment or greater, and 15% had no discharge. Facilities having no discharge use a variety of treatment systems and may discharge plant effluent to evaporation basins, or for irrigation or some other water reuse purpose.

The number of POTWs serving population centers in the U.S. actually decreased by about 5% over the last couple of decades (from 1988 to 2008), as illustrated in Table 3-3. However, during the same timeframe, the total existing flows to the facilities increased by about 13%. In addition, the number of people served by these wastewater treatment facilities increased by 26% from 1988 to 2008.

The mix of POTWs is changing as well. For example, about 50% of the population served by POTWs is provided with advanced wastewater treatment; by comparison, only 7.8 million people were provided with advanced treatment in 1972 (see Figure 3-1). Another major trend is that the share of treatment facilities providing less than secondary treatment has decreased to an insignificant number today, representing less than 4% of the total served. This will continue, as about 300 facilities providing secondary treatment or less in 2008 are expected to be replaced or upgraded to higher levels of treatment (see Table 3-2). For purposes of this report it can be assumed that municipal wastewater facilities include at least secondary treatment.

Table 3-2
Number of Wastewater Treatment Facilities by Level of Treatment, 2008 and Projections

Level of Treatment	In Operation in 2008[a]			In Operation if Documented Needs are Met[a]		
	Number of Facilities	Existing Flow (MGD)	Number of People Served	Number of Facilities	Projected Design Capacity (MGD)	Number of People Served
Less than secondary[b]	30	422	3,751,787	19	497	3,880,548
Secondary	7,302	13,142	92,650,605	7,015	16,334	89,100,487
Greater than secondary	5,071	16,776	112,947,134	5,909	29,032	161,163,736
No discharge[c]	2,251	1,815	16,946,528	2,526	3,576	29,956,126
Partial treatment[d]	115	190	-	140	863	-
N/A[e]	11	-	6,159	8	-	1,606
Total	**14,780**	**32,345**	**226,302,213**	**15,617**	**50,302**	**284,102,503**

[a] Alaska, North Dakota, Rhode Island, American Samoa, and Virgin Islands did not participate in CWNS 2008.

[b] Less-than-secondary facilities include facilities granted or pending section 301(h) waivers from secondary treatment for discharges to marine waters.

[c] No-discharge facilities do not discharge treated wastewater to the Nation's waterways. These facilities dispose of wastewater via methods such as industrial reuse, irrigation, or evaporation.

[d] These facilities provide some treatment to wastewater and discharge their effluents to other wastewater facilities for further treatment and discharge. The population associated with these facilities is omitted from this table to avoid double accounting.

[e] Totals include best available information for States and Territories that did not have the resources to complete the updating of the data or did not participated in the CWNS 2004 to maintain continuity with previous Reports to Congress. Forty operational and 43 projected wastewater treatment plants were excluded from this table because the data related to population, flow and effluent were not complete.

Source: *Clean Watersheds Needs Survey 2008: Report to Congress*, U.S. EPA, Washington, DC: 2008. EPA-832-R-10-002. http://water.epa.gov/scitech/datait/databases/cwns/upload/cwns2008rtc.pdf.

Table 3-3
Comparison of Wastewater Treatment Statistics for 1988 and 2008

Survey Year	Number of Facilities	Existing Flow (MGD)	Number of People Served
1988	15,591	28,736	~180 million
2008	14,780	32,345	226 million
% Change	-5%	13%	26%

Sources:
1. *Clean Watersheds Needs Survey 2008: Report to Congress*, U.S. EPA, Washington, DC: 2008. EPA-832-R-10-002.
2. *Assessment of Needed Publicly Owned Wastewater Treatment Facilities in the United States, 1988 Needs Survey to Congress*, U.S. EPA, Washington, DC: 1989. EPA/430/09-89/001.

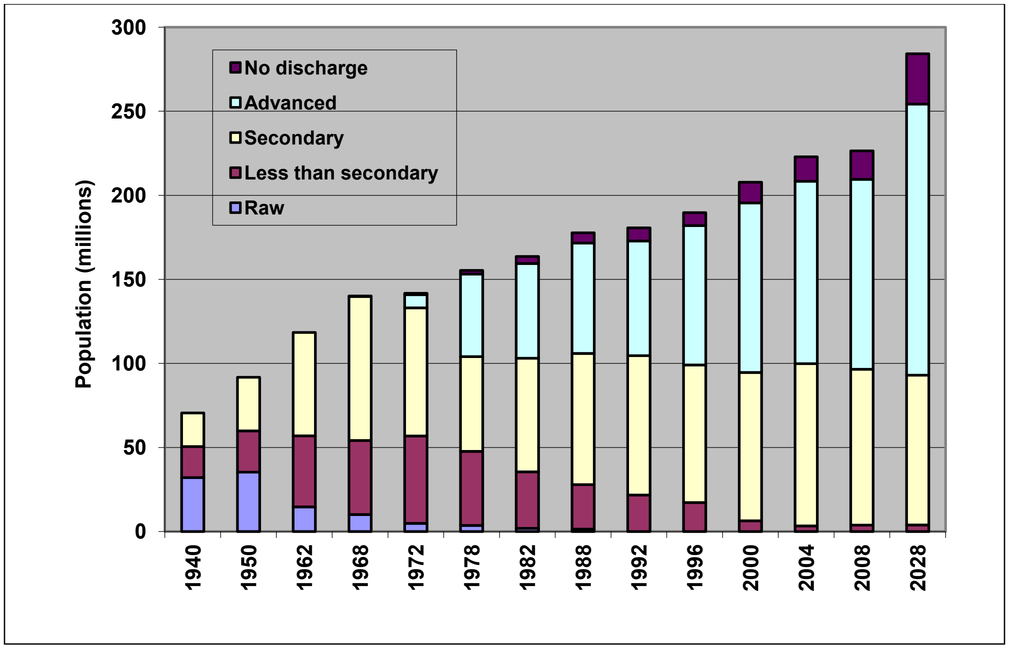

Figure 3-1
Population Served by POTWs Nationwide for Select Years and Projected

Source: U.S. Public Health Service and EPA Clean Watersheds Needs Surveys

Much of this change is due to implementation of the federal Clean Water Act (CWA) of 1972, which has brought about substantial improvements in U.S. water pollution control infrastructure. As a result, not only have the numbers of facilities increased, but the size and complexity as well. This trend is expected to continue and we should see a greater share of advanced and non-discharging facilities in the future. These trends continue to impact the financing of facilities expansion and upgrading and have led to higher operating costs.

It is also interesting to consider the regional breakdown of wastewater treatment facilities. CWNS 2008 contains detailed information on the number of treatment facilities and population served at the state and U.S. territory level.

The top 10 states serving the most people are listed in Table 3-4. The table shows the total population served by facilities in each state as well as the population served by the level of treatment. Facilities treating to less than secondary levels are limited to those states where it is possible to discharge directly to marine waters, such as California and Massachusetts. In general population served by municipal wastewater treatment corresponds to general population, so the most populous states generally have the most treatment capacity.

Table 3-4
Population Served by Treatment Facilities, Top 10 States in 2008

State	Population Served by Listed Effluent Level				
	Less than Secondary[a]	Secondary	Greater than Secondary	No Discharge[b]	Total Population Served
1. California	1,942,489	18,691,625	10,555,037	4,059,128	35,248,279
2. Texas	0	2,182,005	16,230,356	823,811	19,236,172
3. New York	0	11,574,292	4,178,653	109,616	15,862,561
4. Florida	0	2,047,000	4,058,535	6,871,354	12,976,889
5. Pennsylvania	0	6,587,453	4,656,801	5,757	11,250,011
6. Ohio	0	1,076,291	7,696,860	956	8,774,107
7. New Jersey	0	6,277,784	1,501,915	61,990	7,841,689
8. Michigan	0	485,747	6,620,924	99,241	7,205,912
9. Virginia	0	1,759,181	3,633,462	1,867	5,394,510
10. Massachusetts	50,326	3,765,115	721,994	48,827	4,586,262

[a] Less-than-secondary facilities include facilities granted or pending section 301(h) waivers from secondary treatment for discharges to marine waters.

[b] No-discharge facilities do not discharge treated wastewater to the Nation's waterways. These facilities dispose of wastewater via methods such as industrial reuse, irrigation or evaporation.

Source: *Clean Watersheds Needs Survey 2008: Report to Congress*, U.S. EPA, Washington, DC: 2008. EPA-832-R-10-00. http://water.epa.gov/scitech/datait/databases/cwns/upload/cwns2008rtc.pdf.

Wastewater Systems and Processes

Wastewater systems generally consist of three principal components:

- Collection system (sewers and pumping stations)
- Treatment facilities (including sludge/biosolids processing)
- Effluent and biosolids disposal or reuse

The equipment and processes associated with these three principal functions within the municipal wastewater industry vary widely. All functions impact energy use, but typically the energy required to collect and dispose of wastewater is less than the energy to treat wastewater; this is inverse to the relationship between pumping and treatment on the drinking water side.

The following three subsections present the general characteristics of each of the above components: wastewater collection, wastewater treatment, and effluent disposal and reuse. The fourth subsection is dedicated to solids management (which includes biosolids processing) because solids management constitutes a significant part of the treatment system. The last subsection focuses on specific technologies for treating the liquid and solid constituents of wastewater.

Wastewater Collection Systems

Collection systems used for wastewater are of two basic types: separate or combined. Separate systems are designed for the exclusive transport of either sanitary wastewater or stormwater and are the common practice today, while combined systems are designed for the transport of both sanitary wastewater and stormwater. The amount of stormwater that enters into the collection system with the sanitary wastewater, either by design or unintentionally due to poor construction or aged piping, can significantly affect the amount of wastewater to be treated and the facilities required to handle a peak hydraulic load.

Combined sewer systems are remnants of the country's early infrastructure and so are typically found in older communities. Combined sewer systems serve roughly 772 communities containing about 40 million people. Most communities with combined sewer systems (and therefore with CSOs) are located in the Northeast and Great Lakes regions, and the Pacific Northwest.[19] The estimated volume of untreated wastewater and storm water discharged as CSO nationwide is 850 billion gallons per year.[20]

To the extent possible, wastewater collection systems rely on gravity flow in non-pressurized conduits (sewers). As a result, most of the pipelines in a collection system handling wastewater are gravity sewers. However, because of local topography, many collection systems require wastewater pumping stations and pressurized pipelines (force mains) to lift and transport wastewater to the treatment plant. When sewers reach depths of 20 to 30 ft below ground, it typically becomes cost-effective to pump the wastewater to a higher elevation. Pumping stations for untreated wastewater must be capable of handling a variety of solids, grease, grit, and stringy material. Therefore, the pumps must contain sufficient clear passages so the pumping units do not become clogged. Because the openings are larger to accommodate solids in the wastewater, efficiencies of wastewater pumps are generally lower when compared to clean water pumps. Chapter 6 presents some opportunities for improved energy management in pumping systems.

Wastewater Treatment Facilities

Wastewater treatment processes depend largely on the level of treatment required as prescribed by the discharge permit issued by the regulating agency. The levels of treatment are usually dictated by the characteristics of the receiving water body or disposal area, if discharged, or by the requirements for reuse, if recycled or reclaimed. There are three general levels of treatment, including primary, secondary, and tertiary (advanced).

Primary treatment is generally used as a precursor to secondary or advanced wastewater treatment. Historically, the term preliminary or primary treatment referred to physical unit operations; secondary treatment referred to chemical and biological unit processes; and advanced or tertiary treatment referred to combinations of all three. These terms are arbitrary, however, and in most cases are of little value even though they continue to be used. In this report, the levels of treatment are defined in the context of the operations or processes generally used.

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[19] *Report to Congress: Impacts and Control of CSOs and SSOs,* US Environmental Protection Agency,, Washington, D.C.: August 2004. EPA 833-R-04-001http://cfpub.epa.gov/npdes/cso/cpolicy_report2004.cfm

[20] Ibid.

Figure 3-2 illustrates commonly used processes and equipment in wastewater treatment. Table 3-5 lists the contaminants of major interest in wastewater and the unit operations, processes, or treatment systems applicable to the removal of these contaminants. The following paragraphs describe application of these operations, processes, and systems to perform specific functions.

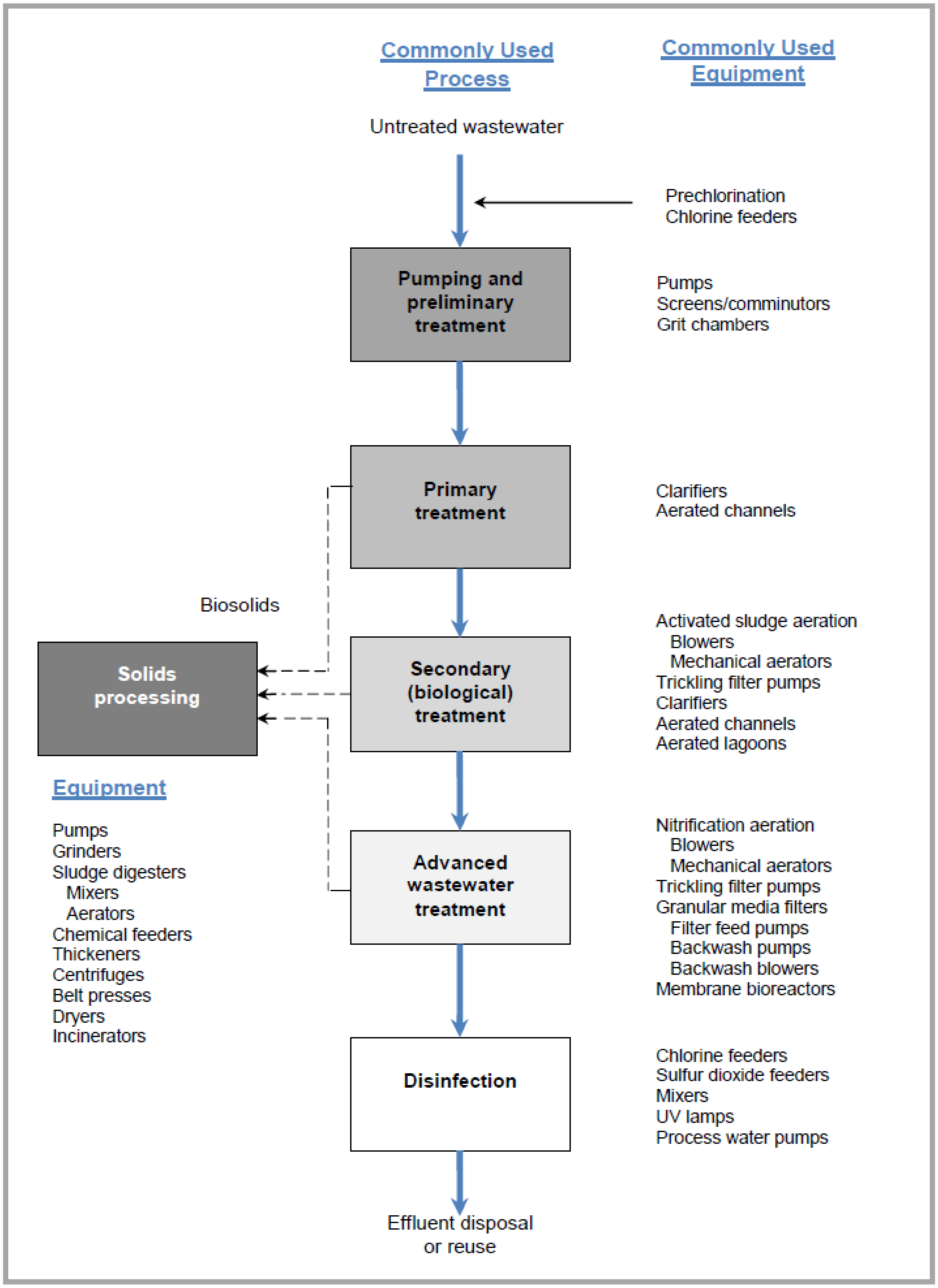

Figure 3-2
Processes and Equipment Commonly Used in Wastewater Treatment

Table 3-5
Major Contaminants in Wastewater and Unit Operations, Processes and Treatment Systems Used to Remove Them

Contaminant	Unit Operation, Unit Process, or Treatment System
Suspended solids	Screening and comminution Grit removal Sedimentation Filtration Flotation Chemical polymer addition Coagulation/sedimentation
Biodegradable organics	Activated sludge variations Fixed film reactor: trickling filters Fixed film reactor: rotating biological contactors Membrane bioreactors (MBRs) Lagoon variations Intermittent sand filtration Physical-chemical systems Natural systems (land treatment)
Dissolved solids	Membranes
Pathogens	Chlorination Hypochlorination Bromine chloride Ozonation UV Radiation
Nutrients:	
Nitrogen	Suspended-growth nitrification and denitrification variations Fixed-film nitrification and denitrification variations Ammonia stripping Ion exchange Breakpoint chlorination Natural systems
Phosphorus	Metal salt addition Lime coagulation/sedimentation Biological phosphorus removal Biological-chemical phosphorus removal Natural systems
Nitrogen and Phosphorus	Biological nutrient removal Natural systems

Primary Wastewater Treatment

Primary wastewater treatment typically involves removing a portion of the suspended solids and organic matter to limit maintenance or operational problems, usually through sedimentation. Examples of other primary operations include screening and comminution (shredding), grit removal, and flotation, which is a less common process. Odors are worst at the primary treatment stages so many treatment plants use odor control in this part of the plant. The effluent from primary treatment will ordinarily contain a considerable amount of organic matter.

Conventional Secondary Wastewater Treatment

The intent of secondary treatment systems is to remove most of the soluble and colloidal organic matter that remains after primary treatment. Generally, secondary treatment implies a biological process. Biological treatment is the application of a controlled natural process in which microorganisms remove soluble and colloidal organic matter from the wastewater and are, in turn, removed themselves.

Conventional secondary treatment includes biological treatment by activated sludge, fixed film reactors, or lagoon systems, generally followed by sedimentation. The definition of conventional secondary treatment frequently includes disinfection.

Disinfection

Disinfection with agents such as chlorine eliminates or substantially reduces microbial organisms to protect public health and to render the water suitable for beneficial uses, such as swimming and fishing. The presence of chlorine may be toxic to aquatic organisms; therefore, plants are often required to remove residual chlorine by dechlorination with sulfur dioxide or sodium bisulfite. UV disinfection is an alternative method being employed to avoid the hazards and hassles of chlorine (see Chapter 6).

Advanced Wastewater Treatment

Advanced wastewater treatment has many definitions. Commonly, the term is used to describe any level of treatment beyond conventional secondary treatment to remove constituents of concern such as nutrients or increased amounts of organic material. Chemical, physical and natural methods, such as constructed wetlands, can be used.

Three situations typically lead to instituting advanced wastewater treatment within a specific treatment plant:

- Discharges to confined bodies of water where eutrophication (excessive growth of aquatic plants such as algae) may be caused or accelerated
- Discharges to flowing streams where the conversion of ammonia to nitrate (nitrification) can tax oxygen resources or where rooted aquatic plants can flourish
- Beneficial reuse of plant effluent water, such as recharge of groundwater that may be used indirectly for public water supplies or industrial cooling water.

Solids Management

Wastewater treatment produces large quantities of sludge, collectively referred to as biosolids, which require subsequent processing. In fact, as much as one-third of the energy use at a treatment facility involves biosolids processing. These solids include inorganic material and a sizeable organic fraction that will putrefy unless properly processed and stabilized.

The operational problem posed by biosolids is increasing significantly due to the construction of more facilities, the upgrading of existing plants, and the requirements for higher degrees of treatment. Greater electricity requirements for powering the equipment used to process the solids has been accompanying this growth. Solids generated from wastewater treatment systems generally include the following:

- Grit and screenings
- Primary biosolids from gravity settling
- Biosolids from aerobic treatment systems such as activated sludge and trickling filters (i.e. biomass)
- Chemical precipitates
- Stabilized (i.e. non-pathogenic) biosolids from anaerobic or aerobic digestion processes
- Grease and scum
- Solids from filter backwashing operations

A summary of the principal solids handling and processing methods used in wastewater systems is presented on Figure 3-3. Chapter 6 discusses emerging technologies for solids reduction and treatment, which continues to be an area of intense interest.

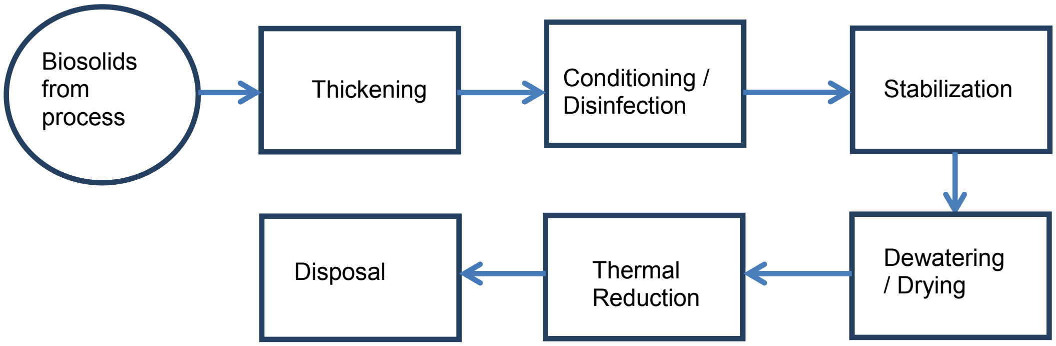

Figure 3-3
Processes Common to Biosolids Processing

After processing, the residual material is usually disposed of by land application or landfill burial or used beneficially as a soil amendment or for landfill cover material. Over the last couple of decades, there have been increases in solids processing facilities for thickening, aerobic digestion, mechanical dewatering, and composting, all of which can be significant users of electricity. Some of the drivers for the increase in composting include the growing markets for compost, more stringent air quality standards that preclude incineration, and the lack of landfill capacity for the future disposal of sludge. An increased number of facilities stabilizing biosolids with anaerobic digestion are looking for ways to cost-effectively utilize the collected methane gas for its potential as an energy resource.

Effluent Disposal and Reuse

Most wastewater treatment plants discharge the plant effluent to a water body, which is referred to as the receiving water. The effluent from the plant flows by gravity to the receiving water; however, in some cases this is not possible (such as in tidally-influenced rivers during high tide), and the effluent has to be pumped. In most instances, the required pumping head is relatively low, so the energy used per unit of effluent volume is small. For reuse applications, additional treatment processes may be necessary, and effluent transport facilities (pumping stations and pipelines) may also be required. In these cases, the energy requirements can increase significantly, especially if the system includes high pressure pumping.

Treatment Process Descriptions

Many types of treatment systems are employed to meet the requirements of discharge permits, ranging from simple oxidation and evaporation-percolation ponds to complex advanced wastewater treatment plants. The purpose here is not to describe every type of process or process modification used in wastewater treatment, but to highlight the basic systems, those used most commonly and those having the greatest impact on energy use. The following discussion is divided into two major elements: processes used to treat the liquid (wastewater) stream and methods used for processing solids removed in the wastewater treatment process. Chapter 5 presents the electricity requirements for the unit processes used in these treatment plant types and presents some examples of how the unit processes can be put together to develop reasonable energy estimates for a specific wastewater treatment plant.

Liquid Treatment Systems

Biological treatment has been found to be effective and reliable. Some form of biological treatment is used in almost every municipal wastewater treatment plant. Lagoons and pond systems use little energy but are only generally suitable for very small flows (less than 0.5 MGD).

Activated sludge or some form of activated sludge is the most commonly selected process for new plants, especially for those larger than 1 MGD, which account for 90% of the designed treatment capacity (see Table 3-1). The reason to its popularity is that the activated sludge process's flexibility in regard to plant layout, reactor design, equipment selection, and operational control allows it to be used to treat almost any municipal wastewater to a desired effluent limitation level. Further, activated sludge systems are highly flexible from an operational viewpoint, enabling system operators to more easily adjust to changes in discharge limits. Secondary clarifiers provide a means to capture biological material that passes through the aeration basin before disinfection and discharge to the environment.

Trickling filters are fixed-film biological systems that are simple and reliable systems well suited for small to medium-sized communities, requiring a moderate level of skill to operate. Trickling filters also are finding application in combination with activated sludge for treating high-strength wastewater in both new and retrofit applications and in advanced wastewater treatment for nitrification. When operated in conventional secondary treatment, trickling filters are prone to "sloughing" of biomass into the filter effluent. Thus, secondary clarifiers are needed to ensure adequate disinfection as the biomass often contains high microbial loads.

Many advanced wastewater treatment plants are required to provide nitrification to reduce ammonia toxicity in the effluent and to reduce the dissolved oxygen demand on the receiving waters (due to the oxidation of ammonia). Many plants are also required to provide filtration for increased suspended solids removal, particularly in reuse applications and where the discharge is to environmentally-sensitive water bodies. Thus, many advanced wastewater treatment plants modify the activated sludge step to increase aeration times or to alternate between aerobic and anaerobic conditions in order to encourage the growth of certain types of biomass in different zones. In addition, advanced wastewater treatment plants include provisions to better remove particulate matter in the treatment effluent.

One type of advanced treatment system that relies in part on activated sludge processing is a membrane bioreactor (MBRs). MBRs combine a suspended growth biological reactor (i.e. activated sludge) with solids removal via filtration. Membrane filters are immersed in the reactor and the water flows from the outside through the membrane and into the annular space. The aeration in the activated sludge reactor serves both to provide oxygen to the microbial population and also to scour the membrane filter surface. MBRs are designed for and operated in small spaces and have high removal efficiency of contaminants such as nitrogen, phosphorus, bacteria, bio-chemical oxygen demand, and total suspended solids.[21]

Figure 3-3 through Figure 3-5 show typical schematic flow diagrams for activated sludge, trickling filter, and advanced wastewater treatment plants, respectively. Figure 3-6 shows an example flow diagram for a membrane bioreactor.

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[21] *Wastewater Management Fact Sheet, Membrane Bioreactors*, U.S. Environmental Protection Agency, Washington D.C.: July 2007, http://water.epa.gov/scitech/wastetech/upload/2008_01_23_mtb_etfs_membrane-bioreactors.pdf

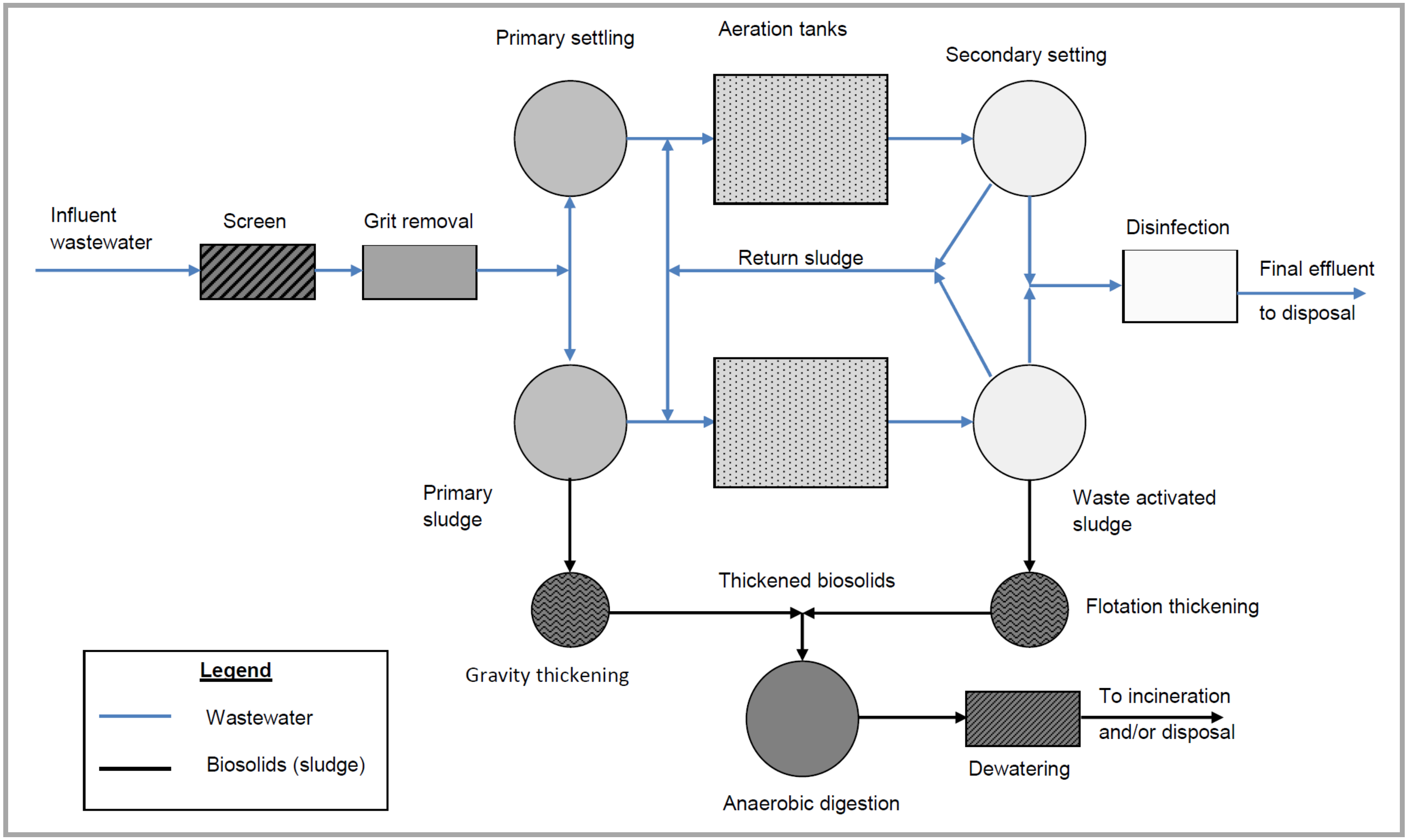

Figure 3-3
Typical Flow Diagram for an Activated Sludge Wastewater Treatment Plant

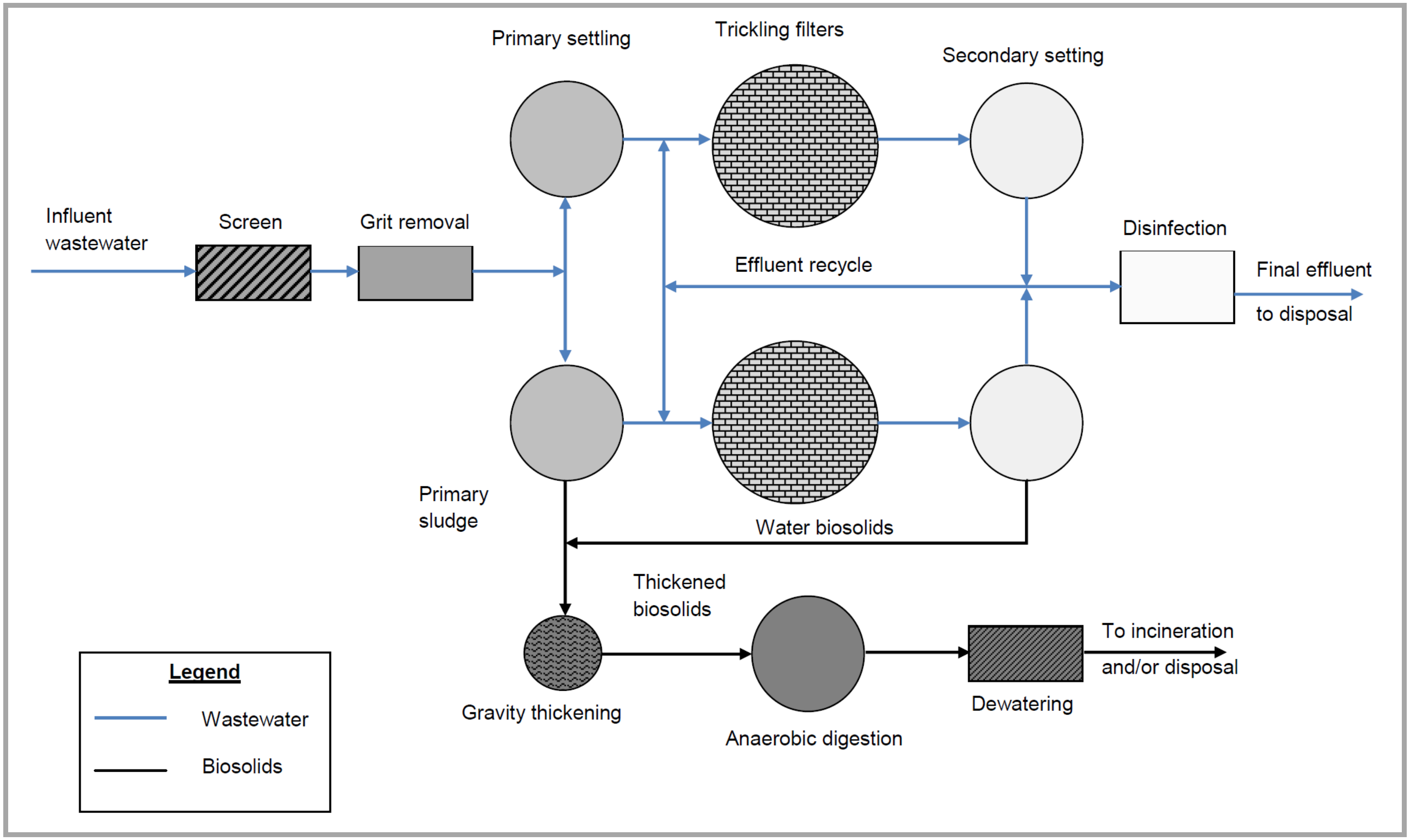

Figure 3-4
Typical Flow Diagram for a Trickling Filter Wastewater Treatment Plant

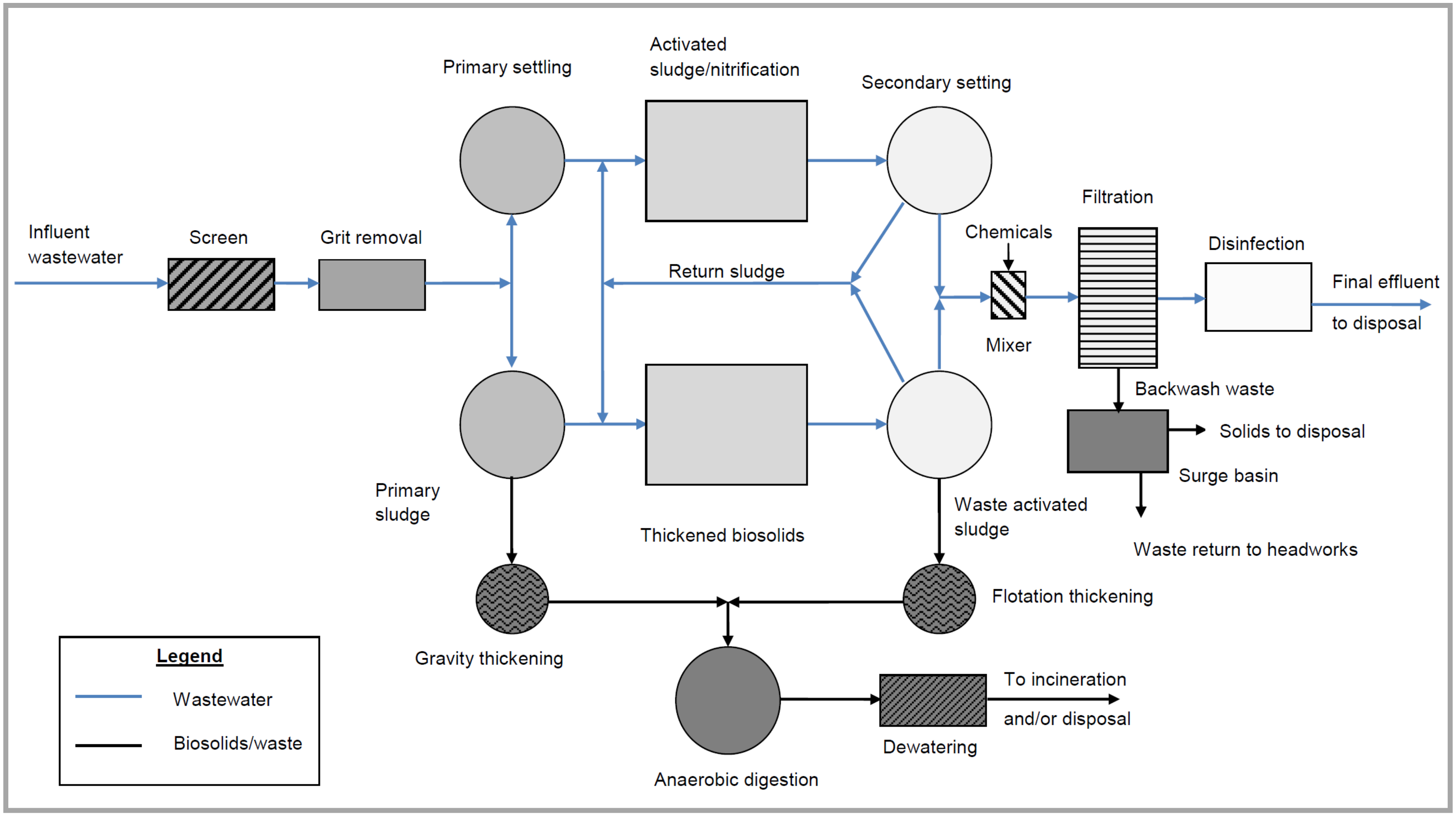

Figure 3-5
Typical Flow Diagram for an Advanced Wastewater Treatment Plant

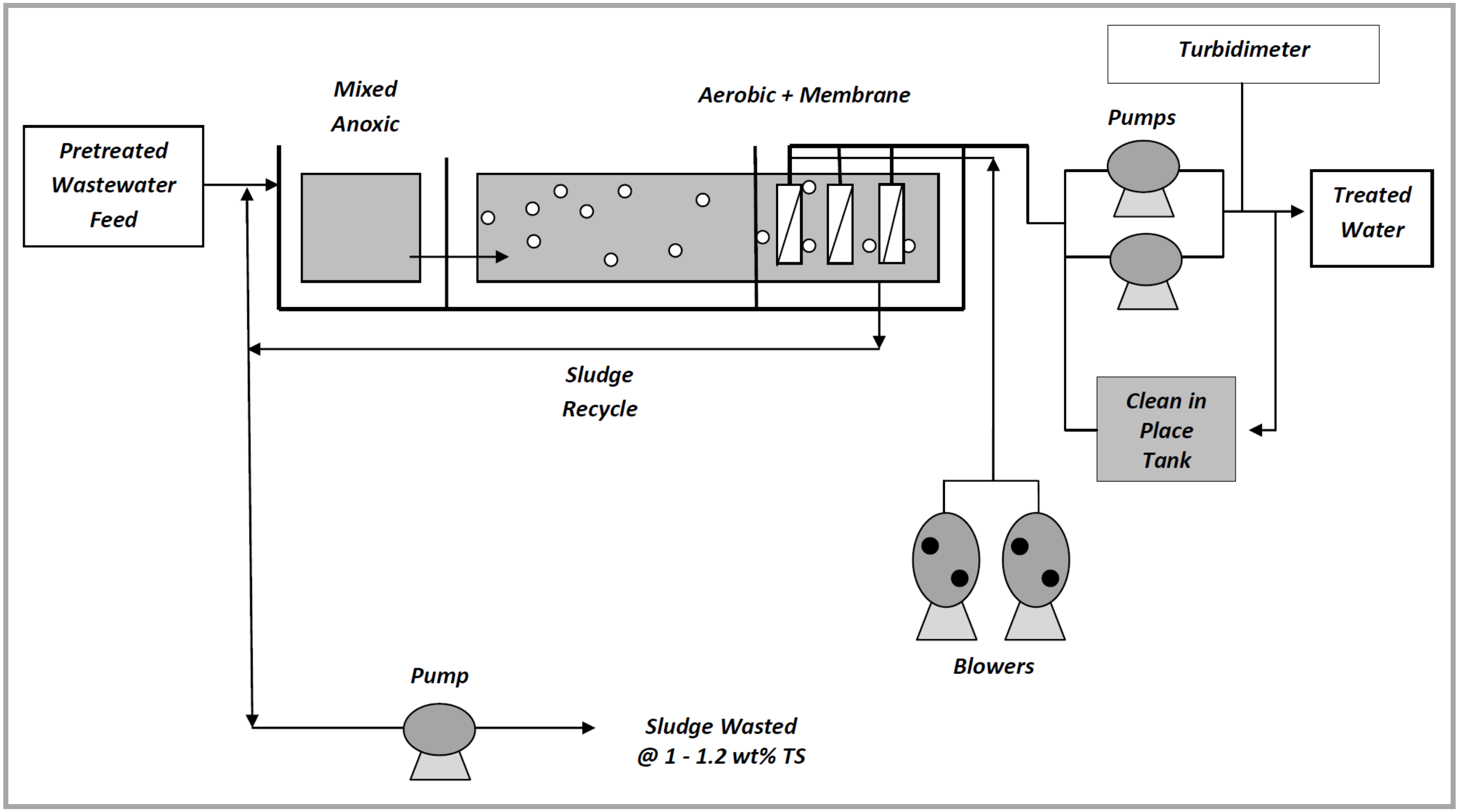

Figure 3-6
Example Flow Diagram for a Membrane Bioreactor System

Source: Redrawn from GE/Zenon image in U.S. Environmental Protection Agency, Wastewater Management Fact Sheet, Membrane Bioreactors, July 2007. http://water.epa.gov/scitech/wastetech/upload/2008_01_23_mtb_etfs_membrane-bioreactors.pdf.

Solids Processing Systems

As mentioned earlier, solids management requires several handling and processing functions. As the wastewater treatment plants increase in size and complexity, the components of the solids system also grow in both number and complexity. Table 3-6 lists the various operations and processes used in solids and biosolids processing. The table also includes an assessment of the relative impact of the unit operation or process on electricity use, if added to the treatment system. Each of these operations or processes usually requires motor-driven equipment.

Figure 3-7 presents a generalized flow diagram showing the sequence of operations and processes generally used in solids management. Most wastewater treatment plants require pumping, thickening, some form of stabilization (usually either anaerobic or aerobic digestion), a method of dewatering, and disposal. Sludge drying is rare, but when used is employed at very large treatment facilities. Processes such as anaerobic digestion and incineration produce byproducts (methane gas or heat) that can be recovered and used in the wastewater treatment plant to reduce the requirements for electricity or fuel. At some plants, excess methane gas is sold to the local gas company for use in its system. As discussed later in this report, such byproducts may offer opportunities for reducing energy costs. Chapter 6 includes a discussion of opportunities in solids processing systems from an energy management viewpoint.

Trends in Municipal Wastewater Treatment

Much progress has been made in cleaning our nation’s water since the beginning of the Clean Water Act in 1972, but challenges still remain. Legacy pollution problems and new sources and contaminants are compounded by factors such as population growth, aging infrastructure, continued urbanization, and the effects of climate change. EPA’s National Aquatic Resource Surveys have found that nutrient and pathogen pollution is a concern affecting surface waters. Sources of these stressors vary regionally, but one of the primary sources of water degradation is municipal wastewater. Regulations requiring advanced levels of treatment, greater control of stormwater, and biosolids management are driving wastewater agencies to seek innovative solutions. At the same time, aging infrastructure is leading to high capital expense for upgrades which results in increased cost to the public. With rising infrastructure demands and decreasing resources, municipalities are looking for cost-saving measures, particularly with respect to operating costs.

The use of electricity for wastewater treatment is growing due to demands for increased service and new regulations for upgraded treatment. Options available to control electricity costs may consist of technological changes, improved management, energy recovery, and participation in electric utility sponsored energy management programs. At the same time, the way traditional method wastewater utilities manage their operations is changing. The wastewater utility’s relationship with their communities and their contributions to local economies is becoming more and more critical to the economic development of the areas they serve. Electric utilities have an expressed motivation to work closely with wastewater agencies as they together shape the future of their service regions and customers by providing sustainable growth for energy and water infrastructure.

An increasing number of wastewater plants will be looking to innovative technologies and approaches for achieving net energy neutral operations and managing wastewater as a resource.

This change will transform the typical business approach of the wastewater utility. In the past, a wastewater agency's business practice was solely to collect and transport wastewater to central treatment plants and provide treatment to meet permit limits prior to discharge to waterways. In moving to a net energy neutral environment, the wastewater agency will now be the manager of a valuable resource. Wastewater agencies will take a holistic approach looking at opportunities for reclaiming and reusing water, extracting and finding commercial uses for nutrients and other constituents, capturing waste heat and latent energy in biosolids and liquid streams, generating renewable energy using land and capturing methane gas, and managing stormwater. Many new and innovative developments in equipment, controls, and technology will support this industry and the challenges they face. The energy component of these solutions will play a major role in wastewater utility decision making.

Table 3-6
Solids Processing and Disposal Methods

Processing or Disposal Function	Unit Operation, Unit Process, or Treatment Method	Impact on Electricity Use
Preliminary operations	Pumping	Moderate
	Grinding	Small
	Degritting	Small
	Solids blending and storage	Small
Thickening	Gravity thickening	Small
	Flotation thickening	Moderate
	Centrifugation	Moderate
	Gravity belt thickening	Small
Stabilization	Lime stabilization	Small/moderate
	Heat treatment	Significant
	Anaerobic digestion	Small/moderate
	Aerobic digestion	Moderate/significant
	Composting:	
	Windrow	Small
	Aerated static pile	Moderate
	In-vessel	Significant
Conditioning	Chemical conditioning	Small
	Heat treatment	Significant
Disinfection	Pasteurization	Moderate
	Long term storage	Small
Dewatering	Vacuum filter	Significant
	Centrifuge	Significant
	Belt press filter	Small/moderate
	Filter press	Moderate/significant
	Biosolids drying beds	Small
	Lagoons	Small
Heat drying	Dryer variations	Moderate
	Multiple effect evaporator	Significant
Thermal reduction	Incineration	Significant when used[22]
	Wet air oxidation	Significant when used[23]
Ultimate disposal	Land application	Small
	Landfill	Small
	Lagooning	Small
	Chemical fixation	Moderate

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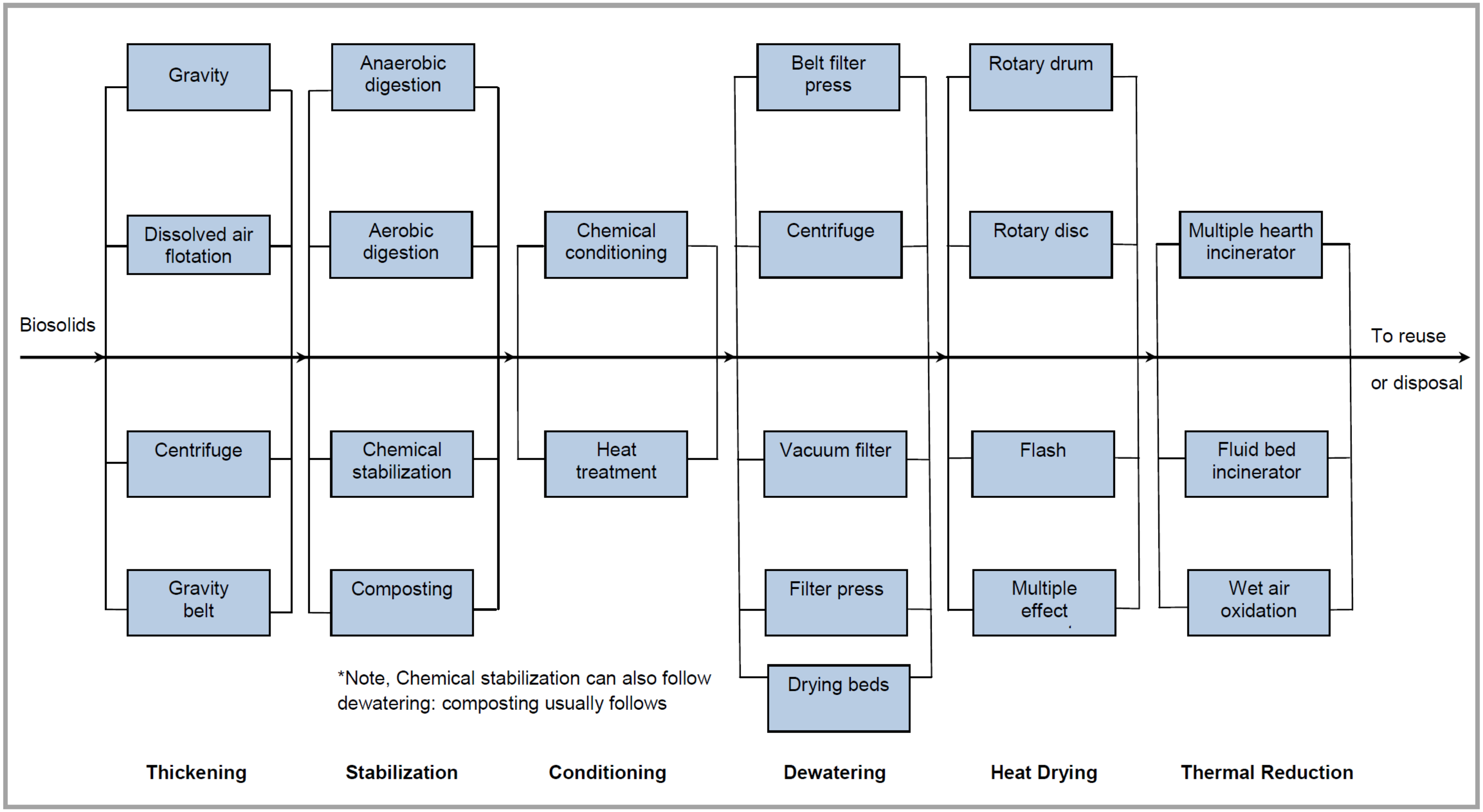
[22] Electricity impact is highly dependent on the specific installation. Age and the degree of waste heat recovery dictate the overall demand for purchased electricity. These technologies are not common so their impact on overall U.S. energy consumption is quite small. For example, there are only about 100 wastewater treatment facilities with incinerators nationwide and even fewer facilities with wet air oxidation.

[23] Ibid.



*Note, Chemical stabilization can also follow dewatering: composting usually follows

Figure 3-7
Potential Operations and Processes Used in Treating Solids and Biosolids (not all are used)

4

ELECTRICITY USE IN PUBLIC WATER TREATMENT AND DISTRIBUTION SYSTEMS

This chapter explores electricity use in the treatment and distribution of public drinking water supply systems in the U.S. The first section of the chapter summarizes current electric use trends in public water treatment and distribution. The second section focuses on expected electric energy intensities for typical and emerging unit processes and provides examples of how to compute an estimate of electric energy use for a water treatment and distribution system by selecting the various unit processes. The final section in this chapter provides estimates for overall electricity use in the U.S. public water supply.

Current Energy Use Trends

Pumping accounts for a very large portion of the overall energy use within a public water supply system. In fact, in 1996 EPRI estimated that on average pumping accounted for 80% of total electricity use in public water systems, meaning electric energy needs for water treatment were relatively minor.[24] EPRI also conjectured that electric energy use would likely grow in the future to meet tighter regulations. Treatment technologies like ozone and membrane filtration are significantly more energy intensive than conventional treatment; however, in 1996 it was generally agreed that advanced treatment technologies were quite possibly the only way many water systems could meet the newest regulations.

Since 1996, however, the growth in energy use associated with advanced treatment technologies has not been as rapid as expected. Two developments have played a role in reducing the growth rate. First, a significant emphasis on energy efficiency has helped lower the growth rate. Second, technological advances in advanced treatment technologies have affected the growth in energy use. The renewed and broader focus on energy efficiency to address rising electricity rates and possible threats from greenhouse gas emissions is an important trend. Indeed, water treatment systems are attractive targets for energy efficiency initiatives, and many research efforts have taken place in the past 20 years on this subject. For example, the Consortium for Energy Efficiency (CEE) formed a Water and Wastewater Facility Initiative in 2002 to sustain focus on facility energy efficiency at both the national and local levels.[25] Other organizations, like the

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[24] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*, EPRI, Palo Alto, CA: 1996. CR-106941.

[25] *Water and Wastewater Initiative Summary Document*, Consortium for Energy Efficiency, no publication date, http://library.cee1.org/sites/default/files/library/2650/ww-init-des.pdf .

New York State Research and Development Authority (NYSERDA) and the Water Research Foundation (WaterRF), have published energy efficiency manuals.[26,27,28,29]

In spite of anticipated upward trends in electrical energy use for the treatment of drinking water, pumping continues to be the greatest electricity end-use in water treatment systems and remains the principal focus of energy efficiency efforts. Both raw water (i.e., source) pumping to transfer the water to the treatment facility, along with treated water pumping to distribution systems, are large energy-consuming processes. Current estimates vary depending on distribution system hydraulics but can range from 55% to 90% of overall electricity use. Chapter 6 includes a more detailed discussion of energy efficiency in water systems in general and pumping systems in particular.

The relative significance of different energy-using systems will vary depending on the system, yet a "typical" treatment system can be developed and presented. Figure 4-1 illustrates one approach that, based on certain key assumptions, shows the distribution of energy within the water treatment conveyance, treatment, and distribution cycle of a surface water system. The data in Figure 4-1 is not applicable to all water treatment systems, but instead provides context as to the energy issues within water treatment facilities. In this case, pumping finished water accounts for 67%, water treatment for 14%, raw water pumping for 11%, and in-plant water pumping for 8%. Groundwater systems typically have a different profile because the energy intensity for treatment is often negligible.

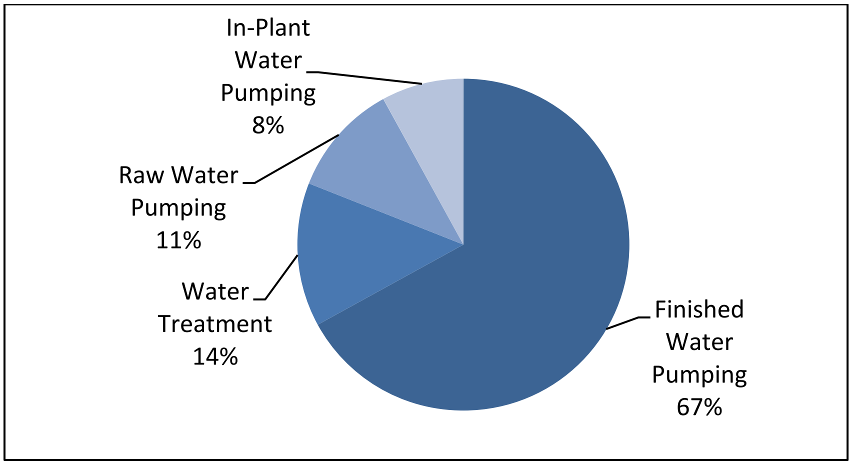

Figure 4-1
Typical Energy End-Uses in Public Surface Water System

Source: Keith Carns, EPRI Solutions, "Bringing Energy Efficiency to the Water & Wastewater Industry: How Do We Get There?," presented at *WEFTEC 2005*, Washington DC, November 2, 2005.

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[26] *Energy Efficiency Best Practices for North American Drinking Water Utilities,* Water Research Foundation and NYSERDA, Denver, CO: 2009.

[27] *Ensuring a Sustainable Future: An Energy Management Guidebook for Water and Wastewater Utilities*, U.S. EPA, Washington DC: January 2008. 832-R-08-002.

[28] *Water and Wastewater Energy Best Practice Guidebook,* Wisconsin Focus on Energy, Madison, WI: 2006.

[29] *Energy Audit Manual for Water/Wastewater Facilities*, EPRI, Palo Alto, CA: July 1994. CEC Report CR-104300.

While pumping is the predominant energy end-use, there continue to be advances in treatment technology that will impact overall energy use in water systems. In the past ten years, advances in material science have given competitive advantages to membranes as a water treatment option. The advances in membrane construction materials translate into lower operating pressures and, thus, lower energy costs for membranes, so membranes typically get a close look from treatment plant designers. Yet, even today's membrane systems require a substantial increase in electricity use relative to conventional treatment. As a result, membrane systems are installed only if there is a compelling reason for their use, such as restricted treatment plant sites or poor quality raw water sources like brackish water. Given a growing population and finite water supplies, wider use of membrane systems seems inevitable. Widespread membrane use for seawater desalination will have a significant impact on overall energy use by the public water supply industry. Under these dynamics, the pie chart in Figure 4-1 is likely to look considerably different in 20 years.

Energy Intensity of Water System Unit Operations

Water treatment systems vary in terms of treatment approaches and distribution system hydraulics, so it is difficult to develop energy use values that are widely applicable to all water treatment facilities in the U.S. Given the wide variability in treatment system design, reported values in the literature must be assessed cautiously. There are differences in terminology, data gathering techniques, and even such mundane issues as meter locations which drive differences in values. This section describes estimates for the electrical energy intensity associated with various common unit operations typically encountered in U.S. water treatment and distribution systems. The unit operations include raw water conveyance, various treatment operations, and distribution pumping.

The study team used EPRI's 1996 list of unit processes as basis for the development of the unit operations, but made some changes to better reflect current practices. For example, UV disinfection and membrane filtration were added as two new treatment options to reflect their widespread implementation. Moreover, several processes, such as rapid mix and flocculation, were combined or eliminated because they use little or no energy. (See Table 4-2 for unit processes included in this study.) The data used to develop the electric energy use estimates came from a variety of published sources, manufacturers' information, and practitioners' experiences. In most cases, the unit operation values are computed based on certain assumptions.

Given that energy use values for pumping are a function of system characteristics, a basis is needed for the assumed system characteristics used to develop "typical" values. One source is the U.S. Environmental Protection Agency (EPA), which hosts an energy data information tool known as Portfolio Manager on the Energy Star website (www.energystar.gov). Portfolio Manager is an on-line tool where users can store energy data and develop a benchmark of a facility based on the facility function and location. The Portfolio Manager system includes data from both water and wastewater treatment facilities. Researchers at Lawrence Berkeley National Laboratories (LBNL) used this data to develop weighted averages of various parameters as a function of treatment plant size.[30] Table 4-1 summarizes the weighted averages for water supply systems.

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[30] *Market Profiles Used in Energy Star's Portfolio Manager for Water and Wastewater Utilities*, Lawrence Berkeley National Laboratory, unpublished data from October 2012.

Table 4-1
Weighted Average Values for Water System Parameters from Filtered Energy Star Dataset

Average Daily Flow Range (MGD)	Energy Use Intensity (kWh/MG)	Water Main length (miles)	Distribution Pressure (psia)	Source Water Distribution		
				Ground Water	Surface Water	Purchased Water
< 3	2,000	126	67	32%	41%	27%
3-5	1,400	138	69	31%	32%	36%
5-20	1,600	346	72	28%	39%	33%
20-600	1,500	2,700	62	7%	68%	25%

Data source: Lawrence Berkeley National Laboratories, “Market Profiles Used in Energy Star’s Portfolio Manager for Water and Wastewater Utilities”, unpublished data from October 2012.

For the current report, the study team developed estimates of electric energy intensity for raw surface water pumping and all unit processes for average flow rates of 1, 5, 10, 20, 50, 100, and 250 MGD. Please note that the average flow rate is not the plant capacity, which is oftentimes twice the average rate or greater. Treatment plant unit processes are typically sized to handle additional flow to account for population growth and other factors. Treated surface water pumping is based on a discharge pressure of approximately 65 psia (448 kPa), but this varies slightly with average flow (see Table 4-1).

Electricity use estimates have also been made for groundwater pumping systems having an average flow rate of 1, 5, 10, and 20 MGD. The energy use estimates are based on use of a well pump with an average lift of 150 ft (45.7 m) from the groundwater table to a ground level storage tank, a distribution system booster pump having a discharge pressure of 65 psia (448 kPa), and chlorination (see Figure 2-3 for a schematic and for a schematic and Table 4-2 for electric energy use intensity values).

The electricity use calculations for water treatment are based on process operations only. Building electricity uses, such as lighting, air conditioning, and office equipment are separate. These uses are typically small compared to process energy use, and in most cases much of the water treatment process occurs in outdoor locations. For smaller plants (<1 MGD) in colder climates, building energy use can account for a significant share of total energy use (30% or more) and should not be ignored.[31]

Table 4-2 presents the electric energy use intensity values for pumping and water treatment processes for a range of treated water flows. Specific unit processes include raw water and distribution system pumping as well as membrane filtration (e.g., microfiltration, ultrafiltration, and reverse osmosis), ozonation, and various other treatment technologies. The values represent the total kilowatt hours used by the process per day.

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[31] Information provided by Bonneville Power Administration Energy Smart Industrial Layne McWilliams and Dawn Lesley on behalf of Jennifer Eskil.

Table 4-2
Estimates of Electric Energy Intensity of Public Water Supply Unit Processes (in kWh/day)

Unit Process	Plant Production (MGD)						
	1	5	10	20	50	100	250
Source Water Pumping							
Raw surface water pumping	145	725	1,450	2,900	7,250	14,500	36,225
Raw groundwater pumping	920	4,600	9,225	18,500	N/A	N/A	N/A
Clarification							
Rapid mixing	40	175	310	620	1,540	3,080	7,700
Flocculation	10	50	90	180	450	900	2,260
Sedimentation	15	45	90	175	440	875	2,190
Chemical feed systems	65	65	65	65	65	65	65
Microfiltration (in lieu of sedimentation)	100	500	1,000	2,000	5,000	10,000	25,000
Ultrafiltration (contaminant removal)	800	4,000	8,000	16,000	40,000	80,000	200,000
Reverse Osmosis (brackish water)	6,000	29,800	59,500	119,000	226,600	453,200	738,400
Reverse Osmosis (ocean water)	12,000	60,000	120,000	240,000	600,000	1,200,000	3,000,000
Dissolved air flotation	110	895	1,790	3,600	8,950	17,900	44,700
Air stripping	375	1,850	3,740	7,475	N/A	N/A	N/A
Repumping within treatment plant	0	0	0	0	1,950	3,900	9,750
Filtration & Solids Handling							
Backwash water pumps	15	60	125	250	660	1,290	3,220
Residuals pumping	4	20	40	80	200	400	1,000
Thickened solids pumping	0	0	0	125	310	620	1,540
Disinfection, Pumping & Nonprocess Loads							
Onsite chlorine generation for disinfection	85	420	830	1,670	4,160	8,325	20,820

Unit Process	Plant Production (MGD)						
	1	5	10	20	50	100	250
Ozone disinfection	140	560	1,125	1,500	3,840	7,670	19,175
UV disinfection	62	310	625	1,250	3,120	6,240	15,600
Finished water pumping	1,040	5,325	11,040	21,560	48,775	97,550	243,870
Nonprocess loads (buildings, HVAC, lighting, computers, etc.)	300	1,200	2,100	3,600	9,000	18,000	45,000

The study team made several assumptions in developing the unit intensity values shown in Table 4-2. The subsections that follow highlight some of the more significant assumptions as they relate to three key unit processes: pumping, membrane filtration (including desalination), and ozonation.

Pumping

Data from Table 4-1 and discussions with industry experts formed the basis for development of the pumping electric energy use intensity values presented in Table 4-2. Pumping electricity estimates are a function of the flow, an assumed distribution system pressure head, and an assumed wire-to-water efficiency, which is the overall efficiency of the pump and motor combination, accounting for friction and motor losses along with any other inefficiencies. For estimating purposes, the study team assumed that a wire-to-water efficiency of all pumping systems of approximately 65%. This value reflects what is commonly observed in practice. Computing pumping electricity estimates is a straightforward process using the following equation:

Electricity (kWh/day) = ((Flow (gpm) x pumping head (in feet)) / (3960 x pumping efficiency)) x 0.746 x 24

Except in cases with electric-intensive treatment processes, most electric energy use at a water treatment facility occurs within the pumping stations. Therefore, efficiency of the pumping system has a significant effect on overall electric energy use. Given the importance of pumping energy on overall energy use in the drinking water treatment process, the study team determined it would be informative to present three values based on efficiency—low, medium, and high—for each water flow rate to illustrate a range of electric energy use associated with the pumping unit processes. As discussed above, the pumping values listed in Table 4-2 assumed a wire-to-water efficiency of 65%. In real-life operations, the efficiency value can vary from 50% or less to more than 75%. Table 4-3 presents energy use estimates for finished water pumping for three wire-to-water efficiencies: 50%, 65%, and 75%. These detailed values can be used to estimate pumping electricity use at plants with higher or lower system efficiencies than the average.

Given the large impact of pumping on overall system energy use, energy efficiency improvements should begin at the pumping systems. Table 4-3 clearly suggests that modest improvements from low (i.e., 50%) wire-to-water efficiency to medium (i.e., 65%) wire-to-water efficiency can save significant energy. In the case of a 100 MGD water treatment system, savings would be nearly 24,000 kWh per day, or about $1,680 per day at an electric rate of $0.07/kWh. Energy management in water treatment facilities will be considered in greater depth in Chapter 6.

Table 4-3
Source Water and Finished Water Pumping Intensity as a Function of Pumping Efficiency (in kWh/day)

Unit Process	Pumping Efficiency[a]	Plant Production (MGD)						
		1	5	10	20	50	100	250
Raw water pumping, surface plant	High	118	589	1,177	2,355	5,887	11,774	29,435
	Medium	145	725	1,449	2,898	7,246	14,491	36,228
	Low	188	942	1,884	3,768	9,419	18,838	47,096
Raw water pumping, groundwater plant	High	750	3,748	7,496	14,992	N/A	N/A	N/A
	Medium	923	4,613	9,226	18,452	N/A	N/A	N/A
	Low	1,199	5,997	11,994	23,988	N/A	N/A	N/A
Finished water pumping	High	845	4,328	8,969	17,520	39,629	79,257	198,143
	Medium	1,040	5,327	11,038	21,563	48,774	97,547	243,868
	Low	1,352	6,925	14,350	28,032	63,406	126,811	317,029

[a] Pumping efficiency is “wire-to-water,” not motor efficiency; high=75%, medium=65%, low=50%

Membrane Filtration and Desalination

Energy use associated with membrane filters is largely dependent on operating pressure, with the higher-pressure systems (like reverse osmosis) using the most energy. Microfiltration (MF) and ultrafiltration (UF) use approximately 0.1 and 0.8 kWh/1000 gallons, respectively.[32] Under most circumstances, the pressure range used for both MF and UF is relatively narrow, so the assumed electric energy use values in Table 4-2 are appropriate. Reverse osmosis, on the other hand, has a much broader pressure range that is mostly a function of the salinity of the feed water. Desalination of a brackish water source, where total dissolved solids is around 5,000 mg/L, will require less pressure (and thus less energy) than desalination of ocean water, where salinity exceeds 30,000 mg/L. Given this difference, the estimates in Table 4-2 are based on average feed water pump power use from a planning document from the U.S. Bureau of Reclamation, or approximately 1.4 kWh/1000 gallons.[33]

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[32] *The Desalting and Water Treatment Membrane Manual: A Guide to Membranes for Municipal Water Treatment*, EPRI, Palo Alto, CA: 1999. TR-112644.

[33] *Desalting Handbook for Planners*, 3rd edition, Table 4-9, U.S. Bureau of Reclamation, Springfield, VA: July 2003, , http://www.usbr.gov/research/AWT/reportpdfs/report072.pdf.

Some estimates suggest that ocean water desalination provides drinking water to as many as 9 million people in the U.S., or almost 3% of the population.[34] Desalination is a very energy-intensive process, so its impact is included in the estimation of total electricity use by the U.S. water treatment industry in the last section of this chapter. Desalination energy intensity is a function of feed water salinity, age of the membranes, and membrane throughput (i.e. concentrate flow). Values in the literature range from 6,000 to over 18,000 kWh/MG; a value of 12,000 kWh/MG is used in our national estimate. Chapter 6 includes a discussion of the strategies employed to reduce energy use in ocean water desalination.

Ozonation

Another unit process where electricity use is highly dependent on raw water quality is ozonation, which is used in water treatment both for disinfection and oxidation purposes. Applied ozone dosages typically range from 1 to 5 mg/L. The assumed value for the applied dose was 3.0 mg/L in the development of Table 4-2.

Ozone energy intensity can also vary as a function of certain system design considerations, such as the use of air or oxygen as a feed gas, the method used to apply the ozonated gas to the process stream, and (in the case of oxygen) if the oxygen is generated onsite or delivered. Though ozone generated from oxygen has a smaller specific energy, because the ozone concentration of the supply gas rises, the purchase or generation of oxygen onsite entails a sophistication and complexity that is often beyond the capabilities of smaller facilities. As a result, ozone is typically generated from air in smaller plants while ozone generated from oxygen (also generated onsite) is most economical in facilities treating in excess of 20 MGD. Estimates in Table 4-2 are based on an assumed specific energy of 10 kWh/1000 gallons for plant flows less than 20 MGD and a specific energy of 5 kWh/1000 gallons for plant flows greater than 20 MGD. These values correspond to energy intensity numbers developed by WaterRF.[35] There is often significant room for energy efficiency improvements in ozone operations, including optimizing the generation of oxygen (if applicable) and ozone, and the application of the gas into the treated water.

Example Uses of Energy Intensity Values

The study team developed Table 4-2 and Table 4-3 to help plant personnel and other interested parties in estimating the composite energy use for hypothetical water treatment systems by aggregating appropriate unit processes. Figure 4-2 illustrates the process, which begins with selection of the plant size (MGD) and the water source and ends with aggregation of the corresponding electric energy intensity values, from Table 4-2 and Table 4-3, for each unit process in the system.

The examples below describe development of composite energy use values for five hypothetical water treatment systems commonly encountered in the U.S. The descriptions and associated flow

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[34] *Desalination: A National Perspective*, National Research Council of the National Academies, Washington D.C.: 2008, ISBN 10:0-309-11924-3, http://www.waterwebster.com/documents/NRCDesalinationreport_000.pdf.

[35] *Evaluation of Dynamic Energy use of Advanced Water and Wastewater Treatment Technologies*, WaterRF and California Energy Commission, Denver, CO: 2008, ISBN 978-1-60573-033-2, http://www.waterrf.org/PublicReportLibrary/91231.pdf.

charts illustrate the manner in which the values were developed. Analogous approaches can be used to build composite energy use values for other types of water treatment systems. Table 4-4 presents a summary of these examples.

Figure 4-2
Process for Estimating Electricity Use for Hypothetical Water Treatment Systems

Table 4-4
Summary of Water Treatment Facility Examples

Treatment Plant Description	Total Daily Electricity (kWh/d)	Electric Energy Intensity (kWh/MG)
Example 1: 18 MGD conventional treatment plant treating surface water	25,605	1,420
Example 2: 80 MGD lime soda softening plant treating surface water	140,389	1,760
Example 3: 8 MGD ultrafiltration plant treating surface water using UV disinfection	20,067	2,510
Example 4: 14 MGD groundwater plant using aeration	30,970	2,210
Example 5: 4 MGD desalination plant treating ocean water	54,247	13,600

Example 1: Conventional Treatment Plant Treating Surface Water

This water system treats an average of 18 MGD of water from a reservoir with conventional water treatment, including flocculation, sedimentation, filtration and chlorine disinfection, and using alum as a coagulant. Figure 4-3 illustrates the components of this system. The treatment system delivers water to a single distribution zone at approximately 75 psig, which is typical for water treatment systems. The efficiency of the pumping systems is considered "medium" (i.e., 65%), with many components 15 to 20 years old or more. Plant staff maintains the system with diligence. To develop an energy estimate, the user needs to interpolate values between the 10 MGD and 20 MGD columns in Table 4-2 for source water pumping, rapid mixing, flocculation, sedimentation, chemical feed systems, backwash water pumps, residuals pumping, thickened solids pumping, finished water pumping, and nonprocess loads. The total of these electric energy intensity values leads to an average electricity use of 25,605 kWh/day, which is equivalent to about 1,420 kWh/MG.

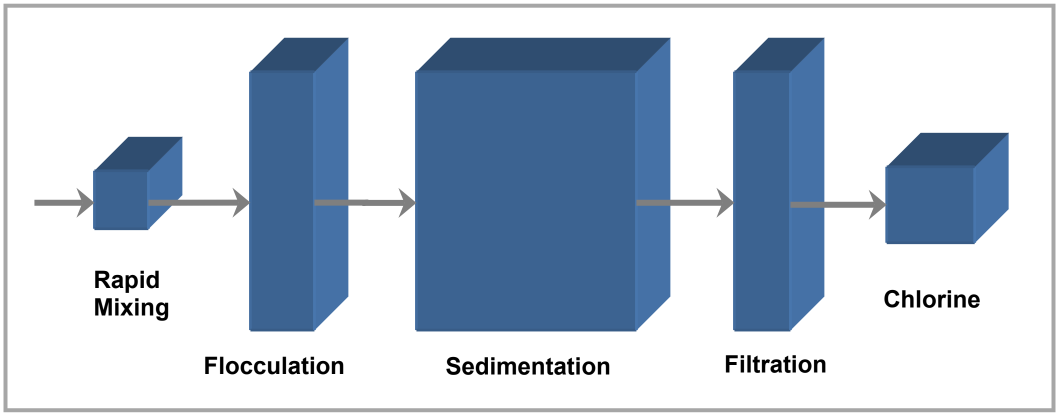

Figure 4-3
Unit Operations in Example 1: Conventional Treatment Plant Treating Surface Water

Example 2: Lime Soda Softening Plant Treating a Surface Water Source

The second water system treats an average of 80 MGD of surface water using a lime soda softening process. Figure 4-4 illustrates the components of this system. The water system has several areas of deferred maintenance and is currently in need of a complete overhaul of its pumping system, which is operating at a low efficiency. The user can develop a more specific energy estimate for the treatment system by interpolating from the values presented under the columns for flow rates of 50 MGD and 100 MGD for rapid mixing, flocculation, sedimentation, chemical feed systems, re-pumping within the plant, backwash pumps, residuals pumping, thickened solids pumping, and nonprocess loads. In addition, to account for the poor condition of the pumps, the user should interpolate for the source water and finished water values for "low" efficiency pumping (i.e., 50%) in Table 4-3. Adding these values produces a total expected electricity use of 140,389 kWh/day, which is equivalent to approximately 1,760 kWh/MG. The lower energy intensity value of example 1 compared to example 2 is directly related to the greater pumping efficiency.

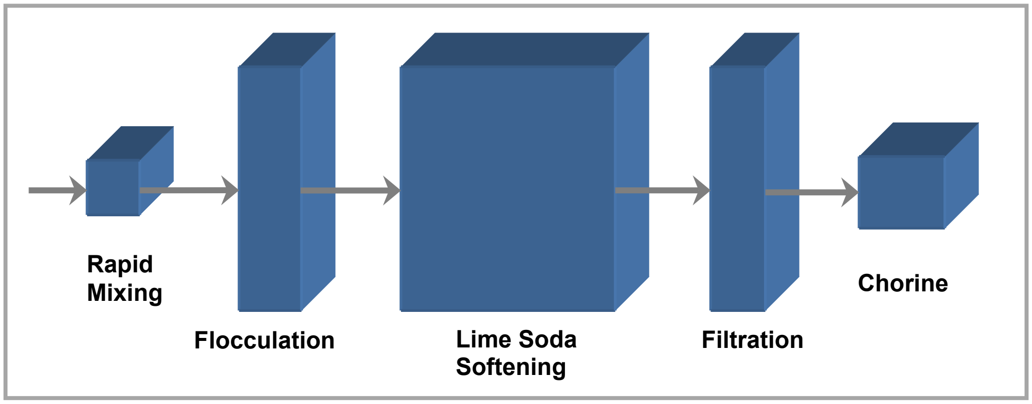

Figure 4-4
Unit Operations in Example 2: Lime Soda Softening Plant Treating Surface Water

Example 3: Membrane Clarification Plant Treating Surface Water Using UV Disinfection

The third plant treats 8 MGD of surface from a reservoir using membranes (in this case ultrafiltration) followed by UV and chlorine disinfection for the distribution system. Figure 4-5 illustrates the components of this system. The surface water pumping system is typical, with "medium" wire-to-water pump efficiency. The ultrafiltration (UF) system operates at modest pressure (20-40 psi) and is equipped with a variety of chemical feeds for water pretreatment and membrane cleaning. Residuals are discharged to lagoons. Using the data in Table 4-2, the total daily electrical use of the plant adds up to 20,067 kWh, or about 2,510 kWh/MG. This includes the electricity use associated with raw water pumping, rapid mixing, chemical feed systems, dissolved air flotation, UF, backwash pumping, residuals pumping, UV disinfection, finished water pumping, and no-process loads. While UV disinfection adds only a modest amount of electricity, the membrane filtration's effect on overall electricity use is significant, accounting for about 30% of total plant electricity use

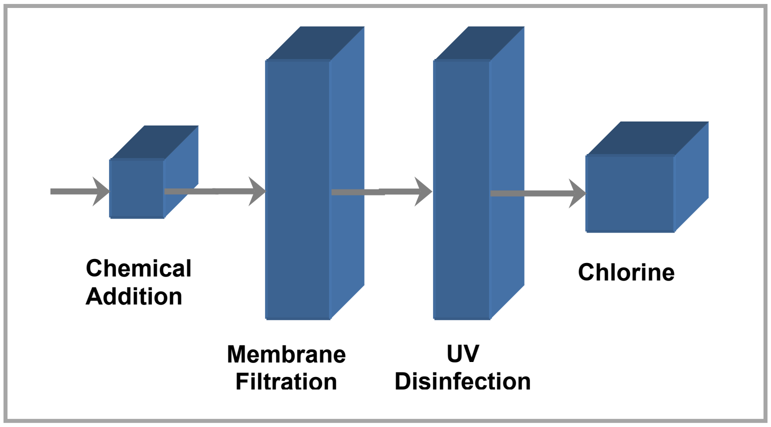

Figure 4-5
Unit Operations in Example 3: Membrane Clarification Plant Treating Surface Water Using UV Disinfection

Example 4: Groundwater Plant Using Aeration to Remove Iron and Manganese

The fourth example is a groundwater treatment plant with an average flow of 14 MGD using aeration to remove iron and manganese, followed by UV disinfection. Figure 4-6 illustrates the components of this system. Aeration is a common unit process in drinking water facilities treating groundwater. The aeration process is relatively simple, as it involves lifting the water high into a contact chamber and mixing it with air to bring the dissolved iron and manganese out of solution. It adds little by way of additional electricity use. The process involves very little chemical addition but additional pumping. Using the data in Table 4-2 and interpolation between 10 and 20 MGD for groundwater pumping, chemical feed system, thickened solids pumping, UV disinfection, finished water pumping, and nonprocess loads, the daily use estimate is 30,970kWh or about 2,212 kWh/MG. It would be appropriate to add an additional 3-5% of the pumping electricity use estimate to account for aeration, which is not specifically noted in Table 4-2. Thus, the total daily electricity use could range as high 31,610 kWh, or roughly 2,260 kWh/MG. This example demonstrates that electricity use in facilities treating groundwater is a function of pumping.

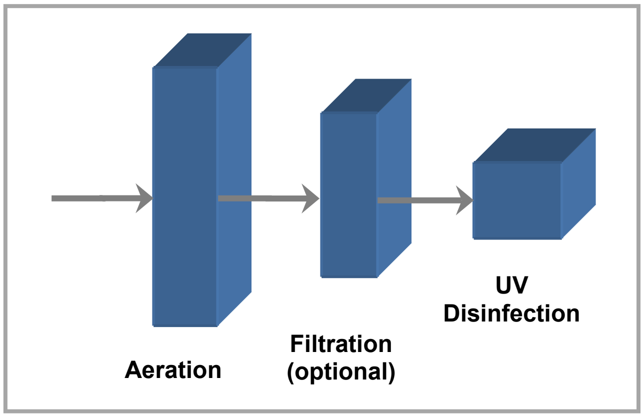

Figure 4-6
Unit Operations in Example 4: Groundwater Plant Using Aeration to Remove Iron and Manganese

Example 5: Desalination Plant

The final example is a small treatment plant desalinating approximately 4 MGD of ocean water. In a desalination plant, pretreatment is necessary and typically includes chemical addition for descalants along with some sort of media filtration. The greatest energy use is associated with the reverse osmosis membranes, but the brine must be disposed of so there are energy required for backwashing and residuals pumping. Using the data in Table 4-2, the daily electric energy use estimate is 54,247 kWh or about 13,600 kWh/MG. Few municipalities would build such a plant given the extraordinary electricity costs associated with its continued operation. Instead, many agencies search for a nearby water source with lower TDS levels. For instance, in North Carolina's Outer Banks there are few alternatives to ocean desalination, but the water agency installed deep wells using brackish water, lowering TDS levels of the raw water from 33,000 mg/L to approximately 6,000 mg/L.

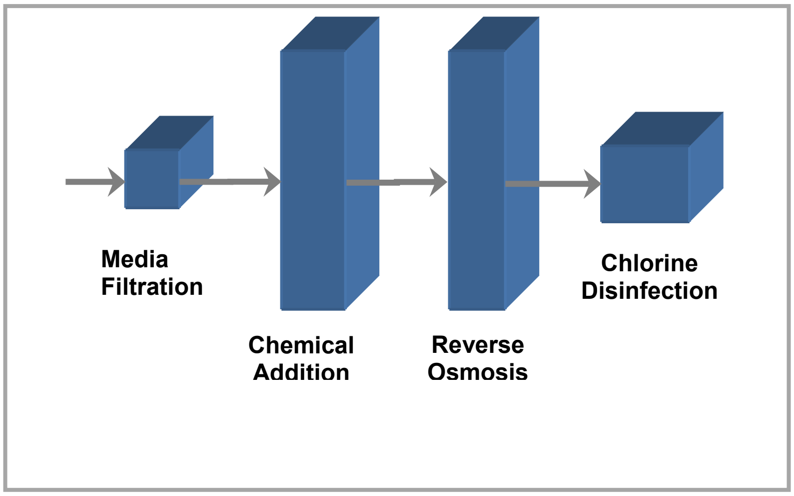

Figure 4-7
Unit Operations in Example 5: Desalination Plant

Estimated U.S. Electricity Use in Public Water Supply

As noted in Table 2-1, there are over 150,000 public water systems in the U.S. About one-third of these systems (or 51,000) are community water systems, which serve roughly 96% of the U.S. population year round. The U.S. Geological Survey estimated in 2005 that public water withdrawals account for 11% of the total of 410,000 MGD of water withdrawn, or approximately 44,200 MGD.[36] Based on an estimated population of 258 million people served during 2005, the usage figure translates into a U.S. per capita use of 171 gallons per day (see Chapter 2 for more details). These data are the basis for national electrical energy use estimates for public water supply.

Summary of Prior Electric Energy Intensity Estimates

EPRI's 1996 estimate of water treatment system intensity was 1,400 kWh/MG.[37] Since publication of that study, several other groups produced estimates. A principal aim of this current study is to refine that initial estimate through a combination of literature reviews, discussions with industry experts, and calculations based on common assumptions. Table 4-5 summarizes several estimates identified during a literature review. The estimates are based on a variety of data-gathering techniques over a wide geographical area. The variability among the studies presents challenges in comparing this information. In some cases, energy use intensities are divided by source water pumping, treatment and distributed water pumping; however, in others a single value is given. Other studies focused on smaller treatment plants or are limited to certain geographic areas. Nevertheless, some comparisons are possible.

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[36] *Estimated Use of Water in the United States in 2005*, U.S. Department of the Interior, U.S. Geological Survey, Circular 1344, Reston, Virginia: 2009, http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf

[37] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*, EPRI, Palo Alto, CA: 1996. CR-106941.

Table 4-5
Estimates of Average Electric Energy Intensity of Public Water Supply and Corresponding Distribution

Reference Source	Year	Total Intensity (kWh/MG)	Relative Percentage of Energy Expended			Comment
			Raw Water Pumping	Treatment	Distribution	
1996 EPRI Report[a]	1996	1,400	9%	6%	85%	Initial report
Massachusetts Dept of Environmental Protection[b]	2008	1,500	N/A			Estimate of MA plants only
Energy Center of Wisconsin[c]	2003	1,900	N/A			Survey of WI plants only
WaterRF US Study[d]	2007	1,900	44%	33%	14%	[e]
U.S. Geological Survey[f]	2000	1,936	N/A			[g]
Iowa Study[h]	2002	2,770	86%[i]		14%	Survey of IA plants only
California Energy Commission (Northern California)[j]	2006	3,500	60%	3%	36%	Included "embedded energy" not metered
California Energy Commission (Southern California)[j]	2006	11,110	88%	1%	11%	Included "embedded energy" not metered
Average (with CEC Studies)		**3,253**	**40%**	**26%**	**34%**	
Average (without CEC Studies)		**1,903**	**18%**	**42%**	**41%**	

[a] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*, EPRI, Palo Alto, CA: 1996. CR-106941.

[b] *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities*, U.S. Environmental Protection Agency, Washington D.C: 2008.

[c] *Energy Use at Wisconsin's Drinking Water Facilities*, Energy Center of Wisconsin, Madison, WI: 2003.

[d] *Energy Index Development for Benchmarking Water and Wastewater Utilities*, WaterRF, the California Energy Commission and The New York State Energy Research and Development Authority, Denver, CO: 2007.

[e] Values interpolated from report charts available in Energy Index Development for Benchmarking Water and Wastewater Utilities, WaterRF, 2007.

[f] *Estimated Use of Water in the United States in 2000*, U.S. Department of the Interior, U.S. Geological Survey, Circular 1268, Reston, Virginia: 2005.

[g] Calculated using a total electric energy use value of 30.6 billion kWh for public water supply utilities and water supply data of 43.2 BGD in 2000.

[h] *Energy Consumption and Costs to Treat Water and Wastewater in Iowa, Part I: An Overview of Energy Consumption and Treatment Costs in Iowa,* Iowa Association of Municipal Utilities, 2002.

[i] Represents relative distribution of combined raw water pumping and treatment.

[j]. *Refining Estimates of Water-Related Energy Use in California*, California Energy Commission, Public Interest Energy Research Program, Prepared by Navigant Consulting. Sacramento, CA: 2006. CEC-500-2006-188.

Table 4-5 includes the geographical focus of each estimate, including Northern California, Southern California, Wisconsin, Iowa, Massachusetts, and national estimates by the U.S. Geological Survey and the Water Research Foundation (WaterRF). If the two estimates for California are excluded, the total energy intensity values average 1,900 kWh/MG, and the range of values is consistent.

The estimates for Northern and Southern California are significantly different from the other values because of California's unique situation. The California study was conducted by staff of the California Energy Commission with a focus on identifying the relationship between energy use and water conveyance, treatment, and use in California. The most populated portions of Southern California, including Los Angeles and San Diego, are desert climates with little in the way of local water resources. Water for those portions of the state must be imported from the Colorado River and from the mountains of northern California through the State Water Project. In both cases of the Colorado River and the State Water Project, large quantities of water are pumped long distances, necessitating the use of large amounts of electricity in source water conveyance.

The California Energy Commission determined that the majority of energy use in both Northern and Southern California is for conveyance of the raw water from its source to water treatment facilities near the population centers. While this is an interesting case study of the energy impact of municipal water and wastewater, the energy intensity values are somewhat unique and so should be used cautiously when applied to the rest of the U.S.

Other studies listed in Table 4-5 have some limitations, too. For instance, the researchers in Wisconsin generated their database through a survey of water plants throughout the state, yet the vast majority of the respondents were very small systems, with most having capacities less than 5 MGD. The USGS intensity value is a gross approximation based on imprecise estimates of both energy use and estimated raw water pumping values. Iowa's municipal water suppliers treat small volumes but maintain large distribution networks, which leads to unique challenges in pumping treated water. The data in Table 4-5 reemphasizes the importance of pumping in water treatment system energy use data, but the averages should be used cautiously.

The challenge of quantifying energy use in the water industry is complicated by a lack of standardized terminology in reporting utility information. For instance, there is no clear distinction between pumping energy for each stage in the water supply process. In general, water must be pumped to the treatment plant where the water then flows through the treatment process unit operations by gravity before the finished (i.e., treated) water is pumped again to the distribution system. However, pumping performed during the "treatment" processes can also complement the "distribution" function, particularly in smaller facilities (less than 5 MGD).

The Water Research Foundation (WaterRF) developed an alternative approach to develop appropriate energy metrics.[38] This method is principally focused on pumping energy. The equation includes values for total system flow, purchased water flow, total pumping horse power,

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[38] *Energy Index Development for Benchmarking Water and Wastewater Utilities*. Joint publication of WaterRF, the California Energy Commission and The New York State Energy Research and Development Authority, Denver, CO: 2007.

production pumping horsepower, distribution system main length, and distribution system elevation change. The authors conducted a literature survey to gather primary data in developing the model. Their data set included information from a 1996 American Water Works Association survey of treatment facilities (AWWA Water:\Stats), along with the documents summarized in xx. The data in the AWWA database is self-reported so the data precision is unknown.

The WaterRF approach has considerable merit, particularly for utilities interested in developing benchmarks for an existing system. It enables a facility to develop a more precise benchmark for its system, and reinforces the importance of pumping of finished water in overall electricity use in water utilities.

Development of a National Estimate

The water source estimates from the USGS Water Survey were coupled with estimates for electric energy use in treatment systems and with water use and population data to develop estimates for nationwide electric energy use. Additionally, desalination energy estimates are included due to its large impact on total energy use.

A small but growing percentage of the surface water sources are either brackish or ocean water and thus must be desalinated. Desalination exerts a tremendous energy cost, on average exceeding 12,000 kWh/million gallons. Various estimates exist on the amount of desalination used in the U.S. According to the International Desalting Association, there were about 1,500 MGD of desalination plants in operation in the U.S. by 2005,[39] which represents approximately 4% of water supply systems. Based on this figure and estimates by others of the continued growth in desalination, we assumed that 3.3% of the surface water capacity in the U.S. is from desalination.

Table 4-6 summarizes the national estimate of total electrical use by the public water supply industry. Using estimated values of 1,600 kWh/MG for surface water plants, 2,100 kWh/MG for groundwater plants, and 12,000 kWh/MG for desalination plants, the study team approximates total electrical energy used by public water supply systems in the U.S. is 107.5 million kWh per day, or 39.2 TWh per year (1 TWh equals 1,000,000 MWh). This estimate represents an increase of nearly 39% relative to the value provided in the original 1996 EPRI report, which was 28.3 TWh per year. Given that the total amount of electricity used in the U.S. was 3,856 TWh in 2011,[40] public water supply systems account for about 1% of overall electricity use in the U.S.

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[39] *Desalination: A National Perspective*, National Research Council of the National Academies, Washington D.C., 2008, ISBN 10:0-309-11924-3.

[40] *Annual Energy Review*, U.S. Energy Information Administration, U.S. Department of Energy, Washington DC: September 2012. Table 8-1. http://www.eia.gov/totalenergy/data/annual/index.cfm.

Table 4-6
Estimated Electric Energy Use by the U.S. Public Water Supply Industry in 2011[a] by System Type and Source Water

System Type	Source	kWh/MG	Estimated Population Served	gpcd	kWh/day
Community	Surface	1,600	199,827,000	171	54,672,700
	Groundwater	2,100	88,370,000	171	31,733,700
	Desalination	12,000	9,416,000	171	19,321,500
Non Community	Surface	1,600	5,354,000	171	1,464,850
	Groundwater	2,100	855,000	171	307,000
Total per day			**107,500,000**		
Total per year			**39.2 TWh[b]**		
Percentage of total U.S. electricity used in 2011			**1%**		

[a] 2011 is the latest year for which population served by water system type is available.

[b] TWh is terawatt hours. One (1) terrawatt hour is equal to 1,000,000 megawatt hours.

Estimates may not add to 100% of totals presented elsewhere due to rounding.

5

ELECTRICITY USE IN MUNICIPAL WASTEWATER TREATMENT SYSTEMS

This chapter considers electricity use in the collection, treatment, and discharge of municipal wastewater in the U.S. The first section of the chapter summarizes current energy use trends in municipal wastewater collection and treatment systems. The second section focuses on expected electric energy intensities for typical and emerging unit processes and includes examples of how to use the unit process estimates to develop facility-wide energy use estimates for a few hypothetical wastewater treatment plants. The final section provides an estimate of nationwide electric energy use associated with municipal wastewater treatment using the data presented in the first two sections.

Current Energy Use Trends

While energy use in drinking water supply systems is principally a function of pumping energy, energy use associated with wastewater treatment systems is more closely related to wastewater treatment needs. Initially, wastewater treatment systems practiced only primary settling and minimal disinfection prior to discharge to receiving waters, but regulations associated with the Clean Water Act in 1972 have led to most treatment plants now providing secondary treatment at a minimum. Secondary treatment usually includes aeration to promote the formation of the microbial populations responsible for removing dissolved organic matter. Aeration is a highly energy intensive process. As a result, aeration is the principal energy-using process in wastewater treatment. Subsequent amendments to the Clean Water Act in the 1980's authorized $18 billion in construction grants, leading to significant expansion of new treatment systems in the following two decades.

More recently, with greater attention on energy efficiency and greenhouse gas emissions, there is a renewed emphasis on maximizing the recovery of the energy available in wastewater. This attention manifests itself in a variety of governmental and non-governmental programs. For instance, the U.S. EPA sponsors a combined heat and power (CHP) initiative which promotes the adoption of CHP technology by U.S. industry. One of the initiative's target industries is wastewater treatment plants because, according to the EPA, one MGD of influent flow equates to 26 kW of electric capacity and 2.4 MMBtu/day of thermal energy.[41] Thus, a primary trend in the U.S. wastewater treatment industry is a focus on energy efficient operation combined with approaches to recover energy from the wastewater stream.

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[41] *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field*, U.S. EPA Combined Heat and Power Partnership, Washington D.C.: October 2011, http://www.epa.gov/chp/documents/wwtf_opportunities.pdf .

Growth in Treatment Levels Across U.S.

As explained in Chapter 3, while the number of treatment systems fell by about 5% since the late 1980's, the treated wastewater volume rose from 28,000 MGD to approximately 32,200 MGD, which is a 13% increase. (The increase is likely greater because the 1980's value is design capacity, which is greater than actual flow.) More importantly from an energy use standpoint, the number of facilities employing processes greater than secondary treatment grew by 48% between 1998 and 2008. As processing needs become more stringent, the energy required to achieve desired water quality increases. Future advances in treatment requirements should be expected, suggesting that energy requirements will grow. However, the wastewater treatment industry continues to develop advances in treatment technology to reduce energy inputs while improving plant performance. Chapter 6 provides examples of some of these advances.

There are significant variations in treatment approaches and treatment objectives across the U.S. These differences are difficult to generalize because they can vary significantly even within individual states and are often driven by the condition of local water resources. Those regions with valuable or pristine water resources typically have more stringent regulatory requirements. In general, those places with significant population growth during the 1990's and 2000's tend to have more advanced wastewater treatment systems than those regions with less growth. Thus, it is not atypical to find advanced and energy-intensive wastewater systems in urban and suburban portions of the country and less energy-intensive systems in rural portions of the country.

One area of wastewater treatment that grows continually and will impact electricity use is the capture and treatment of stormwater flows. Combined sewers are a particularly expensive problem plaguing many U.S. communities. Large rainfall events overwhelm the capacity of the sewers and, in many locations, diluted sewage flows directly to receiving streams without any treatment. The U.S. EPA is forcing many of these communities into consent decrees which will raise energy use and treatment costs.

One common strategy is storage of the excess flow in pipes and tunnels followed by slow treatment in the wastewater facility. This results in a rise in average daily flow, as water previously discharged without treatment is now slowly released into the plant for processing. This, in turn, results in increased energy use. Another strategy for stormwater management involves installing decentralized treatment systems at overflow points. Focused discussion of this topic is beyond the scope of this report, but the reader should understand that the impact of stormwater management on wastewater energy use in the future will be significant.

Energy Recovery Potential

While energy recovery potential exists in wastewater treatment through the recovery of pumping energy, under many circumstances it is not currently economically viable. On the other hand, biogas recovery is an accepted and widely implemented practice in the wastewater treatment industry. The most common biogas recovery path is capture of methane generated during the anaerobic digestion of biosolids. Biosolids contain significant quantities of organic material which is stabilized through anaerobic digestion, and in the process produces methane. Typically, the biogas is used to heat the digester or provide seasonal heating.

More recently, practitioners have recognized the potential of biogas recovery for electricity production. The EPA estimates the theoretical potential energy that can be recovered from biogas from all wastewater treatment plants greater than one MGD exceeds 400 MW of electricity and nearly 38,000 MMBtu/day of thermal energy.[42] For electric utilities interested in diversifying their generation portfolio with renewables in an industry which cannot be moved overseas or otherwise "downsized," combined heat and power (CHP) systems at wastewater treatment facilities is unexplored territory deserving of more scrutiny. However, installing CHP systems in wastewater treatment facilities presents a number of economic and administrative challenges, which are beyond the scope of this report.

Though methane production is generally recognized as a useful benefit, it is not the primary focus in digestion because the principal goal of anaerobic digestion is to render the biosolids pathogen-free. In most instances, the methane gas is either used for fairly low-energy purposes (such as heating the digester) or flared. In order to use it for beneficial purposes, it must be cleaned, and these material handling requirements make its capture and reuse more challenging economically. Figure 5-1 shows a biogas cleaning system for a CHP installation in Minnesota. More recently, practitioners are increasingly reviewing digester operations to achieve the twin objectives of both inactivating the biosolids and maximizing methane production. Chapter 7 includes a case study of one such approach at the East Bay Municipal Utility District in Oakland, California.

Figure 5-1
Biogas Cleaning System for CHP Installation at Albert Lea, MN WWTF

Courtesy of Albert Lea, MN

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[42] Ibid. (EPA, 2011)

There is additional energy recovery potential in wastewater. Raw wastewater returns to the treatment plant at a relatively constant temperature, which is maintained throughout the treatment process. At a minimum, heat pumps can capture the energy from the wastewater stream for facility (and digester) heating and cooling needs. In fact, plant effluent is very clean, and should not present problems for cross contamination.

Water reuse also presents significant energy optimization potential. Highly treated wastewater is often released back to the natural environment where it is typically diluted with water of lower quality (e.g. a river or creek). Further downstream, the water is withdrawn again for treatment in a drinking water facility. The energy benefits of water reuse cannot be understated and are worth a very close look in water-short portions of the U.S. This is especially true in those regions, such as Southern California, where an expensive option like ocean water desalination is under serious consideration**.**

Figure 5-2 presents a typical breakdown of energy using processes in wastewater treatment plant. Hazen & Sawyer, a well-known engineering consulting firm, developed this pie chart based on results of energy audits conducted at numerous wastewater treatment facilities, so the values represent averages across many different types of facilities. Others have developed graphs suggesting similar percentages for energy end uses in wastewater treatment.[43] As with the information presented in Chapter 4 on public water supply systems, these data provide initial guidance in evaluating energy use, but the values should not be used as a benchmark for any specific facility. Instead, the information guides the user on what processes to consider when developing procedures to reduce energy use.

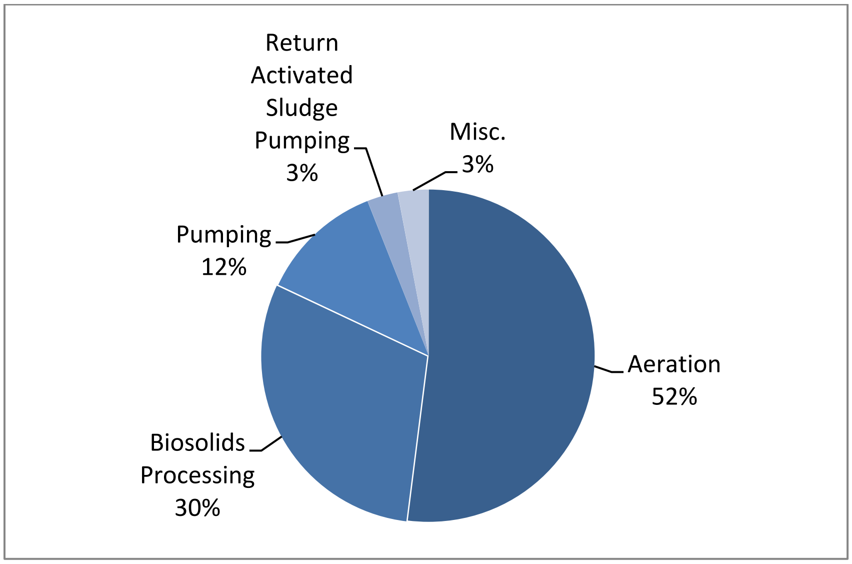

Figure 5-2
Typical Energy End-Uses in Municipal Wastewater Treatment

Source: Hazen & Sawyer

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[43] *Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities*, U.S. Environmental Protection Agency, Washington, DC: January 2008. EPA 832-R-08-002.

Optimization potential exists throughout the typical wastewater treatment facility. Figure 5-2 shows that aeration processes are the principal energy savings target. Aeration efficiency has advanced through the use of better diffusion technologies, such as fine bubble systems.

While pumping does not have the same impact on overall energy performance as it does in drinking water treatment systems, it can often range from10% to 15% of overall energy use at the facility. By including the energy used by lift stations scattered throughout the collection area, the overall impact can be significant.

Finally, biosolids processing represents one-quarter to one-third of overall energy use. Improvements in processing techniques and practices have followed the tightening of the regulations, which now govern all aspects of the treatment and ultimate disposal of the material. Efforts in improving biosolids processing focus on both minimizing the biosolids produced through more complete secondary treatment, and maximizing digestion through enhancements to stabilization techniques. Chapter 6 presents details on several current and emerging technologies to improve biosolids treatment unit processes.

Energy Intensity of Wastewater System Unit Operations

EPRI's 1996 list was the basis for the development of the current list of unit operations presented here;[44] however, some changes were needed to better reflect current practices. Several processes, such as screens and gravity thickening, use little or no energy, so these processes were combined or eliminated. Several treatment options have been added, reflecting their widespread use or acceptance within the industry, including odor control, sequencing batch reactors, membrane bioreactors, UV disinfection, and various filtration methods. The data used to develop the estimates came from a variety of published sources, manufacturers' information, and practitioners' experiences. In most cases, the unit operation values are computed based on assumptions developed from these sources.

As in Chapter 4, averages developed from survey data in the U.S. EPA's Energy Star Portfolio Manager and subsequently analyzed by the Lawrence Berkeley National Laboratories (LBNL) are the basis for our energy assessment.[45] The researchers at LBNL developed weighted averages for a variety of information on the wastewater treatment facilities based on treatment plant size. Those data are summarized in Table 5-1.

The data in Table 5-1 provide some interesting trends. Energy intensity unit values decrease with increasing flow, most likely the result of economies of scale. Fine bubble diffusion predominates as the secondary treatment of choice in all but the smallest of plants, and the average effluent biochemical oxygen demand (BOD) is around 10 mg/L regardless of plant capacity. Those values are much lower than the regulated value, which is typically 30 mg/L BOD. Larger treatment plants are more likely to generate electricity onsite; in fact, nearly one-half of the plants between 7 and 100 MGD reported generating some electricity onsite. Finally, most wastewater treatment facilities dispose of biosolids through land application. This method

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[44] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*, EPRI, Palo Alto, CA: 1996. CR-106941.

[45] *Market Profiles Used in Energy Star's Portfolio Manager for Water and Wastewater Utilities*, Lawrence Berkeley National Laboratory, unpublished data from October 2012.

necessitates the stabilization of the biosolids, meaning anaerobic digestion (and the resulting formation of methane gas) is a common practice.

Table 5-1
Weighted Average Values for Wastewater System Parameters from Filtered Energy Star Dataset

Average Daily Flow Range (MGD)	Energy Use Intensity (kWh/MG)	Average Effluent BOD (mg/L)	Generating Electricity Onsite (%)	Predominant Treatment Processes		
				Secondary Treatment	% Nitrifying	Biosolids Disposal
< 2	3,300	7.3	10	mechanical aeration	68%	land application
2-4	3,000	6.7	14	fine bubble	66%	land application
4-7	2,400	7.5	7	fine bubble	59%	land application
7-16	2,000	6.5	45	fine bubble	59%	land application
16-46	1,700	7.2	39	fine bubble	61%	landfills
46-100	1,700	12.2	44	fine bubble	33%	land application
101-330	1,600	11.5	18	fine bubble	46%	land application

Table 5-2 presents the energy use intensity values for wastewater treatment unit processes for a range of average flow rates. Unit processes are provided for wastewater pumping, primary treatment, secondary treatment, solids handling, treatment and disposal, filtration and disinfection, finished water pumping, plant utility water, nonprocess loads, and energy recovery. The values represent the total kilowatt hours used by the process per day. It may make more sense to change future energy intensity metrics from kWh/day to kWh/unit of pollutant. As concerns over climate change and water stress rise, there is a renewed emphasis on water conservation. The net effect of water conservation on municipal wastewater treatment in the U.S. will be lower flow rates but higher pollutant concentrations. Barring significant leaps in technological approaches, energy use will not change based on pollutant load; however, energy use will change on a flow basis with more concentrated flows. Alternative energy use intensity metrics should be considered when normalizing energy use at wastewater treatment plants; future issues of this handbook should also employ alternatives.

Table 5-2
Estimates of Electric Energy Intensity of Wastewater Treatment Unit Processes (in kWh/day)

	Unit Process	Average Plant Flow (MGD)						
		1	5	10	20	50	100	250
Wastewater pumping		220	1,100	2,200	4,400	10,990	22,000	55,950
Primary Treatment	Odor control	150	600	1,550	5,000	12,000	22,000	52,000
	Grit removal, aerated	130	160	280	320	800	1,600	3,390
	Grit removal, forced vortex	160	200	220	240	430	850	2,120
	Primary clarifiers	30	140	300	620	1,550	3,100	5,400
	Ballasted sedimentation	75	370	755	1,530	3,825	7,650	16,770
Secondary Treatment	Trickling filters	630	2,540	5,070	10,140	25,360	50,720	126,800
	Biological nutrient removal (BNR) mixing	110	550	1,100	2,110	5,115	11,000	23,375
	Aeration without nitrification	720	3,600	7,200	13,825	33,480	63,400	153,000
	Aeration with nitrification[a]	1,080	5,400	10,800	20,700	50,200	95,000	230,000
	Secondary clarifiers	85	350	700	1,400	3,525	7,000	17,550
	Sequencing batch reactors	1,090	5,450	10,900	20,950	50,800	N/A[b]	N/A
	Membrane bioreactors	2,700	13,530	27,060	54,120	135,300	N/A	N/A
Solids Handling, Treatment & Disposal	Aerobic digestion	1,000	5,000	10,000	N/A	N/A	N/A	N/A
	Anaerobic digestion	N/A	550	1,100	2,100	5,000	10,000	25,000
	Gravity belt thickener	30	140	240	480	1,200	2,400	6,015
	Dissolved air flotation	N/A	N/A	1,805	2,920	6,260	11,820	44,740
	Centrifuge thickening	80	290	390	775	1,950	3,890	9,715
	Belt filter press		230	460	690	1,390	2,550	4,400
	Screw press	20	90	160	340	560	1,120	2,520
	Centrifuge dewatering	260	1,300	2,610	5,215	13,040	26,070	65,175

	Unit Process	Average Plant Flow (MGD)						
		1	5	10	20	50	100	250
	Thermal drying	221	1,105	2,210	4,425	N/A	N/A	N/A
Filtration & Disinfection	UV disinfection	225	1,170	2,340	4,680	11,700	23,400	58,500
	Depth filtration	100	350	580	1,160	2,900	5,800	14,500
	Surface filtration (e.g. cloth filters)	50	175	290	580	1,450	2,900	7,250
Plant utility water		45	220	420	800	1,990	3,990	9,960
Nonprocess loads (buildings, lighting, computers, pneumatics, etc.)		300	1,200	2,100	3,600	9,000	18,000	45,000
Energy recovery (from biogas combustion) (c)		N/A	(1,440)	(2,880)	(5,760)	(14,400)	(28,800)	(72,000)

[a] Some plants with flows in excess of 50 MGD use sidestream treatment to reduce aeration costs; these plants should reduce the electric energy intensity values by approximately 25%

[b] N/A=not applicable; generally pertains to unit processes not commonly found in plants of given flow (e.g., sequencing batch reactors are not used in plants with average flows in excess of 50 MGD)

[c] Energy recovery values are reductions in energy use; values are based on assumption of using conventional internal combustion engine burning biogas after treatment; alternative generation technologies may improve these estimates

The bases for estimating electricity use for a variety of unit processes are discussed below.

Trickling Filters

Energy use in trickling filters (a secondary treatment method) comes from pumping and, in some cases, fans used to provide aeration. Most trickling filters do not use fans but many recirculate the flow through the filter so that flow through the filter exceeds the plant flow. Thus, trickling filter pumping is high flow/low head. Older trickling filters used large river rock (diameter of 75 to 100 mm) as fill, which limited the effective height to about 10 feet. Newer ones employ synthetic packing which has a greater surface area and can be packed to depths in excess of 30 feet. The values in Table 5-2 assume a recirculation rate of 1.25 and a 35 foot lift.

Diffused Air and Channel Aeration

There is no other wastewater unit process with a bigger impact on energy use than diffused air, which is the most common approach to secondary treatment currently in use in the U.S. Fine bubble diffusion is the most common and effective way to dissolve oxygen into the wastewater. Aeration values in Table 5-2 are based on using fine bubble diffusers with an assumed aeration tank depth of 25 feet. Two different aeration values are given, depending on whether the plant employs nitrification. Some plants use channel aerators to minimize odors and settling of grit or other solids. For purposes of this report, it was assumed that channel aeration accounts for 5% of overall aeration use.

Additional Aeration Processes

As already noted, aeration is the principal energy end use in wastewater treatment. Because of its importance, electric energy use estimates were developed for a variety of aeration processes beyond the values presented in Figure 5-2. Despite the inroads made with fine bubble diffusers, there continue to be numerous wastewater treatment plants that still rely on surface aerators, coarse bubble diffusers, and other systems for aeration. The daily electricity use for a variety of aeration methods are presented for a variety of plant flow rates on Figure 5-3. The values should be considered approximate because various parameters besides the delivery method impact aeration efficiency. Some factors include solids retention time, grit and removal efficiency in the primary clarifier, aeration basin water temperature, and the need for nitrification. Despite these uncertainties, the estimates developed for the figure clearly reflect the energy impact from using fine bubble diffusers over other, less energy-efficient alternatives. Further, a final curve represents estimates of electricity associated with fine bubble diffusers with dissolved oxygen (DO) control, which enables the user to reduce dissolved oxygen levels to a minimum level.

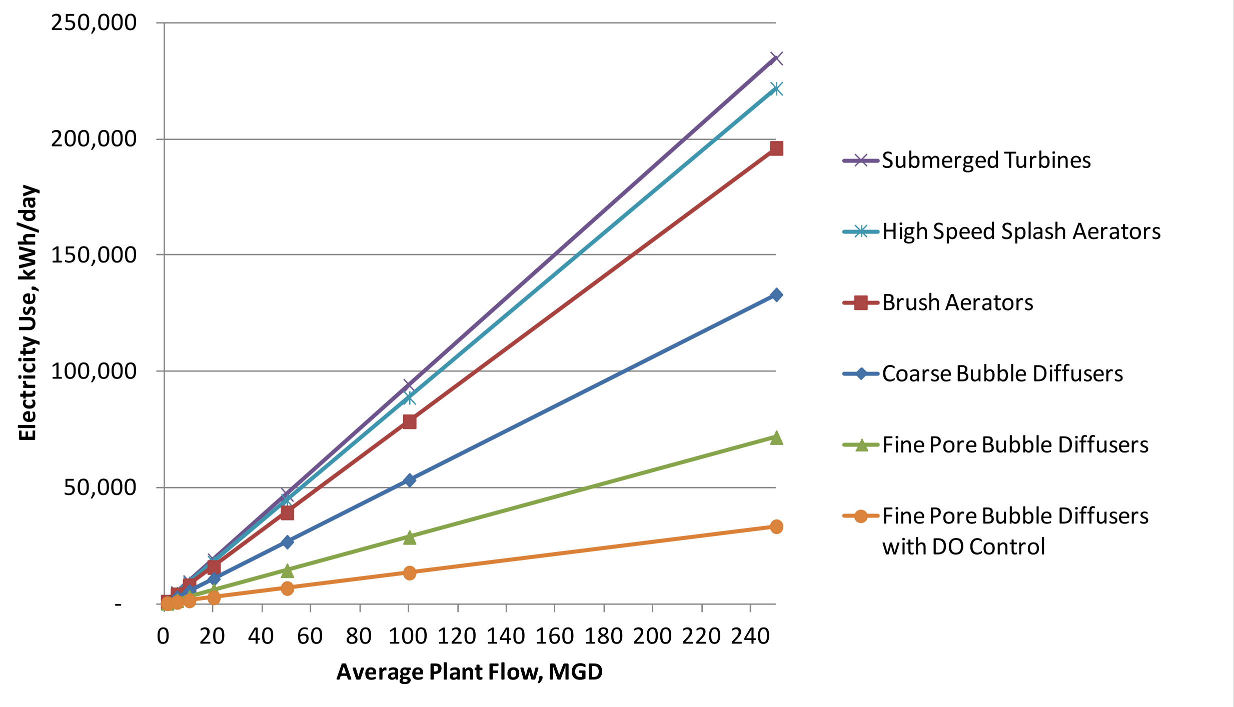

Figure 5-3
Electricity Use for a Variety of Aeration Types at a Range of Plant Flow Rates (in kWh/day)

Biological Nutrient Removal

Biological nutrient removal (BNR) is an advanced wastewater treatment unit process that can remove nutrients like nitrogen and phosphorus. There are many methods used to achieve biological nutrient removal described in literature.[46] From an energy use standpoint, BNR requires additional pumping over aeration with nitrification. Membrane bioreactors also provide BNR, but the data in Table 5-2 separate the two uses; thus, the membrane bioreactor energy values assume the process is used for BNR. The energy associated with BNR was based on using an additional 0.4 hp of aeration per 1,000 cubic feet of added basin. Thus, a treatment plant using BNR would sum the aeration value for nitrification and the BNR mixing value.

Sequencing Batch Reactors

The chemical reactions and biological processes in Sequencing Batch Reactors (SBRs) are identical to a conventional plant except the process occurs in a single basin (i.e., reactor). Therefore, energy use requirements are quite similar to conventional secondary treatment approaches (see Table 5-2) but SBRs require more wastewater pumping since treatment occurs in a single reactor. SBR energy use estimates are the sum of aeration energy requirements and pumping energy based on total dynamic head of ten feet.

Biosolids Handling and Treatment

Biosolids treatment and disposal can account for one-third of overall wastewater treatment plant energy use. However, it is also where significant energy recovery is possible as discussed previously. For purposes of estimating electrical energy intensity, this report considers conventional approaches to biosolids. Thus, the implied goal of biosolids handling and treatment is to render the material harmless so that it can be disposed. Figure 3-7 presents the possible steps used in processing biosolids; no plant employs all of the processes in this figure so oftentimes many steps are eliminated. For instance, plants may dewater the biosolids after digestion but not necessarily thermally dry the biosolids. There is wide variability in the choice of processes employed in processing the biosolids.

The estimates of the energy required for processing biosolids in Table 5-2 are based on assuming that the biosolids consist of both solids from the primary clarifiers as well as waste activated sludge (from secondary clarifiers or the aeration step). The incoming biosolids stream represents approximately 5% of overall plant flow and is assumed to contain approximately 3% solids. Gravity thickening can achieve roughly 10% solids; belt press thickeners can achieve 25%; and centrifuges are capable of producing biosolids with a solids content of about 40%.

Both thermal drying and incineration unit processes consume energy which is not quantified for this report. Typically, the greatest percentage of energy used is in the form of natural gas, although there are electric-based alternatives. Even using natural gas, the combustion processes require blowers for combustion air and so the figures in Table 5-2 represent the typical electrical requirements of these processes.

Comparison of Treatment Processes

As suggested in Table 5-2, normalized wastewater treatment energy use is highly flow-dependent and treatment-specific, so certain technologies and lower flows have higher energy

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[46] JL Barnard, "Biological Nutrient Removal: Where We Have Been, Where We Are Going?", presented at WEFTEC, 2006.,Water Environment Foundation, Arlington, VA: 2006, http://www.environmental-expert.com/Files/5306/articles/8469/001.pdf.

use per unit flow. Figure 5-4 provides a comparison of electric energy intensity values based on plant flow rate for four different types of wastewater treatment facilities. Advanced wastewater treatment plants produce effluents of the highest quality but at the cost of significant energy use. Trickling filter plants, on the other hand, rely on a conventional technology that requires less energy to achieve process objectives.

Regardless of the type of treatment plant, electric energy use intensities at treated flows in excess of about 20 MGD are fairly consistent. For the more established treatment processes, such as trickling filters and biological nutrient removal (i.e., advanced treatment), electric energy use intensities fall along a rather narrow range from 1,300 to 2,500 kWh/MG. However, using more advanced systems, like membrane bioreactors, entails a sizeable increase in electricity use. For the cost of higher electricity use, users gain a much higher quality effluent and a treatment package well-suited for sites with tight constraints.

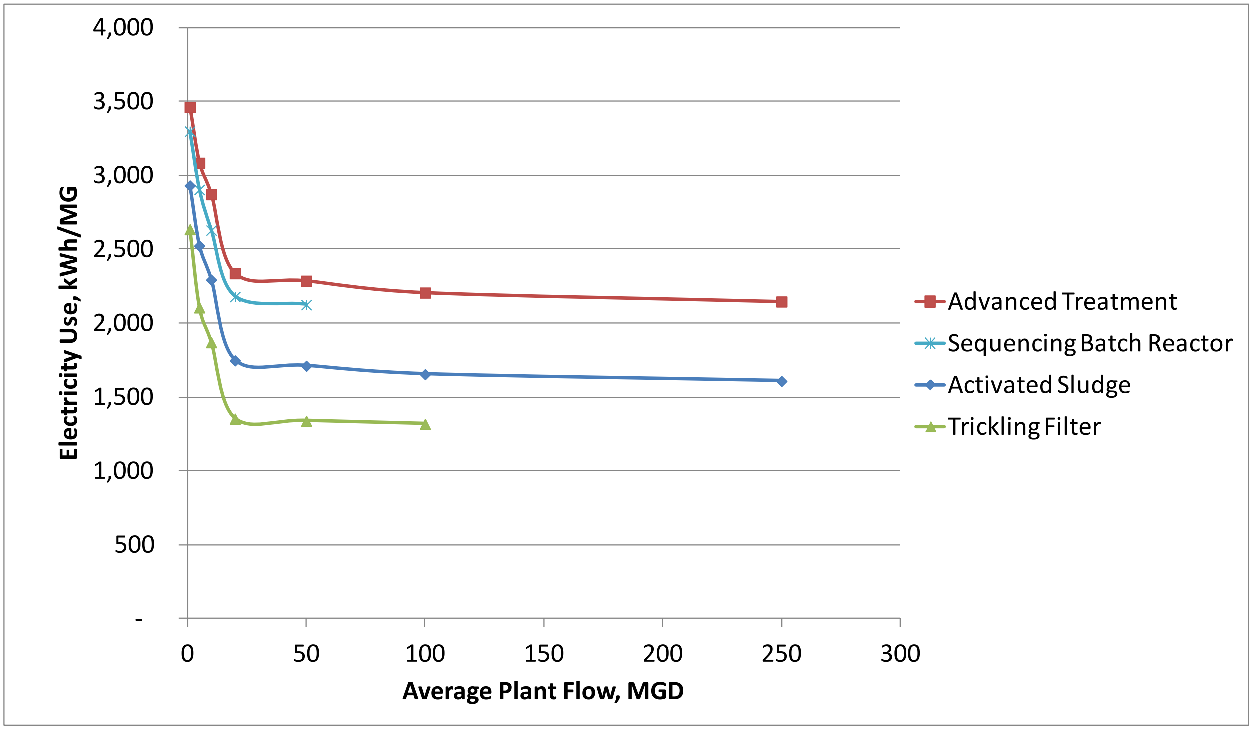

Figure 5-4
Daily Electricity Use by Average Plant Flow and Type of Treatment Processes Employed at U.S. Wastewater Treatment Facilities

Example Uses of Energy Intensity Values

The study team developed Table 5-2 to help plant personnel and other interested parties in estimating the composite energy use for hypothetical water treatment systems by aggregating appropriate unit processes. As was done for the water supply industry, the study team developed four hypothetical examples of wastewater treatment systems commonly encountered in the U.S. The examples pull from the unit process data summarized in Table 5-2 to build composite systems that can be used by plant personnel to represent specific types of wastewater treatment facilities. Table 5-3 presents a summary of these examples. Analogous approaches can be used to build composite energy use values for other types of wastewater treatment systems. Figure 5-5 illustrates a process which can be used to develop estimates based on specific unit processes. The process begins with selecting the average plant flow, and then moves through the various stages of treatment, including primary and secondary treatment, biosolids processing, and disinfection. Adjustments for odor control, channel aeration, and energy recovery from conversion of biogas to electricity are also included. The following examples demonstrate the process.

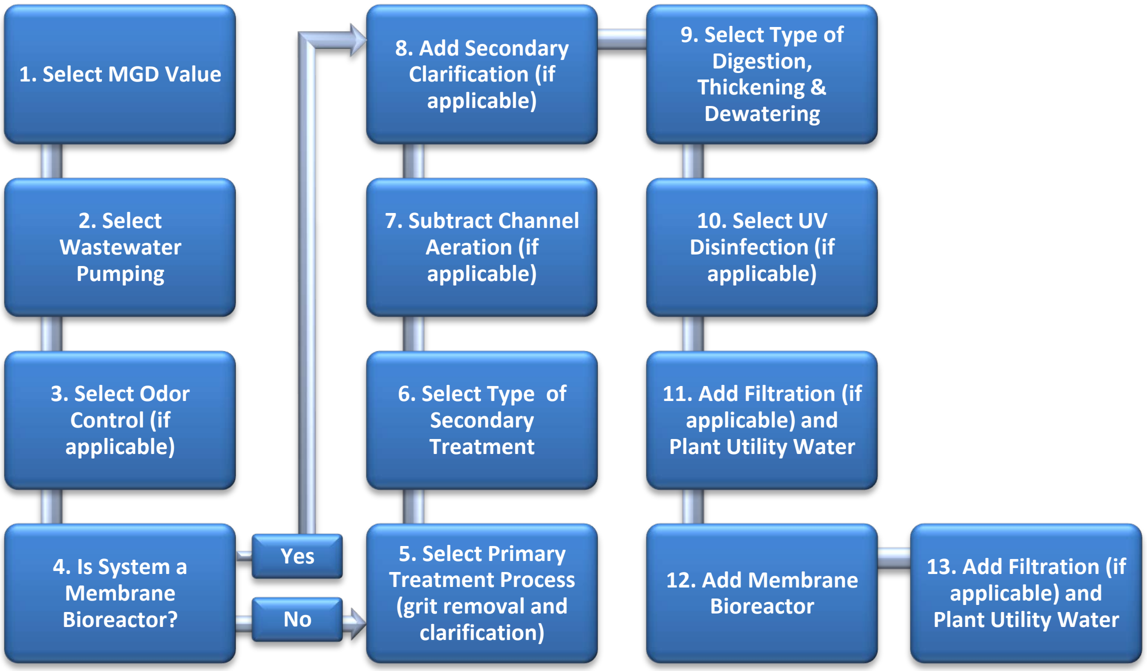

Figure 5-5
Process for Estimating Electricity Use for Hypothetical Wastewater Treatment Systems

Table 5-3
Summary of Wastewater Treatment Facility Examples

Treatment Plant Description	Total Daily Electricity (kWh/d)	Electric Energy Intensity (kWh/MG)
6 MGD sequencing batch reactor, dried biosolids sold for reuse, UV disinfection	13,513	2,250
20 MGD trickling filter with anaerobic digester	30,458	1,520
3 MGD membrane bioreactor for water reuse	14,739	4,910
85 MGD advanced wastewater plant using BNR	173,040	2,040
Total daily electricity values are the sum of applicable unit processes from Table 5-2. Some discrepancies may result due to rounding.		

Example 1: Sequencing Batch Reactor, Dried Biosolids Sold for Reuse, UV Disinfection

The first example plant consists of a sequencing batch reactor (SBR) and UV disinfection with an average daily flow of 6 MGD. The facility employs odor control at the headworks along with aerated grit removal; the primary and secondary clarifiers' energy values are included in the SBR line, along with any aeration costs. Biosolids pass through a gravity belt thickener and belt filter press. The plant effluent passes through a media filter and a UV disinfection system before discharge to the receiving stream. Using Table 5-2 and interpolating values between the 5 MGD and 10 MGD plant capacity columns, overall electricity use sums to about 13,513 kWh/day; this translates into an overall energy intensity of 2,250 kWh/MG.

See Figure 3-3 for the unit operations of an SBR. The major difference between an SBR plant and an activated sludge wastewater treatment plant is that an SBR operates in a batch mode with aeration and sludge settlement both occurring in the same tank. Consequently, the SBR tank carries out the functions of equalization aeration and sedimentation in a time sequence rather than in the conventional space sequence of continuous-flow activated sludge system.

Example 2: Trickling Filter, Anaerobic Digester

The second example treats an average of 20 MGD using a trickling filter, including primary and secondary clarifiers. Biosolids are anaerobically digested after dewatering with belt filter presses and dissolved air flotation. Biogas from the digestion process provides heat to the digester and the excess is flared. Total electricity used is 30,458 kWh per day which equates to an overall energy intensity of 1,520 kWh/MG using data from Table 5-2 for the electricity use associated with wastewater pumping, odor control, aerated grit removal, primary and secondary clarifiers, trickling filter, anaerobic digestion, dissolved air flotation, belt filter press, plant utility water, and non-process loads. It is important to consider that the quantity of biogas could provide up to 180 kW of electricity.

See Figure 3-4 for the unit operations of a trickling filter plant.

Example 3: Membrane Bioreactor for Water Reuse

This third facility is a small (3 MGD average flow) membrane bioreactor plant which provides process water for a nearby industrial facility. The membrane bioreactor has odor control and the biosolids are anaerobically digested. The biogas is recovered and operates a small gas-fired 25 kW generator set. Based on the unit process data in Table 5-2 and interpolation between 1 and 5 MGD for the various processes, the plant uses an average of 14,739 kWh per day, or approximately 4,910 kWh/MG. The membrane bioreactor accounts for as much as 65% of total plant electricity use. If energy recovery is included, total plant use drops to 14,259 kWh/day which translates into an energy intensity of 4,750 kWh/MG.

See Figure 3-6 for the unit operations of a membrane bioreactor plant.

Example 4: Advanced Wastewater Plant using Biological Nutrient Removal

The final example is an advanced wastewater treatment plant providing biological nutrient removal (BNR) and treating an average flow of 85 MGD. The facility is equipped with odor control facilities, but also employs the sidestream deammonification process which saves a significant amount of electricity. Biosolids are thickened prior to anaerobic digestion and then dewatered in centrifuges. The wastewater passes through media filters prior to discharge. Using Table 5-2 and interpolation between 50 and 100 MG for the processes employed in the facility, electricity use is 173,040 kWh/day, which translates into 2,040 kWh/MG before energy recovery. Without the sidestream deammonification process, total daily electricity use is nearly 193,000 kWh/day, or approximately 2,270 kWh/MG.

See Figure 3-3 for the unit operations of an advanced wastewater plant.

Estimated U.S. Electricity Use in Wastewater Treatment

Chapter 4 described an approach that estimates public water treatment and distribution currently accounts for approximately 1.0% of U.S. electricity use. The study team followed a similar approach to estimate the current share of electricity use associated with municipal wastewater treatment systems. The methodology incorporates treated flow data from the EPA's Clean Watershed Needs Survey (summarized in Chapter 3), estimates of normalized electric use data (provided in Table 5-2 and Figure 5-4) and a review of prior estimates from other organizations.

Summary of Prior Electric Energy Intensity Estimates

The EPA presented one of the first estimates of electrical intensity of wastewater treatment in 1978 as a range from 2,300 to 3,700 kWh/MG.[47] Subsequent estimates were smaller, including the initial EPRI report[48] and an EPA energy management guidebook,[49] which provided an estimate of 1,750 kWh/MG. More recently, the Water Environment Federation (WEF) published energy intensity values for various types of wastewater treatment plants. Table 5-4 summarizes the findings by WEF.

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[47] United States Environmental Protection Agency. *Total Energy use for Municipal Wastewater Treatment.* EPA-600/2-78-149, August 1978.

[48] *Water and Wastewater Industries: Characteristics and Energy Management Opportunities*, EPRI, Palo Alto, CA: 1996. CR-106941.

[49] USEPA, *Ensuring a Sustainable Future: AN Energy Management Guidebook for Wastewater and Water Utilities*, EPA 832-R-08-002, January 2008.

Table 5-4
Estimates of Average Electric Energy Intensity of Various Wastewater Treatment Facilities

	Average Flow (MGD)					
Treatment Plant	**1**	**5**	**10**	**20**	**50**	**100**
Trickling Filter	1,811	978	852	750	687	673
Activated Sludge	2,236	1,369	1,203	1,114	1,051	1,028
Advanced Treatment without Nitrification	2,596	1,573	1,408	1,303	1,216	1,188
Advanced Treatment with Nitrification	2,951	1,926	1,791	1,676	1,588	1,588

Source: *Energy Conservation in Water and Wastewater Treatment Facilities*, Manual of Practice 32, WEF Press, Alexandria, VA: 2009

Based on the WEF data, electrical energy intensity ranges from less than 1,500 to about 3,000 kWh/MG for wastewater treatment in the U.S. However, it is unclear how these data were developed. They are lower than the values computed in this report for similar plants, as shown in Figure 5-4. This is particularly true for plants with an average flow exceeding 10 MGD. It is important to note that the estimates in Figure 5-4 are based on observed values, which are generally greater than the theoretical values calculated based on the scientific principles.

Development of a National Estimate

The EPA's Clean Water Needs Survey provides estimates of wastewater treatment in the U.S. based both on flow rate and on treatment. Given that energy use in wastewater treatment is a function of the treatment process, this study uses flow data by level of treatment to develop estimates of the amount of electricity used nationwide in municipal wastewater treatment. As suggested by Figure 5-4 and in Table 5-4, energy use intensity is greatest at very low flows, but fairly constant once treated flow rates exceed about 10 MGD.

The study team's development of an estimate of the amount of electricity used by wastewater treatment follows the procedure used to develop the original EPRI estimate in 1996. The method employs EPA's Clean Watershed Needs Survey plant flow data based on level of treatment. It also calls upon energy intensity values listed in Table 5-2.

Specific assumptions made by the study team in development of the national estimate include the following:

- The energy intensity for treated flows below secondary level (primarily for ocean disposal) is 750 kWh/MG
- The energy intensity for secondary treatment is a weighted average based on 80% of the treatment plants using activated sludge and 20% using trickling filters
- The energy intensity for treatment greater than secondary is a weighted average based on 90% of the treatment plants using biological nutrient removal and 10% using membrane bioreactors

"No discharge" treatment facilities include those which do not discharge to receiving water bodies, such as treatment facilities discharging to evaporation ponds or situations where the treated water is reused. Thus, assumed electric energy intensity for "no discharge" plants is 110% of advanced treatment, or 2,980 kWh/MG. For partial treatment, the assumed value is 40% of the value for secondary treatment, or 830 kWh/MG. The number of plants with water reuse has grown significantly in many parts of the country, and in those cases treatment levels are advanced. Further, this water must be pumped in order to be reused, always in separate distribution systems from the ones used for drinking water. This pumping intensity was assumed to be 80% of the energy intensity of surface water treatment plants, or approximately 1,280 kWh/MG.

The results of this analysis are presented in Table 5-5. The estimate of total annual use for the municipal wastewater industry of 30.2 TWh represents 0.8% of total electricity use in the U.S. and is a 74% increase relative to the first EPRI estimate in 1996, which was 17.4 TWh per year. The values developed in the tables above do not account for certain loads related to wastewater treatment that cannot be quantified. For instance, on-site or decentralized systems are not included. Most of these systems are small flows with limited electricity impacts (e.g., septic systems), but advanced treatment systems are making inroads into this market and will continue to grow. More significantly, pump stations located significant distances from a treatment facility are typically not considered in this assessment. Pump station electrical requirements are mostly a function of system hydraulics, and thus are related to topography and population growth in the collection area. It is not possible to adequately characterize a standard "average," as wastewater utilities should evaluate the impact of topography on a case-by-case basis.

Table 5-5
Treatment-based Estimate of Nationwide Electric Use by the Municipal Wastewater Industry

Type of Treatment	Electrical Energy Intensity (kWh/MG)	Total Treated (MGD)	Electricity Estimate (kWh/d)
Less than secondary	750	422	316,500
Secondary	2,080	13,142	27,335,360
Greater than Secondary	2,690	16,776	45,127,500
No Discharge	2,960	1,815	5,372,400
Pumping Reuse Water	1,280	3,500[a]	4,480,000
Partial	830	190	157,700
	Total per day	**32,845**	**82,789,400**
		Total per year	**30.2 TWh**
		Percentage of total U.S. electricity used in 2011	**0.8%**

[a] Value obtained from the Water Reuse Foundation; all other flow data from U.S. EPA Clean Watershed Needs Survey, 2008

The increase is the result of increases in treatment intensity and treatment levels, an increase in water reuse, and increases in population covered by municipal wastewater treatment systems. While the increase is significant in absolute numbers, it is partially the result of our estimate including a larger number of factors (e.g. pumping of reuse water), and a significant drop in the number of facilities providing only primary treatment. It is worth noting that there have been some inroads made from more energy efficient practices by wastewater treatment agencies that have probably decreased the magnitude of the potential increase, but substantial progress is still possible in this area.

The regulatory burden on water and wastewater treatment facilities shows no sign of slowing. The U.S. population demands safe drinking water along with clean rivers and lakes. Water and wastewater, as a largely municipally-owned and operated industry, will continue to provide what the customers demand. More widespread adoption of energy efficient methods, along with more widespread recovery of the energy embodied in water and wastewater, can be expected in the next 10 to 15 years. Opportunities for energy management are the subject of the next chapter.

6

OPPORTUNITIES AND CONSTRAINTS FOR ENERGY MANAGEMENT

In an industry where energy represents the second-largest operating cost, energy management should be a key consideration. Water and wastewater agencies are largely owned by municipalities, and local governments must manage resources carefully in order to minimize the tax revenues needed to operate them. In fact, energy efficiency and energy recovery strategies have evolved significantly over the past 20 years. This chapter explores current energy management trends and approaches, current and emerging technologies, and potential savings from energy management and energy recovery schemes.

Current Trends in Water and Wastewater Energy Management

Since the release of the first report in 1996, the nation has experienced a "second energy crisis." The volatility of energy prices combined with concerns over climate change and emissions from fossil fuels has focused the nation's attention on energy efficiency. The 1996 report was one of the first reports to address energy efficiency in the water and wastewater industries. Today, many municipal agencies, which typically own and operate water and wastewater facilities, have begun adopting energy efficient practices. Furthermore, many governmental and trade associations now produce energy management guidebooks. For example, the U.S. EPA, the California Energy Commission, the New York State Energy Research and Development Authority (NYSERDA), the U.S. Bureau of Reclamation, the Water Environment Federation, and the Water Research Foundation have all produced energy efficiency guidebooks for the water and wastewater industry.

Given the emphasis on energy efficiency, overall electrical energy intensity should have decreased slightly in both the water and wastewater industries. However, estimates in this study show that in the water industry values for energy use on a flow basis (energy intensity) have changed very little from the 1996 report, while absolute energy use has increased at about the same rate as population growth (see Chapter 4). For the wastewater industry, both energy intensity and absolute energy use values have likely increased given the growth in population, expanded use of secondary treatment, and the more widespread treatment of wet weather flows (see Chapter 5). These observations are somewhat speculative as there has been little analysis of industry-wide practices; however, experiences of the project team members reinforce the belief that while there is renewed focus on energy use, the actual energy use has remained the same or increased slightly based on a higher degree of treatment required and the use of more electric based technologies.. The subsections below describe reasons for these trends.

Water Industry

Today, as in the mid-1990's, conventional, low-energy, treatment technologies predominate in the water treatment industry. More energy-intensive advanced treatment processes, such as ozone, have not had a significant impact on overall energy intensity, perhaps due to rather low rates of implementation within the industry. Moreover, water pumping continues to be the primary energy-using unit process and, despite some energy efficiency progress in pumping systems, there has not been a notable impact on intensity values.

In the future, overall intensity values could actually increase due the growth of desalination, which according to the EPA is the drinking water supply for over 9 million people. The energy intensity of desalination is at least 5 to 7 times the energy intensity of conventional treatment processes, so even though the population served by desalination is only about 3%, we estimate that approximately 18% of the electricity used in the municipal water industry is for desalination plants. In fact, the principal impediment to broader use of desalination may be the high energy costs. Another impediment is environmental regulations.

Considering these trends, it is not surprising that overall energy intensity values in the drinking water segment are comparable with those estimated in the 1996 study. The growth in overall energy use within the water industry is primarily the result of population growth and the increased application of membrane treatment for desalination.

Wastewater Industry

Estimates in this study show that energy intensity values for wastewater treatment systems are slightly greater than the estimates from 1996. A closer inspection of the current values in Table 5-2 when compared to similar tables in the 1996 EPRI report reveals that additional technologies like UV disinfection and odor control are now included. On the other hand, current overall aeration estimates are lower than the 1996 values and energy-saving technologies, like fine bubble diffusers, are more widely implemented now. The net effect is that current electrical energy intensities are greater than the estimates from 1996.

Observations of current practices in the industry reinforce this conclusion. More stringent regulations, including demands for extensive odor control and enhanced disinfection, lead to higher energy intensity estimates. In addition, though aeration values have decreased, aeration continues to represent 30% to 50% of overall energy use at a treatment plant, despite a significant market share taken by fine bubble diffusers. Energy-efficient technologies like fine bubble diffusers lower overall energy intensity, yet the implementation of more stringent regulations, the wider use of secondary treatment, and the wider embrace of additional technologies like odor control have the net effect of increasing wastewater energy intensity by approximately 15% over the past 15 years, since the publication of the last EPRI report.

Impacts on the Future

Energy efficiency continues to make inroads into the water and wastewater industry, with efficient aeration and optimized pumping systems becoming standard procedure. As market penetration for these solutions increases, more attention will be paid to energy recovery. Indeed, the quest for net-zero energy water and wastewater treatment hints toward a new paradigm where energy generation and use is integral to the treatment process. The next section presents opportunities and constraints for improving energy management.

Opportunities and Constraints for Energy Management

There are several general types of opportunities for improving energy management in the water and wastewater industries. This report categorizes the opportunities into three main groups: 1) energy efficiency, load management, and demand response strategies; 2) emerging technologies and processes with an impact on energy use; and 3) energy recovery and generation methods. Energy efficiency, load management, and demand response strategies involve both technological solutions and the institution of certain practices or procedures to improve energy management. Emerging technologies and processes are technological advancements that improve water and wastewater treatment and use, sometimes with the effect of increasing the energy intensity of the processes. Energy recovery involves implementing specific techniques or practices to capture the potential energy in water or wastewater for subsequent reuse. Energy generation in the context of wastewater treatment consists of generating heat and power from biogas produced during treatment processes. Table 6-1 lists the energy management opportunities presented in this study. The following paragraphs describe the opportunities in more detail.

Table 6-1
Energy Management Opportunities Presented in the Study

Energy Efficiency, Load Management, and Demand Response	Emerging Technologies and Processes	Energy Recovery and Generation
• Strategic Energy Management Practices • Data Monitoring and Process Control • Water Conservation • High-Efficiency Pumps and Motors • Adjustable Speed Drives • Pipeline Optimization • Advanced Aeration • Demand Response	• Odor Control • Membrane Bioreactors • Deammonification Sidestream Process • Water Reuse • Residuals Processing • Microbial Fuel Cells • LED UV Lamps	• Cogeneration Using Digester Biogas • Use of Renewable Energy to Pump Water • Recovery of Excess Line Pressure to Produce Electricity

Category 1: Energy Efficiency, Load Management, and Demand Response

This section summarizes some of the more promising programmatic and technological methods for improving energy efficiency and managing peak loads. The section begins with a discussion of the broader potential for energy efficiency within the water and wastewater industry, and then continues with more specific technologies and programs that can lead to achieving that potential.

U.S. Energy Efficiency Potential in the Water and Wastewater Industry

EPRI conducted an energy efficiency potential study in 2009 that assessed the potential for energy efficiency and demand response in the U.S. from 2010 to 2030.[50] The study quantified a range of savings estimates from technically feasible (the highest level of savings) to realistically achievable (the most realistic level of savings). The technical savings are greater than the

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[50] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030).* EPRI, Palo Alto, CA: January 2009. Product No.1016987.

realistically achievable savings because the realistically achievable estimates take into account economic and market acceptance factors. The realistically achievable estimates are projected to grow significantly over the 20-year study period, in part because as old equipment reaches the end of its useful life it will be replaced with more energy-efficient equipment in response to technological advances, codes and standards, and programmatic influences.

The EPRI study provides overall estimates of realistic achievable savings potential through energy efficiency both for sectors (i.e., residential, commercial and industrial) and by census region (i.e., Northeast, Midwest, South and West). Overall, the estimates range from 7.5% of the regional baseline use in the Midwest to 9.0% in the Northeast, or between 55 TWh and 205 TWh depending on the region, as shown on Figure 6-1. The South region accounts for the greatest share (48%) of the total realistic achievable potential.

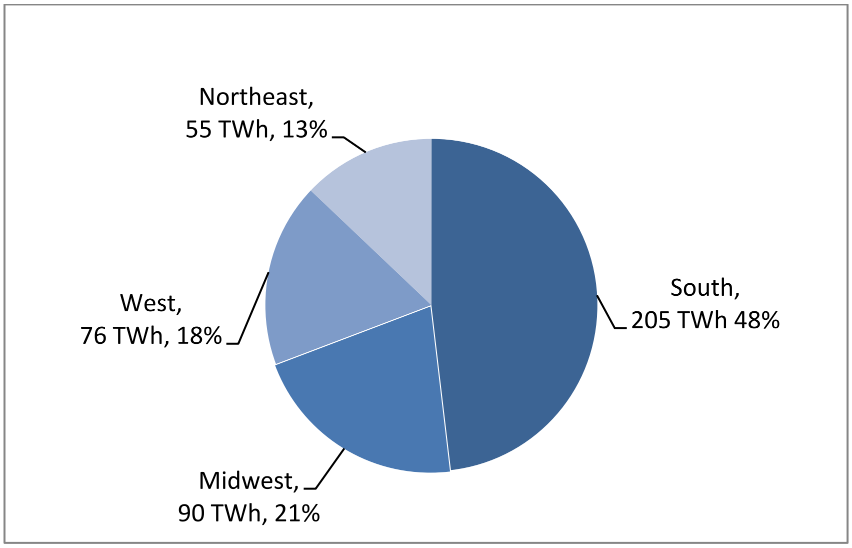

Figure 6-1
Realistic Achievable Energy Efficiency Potential in 2030 by Region

Source: *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030).* EPRI, Palo Alto, CA: January 2009. Product No.1016987.

There has been no specific analysis of the water and wastewater industry, nor any attempt to quantify potential savings. Thus, the EPRI 2009 potential study was used to provide only a very high level estimate of potential energy savings in the water and wastewater industry. Based on the macroscale analysis in the potential study, we estimate that the realistic achievable potential for the water and wastewater industry by 2030 is approximately 8% of baseline. Using a baseline energy use for the water and wastewater industry of 69.4 TWh, a reasonable estimate of energy efficiency potential reduction in this sector is 5.6 TWh. This value represents 1% to 2% of the entire U.S. realistic achievable energy efficiency potential, depending on the baseline used.

Additionally, if one assumes that the water and wastewater industry can meet 1-2% of the nation’s realistic achievable energy efficiency potential by 2030, then regional potential can be quantified. Using the information provided in Figure 6-1, the 2030 regional energy efficiency potential in the water and wastewater industry would be as follows:

- Northeast – 0.73 TWh

- West – 1.01 TWh
- Midwest – 1.18 TWh
- South –2.69 TWh

Clearly, the greatest opportunity resides in the South, which has experienced significant population growth and includes states that rank low on the State Energy Efficiency Scorecard.[51]

The climatic conditions in the South that lead to a significant use of air conditioning may also contribute to high pumping rates for water required for irrigation and other cooling uses. Regardless of the location, the water and wastewater industry represents an excellent candidate for targeted energy efficiency measures. The reality of actual energy efficiency potential could be much greater due to regional regulations, water supply concerns, and energy costs. A more detailed study in this area is needed to develop strategic energy efficiency programs for the water and wastewater industry. There are a variety of technologies and practices that can be adopted by a facility looking to become more energy efficient. The remainder of this section includes a discussion of various strategies and ideas. Those water and wastewater utilities interested in conducting energy audits can find guides available from EPRI, the California Energy Commission, the Environmental Protection Agency, and a number of other public, private and nongovernmental organizations.[52]

Strategic Energy Management Practices

Strategic Energy Management (SEM) is emerging as a new focus area for the water and wastewater industry. In short, SEM involves engaging the broader organization in a structured way to make lasting energy efficiency improvements. SEM activities include the following:

- Gaining executive buy-in
- Committing to an energy goal
- Setting and tracking performance indicators
- Initiating an energy team to regularly act on energy projects
- Engaging employees to be aware of energy, to suggest improvements, and to take action
- Addressing operations and maintenance of equipment, not just focusing on replacement

For over 60 years these concepts have been proven in continual improvement initiatives in areas such as quality and safety, and for over a decade facilities have seen the positive impact of applying this approach to energy.

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[51] American Council for an Energy Efficient Economy (ACEEE), *State Energy Efficiency Scorecards,* scorecards for 2006-2012. They can be accessed here: http://aceee.org/sector/state-policy/scorecard

[52] Publicly available energy efficiency guides for the water and wastewater industry can be downloaded here: http://www.epa.gov/statelocalclimate/documents/pdf/wastewater-guide.pdf ; http://www.nyserda.ny.gov/Energy-Efficiency-and-Renewable-Programs/Commercial-and-Industrial/Sectors/Municipal-Water-and-Wastewater-Facilities/Final-Reports-for-Water-and-Wastewater-Technology-and-Demonstration-Projects.aspx ;

Facilities that engage on SEM can achieve savings in the 2-20%, with savings usually about 4-5%. It is important to note that these savings are independent of other equipment-based energy efficiency improvements that the facility is undertaking.

Though many water and wastewater treatment plants have targeted energy efficiency as a key strategy to control costs, they have not always done so in a comprehensive way. More recently, leaders in the area have begun to deploy SEM to produce greater and longer lasting results. Some plants have deployed SEM practices on their own, while others have leveraged SEM-based energy efficiency programs from their local electric utilities. In either case, they usually take the following SEM actions:

- Establishing energy performance indicators: Such indicators enable plants to understand if they are improving and using less energy for the water they treat. Often plants benchmark with other similar-sized water and wastewater treatment facilities to see how they compare in energy use.
- Improving operations and maintenance practices: Plants query their processes using a Root Cause Analysis approach, asking questions such as: “Can I use this piece of equipment less?”; “Can I replace the equipment with a smaller alternative when it burns out or is at end of life?”; “Can I reduce the start-up, shut-down, or idle time for this system?”; “How do I know if the equipment and controls are optimized and running correctly?”; “Can I install a VFD to better match the load?”; “Are new technologies available that can improve my efficiency along with reliability or other benefits?”
- Focusing on the management system process: While many plants already implement energy project, in the SEM process, they do so by investing in the process more thoroughly to yield greater energy saving results.

SEM and ISO 50001 Standard

Several industrial standards are governed by a series of practices developed in a collaborative method by the International Organization for Standardization (ISO). Well-known standards include the family of ISO 9000 Standards for Quality Management and the family of ISO 14000 Standards for Environmental Management. [53] The ISO Standard for Energy Management is ISO 50001[54] is an international standard intended to assist organizations in making better use of existing energy-using assets, promoting best practices, providing a framework for promoting energy efficiency throughout the supply chain, and enabling integration of energy efficiency through other organizational management systems like ISO 9000 and ISO 14000.

Water and wastewater organizations interested in formalizing their SEM practices can pursue the implementation of the ISO 50001 Standard for Energy Management Systems. ISO 50001 essentially codifies SEM, collecting the set of SEM practices into a framework that is comparable internationally between facilities and that is certifiable by third party registrars.

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[53] See the International Organization for Standardization for more information on ISO standards: http://www.iso.org.

[54] The current version of the ISO 50001 Energy Management standard is dated June 9, 2011. It can be downloaded here: http://www.iso.org/iso/iso50001.

Plants that implement ISO 50001 achieve energy efficiency gains and improved energy management by developing policies and energy savings targets, making informed decisions about how best to use energy resources, and measuring results to compare with established targets. Once the ISO 50001-based program is instituted, the standard assists organizations in reviewing program effectiveness so that energy management practices can be continually improved.

The programmatic and routine approach associated with the ISO 50001 Standard helps organizations determine how best to operate their facilities in the most energy-efficient way possible. The principle operational goal of water and wastewater plants is satisfying regulatory requirements, and in the case of uncertainty, many operators will operate more equipment rather than risk a regulation violation. An ISO Standard assists an organization in identifying this energy-wasting tendency and, more importantly, helps identifying both the root causes and the most appropriate solution.

One example of the benefits of a programmatic SEM approach could be a wastewater treatment plant with little or no remote monitoring of its activated sludge basin. An energy audit would assess the aeration capabilities of the plant, determine the need for turndown ability in the blowers, and specify need for remote monitoring, and finally provide an estimate of capital expenditures needed to make the project work. However, an operator is not likely to lower aeration and risk subsequent permit violations without appropriate tools. An energy efficiency program through the ISO 50001 Standard, on the other hand, would include the energy audit along with a program to train staff members and verify energy savings once the system is installed.

Data Monitoring and Process Control

As with any complex industrial process, the potential for computer-based monitoring and control in water and wastewater systems is enormous. Monitoring and control technologies vary from simple devices to advance Supervisory Control and Data Acquisition (SCADA) systems. SCADA systems are used for precise control of key equipment and processes, including raw water wells, water treatment, and distribution pumping. Typically, SCADA systems pull data from field devices such as programmable logic controllers (PLCs), remote terminal units (RTUs) and electric meters, and format the data to be viewed by operations staff or used for process analysis. Monitoring and control of processes is occurring to some extent in the water and wastewater industries, but traditionally there has been a greater focus on improving process quality and reliability than on controlling systems to optimize energy efficiency. Today, nearly all electric utilities make interval data available to customers via the internet for free or at a low cost. Additionally, most electric utilities can provide energy pulse data (i.e., “dry contacts”) for a low cost.

Water Industry

A 2009 EPRI study found that the potential to increase energy efficiency in the public water supply through advanced control of water pumping and treatment equipment is significant. The researchers estimated an electric energy savings potential of 5-10% across the U.S. public water supply associated with advancements in pumping and water treatment process control.[55]

Assuming public water supply currently uses about 39 billion kWh/yr, the potential electric energy savings associated with advanced SCADA systems ranges from 2.0 to 3.9 TWh/yr. This translates into electricity savings ranging between 5.4 and 10.9 million kWh per day across the U.S.

Typically, water monitoring and control systems pull data from field devices on key operational parameters such as pump status, water flows and pressures, storage levels, alarms, and energy prices and format the data so it can be viewed by operations staff or used for process analysis. The primary interface to the operator is a computer monitor that portrays a representation of valves, pumps, storage levels etc. It is frequently web-based. Figure 6-2 shows an example of a SCADA workstation where the treatment facility is arranged on the screen and each process can be accessed for more detailed information by clicking on its icon on the screen.

Figure 6-2
Example of a SCADA Workstation at a 25 MGD Water Treatment Facility

Courtesy of Ray Ehrhard

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[55] *Electric Efficiency through Water Supply Technologies: A Roadmap.* EPRI, Palo Alto, CA, 2009. 1019360. Table 4.1.

From an energy efficiency standpoint, optimizing pumping systems in the public water industry is highly critical because of the magnitude of pumping electricity requirements. Advanced controls can be used to collect and analyze individual pump electric meter data and thereafter determine and recommend changes to pumping operation to minimize energy use. They can also be used for system-wide control of complex networks, including remote groundwater wells, multiple water treatment plants, and pumping facilities.

An energy saving technique is to use the SCADA system for automatically selecting the best pump combination, reducing system pressure when possible, checking the system efficiency in real time, and then notifying the operator when changes are required.

Another promising application of advanced controls is to control peak demand. Control systems can operate high service and pump station pumping to maximize pumping potential and pumping use by staggering start and duty cycles of transfer pumps, finished water pumps, and similar devices. This sort of control system can be programmed to manage peak demand to avoid starting and operating large motors during periods of peak electrical demand.

The principal limitation to using control systems to manage demand is in the hydraulic characteristics of the distribution systems. Sufficient storage is required to enable the water supply to coast through the heavy demand periods without starting additional pumps. The most sophisticated control systems “learn” the characteristics of the distribution system, relying predictive modules to help in scheduling pumping. This option is extremely valuable in systems where the pump station takes advantage of time-of-day rate schedules. Periods of peak water demand tend to coincide with the highest time-of-day electric rates, so predictive control of pumping (along with adequate water storage) is essential to reduce electricity costs. A subsequent section of this chapter describes strategies to reduce peak demand in greater detail.

Wastewater Industry

SCADA use in wastewater systems for process monitoring and control is arguably ahead of its use for process control in the water industry. Wastewater treatment is inherently more complex and, with the reliance on biological processes, more volatile. For instance, loss of aeration can lead to catastrophic failures within the treatment process, resulting in permit violations. Thus, both instrumentation needs and the benefits from computer-control of the wastewater process have spurred the more widespread adoption of SCADA.

One principal focus for advanced controls is to control aeration. Specifically, treatment processes can benefit from instrumentation and controls. For example, advanced controls for the aeration equipment can monitor dissolved oxygen (DO) in the aeration basins, control the aeration equipment to maintain set DO levels, and optimize the overall performance (including electricity use) of the aeration system. Control systems can be quite sophisticated, preventing over-aeration and excessive power use during low-flow periods. If aeration accounts for 40% of total electricity use at wastewater treatment facilities, advanced aeration monitoring and controls could achieve as much as 3.6 TWh/year of electricity if fully implemented.

Another SCADA use is in the starting and stopping of biosolids processing equipment, such as waste activated sludge (WAS) pumping, or dewatering devices. These systems are often operated sporadically based on process needs and labor availability, so SCADA provides the plant operator with the option of remotely starting and stopping the processes. Additionally, with the more widespread use of UV disinfection systems, an operator must be aware of any lamp failures. SCADA systems allows for the disinfection system to be monitored in real-time so that the operator can take immediate action if a failure occurs.

Water Conservation

Water conservation is an overlooked energy efficiency measure in both water and wastewater treatment. Lowering water demand reduces the volume of water drawn from public water supplies, which, in turn, reduces the energy required to pump and treat the water supplied to end-users. A lower demand for freshwater also translates directly into a reduced demand for wastewater treatment, and a corresponding reduced energy use for wastewater treatment and transport.

Water and Wastewater Utilities

There are two main opportunities for water conservation in water supply and wastewater disposal. On the water supply side, the opportunity lies in detecting and eliminating leaks in the supply system. Monitoring and control systems like those discussed in the previous section utilizing devices such as acoustic leak detectors located at fixed locations along the distribution line can help identify and reduce losses that occur via leaks upstream of the end-users. Estimates suggest that water loss for a well-operated municipal water utility is about 10%; however, many utilities operate with water losses of 20% or greater.[56] On the wastewater side, inflow and infiltration lead to significant increases in flow to the treatment facility, particularly during rain events. The additional volume of inflow water combines with wastewater effluent and increases the amount of wastewater that must be pumped and treated. Improving isolation of wastewater systems from freshwater sources helps to prevent loss of potential freshwater supplies.

End-Users

Some of the most significant opportunities for conserving water relate to lowering end-use water demand. Two EPRI studies discuss several such opportunities in greater detail.[57,58] The following section summarizes water conservation strategies for residential and commercial customers of water and wastewater utilities, thereby saving energy that would otherwise be required to transport, treat, and dispose of the water.

Residential and commercial customers mainly consume water in appliances and for irrigation. Most water conservation efforts have focused on improving the efficiency of water-intensive appliances, such as clothes washers and dishwashers, and on replacing fixtures with water saving alternatives, including low flow toilets, showerheads, rinse valves, and faucets. Some energy efficiency programs attempt to increase the value proposition of improvements by highlighting the water and energy benefits for customers, but the energy efficiency focus has been mainly on

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[56] *Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use*. EPRI, Palo Alto, CA: 2008. 1016460.

[57] Ibid.

[58] *Electric Efficiency through Water Supply Technologies: A Roadmap.* EPRI, Palo Alto, CA, 2009. 1019360.

energy savings due to reducing hot water demands with low flow devices, rather than on the associated electricity savings for the water and wastewater utilities.

Considerable opportunities exist for reducing freshwater demand for landscape irrigation. Estimates suggest that up to 50% of landscape irrigation water is wasted due to inefficient practices.[59] Inefficiencies occur from runoff, percolation below the root zone, evaporation, and wind drift. Opportunities include better weather-based and/or moisture-based control systems, drought tolerant designs, drip irrigation, run-off prevention, and avoidance of irrigation during peak daytime temperatures and windy periods. Based on EPA and U.S. Bureau of Reclamation data, EPRI estimates potential savings due to advanced irrigation controls in residential and commercial applications to be 1.5% to 3% of total electricity use in the public water supply.[60] At a current electricity use rate of 39,000 million kWh/yr, this equates to potential savings of 0.5 to 1.2 TWh/yr in the public water supply. While this is not a small number, the nature of the savings through numerous, small actions, make the impact of this measure extremely challenging to measure.

Providing timely information on usage patterns has been proven in both the energy and water industries to be an effective way to increase awareness and transform consumer behavior. There is a substantial opportunity to modify consumer behavior and detect leaks by providing a greater degree of visibility into use patterns. For example, automatic meter reading (AMR) technology coupled with acoustic leak detectors within residential and commercial water distribution systems can help identify leaks and/or anomalous behavior, such as faucets that have been left on accidentally.

Storm water collection and water reuse, which are discussed in a subsequent section, also reduce demand for public water supplies, without decreasing overall water utilization at the end-use.

Equipment and Processes

Improving the efficiency of equipment and processes is another way to save energy. Opportunities relate to installing higher efficiency pumps, motors, and drives and reducing friction losses in pumping systems with better pipeline design. Opportunities also exist in improving the efficiency of treatment processes, such aeration and processing of biosolids,

High-Efficiency Pumps and Motors

The efficiency of the pump and motor combination affects the pumping performance significantly. Selecting pump/motor systems based on actual process flow parameters results in improved wire-to-water efficiency. Because pumps are typically oversized, the wire-to-water efficiency of pump/motor systems is often relatively low. Indeed, an assessment of 20 plants and 1,690 pumps in Finland revealed that the average pumping efficiency was less than 40%, with

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[59] Ibid.

[60] Ibid. Table 4.1

10% of all pumps operating at efficiencies below 10%.[61] The study also revealed that oversized pumps and throttled valves were the primary causes of poor pumping performance.

Adjusting or replacing pump impellers to better match actual flow requirements improves efficiency relative to operating with partially closed valves. Additionally, selecting pumps to match base or average flow and then using supplemental pumps for peak flow further improves efficiency. The most efficient pumps should be operated first. Matching the pump flow also helps manage demand better, as it avoids the use of additional pumps. Another way to reduce demand is to turn one pump off before starting another.

Though electric efficiency gains in pumping systems can be achieved by replacing motors (e.g., replacement of an old motors with a premium-efficiency one), greater efficiency gains typically can be achieved through *system* efficiency measures that improve the efficiency of a pump/motor system or a group of pumps/motors as a whole. The U.S. Department of Energy claims that replacing typical pumps or motors with most efficient models usually provide system energy savings of 1-2% and 1-3%, respectively, while improvements of the whole pump/motor design can generate system energy savings of 10-30% depending on the initial system design.[62]

Consequently, the entire pump/motor system needs to be assessed for optimal pumping performance.

Performing periodic pump efficiency tests to determine pump performance can identify opportunities for electricity efficiency gains. It also allows for timely and cost-effective preventive maintenance before pump failure. There are several ways to determine a pump's efficiency. For example, the pump's operating point can be determined by simply measuring either flow or the differential head across a pump (pressure readings in inlet and outlet) and then using the manufacturer's pump curve.

Unlike positive displacement pumps, centrifugal pumps have variable flow rates even when rotating at a constant speed, which can be described by a performance curve. Understanding a pump's performance curve is essential to properly sizing a pump and designing a pump/motor system that performs efficiently. At the best efficiency point (BEP), the pump operates most efficiently. In high efficiency systems, the pump operates within reasonable range of its BEP even when the flow rate varies. The use of multiple pumps typically results in higher overall efficiency, as each pump can operate close to its respective BEP. Another way to handle widely varying operating conditions is to use variable frequency drives (which are discussed in the next section). Pump selection is a complex process that requires repeated evaluations of many pump characteristics, including the BEP, pump speed, net pressure suction head, and pump type. Fortunately, software is available to assist in selecting a correctly-sized pump.

Software is also available for pump performance assessments. The *Pumping System Assessment Tool (PSAT)*, developed by the U.S. DOE, provides a relatively simple and quick way to determine pump system efficiency. *PSAT* compares field measurements of the power delivered

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[61] *Variable Speed Pumping, A Guide to Successful Applications*, Hydraulic Institute and Europump, Elsevier Ltd., 2004.

[62] *Variable Speed Pumping – A Guide to Successful Applications, Executive Summary*, U.S. Department of Energy, Hydraulic Institute and Europump, 2004. http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/variable_speed_pumping.pdf

to the pump/motor with the flow and head data required by the pumping application. By using the Hydraulic Institute's *Achievable Efficiency Estimate Curves* and performance characteristics of motors from the *MotorMaster+* database, *PSAT* determines the achievable and optimum efficiencies for the selected pump type as well as correction factors at the specified operating conditions. *PSAT* can also calculate the electricity savings based on the difference between the anticipated electricity use of a high-efficiency pump and the baseline energy use associated with the inefficient or oversized pump.

Because pumping accounts for the majority of total energy use in the public water supply industry (>85%), the potential impact of high-efficiency pump/motor systems on electric efficiency is significant. Though the system energy savings will greatly depend on the initial design, it is estimated that high-efficiency pump/motor systems can provide pumping system energy savings of approximately 10-30%.[63] This translates into electricity savings of 3.3-10 TWh/yr; based on an annual public water supply electricity use of 39.2 billion kWh and assuming 85% of total electricity use is attributed to pumping.

Because high-efficiency pump/motor systems operate more closely to the BEP, the wear and tear on equipment is minimized. This, in turn, translates into lower maintenance costs. Additionally, high-efficiency pump/motor systems have lower life cycle costs than standard pump/motor systems even if they tend to be more expensive. For example, Figure 6-3 illustrates how the purchase price of an efficient pump/motor system is about twice that of the inefficient pump/motor system, but the higher capital cost of the efficient system is quickly recovered through annual energy savings.

Though operators pay close attention to controllability, reliability and availability of pumping systems, they usually pay little attention to pumping system performance and the fact that many pumps are oversized and thus operate inefficiently. Unfortunately, pump selection and sizing is typically not considered in the context of the overall system. Instead, components are often selected based on their individual performance, resulting in poor pumping efficiency. Furthermore, pumping system selection is often based on initial first cost instead of life cycle cost. As a result, the adoption of high-efficiency pump/motor systems is limited.

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[63] *United States Industrial Electric Motor Systems Market Opportunities Assessment,* U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington D.C.: December 2002.

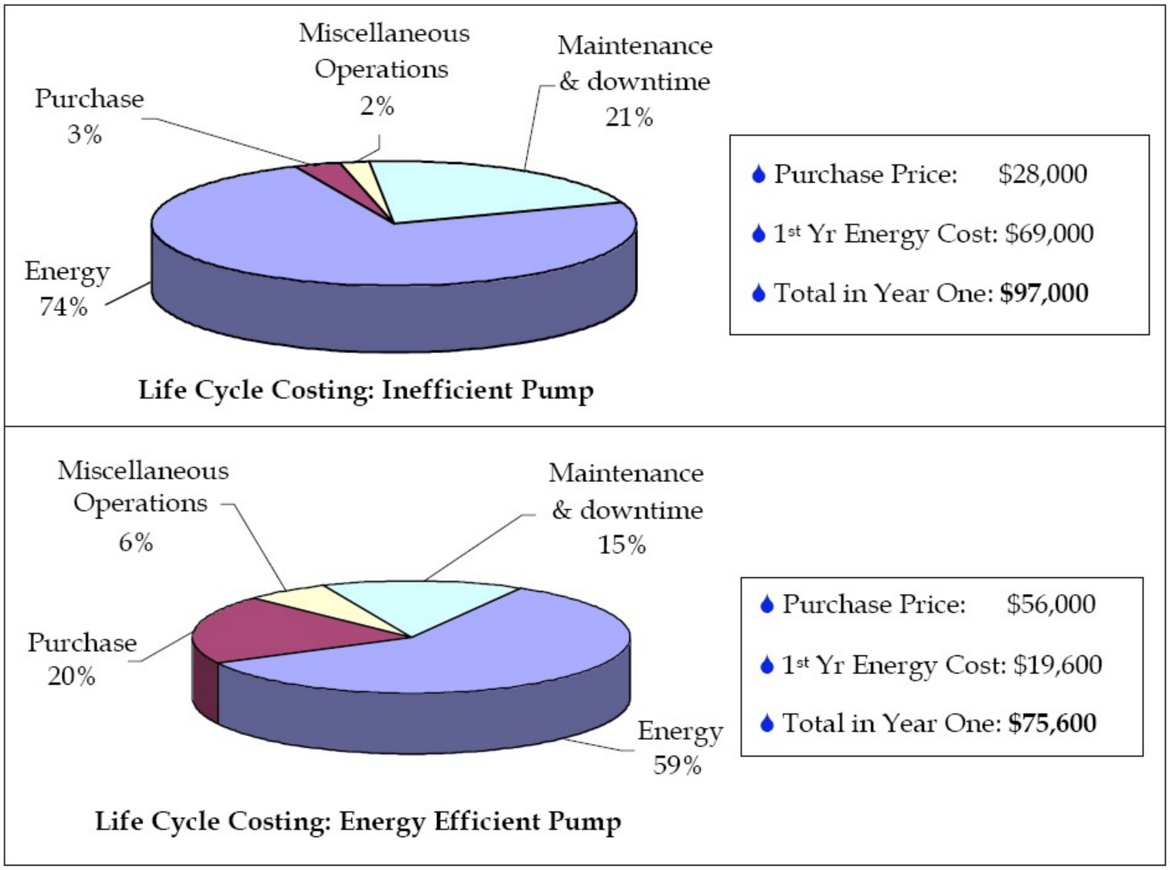

Figure 6-3
Life Cycle Cost Comparison of Efficient vs. Inefficient Pump System

Courtesy of Alliance to Save Energy

Adjustable Speed Drives (ASDs)

Most pumps are selected to meet a maximum system demand. As a result, many pumps are oversized and rarely operate at their full design capacity. Additionally, pumps are often used in systems with multiple operating points that coincide with flow requirements. When the required flow is less than the flow at the pumping system's natural operating point, a throttling valve or a bypass line is typically used. However, throttling valves reduce efficiency because the pump's operating point is shifted to the left along its performance curve and away from its optimum efficiency point. Bypass lines are also extremely inefficient because they do not reduce flow; they only redirect part of the flow.

In contrast, adjustable speed drives (ASDs) efficiently control flow by varying the pump's rotational speed. ASDs are generally categorized as mechanical or electrical. Mechanical ASDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys. Electrical ASDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). Because they offer superior control and improved energy savings, pulse-width modulated VFDs are the most commonly used type of ASD.

VFDs use an electronic controller to adjust the frequency of the power supplied to a motor to change the motor's rotational speed, thereby matching it to the operational load. Thus the motor is continually adjusted relative to the power required, resulting in energy and maintenance cost savings. The effect a VFD has on pumping operation is illustrated in Figure 6-4. The pump head/flow and brake horsepower (bhp) curves drop down and are displaced to the left when a VFD reduces the pump speed. This shifts the pump efficiency curve to the left. As a result, the pump operating efficiency improves across variations in the system's flow demand.

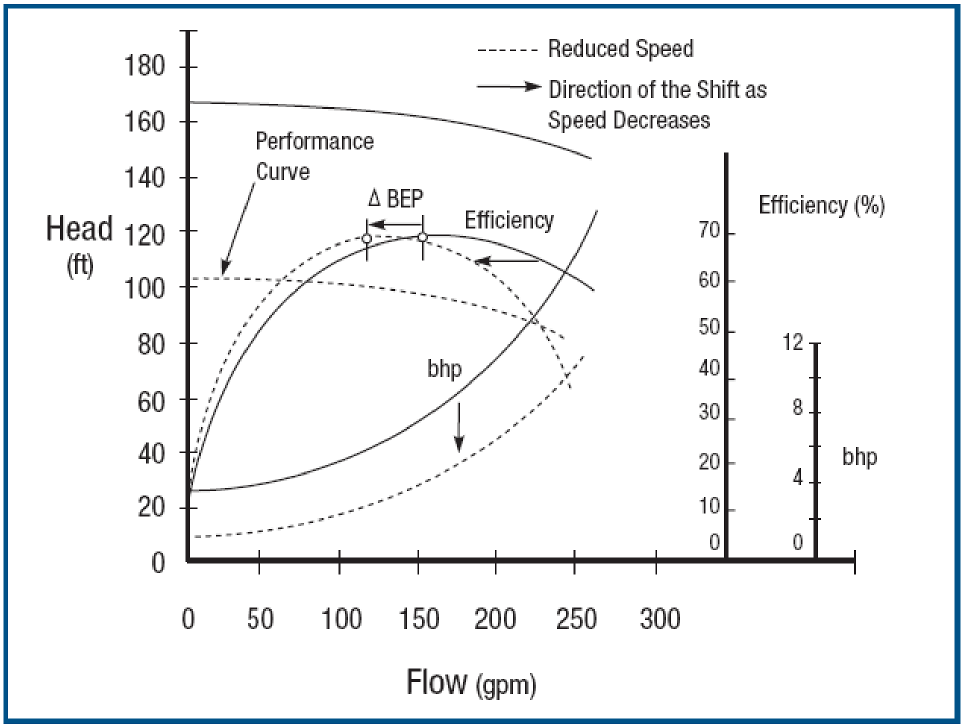

Figure 6-4
Effects of Reduced Speed on Pump's Operating Performance

VFDs can be used in a wide array of applications, and are particularly beneficial for controlling pumps with variable loads, like water supply booster pumps. In these applications it is important to match the electrical characteristics of the pump, motor, and drive to maximize electric efficiency gains and prevent premature failure. However, some applications may be inappropriate. For example, VFDs are not beneficial in applications with high static head because slowing a pump could induce vibrations and create performance problems (similar to those occurring when a pump operates against its shutoff head). Furthermore, VFD control of positive displacement pumps requires careful selection because these pumps need to produce a constant torque. Unlike centrifugal pumps, where power varies with the cube of the speed, in constant torque pumps, power varies in direct proportion to speed. VFD control of positive displacement pumps typically generates lower energy savings compared to VFD control of centrifugal pumps.

Implementing VFD control to meet variable pumping loads can generate pumping system energy savings of 5-50% relative to other methods used to accommodate fluctuating flow demand (e.g. throttling or bypassing), depending on initial design. The Hydraulic Institute estimates a more precise energy savings range of 30% to 50% for VFD-controlled centrifugal pumps.[64] For example, reducing the speed of a pump by 20% can reduce input power requirements by approximately 50%.

VFDs are especially beneficial in large pump applications with high annual operating hours and widely variable flow rates such as booster pumps. Based on audits of more than 200 water facilities, EPRI determined that VFDs can provide pumping energy savings of 5-15% in the public water supply industry.[65] Other work by EPRI has revealed that PV-integrated VFDs have the potential to reduce electricity use in water pumping applications by perhaps another 5%. Consequently, advanced VFDs can potentially reduce energy requirements by an estimated 10-20% in pumping applications. Therefore, advanced VFDs can potentially save 3,300-6,600 million kWh/yr in the public water supply sector, assuming 85% of total annual electric use is associated with pumping applications.

Because VFDs control pumping speed precisely and match flow to process requirements, they improve process control and help maintain water quality. VFDs also offer soft-starting capability, as they have the ability to reduce voltage fluctuations that can occur when starting large motors. A VFD-controlled motor's locked rotor current is approximately one and one-half times the full-load current. This can be compared to the across-the-line starting draw of induction motors which can be as high as six times the full-load current. Because VFDs offer soft-starting capability and reduce the operating speed of the pump, the wear on bearings, seals, and shafts is reduced. This, in turn, translates into lower maintenance costs. Less wear and tear on equipment also reduce downtime, thus improving system reliability.

Unlike network connected fixed speed pump/motor applications, VFD-controlled pump applications provide good supply-side displacement power factors, reducing or eliminating the need for power factor compensation. Additionally, VFDs have the ability to incorporate pump and motor diagnostics, thereby improving fault detection. Intelligent VFD-controlled pumps that use algorithms to monitor and control pump performance are emerging.

Even though the use of VFDs in industrial and public water supply applications has been growing at a rate of 5% annually, there is still plenty of opportunity for significantly higher field implementation of the technology. It has been estimated that only 5% of motors used for industrial and public water supply applications are currently VFD-controlled.[66] For larger motors, the share is somewhat greater, at 20%.

VFDs specifically designed for pumping applications in the water and wastewater industries have recently been developed. Though the capital cost of a VFD can often be off-set by eliminating control valves, by-pass lines and conventional starters in new pump systems, the capital cost must generally be recovered through energy and operation and maintenance (O&M) cost savings in retrofit applications. The simple payback of VFD retrofits is still quite high. It can

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[64] *Variable Speed Pumping, A Guide to Successful Applications*, Hydraulic Institute and Europump, Elsevier Ltd., 2004.

[65] Keith Carns, EPRI Solutions, *Bringing Energy Efficiency to the Water & Wastewater Industry: How Do We Get There?*, presented at WEFTEC 2005, Washington DC: November 2, 2005.

[66] Allan R. Budris, *Variable Speed Drives*, WaterWorld Webcast, July 17, 2008.

range from 5-10 years in larger distribution pump applications (>75 hp) with high annual operating hours and widely fluctuating flow rates. Reinforced inverter-duty insulation is often required when retrofitting a motor with a VFD in a network that exceeds 440 V. Additionally, undesirable harmonic distortions resulting from the addition of a VFD must often be addressed.

Pipeline Optimization

Head losses increase energy costs as the pump system must work harder to overcome friction. The friction losses of pipe tend to increase with time due to increased roughness from scale on the inside of the pipe. Pipeline optimization is a concept developed by the U.S. Department of Energy that connects replacement of piping systems to the expected energy impacts. Municipality-owned hydraulic models can be used for pipeline optimization. One aspect of pipeline optimization deals with relining pipes to reduce friction. Another aspect proposes replacing existing pipes with larger diameter ones to reduce turbulent flow within the pipe. While installing large diameter piping will reduce pumping requirements, the costs of excavating and installing new pipes far outweigh any energy benefits. Instead, water utilities should focus on optimizing the pipe during routine replacement, such as in the event of water main breaks.

Advanced Aeration Technologies

Diffused air systems use a combination of blowers, an air piping system, and submerged air diffusers in the aeration tanks. Fine pore diffusers produce fine air bubbles that provide better oxygen transfer efficiency in wastewater than other types that produce larger ones. In fact, the technology is now the predominant aeration technology in activated sludge plants. By using fine pore diffusers, the amount of air required for biological treatment can be reduced without sacrificing treatment performance. Consequently, energy use by blowers can be reduced significantly from 10% to 40%. The major difficulty found with fine pore diffusers has been their tendency to clog, so regular cleaning is required to ensure consistent performance.

Other aeration technologies may improve on fine bubble diffusers, or address some of the drawbacks. Membrane diffuser panels do not clog as quickly. Submerged turbine injectors are simple devices with no moving parts, offering reduced maintenance. One of the more significant advances in aeration technology in recent years has been the introduction of high-speed turbo blowers (see Figure 6-5). Introduced to North America in 2007, high-speed turbo blowers offer both energy savings and reduced maintenance costs. Their nominal blower efficiency ranges between 70% and 82% while the turndown is 50% of rated flow. The turndown is comparable to other blower types, but the efficiency is significantly better than positive displacement blowers and multi-stage centrifugals, regardless of how they are controlled.

High-speed turbo blowers gain efficiency through the use of high-speed permanent magnet motors, VFDs integrated into the blower unit, and advanced bearing designs that require no lubrication system. They are quiet and have few moving parts, and maintain their high efficiency over a wide range of flows. However, given their relatively new status in North America, their long-term reliability is unknown. In addition, there are limited sizing options available, so they are currently finding markets only in larger facilities.

Figure 6-5
New Turbo Blower Installed at Lakota Wastewater Treatment Plant, WA

Courtesy Lakehaven Utility District

Demand Response Strategies

Water and wastewater treatment facilities are good candidates for demand response (DR) because they are energy intensive and typically rely on water storage to address variation in water flows. The water storage capability offers them some flexibility in the operation of certain processes, including pumps and centrifuges. This operational flexibility, in turn, can be leveraged for DR if properly coordinated, making these facilities ideal partners for electric utilities seeking to manage electric load through DR programs. Furthermore, water storage can be used in conjunction with onsite power generation to provide greater demand reduction.

This section begins with a primer on DR. That is followed by a discussion of common approaches for DR in water and wastewater treatment facilities and a presentation of some innovative DR program pilots. Additionally, Case Study 8 in Chapter 7 describes in greater detail how one water district in California is aggressively achieving peak demand reductions and getting handsomely paid for its DR efforts.

Primer on Demand Response

The Federal Regulatory Commission (FERC) defines Demand Response as:[67] "*changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized*." Some of the purposes of demand response include improving grid reliability, supporting infrastructure optimization or deferral, reducing utility costs, and lowering energy prices for customers.

There are four general ways a facility can reduce its use of grid electricity during peak periods:

1) **Load Shedding:** Load shedding is sometimes referred to as load curtailment. Popular load shedding strategies include dimming or turning off lights, changing HVAC temperature set-points, and turning off non-critical equipment.

2) **Load Shifting:** Load shifting involves shifting use of equipment from on-peak to off-peak time periods (e.g., using off-peak power to pump water).

3) **Switching to Onsite Generation:** Some facilities prefer to respond to DR events by meeting a portion of their on-peak loads with an onsite power generator rather than shedding of shifting of loads.

4) **Combination of Above Strategies**

All four DR strategies are employed by water and wastewater treatment facilities. Typical DR strategies used by water and wastewater treatment facilities are discussed in greater detail following the DR Primer section. Because water and wastewater treatment facilities have many energy intensive processes, they are usually capable of reducing demand significantly. Figure 6-6illustrates facility-wide load shedding at a 10 MGD wastewater treatment facility in San Diego County in Southern California. The facility operates at an average demand of 2 MW, with peak demand reaching 2.5 MW.[68] The red line in the figure illustrates the DR Baseline and the blue line illustrates the reduction in demand when the facility shed two effluent pumps on May 21, 2009. On this specific day, the facility was able to reduce electric demand by 540 kW, or 30% of total facility load.[69] On a different day, the facility shut down a centrifuge, reducing facility load by an additional 55 kW.[70]

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[68] *Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California – Phase I Report*, Lawrence Berkeley National Laboratory, Berkeley, CA: April 2009, LBNL-2572E.

[69] Ibid.

[70] Ibid.

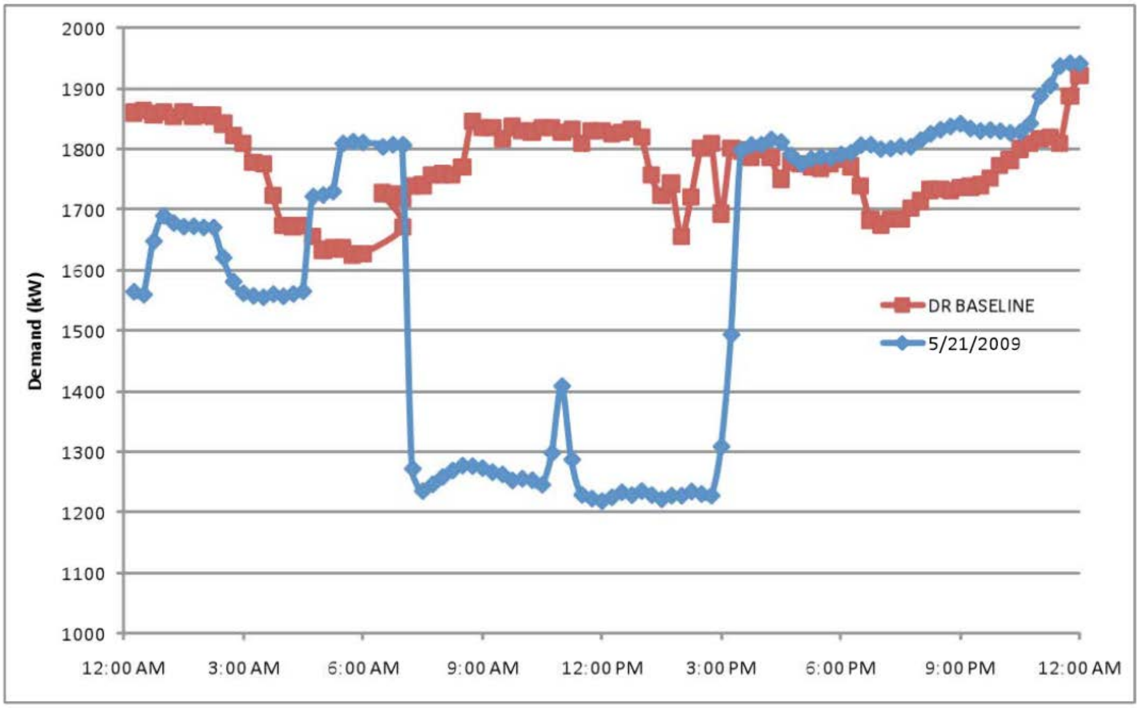

Figure 6-6
Load Shedding at a Wastewater Treatment Facility in San Diego County, CA

Courtesy of Lawrence Berkeley National Laboratory

There are two types of DR – Manual DR and Auto-DR – both of which are initiated by notification from a utility or Independent System Operator (ISO), Regional Transmission Operator (RTO), or third-party DR aggregator. Manual DR relies on manual notification and requires facility operation staff to first receive emails, phone calls or pager signals, and then to be physically present to initiate and execute DR strategies. In contrast, Auto-DR does not require human intervention, but instead relies on fully automated signaling to provide automated connectivity to facility end-use control systems, devices, and strategies. Specifically, Auto-DR interfaces with Supervisory Control and Data Acquisition (SCADA) systems, Building Automation Systems (BASs), and other controls to manage and curtail loads automatically and in real-time in response to price and system reliability triggers.[71] While Manual DR typically involves a lead time of 24 hours, Auto-DR can be used to respond in seconds or minutes just as readily as it can be used with 24-hour notifications.[72] A detailed description of Auto-DR can be found in the EPRI report *Automated Demand Response Today*.[73]

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[71] *Auto-DR: Smart Integration of Supply and Demand for Rapid Grid Response*, Global Energy Partners, LLC, Walnut Creek, CA: 2010, http://www.gepllc.com/AutoDR_GridResponse.pdf.

[72] Ibid.

[73] *Automated Demand Response Today*. EPRI, Palo Alto, CA: March 2012. 1025008. http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001025008

During a manual DR event, loads can effectively be controlled using conventional methods such as on/off switches, timers, and manual dimmers (for lighting), and standard thermostats (for HVAC systems). New technologies and control systems to enable load control of end-use devices are entering the market at an increasing rate.[74]

The Auto-DR architecture consists of two major elements: a DR Automation Server (DRAS) and a DRAS client. The DRAS is a client/server architecture-based middle-ware that automates the interaction between the utility and the facility, as illustrated Figure 6-7. A DRAS client, located at the facility, receives the automation signals and is linked to existing pre-programmed DR strategies independent of control network protocols such as BACnet, Modbus, or others. The pricing and reliability signals are communicated directly to the SCADA or end-use equipment controllers in the building. Pre-determined energy management and curtailment strategies agreed upon with the facility are automatically deployed in response to pricing and reliability events. Therefore, Auto-DR eliminates the requirement of facilities to curtail loads manually. As illustrated in Figure 6-7, the basic steps involved in the Auto-DR signal-communication process during a DR event include the following: [75]

1. The utility or ISO defines the DR event and price/mode signals which are set in the DRAS by the program operators.
2. The DR event and price services are published on the DRAS.
3. The DRAS clients request real-time event data from the DRAS every minute.
4. Customized pre-programmed DR strategies, such as shutting down water pumps, determine action based on event price/mode.
5. The facility's SCADA system, BAS, or related controls carry out load reductions based on the DR event signals and strategies initiated.

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[74] *Energy Efficiency Planning Guidebook* . EPRI, Palo Alto, CA: June 2008. 1016273.

[75] Ibid.

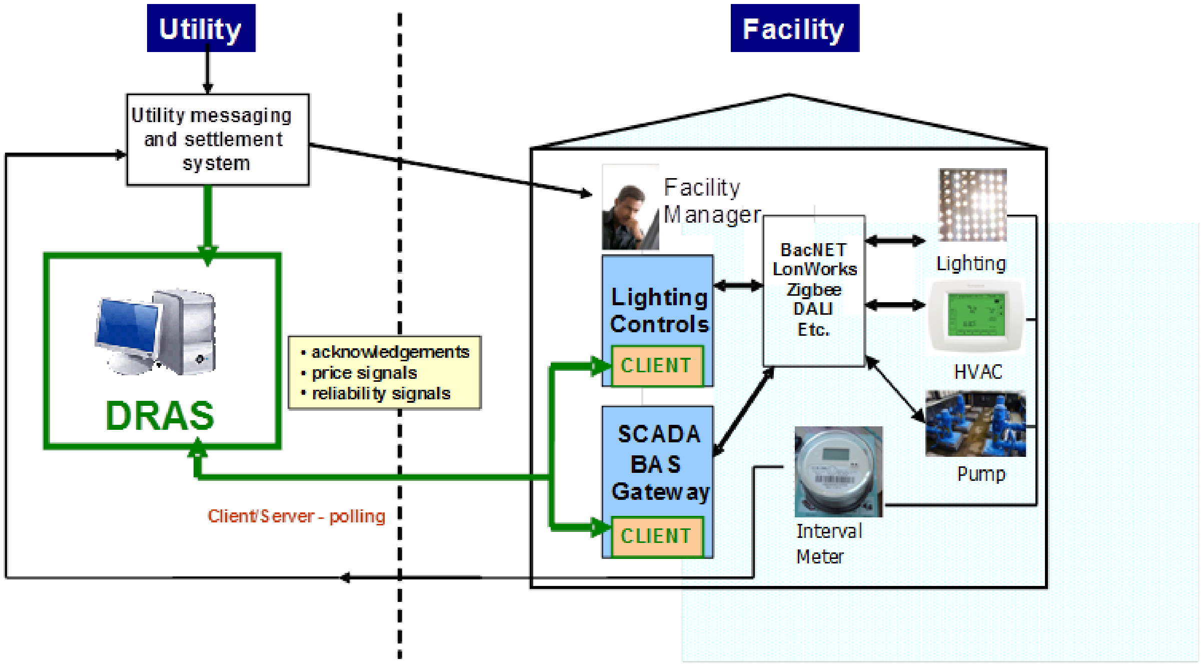

Figure 6-7
Generic Auto-DR Architecture

Courtesy of EnerNOC

There are a variety of issues motivating electric utilities to explore DR and Auto-DR programs. The primary drivers include:

- **Mitigate Grid Reliability Concerns:** An aging infrastructure, national security concerns, generation and transmission capacity constraints, growing demand, increasing requirements for high quality power, and the shift to low-carbon generation have made it increasingly difficult to balance generation and load in a rapid and seamless manner. Utility DR programs offer a valuable tool to leverage when faced with system emergencies and reserve shortages. DR resources are especially valuable if supply-side operating reserve margins are too tight to handle a large loss or inadequacy in generation capacity.
- **Address Regulatory Pressures Concerning Renewables:** Utilities are increasingly incorporating more renewables into their generation mix as a result of more and more states adopting Renewable Energy Portfolio Standards. Because of the intermittent nature of solar and wind generation, renewables can cause increased grid variability and uncertainty. Auto-DR, and in particular "Fast Auto-DR" with a notification time of 10 minutes or less, can supplement traditional spinning reserves.[76] Utilizing Auto-DR as a hedge against the uncertainties posed by renewable resources is an emerging concept that is currently being investigated by the California, Texas, and the Midwest grid system operators.

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[76] *Fast Automated Demand Response to Enable the Integration of Renewable Resources*, Lawrence Berkeley National Laboratory, Berkeley, CA: June 2012. LBNL Report 5555E.

- **Reduce Electricity Costs:** DR resources can be less costly to implement than supply-side actions, such as building a new power plant. As a result, DR can potentially be a cost-effective way to help reduce electricity costs while also reducing environmental impacts.

The automated feature of Auto-DR has historically been applied to dynamic pricing programs such as critical peak pricing (CPP), as well as to capacity-based options such as demand bidding programs (DBP), capacity bidding programs (CBP), and interruptible load programs. CPP programs currently account for the majority of Auto-DR programs. However, Auto-DR is now opening up more opportunities for customer participation in load curtailment programs, including ancillary services aimed at helping grid operators meet supply constraints.[77] (Two DR pilots presented later in this section discuss how water and wastewater treatment facilities can provide ancillary services to grid operators.) Table 6-2 presents a matrix of various program options that benefit from Auto-DR.

Table 6-2
Typical DR Program Options

	Customer Class			
DR Program Option	**Residential**	**Small C&I**	**Medium C&I**	**Large C&I (incl. Water & Wastewater)**
Direct Load Control (DLC)	√	√	√	
Interruptible			√	√
Critical Peak Pricing (CPP)	√	√	√	√
Demand Bidding Program (DBP)			√	√
Capacity Bidding Program (CBP)			√	√
Ancillary Services	√	√	√	√

Source: *Auto-DR: Smart Integration of Supply and Demand for Rapid Grid Response*, Global Energy Partners, LLC. Walnut Creek, CA: 2010.

Typical Demand Response Strategies Employed by Water and Wastewater Treatment Facilities

Water distribution systems contain vast amounts of storage which provide system pressure and backup in the event of a major fire. If managed correctly, water utilities can reduce distribution system pumping and allow the water supply system to “coast” during peak electrical periods. Wastewater systems, on the other hand, may divert a portion of the incoming sewage into holding cells or reduce aeration during peak electrical periods. Under the right circumstances,

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[77] Mary Cain, *Markets Enabling Ancillary Services From All Technologies*, presented at the 2nd Workshop on Active Power Control from Wind Power, May 16-17, 2013.

DR from water and wastewater facilities can be significant, benefiting both the electric utilities by reducing the need for peak generation, and benefiting the water and wastewater treatment facility through DR incentives. For example, EnerNOC, a third-party DR aggregator, has enrolled in excess of 100 MW of curtailable loads and onsite generator capacity at about 700 U.S. water and wastewater treatment facilities.

Wastewater systems struggle with significant flow changes, particularly during rainfall events. Infiltration into the collection system represents a challenging problem for many systems, so many plants have storage available at the front of the treatment plant to capture excess flow for treatment at a later period. Basin management decisions are usually based on keeping storage available for the next storm event, but depending on the plant can be used to manage peak electric demand. Wastewater could be shifted to the basin during peak electric periods to avoid excessive energy use. Fortunately, peak electric demand periods often coincide with hot and dry weather, giving the plant manager some flexibility in keeping storage available while reducing electrical demand.

Every water and wastewater system is unique, so the specific pumps and processes selected for DR strategies must be chosen carefully. Furthermore, the DR event period is highly specific to the electric grid serving the facility. Some regions of the country have longer or larger constraints on the electric grid than others. In those parts of the country with active DR programs, DR periods are typically 1 to 4 hours in the afternoon or early evening. Taking full advantage of the DR programs requires the water and wastewater utility to weigh the financial benefits of load reduction against any costs. DR is not typically an “all-or-nothing” affair. Usually the water or wastewater utility can participate in DR programs by pledging some fraction of their load or onsite generator. In most instances, the DR programs include provisions to opt-out in extraordinary circumstances. On the other hand, the DR programs typically include financial incentives only to those participants who actually shed their load or bring onsite generators online.

From an electric utility standpoint, DR is best accomplished through automating the process with Auto-DR. Auto-DR programs exist in several utility services areas across the country. Water and wastewater utilities can be excellent candidates for participation in these DR programs. The key stumbling block for any potential participant is in identifying and enabling what equipment can be turned off for short periods without impacting system performance. Thus, water and wastewater utilities must identify the pumps, blowers, and motors that can be shut down without causing problems from either a supply or water quality standpoint.

Turning off equipment for short periods is the simplest and most effective method to achieve DR. For example, by storing excess water in the distribution system during off-peak periods, water utilities can shut off equipment and continue to meet system requirements. As with any strategy, though, redundancies and backups are needed to ensure safe water supplies. Complex water storage and distribution systems with integrated zones are particularly well suited to utilize storage volume to manage pump scheduling during high electric demand periods and DR events. More sophisticated computer control schemes give water and wastewater utility operators additional options. These control schemes, combined with more efficient pumping systems and VFDs, can optimize pumping scenarios to accurately predict water and wastewater use patterns and operate the systems accordingly. Below follows a discussion of DR strategies that a water or wastewater treatment facility can undertake for load shedding, load switching, and onsite generation.

Examples of Load Shedding Strategies

There are numerous load shedding strategies for water and wastewater treatment facilities. For example, water and wastewater treatment facilities can shut down unnecessary equipment during peak demand periods or use VFDs to operate equipment at reduced capacities. Examples of equipment that a wastewater treatment facility may be able to shut during DR events include pumps, HVAC systems, lighting, centrifuges, and aerator blowers.[78] However, careful monitoring of the wastewater stream is required to assure its quality is not adversely affected by shutting down process equipment. Load shedding can also be achieved by staging equipment or using equipment with VFD capability. If the water or wastewater treatment facility has several pumps operating in parallel, the use of VFDs allow for staging of pumps so some pumps can operate at lower capacities.[79] Because pumping accounts for the majority of electricity end-use in drinking water facilities and pumps and aerator blowers account for a significant share of total electricity use in wastewater treatment facilities, VFD-controlled pumps and aerators can provide significant demand reductions.

Examples of Load Shifting Strategies

Load shifting strategies involve the rescheduling of electric demand to off-peak hours. This can be done during DR events, only, or regularly as a load management strategy. Examples of load shifting strategies used by wastewater treatment facilities include the following:[80,81]

- **Pre-aeration (or, over-oxygenation):** Over-oxygenation involves over-aerating wastewater prior to a DR event, allowing the facility to reduce aeration during the actual DR event. However, it is critical that the facility monitors effluent to ensure that over-oxygenation meets the facility and operational needs as dissolved oxygen (DO) concentrations can inhibit denitrification. Additionally, excessive air input once effluent reaches maximum DO concentration must be avoided to prevent unnecessary electricity use.
- **Scheduling dewatering, anaerobic digestion, and backwash filter processes to off-peak periods:** Some processes can be rescheduled to off-peak times, allowing for certain equipment to be turned off during a DR event. For example, biosolids thickening/dewatering and backwash filter pump operation can possibly be rescheduled for operation off-peak and partial-peak rate periods. Again, it is important to install controls to ensure the filters can operate continually during on-peak hours without backwashing.

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[78] *Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California – Phase I Report*, Lawrence Berkeley National Laboratory, Berkeley, CA: April 2009.LBNL-2572E.

[79] Ibid.

[80] Ibid.

[81] *Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California – Phase II Report: San Luis Rey Wastewater Treatment Plant Case Study*, Lawrence Berkeley National Laboratory, Berkeley, CA: August 2010. LBNL-3889E.

- **Water storage:** Water storage allows water and wastewater treatment facilities to store water and process it during off-peak hours. For example, one LBNL research study revealed wastewater treatment facilities can divert treated wastewater to effluent storage ponds and then pump the treated effluent during off-peak hours. Indeed, using this strategy, the San Luis Rey Wastewater Treatment Plan reduced its demand by 300 kW throughout the duration of a DR event test. Unfortunately, many facilities are not equipped with adequately sized excess water storage and building additional storage can be expensive, so facilities should consider converting unused tanks into equalization basins during facility upgrades and retrofits.

Examples of Onsite Generation Strategies

If shutting equipment off is insufficient to meet demand reduction requirements, alternative generation is often required. Nearly all water and wastewater facilities have some backup generators, although there may be limits on their use (such as air quality regulations for diesel generators) making them unsuitable for use as frequently as some DR programs require. In those cases, water and wastewater utilities can install natural gas-fired or biogas-fired power generation that can be used more frequently because they are considered more environmentally friendly. This sort of generation is commercially available at a variety of scales. Biogas-fired CHP systems at wastewater treatment plants that can generate both electricity (for use in the plant) and heat (for keeping the anaerobic digester warm) are especially interesting to plants striving to become net-zero facilities. Biogas-fired CHP systems are explored in greater detail later in this chapter. Renewable onsite generation technologies may also be possible alternatives. Though photovoltaic (PV) systems and wind turbines are generally more expensive than natural gas-fired turbines, incentives and credits offered by utilities, states and the federal government for renewable generation can bring the cost down. However, water pumping and wastewater aeration are energy-intensive processes. Therefore, large-scale solar and wind turbines are needed in order to make a sizeable impact on a facility's peak load.

The following section presents three DR pilots. The first involves an overview of how water storage is used effectively to reduce peak electric demand by a water utility. The second DR pilot discusses American Water's participation in the PJM market, providing grid balance by ramping up and down pumping operations. The third involves an innovative DR pilot that assesses the capability of DR resources to respond to 10-minute deployment required for balancing wind power integration in the electric grid.

Example DR Pilot: Strategic Pump Scheduling Reduces Electric Peak Demand by 4 MW at WaterOne[82,83]

WaterOne is a water utility serving more than 400,000 customers in Johnson County, KS. Its peak supply of treated water is 200 MGD. In 2006, WaterOne installed strategic pump scheduling in an effort to reduce peak electric demand costs. Specifically, WaterOne installed Derceto's Aquadapt software and used it in conjunction with data collected by its existing

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[82] Tom Nevins and Chuck Weber, *Reduce Pumping Energy Costs by Strategic Management of Distribution, Storage and Pumping*, presented at the AWWA DSS 2009, Sept. 1, 2009.

[83] Derceto, *Case Study WaterOne*, April, 2012.

SCADA system to reduce pumping at high-lift pump stations during the daily peak demand period.

Because WaterOne has very limited elevated storage (<5% of peak daily water demand), pumping during the on-peak electric period is unavoidable. However, the strategic pump scheduling system can leverage storage available at the most cost-effective field pump stations throughout the network instead of using the high-lift pumps during on-peak energy periods. In addition, WaterOne's large below-the-grade storage reservoirs are replenished overnight when the high-lift pumps operate in the off-peak energy period.

The Pilot demonstrated that the pump scheduling scheme was capable of reducing WaterOne's peak electrical demand throughout the summer months by about 5 MW (see Figure 6-8), which resulted in annual energy cost savings of \$800,000 (~20% of total energy costs). (WaterOne believes the annual savings are currently in excess of \$1,000,000, with a peak summer demand reduced by up to 4 MW.) The simple payback for the strategic pump scheduling system was about 2 years.

Strategic Pump Scheduling Substantially Reduced Peak Electric Power Demand

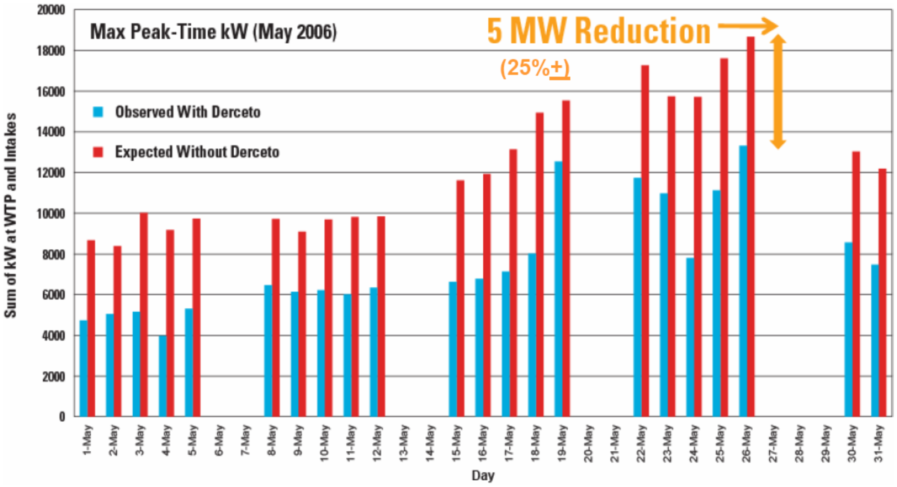

Figure 6-8
Strategic Pump Scheduling Reduces Peak Demand for WaterOne, KS

Courtesy of Derceto, Inc.

Example DR Pilot: American Water Provides Grid Balance to Electricity System Operators[84] [85] [86]

American Water is the nation's largest publicly traded water and wastewater utility. It was the first U.S. water or wastewater utility to join the U.S. EPA's Climate Leaders Program and the Carbon Disclosure Program. As part of its effort to reduce greenhouse gas (GHG) emissions by 16% by 2017, American Water launched the Innovation Development Process (IDP) in 2007.

The first innovation produced through IDP is a partnership with ENBALA Power Networks (ENBALA) to harness the flexibility of American Water's facilities and systems to provide grid balance to electricity system operators. Because approximately 97% of American Water's electricity use and 90% of its GHG emissions are associated with pumping, it is highly critical to manage and optimize pumping operation. Therefore, the work began as a DR pilot to demonstrate and assess ENBALA's technology in managing pumping energy use to match the needs of the electrical grid. The pilot involved Pennsylvania American Water's Shire Oak Pumping Station and was focused on providing grid balance services to PJM Interconnection, the regional electricity system operator.

Shire Oak Pumping Station uses an average 1.1 million kWh each month, with a peak demand of 1,650 kWh. In the DR pilot, one 10 MGD relay pump was selected for connection to ENABLA's network. This network consists of existing electrical end-use equipment (or "assets") owned by various clients. The network adjusts demand by enabling assets to use more electricity when grid demand is low and less when it is high. Each asset in the network has its own set of constraints and responds to grid balance requests when available. The 10 MGD pump, equipped with VFD (85-100% speed), provided 80 to 200 kW operating range. Tank level constraints were programmed into ENBALA's network to test its performance in responding to grid balance requests. The results and outcome from the 120-hour demonstration are summarized below:

- Relay pump successfully responded to grid balance requests
- Pump speed stayed within operating parameters set by plant
- Shire Oaks Pumping Station bid into the live PJM market in fall 2011
- Typical payments for grid balance in the $35,000-50,000 per MW/year range
- Grid balance has the potential to offset 2-3% of Shire Oaks Pumping Station's energy costs
- Shire Oaks Pumping Station is planning to relocate a VFD to a second 10 MGD pump
- American Water currently participates in DR programs through its subsidiaries in New Jersey, Ohio, Pennsylvania and Long Island
- American Water is connecting additional water and wastewater facilities to provide grid balance to PJM Interconnection

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[84] American Water*, Bridging the Water Innovation Gap*, WHITE PAPER, February, 2013.

[85] *Utility Innovations Reduce Energy Consumption*, World Water, January/February 2012.

[86] Dan Hufton, *Revenue Generating Smart Grid Technology – A Pennsylvania American Water Case Study*, presented at Pennsylvania American Water Works Association (PA AWWA) 65th Annual Conference & Expo, April 23-25, 2013.

Example DR Pilot: Demand Response Helps Balance Wind Integration[87, 88]

The Bonneville Power Administration (BPA) is a self-funded agency that markets wholesale electricity (from numerous federal hydro projects and one nuclear power plant) to 142 utilities in eight western U.S. states, including Idaho, Oregon, Washington, Montana, and small parts of California, Nevada, Utah, and Wyoming. BPA also owns, operates, and maintains the majority of the transmission system in the Northwest. It also manages the balancing authority for rural parts of Oregon and Washington and small segments of Idaho and Montana. Historically, BPA has met peak load requirements through the flexibility of its hydropower system. However, load growth, wind power integration, and fish operations are beginning to limit this flexibility.

BPA currently has almost 5,000 MW of interconnected wind capacity that may double to 10,000 MW in the next few years. This is significant penetration for a region with roughly 39,000 MW of generation capacity. Indeed, BPA has the greatest percentage of wind penetration, compared to loads, of any balancing authority in North America. Though BPA's hydro power system can provide +/- 1,000 MW of balancing reserves, it is approaching its limit. A BPA wind integration analysis has indicated a potential need to increase regulation, load following, and balancing requirements. Because BPA is responsible for constantly balancing load and supply on the electrical grid within its service area, even though most of the region's wind power serves loads outside BPA's balancing authority, such as California, it faces significant balancing reserve demands. As a result, BPA is evaluating new near-term tools that can assist in balancing the intermittency of wind power. As a result, BPA is evaluating new near-term tools that can assist in balancing the intermittency of wind power. One such tool is DR. BPA has launched two DR pilots to assess the ability of DR to support wind integration. The most recent DR pilot—*City of Port Angeles, Commercial & Industrial DR Pilot*—is discussed in greater detail below. It is followed by a brief overview of another DR pilot—*Eugene Water and Electric Board DR Pilot*—that BPA recently initiated with the Eugene-Springfield Wastewater Pollution Control Facility located in Eugene, OR.

City of Port Angeles, Commercial & Industrial DR Pilot

The City of Port Angeles, Commercial & Industrial DR Pilot involved nine facilities, as illustrated in Figure 6-9, including the Nippon paper mill and the City of Port Angeles Water Treatment Plant. (The water treatment facility had three lighting circuits and all process area radiant heaters, totaling 36.5 kW, enrolled in the DR pilot.)

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[87] Christopher Ashley, Leigh Holmes, and Greg Wikler, *Using More Energy Can Be A Good Thing: C&I Loads as a Balancing Resource for Intermittent Renewable Energy*, American Council for an Energy Efficient Economy, Industrial Summer Study, Niagara Falls, NY.

[88] Lee Hall, *Bonneville Power's Award-Winning Demand Response Initiative*, Peak Load Management Alliance (PLMA), Web Workshop, August 8, 2013.

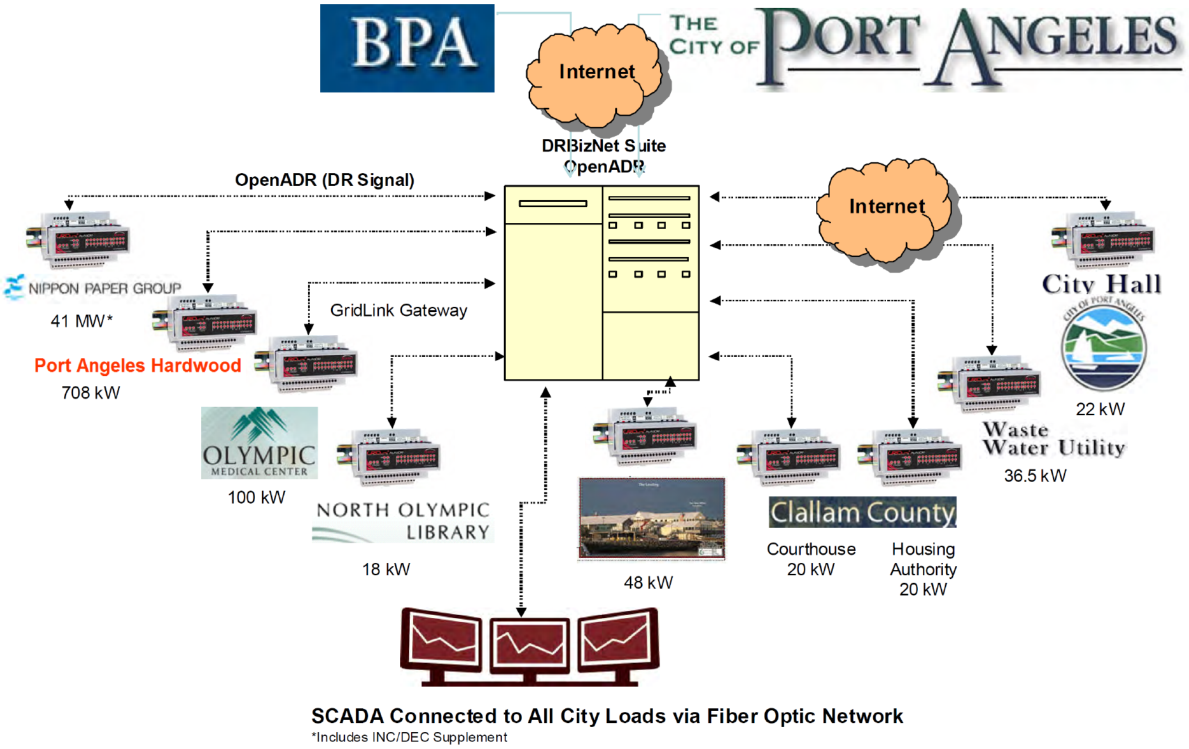

Figure 6-9
Participants in the City of Port Angeles, Commercial & Industrial DR Pilot

Courtesy of Bonneville Power Authority

All nine facilities have loads that are connected to SCADA systems via fiber optic network. The goal of the DR pilot was threefold:

1. **Test Multiple Types of DR:** BPA was interested in testing 10-minute deployment of loads up and down. The local utility tested DR for day-ahead peak shave.
2. **Test DR Platform:** The DR Platform was tested in numerous ways. For example, the DR Platform was tested for its capability of supporting multiple parties as DR event initiators and using a signal for load down/up. Furthermore, the DR Platform must support 1-minute communication intervals and 1-minute interval load availability.
3. **Test Auto-DR vs. Communication with End-Load Control Room:** This pilot assesses the performance of both Auto-DR and non-automated DR. Though Auto-DR is typically the preferred method of communicating and dispatching DR events because it is faster, some facilities do not want to give up the control of end-use equipment. For example, one of the nine participating facilities, a large paper mill, required all DR requests to be decided by mill personnel with no direct control of load by BPA.

The BPA pilot demonstrated the technical feasibility of using 10-minute deployment of DR resources. From April to August in 2012, 26 load increase requests and 20 load decrease requests with 10-minute deployment were delivered. The facility loads were able to respond to both types of requests within 10 minutes. However, not all requests were accepted due to production and other considerations. Because the majority of electricity available for load control is central to core business activities at most industrial and water and wastewater treatment facilities, maintaining the flexibility to put operation needs first is paramount to getting these sites to participate in DR programs.

One important lesson learned from this pilot is that DR incentives must be better aligned. For example, a facility's desire to increase loads during "load up" events" was constrained by the risk of setting new monthly peaks and thus incurring increased demand charges. Moving forward, BPA and City of Port Angeles are conducting a commercial DR demonstration in 2013-2014. BPA is also extremely interested in conducting larger-scale commercial demonstration projects to assess the availability and reliability of DR to address multiple *regional* needs, moving beyond peak load management.

Eugene Water and Electric Board DR Pilot

BPA also has an ongoing pilot study with Eugene Water and Electric Board (EWEB), which is focused on the Eugene-Springfield Wastewater Pollution Control Facility located in Eugene, Oregon. This DR pilot aims to demonstrate that the wastewater treatment facility can act as a dispatchable utility-scale DR resource (>1 MW) to reduce load during peak periods, capacity constraints, grid emergencies, or when renewable resources experience intermittency. When BPA informs the facility of a need to reduce load, the facility operators will attempt to ramp down the aeration blower and/or pump stations for a set duration. Future scenarios will strive to expand DR objectives. This may include shorter response time, longer response duration, or seasonal strategies as determined by the team and as lessons learned dictate. Plant SCADA control of equipment is extensive and additional load shedding opportunities can be integrated into request/response structure.

Alternative Generation, including Renewables

If shutting equipment off is insufficient to meet demand reduction requirements, alternative generation is often required. Nearly all water and wastewater facilities have some backup generators, although there may be limits on their use (such as air quality regulations for diesel generators) making them unsuitable for use as frequently as some DR programs require. In those cases, water and wastewater utilities can install natural gas-fired or biogas-fired power generation that can be used more frequently because they are considered more environmentally friendly. This sort of generation is commercially available at a variety of scales. Biogas-fired CHP systems at wastewater treatment plants that can generate both electricity (for use in the plant) and heat (for keeping the anaerobic digester warm) are especially interesting to plants striving to become net-zero facilities. Biogas-fired CHP systems are explored in greater detail later in this chapter.

Renewable onsite generation technologies may also be possible alternatives. Though photovoltaic (PV) systems and wind turbines are generally more expensive than natural gas-fired turbines, incentives and credits offered by utilities, states and the federal government for renewable generation can bring the cost down. However, water pumping and wastewater aeration are energy-intensive processes. Therefore, large-scale solar and wind turbines are needed in order to make a sizeable impact on a facility's peak load.

Category 2: Emerging Technologies and Processes

New regulations and the wider use of new technologies continue to raise the potential for increased electric intensity in water and wastewater treatment. This section summarizes technologies and processes that will lead to an increased electric use by water and wastewater facilities.

Odor Control

Municipalities construct wastewater treatment plants in less-populated regions to minimize nuisance complaints, but population growth has led to existing plants getting new neighbors. Further, suburban sprawl limits the suitable areas for siting wastewater plants. Wastewater treatment plant staff increasingly installs odor control to minimize complaints. Odor control systems consist of covers, ducting, and the pumps and blowers to route odorous air through appropriate filters. The filters most often are granular media so the blowers must be large enough to overcome any static drop due to the ducting and the media; usually, these are small motors (relatively speaking) and even in the largest of plants do not exceed 25 or 50 hp. The scrubbed air is discharged to atmosphere. Odor control is a small but growing electric load. Odor control for large facilities in metropolitan areas can account for a significant share of total electricity use so should not be overlooked.

Figure 6-10 provides a photo of odor control devices at a 10 MGD wastewater treatment facility. The white piping in the figure is the ductwork to convey odorous air to the scrubber, positioned along the left side of the photo. The air is pulled from the basins and pushed through the scrubber using the centrifugal fan located on the left side of the photo. Odor control is most often implemented in facilities close to residential areas so there is little relation to plant size. The energy penalties are small, constituting less than 5% of total electric use at treatment plants using the process.

Figure 6-10
Example of a Typical Odor Control Installation at a Wastewater Treatment Plant

Courtesy of HDR

Membrane Bioreactors

Membrane bioreactors (MBRs) consist of membrane immersed into an activated sludge basin. The basin is aerated and flow through the membranes is from the outside in, so the aeration produces turbulence that helps reduce plugging of the membrane. One opportunity involves the use of optimized scour air; several manufacturers now offer retrofits than can reduce scour air by 40% or more.[89]

Cooper et. al. (2006) suggests total connected horsepower for MBRs may be 500 hp or greater per MGD, but recognize that considerable optimization can lower the connected horsepower.[90] In fact, energy costs are perhaps the principal reason these systems are not adopted more widely, particularly in light of the tight treatment requirement on many wastewater treatment facilities. The estimates in this report are based on assuming that total working load for the membrane bioreactor is 350 hp, one-half of which operates loaded 80% of the time and one-half of which operates loaded 50% of the time. Based on the data in Table 5-2, MBR plants have an energy intensity that is 3 to 4 times greater than conventional secondary treatment (i.e., activated sludge).

Under many conditions such a high degree of treatment is not necessary. However, in water reuse applications the high quality of the effluent is a significant benefit. MBRs also reduce construction costs and have a small footprint, so they find applications in ecologically-sensitive locations. Siemens, one manufacturer of MBR systems, projects annual growth in sales of MBRs of 12% for the U.S. between 2005 and 2015.[91]

Deammonification Process and other Low Energy Alternatives

One technology widely accepted in Europe that is now under consideration in the U.S. is the deammonification sidestream process. Trade names for the process include DEMON and ANITA Mox. Traditional nitrification/denitrification converts ammonia, which is present in all raw wastewater, to harmless nitrogen gas in a stepwise process of converting ammonia to nitrite and then to nitrate in the presence of oxygen, then converting the nitrate to nitrite and then to nitrogen gas in the absence of oxygen. The conversion from nitrite to nitrate (aerobically) and nitrate back to nitrite (anaerobically) requires significant oxygen and carbon, respectively. Deammonification circumvents this process by taking the nitrite directly to nitrogen gas through careful selection of the microbes and careful control of aeration and pH.

Though the process works well in Europe, it requires careful controls and attention from plant operators. It is also a slow process to bring into operation (two to five months before steady state can be attained). The process includes rerouting concentrate from the dewatering of the digested sludge back to the front of the plant, so there are additional pumping and treatment costs, but the

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[89] Information provided by Bonneville Power Administration Energy Smart Industrial Layne McWilliams and Dawn Lesley on behalf of Jennifer Eskil.

[90] N.B Cooper, Marshall, J.W., Hunt, K and Reidy, JG. "Energy Usage and Control at a Membrane Bioreactor Facility," presented at WEFTEC, Atlanta, GA: 2006.

[91] "*Advanced Membrane Filtration for Water Reuse Applications*", Siemens Water Technologies, available at http://www.water.siemens.com/en/applications/water_recycle_reuse/Pages/membrane-filtration-water-resue.aspx.

reduction in aeration needs is potentially significant. Given the demands for technical sophistication along with additional pumping and instrumentation, the system makes economical sense plants with larger flows, but it promises to cut electric aeration needs by as much as 25%. However, recent advances are making this technology more economical for smaller facilities. Based on the EPA's estimates of treatment plant flow and our estimates of energy use, the total savings associated with deammonification could be as much as 1.5 TWh/year in the U.S.

Deammonification sidestream processes focus on reducing aeration needs in the activated sludge process. A similar but different process currently under consideration by the WERF entails separating the process stream into two separate trains where one is treated anaerobically while the other can be treated more conventionally, such as with nitrification and denitrification. The anaerobically treated stream is combined with the conventionally treated one to complete the process. While initial results are encouraging, additional research into designing and optimizing these processes is needed.

Water Reuse

Water reuse encompasses a wide variety of programs and projects by governmental, industrial, and commercial entities. The term is used interchangeably with other terms, such as water reclamation, water recycling, and water mining. In all cases, it entails capturing water used in one process and using it, with or without treatment, for another secondary purpose. In nearly all cases, the secondary purpose has lower water quality requirements than the primary one. For instance, water used in a shower is recycled to water landscaping. Water reuse plans range from a homeowner collecting bath water to water potted plants, to a California utility injecting reclaimed wastewater into aquifers to prevent groundwater intrusion. Given the breadth and scope of water reuse schemes, it is not possible to quantify electrical impacts.

Yet water reuse will continue to grow as a viable approach to meeting drinking water needs in the U.S. While the U.S. population continues to grow, our volume of drinking water is limited, particularly in certain parts of the country. Given the many competing needs for water and the high energy costs associated with desalination, many municipalities will opt to implement various approaches to water reuse.

Under the terms of this assessment, water reuse involves the collection, treatment, and direct reuse of wastewater. Direct reuse of wastewater, wherein the wastewater is treated and directly pumped into the potable water system, is unlikely to be widely implemented due to its poor public perception, Instead, municipal water reuse will involve secondary distribution systems where the water is used for industrial processes or in the irrigation of golf courses or parks. Case Study 4 in Chapter 7 presents a water reuse scheme where the treated wastewater is used for both power plant cooling water and by a nearby industrial customer.

Under such water reuse schemes, electrical energy use associated with water and wastewater use is likely to grow because water reuse projects typically require the use of more advanced treatment technologies, including ozone disinfection or membrane filtration. Further, pumping energy usually rises also as the reused water, which was previously released to the environment, must now be transmitted to its intended point of use. It is difficult to predict and quantify the impact of water reuse on a national basis. However, water reuse will become critical in water stressed regions of the country. This includes the arid west, especially southern California and Arizona, along with large portions of Texas. Additionally, certain regions experience occasional but routine water shortages, such as the Front Range of Colorado, southern Alabama and Georgia, and sections of the Northeast.

Water reuse presents certain technological challenges. In a sense, nearly all surface water sources contain “recycled water” because some of the discharges upstream become withdrawals downstream. However, natural processes serve to help clean the water, such as through microbial degradation and aeration. Direct recycling usually demands advanced wastewater treatment followed by conventional water treatment before any use. Even in those cases, there is the potential for microbial regrowth. Water reuse is an immense subject which is continuously being addressed by the Water Reuse Association and the Water Reuse Research Foundation, two independently governed organizations with a unified mission and staff. Several EPRI studies also address the technological and energy impacts of water reuse. [92] [93]

Residuals Processing

Residuals processing in water and wastewater treatment facilities can benefit from improvements. Water treatment residuals are largely inert, consisting of chemical precipitates and solids in the raw water. Current efforts in processing residuals focus on better separation technologies, such as improved settling basins. Characterizing the residuals from wastewater treatment is particularly important from an energy balance standpoint because wastewater biosolids represent an energy source. Thus, many of the more promising avenues for processing biosolids focus on improving energy yield. Two different technologies are worthy of mentioning. They include the augmentation of anaerobic digesters with high-strength waste and cell lysis.

Codigestion is the process of adding organic waste to anaerobic digesters. The most common examples of suitable organic wastes include fats, oils, and grease as well as food waste. Codigestion process can improve digester performance and also increase the amount of methane produced, but the additional organic waste must be added carefully and mixed well. WERF is currently working on reducing the need for pilot scale evaluations of this process, leading to more widespread implementation. The organic waste stream must be secured. This often entails trucking the material to the wastewater treatment plant. Modifications to collection routes (by the waste haulers) and dump stations (by the wastewater treatment facility) are needed.

A different but complimentary approach to improving methane yield from anaerobic digester is cell lysis. Both physical and chemical approaches have been evaluated to promote cell lysis. They include ultrasound, heat and pressure, pasteurization, high shear mixing, ozone and peroxide, sonification, and focused electric pulse. In all cases, the goal is to destroy the cell membrane of the microbes, leading to faster and more complete digestion. The cell lysis process improves methane yield and reduces the volume of sludge that must be disposed. Figure 6-11 illustrates a cell disruptor based on high pressure cell lysis technology. Various manufacturers have developed and marketed products and there are significant differences in claimed benefits, costs and savings. It would be immensely beneficial to the wastewater treatment industry to have a comprehensive evaluation of the various cell lysis technologies.

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[92] *Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use*. EPRI, Palo Alto, CA: 2008. 1016460.

[93] *Program on Technology Innovation: Electric Efficiency Through Water Supply Technologies– A Roadmap.* EPRI, Palo Alto, CA: 2009. 1019360

Figure 6-11
High Pressure Homogenizer Marketed as MicroSludge Cell Disruptor

Courtesy of Paradigm Environmental Technologies, Inc.

Microbial Fuel Cells

Microbial fuel cells (MFCs) generate electricity from the organics present in wastewater. Specifically, they utilize the bacteria commonly found in biological wastewater treatment processes to harvest the chemical energy stored in contaminants and convert it to electricity. A significant amount of research effort has been invested to test MFCs at the bench-scale level for wastewater treatment, yielding increasingly effective power generation rates. However, full-scale evaluation of MFCs will be required in the future. Also, chemical hydrogen peroxide (H_2O_2) can be produced from a bioelectrochemical system. Studies suggest that the bioelectrical system used to make H_2O_2 is a better option than the MFC itself.

LED UV Lamps

Conventional systems that use mercury lamps operate at 254 nm. This is not the peak absorption wavelength of bacteria and viruses, but it is close enough to have a significant germicidal effect. LED-based UV lamps can be crafted to emit UV light at any specific wavelength. Therefore, the lamps can be designed to emit light at a single, optimal wavelength. Their biggest advantage over conventional lamps is that LED-based UV lamps are mercury-free, so there is no possibility of mercury contamination of the water during the disinfection process. From an operational standpoint, LED UV lamps do not need a warm-up period. Furthermore, they emit light in one direction only, enabling more efficient application.

While LED UV lamps are currently being researched, the only commercially available LED UV lamps are limited to point-of-use applications (e.g., under a kitchen sink). Therefore, additional efforts to scale up the technology are required to make the systems technologically and economically feasible for flows encountered in municipal water and wastewater treatment. One research goal is to develop a UV disinfection system that could be feasibly powered by renewables or batteries, greatly enhancing the energy efficiency of the disinfection process.

Category 3: Energy Recovery and Generation

A new and growing trend in the water and wastewater industry is the emphasis on recovering energy whenever possible. In water treatment the focus is on recovering some of the pumping energy through the use of energy recovery devices in the distribution system. In wastewater treatment, the emphasis is on biological treatments combined with opportunities in capturing energy in the wastewater itself. Those ideas are discussed below.

Cogeneration Using Digester Biogas

If anaerobic digesters are used for biosolids stabilization, the biogas produced by the fermentation of organic matter can be used to power engine-driven equipment or to generate electricity. The waste heat from the engines can be used to maintain temperatures in the digesters for proper stabilization of biosolids. The biogas consists of methane and carbon dioxide and has a heating value of 600 Btu per cubic foot. Approximately 350 kWh of electricity can be produced for every dry ton of biosolids produced in the treatment plant. Collection of biogas from digesters is relatively easy. The U.S. EPA and EPRI have produced excellent resources for utilities interested in biogas-fired CHP systems.[94] [95]

In the past, much of the biogas was simply burned in boilers to keep the digester warm. Reciprocating engines were the method of choice used to generate electricity. Today, wastewater treatment plant staff has a variety of generation choices, including gas turbines, microturbines, and fuel cells. For example, Figure 6-12 shows 30-kW turbines installed in a wastewater treatment facility in Minnesota. Further, CHP systems can raise the system efficiency above 60% making the entire investment more cost effective. In fact, CHP systems are a key component in any attempt to develop a “net-zero energy” wastewater treatment plant. “Net-zero” refers to the goal of making wastewater treatment plants self-sufficient on an energy basis. In other words, a net-zero treatment facility would produce as much energy as it consumes. Converting the biogas to electrical energy, which can be used at the plant or sold back to on grid, is crucial in the net-zero strategy. There are few “net-zero” facilities currently in operation in the U.S., although one wastewater treatment plant in California recently became a net producer of electricity. This facility is discussed in Case Study 3 in Chapter 7.

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[94] *Opportunities for Combined Heat and Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field,* U.S. EPA, Combined Heat and Power Partnership, Washington D.C.: October 2011.

[95] *Biogas-Fueled Electric Power: An Assessment of Systems and Technologies*. EPRI, Palo Alto, CA: May 2005. TR-1012019.

Figure 6-12
Capstone 30 kW Turbines Installed at the Albert Lea, Minnesota Wastewater Treatment Facility

Courtesy of Albert Lea, Minnesota Wastewater Treatment Facility

Energy Recovery from Distribution Systems

The following subsections describe the equipment and processes associated with water distribution and storage systems. Much of this information is updated and summarized from another EPRI report focused on the characteristics of water storage tanks and pumping systems.[96]

Approximately 25,000-26,000 finished water storage tanks are currently in operation in the U.S. public water supply, based on extrapolation of results from the American Water Works Association's (AWWA's) WATER:\STATS 2002 survey of 335 water supply utilities.[97]

Opportunities exist to alter electric demand patterns by changing the way water is pumped and by taking advantage of water storage systems. Two potential novel opportunities include: 1) the use of renewable energy to pump water and 2) the recovery of excess line pressure to produce electricity. They are discussed next.

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[96] *Public Water Storage Tank Operation Data: Characteristics of Water Storage Tanks and Pumping Systems.* EPRI, Palo Alto, CA: 2010.

[97] American Water Works Association, George Kunkel, *Using the WATER:\STATS 2002 Distribution Survey to Assess Finished Water Storage in Drinking Water Utilities*, September 29, 2003.

Use of Renewable Energy to Pump Water

Renewable energy such as solar PV or wind can be used to pump water in the distribution system and/or to gravity storage tanks. The presence of water storage tanks makes it relatively easy for water utilities to incorporate the variability of renewables. Using renewables to augment pumping power requirements during on-peak periods would lower peak demand (e.g., solar PV during the day), while using renewables to augment off-peak pumping to storage would help leverage storage for load shifting (e.g., wind during the evening). When coupled with water storage, renewables could also find a special application in remote, hard-to-reach areas as a backup energy source during power disruptions. Depending on the specific application, the costs of renewable technologies may be a limiting factor. Renewables are likely to be most economically viable if they are used for augmenting electric power from the grid during peak periods.

Recovery of Excess Line Pressure to Produce Electricity ("Micro Hydro")

The recovery of excess line pressure represents an exciting, relatively-untapped potential for changing electric demand patterns. Though reversible pump/turbine technologies currently exist for recovering line pressure, they have not been implemented to a great extent. The potential for energy recovery from excess pressure in water distribution systems in the U.S. is estimated to be on the order of hundreds of megawatts.[98] However, one large U.S. water utility suggests that the economical potential for energy recovery using this method is small. To be most economical, the energy recovery device must be fairly close to an appropriate connection to the electric grid and this is often not the case. Furthermore, the energy recovery devices currently on the market are limited to fairly large distribution mains, thereby eliminating many possible application sites. The industry could benefit from the development of more cost-effective energy recovery devices for small flows that could be more easily connected into the power grid.

Energy Savings Potential from Advanced Technologies

Estimates of the potential energy savings from the water and wastewater industry were discussed previously in this chapter, in the energy efficiency section. Using the methodology developed by EPRI for achievable electric energy potential savings, savings in the water and wastewater industry could be as much as 5.6 TWh by year 2030, or 1-2% of the nation's total achievable potential.[99] Though there are numerous technological solutions available that can help achieve these savings, they would require the coordinated efforts of electric utilities, water and wastewater utilities, and other stakeholders within the industry.

Energy efficiency gains are achieved through judicious use of appropriate technologies. While assessments of specific technologies are rare, EPRI developed estimates of potential energy savings from a variety of water technologies in a 2009 roadmap report on water use from public

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[98] Rentricity Inc., New York, NY, http://www.rentricity.com/.

[99] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030).* EPRI, Palo Alto, CA: January 2009. Product No. 1016987.

water suppliers and in agricultural irrigation.[100] According to that EPRI study, the most promising technologies (and their associated projected savings) include the following:

- High-efficiency pumps and motor systems (2,600-7,800 million kWh/year)
- Variable frequency drives (2,600-5,200 million kWh/year)
- Pipeline optimization (1,200-5,200 million kWh/year)
- Advanced SCADA systems (3,050-6,100 million kWh/year)
- Automatic meter reading (1,500-4,500 million kWh/year)

The energy efficiency measures listed above are focused on improvements in the pumping of treated water. It is likely that there is considerable overlap in the estimates, so the total savings would not be cumulative but rather something considerably less. However, the magnitude of expected savings suggests that as much as 50% of the achievable energy efficiency potential in water and wastewater is associated with the optimization of water pumping.

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[100] *Program on Technology Innovation: Electric Efficiency through Water Supply Technologies-A Roadmap.* EPRI, Palo Alto, CA: June 2009. Product No. 1019360.

7

FACILITY CASE STUDIES

U.S. water and wastewater treatment facilities are increasingly assessing and implementing innovative strategies for energy efficiency, energy recovery, demand response, and water conservation and water reuse. This chapter begins with a brief overview of these four areas. This is followed by eight real-life examples of facilities that have implemented innovative energy strategies:

1. Sheboygan, Wastewater Treatment Plant, WI
2. Las Vegas Valley Water District, NV
3. East Bay Municipal Utility District, CA
4. Emerald Coast Utilities Authority, FL
5. Tampa Bay Seawater Desalination Plant, FL
6. Eugene/Springfield Regional Wastewater Pollution Control, OR
7. Gloversville-Johnstown Joint Wastewater Treatment Facility, NY
8. Eastern Municipal Water District, CA

Error! Reference source not found. summarizes what is covered in each case study.

Table 7-1
Case Study Index

Case Study	Drinking Water	Waste-water	Energy Efficiency	Energy Recovery/DG/CHP	Demand Response	Water Reuse	Desalination
1		√	√	√			
2	√		√	√	√		
3	√			√			
4		√				√	
5	√						√
6		√	√	√			
7		√		√			
8	√			√	√		

Energy Efficiency

Local and regional energy efficiency incentive programs have helped reduce energy use at many water and wastewater treatment facilities. Indeed, most states offer energy incentive programs to help offset the costs of implementing energy efficiency measures in the water and wastewater industry.[101] The greatest energy efficiency opportunities at water and wastewater treatment plants involve efficiency gains in pumping systems and aeration, as they are the two largest electric end-uses in the water and wastewater sector. This chapter presents several case studies where facilities have taken an active approach in reducing energy use (see Case Study 1, Case Study 2, and Case Study 6).

Energy Recovery

According to WERF, the energy contained in wastewater and biosolids exceeds the energy needed for treatment by a ten-fold. [102] However, the ability to economically harness this energy to produce energy-neutral (or net-zero) wastewater treatment is a complex challenge, significantly impacted by facility size, operations, energy content of the influent wastewater, energy demand of the wastewater processes used, and where that energy will be used (i.e., either onsite or offsite). Energy recovery presents a unique challenge to industry stakeholders. In fact, WERF has developed a new five-year research plan for energy production and efficiency, with the goal of increasing the number of treatment plants that are net-zero while establishing energy recovered from wastewater as a renewable energy source.

While methane recovery of digester biogas at wastewater treatment plants is not new, there is renewed emphasis on maximizing energy recovery by enhancing digester operation. A recent approach by some wastewater treatment plants is to combine a rigorous program of energy efficiency improvements with an enhanced methane recovery program that augments digesters with high-strength waste from other sources, such as food processing waste. This chapter presents several case studies on energy recovery where the facilities are striving to become energy-neutral or even net producers of electricity (see Case Studies 1, 2, 3, 6, 7, and 8).

Demand Response

Demand Response (DR) involves measures to modify energy use patterns in order to reduce or shift peak demand loads. In the water and wastewater industry this is typically achieved by utilizing available water storage tanks and shifting pumping or large motor loads to off-peak demand periods. Several electric utilities offer DR programs where a water or wastewater treatment facility can enroll in a program with an electric service provider or third-party aggregator to curtail load over short periods of time during a high demand condition. The water or wastewater agency is rewarded with incentive payments. With the advent of the Smart Grid, utility and state DR programs are also increasingly being used as an effective tool to integrate renewables into the grid. This chapter presents two DR case studies (see Case Study 2 and Case Study 8.)

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[101] U.S. Department of Energy, Energy Efficiency and Renewable Energy Office, *Energy Efficiency Programs*, http://www1.eere.energy.gov/femp/financing/energyincentiveprograms.html.

[102] *Energy Production and Efficiency Research –The Roadmap to Net-Zero Energy*, Water Environment Research Foundation, Alexandria, VA: August 2011.

Water Conservation and Water Reuse

The U.S. Department of Energy (DOE) launched the Water-Energy NEXUS in 2006.[103] In the DOE summary report, it was stated that, "…there are many signs that use, if not growing, may still be outpacing available supplies: aquifers are declining, stored water levels are low, and communities are seeking to improve their access to water supplies, in part through desalination and re-use of water." Indeed, water conservation, water reuse, and desalination are increasingly being used in water-short regions to meet water demand. For example, the reuse of water from wastewater treatment plants for power plant cooling and industrial processes can address water shortages. This chapter discusses one water reuse and one water reuse case study from Florida (see Case Study 4 and Case Study 5).

Case Study 1: Sheboygan Wastewater Treatment Plant Strives to Become a Net-Zero Energy Plant[104]

The City of Sheboygan owns and operates a wastewater treatment plant (WWTP) in eastern Wisconsin along Lake Michigan. The Sheboygan Regional WWTP has a design capacity of 18.4 MGD and treats an average daily flow of 10.5 MGD. The plant is a two-stage activated sludge plant with biological nutrient removal. The plant was originally built over 30 years ago. Solids-handling consists of three primary anaerobic digesters and one secondary anaerobic digester.

Beginning with a 2002 assessment of the energy efficiency and renewable energy potential at the facility, Sheboygan WWTP has closely focused on eventually becoming energy self-sufficient. A dual approach of combining energy efficient measures along with an enhanced biogas recovery program is used to achieve this goal.

Plant management began by reviewing the facility's current energy use and evaluating potential energy efficiency measures. Data collection and benchmarking energy use were undertaken in order to understand the energy impact of new measures. To allow for sub-meter data input to the plant SCADA (Supervisory Control and Data Acquisition) system, nine power meters were installed at the plant. Plant management has also used the *EPA Portfolio Manager Tool for Wastewater Facilities*[105] to benchmark plant energy use. A number of energy efficiency measures have been implemented to reduce the overall plant energy use:

- Replaced four 250-hp positive displacement blowers with two 350-hp single-stage centrifugal blowers (with inlet guide vanes and variable outlet vanes)
- Installed air control valves on headers to aeration basins

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[103] *Demands on Water Resources*, *Report to Congress on the Interdependency of Energy and Water*, U.S. Department of Energy, Washington D.C.: December 2006.

[104] Information provided by Date Doerr, Wastewater Superintendent City of Sheboygan, Wisconsin and taken from the following reports: ACEEE Case Study – Sheboygan, WI, Energy Efficiency in Wastewater Treatment Plant April 2011; and WERF Report titled *Barriers to Biogas Use for Renewable Energy*, Report Number OWS011C10, 2012.

[105] EPA, ENERGY STAR for Wastewater Plants and Drinking Water Systems, http://www.energystar.gov/index.cfm?c=water.wastewater_drinking_water.

- Upgraded SCADA system and replaced blower controls/programming
- Upgraded older motors with premium-efficiency motors and VFDs

The additional approach is to increase the amount of digester gas available to produce renewable energy. Solids-handling at the WWTP consists of three primary anaerobic digesters and one secondary anaerobic digester. The digesters were producing about 200,000 standard cubic feet per day (scfd) of digester gas, which was used primarily to fuel three boilers for digester heating. A portion of the digester gas was also used to power an engine-driven, influent wastewater pump. The excess digester gas was flared. After the plant-wide evaluation, the City of Sheboygan elected to install a CHP system at the WWTP. Digester gas production has increased significantly with the addition of alternative feed stocks to the digesters.

Most of the credit for the energy efficiency measures at the Sheboygan plant resides with the plant personnel and city officials. Resources were also leveraged from the local utility, State of Wisconsin Focus on Energy (FOE), and vendors to achieve impressive energy efficiency gains and cost savings for the city. The State of Wisconsin has taken a proactive approach to energy efficiency in its regulations of wastewater treatment facilities. Following the release of the *Water and Wastewater Energy Best Practice Guidebook*[106], by Focus on Energy in 2006, the Wisconsin Department of Natural Resources issued a statement that encouraged energy considerations to be included in the required project cost-effectiveness calculations (included in Appendix B of the Guidebook). Plant management was able to use these resources to gain approval for implementing energy efficiency measures as summarized in Table 7-2.

Table 7-2
Energy Efficiency Measure Results for Sheboygan Wastewater Treatment Plant

Energy Efficiency Measure	Installed Cost	Annual kWh Reduction
Replaced two 200 HP influent pump station motors with premium efficient motors and VFDs	$170,000	157,000
Replaced two 2125 HP process motors with premium efficient motors and VFDs	$150,000	79,140
Blower replacement	$773,000	358,000
Dissolved oxygen control[a]	$128,000	459,000
Total	$1,221,000	1,053,140

[a] Savings achieved via dissolved oxygen control could not have been achieved without the new blowers

Data sources: 1) Information provided by Dale Doerr, Wastewater Superintendent Sheboygan Regional Wastewater Treatment Plant; 2) ACEEE Case Study – Sheboygan, WI Energy Efficiency in Wastewater, 2011.

Alliant Energy, the electric utility serving Sheboygan WWTP, has been an important partner for the plant's CHP system. When a boiler upgrade was planned in late 2005, plant management studied how the facility might be able to use its biogas to produce electricity and heat. The plant

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[106] *Water and Wastewater Energy Best Practice Guidebook,* Wisconsin Focus on Energy, Madison, WI: 2006, http://www.focusonenergy.com/sites/default/files/waterandwastewater_guidebook.pdf.

decided to partner with Alliant Energy, which is a distributor of Capstone™ Micro-Turbines, to install ten 30-kW microturbines, along with heat exchangers and gas conditioning equipment. The CHP project was completed in 2006. The microturbines allow the plant to use biogas from its anaerobic digesters to produce 2,300 MWh of electricity annually, resulting in about $78,000 in electric energy cost savings per year, and produce 84,000 therms of heat, valued at over $60,000 per year at today's natural gas rates. The biogas fuel is provided by the plant to the CHP system, the electricity produced by the CHP systems is sold by Alliant Energy to the city, and the heat is used by the plant to maintain the proper temperature in the digesters.

Because of the successful operation of the original ten microturbines and the dramatic increase in biogas production from high-strength wastes, the WWTP installed two new 200-kW Capstone microturbines in December 2010. The expanded CHP system also includes new and dedicated heat recovery and biogas treatment systems. The total full rated capacity of the expanded CHP system is now 700 kW. Improvements to digester cover and digester gas piping were completed during the fall of 2011. The WWTP currently generates about 90-115% of electrical energy and 90% of heating energy required onsite.

Case Study 2: Las Vegas Valley Water District Relies on an Energy and Water Quality Management System for its Energy Conservation Efforts[107]

The Las Vegas Valley Water District (LVVWD) delivery system consists of several different types of facilities that pump and store water around the valley. Since 2002, when a drought response plan was first developed, Southern Nevada has reduced its water demand by 29%, from 314 gallon per capita day (GPCD) to 222 GPCD in 2011. While this reduction in water use can be attributed to community conservation efforts, recent economic conditions also may be a factor in the GPCD reduction.

The LVVWD facilities include:

- 68 reservoirs and tanks with more than 900 MG storage capacity
- 46 pumping stations
- 76 production wells capable of producing 175 MG of water per day
- More than 4,500 miles of water transmission pipelines
- Six facilities generating up to 3.1 MW of power from onsite solar array panels

Once water has been treated or has gone through the delivery system, it is pumped uphill through 24 pressure zones. High service pumps at pumping stations force water through the transmission pipelines, usually at night when the cost of electricity is less. Pump stations move water from reservoirs starting at elevation 1,845 feet, with portions ending at elevation 3,550 feet. Reservoirs store the water until it is needed, and gravity then delivers water from the reservoir to the community.

Due to the complexity of LVVWD's distribution system, it was recognized (in retrospect) that both energy and water quality improvement opportunities were being overlooked or lost in the

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[107] Personal communication with Kevin Fisher, Director of Operations, Las Vegas Valley Water District, 2013.

day-to-day operations. In April of 2002, the District embarked on the development and installation of an Energy and Water Quality Management System (EWQMS) for the District's distribution system. This system, as installed, somewhat emulated the WaterRF's direction for implementing a prototype EWQMS. It integrates equipment availability, energy requirements, time-of-use energy costs, water quality parameters, and historical water delivery data to develop daily operations schedules optimized for energy savings. It is a collection of software applications and operational processes focused on efficiently operating a water system.

Since 2005, the current system, as installed, has proven to be effective in reducing energy costs while improving water quality. Electric demand and facility charge costs are reduced by balancing groups of pumps in optimized strategies giving consideration to time of use and variable group efficiencies. The EWQMS process aims to improve water quality by limiting limit the age of the water within the distribution system, thereby, limiting the time that the disinfection by-products can form. The system balances water quality with energy use using heuristic programming and hydraulic modeling.

Figure 7-1 illustrates how the Las Vegas Valley grew and the average weighted elevation went from 2,436 to 2,488 feet. Electricity cost for pumping typically increases as the weighted elevation increases. However, a review of the data presented in Figure 7-2 shows the electricity cost dropped due to the EWQMS process starting in early 2006. Although the total lift continued to grow, the kWh/MG has remained level since 2006.

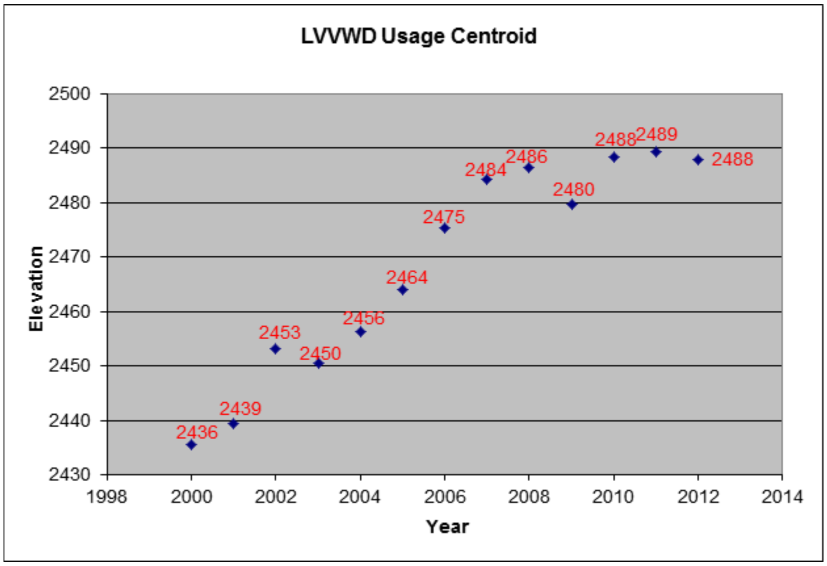

Figure 7-1
Weighted Elevation Increase of the LVVWD System

Source: Kevin Fischer, LVVWD, 2013

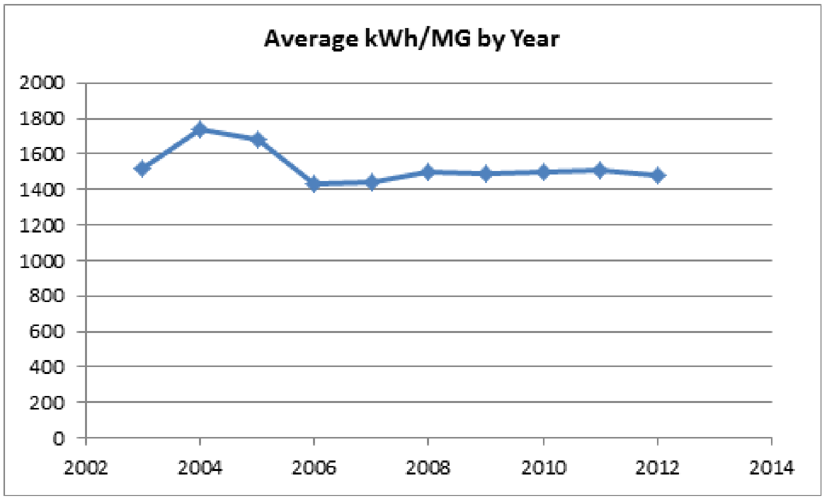

Figure 7-2
Electric Power Use of the LVVWD System

Source: Kevin Fischer, LVVWD, 2013

The EWQMS approach has helped the District achieve the following process and energy goals:

- Improve water quality by minimizing the age of water in the system
- Optimize energy use
- Optimize equipment use
- Achieve optimization faster and more accurately
- Make optimization decisions more objective than subjective
- Increase its ability to flexibly respond to future changes in the energy market

Case Study 3: East Bay Municipal Utility District's Net-Zero Energy Wastewater Treatment Plant[108, 109]

The East Bay Municipal Utility District (EBMUD) is a publicly-owned utility that provides water service to portions of two counties in the San Francisco Bay Area. Its water supply system covers 332 square miles and serves some 1.3 million customers, and EBMUD's wastewater treatment service includes 650,000 customers in an 88-square mile area. For many years, EBMUD has been generating electrical power at its 65 MGD wastewater treatment plant in Oakland, CA from digester gas with the help of three 2.1 MW combustion engines. In 2011, the utility added a modern 4.6-MW gas turbine to produce additional power from a growing supply of wastewater and trucked in food waste treated in its anaerobic digesters. In 2012, EBMUD became the first wastewater treatment plant in North America to produce more energy than is required onsite. The excess electricity is sold back to the grid.

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[108] Personal communication with EBMUD Engineer John Hake, 2013.

[109] U.S. DOE Pacific Clean Energy Application Center, East Bay Municipal Utility District 11 MW Gas Turbine CHP System, Project Profile, 11/19/12.

Similar to many medium and large wastewater treatment facilities, the EBMUD Oakland facility stabilizes biosolids in anaerobic digesters where bacteria convert the organic material into biogas (65% methane and 35% carbon dioxide). Prior to combustion in the engines and turbine, the biogas is treated in a gas conditioning system where moisture and siloxane are removed using heat exchangers and activated carbon. The Oakland plant operates eleven active digesters, a gas conditioning system, and several gas compressors to feed gas to the engines and turbine.

To enhance biogas production beyond that which would be possible on domestic wastewater alone (by a factor of approximately two-fold), additional “high-strength” feedstocks are delivered to the digesters in the form of trucked-in food waste and waste from food processing operations such as poultry and food crops. These trucks pay lower “tipping fees” to EBMUD for receiving the waste than they would at landfills, and methane that would have been released to the atmosphere is captured for electricity production. This, in turn, reduces greenhouse gas emissions. By producing renewable electricity, the project also generates renewable energy credits that can be sold to electric utilities, enhancing the value of the power delivered to the grid by about $0.035/kWh. The San Francisco Bay area generates 1,700 tons/day of commercial food waste. This is a locally sustainable high methane value feed stock to EBMUD. Along with installing cost-effective contaminate control measures both at the food waste source and at the wastewater treatment plant, EBMUD had to develop new relationships with food waste providers, solid waste haulers, and solid waste authorities.

The addition of the 4.6-MW gas turbine to the existing set of older engines means that the turbine can be used as the primary electricity generation system, supplemented by one or more of the engines when there is additional biogas available. The overall system currently produces an average of 6 MW of renewable electricity, with a peak capacity of 11 MW. The system currently produces an average of about 2,000 cubic feet per minute (CFM) of biogas. About 1,200 CFM is used in the gas turbine and an additional 800 CFM is available for the older engines. Due to the primarily Monday-Friday schedule of trucked high-strength waste deliveries to the digester system, biogas production peaks in the late week and early weekend and then drops off by Sunday and into the start of the next week.

Figure 7-3 presents the plant power demand met by onsite generation. During 2012, the EBMUD plant became a “net-zero” energy plant with extra electricity available to be exported to the electric grid.

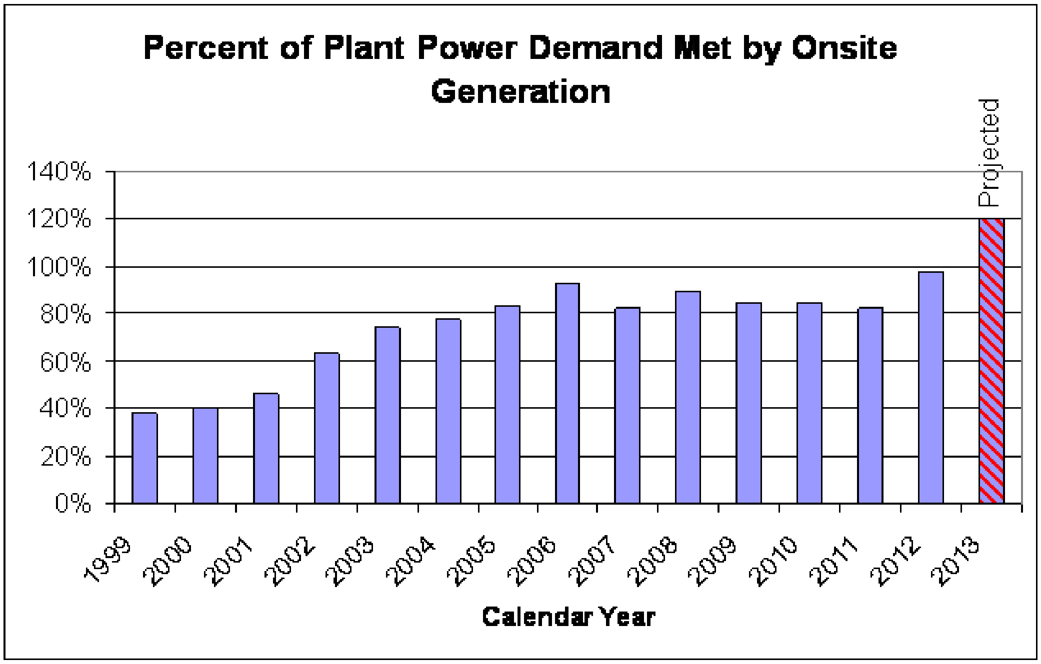

Figure 7-3
EBMUD Plant Power Met by Onsite Generation

Source: EBMUD Engineer, John Hake

Case Study 4: Emerald Coast Utilities Authority Central Municipal Wastewater Reclamation Facility, a Zero-Discharge Facility[110]

The Emerald Coast Utilities Authority’s (ECUA) Central Water Reclamation Facility (CWRF) is a new plant that was relocated and built six years after Hurricane Ivan devastated the area, including the ECUA’s Main Street Wastewater Treatment Plant. CWRF began operation on August 30, 2010. It is located 25 miles north of Pensacola, FL on 2,000 acres of open area, near an industrial park (see Figure 7-4).

The plant is designed to treat a daily average flow of 22.5 MGD, but includes a 40-acre wet weather storage pond with a capacity of 70 MG, that is capable of holding up to three days of storm flow. Treatment facilities include screening and grit removal, oxidation ditches, final clarifiers, rotary disk filters, chlorination using onsite chlorine generators, effluent water storage tanks totaling 8 million gallons, reject water tanks totaling 22 MG, and a final effluent pump station. Wastewater biosolids are managed using aerated sludge thickeners, sludge screw presses, and sludge paddle dryers.

Energy efficiency and sustainability are key drivers of water reuse, which is why water reuse is so integral to sustainable water management. The water-energy nexus recognizes that water and energy are mutually dependent: energy production requires large volumes of water, and water infrastructure requires large amounts of energy. While the increased use of reclaimed water

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[110] Information provided by the Emerald Coast Utilities Authority.

typically poses greater financial, technical, and institutional challenges than traditional sources, a range of treatment options are available such that any level of water quality can be achieved.

Figure 7-4
View of ECUA Central Water Reclamation Facility Site

Source: Emerald Coast Utilities Authority, Central Water Reclamation Facility, Commemorative Edition, December 2010

Water injected into an aquifer to replenish a groundwater supply must meet a variety of rigorous regulations for dissolved solids, hardness, iron and manganese, and microbiological contaminants, in addition to a number of other organic and inorganic chemicals. On the other hand, water reclaimed for industrial use can be achieved by treating municipal wastewater to a prescribed level and managing water volumes to meet the specific industry needs. That paradigm drove the development of a unique public-private partnership to benefit residents, ratepayers, and the environment in Pensacola, Florida.

Treated wastewater is pumped from effluent storage tanks to local industries for reuse. A local paper industry will use up to 6 MGD of treated water with the remaining sent to Gulf Power's Crist Power Plant for cooling and scrubber operation, which reduces Gulf Power's water withdrawal from the Escambia River. In the unanticipated case of an overabundance of water, two effluent spray fields are in place to absorb the excess discharge. The ability to manage water volumes through the use of both influent and effluent storage allows the facility flexibility in meeting industrial needs and managing treatment processes. In addition, the treatment process is designed to meet the industrial water quality needs and the land application permit requirements.

CWRF operates as a "zero-discharge" facility, which is possible due to the collaboration between local industries and ECUA to understand the water quality requirements and service needs at each site of reuse. The plant was specifically designed to meet these needs. Special treatment equipment such as the onsite chlorine generation (see Figure 7-5) and the sludge drying facilities mitigate other environmental concerns, such as chemical transportation and handling and solid waste problems. The facility's energy use is about 3,000 kWh/MG, which is slightly greater than a typical treatment plant. This is due to the special equipment and effluent pumping requirements, but is a reduction in the overall energy requirement that would be needed to supply treated water to feed the industrial operations.

Figure 7-5
On-Site Chlorine Generators

Courtesy of Ray Ehrhard

Case Study 5: Tampa Bay Water Augments with Seawater Desalination[111]

Tampa Bay Water is Florida's largest wholesale water provider and supplies potable water to over 2.4 million residents in the Hillsborough-Pasco-Pinellas tri-county area. The agency provides water to six Member Government utilities, including the three counties mentioned above and the cities of Tampa, St. Petersburg, and New Port Richey. The Tampa Bay Seawater Desalination Plant is a drought-proof, alternative water supply that provides up to 25 MGD of drinking water to the region. Seawater coming into the plant goes through a rigorous pretreatment process and then freshwater is produced from the seawater using reverse osmosis (RO). The end product is high-quality drinking water that can supply up to 10% of the region's needs.

The desalination plant is located next to Tampa Electric's Big Bend Power Station, which already withdraws and discharges up to 1.4 BGD of seawater from Tampa Bay, using it as cooling water for the power plant. The Tampa Bay Seawater Desalination plant "catches" up to 44 MGD of that warm seawater, separates it into drinking water and concentrated seawater and dilutes the twice-as-salty seawater before returning it to the bay. The membrane system consists of the following components:

- 7 process trains each sized at 4.16 MGD

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[111] Information provided by David Bracciano, Demand Management Coordinator, Tampa Bay Water, 2013.

- First pass includes 168 pressure vessels with 8 membranes each totaling 1,344 membranes
- Second pass includes a two-stage array of 78 pressure vessels totaling 624 membranes
- An energy recovery turbine designed at a recovery rate of 30-40%

At full capacity, the RO process leaves about 19 MGD of reject.. The reject is discharged to Big Bend's cooling water stream and blended with up to 1.4 BG of cooling water, achieving a blending ratio of up to 70-to-1. The cooling water mixture moves through a discharge canal, blending with more seawater, diluting the discharge even further. By the time the discharged water reaches Tampa Bay, its salinity is nearly the same as the Bay's.

The Tampa Bay Seawater Desalination Plant faced several major delays before it was completed in 2008. It is the first large-scale seawater desalination project constructed in the U.S. The initial capital cost for the desalination plant and the 15-mile pipeline to connect it to the water system was estimated to be $110 million. After initial construction, major improvements were made to the pre-treatment, RO, and post-treatment system, and the final capital cost of the project was $158 million. Tampa Bay Water estimated the unit cost of water from the desalination plant would be $4.00 per 1,000 gallon if the plant is operating at full capacity.[112] However, the plant will operate at an average production of 11 MGD from October 2012 through October 2013, which is considerably less than full capacity.[113] At this reduced capacity, the unit cost of water is estimated at $5.00 per 1,000 gallons. A recent WaterRF study stated that desalination water cost are now between $2.50-4.50 per 1,000 gallons with energy costs accounting for 20-30% of the total operating cost.[114] Electric energy use for a seawater desalination plant (for the entire facility) ranges from 12 to17 kWh per 1,000 gallons.

Since its completion, the plant has operated far below its design capacity of 25 MGD. During some periods, when surface water supplies are lowest, the plant operates at or near capacity. In others, the plant operates at reduced capacity or is in standby mode. In 2013, Tampa Bay Water has operated the plant at higher capacity (averaging 11 MGD) because a local water reservoir is undergoing repair, which reduces surface water supply availability during the dry season. Once this is complete, however, production from the desalination plant will likely be reduced because cheaper water supply alternatives are available. Tampa Bay Water is seeking to provide the water supply needs to the region through increases in water use efficiency coupled with treatment of groundwater, surface water, and seawater desalination. While seawater desalination requires a higher operational cost of water, it is an alternative that is necessary during drought and low-flow surface water conditions, when other regional options are limited.

Table 7-3 presents data for energy cost and water production associated with the desalination plant over the past several years. The energy use in kWh/MG is much greater at lower flow production rates and lowers as the production flow increases. This indicates that the process is most energy efficient when operated closer to its design condition and drops significantly when operated at lower flow rates.

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[112] This estimate includes O&M plus the annual debt service cost assuming that the full capital cost of project was financed at Tampa Bay Water's average bond rate over 30 years.

[113] Information provided by David Bracciano, Demand Management Coordinator, Tampa Bay Water, 2013.

[114] *Desalination Facility Design and Operation for Maximum Energy Efficiency* #4038, Final Project Update, WaterRF, Denver, CO: January 2010.

Table 7-3
Annual Data for Tampa Bay Seawater Water Desalination Plant

Fiscal Year	Total Energy Use (kWh)	Water Production (MG)	Energy Costs ($)	Average Energy Cost ($/MG Water Produced)	Average Energy Cost ($/kWh)	Energy Use (kWh/MG)
2007	29,279,472	1,769	$2,623,705	$1,483	$0.0896	16,551
2008	98,695,350	6,961	$8,282,059	$1,190	$0.0839	14,178
2009	92,122,660	6,192	$8,397,281	$1,356	$0.0912	14,878
2010	63,555,285	4,161	$5,530,907	$1,329	$0.0870	15,274
2011	24,423,120	1,355	$2,146,906	$1,585	$0.0879	18,027
2012	11,549,330	474	$1,031,581	$2,175	$0.0893	24,355

Data source: David Bracciano, Demand Management Coordinator, Tampa Bay Water

Case Study 6: Eugene/Springfield Regional Wastewater Pollution Control Facility has a Comprehensive Energy Management Program[115]

The Metropolitan Wastewater Management Commission is the governing body for the Regional Wastewater Pollution Control Facility located in Eugene, Oregon. The facility services the cities of Eugene and Springfield and the surrounding areas (population 240,000). The treatment facility uses a four-stage step feed anoxic selector activated sludge plant designed to treat an average daily dry weather flow of 49 MGD. The treatment process includes an influent pump station with bar screens and grit removal, odor control scrubbers, four primary clarifiers, eight aeration basins equipped with five 1,000-hp centrifugal blowers and two 350-hp turbo blowers, ten secondary clarifiers, and chlorine contact tanks for disinfection and de-chlorination. Sludge conditioning and anaerobic digestion are the main elements of the solids treatment process. Solids removed in primary treatment are pumped directly to anaerobic digesters. Sludge from secondary treatment is thickened by a gravity belt thickener process and is then fed to the mesophilic anaerobic digesters, each with a capacity of 1 MG.

The regional wastewater treatment facility is ISO 14001 Certified. An Environmental Management System (EMS) manages the environmental impacts of the activities, products and services of the facility, mitigates adverse environmental impacts, and continually moves towards a more sustainable facility. Energy management is a key component of the EMS, as plant staff continuously looks for innovative ways to reduce power use while meeting regulatory requirements. Although capacity of the facility has been significantly expanded in recent years, energy use has remained relatively flat. This is due to strategies such as:

- Evenly distributing equipment operation throughout the day
- Partnering with the local utility provider to change to more efficient equipment

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[115] Personal communication with Bob Sprick, Operation Supervisor, Eugene/ Springfield Water Pollution Control Facility, 2013.

- Purchasing premium efficient motors and VFDs where applicable
- Turning down HVAC equipment when spaces are not occupied
- Instituting behavioral changes, such as turning off lights and computers when not in use, stop before start when rotating equipment

The facility is successfully capturing methane gas from its digesters and beneficially uses the biogas to supply heat and power for the plant. Specifically, methane is used to fuel engines for power generation. Heat also is recovered from the engines in a closed loop hot water supply system that provides the heat necessary for the sludge digestion process.

Energy efficiency projects at the plant began in 1996 with the conversion of coarse bubble diffusers in the aeration basins to fine bubble diffusers. These improvements have continued each year by capitalizing on the ongoing utility incentive program to offset equipment costs. The most recent energy savings project is the replacement of one of the existing multi-stage blowers with an energy-efficient turbo blower. The cumulative energy savings for 1996-2013 are summarized in Table 7-4.

Table 7-4
Eugene/Springfield Regional Wastewater Pollution Control Facility Energy Efficiency Project Summary, 1996-2013

Annual kWh Savings	Utility Incentives	Project Cost	Annual Cost Savings
10,572,860	$958,377	$3,293,945	$655,517

Source: Bob Sprick, Operation Supervisor, Eugene/ Springfield Regional Water Pollution Control Facility

Figure 7-6 presents the total annual electric use of the plant and how it has changed since 1994. The normalized energy use (in kWh/MG) includes power purchased, generated, pump stations that discharge directly into the headworks, and power used at the biosolids management facility.

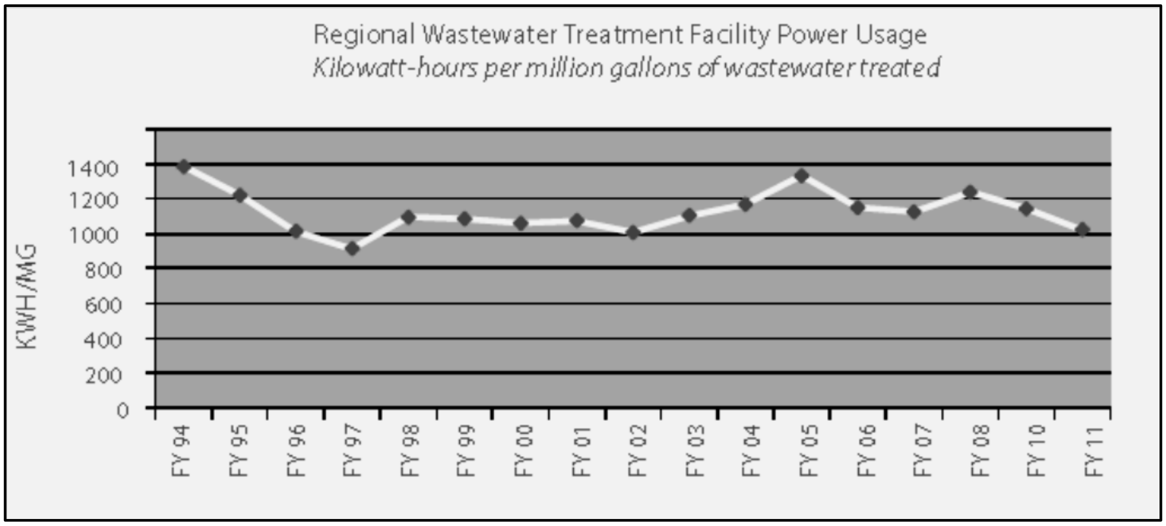

Figure 7-6
Annual Electricity Use for the Eugene/Springfield Regional Wastewater Pollution Control Facility

Source: Metropolitan Wastewater Management Commission Annual Report, 2011

Methane gas is sent to an 800-kW generator which supplies 53% of the onsite power as well as hot water for digester heating. The generator is connected to the plant SCADA system and can trigger a mechanism to drop the blowers off the grid should the generator set fault. Table 7-5 illustrates the amount of energy generated onsite from the methane recovery equipment.

Table 7-5
Energy Generated from Methane Recovery

Year	kWh Generated
2008	6,359,645
2009	5,094,612
2010	6,345,866
2011	5,613,758
2012	5,374,490

Case Study 7: Gloversville-Johnstown Joint Wastewater Treatment Facility Generates Close to 100% of Site Electricity[116]

The Gloversville-Johnstown Joint Wastewater Treatment Facility (GJJWTF) is designed to treat up to 13.8 MGD of domestic sanitary sewage from the cities of Gloversville and Johnstown in New York, as well as industrial wastewater from two dozen industries, including food, leather tanning and finishing, metal finishing, and textile manufacturers. The facility also serves

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[116] Personal communication with Masick, Wastewater Engineer, Gloversville-Johnstown Joint Wastewater Treatment Facility, 2013.

approximately 100 users outside the corporate limits of the two cities. Peak treatment capacity is 30 MGD.

The facility provides secondary treatment for organic removal and advanced wastewater treatment for ammonia removal via the activated sludge process. The treated effluent is discharged to the nearby creek. Wastewater sludge generated at the plant are thickened, anaerobically digested, dewatered, and hauled to a landfill for disposal. The treatment plant is also designed to receive and treat septic tank waste and leachate from the County landfill, as well as high-strength dairy wastewater conveyed by separate sewers to the facility.

The majority of wastewater conveyed to the wastewater treatment facility is treated biologically by aerobic microorganisms. High-strength wastewater is also accepted and treated in the facility's 1.5 MG primary or 1.3 MG secondary digester. The high-strength waste, predominately cheese and yogurt whey, is stored in above ground equalization tanks, and then pumped to the digester 24 hours per day, 7 days a week for consistent biogas generation.. Anaerobic microorganisms convert the high-strength waste to biogas, a renewable blend consisting of ~50% methane, ~40% carbon dioxide, and other trace gases. The anaerobic digester system produces an average of 13.4 million cubic feet of biogas per month, representing a 6% increase from the previous year. This lean mixture is an excellent fuel source and is predominately used by the plant to generate electrical power in two 350-kW engines housed in a separate building at the plant. Additionally, heat is recovered from the engines to heat the digesters.

A significant portion of the biogas powers the facility's CHP system. Due to existing regulations, however, excess power cannot be exported to the grid so remaining biogas is flared Electricity produced by the engines is fed into the plant electrical distribution system for use where needed. Heat recovered from the engines is used for heating the digester and the Energy Recovery Building. In excess of 90% of the plant's electrical need is met by the onsite generation of electricity. In 2012, 5.2 million kWh of electricity were generated, as illustrated by Figure 7-7. Electricity generation increased by 3.9% from 2011 since both of the biogas generators were operational during the entire year. During 2012, the biogas-fired engines averaged 90% electrical production. For several months, in excess of 96% power generation was realized. The facility realized approximately $400,000 in electrical energy savings as a result of the onsite production of renewable electricity.

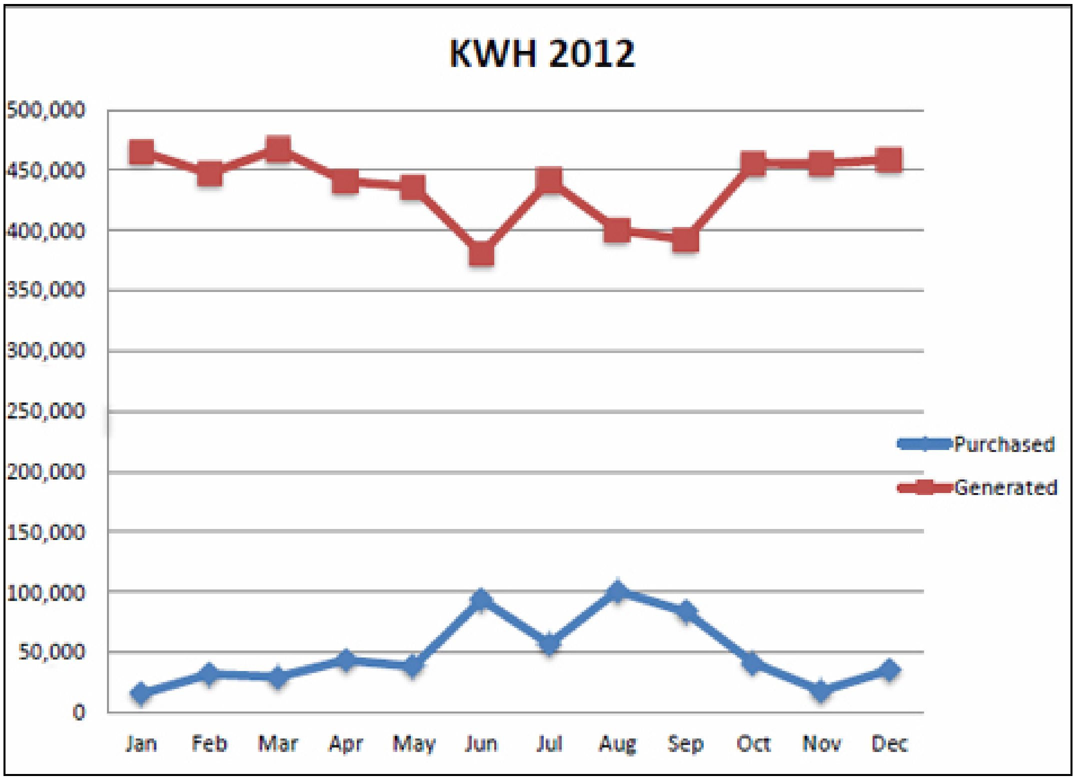

Figure 7-7
Gloversville-Johnstown Joint Wastewater Treatment Facility Power Met by Onsite Generation

Source: Gloversville-Johnstown Joint Wastewater Treatment Facility, 2012 Annual Report

Case Study 8: Eastern Municipal Water District of Southern California Receives Annual Demand Response Payments of $600,000[117]

The Eastern Municipal Water District (EMWD) is one of the largest water providers in Southern California, serving a population of more than 758,000 in a 542 square-mile area. The district provides water service to approximately 136,000 retail customer accounts and also provides sewer service to 228,000 customer accounts located within its service area. In addition, the district supplies water on a wholesale basis to other water agencies, and recycled water to certain customers, such as agricultural sites, golf courses, and landscape irrigation sites. The district is a major consumer of electricity, costing it more than $14 million a year from an annual operating budget of $224 million.[118] The EMWD facilities include two water filtration plants, two brackish groundwater desalting plants, five wastewater treatment plants, over 70 water storage tanks, over 100 pump stations, 47 sewage lift stations, and 29 water wells. As part of a balanced energy portfolio, EMWD uses a variety of renewable energy and alternative energy sources, including the following:

- Biogas-fired fuel cells (1,500 kW)

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[117] Personal communication with Dan Howell, EMWD Director of Purchasing and Contracts, 2013.

[118] Dan Howell, EMWD presentation at the May 9, 2013 Association of California Agencies (ACWA) Conference.

- Biogas-fired engines (1,465 hp)
- Natural gas-fired engines (20,000 hp)
- Natural gas-fired microturbines (540 kW)
- Photovoltaics (500 kW)

As an alternative to running costly backup power plants, power providers can use larger energy users to relieve the grid of excess demand at critical times. To meet this challenge, EMWD designed an energy curtailment plan to reduce non-essential energy use during critical periods of imbalance between electricity supply and demand on the grid. The electric curtailment potential for its operations is maximized to minimize impact on day-to-day operations.

During critical power need periods, a DR dispatch is triggered, and utilities and grid operators call upon energy reduction plans. DR programs are administered by utility companies, independent system operators (ISOs) or third-party aggregators that contract with utilities or ISOs. EMWD's DR activities are managed through three distinct DR programs. EMWD has 16 accounts enrolled with a third-party aggregator (EnerNOC, Inc.) to manage a portion of their load. [119] They also have 3 accounts enrolled in the California Base Interruptible Program and 20 accounts enrolled in the California Agricultural/Pumping Interruptible Program. EMWD achieves demand reductions by shutting down major electricity-using equipment (e.g., pumps) at various treatment plants and pumping facilities, and by utilizing its biogas-fired and natural gas-fired onsite generators. By participating in DR programs, EMWD helps to stabilize the electric grid and gets paid for the energy not used, and is provided an incentive year-round simply for being on call.

EMWD has currently 12.2 MW enrolled in the various DR programs in California, representing approximately 33% of its peak demand. Table 7-6 summarizes the EMWD's DR portfolio for 2013. The district has experienced several events and routine tests, all of which have proceeded smoothly. During a DR event, EMWD receives a thirty-minute advanced notification, and then manually shuts down a portion of its facilities, such as water treatment plants and pumping stations. EMWD has redundant resources available for supplying water, so the system reserves enable operators to run at reduced capacity temporarily. Financial payments through the DR programs have exceeded $600,000 annually, which are credited back to the facilities participating. The payments help offset electricity cost.

The most important benefit of DR is that it can be easily implemented by EMWD without requiring major changes or affecting its core mission of providing clean water to its constituents. Under the program terms, EMWD can choose to participate in an event at varying levels by choosing to run its equipment at lower levels or shutting them down completely. And it always has the option of manually restarting whenever necessary, although any financial benefits would be lost.

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[119] EnerNOC Case Study, *Eastern Municipal Water District Works with EnerNOC to Reduce Significant Electrical Load.*

Table 7-6
EMWD 2013 Demand Response Portfolio

DR Program Type	Program Manager	Number of Accounts	Demand Enrolled	Annual Savings
Third Party Aggregator	EnerNOC, Inc.	16	3.7 MW	$200,000
Base Interruptible Program	Southern California Edison	3	6 MW	$400,000 combined
Agricultural/Pumping Interruptible	Southern California Edison	20	2.5 MW	
Total		39	12.2 MW	$600,000

Data source: Dan Howell, EMWD Director of Purchasing and Contracts

Initial testing of DR at two of EMWD's facilities has proven successful, so the district is evaluating other likely DR candidates among its 250 additional facilities. In addition, EMWD is investigating if some facilities can participate through an Auto-DR system.. Auto-DR automates the implementation of DR events, enabling greater enrollment in DR programs and enhancing EMWD's ability to participate in other utility pricing programs, such as critical peak pricing, demand bidding, scheduled load reduction, and real time pricing.[120]

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[120] Personal communication with Dan Howell, EMWD Director of Purchasing and Contracts.

8

OPPORTUNITIES FOR DEMONSTRATION PROJECTS

Chapters 4 and 5 show the U.S. water and wastewater industry accounts for an estimated 2% of total U.S. electricity use. Given the significant electrical use of the water and wastewater industry, the commonalties between the electric utility and the water and wastewater industries, and the importance of solid infrastructure to economic growth, it makes good business sense for electric utilities and EPRI to participate in water and wastewater research, development and demonstration (RD&D) projects. This chapter discusses RD&D opportunities, with a focus on technologies showing promise for demonstration projects. The chapter begins with a brief overview of RD&D organizations active in the water and wastewater space. In particular, past activities in EPRI's Municipal Water and Wastewater Program are presented. It then segues into a discussion of four target areas with significant RD&D opportunities. For each target area, the RD&D needs of selected technologies are identified and specific demonstration projects that EPRI and its member utilities can initiate are highlighted.

RD&D Organizations Active in the Water and Wastewater Space

RD&D can take a variety of forms, from the development of the scientific principles behind various phenomena to full-scale evaluations of emerging technologies. Though all aspects of RD&D are essential to bring new technologies to the market, research organizations focus on different areas. While larger organizations may conduct broad research efforts to take ideas from conception to product development, smaller organizations often focus their RD&D efforts on specific target areas.

Water and wastewater RD&D is the function of a wide variety of public and private organizations. Governmental agencies, including the U.S. EPA, the U.S. Bureau of Reclamation, the U.S. DOE, the U.S. Corps of Engineers and various state and local environmental and health agencies, are actively involved in conducting water and wastewater RD&D. Public and private universities, equipment manufacturers, and a number of engineering consulting firms servicing the industry are also conducting significant water and wastewater RD&D efforts. Furthermore, there are several trade organizations that conduct RD&D specifically for the water and wastewater industry, including the Water Environmental Research Foundation (WERF), the Water Research Foundation (WaterRF), and the Water Reuse Foundation. All three organizations are similar in structure to EPRI in that they are private, non-profit organizations funded by and oriented towards a specific industry. Given the mutual interests in furthering the science behind the treatment of water and wastewater in as energy-efficient a manner as possible, EPRI should continue to collaborate with these organizations in the development, funding, and execution of RD&D in the water and wastewater arena.

Because EPRI conducts RD&D associated with the generation, delivery and use of electricity for the benefit of the public, it has worked extensively in the water-energy arena for many years. For example, EPRI's Municipal Water and Wastewater (MWW) Program sponsored collaborative research for the water and wastewater industry from 1992 through 2001. The MWW Program served as a clearinghouse for unbiased information on emerging technologies, advocated for energy efficiency within the industry, and sponsored demonstration projects of numerous technologies that addressed some of the problems within the industry. Specifically, EPRI's MWW Program targeted four areas:

- Energy Efficiency
- Electrotechnologies
- Decentralized Wastewater Treatment Systems
- Desalination and Membrane Treatment

Because the EPRI MWW Program focused on the development of viable products and technologies, including sponsoring bench-scale and pilot-scale demonstrations, much of the emphasis was on the development of the operating and economic data required to both improve emerging technologies and enable decision makers within the industry to implement them.

Another important aspect of the MWW Program was its collaborative nature with applied research activities, reaching across governmental, non-governmental, and private agencies. The collaborative nature yielded many benefits, including the opportunity to quickly ascertain a technology's potential worth under real-world conditions. For instance, a private entrepreneur may complete a proof-of-concept evaluation of a disinfection technology which the MWW Program then evaluated at a participating water or wastewater treatment facility.

While EPRI's MWW Program provided numerous solutions to meet the new challenges to water and wastewater industry in the 1990's, it also set the stage for the energy efficiency programs of the past decade. Many challenges still remain in the water and wastewater industry, so a similar programmatic approach by EPRI is recommended today. However, it will require participation and financial support from a number of electric utilities and collaborative partners. In the meantime, there are certain topical areas that could benefit from a range of demonstration projects and where EPRI could take the lead. Those demonstration projects are the focus of the next section.

Target Areas of Interest and Potential Demonstration Projects

The four focus areas of past EPRI RD&D initiatives in the water and wastewater industry still remain relevant today. For example, new electric-based treatment methods, such as UV disinfection and more efficient membranes, continue to improve the treatment process. Indeed, the improvement of existing electrotechnologies as well as the development of new electrotechnologies is essential to meeting the water requirement for growing populations. Additionally, as this report suggests, energy efficient practices have made tremendous inroads into the water and wastewater industry but there continues to be room for improvement. Finally, water agencies will have no choice but to pursue desalination and water reuse to meet future U.S. water needs.

Decentralized water and wastewater systems are a special focus area that was originally brought into the EPRI MWW program by the National Rural Electric Cooperative Association (NRECA). NRECA realized that its many electric co-ops and rural utilities faced different water and wastewater challenges. A lack of regulations, technologies, and resources in the water sector was affecting economic growth, and in many areas the electric co-op was the lead agency with the business capacity to address these issues. With over 900 co-ops nationwide,[121] NRECA provided a real-world test bed for demonstrating the viability of emerging technologies. NRECA began by partnering with EPRI and other national labs, academic institutions and industry to address the decentralized water community. Following an EPA report to congress in 1997,[122] which stated that small communities' wastewater needs are 10% (at that time) of the national wastewater demands and were severely lacking, congress set aside funding to address these issues. EPRI partnered with other groups including WERF to form the National Decentralized Water Resources Capacity Development Project (NDWRCDP).[123] This project continues to conduct decentralized water research and is being managed by WERF with EPRI participating on the steering committee. The focus area of decentralized water and wastewater differs from the central water and wastewater programs covered in this report and should continue to be pursued separately.

As with any complex industry, new processes, approaches and problems are identified and vetted daily in the water and wastewater industry. Consequently, there are hundreds or even thousands of potential demonstration projects that could be proposed. Yet there are certain projects where the interests of electric utilities align with those of the water and wastewater industry, most notably in the use of electrotechnologies and energy recovery. The project team leveraged a variety of technical reports and summary articles from EPA, WaterRF, and EPRI for ideas on specific topics and individual projects that are beneficial to the water and wastewater industry as well as the electric industry. Readers interested in additional information on specific RD&D topics and projects are encouraged to consult these sources. Some of the most informative and promising include:

1. *Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management,* US EPA, EPA 832-R-12-011, Washington, DC: March 2013.
2. *Program on Technology Innovation: Electric Efficiency through Water Supply Technologies—A Roadmap*, EPRI, Palo Alto, CA: 2009, 1019360.
3. *Desalination Product Water Recovery and Concentrate Volume Minimization*, Water Research Foundation, Denver, CO: 2009.
4. *Emerging Technologies for Biosolids Management*, US EPA, EPA 832-R-06-005, Washington, DC: September 2006.
5. A. Suramani, Bardruzzaman, M, Oppenheimer, J and Jacangelo, J. "Energy minimization strategies and renewable energy utilization for desalination: A review," Water Research 45 (2011) 1907-1920.

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[121] Cooperative Research Network™ (CRN), a technology research arm of the National Rural Electric Cooperative Association (NRECA), http://www.nreca.coop/programs/CRN/Pages.

[122] *Response to Congress on Use of Decentralized Wastewater Treatment Systems*, US EPA, Washington D.C.: April 1997.

[123] National Decentralized Water Resources Capacity Development Project (NDWRCDP), administered through the Water Environment Research Foundation (WERF), http://www.ndwrcdp.org.

6. *Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use*, EPRI, Palo Alto, CA: 2008, 1016460.

The remainder of this section summarizes potential demonstration projects that could be of great benefit to both the water and wastewater industry and the electric utilities who serve them. The recommended demonstration projects are categorized into four target areas:

- Target Area 1: Energy Efficiency, Load Management, and Demand Response
- Target Area 2: Energy Recovery
- Target Area 3: Improved Biosolids Treatment
- Target Area 4: Water Reuse and Desalination

Each target area includes a discussion of general assessment needs followed by a summary table listing the developmental status of specific technologies. The tables contain three levels of developmental status: 1) Research, 2) Under Development, and 3) Demonstration Needed. The "Demonstration Needed" column indicates those technologies showing particular promise for demonstration by EPRI and its electric utility members. The tables also provide sources for additional information. The source numbers refer back to the numbered list of references provided on page 8-3. The discussion and tables are intended to present ideas for some technologies and how they can be further developed. A more exhaustive review of the literature cited is suggested to develop a formal research initiative on energy efficient technologies.

Though there is significant technology development potential in all four key target areas, it is important to consider that in both energy efficiency and energy recovery (Target Areas 1 and 2), there are numerous established technologies that simply need to be more widely implemented. In those cases, EPRI can serve as a change leader in market transformation through the publication and dissemination of fact sheets and technical summary documents. Specifically, EPRI can work with its electric utility members in collaborating with water and wastewater treatment facilities to publicize success stories and promote under-utilized technologies.

Target Area 1 – Energy Efficiency, Load Management, and Demand Response

The electric load shape of water utilities typically mirrors the load of many U.S. electric utilities. Thus, there are direct benefits to electric utilities to aggressively pursue load management in water and wastewater treatment facilities. While many tools and technologies exist to assist water and wastewater treatment facilities in meeting energy efficiency and load management goals, their use within the industry is sporadic and far from universal.

EPRI can play an instrumental role in developing a toolbox for energy efficiency, peak management strategies, and Best Practices. For example, the EPRI MWW Program developed some of the first energy efficiency guidebooks for water and wastewater facilities. In subsequent years, several other water agencies and associations have developed similar guidebooks and Best Practices. Ensuring that energy efficiency gains remain, however, entails the institution of formal programs such as the ISO 50001 Energy Management Standard. Progress is also needed in the development and implementation of advanced computer controls for load management and energy efficiency. One previous EPRI effort was the Energy and Water Quality Management System, or EWQMS, which sought to develop a computer control system that could best balance energy use with water quality concerns in potable water distribution systems. This effort has continued under the WaterRF, but there is a need for further work. In addition, the area of DR strategies is now offering many opportunities for innovative cost savings to water and wastewater agencies. Case Study 8 in Chapter 7 presented the Eastern Municipal Water District's DR strategy for managing and controlling peak energy use during DR events. The facility is considering improving this system by providing an Auto-DR (automated demand response) function to the SCADA platform. The advances in SCADA systems combined with remote sensing and monitoring will allow even greater flexibility and controls to manage energy demand and use, and participation in DR programs. Remote sensing technology can be used in conjunction with SCADA systems and involves pulling data from field devices, such as electric meters and programmable logic controllers. SCADA, remote sensing, DR, and Auto-DR are discussed in greater detail in Chapter 6.

In the EPA report cited above (*Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management*), a summary of innovative treatment technologies was presented that provided applications for energy conservation. Table 6.1 of that report provides a listing of these technologies and is followed by a technology summary of specific applications. Additional details on these technologies can be found in the EPA report titled *Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities*.[124] Some of these technologies are listed below. For instance, recent advances in membrane materials have led to ultrafine bubble diffusers, which generate much smaller bubbles. The primary appeal of ultrafine bubble diffusion is improved oxygen transfer efficiency (OTE). There is little field experience in using these membranes although one manufacture claims energy efficiencies 10% to 20% greater than the traditional ceramic and elastomeric membrane diffuser configurations.[125]

High-speed gearless, or "Turbo," blowers use advanced bearing design to operate at higher speeds with less energy input compared to multistage and positive displacement blowers. The efficiency improvements of these blowers are not well documented since they are new, however there are some reports of energy savings of around 10% to 20% as compared to conventional multi-stage centrifugal or positive displacement equipment.[126]

Table 8-1 summarizes the developmental status and demonstration opportunities associated with technologies for improving energy efficiency, load management, and demand response.

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[124] *Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities*, U.S. EPA, Washington, DC: September 2010, EPA 832-R-10-005.

[125] AeroStrip®, a proprietary diffuser design manufactured in Austria by Aquaconsult.

[126] Gass, J.V., "Scoping the Energy Savings Opportunities in Municipal Wastewater Treatment", presented at the CEE Partner's Meeting, September 2929, 2009.

Table 8-1
Summary of RD&D Opportunities in Energy Efficiency, Load Management, and Demand Response

Technology	Status			Source
	Research	Under Development	Demonstration Needed	
Solar drying of sludge	X	X		(1)
Online respirometry		X		(1)
Deammonification and other low energy alternatives to activated sludge	X	X	X	(1)
Ultrafine bubble diffusers	X			(1)
Advanced SCADA systems			X	(2)
Automatic Demand Response (Auto-DR)			X	(6)
Distributed power generation		X	X	(6)
Remote sensing technology			X	(6)
High-speed gearless (Turbo) blowers			X	(1)

Target Area 2 – Energy Recovery

Energy recovery in the water and wastewater industry is getting considerable attention. In particular, energy recovery within water distribution systems and wastewater treatment systems should be targeted for RD&D opportunities. For example, small energy-recovery devices that use pipe flow to drive small turbines offer potential for demonstration projects. Because existing energy recovery devices, such as the Pelton turbine and the Francis turbine, are too expensive to be economically viable, except in rare circumstances, initiatives to improve the efficiency and economics associated with them are greatly needed. Some of the more promising applications include the use of Pelton turbines for recovery of energy from water distribution systems and the use of Francis turbines to recover energy from the RO concentrate in desalination plants.

There are two prime areas for energy recovery demonstration projects in wastewater treatment systems. The first area involves maximizing the production of methane from anaerobic digesters. Anaerobic digesters have historically been used to stabilize biosolids in order to minimize their environmental impact. As a result, the methane produced has mostly been considered a byproduct to be discarded or used in the simplest manner possible. However, the perception of methane has evolved so that now there is a need for guidance on the best ways to maximize methane production and to convert it to useful energy. There are a number of methods to convert the methane to both thermal and electrical energy. The specific advantages and disadvantages of each method will depend on local economic conditions and plant specifics.

The second area that offers potential for energy recovery in wastewater treatment systems is the recovery of heat from wastewater flow. Although wastewater flows are remarkably consistent, there have been few attempts to evaluate efficient ways to recover and reuse the thermal energy available in wastewater. Therefore, it is recommended that EPRI initiate demonstration projects to quantify the energy potential, identify existing heat recovery technologies, and assess the economics of heat recovery from wastewater flows.

Table 8-2 summarizes the developmental status and demonstration opportunities associated with energy recovery technologies.

Table 8-2
Summary of RD&D Opportunities in Energy Recovery

Technology	Status			Source
	Research	Under Development	Demonstration Needed	
Microbial fuel cells	X			(1)
Solar ponds for desalination and energy reduction	X			(5)
Thermal heat recovery from wastewater		X	X	(1)
Pelton turbine for water distribution systems			X	(2)
Francis turbines for energy recovery from desalination plants			X	(5)
Distributed power generation			X	(6)
Digester enhancements to improve methane yield			X	(4)

Target Area 3 – Improved Biosolids Treatment

As noted previously in Chapter 6, biosolids treatment accounts for about 30% of the operating costs of wastewater treatment plants. Because regulations limit the ultimate disposal of biosolids, the majority of treatment facilities currently use land application. The population growth and sprawl present large challenges for future wastewater system managers in addressing biosolids disposal. Thus, there is a great need to examine and improve the treatment of biosolids to reduce the volume that must be disposed. For instance, cell lysis treatment can be used to better destroy the biological component of biosolids, thereby reducing the volume of biosolids that must be treated and disposed. Cell lysis also increases the yield of methane from digestion, which, in turn, helps wastewater treatment facilities achieve gains towards net-zero energy facilities. Cell lysis involves cell wall damage to full cell disruption depending on energy intensity of process. Several cell lysis processes are available, including biological, chemical, and physical. Example physical processes include cavitation/sonification, thermal hydrolysis, homogenization, shearing, pressure release, and pulsed electric field.

Cell lysis shows great promise, but has so far seen limited application and limited operating data is available. An EPRI demonstration project of cell lysis, where data is carefully collected and the system optimized, could lead to more widespread use. Interestingly, cell lysis expands the use of electricity in wastewater treatment but could yield tremendous increases in methane yield from digestion, such that overall energy use decreases.

Another potential EPRI demonstration project involves microwave technology for drying of sludge. In this application, a high-efficiency multi-mode microwave system generates heat within the biosolids material, eliminating heat losses.

Table 8-3 summarizes the developmental status and demonstration opportunities associated with technologies for improved biosolids treatment.

Table 8-3
Summary of RD&D Opportunities in Improved Biosolids Treatment

Technology	Status			Source
	Research	Under Development	Demonstration Needed	
Electrocoagulation	X			(4)
Membrane thickening	X			(4)
Electroacoustic & electroosmotic dewatering	X			(4)
Supercritical water oxidation		X		(4)
Oxygen enhanced incineration		X		(4)
Gasification		X		(4)
Cell lysis through chemical or ultrasonic means			X	(4)
Electrodewatering			X	(4)
Microwave drying of biosolids			X	(4)
Lystek process			X	(4)

Target Area 4 – Water Reuse and Desalination

Water reuse is a broad topic with many potential demonstration needs. Though the technical challenges associated with water reuse are usually insignificant, the unit energy costs associated with water reuse is high because in essence the wastewater must be treated as wastewater and then again as potable water. The challenges of water reuse tend to be programmatic and include issues such as public acceptance, how the water is used, and conveyance methods. Because electric utilities use vast quantities of water for cooling of power plants, power plants are ideal candidates for water reuse. For example, the Emerald Coast Utilities' water reuse facility near Pensacola, Florida provides recycled water to one of Gulf Power's power plants and a private paper mill. (See Case Study 4 in Chapter 7.) Similarly, sustainable practices for water reuse are possible in many other locations throughout the U.S.

The energy cost for desalination technologies is extremely high. As shown in the case study example of the Tampa Bay Water desalinization plant in Chapter 7 (see Case Study 5), energy use can be 12,000 – 17,000 kWh/MG. Energy cost are a barrier to the wider implementation of desalination technologies. In the WaterRF report referenced above (*Desalination Product Water Recovery and Concentrate Volume Minimization*) several technologies were examined that showed promise for lowering energy costs. Some of these are listed below. For instance, dew-vaporation technology is a process of humidification-dehumidification desalination where the brackish water is evaporated by heated air, which deposits fresh water as dew on the opposite side of a heat transfer wall. The energy needed for evaporation is supplied by the energy released from dew formation. Heat sources can be combustible fuel, solar, or waste heat.

Forward osmosis is a process that shows much promise for providing a high recovery, low fouling, and low energy use. This process is still under development and lacks suitable membrane materials which are its primary obstacle. As membrane materials evolve processes like forward osmosis will offer great potential for reducing energy.

Dual reverse osmosis with chemical precipitation offers potential for energy efficiency gains relative to conventional RO. This technology has application in brackish water desalination.

Table 8-4 summarizes the developmental status and demonstration opportunities associated with water reuse and desalination technologies.

Table 8-4
Summary of RD&D Opportunities in Water Reuse and Desalination

Technology	Status			Source
	Research	Under Development	Demonstration Needed	
New membrane materials to improve performance (biomimetics, nanocomposite, nanotube)	X			(5)
Forward osmosis	X			(2)
Capacitive deionization	X			(2)
Ion concentration polarization	X			(4)
Dew-vaporation	X			(3)
Membrane distillation		X		(2)
Dual reverse osmosis with chemical precipitation			X	(3)
Nanotube membranes		X		(5)

Formal EPRI Program for Water & Wastewater RD&D

The list of potential demonstration projects above is by no means exhaustive. The range of challenges facing utilities across the country is daunting, and the number of possible solutions is overwhelming. Separating fact from fiction is a tough task where electric utilities can provide important assistance. A formal EPRI program, directed by a mix of professionals from the water and wastewater industry along with their electric utility representatives, offers the best option for addressing these problems. Short of a more formal program, several possible collaborative projects exist as illustrated by Table 8-1 through Table 8-4.

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CONCLUSIONS

Clean drinking water and effective wastewater treatment are vital services needed in all communities. These safeguards protect the public health, strengthen the community infrastructure, and provide a foundation for economic growth. Yet increasing concerns about the adequacy of existing services are posing serious challenges to local communities. These concerns are felt not just in the U.S., but internationally as well. The relationship between water and energy and opportunities for better managing energy use continues to be an area of great interest for electric utilities and water and wastewater treatment facilities.

The use of electricity for water and wastewater treatment is increasing due to demands for expanded service capacity and new regulations for upgraded treatment. Options available to control the electricity costs consist of technological changes, improved energy management, and participation in electric utility sponsored energy management programs. Appropriate options for a specific system will vary depending on the system characteristics, availability of electric utility programs to assist water and wastewater treatment facilities, and adequate funding and management skills to implement changes.

The Market for Electric Energy

Approximately 51,360 community drinking water systems and 14,780 publicly owned treatment works (POTWs) are now operating in the U.S. These facilities are among the country's largest energy users, requiring an estimated 70 billion kWh nationally each year, or about 2% of annual U.S. electricity use. Their electricity requirements will increase as plants expand treatment capacity to meet population growth and as additional treatments are applied to meet the rigorous mandates of the Safe Drinking Water Act and the Clean Water Act. Emerging non-regulatory issues, such as improvement in drinking water taste and color, odor control, and water shortages, are expected to create additional energy needs. It should be noted that this report only covers energy use at the drinking water and wastewater treatment facilities. Greater amounts of energy are also used for other means of water use such as inter-basin and trans-basin transfers, agricultural irrigation, electric generation, industrial use, mining, and petroleum and gas production.

The increase in energy efficiency is stimulated by a function of energy pricing, equipment technology, and the availability of energy efficiency programs. Energy efficiency potential studies conducted by EPRI assessed the potential for energy efficiency and demand response in the U.S over the next 20 years. Those studies quantified a range of savings from technically feasible to realistically achievable. Based on the macroscale analysis in the potential study, it is estimated that the realistic achievable energy efficiency potential for the water and wastewater industry by 2030 is approximately 8% of baseline, or 5.6 TWh per year.

At the same time the water and wastewater industry will see an increase in energy to process and treat more water, the industry will also use more energy efficient methods to meet its needs. In addition, renewable energy practices and the increase of biogas recovery in the wastewater industry will affect the energy mix. The net energy increase is difficult to project based on all the various components and would take a detailed study to develop future scenarios. In absence of a detailed study and based on the information analyzed in this report, the study team makes the following assumptions:

- Current electricity use in the public water supply and municipal wastewater treatment industry is about 70 TWh/yr
- Increase in electricity use will follow past patterns at about 1-2% per year or about 1 TWh per year
- The growth rate of electricity demand could be dramatically greater if desalination technology achieves greater adoption
- Energy efficiency has the potential to decease energy use by 5.6 TWh/yr in the next 15-20 years

Use of Energy in Water and Wastewater Processes

Chapters 4 and 5 provide descriptions of technologies used in water and wastewater treatment, together with companion electricity use characteristics. The study team developed tables of energy intensity values to help plant personnel and other interested parties estimate the composite energy use for hypothetical water treatment systems by aggregating appropriate unit processes. This study expanded upon and updated the unit operations contained in the 1996 EPRI report to better reflect current practices. Several processes that use little or no energy were combined or eliminated. New treatment options such as UV disinfection, membrane filtration, and alternative wastewater treatment processes have been added to reflect their widespread use. The data utilized to develop the estimates came from a variety of published sources, manufacturers' information, and practitioners' experiences. The primary assumptions the team used to compute the unit operation values are described in Chapters 4 and 5.

For drinking water plants much of the electric energy use is associated with pumping. The team developed estimates of energy intensity for raw surface water pumping and all unit processes for average flow rates.. The average flow rate is not the plant capacity, which is oftentimes twice the average rate or greater. Treatment plant unit processes are typically sized to handle additional flow to account for population growth and other factors. Table 4-2 presents all unit processes for average flow rates of 1, 5, 10, 20, 50, 100, and 250 MGD. Since pumping represents a large portion of the electric energy use at drinking water plants, the team developed a separate Table 4-3 so that plant personnel or other energy analysts can better match a given plant's source water and finished water pumping energy intensity as a function of pumping efficiency. Any user can chose the specific unit operations and plant capacity for a drinking water plant and make comparisons of facility energy use. Table 4-4 provides a summary of five different example plants selected to show total plant energy intensity derived from the energy intensity unit operation values:

- 18 MGD conventional treatment plant treating surface water = 1,420 kWh/MG
- 80 MGD lime soda softening plant treating surface water = 1,760 kWh/MG
- 8 MGD ultrafiltration plant using UV for disinfection = 2,510 kWh/MG

- 14 MGD groundwater plant using aeration = 2,210 kWh/MG
- 4 MGD desalination plant = 13,600 kWh/MG

Table 4-6 summarizes the estimate of total electrical use by the U.S. public water supply systems. Using estimated values of 1,600 kWh/MG treated for surface water plants, 2,100 kWh/MG for groundwater plants, and 12,000 kWh/MG for desalination plants, the team estimates total electrical energy used by public water supply systems in the U.S. is 107.5 million kWh/day, or 39.2 TWh/yr.

While energy use in water supply systems is principally a function of pumping energy, wastewater treatment is more closely related to wastewater treatment needs. Advanced wastewater treatment usually includes aeration for removing dissolved organic matter and nutrients; thus, aeration is the principal energy-using process in wastewater treatment. The team developed estimates of energy intensity for typical unit processes for average flow rates of 1, 5, 10, 20, 50, 100 and 250 MGD. Table 5-2 presents the energy use intensity values for wastewater treatment unit processes for these flow rates. Unit processes are provided for wastewater pumping, primary treatment, secondary treatment, solids handling, treatment and disposal, filtration and disinfection, finished water pumping, plant utility water, nonprocess loads, and energy recovery. Several treatment options have been added since the 1996 report reflecting their widespread implementation or acceptance within the industry, including odor control, sequencing batch reactors, membrane bioreactors, UV disinfection, and various filtration methods. Table 5-3 provides a summary of four different example plants selected to show total plant energy intensity derived from the energy intensity unit operation values:

- 6 MGD sequencing batch reactor, dried biosolids sold for reuse, UV disinfection = 2,250 kWh/MG
- 20 MGD trickling filter with anaerobic digester = 1,520 kWh/MG
- 3 MGD membrane bioreactor for water reuse = 4,910 kWh/MG
- 85 MGD advanced wastewater treatment plant using BNR = 2,040 kWh/MG

The team developed an estimate of the amount of electricity used by U.S. municipal wastewater treatment facilities following the procedure used to develop the original EPRI estimate in 1996. This new estimate uses EPA's Clean Watershed Needs Survey plant flow data based on level of treatment along with the energy intensity values listed in Table 5-2. Energy intensity for a number of treatment process types and size ranges is given in Table 5-5 resulting in an estimate of total electrical energy used by wastewater treatment systems in the U.S. at 82.8 million kWh per day, or 30.2 TWh/yr.

Energy Management Opportunities

This report categorizes the opportunities for improving energy management in the water and wastewater industries into three main groups:

1. Energy Efficiency, Load Management, and Demand Response
2. Emerging Technologies and Processes
3. Energy Recovery and Generation

EPRI sponsored an energy efficiency potential study that assessed the potential for energy efficiency and demand response in the U.S. from 2010 to 2030. The study quantified a range of savings from technically feasible to realistically achievable. The study provided no specific analysis of the water and wastewater industry, but the industrial sector level findings can be used to provide a high level estimate of potential energy savings in those industries. Based on the macroscale analysis in the potential study, the team approximates that the realistic achievable potential for the water and wastewater industry by 2030 is approximately 8% of baseline, or 5.6 TWh. As energy prices rise and additional energy efficiency programs are instituted, energy efficiency gains will continue to grow. The actual energy efficiency potential could be much greater due to regional regulations, water supply concerns, and energy costs. A more detailed study in this area is needed to develop strategic energy efficiency programs for the water and wastewater industry.

Improving the efficiency of equipment and processes is one of the primary ways to save energy. Opportunities relate to installing high-efficiency pumps, motors, and drives and reducing losses in pumping systems with better pipeline design. Opportunities also exist in improving the efficiency of treatment processes, such aeration and processing of biosolids and developing SCADA systems to incorporate energy efficient operating strategies. New regulations and the wider use of new technologies continue to raise the potential for increased electric intensity in water and wastewater treatment, therefore much research and development is needed to advance these technologies in an energy efficient approach. New technologies have a high capital cost and there is often uncertainty on their ability to meet treatment standards in a cost effective and sustainable manner.

Chapters 6 and 8 discuss various new treatment technologies. Chapter 8 includes a listing of technologies recommended for demonstration project testing. Development of new technologies in the water and wastewater industries is the function of a wide variety of public and private organizations including government, private industry, and several trade organizations. The trade organizations for the water and wastewater industry include the Water Environmental Research Foundation (WERF), the Water Research Foundation (WaterRF), and the Water Reuse Foundation. All three organizations are similar in structure to EPRI in that they are private, non-profit organizations funded by and oriented towards a specific industry. A partnership between EPRI and various stakeholders will offer a collaborative effort to develop and promote energy-efficient new technologies.

Finally, energy recovery is the latest target area to hit the industry. In water treatment the focus is on recovering some of the pumping energy through the use of energy recovery devices in the distribution system. In wastewater treatment, the emphasis is on biological treatments combined with opportunities in capturing energy in the wastewater itself. In the past, much of the biogas was simply burned in boilers to keep the digester warm. The initial CHP systems typically relied on reciprocating engines. Today, wastewater treatment plant staff has a variety of generation choices, including gas turbines, microturbines, and fuel cells. Further, CHP systems raise the system efficiency above 60%, making the entire investment more cost effective. In fact, CHP systems are a key component in any attempt to develop a “net-zero energy” wastewater treatment plant. WERF is currently instituting a five-year research plan for energy production and efficiency to increase the number of wastewater treatment plants that are net energy neutral.

Chapter 7 includes eight case studies of drinking water plants and wastewater treatment plants. There are four focus areas for these case studies:

1. Energy efficiency
2. Energy recovery
3. Demand response
4. Water conservation and water reuse

Each case study exemplifies a facility that has successfully implemented innovative energy management strategies in practice.

Conclusions and Recommendations

Electric utilities and water and wastewater treatment facilities can use this report to gain a better understanding of the inextricable link between water and energy. It is intended to serve as a resource for water and wastewater treatment plant characteristics, electricity requirements, and opportunities for improving energy management practices. The report contains descriptions of well known energy efficiency and demand response measures that still offer potential for greater adoption as well as case studies and demonstration ideas for novel and emerging technologies, processes, and energy management programs. Water and energy engineers and practitioners can use the unit operation data to "build" hypothetical plants for estimating typical electrical energy use. They can then assess the effects of selecting different types of unit operations with different levels of efficiency on overall plant electric energy intensity. Moreover, data on the ranges of energy savings possible with the various technological and programmatic solutions, along with information on regional areas of focus, can serve as a guide to prioritize next steps.

To further advance knowledge for the industry as a whole, the study team has four primary recommendations:

- Develop a formal program directed by a mix of professionals from the water and wastewater industry along with electric utility representatives to study and demonstrate innovative energy management solutions such as those listed in Chapter 8 and to disseminate knowledge.
- Identify host sites for technology demonstration projects.
- Design a software tool to facilitate estimation of plant level energy intensity and annual energy use by aggregation of unit operations.
- Conduct a comprehensive energy efficiency and demand response potential study focused specifically on the water and wastewater industries as a follow on to EPRI's 2009 study.[127]
- Carry out an assessment of the potential for energy recovery and generation from the water and wastewater industries.

Electric utilities interested in maximizing energy efficiency in the water and wastewater industry would benefit from a targeted approach that must include early engagement with the design

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[127] *Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030).* EPRI, Palo Alto, CA: January 2009. Product No.1016987.

consultant community. Establishing working relationships with the designers at the earliest stages of a project will help ensure efficient equipment and processes are incorporated into the design from the beginning, rather than later when design changes can be cost-prohibitive.

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ANNOTATED BIBLIOGRAPHY

#	Published by	Date	Title	Market	Annotation
1	CEE	2002	CEE National Municipal Water and Wastewater Facility Initiative (Initiative Description)	Both Drinking Water & Wastewater	The Initiative is focused on promoting energy efficiency activities in municipal water utilities, as well as promoting these activities at the national level and integrating energy efficiency as standard business practice. Possible benefits for water utilities as a result of energy efficiency include a reduction in energy costs and peak load demand, in addition to non-energy benefits. The barriers that exist to reach and/or implement energy efficiency are also included.
2	EPRI	2012	Automated Demand Response Today	All Industry	This White Paper provides a review of DR, an examination of accumulated experience with AutoDR, and an assessment of the current status of OpenADR. It also includes information on existing experience with bidding DR resources in the market for ancillary services.
3	EPRI	2010	Public Water Storage Tank Operation Data: Characteristics of Water Storage Tanks and Pumping Systems	Drinking Water	This report identifies and quantifies the typical operating characteristics of water storage tanks and finished water pumping systems employed in the U.S. public water industry.
4	EPRI	2009	Program on Technology Innovation: Electric Efficiency Through Water Supply Technologies - A Roadmap	Both Drinking Water & Wastewater	This is a technical report that identifies and researches water technologies with electric energy savings potential in four application areas: pumping systems and controls, water use efficiency, advanced treatment, and desalination. Specifically, it focuses on freshwater transportation, treatment and end-use technologies in the public water supply and agricultural sectors, which present considerable potential energy savings. It also provides next steps for utilities to take in order to implement electric efficiency technology in their practice. Non-energy benefits derived from each technology explored are included. The report builds off of EPRI's previous publication, "Technology Research Opportunities for Efficient Water Treatment and Use."

#	Published by	Date	Title	Market	Annotation
5	EPRI	2009	Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010-2030)	All Industry	This report documents the results of an exhaustive study to assess the achievable potential for electricity energy savings and peak demand reduction from energy efficiency and demand response programs through 2030. This “achievable potential” represents an estimated range of savings attainable through programs that encourage adoption of energy-efficient technologies, taking into consideration technical, economic, and market constraints.
6	EPRI	2009	Program on Technology Innovation: Technology Research Opportunities for Efficient Water Treatment and Use	Both Drinking Water & Wastewater	The report explains the uses of freshwater in the U.S. within the major market sectors (power generation, water and wastewater utilities, agriculture, industrial, commercial, and residential), and the technologies used to treat and utilize water. It identifies opportunities to improve water use efficiency as well as areas in need of further research. The opportunities outlined as potentials for water use efficiency are water reuse, water reclamation, and water use reduction. The publication includes an overview of a workshop that focused on reviewing an initial list of technologies and opportunities included in "Advanced Technologies for Water Use Efficiency," and discussed further ideas for the application of advanced treatment and water use technologies.
7	EPRI	1999	Energy Audit Manual for Water/Wastewater Facilities	Wastewater	This is guide that was developed to help electric utilities understand specific unit processes and their energy/demand relationships at water and wastewater treatment facilities.
8	EPRI	1996	Water and Wastewater Industries: Characteristics and Energy Management Opportunities	Both Drinking Water & Wastewater	This report provides electric utility planning, marketing, and customer service staff with a practical tool to better understand the water and wastewater industries and challenges they face. The report may also be used by water and wastewater utilities to determine how energy management systems might be applied to their particular system. It includes descriptions of technologies used in water and wastewater treatment. It also provides electricity use characteristics per process unit.

#	Published by	Date	Title	Market	Annotation
9	EPRI/TVA	2005	Biogas-Fueled Electric Power: An Assessment of Systems and Technologies	Wastewater	This report summarizes the practice of generating electric power from biogas, a mixture of methane and carbon dioxide with trace contaminants, produced as a byproduct of biological treatment of organic waste under anaerobic (no oxygen) conditions. Biogas is commonly produced during treatment of municipal solid waste in sealed landfills and anaerobic digestion of wastewater treatment plant sludge, animal manure, and organic industrial waste.
10	Focus on Energy	2006	Water and Wastewater Energy Best Practice Guidebook	Both Drinking Water & Wastewater	This guidebook offers information to management and staff on how to implement better energy management at water/wastewater facilities in Wisconsin. The guidebook includes potential opportunities for energy savings in water and wastewater facilities, as well as benchmarking, management, and technical best practices. The appendices include further support for energy management at facilities through the use of management quotes and examples of energy saving utilities. Additionally, the appendices are also composed of: regulations from the Department of Natural Resources, the variation of energy use in different wastewater treatment facilities, and best energy practices for common systems in industrial facilities.
11	Global Energy Partners	2010	Auto-DR: Smart Integration of Supply and Demand for Rapid Grid Response	All Industry	This White Paper discusses the use of Auto-DR to balance electric supply and demand for rapid grid response.
12	Hydraulic Institute/ Europump/U.S. DOE	2004	Variable Speed Pumping, A Guide to Successful Applications	All Industry	This guide emphasizes the potential for energy reduction through implementation of variable speed drives, however, it also mentions that pump speed adjustment may not be adequate for all pumping systems. It provides an overview of pumping systems, pumping system hydraulic characteristics, and different pump types. It also describes the interaction of pumps and systems, explains the influence on speed variation on specific pump types, and points out the significant energy consumption of motors in the system. It includes a flow chart meant to aid in the selection process of variable speed drives. Possible benefits and disadvantages are also outlined.

#	Published by	Date	Title	Market	Annotation
13	Lawrence National Berkeley Laboratory	2012	Fast Automated Demand Response to Enable the Integration of Renewable Resources	Wastewater	This study examines how fast automated demand response (AutoDR) can help mitigate grid balancing challenges introduced by upcoming increases in intermittent renewable generation resources such as solar and wind in an environmentally friendly and cost effective manner. This study gathers data from multiple sources to determine the total electric end-use loads in the commercial and industrial sectors of California, including municipal wastewater treatment facilities.
14	Lawrence Berkeley National Laboratory	2010	Improving Energy Efficiency and Reducing Costs in the Drinking Water Supply Industry	Drinking Water	This guide describes resources for cost-effectively improving the energy efficiency of U.S. public drinking water facilities. The guide describes areas of opportunity for improving energy efficiency in drinking water facilities; provides detailed descriptions of resources to consult for each opportunity; offers supplementary suggestions and information; and presents illustrative case studies, including analysis of cost-effectiveness. Appendix B of the guide describes the Market Profiles used in ENERGY STAR's Portfolio Manager for Drinking Water Utilities.
15	Lawrence National Berkeley Laboratory	2010	Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California - Phase II Report: San Luis Rey Wastewater Treatment Plant Case Study	Wastewater	This case study enhances the understanding of open automated demand response (Open Auto-DR) opportunities in municipal wastewater treatment facilities. Specifically, this report summarizes the findings of a 100-day submetering project at the San Luis Rey Wastewater Treatment Plant in Oceanside, California. The report reveals key energy-intensive equipment such as pumps and centrifuges can be targeted for large load reductions.
16	Lawrence National Berkeley Laboratory	2009	Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California - Phase I Report	Wastewater	This report summarizes the LBNL's research in characterizing energy efficiency and automated demand response (Auto-DR) opportunities for wastewater treatment facilities in California. It describes the characteristics of wastewater treatment facilities, the nature of the wastewater stream, energy use and demand, as well details of the wastewater treatment process. It also discusses control systems and energy efficiency and Auto-DR opportunities. Finally, it presents several case studies.

#	Published by	Date	Title	Market	Annotation
17	National Research Council of the National Academies	2008	Desalination: A National Perspective	Drinking Water	This book assesses the state of the art in relevant desalination technologies, and factors such as cost and implementation challenges. It also describes reasonable long-term goals for advancing desalination technology, provides recommendations for action and research, estimates the funding necessary to support the proposed research agenda, and identifies appropriate roles for governmental and nongovernmental entities.
18	U.S. Bureau of Reclamation	2003	Desalting Handbook for Planners	Drinking Water	The handbook explains the global issue of scarce fresh water sources and the importance of desalination technologies. It gives an introduction of the two general types of desalination technologies -- thermal technologies and membrane technologies -- and also explains the different source waters used for conversion into public water sources. It presents a series of case studies that use desalination technologies to desalinate various source waters. Basic water chemistry is explained such as water cycles, chemical formulas for compounds, measurement of water samples (pH and conductivity), and the types of water and treatments. It also focuses on describing the desalination process in facilities, the need for pretreatment, and post-treatment. The handbook also provides guidance for choosing the appropriate process and gives the cost for the specific process.
19	U.S. Bureau of Reclamation	1998	The Desalting and Water Treatment Membrane Manual: A Guide to Membranes for Municipal Water Treatment	Drinking Water	This manual describes various membrane technologies for use in municipal water treatment.
20	U.S. Department of the Interior, U.S. Geological Survey	2009	Estimated Use of Water in the United States in 2005	Groundwater, Surface Water	In this report, water withdrawals were estimated for the United States for 2005. Eight water withdrawal sources were included: public supply, domestic water use, irrigation, livestock, aquaculture, industrial, mining, thermoelectric power. Tables summarize total withdrawals by source and state. The report also includes trends in water use from 1950 to 2005.

#	Published by	Date	Title	Market	Annotation
21	U.S. DOE	2013	East Bay Municipal Utility District 11 MW Gas Turbine CHP System	Wastewater	An addition of 4.6 MG gas turbine system was implemented to existing engines, allowing for the turbine to be a primary electricity generation system in the facility. The facility uses digester gas for fuel. In addition to domestic wastewater, the facility also receives "high-strength" (trucked-in food waste) to enhance digester gas production. This is societal beneficial as it reduces landfill waste and GHG emissions by capturing methane for electricity production.
22	U.S. DOE	2006	Energy Demands On Water Resources - Report to Congress on the Interdependency of Energy and Water	Both Drinking Water & Wastewater	The report informs on the various relationships of energy and water, specifically on how water is a vital factor of energy resource development and use. Because of future higher demand and water shortages, the report advises the U.S. to consider energy and water development and management so that each is used fully. It outlines the ways in which the Federal government can help overcome the energy-water issues.
23	U.S. DOE	2002	United States Industrial Electric Motor Systems Market Opportunities Assessment	All Industry	The market assessment intends to be a design plan for the implementation of DOE's Motor Challenge Program. It develops profiles on the current status of motor-driven equipment in industrial facilities and of current motor system purchase and maintenance practices, characterizes and estimates the significance of potential opportunities to improve efficiency of industrial motor systems, and develops and implements a process to update the motor profile regularly using available market information, including the creation of methods to estimate energy savings and market effects attributable to the Program. Economic and environmental impacts of potential savings are included in the findings.
24	U.S. EPA	2013	Fiscal Year 2011 Drinking Water and Ground Water Statistics	Drinking Water & Groundwater	This report highlights the similarities and differences that exist among the 152,713 (as of October 2011) active public drinking waters in the U.S. It also includes figures from SDWIS/Fed, which keeps official record of the U.S. public drinking water systems, violations of state and EPA regulations, as well as the actions taken by the EPA or the states responding to the violations.

#	Published by	Date	Title	Market	Annotation
25	U.S. EPA	2010	Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities	Wastewater	The document explores energy conservation measures (ECMs) that apply to equipment upgrades and operations strategies, specifically focusing on new technology. As a means to optimize energy savings at wastewater treatment facilities, it is recommended to incorporate ECMs into comprehensive energy management programs. It presents information on ECMs for pumping systems, design and control of aeration systems, and blower and diffuser technology for aeration systems. It also includes information on new ECMs for specific treatment processes (UV disinfection, membrane bioreactors, anoxic and anaerobic zone mixing), and ECMs for solids processing. Case studies regarding ECMs for municipal wastewater treatment plants are also presented.
26	U.S. EPA	2008	Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities	Both Drinking Water & Wastewater	The guidebook is a tool for water and wastewater utilities to implement energy efficiency in their facilities. It was created in response to the escalating costs of energy, and as a consequence, the operational cost of water and wastewater utilities, since these are energy intensive.
27	U.S. EPA	2008	Clean Watershed Needs Survey (CWNS) 2008, Report to Congress	Wastewater	This survey (in Appendix I) provides technical information on number and type of operational wastewater treatment facilities and pipe systems per state in the U.S. It also contains data on number of wastewater treatment facilities, total existing flow, and design capacity, by flow range. Additionally, it contains data on level of treatment.
28	U.S. EPA	2007	Wastewater Management Fact Sheet, Membrane Bioreactors	Wastewater	The fact sheet outlines the advantages of microfiltration membrane bioreactors (MBRs) over the usual systems used for secondary treatment of municipal wastewater. Disadvantages are also mentioned such as higher capital and operational cost than the usual systems. Despite their high-capital cost, MBR systems are also used in industrial and commercial applications. An overview of membrane filtration, and design specifics are included, as well as a case studies of facilities using MBR systems.
29	U.S. EPA	2005	Membrane Filtration Guidance Manual	Drinking Water	The guidance manual's purpose is to provide support for the "Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)." This report identifies membrane filtration as one of many treatment approaches to achieve required level of Cryptosporidium treatment.

#	Published by	Date	Title	Market	Annotation
30	U.S. EPA	2004	Impacts and Control of CSO and SSOs - Report to Congress	Wastewater	The report to Congress defines CSOs and SSOs and explains the health risk they impose to the public, as well as the cost to municipalities when addressing these. The Agency focused on reviewing EPA and other governmental and non-governmental organizations, compiling a literature review concerning health impacts, creating an inventory of CSO outfalls, gathering SSO event information, developing national estimates of the volume and frequency of CSOs and SSOs, and developing models to estimate environmental and health impacts. The publication includes a summary of legislation attempts to regulate CSOs and SSOs, as well as specifics aspects on which to concentrate for creation and implementation of future legislation.
31	U.S. EPA	1997	EPA Response to Congress on Use of Decentralized Wastewater Treatment Systems	Wastewater	This document presents the advantages of using decentralized systems as opposed to other systems. It also evaluates potential costs and savings, explains the various barriers to implement, and informs on the EPA's ability to implement these systems.
32	U.S. EPA	1978	Total Energy Consumption for Municipal Wastewater Treatment	Wastewater	The report investigates the level of importance of the greatest consumptive uses of energy by using the total energy budget of the utility as a basis to gauge the potential for energy conservation or recovery within the plant.
33	U.S. EPA Combined Heat & Power Partnership	2011	Opportunities for Combined Heat & Power at Wastewater Treatment Facilities: Market Analysis and Lessons from the Field	Wastewater	The publication provides an overview of combined heat and power (CHP) and its benefits at wastewater treatment facilities. It presents an analysis of CHP systems fueled by biogas. It summarizes the existing capacity of these at wastewater treatment facilities and the market potential as well as the electric and thermal energy generation potential for additional CHP at treatment facilities. Results from wastewater treatment facility staff interviews are also summarized. Interviews were conducted with the purpose of investigating the motivators behind incorporating CHP, the CHP benefits and challenges, and gaining operational insight.

#	Published by	Date	Title	Market	Annotation
34	WaterRF	2011	Energy Efficiency Best Practices for North American Drinking Water Utilities	Both Drinking Water & Wastewater	The report presents a literature review of case studies and best practices of energy efficiency in water utilities that serve as an example for other utilities to implement. The practices are categorized in the following major areas: management tools, plant improvements and management changes, water treatment, water distribution, water conservation, alternative/renewable energy sources, financial assistance, and partnerships. The efficiency practices result in cost savings, reduction of greenhouse gas emissions, operational benefits (long-term sustainability), as well as customer relations benefits.
35	WaterRF	2009	Product Water Recovery and Concentrate Volume Minimization	Drinking Water	This report provides state-of-science reviews and assessments of promising and emerging configurations and technologies for desalination. It also conceptualizes an innovative desalination configuration for recovery enhancement and concentrate minimization. The innovative configuration included a primary reverse osmosis (RO) step followed by a concentrate treatment scheme.
36	WaterRF	2010	Desalination Facility Design and Operation for Maximum Energy Efficiency #4038, Final Project Update	Drinking Water	This project update summarizes the WaterRF's efforts to investigate the reasons for energy consumption in desalination facilities and to research ways in which the consumption can be reduced. The methodology used for this effort included a literature review of existing desalination processes, a survey that assisted in identifying ways to improve efficiency, and on-site visits that were performed specifically to evaluate design and operational practices by utilities that dealt with wastewater, brackish water, and seawater. The study was conducted with 49 utilities around the world.

#	Published by	Date	Title	Market	Annotation
37	WaterRF	2008	Evaluation of Dynamic Energy Consumption of Advanced Water and Wastewater Treatment Technologies	Both Drinking Water & Wastewater	The study quantifies the actual and theoretical energy consumption of specific water and wastewater advanced treatment unit procedures to evaluate factors that affect energy consumption, as well as investigates energy optimization opportunities. The study approach consists of a literature review to identify possible energy optimization measures for each advanced technology; the development of a specific scheme for evaluating energy consumption of the advanced technologies of focus; energy audits to compare actual energy consumption to theoretical values; and data analysis to find energy optimization potentials. One chapter is dedicated to the energy consumption of each advanced treatment technology (low-pressure membrane, reverse osmosis, UV, membrane bio-reactors, electrodialysis reversal). Case studies are also included.
38	WaterRF	2007	Energy Index Development for Benchmarking Water and Wastewater Utilities	Both Drinking Water & Wastewater	The publication reports on a project that focused on developing metrics that allowed for comparisons among wastewater treatment plants and other water utilities. The research was conducted as follows: literature review of existing energy use data and utility characterization methods; development of statistically representative sample of utility energy use and characteristics; development of relationships between characteristics and energy use; application and evaluation of multi-parameter benchmark score method; and the review of resulting metric application at sample utilities.
39	WEFTEC	2006	Biological Nutrient Removal: Where We Have Been, Where We Are Going?	Wastewater	The report covers a literature review of past research on biological nutrient removal technology. It also summarizes its present use and the future of this technology.
40	WEFTEC	2006	Energy Usage and Control at a Membrane Bioreactor Facility	Wastewater	The report presents a case study of Fowler Water Reclamation Facility, an advanced treatment plant that uses membrane bioreactors. This facility incorporated changes in its treatment process design in order to reduce high power consumption. The changes consisted of consolidating functions to reduce attached horsepower, the elimination of intermediate pumping and duplicate functions, and the use of VFDs.

#	Published by	Date	Title	Market	Annotation
41	WERF	To be published	Energy Balance and Reduction Opportunities, Case Studies of Energy-Neutral Wastewater Facilities and Triple Bottom Line (TBL) Research Planning Support	Wastewater	This report explores zero-energy solutions for wastewater treatment plants. It uses Triple Bottom Line (TBL) assessments (economics, environment, community) to discover sustainable options for managing biosolids. The report provides guidance for achieving energy self-sufficiency.
42	WERF	2012	Demonstration of Membrane Zero Liquid Discharge for Drinking Water Systems: A Literature Review	Drinking Water	The report is a literature review of five Zero Liquid Discharge (ZLD) categories: intermediate treatment, thermal-based technologies, pressure-driven membrane technologies, electric potential driven membrane technologies, alternative technologies
43	WERF	2011	Energy Production and Efficiency Research - The Roadmap to Net-Zero Energy	Wastewater	This fact sheet summarizes the types of energy available in wastewater, the ways in which it can be used or converted, and the ways of accomplishing energy neutrality at the plants. The research conducted and information presented in the fact sheet is intended to guide large facilities in becoming energy neutral and also to direct future research.
44	WERF/IWA Publishing	2012	Barriers to Biogas Use for Renewable Energy	Wastewater	The known barriers were categorized into ten general sections. A study was conducted to determine the greatest barriers to utilities. This was done through an online survey of over 200 respondents. As a result of the study conducted, 9 out of 10 identified barriers were significant. The document includes actions to increase biogas-generated renewable power at treatment facilities. Case studies are also included in the appendices.
45	WERF/ WaterRF/ WateReuse Association	2008	Survey of High-Recovery and Zero Liquid Discharge Technologies for Water Utilities	Wastewater	The report identifies, characterizes, and evaluates commercially available high-recovery and zero liquid discharge (ZDL) processing schemes. Twelve cases in which process size, salinity, and composition varied, in addition to five processing schemes, were studied. The economic and performance results were summarized. The publication also includes regulatory issues attributed to highly concentrated residuals product of volume minimization and ZLD processing schemes.

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