Title

Opportunities for Automated Demand Response in California Wastewater Treatment Facilities:

Authors

Aghajanzadeh, Arian
Wray, Craig
McKane, Aimee

Publication Date

2015-08-30

LBNL-XXXXX

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Opportunities for Automated Demand Response in California Wastewater Treatment Facilities

Arian Aghajanzadeh, Craig Wray and Aimee McKane
Environmental Technologies Area

August 2015

DISCLAIMER

Acknowledgements

This work described in this report was coordinated by the Demand Response Research Center and funded by the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy and Office of Electricity Delivery and Energy Reliability, under Contract No. DE-AC02-05CH11231 and by the California Energy Commission (CEC), Public Interest Energy Research (PIER) Program, under Work for Others Contract No. 500-03-026.

The authors would like to thank Anish Gautam and the California Energy Commission for their continued support of Demand Response Research in the Industrial, Agriculture, and Water sectors. The authors would also like to thank our reviewers Daniel Olsen, Peter Therkelsen and Prakash Rao. The authors would also like to thank AutoGrid Systems Inc. for their collaboration on the Sunnyvale Water Pollution Control Plant case study.

Abstract

Previous research over a period of six years has identified wastewater treatment facilities as good candidates for demand response (DR), automated demand response (Auto-DR), and Energy Efficiency (EE) measures. This report summarizes that work, including the characteristics of wastewater treatment facilities, the nature of the wastewater stream, energy used and demand, as well as details of the wastewater treatment process. It also discusses control systems and automated demand response opportunities.

Furthermore, this report summarizes the DR potential of three wastewater treatment facilities. In particular, Lawrence Berkeley National Laboratory (LBNL) has collected data at these facilities from control systems, submetered process equipment, utility electricity demand records, and governmental weather stations. The collected data were then used to generate a summary of wastewater power demand, factors affecting that demand, and demand response capabilities. These case studies show that facilities that have implemented energy efficiency measures and that have centralized control systems are well suited to shed or shift electrical loads in response to financial incentives, utility bill savings, and/or opportunities to enhance reliability of service.

In summary, municipal wastewater treatment energy demand in California is large, and energy-intensive equipment offers significant potential for automated demand response. In particular, large load reductions were achieved by targeting effluent pumps and centrifuges. One of the limiting factors to implementing demand response is the reaction of effluent turbidity to reduced aeration at an earlier stage of the process. Another limiting factor is that cogeneration capabilities of municipal facilities, including existing power purchase agreements and utility receptiveness to purchasing electricity from cogeneration facilities, limit a facility's potential to participate in other DR activities.

Keywords: Demand response, automated demand response, Auto-DR, energy efficiency, wastewater, water, treatment, controls, load shed, load shift.

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EXECUTIVE SUMMARY

Overview

This report summarizes Lawrence Berkeley National Laboratory's Demand Response Research Center (DRRC) work involving California wastewater treatment facilities from 2008 through 2014. Through sector specific research, the DRRC's Industrial Demand Response team assessed the potential opportunities for and barriers to implementing automated demand response (Auto-DR) capabilities in these facilities.

DR refers to a set of strategies and systems used by electricity consumers to temporarily modify their electrical load in reaction to electrical grid or market conditions. Three case studies carried out as part of this work suggest that wastewater treatment plants are prime candidates for Auto-DR due to their large energy consumption during utility peak periods, process storage capacity, high incidence of onsite generation equipment, and control capabilities.

Research Goal

The study of wastewater treatment plant DR potential has been conducted to provide policy makers, utilities, and facility management with the information necessary to understand how wastewater treatment facilities can participate in DR events. More specifically, decisions about participating in Auto-DR and load management require that facility operators possess knowledge about the magnitude, time, and duration of their energy consumption (Thompson, et al. 2010). The knowledge compiled in this report can assist a facility in evaluating:

1. The potential benefits of energy efficiency and DR.
2. The limitations and risks of DR depending on facility technologies, energy use profile, and the characteristics of the wastewater.
3. The type of technology installations or retrofits needed for energy efficiency and Auto-DR.
4. The impact of different strategies for DR events.
5. How specific facility equipment or systems can be controlled during a DR event.

Methods

The knowledge and information summarized in this report regarding opportunities and barriers for DR in wastewater treatment facilities came from six reports, some of which discussed three case studies. The following lists the six reports:

1. Thompson, Lisa, Katherine Song, Alex Lekov, and Aimee McKane. 2008. *Automated Demand Response Opportunities in Wastewater Treatment Facilities.* Berkeley: LBNL-1244E.

2. Lekov, A, L Thompson, A McKane, K Song, and M A Piette. 2009a. *Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California - Phase I Report*. Berkeley: LBNL-2572E.

3. Thompson, L, A Lekov, A McKane, and M A Piette. 2010. *Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California - Phase II Report: San Luis Rey Wastewater Treatment Plant Case Study.* Berkeley: LBNL-3889E.
4. Goli, Sasank, Daniel Olsen, Aimee McKane, and Mary Ann Piette. 2011. *2008-2010 Research Summary: Analysis of Demand Response Opportunities in California Industry.* Berkeley: LBNL-5690E.
5. Olsen, Daniel, Sasank Goli, David Faulkner, and Aimee McKane. 2012. *Opportunities for Automated Demand Response in Wastewater Treatment Facilities in California - Southeast Water Pollution Control Plant Case Study.* Berkeley: LBNL-6056E.

Key Findings

This report combines the findings of previous reports to show that municipal wastewater treatment facilities are good candidates for automated demand response. In particular, energy use for wastewater treatment is large and continuing to grow. There are opportunities for energy efficiency and demand response in several areas of treatment plants, depending on their configurations. For example, pumps and aeration systems in wastewater treatment facilities account for 75% of total energy consumption. Installing variable frequency drives (VFDs) on blower equipment typically lowers energy use about 10 to 20%, which can lead to a considerable reduction in energy use and demand (Lekov, et al. 2009a).

Other key findings are as follows:

1. Energy efficiency and load management technologies can enable successful participation in DR events.
2. Rescheduling periodic loads can reduce facility demand.
3. Wastewater treatment facilities with storage capacity (influent, effluent, or sludge) are good candidates for Auto-DR.
4. Facility control systems are suitable for Auto-DR, when they are integrated into centralized control systems.
5. Barriers to DR implementation include lack of suitable controls, inadequate payback, or perceived process inflexibility.
6. Constraints to achieving full DR potential include: insufficient storage capacity, regulations regarding effluent turbidity, cogeneration capabilities, and existing power purchase agreements.

Next Steps and Future Research

Future research is needed to develop strategies to overcome barriers and constraints to DR and Auto-DR participation. That work should include:

- Studying the effect that modulation of variable-demand aeration loads has on effluent quality.

- Conducting further study to understand the prevalence of cogeneration in wastewater treatment facilities and its relationship to DR potential.
- Continuing to survey the literature for case studies and technology advances that might affect Auto-DR potential in wastewater treatment facilities.
- Scaling and standardizing Auto-DR for control systems to apply to wastewater treatment facilities to reduce implementation cost, and to increase DR reliability and effectiveness.

Improving the understanding of how facility operators impact the effectiveness of DR strategies and identifying the best operation practices and behaviors to enhance the impact of DR activities.

Chapter 1: Introduction

Figure 1: A typical wastewater treatment plant.

Wastewater treatment is an energy intensive process that, together with water treatment, comprises about 3% of U.S. annual electricity consumption between 75,000 and 100,000 GWh (Lekov, et al. 2009a). In 2001, California municipal water and wastewater treatment consumed about 13 billion kWh, or about 5% of the state's total electricity use (CEC 2005). However, opportunities for reducing energy consumption and implementing demand response (DR) in industrial wastewater treatment facilities are frequently overlooked, because these facilities are peripheral to the core business of major electricity-using industries (Thompson, et al. 2008).

DR, involves a set of actions taken to modify electric loads when contingencies, such as emergencies or congestion, occur that threaten supply-demand balance, and/or market conditions occur that raise electric supply costs. DR programs are designed to decrease electricity use during peak times, to reduce total system costs, and to improve the reliability of the electric grid (Thompson, et al. 2008).

There are three types of DR strategies:

- Auto-DR, where loads are shed automatically in response to grid control signals, unless the customer opts-out.
- Manual DR, where a customer must act to shed load.
- Semi-Auto-DR, where a customer has pre-programmed load shed strategies, but still must act in order to shed load (opting-in rather than opting-out).

Compared to the latter two strategies, Auto-DR allows quicker, more reliable load sheds with less effort required by grid operators and plant operators. Auto-DR also has the potential to be used for ancillary services, which are growing in importance due to the load uncertainty and variability caused by the integration of large shares of renewables (Watson, et al. 2012). The installation of controls to support Auto-DR may also result in improved energy efficiency through real-time access to operational data (Thompson, et al. 2008).

DR in wastewater treatment facilities is important for the following reasons (Lekov, et al. 2009a):

- In addition to being energy intensive, wastewater treatment facilities have significant electricity demand[1] during utility peak periods. The potential to schedule equipment usage in these facilities makes this a key sector with promising DR potential.
- Some wastewater treatment facilities have already implemented energy efficiency measures that can: provide a base for participation in Auto-DR programs, take advantage of utility incentives, and avoid demand charges.

For facilities to automate their demand response with no "human in the loop", standardized DR event information needs to be exchanged between DR service providers (utilities/Independent System Operators) and consumers (facilities/participants and aggregators). OpenADR provides an information model for continuous and open communication signals over the internet.

Implementing Auto-DR in an industrial setting presents a number of challenges, both practical and perceived. Some of these include: the wide variation in loads and processes, resource dependent loading patterns that are driven by outside factors such as time-critical processing, the perceived uncertainties associated with the control capabilities for implementing Auto-DR strategies, and concerns about interrupting scheduled processes and still being able to assure that product quality regulations are met (Thompson, et al. 2010).

Report Organization

The remainder of this report describes the context, rationale, and potential for Auto-DR in wastewater treatment facilities. In particular:

Chapter 2: summarizes characteristics of the wastewater treatment process, and the magnitude and timing of related energy use.

Chapter 3: provides an overview of control systems and their application to wastewater treatment.

Chapter 4: summarizes demand response opportunities, including load shed and load shift strategies for wastewater treatment facilities.

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[1] The energy intensity for water collection and treatment in California ranges from 1,100 kWh to 4,600 kWh per million gallons depending on the facility (Thompson, et al. 2008); the average is 2,850 kWh per million gallons. According to the EPA, the average water/wastewater needs per person in the US are 100 gallons per day. Based on this information, the average energy demand due to water use alone is about 3,800 MW.

Chapter 5: discusses the constraints and challenges faced by wastewater treatment facilities in adopting demand response strategies.

Chapter 6: summarizes three case studies carried out by Lawrence Berkeley National Laboratory (LBNL) at wastewater treatment facilities, and presents the key findings in each case.

Chapter 7: provides conclusions and recommendations for future research.

The information provided in this report can assist a wastewater treatment facility in evaluating:

- The potential to incorporate Auto-DR measures.
- The control technology needed for Auto-DR.
- How equipment or systems could be controlled during a DR event.
- The impact of different strategies for DR events.
- The limitations and risks of DR depending on facility technologies, energy-use profile, and characteristics of the wastewater treatment process.

Chapter 2:
Characteristics of Wastewater Processing Industry

Wastewater is treated to remove pollutants and to ensure that the effluent complies with conditions of federal or state permits (Lekov, et al. 2009a). Understanding the treatment process and its energy use and consumption characteristics is essential to identifying potential opportunities to implement Auto-DR measures.

Wastewater Treatment Process

The treatment process can be subdivided into four major steps: preliminary, primary, secondary, and tertiary treatment (including disinfection), followed by discharge into receiving waters such as a river or stream. The various treatment steps are illustrated schematically in Figure 2 (Lekov, et al. 2009a) and are summarized below:

- Preliminary treatment involves the mechanical removal of coarse solids that may interrupt treatment operations (e.g., paper, rocks, plastic, and rags), usually by screening, or by reduction in size of these solids using a grinder.
- Primary treatment removes suspended solids and organic matter by sedimentation. Larger solids such as gravel and coarse sand are removed first in grit removal tanks, sometimes with aeration to agitate the mixture, followed by centrifugal separation. In some facilities, the removed sediment is processed as sludge. That process involves the use of a thickener, anaerobic digestion, and dewatering, with the resulting biosolids used as fertilizer or soil conditioner.
- Secondary treatment involves aerating the remaining waste stream to raise the dissolved oxygen levels, which helps promote the growth of microorganisms. Sedimentation and filters can then be used to remove the majority of the remaining soluble and organic material (e.g., sugars, fats, and proteins). Some of the sediment ("activated sludge") is recycled back into the aeration basin to maintain an environment for organic decomposition.
- Tertiary, or advanced, treatment is the extended level of treatment to remove nutrients, toxic compounds, and other organic material and suspended solids that are still left in the wastewater after secondary treatment. Depending on the industry, wastewater treatment may not include this part of the tertiary step. Disinfection is usually the last part of the process. Typically, chemicals are used for disinfection, but some facilities now use other technologies instead such as ultraviolet (UV) light irradiation of the process stream.

In some facilities, tertiary and sometimes quaternary treatment steps are also used to clean some effluent to a quality suitable for landscape irrigation, or for input to municipal water treatment. Throughout the process, pumps are used to move the waste streams through the various steps. Figure 3 illustrates the process flow in more detail for an actual treatment facility.

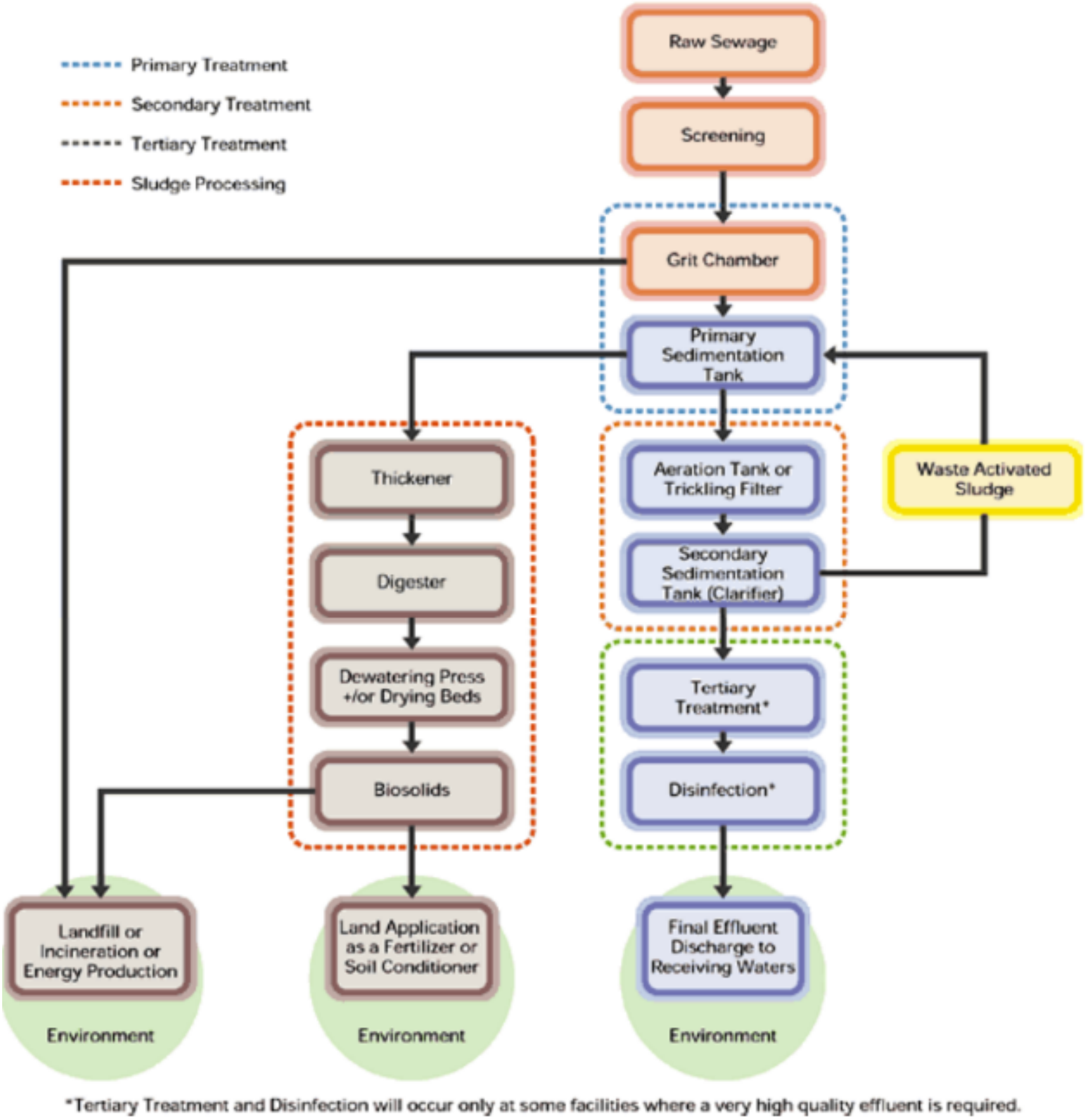

Figure 2: Municipal wastewater treatment process schematic (Lekov, et. al. 2009).

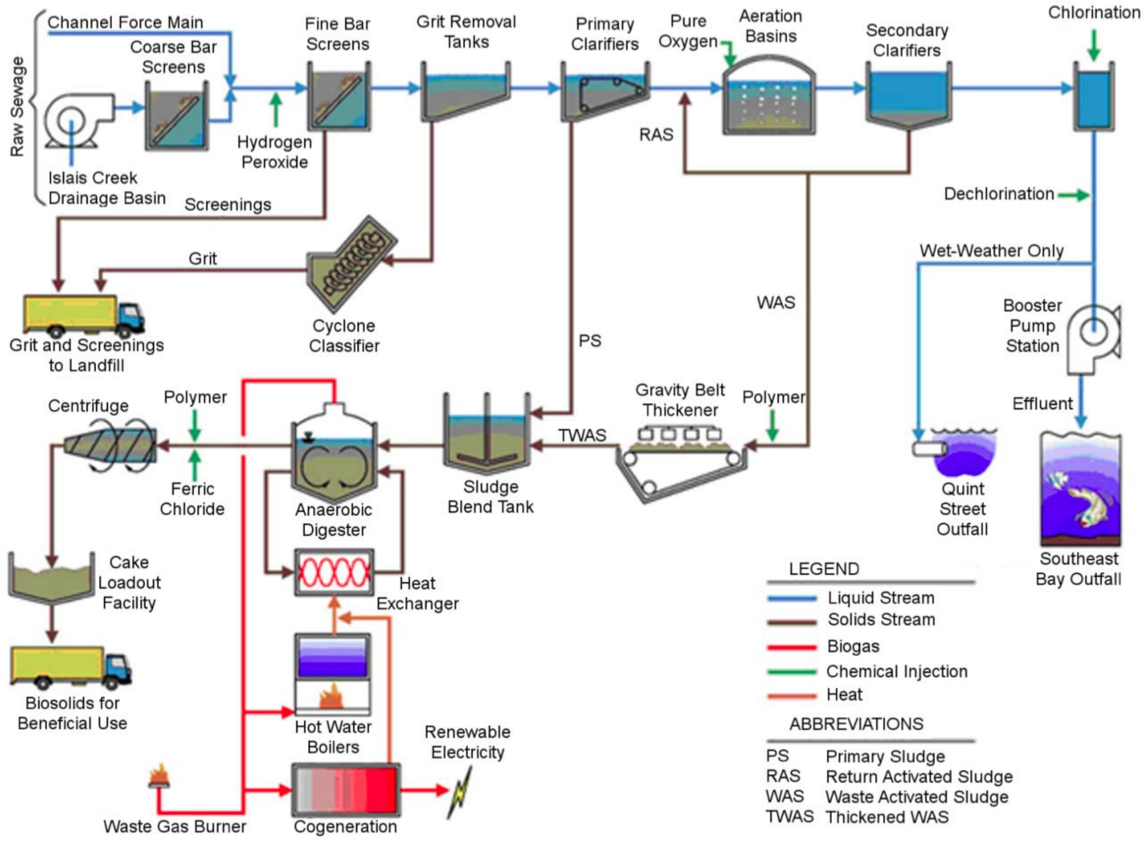

Figure 3: Wastewater treatment process flow example (Olsen, et. al. 2012).

Energy Use

Magnitude of Energy Consumption

To assess the potential for automated demand response in wastewater treatment facilities, it is important to understand the magnitude of energy use and demand in wastewater treatment facilities, the daily and seasonal load patterns, and the role of each piece of energy-intensive equipment in the treatment process (Lekov, et al. 2009a).

In 2004, there were 619 municipal wastewater treatment facilities in California (EPA 2008a). Electrical energy use in the treatment process accounts for a significant portion of overall processing expenses (Lekov, et al. 2009a). In particular, the California Energy Commission (CEC) reported that in 1995 wastewater treatment facilities in California consumed approximately 1,600 GWh of statewide electricity. This increased by about 26% to 2,012 GWh in 2001 (Lekov, et al. 2009a). In 2008, it was estimated that loads in water and wastewater treatment facilities will increase by 20% over the following 15 years due to increasing populations and more stringent regulations (EPA 2008b).

In 2001 within these facilities, the energy intensity for water collection and treatment ranged from 1,100 kWh/million gallons to 4,600 kWh/million gallons. One reason for this wide range is the variability in the average amount of electricity used for transporting and pumping wastewater from a residential or commercial area to a municipal wastewater treatment facility.

More specifically, the energy intensity can vary greatly depending on wastewater treatment facility topography, as well as system size and age (Thompson, et al. 2008).

For example, some wastewater collection systems rely on gravity to transport wastewater to a treatment facility, while others use energy-intensive pumps to lift or transport wastewater. As another example, the energy intensity in large facilities is much lower than in small facilities, because the large facilities process a significantly higher portion of wastewater, bringing the average to the lower end of the range.

Other reasons for the variability are the dependence of energy use on the quality of the wastewater stream, the level of treatment required to meet regulations, the type of processing, the treatment technologies used, and the efficiency levels of the equipment (Lekov, et al. 2009a).

Timing of Energy Consumption

Temporal load variation in a wastewater treatment facility depends on many factors including diurnal and seasonal load patterns, location, population size, and whether the nature of the facility's discharge is municipal or industrial (Thompson, et al. 2008). For example, Figure 4 shows sample summer and winter load patterns for a municipal wastewater treatment facility.

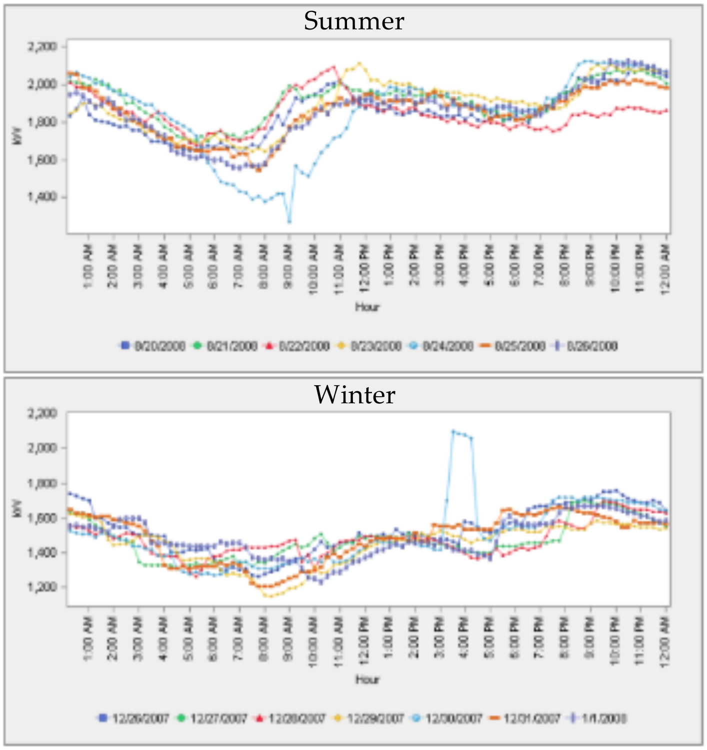

Figure 4: Sample municipal wastewater treatment facility load patterns (Thompson, et. al. 2008).

As shown in Figure 4, wastewater flows and demand for municipal treatment facilities often follow a diurnal pattern where the peak flows occur twice a day: once in the late morning when wastewater from the peak morning water use reaches the treatment facility and a second peak flow during the early evening between 7 and 9 pm (Thompson, et al. 2008). Electricity demand for wastewater treatment facilities is typically higher during the summer months, especially in areas with hot summers like Southern California.

Although wastewater influent flow can vary dramatically throughout the day, some wastewater treatment facilities use load equalization tanks to maintain a constant secondary effluent flow (Thompson, et al. 2010).

Significant Energy Using Processes and Equipment

The energy use by individual pieces of equipment in the wastewater treatment process plays an important role in formulating automated demand response strategies, because energy intensive equipment should be the primary target for DR. In many wastewater treatment facilities, the main end users of electricity are aeration, wastewater and sludge pumping, dissolved air floatation, anaerobic digestion, trickling filters, and lighting (Lekov, et al. 2009a). Figure 5 shows the average distribution of energy end-uses in the municipal treatment process based on sub-metered data from eight municipalities in New York State (Thompson, et al. 2008).

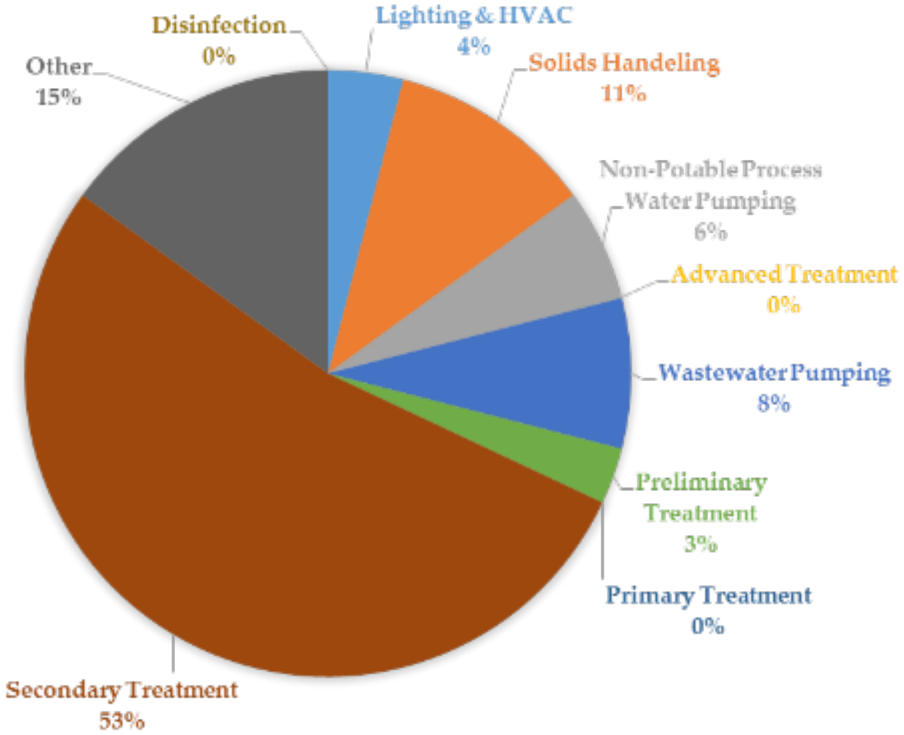

Figure 5: Wastewater treatment equipment energy uses (Kleyman 2006).

The largest energy use in Figure 5 is secondary treatment (53%). It includes sludge compressors, blowers, and pumps; mechanical aerators; oxygen generation air compressors and mixers; trickling filter pumps; and biological contactor drive motors and blowers. Together with the pumping energy for wastewater pumping (8%) and non-potable process water pumping (6%), the combined energy use in these three categories is about two-thirds of the total energy use. Most of the remainder of the energy use is made up of solids handling (11%) and "other" uses (15%, equipment with motors rated at less than five horsepower, which were not metered).

The remainder of this section provides further details about each of the major electricity end-uses in the treatment process.

Aeration

Federal and local permits typically regulate conventional pollutants such as biological oxygen demand, suspended solids, fecal coliform, pH, oil, and grease (Environmental Protection Agency 2002). Total dissolved solids, nitrogen, phosphorous, heavy metals, and organics are also important measures of the wastewater quality and are used in establishing wastewater effluent regulations.

To help meet these regulations, aeration systems inject air into reactor tanks to allow for microbial degradation of organic matter. Aeration equipment also helps provide adequate mixing in the tanks to prevent solids from settling, thus maintaining the necessary solids retention time. These systems also help wastewater treatment facilities meet effluent ammonia nitrogen levels, since oxygen demand greatly increases during nitrification. Nitrification is the oxidation and thus conversion of ammonia to nitrite and then nitrate. Doing so requires monitoring of the effects of temperature, dissolved oxygen levels, and pH on nitrification.

Common types of mechanical surface aeration equipment are low-speed mechanical aerators, direct-drive surface aerators, and brush-type surface aerators. Diffused aeration systems consist of a blower (low-pressure, high-volume air compressor), air piping system, and diffusers. Some aeration systems combine diffusers with mechanical aerators. The size and number of aerators in the wastewater treatment system is determined by the biological oxygen demand of the wastewater and by the aerator efficiency.

Figure 6: Blower (left) and an aeration basin (right).

Aeration devices such as aerator blowers are the most significant consumers of energy in a wastewater treatment system. A typical treatment facility with a diffused aeration system uses 50 to 90% of its electric power to run blower motors. Using fine bubble diffusers coupled with variable flow compressors and energy efficient motors can reduce aeration energy consumption by 50%. Installing variable-speed drives for blowers and matching the blower output with air requirements can also reduce energy use (Lekov, et al. 2009a).

Figure 7: Example primary clarifiers.

Typically, grit removal does not consume much energy. However, in *aerated* grit chambers, as opposed to velocity-type grit basins, blowers used for chamber aeration consume a considerable amount of energy. Reducing the air produced by these blowers can reduce facility energy use (Lekov, et al. 2009a).

Inefficient operation of primary clarifiers such as the ones shown in Figure 7 can lead to high total suspended solids and biological oxygen (aeration) demand loadings. By retrofitting the primary clarifiers, biological oxygen demand will be improved, thus increasing oxygenation capacity and reducing related energy use (Lekov, et al. 2009a).

Wastewater and Sludge Pumping

Figure 8: Example lift pump.

The energy required to pump influent wastewater can range from 15 to 70% of the total electrical energy depending on the wastewater treatment facility site elevation and influent sewer elevation. Lift pumps like the one shown in Figure 8 typically raise water from the sewer system to the plant. If the energy required to operate all of the pumps in the collection system is considered, including effluent pumping and pumping within the facility, total pumping energy requirements for the system may represent as much as 90% of the total energy used (Lekov, et al. 2009a).

Return-activated sludge pumping is also required for the activated-sludge process. Return-activated sludge rates are usually expressed as a percentage of the influent flow and typically range between 40 to 100% of the influent flow. Return-activated sludge pumps require almost as much energy per unit volume of flow as influent pumps, but usually have slightly lower total head and energy requirements (Lekov, et al. 2009a).

Trickling filters are used in treating both municipal and industrial wastewater. Trickling filters require energy for influent pumping and circulation. The filter is a porous seal that covers a rock or plastic packing. The wastewater trickles downward through the packing to the underdrain where the effluent liquid is collected and passed to a sedimentation tank where the effluent is separated (Lekov, et al. 2009a).

Sludge Dewatering

Figure 9: Example centrifuges used for sludge dewatering.

Sludge dewatering equipment is ubiquitous in wastewater treatment facilities due to the high water content of sewage sludge. An activated sludge wastewater treatment facility typically uses 7% of its total energy for solids dewatering (Lekov, et al. 2009a). This large amount of energy is required to break down the bond strength of the sludge moisture content.

Dewatering commonly involves using equipment with varying energy-intensities, including centrifuges such as the two shown in Figure 9, belt-filter presses, recessed-plate filter presses, drying beds, and lagoons. Therefore, choosing the most efficient dewatering method for the particular wastewater treatment facility is important in reducing energy consumption. Two case studies conducted by LBNL demonstrated that centrifuge loads can be successfully shifted, which suggests that this may be a DR opportunity worth pursuing (Olsen, Goli, et al. 2012).

Anaerobic Digestion

Anaerobic digesters break down the volatile fraction of the sludge so that the non-volatile solids can be disposed of in landfills or used as fertilizers. During anaerobic digestion, anaerobic selectors are used to stress the organisms before they are released back into an oxidative environment. A byproduct of this process is biogas which contains 50 to 70% methane, 30 to 45% carbon dioxide, and water vapor. This biogas can be used to generate heat and electricity (Lekov, et al. 2009a). Generation equipment using carbon based fuels such as diesel, natural gas or biogas may be subject to restrictions on annual operating hours (California Air Resources Board 2011). If biogas can be stored, then it can also be used to effectively shift loads to outside of peak periods or DR events.

Emerging Treatment Technologies

Several emerging wastewater treatment technologies may impact the energy use in these facilities, particularly the use of nanotechnology and electron beams. For example, solar nano-photocatalysts can disinfect microorganisms and break down previously undegradable compounds. Nanostructured silica is another emerging technology that detects and eliminates toxic contaminants. Nanotechnology research states that nano-based filters achieve 99.95% filtration efficiency compared to conventional disinfection technologies (Lekov, et al. 2009a). Many newer alternatives to the use of chlorine in wastewater disinfection rely on electricity and electron beams, which are effective, but very energy intensive (Lekov, et al. 2009a). For a complete list of emerging wastewater treatment technologies please refer to Environmental

Protection Agency's report titled "Emerging Technologies for Wastewater Treatment and In-Plant Wet Weather Management" (EPA 2013).

Chapter 3:
Wastewater Treatment Controls

Overview

Control systems are essential for automating demand response strategies in wastewater treatment facilities. The introduction of centralized controls integrated with existing standalone controls or distributed control systems can improve operational efficiency and facilitate the automation of demand response strategies (Thompson, et al. 2008).

In particular, centralized control systems allow for integrated data collection and analysis, and provide opportunities to improve overall facility performance. Control technologies installed for energy efficiency and load management purposes can often be adapted for Auto-DR at little additional cost. These improved controls may also prepare facilities to be more receptive to Auto-DR due to both increased confidence in the opportunities for controlling energy use (and thus expenses) and access to real-time data (Olsen, Goli, et al. 2012).

For example, in wastewater treatment facilities, the integration of Supervisory Control and Data Acquisition (SCADA) systems provides a central location at the master terminal unit or human-machine interface (MTU/HMI) for monitoring and controlling remote equipment, allows for faster data collection and analysis, and provides ways to improve facility performance. Figure 10 shows an overview of the SCADA system, including the remote terminal unit (RTU) and programmable logic controller (PLC) interfaces with sensors and equipment, respectively.

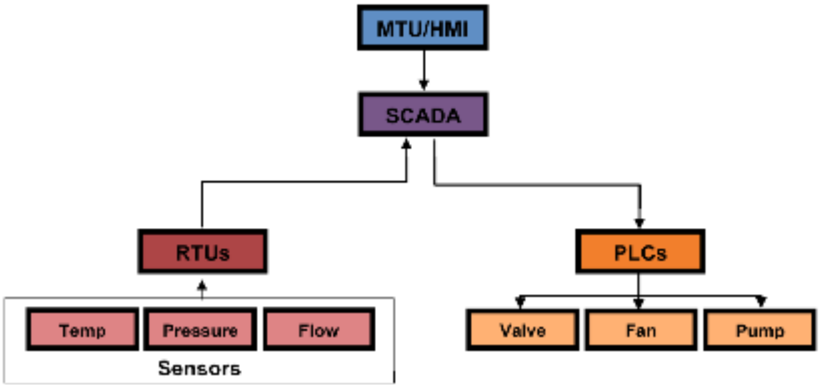

Figure 10: SCADA system schematic (Lekov, et al. 2009a).

Using the SCADA system, wastewater treatment facility operators can direct when to operate remote equipment and make complex decisions based on input from the system. In particular, such a system provides the ability to continuously and precisely control process variables and can start, slow down, or stop equipment such as aerators, blowers, pumps, valves, and chemical feed systems when monitored process information such as flow rates and dissolved oxygen levels deviate from pre-established parameters. More specifically, SCADA systems can be programmed to monitor and automatically adjust: air density, blower efficiency, and facility flow on a real time basis, and meet discharge regulations with better control at the treatment level (Thompson, et al. 2008).

Equipment Controls

The following describes specific control opportunities for four types of equipment in the wastewater treatment process:

> ***Aerators*****:** Implementing automatic dissolved oxygen control for an aeration system can reduce facility energy use by as much as 25%. The control system can automatically adjust blower output at preset time intervals based on a comparison between an average of dissolved oxygen readings in the aeration basins and a recommended dissolved oxygen concentration. Dissolved oxygen sensors are located in strategic locations to transmit signals to the controlling SCADA-RTU. Blower speeds can also be adjusted using a variable frequency drive (VFD) controlled directly by a programmable logic controller (PLC) to accommodate varying loads during different periods of the day or unexpected events (Lekov, et al. 2009a).
>
> Although automatic dissolved oxygen (DO) control systems can save significant energy, they have not been used in many facilities. One reason is that older sensors and probes used in these systems for measuring DO levels need frequent maintenance. However, newer sensor technology and self-cleaning probes have fixed this problem. Treatment facilities should also consider adding variable capacity blowers and automated DO control when replacing any aeration system with fine-bubble diffusers (Lekov, et al. 2009a).
>
> ***Pumps*****:** Like the aeration blowers, pump speed also can be varied using a VFD controlled directly by a PLC or through a SCADA system. Using variable speed instead of constant speed matches the pump output to system head and allows for greater pump operating range and improved operating efficiency (Lekov, et al. 2009a).
>
> ***Motorized Valves***: As in the cases of aerator blower and pump speed control, motorized valves can be controlled to continuously and automatically adjust the amount of air supply to achieve the optimal dissolved oxygen concentration required in each aeration zone. Such control can reduce the system head, thereby reducing the demand on blower motors, and in turn can reduce facility energy consumption by as much as 25% (Lekov, et al. 2009a).
>
> ***Disinfection Equipment*****:** Irradiating the waste stream with ultraviolet (UV) light is becoming a common method of disinfection, because unlike traditional processes such as chlorination and ozonation, using UV light does not involve the addition of chemicals. However, UV disinfection uses more electrical power than the chemical based methods.
>
> Implementing UV light control strategies can help minimize the impact of this disinfection method on energy costs. For example, control data from the SCADA system can enable facilities to respond to changes in the waste stream, such as increased levels of total suspended solids, turbidity, and biological oxygen demand. Using new on-line sensing technologies can also reduce the UV light related power costs. For example, turbidity sensors and UV absorbance sensors can be used in a SCADA system to automatically control power applied to UV lights and to optimize disinfection while eliminating unnecessary power consumption, as well as extending the life of expensive UV lamps (Lekov, et al. 2009a).

In conclusion, centralized control systems make wastewater treatment facilities excellent candidates for Auto-DR by bringing together the actions of the individual equipment controls and locally distributed controls. Such integration allows the Auto-DR infrastructure to interact with a single control system, creating a cost-effective and easy to manage reliable base for Auto-DR implementation. Centralized systems assist communication between higher-level controls and lower-level hardware, thus facilitating the implementation of Auto-DR strategies. Such integration could be a powerful tool for wastewater treatment facilities when developing energy efficiency and demand response programs.

Chapter 4:
Demand Response Opportunities

The technologies that enhance efficiency and controls within wastewater treatment facilities could also enable these facilities to become successful demand response participants. Comprehensive and real-time demand control from centralized computer control systems can allow facility managers to coordinate and schedule load shedding and shifting through equipment-level controls to reduce energy demand during utility peak hours. This section outlines several load shedding and load shifting opportunities that could be successful in wastewater treatment facilities.

Load Shed Strategies

There are several opportunities to consider for load shedding in a wastewater treatment facility during demand response events. These include turning non-essential equipment off and transitioning essential equipment to onsite power generators. In addition, facilities can use VFDs to operate motor-driven process equipment (i.e., aerator blowers and pumps) at lower speeds, which reduces demand and better enables process operations to maintain effluent quality within regulatory limits. Lighting systems, as well as heating, ventilating, and air conditioning (HVAC) systems also can be retrofitted to save energy and reduce overall energy demand and operating expenses. Some of the opportunities are more appropriate than others, depending on the equipment type. Further information about specific equipment follows.

Aerator Blowers

In many cases, treatment facilities with diffused aeration systems use 50 to 90% of total electric power demand to run aerator blower motors (Thompson, et al. 2008). Using VFDs to control blower speed and reduce this large demand when possible should be considered. Simply shutting down blowers during demand response events also could be an effective way to significantly reduce the plant's energy demand. However, in previous studies (Thompson, et al. 2010), this shutdown strategy resulted in a short-lived turbidity increase, which is discussed further in Chapter 5:

Pumps

Pumps are used in the majority of wastewater treatment processes, including influent pumps, grit pumps, and lift pumps (Lekov, et al. 2009a). Given that the energy required for influent wastewater pumping alone can range from 15 to 70% of the total electrical energy, there is a significant opportunity to shed loads associated with pumping. (Thompson, et al. 2008). Pumps are often oversized for the average wastewater flow and thus operate inefficiently. Wastewater treatment facilities can frequently address inefficiencies due to pump oversizing by using VFDs or applying operational strategies that involve staging multiple pumps, which allows for more efficient utilization of pumping capacity (Lekov, et al. 2009a).

Onsite Power Generators (Cogeneration)

In the United States, about 22% of wastewater treatment plants use anaerobic digesters. However, most facilities flare the anaerobic digester gas produced; less than 1% of facilities currently use biogas recovery. In particular, onsite power generators running on biogas, a byproduct of the treatment process, can provide off-grid power during demand response events. This equipment also produces waste heat that can be used for process heating as well as space heating.

Currently in California, ten municipal wastewater treatment facilities generate a combined 38 MW of electrical power from biogas, even though there is the potential to recover another 36 MW from anaerobic digesters at other facilities. However, this potential is spread in part across 220 municipal treatment facilities, and most of these sites have a potential for cogeneration of less than 1000 kW. In addition, there are 168 municipal treatment facilities that have a biogas to electricity potential of less than 200 kW (Lekov, et al. 2009a).

Load Shift Strategies

Implementing load shift strategies in wastewater treatment facilities allows the main energy-intensive treatment process to be rescheduled to off-peak hours. Electrical load management is a frequently used method for reducing energy use in these facilities and can result in 10 to 15% energy savings. The following discusses over-oxygenation, untreated wastewater storage, process rescheduling, and anaerobic digestion opportunities to shift load.

Over-Oxygenation

Dissolved oxygen (DO) is necessary for microorganisms to breakdown organic material present in water (Lekov, et al. 2009a). A major opportunity for shifting wastewater treatment loads from peak demand hours to off-peak hours is over-oxygenating stored wastewater prior to demand response event. Doing so allows aerators to be turned off during the peak period. However, facilities must be careful to monitor and maintain the correct range of aeration, because over-oxygenation due to prolonged detention time can also adversely affect effluent quality (Goli, et al. 2011).

Dissolved oxygen concentrations vary daily and seasonally and tend to be lower during summer months, because biochemical reactions use more oxygen in higher temperatures. Further, overall oxygen levels are lower during summer months due to decreased stream flow (Lekov, et al. 2009a). A plant operator should consider all of these factors prior to over-oxygenation to ensure that an acceptable effluent quality is maintained.

Figure 11 shows the impacts on blower and total facility demand of a 2 hour manual shutdown of both blowers at the San Luis Rey wastewater treatment facility (Thompson, et al. 2010). No over-oxygenation occurred before or after this test. Figure 12 shows the impact of the test on blower demand and dissolved oxygen.

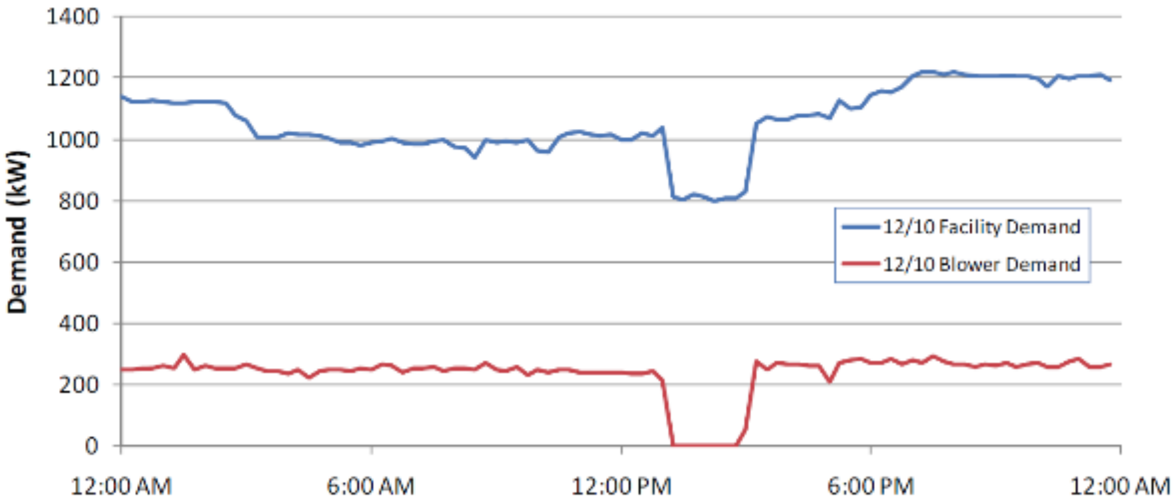

Figure 11: Blower and facility demand response to over-oxygenation test.

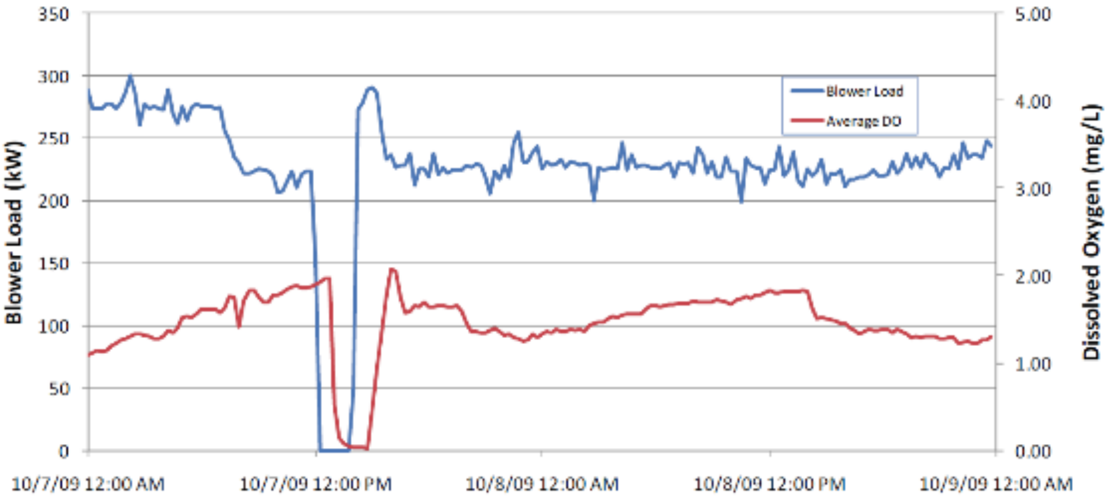

Figure 12: Blower load and dissolved oxygen response to over-oxygenation test.

The manual demand response test indicated that shutting down the San Luis Rey facility's blowers significantly reduced the facility demand during the peak period. More specifically, this test resulted in a 79 kW peak period demand reduction from blower load and a 161 kW peak period demand reduction at the facility. However, discussions with facility staff revealed that the blower tests negatively impacted key facility parameters.

In particular, as Figure 12 shows, the DO concentration dropped from 2.0 mg/L to nearly zero for about a two hour period, and quickly rose when the blowers came back online. The facility manager noted that 24 hours *after* this test occurred, there was a sharp increase in secondary effluent turbidity (lasting about 5 hours), which indicates that the total solids in the system were high (Thompson, et al. 2010). However, the effluent did not exceed regulatory limits for turbidity. Had over-oxygenation prior to blower shutdown occurred, then a desired level of DO could have been sustained during the DR event to avoid the increased turbidity later.

Storing Wastewater

If site conditions allow, wastewater treatment facilities can utilize excess storage capacity to store untreated or partially treated wastewater during demand response events and then process it later during off-peak hours. However, building storage basins can be expensive, so equalization basins can be used instead. Equalization basin drains open and close as needed to maintain a constant level in the influent wet well, which creates a near constant flow through the treatment process. Unused tanks can be converted into equalization basins during upgrading and expanding facilities (Lekov, et al. 2009a). Treated waste water can be stored as well. In one of the case studies, pumping treated effluent to the ocean was simply shifted to off-peak hours (Thompson, et al. 2010).

Process Rescheduling

Facility processes such as backwash pumps, biosolids thickening, dewatering and anaerobic digestion can be rescheduled for operation during off-peak periods, providing peak demand reductions in wastewater treatment facilities (Goli, et al. 2011).

Anaerobic Digestion

Using the biogas from anaerobic digestion to produce electricity can be an important demand response resource for the wastewater facilities. However, several issues may restrict the plant's ability to use cogeneration as a DR strategy. These constraints are discussed in more detail in Chapter 5:.

Chapter 5:
Constraints

Implementing Auto-DR in an industrial setting presents a number of challenges, both practical and perceived. Some of these include: the wide variation in loads and processes, resource dependent loading patterns that are driven by outside factors such as time-critical processing, the perceived uncertainties associated with the control capabilities for implementing Auto-DR strategies, and concerns about interrupting scheduled processes and still being able to assure that product quality regulations are met. From a literature review and our consultations with wastewater treatment experts, we found the following three main deterrents to Auto-DR:

1. Insufficient storage capacity.
2. Effluent turbidity due to reduced aeration load.
3. Cogeneration capabilities and existing power purchase agreement.

Each is described further below.

Insufficient Storage Capacity

In the Southeast Water Pollution Control Plant case study (Olsen, Goli, et al. 2012), it was demonstrated that there are several days of influent storage built into the San Francisco sewer system and the facility had excellent flexibility to curtail lift pump demand due to this storage capacity. However, plant operators may be unwilling to use lift pumps as a DR resource when the city's sewers are already carrying a greater volume of influent (which translates to less storage being available).

Effluent Turbidity Due to Reduced Aeration

A manual DR test conducted at the San Luis Rey facility (Thompson, et al. 2010) that involved turning off both aeration blowers for 2 hours. Implementing this measure resulted in sharp, short-lived turbidity increases in the facility effluent. In this case, regulatory turbidity limits were not exceeded. However, there may be facilities where shutting down blowers might cause these limits to be exceeded, such that this DR strategy may not always be feasible.

Cogeneration Capabilities and Existing Power Purchase Agreement

Only a fraction of wastewater plants use biogas to generate electricity, but those with storage have the ability to run dispatchable, distributed generation using this renewable resource as fuel (Olsen, Goli, et al. 2012). However, cogeneration capabilities can severely limit the plant's DR potential.

For example, the San Luis Rey wastewater treatment facility (Thompson, et al. 2010) produces biogas as a byproduct of anaerobic digestion. It provides this gas at no cost to CalPower, who uses it to generate electricity in the cogeneration plant that it operates. In turn, CalPower supplies that electricity to the treatment facility at a fixed cost, which is lower than the normal utility rate. CalPower requires that the total demand from the facility's equipment always must be greater than the power produced by cogeneration (a minimum of 560 kW). Because of this requirement and because the treatment facility's cogeneration capacity is a large fraction of its total demand, the facility has few options in terms of demand response measures.

In general, with a large cogeneration capacity, wastewater treatment facilities may have even fewer options for DR as the site becomes more energy efficient. Unless the power purchasing agreement allows for the utility to purchase excess power from the cogeneration unit, there is less incentive for these facilities to participate in DR programs.

In addition, generation equipment using diesel, natural gas, or biogas may be subject to restrictions on annual operating hours (California Air Resources Board 2011).

Chapter 6:
Case Studies

Southeast Water Pollution Control Plant

Overview

This case study (Olsen, Goli, et al. 2012) evaluated the demand response potential of a large wastewater treatment facility located in San Francisco, California. In particular, this study was conducted to investigate facility attributes that are conducive to demand response or that hinder its implementation. One year of operational data were collected from the facility's control system, submetered process equipment (lift pumps and centrifuges), utility electricity demand records, and governmental weather stations. These data were then analyzed to determine factors that affected facility power demand and demand response capabilities.

Plant Description

The Southeast Water Pollution Control Plant was originally constructed in 1952, and was upgraded in the early 1980s. It treats 80% of the City's combined stream of wastewater and storm water (SFwater 2014). In particular, the plant was designed for a dry-weather capacity of 85 million gallons per day (MGD) on average, and 142 MGD peak-hour flow. In wet weather, usually October through March, additional equipment is brought online to raise the plant's capacity to 250 MGD: 150 million gallons of which goes through primary, secondary, and disinfection treatment before discharge, and 100 million gallons of which is discharged after only primary treatment and disinfection.

Figure 13: Southeast Pollution Control Plant in San Francisco (Source: Google Earth).

Figure 13 shows an aerial view of the facility. The treatment process at this plant is illustrated in Figure 3. In terms of key equipment, the plant has four lift pumps that are operated with variable frequency drives (VFDs). These pumps raise wastewater from the sewer system to the Southeast plant. Figure 8 shows one of these pumps. The plant's six centrifuges dewater digester sludge as the final step in producing biosolids. Figure 9 shows two of the centrifuges.

Case Study Findings

The average baseline demand at the Southeast facility was approximately 4 MW. During the rainy season (October-March), the facility treated 40% more wastewater than during the dry season, but demand only increased by 4%. More specifically, analyses of the collected data found a strong correlation between daily influent flow and total lift pump demand (R^2=0.55), but no correlation between influent flow and centrifuge demand. The data also indicated that the demand from the lift pumps and centrifuges during normal utility peak hours (12 pm to 6 pm) was not substantially different than the demand during the rest of the day.

Based on the submetered data, on average, 154 kW and 86 kW of load shift are available from the lift pumps and centrifuges, respectively, for a total shift of 240 kW (approximately 6% of average plant demand). Similar shifts were observed during partial-day plant shutdowns. A reduction in demand from lift pumps and centrifuges during one such shutdown is shown in Figure 14.

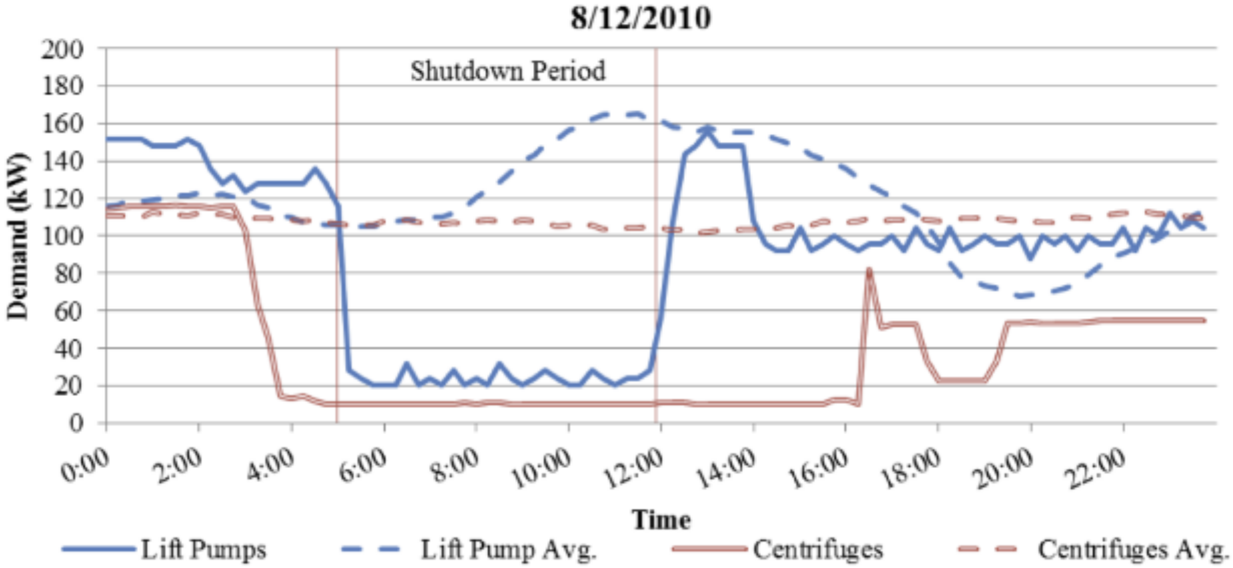

Figure 14: Reductions in lift pump and centrifuge demand during a partial-day plant shutdown.

Because there are several days of influent storage built into the San Francisco sewer system, the Southeast plant has excellent flexibility to curtail lift pump demand. While the load shift from the centrifuges remains constant throughout the year, the load shift available from the lift pumps would be greater during the rainy season, due to the increased baseline usage. However, plant operators may be unwilling to use lift pumps as a DR resource when the city's sewers are carrying a greater volume of influent.

Analyses of demand data collected during maintenance events indicated that there are four other areas of the facility with demand response potential:

1. Large load shifts (1,069 kW on average, or 72% of baseline) appeared to be available from shutting down the network of monitored pump stations throughout the city, due to the large capacity for storing influent in the city's sewers. Large load shifts were also likely at other non-monitored pumping stations.
2. Smaller load shifts (264 kW on average) appeared to be available by rescheduling the operation of centrifuges and the gravity belt thickener.
3. Although the operation of the plant's oxygen-generating equipment was not the subject of this study due to the complexity of startup and shutdown procedures, small load sheds (132 kW on average) appeared to be available by shutting down some aeration trains and mixers. Note that this is a non-standard process, where pure oxygen is generated and injected into the wastewater. It is more sophisticated than other aeration techniques, but is also more complicated to start and stop.
4. On days where the cogeneration plant was operational throughout the day, net plant demand was on average 2,065 kW lower than it would have been had the cogeneration unit not been running. This represents a net demand reduction of 45 to 50% from total demand. However, the plant's normal operating procedures are to run the unit continuously at full power, precluding its contribution to demand response.

Loads from the lift pumps, centrifuges, and distributed pumping stations appeared to be able to ramp down within one hour. Similarly, the electrical generation from the plant's cogeneration unit was able to ramp up within one hour. With appropriate controls and telemetry, these resources could participate in demand response events with short notice, which is often called "Fast-DR".

The study also identified other potential demand response opportunities that warrant further study: modulating variable-demand aeration loads, shifting operation of sludge-processing equipment other than centrifuges, and utilizing schedulable self-generation.

San Luis Rey Water Treatment Plant

Overview

This case study (Thompson, et al. 2010) evaluated the demand response potential of a smaller municipal wastewater treatment facility located in Oceanside, California. It focuses on manual demand response tests conducted on the major energy using equipment. In particular, 100 days of submetered data were collected. These data included the energy usage and demand of key equipment at the treatment plant such as effluent pumps, blowers, and centrifuges. Additional data were collected from the facility and various other sources, including influent and secondary effluent flow, pH, dissolved oxygen levels, temperature, humidity, and effluent turbidity. These data were then analyzed to determine factors that affected facility power demand and demand response capabilities. These findings were augmented with insights from the plant's facility manager.

Plant Description

Two wastewater treatment process chains are operated within the San Luis Rey Wastewater Treatment Plant, termed Plant 1 and Plant 2. The original wastewater treatment process chain, Plant 1, was built in 1970, and has a capacity of 10.7 million gallons of wastewater per day (MGD). Plant 2 was built in 2004 and has a capacity of 4.7 MGD. Currently, the two process chains together treat an average of 9.5 MGD, with peak processing during wet weather reaching about 11.0 MGD. The facility operates at an average electricity demand of 1.3 MW, with peak demand reaching 2 MW. The facility typically draws between 900 to 1100 kW from the grid, and utilizes an additional 600 to 700 kW produced by the cogeneration facility.

Figure 15 shows an aerial view of the San Luis Rey treatment facility and the locations of the targeted energy-intensive equipment that was submetered as part of this study. The key equipment included the three effluent pumps, two centrifuges, and two blowers, which account for 45% on average of the total facility electricity demand. During normal facility operation, the facility runs two of the three pumps, with the third serving as emergency backup. These pumps are used to pump treated wastewater effluent from the secondary clarifiers to water reclamation facilities or out to the Pacific Ocean. Only one centrifuge and one blower run during normal plant operation; the other centrifuge and blower serve as emergency backups. The centrifuge system receives wastewater from the digesters and separates out the treated solids from the wastewater effluent downstream of the digesters. The blowers are used in the aeration basins.

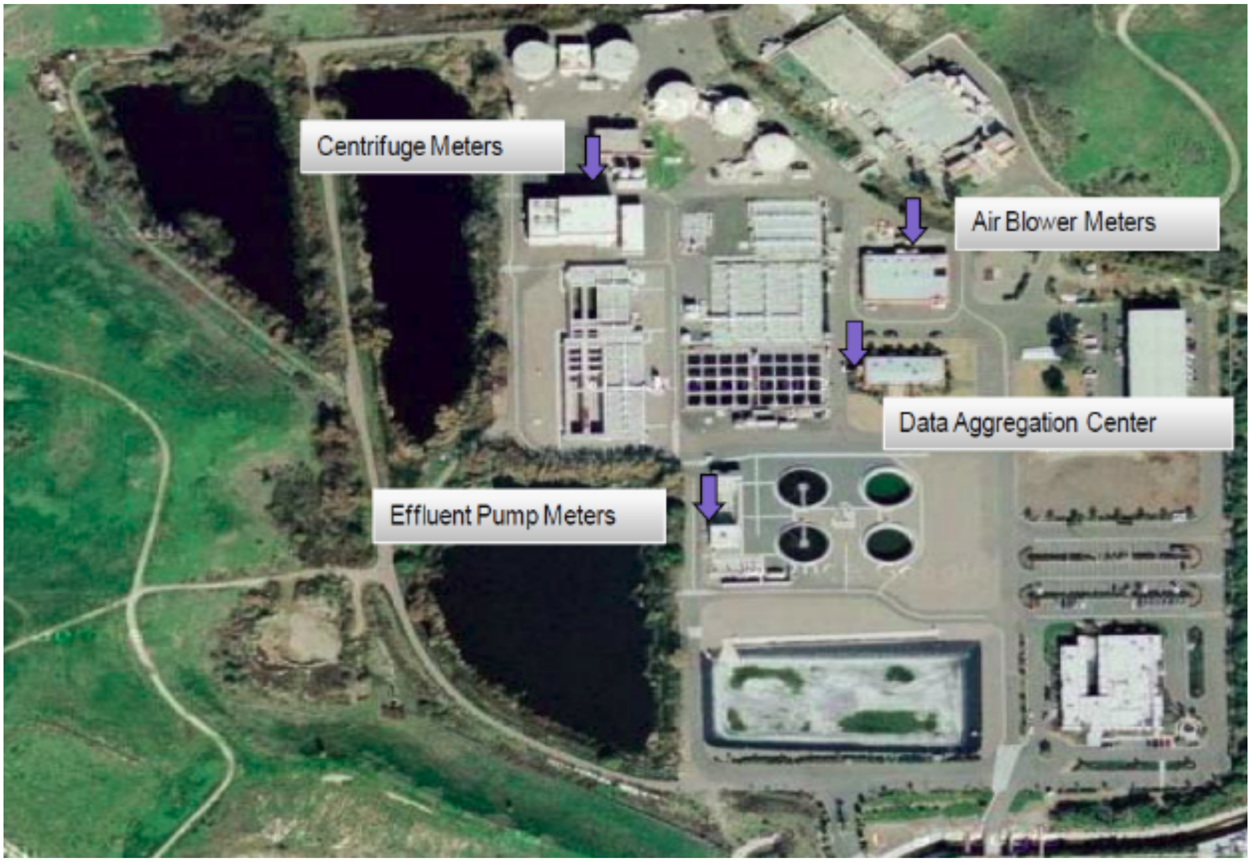

Figure 15: San Luis Rey Wastewater Treatment Plant (Thompson, et al. 2010).

Case Study Findings

In this case study, the plant's influent flow followed a diurnal pattern of a morning and evening peaks, with a sharp dip at night. There was a small positive correlation between outdoor air temperature and influent flow. Further, this study observed that this facility maintains a stable level of dissolved oxygen even as influent varies. This was accomplished through the use of a modulating value that adjusts the amount of air reaching the basin. There was a slight correlation between the outdoor air temperature and dissolved oxygen levels at this facility.

Demand response tests on the effluent pumps resulted in a 300 kW load reduction, as shown in Figure 16. Tests on the centrifuges resulted in a 40 kW load reduction, as shown in Figure 17. These reductions from the centrifuges and effluent pumps were enabled by the large potential for onsite storage of sludge and effluent, respectively. Although tests on the facility's blowers resulted in peak period load reductions of 78 kW, as discussed in Chapter 4:, sharp, short-lived increases in effluent turbidity occurred within 24 hours of the test.

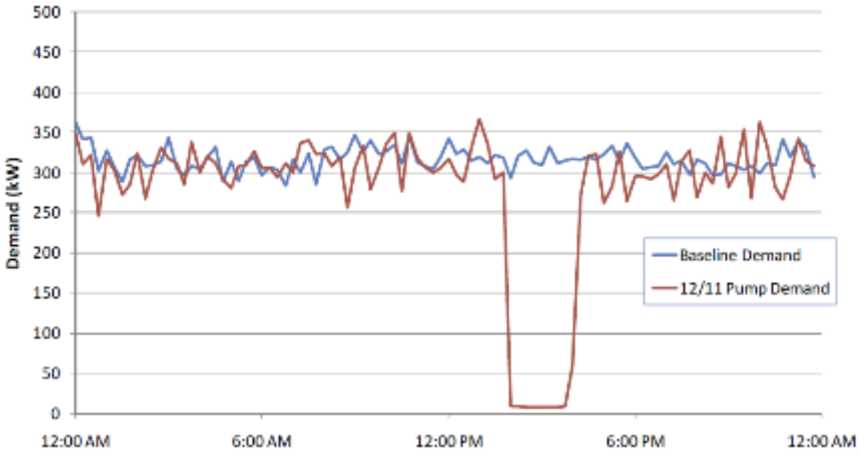

Figure 16: Pump demand reduction from shutting down all three effluent pumps.

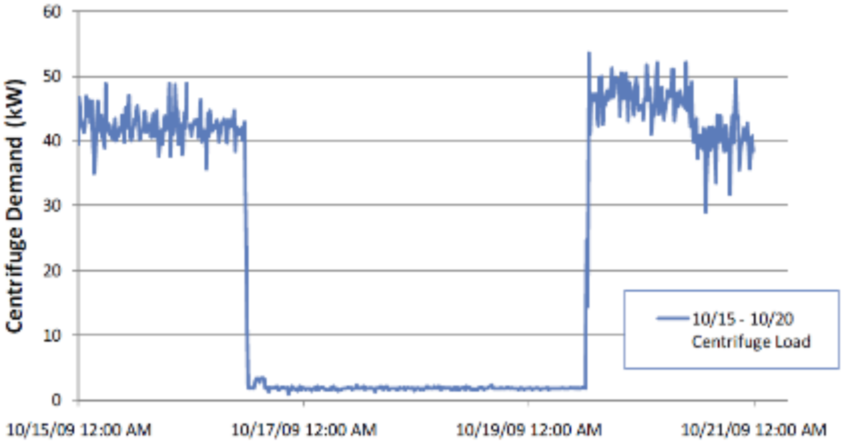

Figure 17: Centrifuge demand reduction from shutting down both centrifuges.

A limiting factor to implementing demand response is the reaction of effluent turbidity to reduced aeration loads. As discussed in Chapter 5: another constraint is that the cogeneration capabilities and power purchase agreements at the San Luis Rey facility restrict the plant's demand response potential. Because the facility's cogeneration capacity is such a large proportion of the total load, the San Luis Rey facility has limited options in terms of demand response measures, especially as the site continues to become more energy efficient. The study concluded that further research is needed to better understand: 1) how aeration blower shutdown affects effluent quality and 2) the prevalence of cogeneration in wastewater treatment facilities and its relationship to DR potential.

Donald M. Somers Water Pollution Control Plant

Overview

The goal of this case study investigating the potential for fast, automatic, continuous control of loads in order to provide Fast-DR to the grid. This case evaluated the deployment of fast and scalable demand response potential of a medium-sized municipal wastewater treatment facility located in Sunnyvale, California. In particular, one year of submetered data were collected from equipment that is typically on and can be controlled for DR including: pond aerators, pond circulation pumps, digester pumps, and fixed growth reactor fans. The mentioned equipment were capable of providing 150kW load shed during a DR event. Plant operators stated that this equipment could be shut down for 4 hours at a time without negative consequences. The collected data were then analyzed to determine factors that affected facility power demand and demand response capabilities.

Plant Description

The Donald M. Somers Water Pollution Control Plant (the Plant) is a tertiary treatment facility whose objective is to remove pollutants and produce a high quality effluent suitable either for safe discharge to San Francisco Bay or for non-potable uses. It was built in 1956 and was expanded incrementally in 1962, 1978, and 1984. It can currently treat approximately 29.5 million gallons per day. Figure 18 shows an aerial view of the plant. The baseline load for submetered equipment was determined to be roughly 275kW.

Figure 18: Aerial view of the Donald M. Somers Water Pollution Control Plant.

The site has three key attributes that make it an ideal candidate for enhanced controls and monitoring/optimization based on AutoGrid's Demand Response Optimization and Management System (DROMS):

1. The site has a 440 acre pond that is used as part of its secondary process. This pond is an asset that could add substantial flexibility in the plants ability to shed and shift electric loads. In addition, its vast surface area provides a natural source of oxygenation to the secondary effluent that is not available at many other wastewater treatment sites. The stable source of dissolved oxygen at the Sunnyvale site removes the challenge of increased turbidity that was observed in the San Luis Rey Wastewater Treatment Plant case study (Thompson, et al. 2010).
2. The site uses onsite natural gas and biogas for power generation and has excess electric generation capacity (approximately 150% of required). However, to date it has not had any information feed involving wholesale prices nor has it had equipment and personnel to optimize the use of the plant's generation and load shedding capabilities. The staff at the site is quite interested in the potential to realized improved operations.
3. The site has begun to evaluate various major capital improvement strategies. Improved data monitoring and analysis could provide information to support better decisions with regard to how capital improvements affect energy efficiency, pay-back periods, and environmental compliance. In addition, new revenue streams introduced through the use of demand response optimization could broaden the choices available to the management team.

Case Study Findings

There are several aspects of wastewater treatment processes at this plant that allow for load curtailment when DR events occur. In total, approximately 187 to 202 hp (140 to 150 kW) of DR potential was identified. The following equipment was identified as having large DR potential:

- *Pond aerators*: Although there are seven aerators, each rated at 15 hp, typically only three or four operate at any given time. All can be shed (total of 45 to 60 hp).
- *Pond circulation pumps*: There are four pond circulation pumps, each rated at 60 hp, and typically two are running at any given time. One must remain on at all times, so typically one pump can be shed.
- *Digester pumps*: There are two operational digesters (numbers 3 and 4 of four), each with a mix pump, rated at 30 hp and 40 hp respectively. Both can be shed (total of 70 hp).
- *Fixed growth reactor fans*: There are 12 fans, each rated at 1 hp. All can be shed (total of 12 hp).

Figure 19, Figure 20 and Figure 21 show the result of the DR test events carried out at the facility. During these events the above mentioned equipment were turned off for a specified period of time (3 hours, 1 hours, 30 minutes and 15 minutes). As expected, load sheds of approximately 150kW were achieved during all test events.

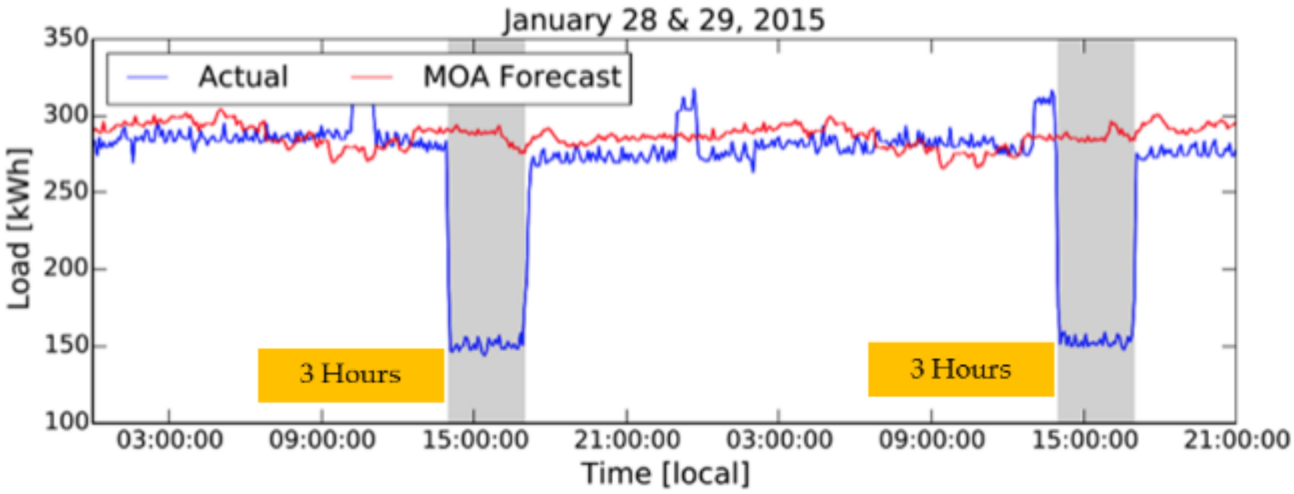

Figure 19: Three hour DR events at WPCP with day-ahead notification

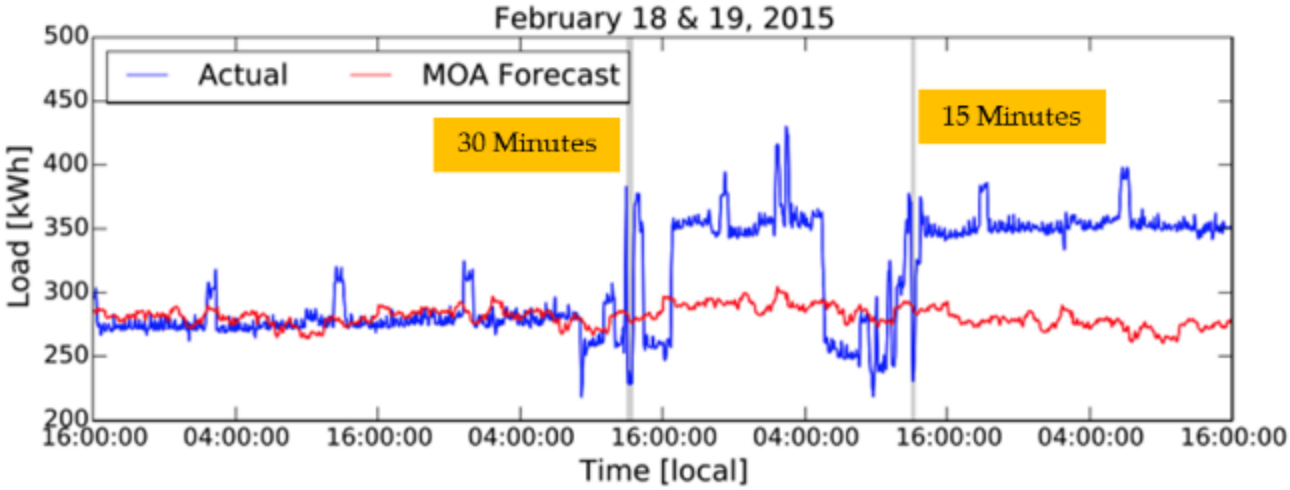

Figure 20: 30 and 15 minute DR events at WPCP with a 10 minute notification

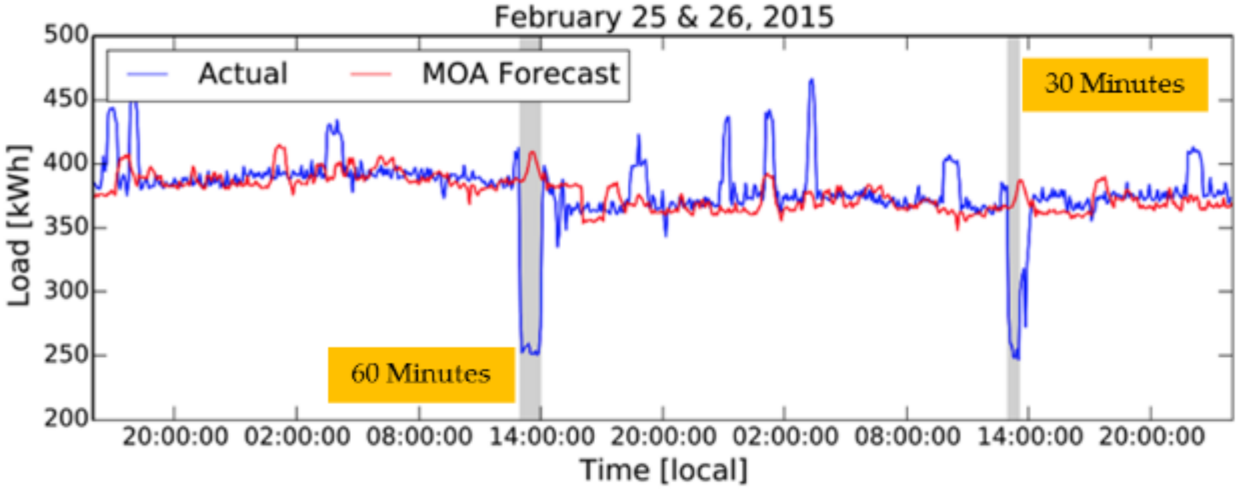

Figure 21: 60 and 30 minute DR events at WPCP with a 10 minute notification

Another strategy for higher DR participation was increasing the cogeneration output. Due to the more complex nature of this strategy, it was not considered in this case study but could be further studied in future research. The two natural-gas fired generators at the plant are usually run at 500-550 kW, even though each is capable of 600 kW. It is possible to increase the output of the two generators temporarily during DR events.

This project successfully demonstrated that we can provide DR and surpass the performance of existing devices at 10%-20% of the cost of what is proposed in SCE's rate case application **Invalid source specified.**. This demonstration project built on previous years of industrial demand response research to bring Low-cost, scalable, fast demand response to municipal wastewater and recycling facilitates.

Chapter 7:
Conclusions and Future Research

This report summarizes the findings of recent years of Auto-DR research at LBNL involving wastewater treatment facilities. These facilities are a valuable resource for demand response, because of: 1) the energy-intensive process equipment that has large electrical loads during utility peak demand periods, 2) the presence of automatic controls, and 3) the inherent wastewater storage capacity in the sewer system and at the facility level.

In particular, loads can be shed or shifted through: 1) lowering the throughput of aerator blowers, pumps, and other equipment (e.g. centrifuges); 2) temporarily transitioning to onsite power generators when it is available; 3) over-oxygenation of wastewater in anticipation of aeration blower shutdown; and 4) storing wastewater for processing during off-peak periods. The largest load reductions can be achieved by targeting effluent pumps and centrifuges.

Even though large load shed and shift potentials are available at wastewater facilities, limiting factors still exist in achieving industry wide Auto-DR adoption. One major factor is the increase in effluent turbidity due to reduced aeration at an earlier stage of the process. Another factor is that cogeneration capabilities of municipal facilities, including existing power purchase agreements and utility receptiveness to purchasing electricity from cogeneration facilities, limit a facility’s potential to participate in other DR activities.

Future Research Needs

Future research is still needed to overcome barriers to DR and Auto-DR participation. That work should include:

- Studying the effect that modulation of variable-demand aeration loads has on effluent quality.
- Conducting further studies to understand the prevalence of cogeneration in wastewater treatment facilities and its relationship to DR potential.
- Continuing to survey the literature for case studies and technology advances that might affect Auto-DR potential in wastewater treatment facilities.
- Scaling and standardizing Auto-DR for control systems to apply to wastewater treatment facilities to reduce implementation cost, and to increase DR reliability and effectiveness.
- Improving the understanding of how facility operators impact the effectiveness of DR strategies and identifying the best operation practices and behaviors to enhance the impact of DR activities.

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Glossary

Auto-DR	Automated Demand Response
CEC	California Energy Commission
DO	Dissolved Oxygen
DOE	Department of Energy
DR	Demand Response
DROMS	Demand Response Optimization and Management System
DRRC	Demand Response Research Center
EPA	Environmental Protection Agency
GW	Gigawatt (10^9 Watts)
GWh	Gigawatt Hour
HMI	Human Machine Interface
HVAC	Heating, Ventilating, and Air-Conditioning
kW	Kilowatt (10^3 Watts)
kWh	Kilowatt Hour
L	Litre
LBNL	Lawrence Berkeley National Laboratory
mg	Milligram (10^{-3} grams)
MGD	Million U.S. Gallons Per Day
MTU	Master Terminal Unit
MW	Megawatt (10^6 Watts)
OpenADR	Open Automated Demand Response
pH	Negative log of the activity of the hydrogen ion in an aqueous solution
PIER	Public Interest Energy Research
PLC	Programmable Logic Controller
PS	Primary Sludge
RAS	Return Activated Sludge

RTU	Remote Terminal Units
SCADA	Supervisory Control and Data Acquisition
TWAS	Thickened Waste Activated Sludge
UV	Ultraviolet
VFD	Variable Frequency Drive
WAS	Waste Activated Sludge