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Opportunities for Automated Demand Response in Wastewater Treatment Facilities in California - Southeast Water Pollution Control Plant Case Study

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December 2012

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ABSTRACT

This report details a study into the demand response potential of a large wastewater treatment facility in San Francisco. Previous research had identified wastewater treatment facilities as good candidates for demand response and automated demand response, and this study was conducted to investigate facility attributes that are conducive to demand response or which hinder its implementation. One years' worth of operational data were collected from the facility's control system, submetered process equipment, utility electricity demand records, and governmental weather stations. These data were analyzed to determine factors which affected facility power demand and demand response capabilities.

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 the dry season, but demand only increased by 4%. Submetering of the facility's lift pumps and centrifuges predicted load shifts capabilities of 154 kW and 86 kW, respectively, with larger lift pump shifts in the rainy season. Analysis of demand data during maintenance events confirmed the magnitude of these possible load shifts, and indicated other areas of the facility with demand response potential. Load sheds were seen to be possible by shutting down a portion of the facility's aeration trains (average shed of 132 kW). Load shifts were seen to be possible by shifting operation of centrifuges, the gravity belt thickener, lift pumps, and external pump stations. These load shifts were made possible by the storage capabilities of the facility and of the city's sewer system. Large load reductions (an average of 2,065 kW) were seen from operating the cogeneration unit, but normal practice is continuous operation, precluding its use for demand response. The study also identified potential demand response opportunities that warrant further study: modulating variable-demand aeration loads, shifting operation of sludge-processing equipment besides centrifuges, and utilizing schedulable self-generation.

Keywords: Wastewater treatment, demand response, automated demand response, submetering, municipal services

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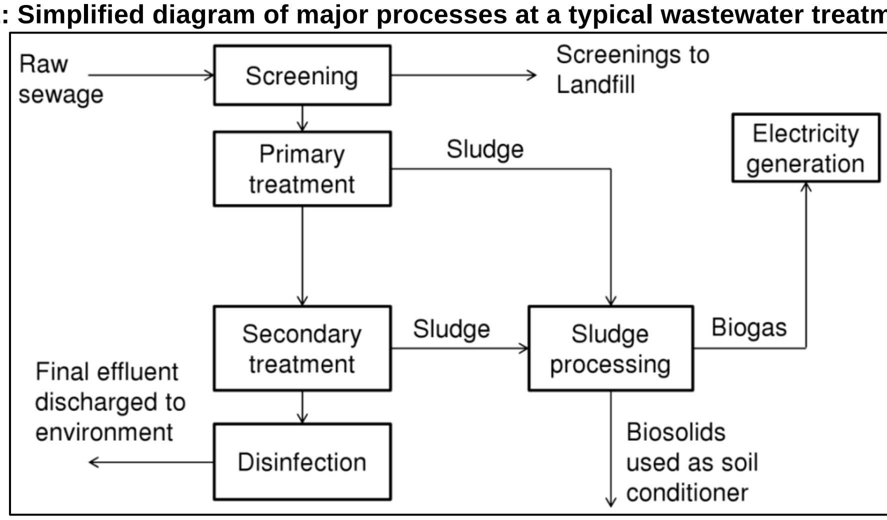
EXECUTIVE SUMMARY

Introduction

This study investigated the ability of the Southeast Water Pollution Control Plant to contribute to demand response (DR). Demand response refers to strategies that temporarily change a customer's utility power demand, triggered by adverse grid or market conditions. In previous research, wastewater treatment plants were found to be good candidates for demand response and automated demand response (Auto-DR) due to their high energy use during utility peak periods, process storage capacity, high incidence of onsite generation equipment, and control capabilities. To demonstrate this DR potential, a submetering project was undertaken at the San Luis Rey wastewater treatment plant in Oceanside, CA, which confirmed the hypothesized DR potential of centrifuges and effluent pumps, but showed that reductions in aeration load can be unacceptably detrimental to effluent quality. The Southeast Water Pollution Control Plant in San Francisco was selected as the subject for an additional submetering study to examine the differences in demand response opportunities and barriers between treatment plants. While San Luis Rey is a small wastewater treatment facility in a hot climate, Southeast is a large facility in a moderate climate treating a combined stream of wastewater and stormwater. A process flow diagram for the plant is shown in Figure 1.

Figure 1: Simplified diagram of major processes at a typical wastewater treatment plant

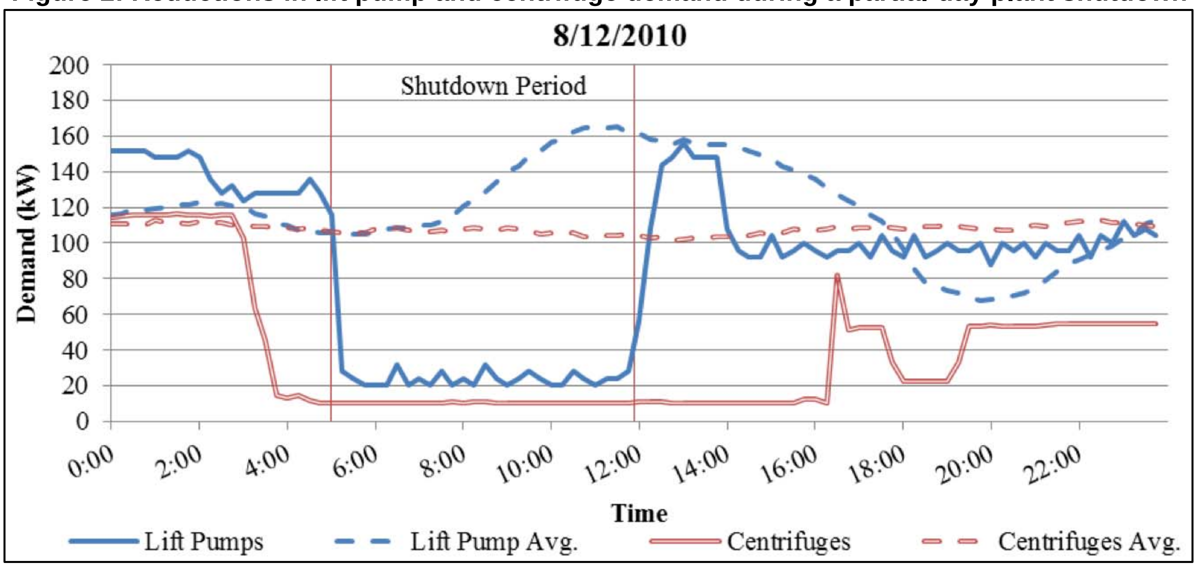


The net demand of the Southeast plant was flat with respect to time of day, averaging just less than 4 MW. A slight correlation was seen between influent flow to the plant and plant electricity demand. Unlike the San Luis Rey plant, where higher outdoor air temperatures were correlated with an increase in influent flow, the main driver of influent flow for the Southeast plant was precipitation in the serviced area. Using a full year's data, an R^2 value of 0.70 was seen between daily precipitation and daily influent. During the rainiest 6 months of the year (Oct-Mar), the plant treated 40% more influent than during the driest 6 months (Apr-Sep), and additional equipment was brought online to handle the increased flows. However, the plant demand was only 4% higher in the wetter months compared to the drier months.

Results

Analysis of the data collected via submetering 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 lift pump correlation is seen despite a significant fraction of influent that is not lifted and a heterogeneous lift pump population. Data also suggest that on average, 86 kW of load shift are available from the centrifuges, and 154 kW of load shift are available from lift pumps, for a total shift of 240 kW (approximately 6% of average plant demand). Similar shifts were observed during partial-day plant shutdowns, and a reduction in demand from centrifuges and lift pumps during one such shutdown can be seen in Figure 2. Because there is several days' worth 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 available 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 the lift pumps as a DR resource when the city's sewers are carrying a greater volume of influent.

Figure 2: Reductions in lift pump and centrifuge demand during a partial-day plant shutdown



The plant operators were reluctant to conduct demand response tests, but maintenance events revealed several opportunities for peak period demand reduction. Load sheds (on average 132 kW) appeared to be achievable by shutting down some aeration trains and mixers. Partial-day plant shutdowns reduced demand by an average of 985 kW. Large load shifts (an average of 1,069 kW, or 72% of baseline) were seen to be available from the network of pump stations throughout the city, due to the large capacity for storage of influent in the city's sewers, and smaller load shifts (on average 264 kW) were seen by rescheduling operation of centrifuges and the gravity belt thickener. Large load reductions (an average of 2,065 kW) were seen from operating the cogeneration unit, but the plant's normal operating procedures are to run the unit continuously at full power, precluding its contribution to demand response. Reducing flow from some of the influent sources generally did not have a noticeable impact on plant demand.

Conclusions

This study confirmed the demand response potential of lift pumps and centrifuges, and also suggested other areas of demand response potential. Data indicate that shutting down some aeration trains, storing influent in the city's sewers, and shutting down sludge processing equipment besides centrifuges all have the potential to temporarily reduce the plant's demand.

Loads from the lift pumps, centrifuges, and distributed pumping stations were seen to be able to ramp down within one hour. Similarly, the electrical generation form 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, often termed "Fast-DR." These Fast-DR events often occur outside the traditional demand response hours (in California, hot summer afternoons), allowing more frequent participation in demand response programs.

The demand response opportunities identified here are also likely applicable to other wastewater treatment facilities, particularly combined sewage systems. Combined sewage systems are increasingly being retrofitted to accommodate peak wet weather flows without overflows, which gives them flexibility in timing the operation of pumps and aeration systems during the dry season. Sludge dewatering equipment is ubiquitous in wastewater treatment facilities due to the high water content of sewage sludge, and both sites submetered as part of LBNL's research shifted centrifuge loads successfully, indicating that this may be a very common opportunity. Though only a fraction of wastewater plants use biogas to generate electricity, those with storage have the ability to run dispatchable, distributed generation using renewable resources as fuel.

Further research to continue to assess the potential for wastewater treatment plants to participate in DR and Auto-DR could include: studying the effect that modulation of variable-demand aeration loads has on effluent quality, studying the potential for faster-starting generation units to contribute to DR, and studying the potential for load shifts in sludge processing equipment other than centrifuges.

CHAPTER 1: Introduction

In 2001, wastewater treatment facilities in California consumed 2,012 gigawatt-hours of electricity, and the California Energy Commission forecasted that energy use in wastewater treatment is likely to become significantly higher, given California's continued growth (California Energy Commission 2005). In the next 15 years, the Environmental Protection Agency (EPA) estimates that demand from water and wastewater facilities will increase by 20 percent due to increasing populations and more stringent regulations (EPA 2008a). Further, wastewater treatment plants use a significant amount of power to run pumps and motors, whose operations can be shifted as allowed by on-site storage. This, combined with the characteristic energy-intensity of the wastewater treatment process, makes wastewater treatment facilities prime candidates for demand response (DR).

Demand response refers to strategies that temporarily change a customer's power demand. These reductions are requested by energy service providers during times of grid strain or high wholesale electricity prices, and customers are usually compensated for their efforts with incentives or favorable electricity tariffs. Automated demand response (Auto-DR) refers to pre-programmed demand reductions strategies which can be triggered without customer action.

The first phase of Lawrence Berkeley National Laboratory's wastewater research resulted in the California Energy Commission report *Opportunities for Energy Efficiency and Automated Demand Response in Wastewater Treatment in California*. This report concluded that wastewater treatment facilities are excellent candidates for open automated demand response (OpenADR), a standardized information model for Auto-DR communications. A key finding from this report is that energy efficiency and load management technologies already installed in many wastewater treatment facilities may enable successful participation in demand response events. Control technologies installed for energy efficiency and load management purposes can often be adapted for OpenADR at little additional cost. These improved controls may 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.

The second phase of this research put these findings into practice in a submetering study at the San Luis Rey Wastewater Treatment Plant in Oceanside, CA. Key findings from that study included:

- Plant influent flow followed a diurnal pattern of a morning and evening peaks, with a sharp dip at night. A small positive correlation was seen between outdoor air temperature and influent flow.
- Demand response tests identified the potential for peak period load reductions from effluent pumps and centrifuges, but tests on aeration blowers resulted in an unacceptable decline in effluent quality.
- Load reductions from centrifuges and effluent pumps were due to the large potential for onsite storage of sludge and effluent, respectively.

As a continuation of the second phase of research, another submetering study was conducted at the Southeast Water Pollution Control Plant. This second submetering study was undertaken to observe the similarities and differences between the two differently configured wastewater treatment plants with regards to their ability to participate in demand response. While San Luis Rey is a small wastewater treatment facility in a hot climate, Southeast is a large facility in a moderate climate treating a combined stream of wastewater and stormwater.

CHAPTER 2:
The Southeast Water Pollution Control Plant

Background

San Francisco is serviced by three wastewater treatment facilities: two of which operate continuously (the Oceanside and Southeast facilities) and one that operates only in wet weather (the North Point Wet-Weather Facility). The boundary between service areas for the continuous operation plants is a geographical one: wastewater which flows west (toward the ocean) is treated by the Oceanside plant, while wastewater which flows east (toward the bay) is treated by the Southeast plant. Intermediate pumping stations are present to convey sewage to the treatment facilities. The San Francisco sewer system is a combined wastewater/stormwater system, and in the past the city has had problems with influxes of stormwater causing overflows of sewage into the bay and ocean.

Combined sewer systems are remnants of early infrastructure construction, and are prone to discharging untreated sewage during heavy precipitation. These discharges are known as combined sewer overflows (CSOs). Due to the risks that CSOs pose to water quality and human health, the EPA has been working to reduce their frequency and impact, producing the *National Combined Sewer Overflow Control Strategy* in 1989 and the *Combined Sewer Overflow Control Policy* in 1994. As part of these mitigation efforts, many cities are constructing subterranean sewage storage systems to accommodate short-lived surges in sewage flows. Most combined sewer systems are in the Northeast, Great Lakes region, and Pacific Northwest, and serve approximately 40 million people (EPA 2008b).

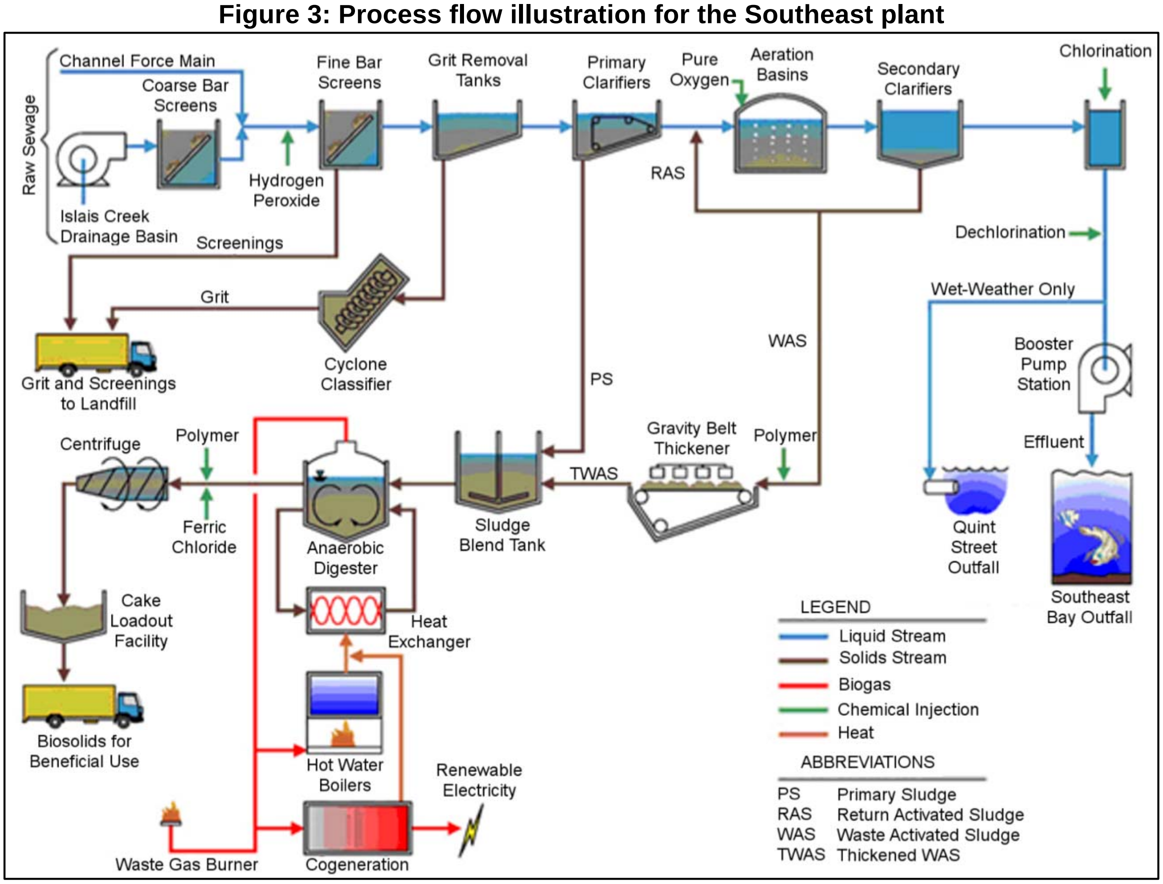
To help alleviate this problem in San Francisco, the city constructed a network of subterranean transport and storage boxes, connected by sewers, to provide storage buffering to the wastewater treatment plants. The boxes also help to passively settle grit and solids and skim away floatables. The transport and storage boxes have a capacity of 166.6 million gallons, and the network of boxes and sewers have a total capacity of 197 million gallons. When wet-weather sewer flow exceeds the combined capacity of the wastewater treatment plants, the storage network, and the pumping stations, a portion of it is still discharged to the ocean and bay, but the frequency, volume, and pollution of the discharges has been reduced compared to before the boxes were installed (San Francisco Public Utilities Commission 2010).

The Southeast Water Pollution Control Plant was originally constructed in 1951, and was upgraded in the early 1980s. Today it treats a majority of the city’s wastewater and stormwater. There are five major drainage basins that feed the plant: four of which have major pumping stations to transport water to Southeast, and one whose flows reach Southeast via gravity or minor pumping stations. The plant was designed for a dry-weather capacity of 85 million gallons per day (MGD) daily 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. Discharged effluent flows out either the southeast bay outfall, which protrudes 800 feet into the bay, or into Islais Creek. Effluent only flows to Islais Creek when the southeast outfall is already operating at capacity, and all effluent flowing to the creek goes through primary, secondary, and disinfection treatment.

Operations

Wastewater treatment at the Southeast plant has six main stages: pretreatment, primary treatment, secondary treatment, disinfection, digestion, and solids stabilization. The process flow diagram of the plant can be seen in Figure 3. Pretreatment consists of mechanically removing debris and grit with screens and grit tanks. Primary treatment directs wastewater into sedimentation tanks, where settleable solids and surface scum are removed (this mixture of solids, scum, and residual wastewater is known as sludge). In secondary treatment, sludge from the secondary clarifiers is mixed with primary effluent, and the resulting combination is sent through the plant's eight aeration trains, where pure oxygen is added and the mixture is agitated to effect microbial removal of dissolved and suspended organic material. The oxygen-generating equipment is run continuously, as startup and shutdown procedures take several days to complete.

Figure 3: Process flow illustration for the Southeast plant



Adapted from: San Francisco Public Utilities Commission 2010

After the aeration trains, wastewater is sent to secondary sedimentation tanks where settleable solids and floating scum are again removed. The resulting wastewater is then disinfected and flows out to the bay. A portion of the sludge from secondary sedimentation is returned to the aeration basins to maintain microbial and solids concentrations for process stability. The majority of secondary sludge is partially dewatered on a gravity belt thickener and then fed into anaerobic digesters, where it is held at an elevated temperature for at least 15 days while organic materials are digested (San Francisco Public Utilities Commission 2010). During digestion, methane-containing waste gas is collected to power the plant's cogeneration unit. The resulting sludge is then stabilized with polymer and ferric chloride ($FeCl_3$) and dewatered by centrifuges. The dewatered sludge is stored before being removed by trucks. In addition to the cogeneration unit, the plant also uses a solar photovoltaic array to generate electricity on-site.

Challenges

The plant has a history of odor control issues, which is problematic as the Southeast plant is near many residential and mixed-use neighborhoods. In addition, much of the plant equipment is over 50 years old and is in need of frequent maintenance, retrofitting, or replacement. As a result, plant personnel are wary of conducting any actions that could lead to operational issues or complaints from neighborhood residents.

CHAPTER 3: Project Overview

For the submetering project at the Southeast plant, key equipment believed to have DR potential were selected for submetering; selection was based on prior research and feedback from wastewater professionals. Data from these submeters, along with data on the total facility electricity demand, facility operating parameters, and weather conditions, were collected and analyzed to assess the plant's DR potential.

Key Equipment

Lift Pumps

The plant has four lift pumps which are operated with variable frequency drives (VFDs). The lift pumps raise wastewater from the sewer system to the Southeast plant. Lift pumps do not operate on influent from the Channel Island or Bruce Flynn Pump Stations. One of the lift pumps is shown in Figure 4.

Figure 4: Examples of lift pumps (left) and centrifuges (right) at the Southeast plant

Centrifuges

The plant's six centrifuges dewater digester sludge as the final step in producing Class B biosolids. Two of the centrifuges are shown in Figure 4.

Data Collection

Data were collected from utility records, from facility personnel, from nearby weather stations, and from installed submeters.

Utility Data

Utility electric meter data were reported at 15-minute intervals from January 2010 through July 2011. These data included:

- Plant demand from utility meter (kW)
- Power generation from cogeneration unit and solar PV array (kW)
- Demand for the two major pumping stations directly feeding the plant, the Channel Island and North Shore Pumping Stations, and two pumping stations which feed into the sewer system beneath the plant, the Rankin and Islais Creek Pumping Stations (kW)

Facility Data

Process data collected from the facility were reported at 15-minute intervals from May 2010 through July 2011. These data included:

- Influent flow from the two pumping stations which feed directly to the plant (million gallons/day)
- Influent flow from the lift pumps (million gallons/day)
- Total influent flow (million gallons/day)
- Flow of wastewater within the plant at six locations (million gallons/day)
- Total effluent flow (million gallons/day)
- Dissolved Oxygen readings from Aeration Pairs and in Secondary Effluent (milligrams/liter)

Weather Data

Weather data were obtained from two National Climactic Data Center (NCDC) datasets. Total daily precipitation data (inches) were obtained from the Cooperative Station (COOP) dataset, from a weather station in downtown San Francisco, approximately 2.9 miles from the Southeast plant. Temperature data (°F) were obtained from the Automated Surface Observation Stations (ASOS) dataset, from a weather station near the San Francisco International Airport, approximately 8.1 miles from the Southeast plant. Temperatures were reported at one minute intervals. A map of the Southeast plant and weather data collection locations is shown in Figure A-1 in Appendix A.

Submetering Data

Submeters were installed to measure the demand (in kW) of the four lift pumps and six centrifuges. For each piece of submetered equipment, demand data were collected and reported at 15 minute intervals from mid-July 2010 through mid-October 2011.

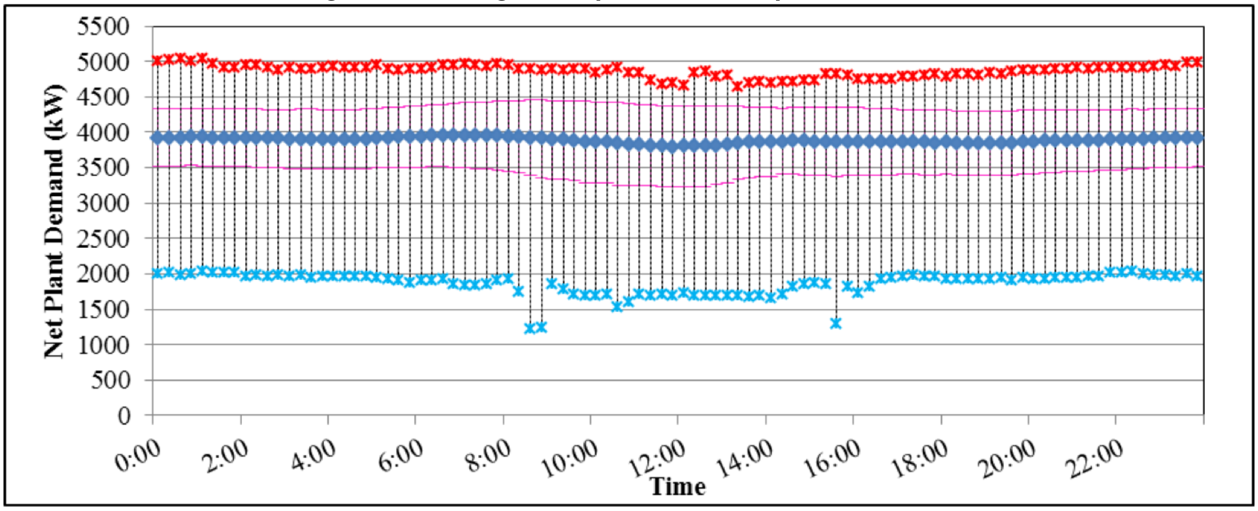
The operation of the plant's oxygen-generating equipment was not a subject of this study, due to the complexity of startup and shutdown procedures. Further research could be conducted to determine the potential of variable-demand aeration equipment to contribute to demand response.

CHAPTER 4:
Facility Baseline Analysis

Net Plant Demand

Net plant demand (demand from the Southeast plant's sole utility meter) was fairly constant, averaging just under 4 MW, with some days of reduced demand that occurred during plant shutdowns or operation of the plant's cogeneration unit. The standard deviation of the net plant demand was 10-15% of average load, with the most variation around mid-day. The plant's load profile can be seen in Figure 5. Average net plant demand was approximately 200 kW higher during the wet portion of the year (October-March averaged 3991 kW) compared to the dry portion of the year (April-September averaged 3774 kW). The net demand of the plant over the course of a year can be seen in Figure A-2.

Figure 5: Average load profile for net plant demand.



Error bars represent one standard deviation and the maximum and minimum recorded demand. Averaged from 7/1/10-6/30/11, with 6/22/11 omitted due to a grid disconnect.

Influent Flow

Plant influent flow was heavily dependent on weather, as the Southeast plant treats both wastewater and stormwater. Daily base flow was approximately 60 million gallons per day. During the dry season, daily flow was rarely more than 100 million gallons, while in the wet season daily flow was frequently more than 150 million gallons. Daily influent flow over the course of a year can be seen in Figure A-3.

Influent flows from the lift pumps and pump stations feeding the plant were modulated to produce a consistent influent profile. Average influent flow was relatively flat from midnight to approximately 7am, began to rise at 8am, peaked around 2-3pm, and returned to nighttime levels around midnight. The plant's influent load profile can be seen in Figure A-4.

On-site Generation

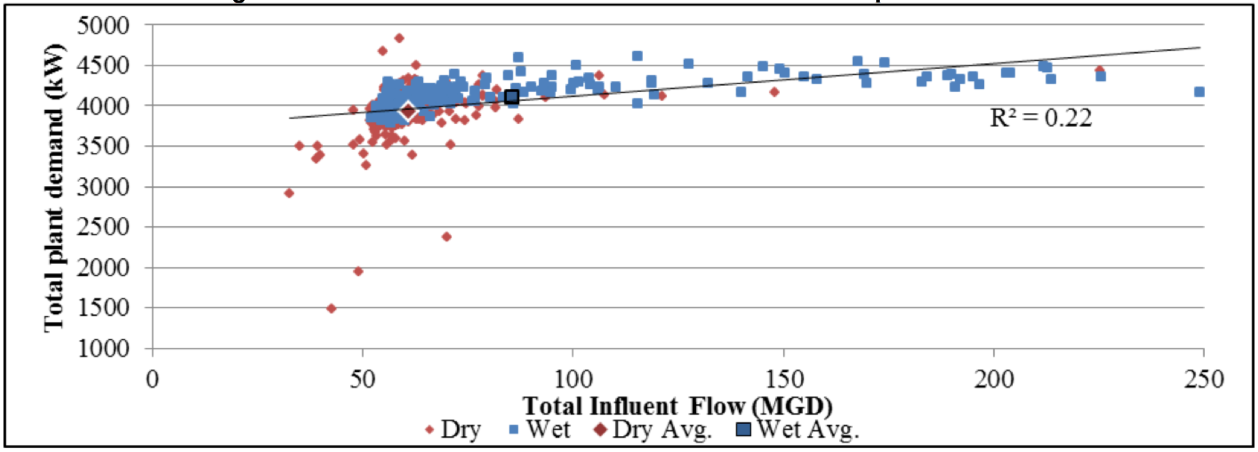
The Southeast plant has on-site generation in the form of a turbo-charged internal combustion cogeneration unit fueled by digester gas, rated at 2,000 kW, and a solar photovoltaic (PV) array, rated at 255 kW. Average total plant demand was highest during the day, but was offset by mid-day peaking generation, resulting in lower average demand during the day than at night. The PV array operated continuously, but was most effective during the dry season. Average daily generation from the PV array was more than twice as large from April-September (1,272 kWh/day) compared to October-March (578 kWh/day). The average generation profile for the wet and dry seasons can be seen in Figure A-5.

Due to problems with the cogeneration engine, the plant's cogeneration unit operated less consistently than the PV array. The cogeneration unit was entirely inactive from January 2010 (the inception of the submetering project) through the end of November 2010. Once operation resumed, the plant had several days where the cogeneration was run uninterrupted throughout the day, which led to sharp decreases in net plant demand. However, operation remained sporadic. The impact of running the cogeneration unit on the net plant demand can be seen in Figure A-6.

Correlations

Unsurprisingly, a strong correlation (R^2=0.70) was seen between rainfall and plant influent flow, due to the plant's treatment of combined wastewater/stormwater. On average, each inch of rainfall increased plant influent by 134 million gallons per day. This correlation can be seen in Figure A-7. A weak negative correlation (R^2=0.12) was seen between temperature and influent flow. This correlation can be seen in Figure A-8. Unlike the San Luis Rey plant, warm temperatures do not seem to be correlated with an increase in influent. A small correlation (R^2=0.22) was seen between daily plant influent flow and total plant demand, with an average increase of 4 kW in demand for each million gallons per day of influent flow, as seen in Figure 6. This correlation was stronger in the wet season (R^2=0.45) and weaker in the dry season (R^2=0.10).

Figure 6: Correlation between influent flow and total plant demand



During the wet season, average plant demand was only 4% higher than in the dry season, despite treating a wastewater volume 40% larger. This equates to a process intensity of 1.15 MWh/MG for the wet season, 26% lower than dry season intensity of 1.55 MWh/MG. Some of this variation can be explained by the lack of modulation capabilities on essential plant equipment, but influent flow is also more dilute during the wet season and thus requires less processing per gallon to meet discharge requirements.

Table 1: Seasonal averages of demand, influent flow, and process intensity

Season	Avg. Total Demand (kW)	Avg. Flow (MGD)	Avg. Intensity (MWh/MG)
Wet	4097	85.4	1.15
Dry	3923	60.9	1.55
Whole-year	4004	70.6	1.36

CHAPTER 5: Submetering

Submetering of the plant's lift pumps and centrifuges indicated that on average, 240 kW of load is available to be shifted if equipment operation can be postponed. This represents approximately 6% of the average total plant load. Submetering also indicated that during the submetered period, demand from the centrifuges and lift pumps during normal utility peak hours (12pm-6pm) was not substantially different than demand during the rest of the day.

Centrifuges

Six centrifuges were submetered: four had significant demand and two appeared to be nonoperational during the submetering period. Centrifuge demand was relatively flat, not following the afternoon-peaking trend of influent flow, as seen in Figure A-9. By constructing load curves for each submetered centrifuge, two distinct operating modes can be observed: a high-powered mode and a low-powered mode, as seen in Figure A-10.

By calculating the average demand in each of these modes and the proportion of time in each, an estimate can be made of the load shift potential of transitioning from high-to-low at any given time. The average shed potential is 86 kW, and can be as high as 222 kW if all centrifuges are active when a DR event begins. Total daily centrifuge load was not seen to be correlated with influent flow (R^2<0.01), as seen in Figure A-11. Thus, the load shifts available from the centrifuges should be constant throughout the year.

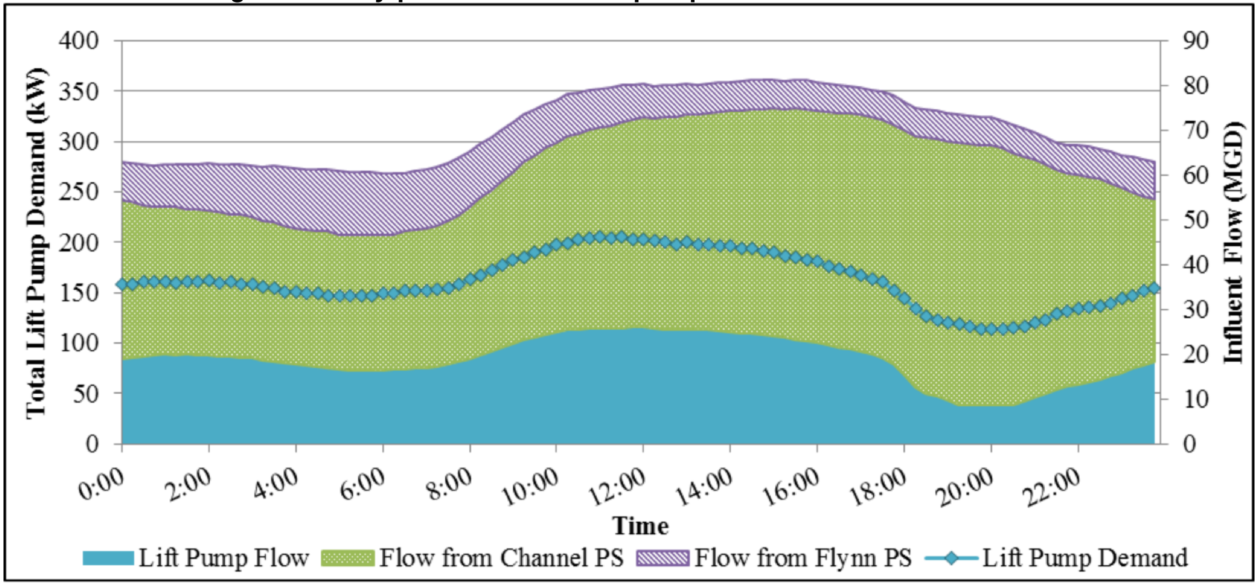
Table 2: Operating characteristics and estimated shed potential for six submetered centrifuges

Centrifuge Number	Avg. demand	Avg. low power demand	Avg. high power demand	% of time in high power mode	Avg. high-to-low shed potential
1	Not in operation during submetering				
2	Not in operation during submetering				
3	28.4 kW	5.1 kW	54.3 kW	47.3	23.3 kW
4	15.2 kW	0.2 kW	40.4 kW	37.2	15.0 kW
5	37.5 kW	4.4 kW	55.6 kW	64.7	33.2 kW
6	14.9 kW	0.8 kW	82.4 kW	17.3	14.2 kW
Total	96.0 kW	10.5 kW	232.8 kW		85.5 kW

Lift Pumps

Four lift pumps were submetered. The average total lift pump demand peaked around noon at just over 200 kW and reached its minimum around 8pm at 114 kW. The average total influent flow for the plant remained high throughout the afternoon due to the large evening peak of influent from the Channel Island Pump Station. The average daily profile for the total lift pump demand and the flows from the plant's three sources of influent can be seen in Figure 7. Average load profiles for each submetered pump can be seen in Figure A-12.

Figure 7: Daily profile for total lift pump demand and influent flows



By constructing load curves for each submetered lift pump, two distinct operating modes can be observed: a high-powered mode and a low-powered mode, as seen in Figure A-13. By calculating the average demand in each of these modes and the proportion of time in each, an estimate can be made of the load shift potential of transitioning from high-to-low at any given time. The average shift potential is 154 kW, and can be as high as 543 kW if all lift pumps are active before an event is called. The potential for load shifts from lift pumps will be greater during the rainy season, due to the higher baseline usage, but the higher throughput of the sewer system may dissuade plant operators from using this resource for demand response.

Table 3: Operating characteristics and estimated shed potential for four submetered lift pumps

Lift pump Number	Avg. demand (kW)	Avg. low power demand (kW)	Avg. high power demand (kW)	% of time in high power mode	Avg. high-to-low shed potential (kW)
1	30.1	2.1	68.4	42.2	28.0
2	22.2	9.1	215.9	6.4	13.2
3	31.0	7.5	161.5	15.3	23.5
4	92.1	3.1	118.5	77.1	89.0
Total	175.4	21.8	564.4		153.7

A strong correlation was seen between influent flow and lift pump demand (R^2=0.55), as seen in Figure A-14. An average increase of 2 kW in demand was seen for each additional million gallons per day of influent flow. This represents half of the influent-dependent increase in total plant load.

CHAPTER 6:
Analysis of Maintenance Events

The plant was reluctant to conduct demand response tests due to the perceived risk to process equilibrium and potential for unpleasant odors in the surrounding neighborhoods. Nevertheless, during the summer of 2010 some plant maintenance activities were conducted which involved equipment shutdowns and turndowns similar to those which might be conducted as demand response strategies. Maintenance and shutdown descriptions obtained from the plant operators could be classified in four categories:

- Shutdown of some of the plant's aeration trains, including mixers
- A complete plant shutdown for several hours, in which influent flow was limited to <5 MGD.
- A shutdown of centrifuges and the gravity belt thickener (GBT)
- Adjustments in the volume of influent received from various pump stations

The changes in average plant demand compared to the dry season average baseline are displayed in Figure 8 and summarized in Table 4. A full list is available in Appendix B.

Figure 8: Average plant demand on event days, compared to average dry season demand

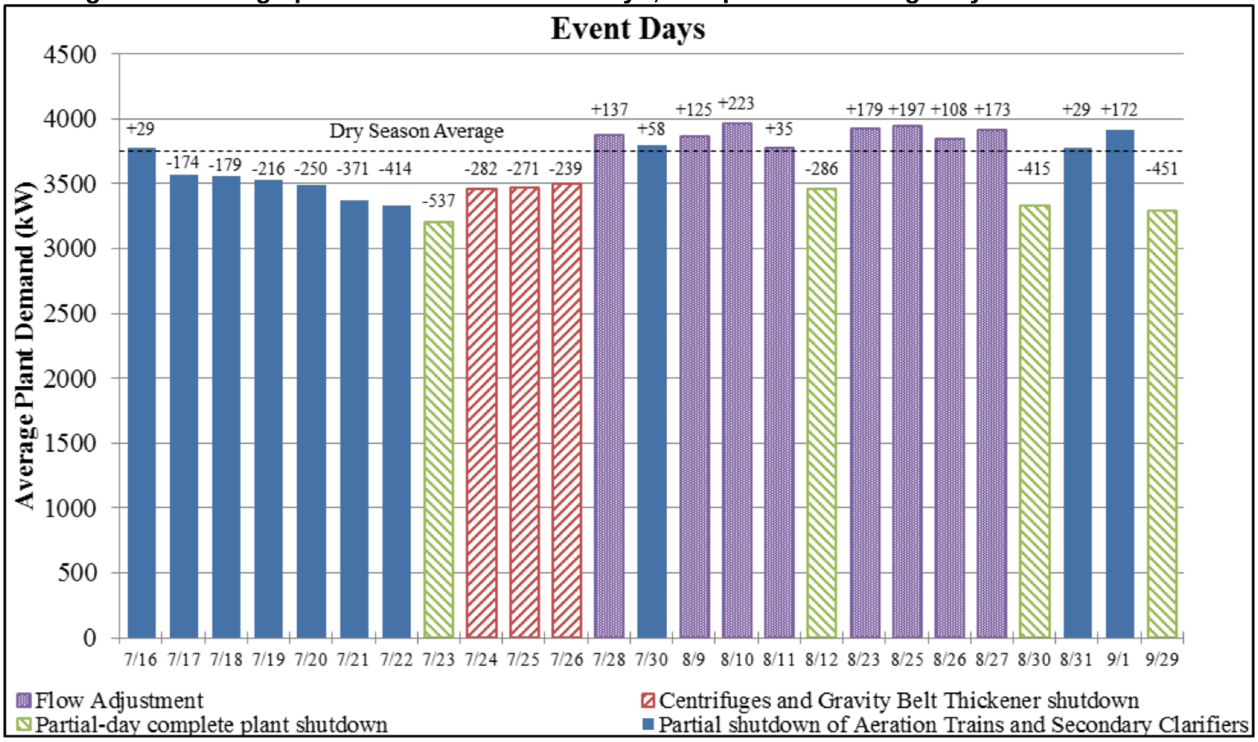


Table 4: Plant demand on event days compared to average dry season demand

Maintenance Event	Minimum Demand	Maximum Demand	Average Demand	Demand Standard Deviation
Partial shutdown of Aeration Trains and Secondary Clarifiers	-414 kW	+172 kW	-132 kW	207 kW
Partial-day complete plant shutdown	-537 kW	-286 kW	-422 kW	103 kW
Centrifuges and Gravity Belt Thickener shutdown	-282 kW	-239 kW	-264 kW	20 kW
Flow Adjustment	+35 kW	+223 kW	+147 kW	65 kW

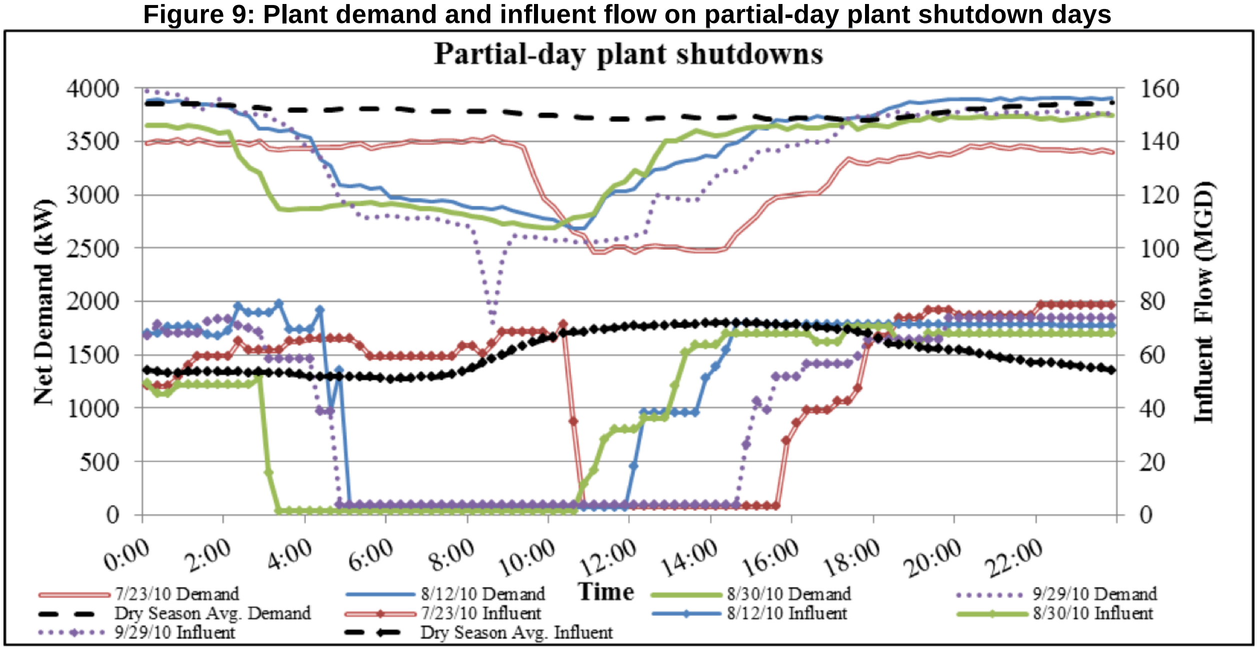
Partial-day complete plant shutdown

The most effective measure for reducing demand was a partial-day complete plant shutdown. For each event, demand was gradually reduced by an average of 985 kW (compared to the dry season baseline) and plant influent flow was reduced to less than 5 MGD. These low levels were maintained for several hours before beginning to rise back to normal operational levels, as seen in Figure 9.

Table 5: Load sheds from average net plant demand

Date	Time	Baseline Demand	Actual Demand	Average Difference	Average Reduction Percentage
7/23/10	10:45 – 15:30	3719 kW	2574 kW	1145 kW	31%
8/12/10	5:00 – 11:45	3760 kW	2902 kW	858 kW	23%
8/30/10	3:15 – 10:30	3780 kW	2828 kW	951 kW	25%
9/29/10	4:45 – 14:30	3753 kW	2733 kW	1020 kW	27%
Avg.		3756 kW	2771 kW	985 kW	26%

Figure 9: Plant demand and influent flow on partial-day plant shutdown days



Demand was also reduced at the pump stations serving the plant: in each instance, total demand from the four monitored pump stations was 900-1200 kW lower (a reduction of 69-80%) during the shutdown than average dry season demand, as seen in Figure 11. Many other pump stations which were not monitored likely saw load shifts as well. Plant shutdowns are not likely to be a regular demand response strategy, but these events show that the DR potential of storing influent exists throughout the wastewater network.

Table 6: Load shifts from monitored upstream pumping stations on partial-day plant shutdowns

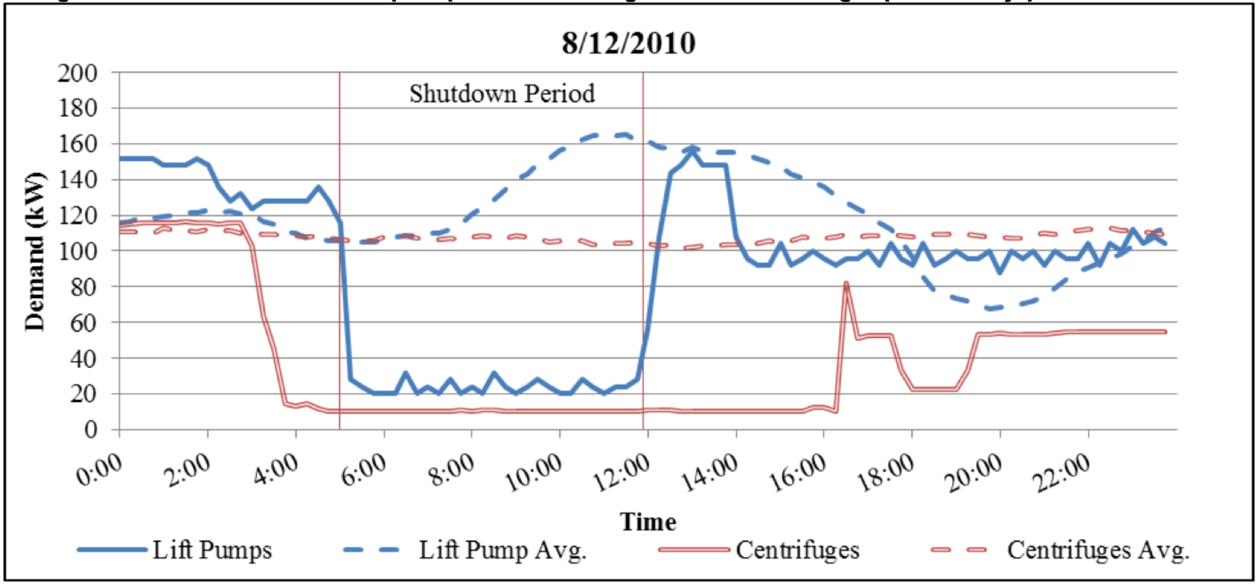
Date	Time	Baseline Demand	Actual Demand	Average Difference	Average Reduction Percentage
7/23/10	10:45 – 15:30	1615 kW	324 kW	1,291 kW	80%
8/12/10	5:00 – 11:45	1460 kW	434 kW	1,027 kW	70%
8/30/10	3:15 – 10:30	1382 kW	435 kW	947 kW	69%
9/29/10	4:45 – 14:30	1487 kW	406 kW	1,081 kW	73%
Avg.		1475 kW	406 kW	1,069 kW	72%

During the shutdowns, total lift pump demand was reduced by 98-132 kW, an average of 81% of baseline dry season demand, as summarized in Table 7. During each of the shutdowns, the total lift pump demand ramped down rapidly, fast enough to completely transition from normal operation to standby in less than an hour. Load reductions for lift pumps and centrifuges on one such day can be seen in Figure 10, and load reductions for the four shutdown days can be seen in Figure A-15.

Table 7: Load shifts from plant lift pumps on partial-day plant shutdowns

Date	Time	Baseline Demand	Actual Demand	Average Difference	Average Reduction Percentage
7/23/10	10:45 – 15:30	156 kW	24 kW	132 kW	84%
8/12/10	5:00 – 11:45	132 kW	27 kW	105 kW	80%
8/30/10	3:15 – 10:30	121 kW	23 kW	98 kW	81%
9/29/10	4:45 – 14:30	138 kW	29 kW	109 kW	79%
Avg.		135 kW	26 kW	109 kW	81%

Figure 10: Reductions in lift pump and centrifuge demand during a partial-day plant shutdown

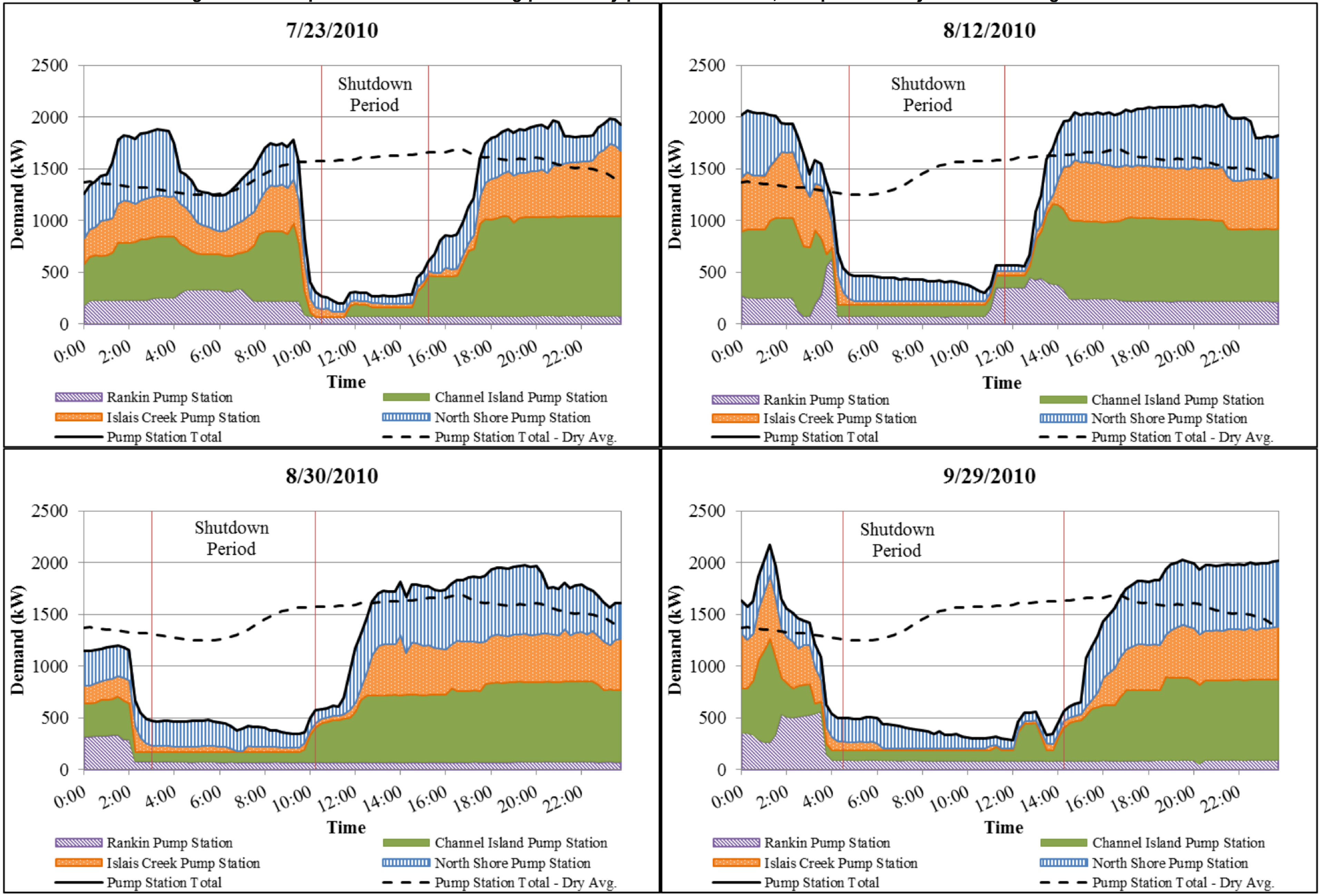


During the shutdowns, total centrifuge demand was reduced by 93-97 kW, an average of 90% of baseline dry season demand, as summarized in Table 8. As seen with the lift pumps, during each of the shutdowns where the centrifuges were active before the event, the total demand ramped down rapidly, fast enough to completely transition from normal operation to standby in less than an hour.

Table 8: Load shifts from centrifuges on partial-day plant shutdowns

Date	Time	Baseline Demand	Actual Demand	Average Difference	Average Reduction Percentage
7/23/10	10:45 – 15:30	104 kW	10 kW	93 kW	90%
8/12/10	5:00 – 11:45	106 kW	10 kW	96 kW	90%
8/30/10	3:15 – 10:30	107 kW	11 kW	97 kW	90%
9/29/10	4:45 – 14:30	106 kW	11 kW	95 kW	90%
Avg.		106 kW	11 kW	95 kW	90%

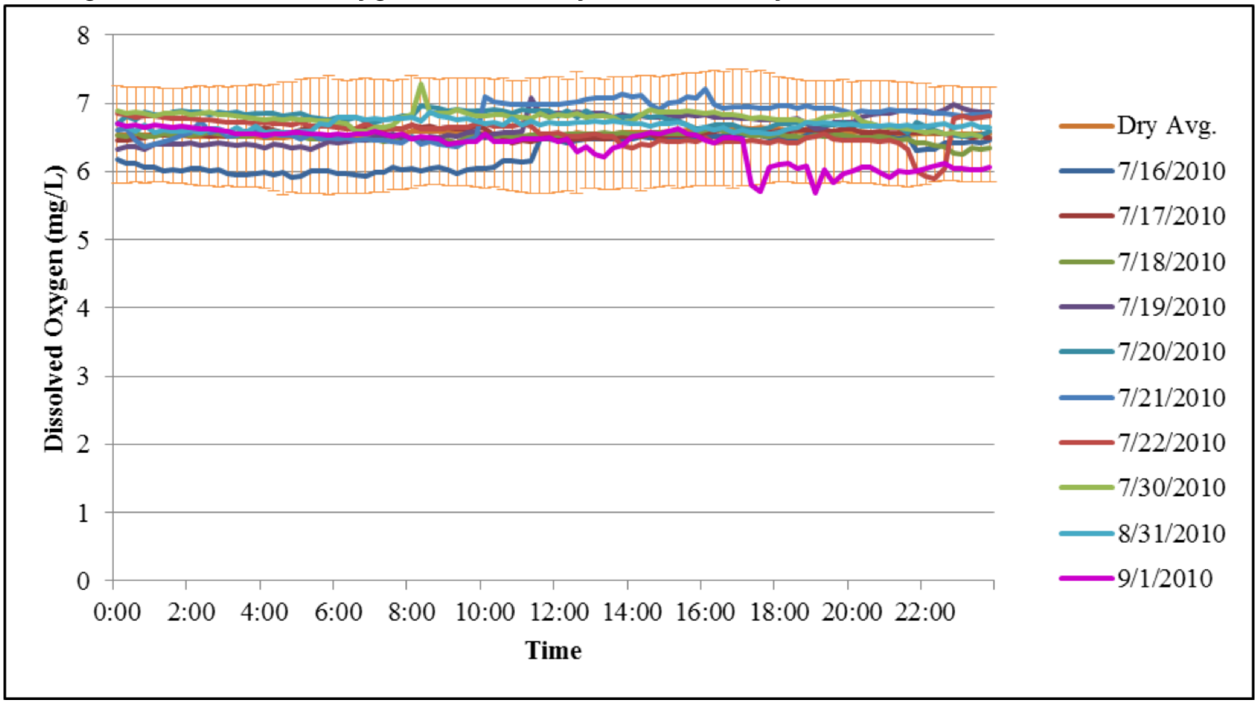
Figure 11: Pump station demand during partial-day plant shutdowns, compared to dry season average demand



Shutdown of aeration trains

The average demand reduction during periods when some of the plant's aeration trains were shut down was 132 kW. The levels of dissolved oxygen in secondary effluent were not seen to be compromised by the aerations train shutdowns. At San Luis Rey, aeration load reductions resulted in a drop of dissolved oxygen, leading to increased turbidity in effluent. Turbidity data were not available at Southeast, but dissolved oxygen in secondary effluent did not deviate from normal levels, as seen in Figure 12. Dissolved oxygen readings were available from within the plant's aeration basins, but were not assumed to be good indicators of process health as there were many several-day long periods in which negligible levels of dissolved oxygen were read by all meters. When asked about these readings, the plant operators suggested that malfunctioning probes may have been at fault.

Figure 12: Dissolved oxygen in secondary effluent on days with aeration train shutdowns.

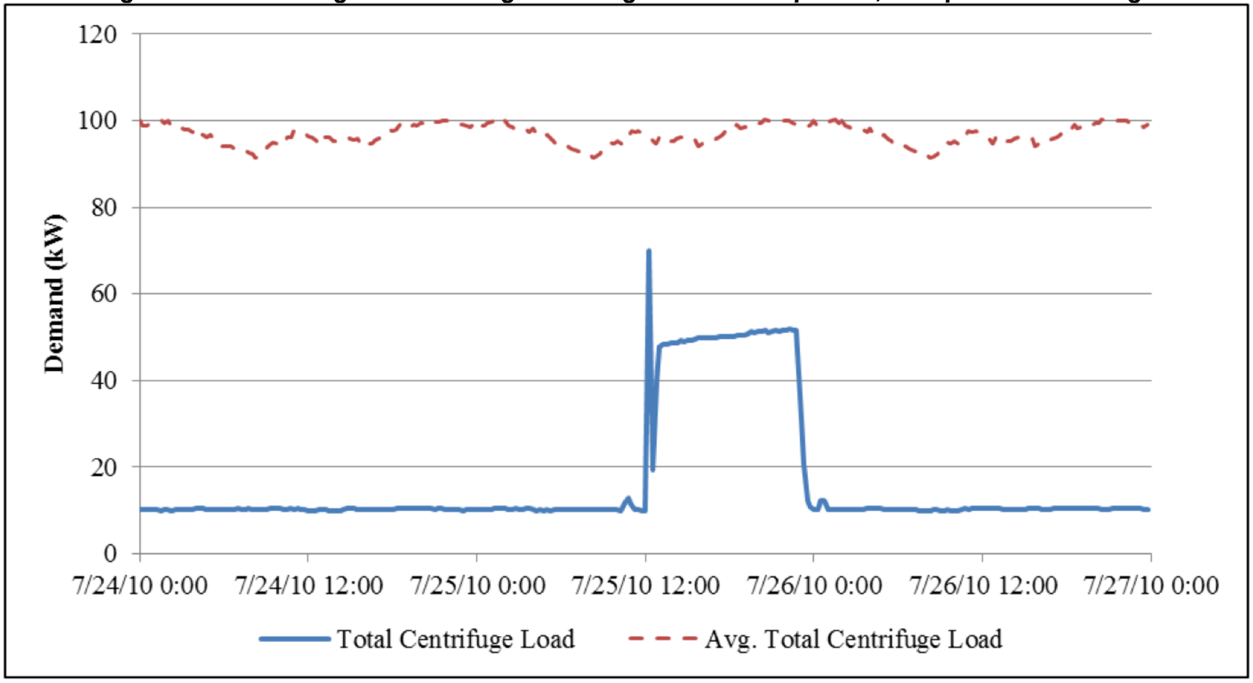


Error bars around the average represent one standard deviation.

Shutdown of centrifuges and gravity belt thickener

Shutting down the plant's centrifuges and gravity belt thickener led to plant consumption 239-282 kW lower than dry season average demand. Centrifuge demand was on average 80 kW lower than baseline, which is consistent with the load shift potential identified via submetering (estimated at 86 kW). Demand from the centrifuges was constant around 10 kW, the low power load identified by submetering, except for a stretch of 11-12 hours on 7/25 when centrifuge #3 was operational, as seen in Figure 13. However, the gravity belt thickener was not submetered, so its load reductions could not be quantified in the study.

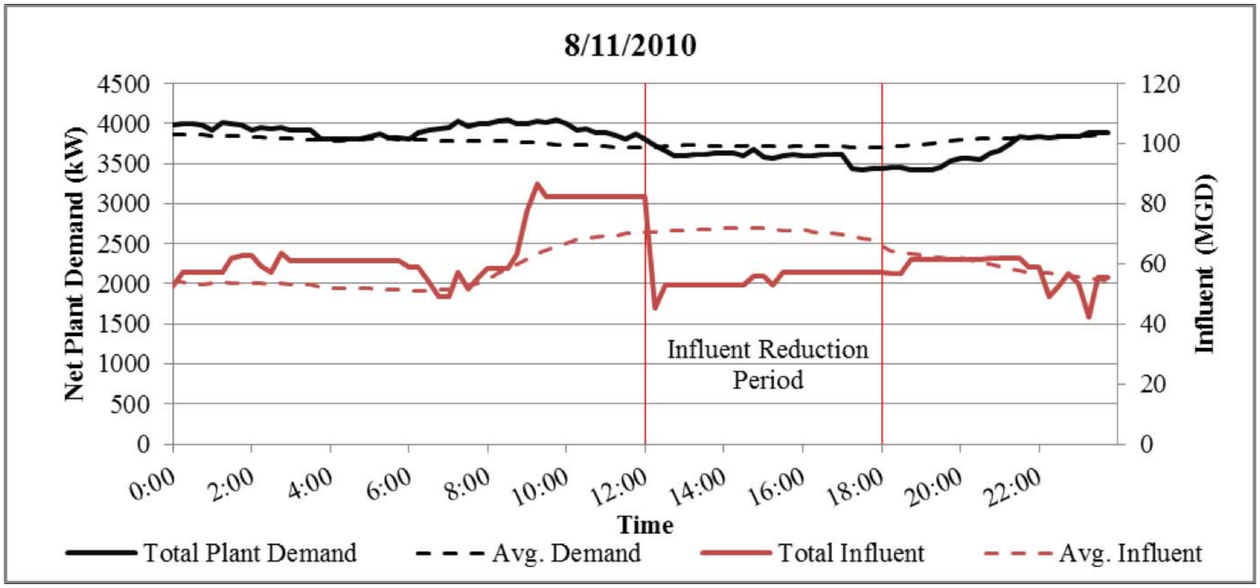
Figure 13: Centrifuge load during centrifuge shutdown period, compared to average



Flow adjustments

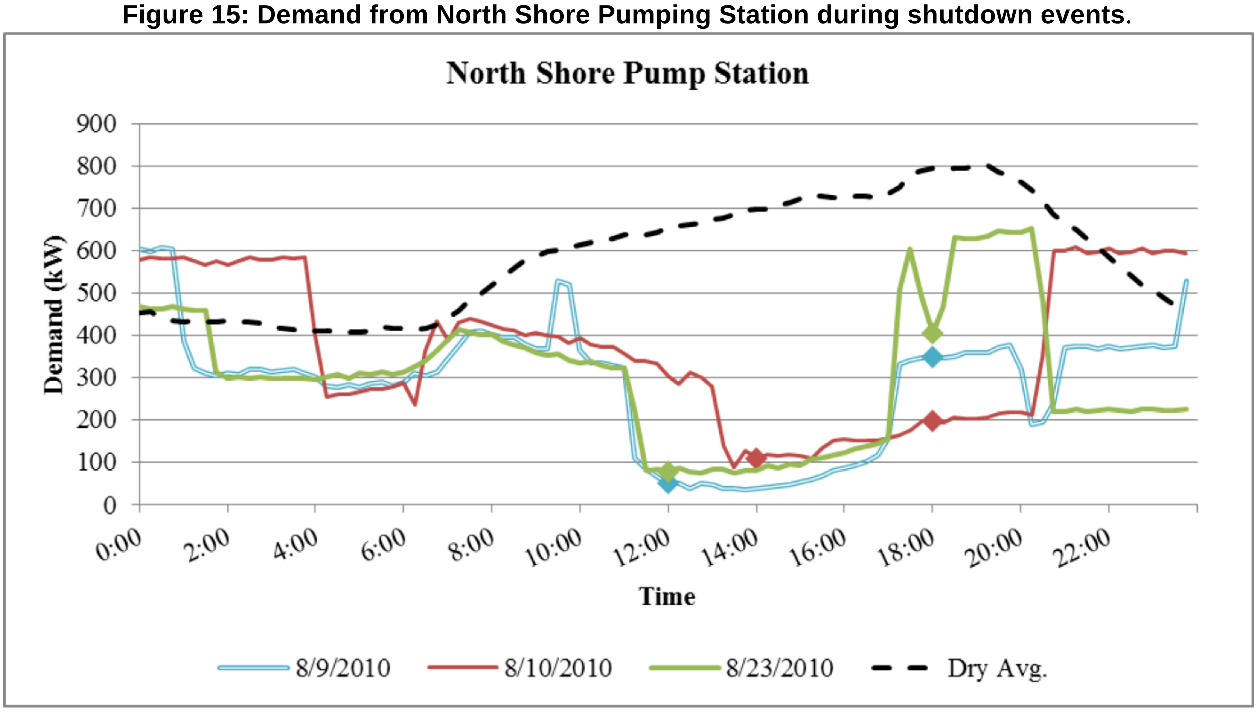
For each of the days where plant influent flow was adjusted, plant demand was higher than the dry season average baseline, by an average of 4%, as seen in Figure A-16. However, on 8/11/10 the influent flow was reduced by about 20 MGD for six hours. Correspondingly, plant demand was reduced by 114 kW, as seen in Figure 14.

Figure 14: Reduction in plant demand coinciding with a reduction in influent flow



On the three days where flow from the North Shore Pumping Station was curtailed, demand from the pumping station was notably lower. On each day, demand was reduced by over 50% during the test period when compared to the dry season average, as seen in Figure 15.

Figure 15: Demand from North Shore Pumping Station during shutdown events.



Shutdown events begin and end at marked points.

The average whole-day demand for each day was also lower than or roughly equal to baseline demand, as seen in Table 9. This suggests that the shutdown events were not detrimental to overall efficiency.

Table 9: Load shift details for North Shore Pumping Station shutdowns

		Test Period			Whole Day		
Day	**Time**	**Demand**	**Baseline**	**Shift (% of baseline)**	**Demand**	**Baseline**	**Shift (% of baseline)**
8/9/2010	12:00-18:00	98 kW	324 kW	226 kW (70%)	285 kW	363 kW	77 kW (21%)
8/10/2010	14:00-18:00	142 kW	333 kW	191 kW (57%)	364 kW	363 kW	-2 kW (0%)
8/23/2010	12:00-18:00	155 kW	324 kW	169 kW (52%)	306 kW	363 kW	56 kW (16%)

Cogeneration Plant Active

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, as seen in Figure 16. This represents a net demand reduction of 45-50% from total demand. The cogeneration unit was seen to reach its rated generation capacity in 45-75 minutes, as seen in Figure 17. If the cogeneration unit could be dispatched at will, it would have the potential to contribute over 2 MW of load shed with less than 90 minutes' notice. However, facility personnel reported that the normal operating strategy for the cogeneration unit was continuous operation, as the facility produced more biogas per day than the cogeneration unit could consume. Therefore, the cogeneration unit would not be available as a demand response resource.

Figure 16: Demand from utility meter, solar generation, and cogeneration during days where cogeneration unit is running throughout the day

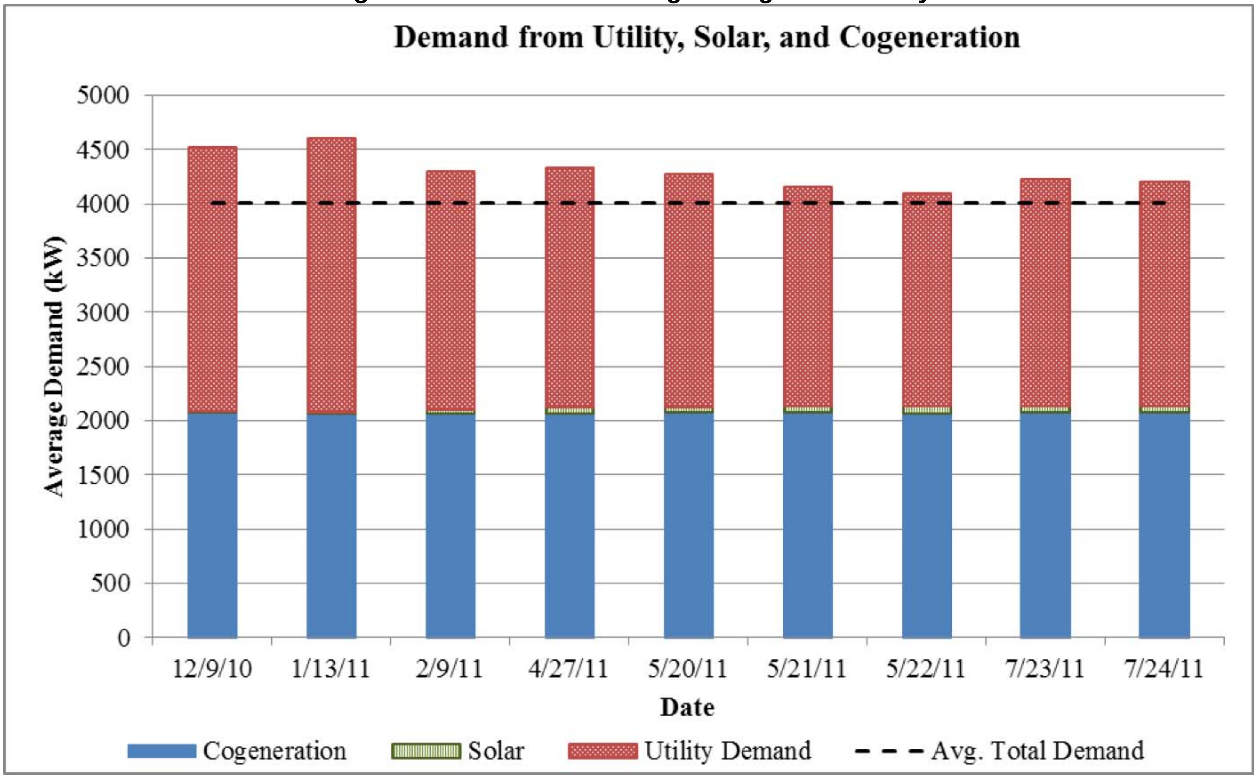
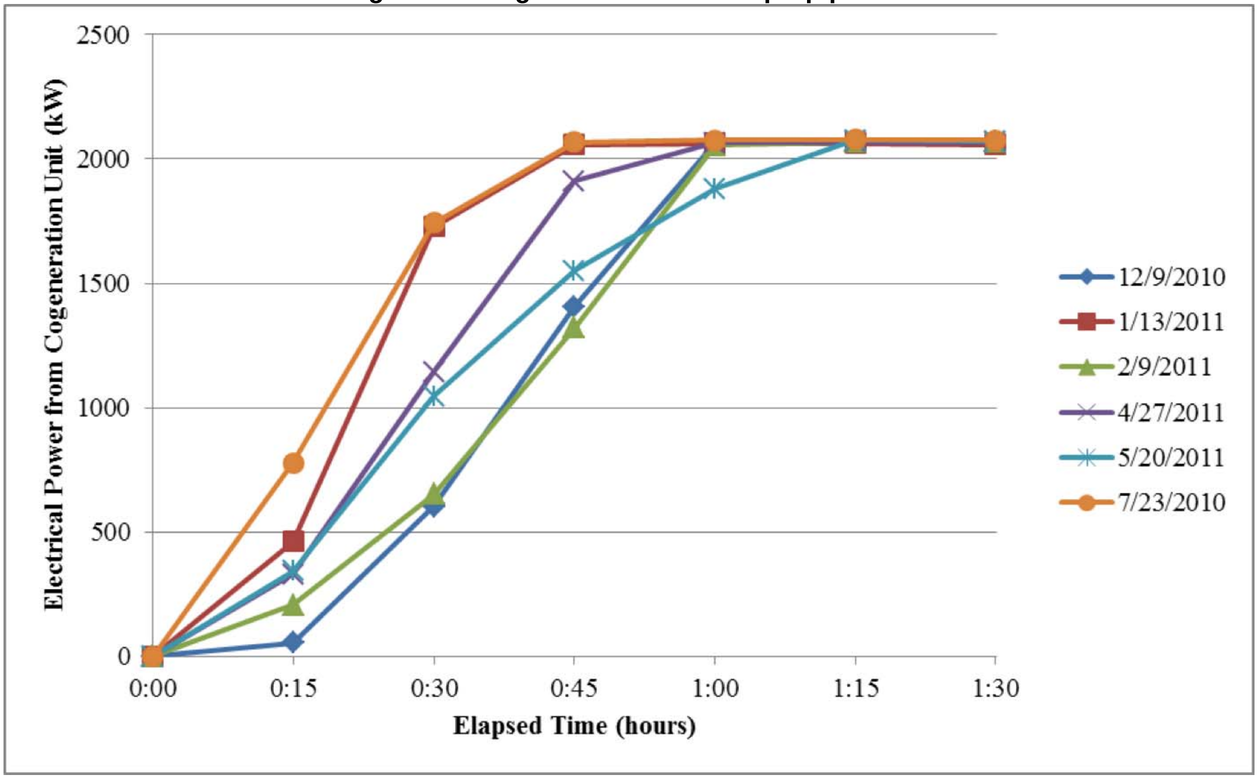


Figure 17: Cogeneration unit ramp-up profile



CHAPTER 7: Conclusions

The Southeast plant was seen to have peak throughput and electricity demand in the rainy fall and winter months, from October through March. A small correlation was seen between total plant demand and influent flow, while influent flow was strongly correlated to precipitation in the area. Roughly half of the increase in plant demand that was seen with increased influent was due to increased demand of lift pumps. Through analysis of submetering data and operational parameters during maintenance events, involving equipment shutdowns and turndowns similar to demand response events, this study identified several potential demand response opportunities at the plant. Potential demand response opportunities were seen from modifying the operation of lift pumps, centrifuges, pumping stations, aeration trains, and cogeneration.

Analysis of the operation of submetered equipment suggests that shutting down plant lift pumps has the potential to shift an average of 154 kW of load, and shutting down centrifuges has the potential to shift an average of 86 kW. These load shifts are made possible by the plant's storage capacity for influent and sludge, respectively. During plant shutdowns, demand from lift pumps was reduced by an average of 109 kW (81% of baseline) and demand from centrifuges was reduced by an average of 95 kW (90% of baseline), affirming the load shift estimations. The lower shed from the lift pumps was due to a lower baseline power demand in dry weather. The lift pumps will have a greater potential for load shifts during the rainy season, due to a higher baseline usage, but plant operators may be wary to use them as a DR resource when the city sewers are carrying a large volume of wastewater and nearing their capacity.

Complete plant shutdowns reduced total plant demand by an average of 985 kW (26% of baseline) for 5-10 hours. As part of these shutdowns, monitored pumping stations were also shut down and seen to shift an average of 1,069 kW (representing 72% of baseline demand). Large load shifts were also likely at other non-monitored pumping stations. These load shifts are made possible by the influent storage capacity in the San Francisco sewer system, which in dry weather can accommodate multiple days of influent.

Other operational deviations were also conducted which yield some insight into additional demand response opportunities. Shutting down centrifuges and the gravity belt thickener led to an average demand reduction of 264 kW. Shutting down a portion of the aeration trains was seen to shed an average of 132 kW, without reducing the dissolved oxygen in secondary effluent. This load shift is made possible by the plant's large aeration capacity relative to dry season throughput. These shutdowns are not likely to be implemented during the wet season when heavy rains are possible. Reducing influent flow yielded a small demand reduction of 114 kW in one event. Though operating the cogeneration unit was the most effective measure to reduce plant demand (by an average of 2,065 kW), the normal operating strategy is to use it at its full capacity; thus, there is no potential for it to contribute to demand response.

The demand response opportunities identified here are also likely applicable to other wastewater treatment facilities, particularly combined sewage systems. Combined sewage systems are increasingly being retrofitted to accommodate peak wet weather flows without overflows, which gives them flexibility in timing the operation of pumps and aeration systems during the dry season. Sludge dewatering equipment is ubiquitous in wastewater treatment facilities due to the high water content of sewage sludge, and both sites submetered as part of LBNL's research shifted centrifuge loads successfully, indicating that this may be a very common opportunity. Though only a fraction of wastewater plants use biogas to generate electricity, those with storage have the ability to run dispatchable, distributed generation using renewable resources as fuel.

This study confirmed the demand response potential of lift pumps, centrifuges, and on-site generation, and suggested additional areas of demand response potential. Further research to continue to assess the potential for wastewater treatment plants to participate in DR and Auto-DR could include: studying the effect that modulation of variable-demand aeration loads has on effluent quality, studying the potential for faster-starting generation units to contribute to DR, and studying the potential for load shifts in sludge processing equipment other than centrifuges.

References

California Energy Commission (2005). California's Water-Energy Relationship.

Environmental Protection Agency (2008a). Ensuring a Sustainable Future: An Energy Management Guidebook. Office of Wastewater Management.

Environmental Protection Agency (2008b). Combined Sewer Overflows Demographics. <http://cfpub.epa.gov/npdes/cso/demo.cfm>. National Pollutant Discharge Elimination System.

Lekov, Alex, Lisa Thompson, Aimee McKane, Kai Song, Mary Ann Piette (2009). Opportunities for Energy Efficiency and Open Automated Demand Response in Wastewater Treatment Facilities in California – Phase I Report. LBNL-2572E.

Natural Resources Defense Council (2004). Energy Down the Drain: The Hidden Costs of California's Water Supply, Pacific Institute.

San Francisco Public Utilities Commission (2010). San Francisco Sewer System Master Plan: Chapter 3: Wastewater Facilities Operations and Performance. June 15, 2010 Draft.

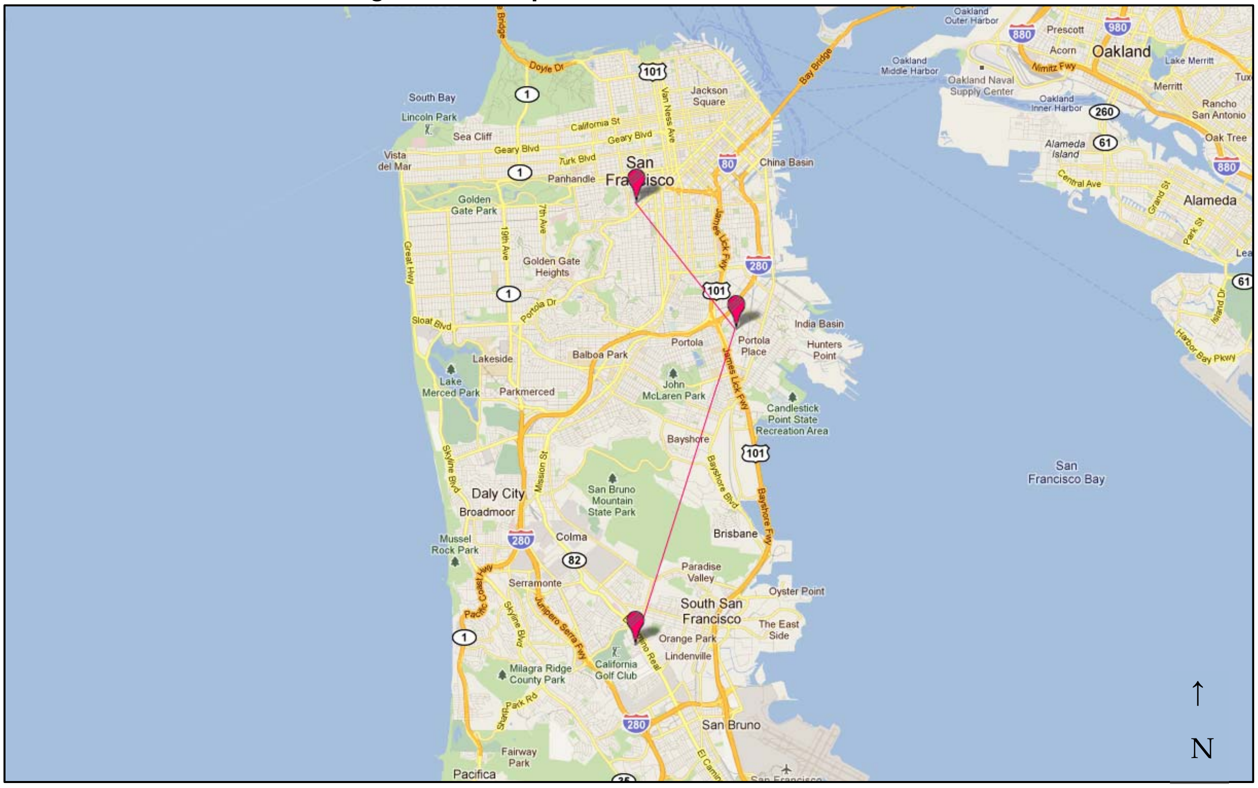
Thompson, Lisa, Alex Lekov, Aimee McKane, and Mary Ann Piette. (2010). Opportunities for Open Automated Demand Response in Wastewater Treatment Facilities in California – Phase II Report: San Luis Rey Wastewater Treatment Plant Case Study. LBNL-3889E.

Glossary

ASOS	Automated Surface Observation System (NCDC dataset)
Auto-DR	Automated Demand Response
CEC	California Energy Commission
COOP	Cooperative (NCDC dataset)
DR	Demand Response
GBT	Gravity Belt Thickener
kW	Kilowatt
MG	Million Gallons
MGD	Million Gallons Per Day
MW	Megawatt
MWh	Megawatt Hour
NCDC	National Climactic Data Center
OpenADR	Open Automated Demand Response
PS	Pumping Station
PV	Photovoltaic
VFD	Variable Frequency Drive

Appendix A: Additional Figures

Figure A-1: Map of data collection locations.



Northernmost is the weather station recording precipitation (COOP), southernmost is the weather station recording temperature (ASOS), and central is the Southeast plant. Image credit Google Maps 2012.

Figure A-2: Net plant demand, 7/1/10-6/30/11

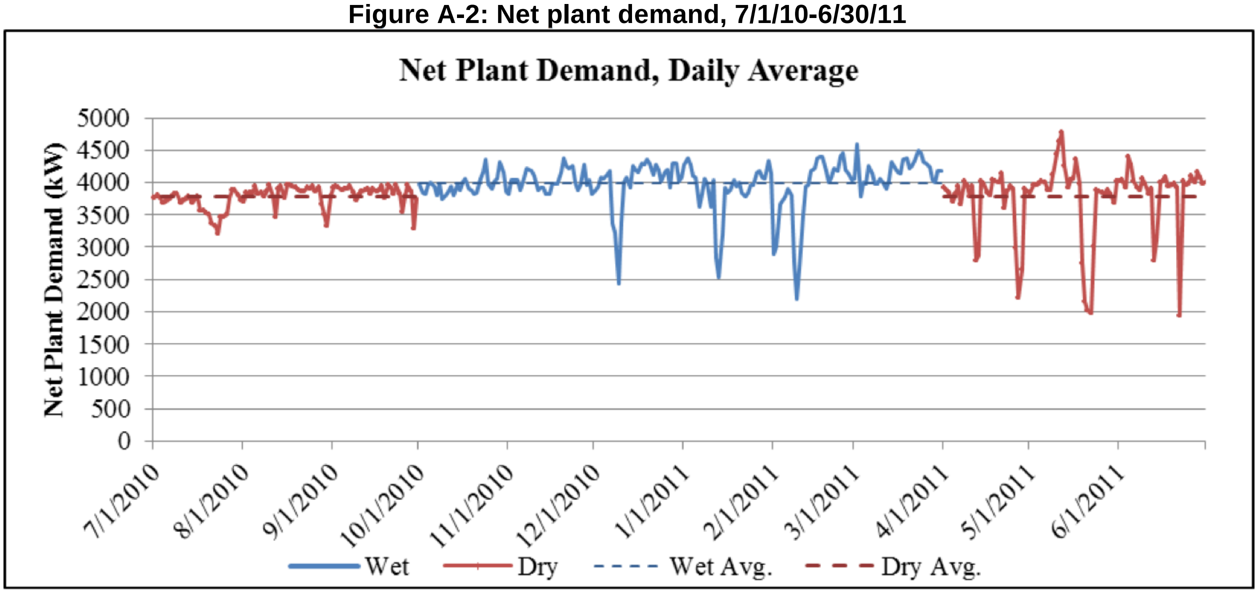
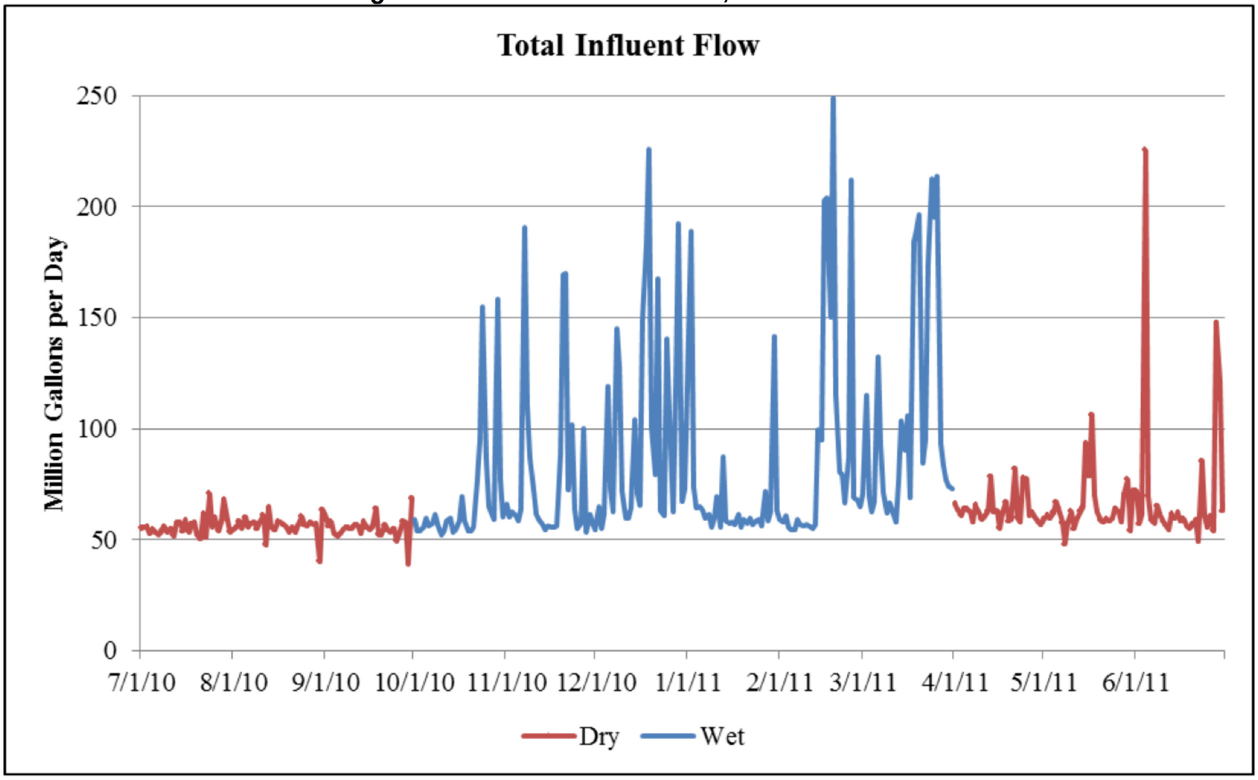


Figure A-3. Plant influent flow, 7/1/10-6/30/11



The precipitation on 6/4/11 was abnormal, and broke several decades-old records for June rainfall.

Figure A-4: Daily profile for net plant demand and influent flow in wet and dry seasons

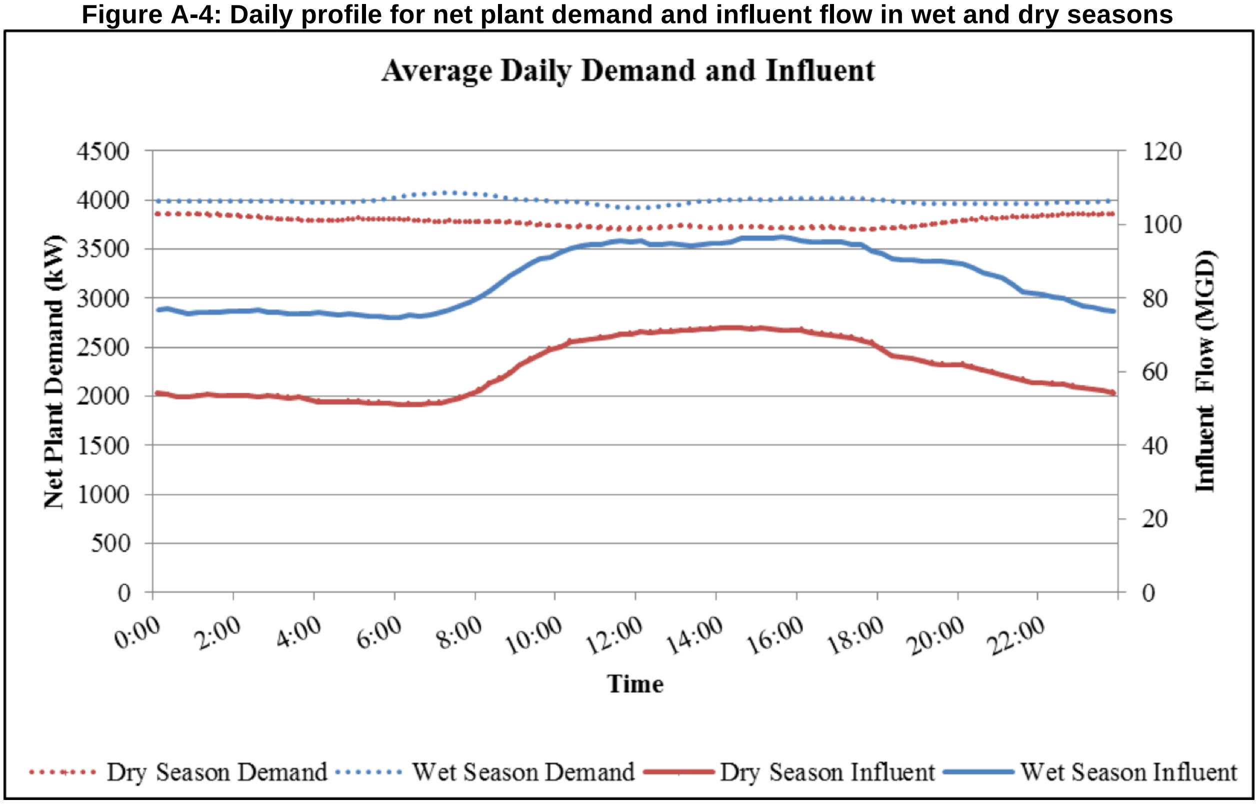


Figure A-5: Average solar generation profile in wet and dry season

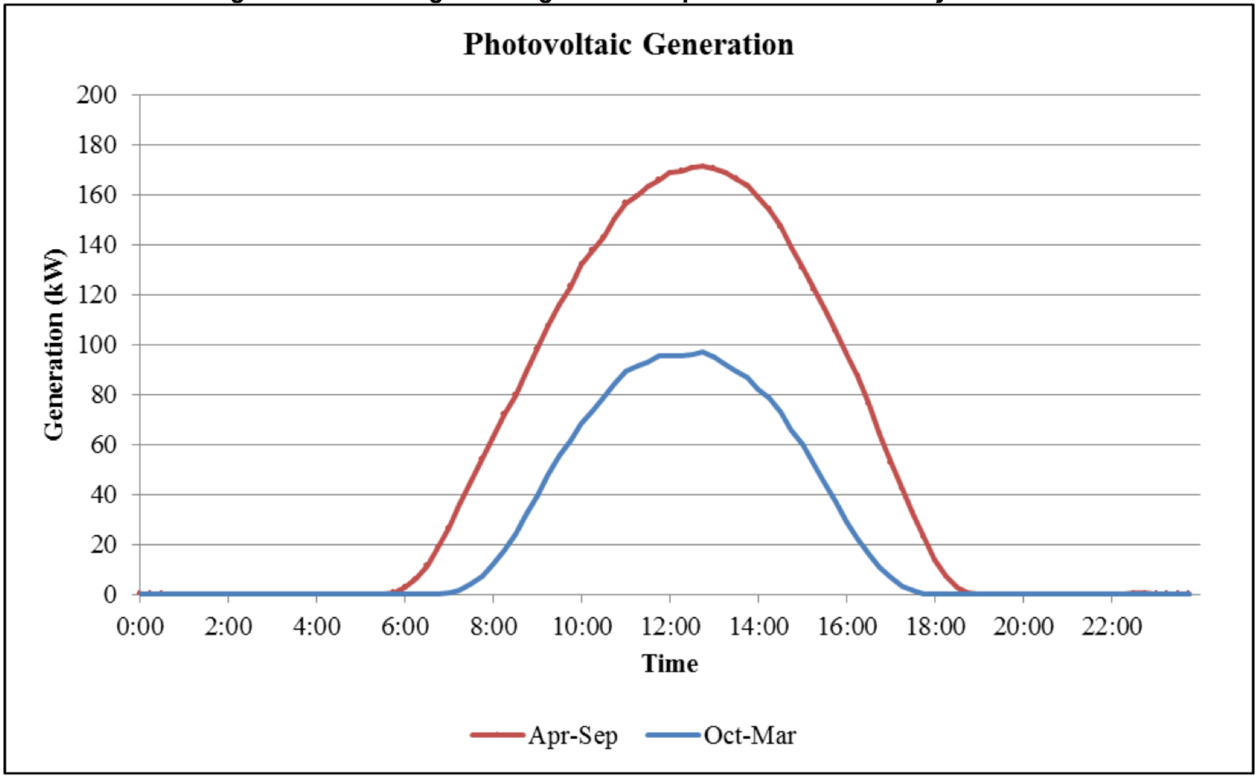


Figure A-6: Daily average of cogeneration and net plant load

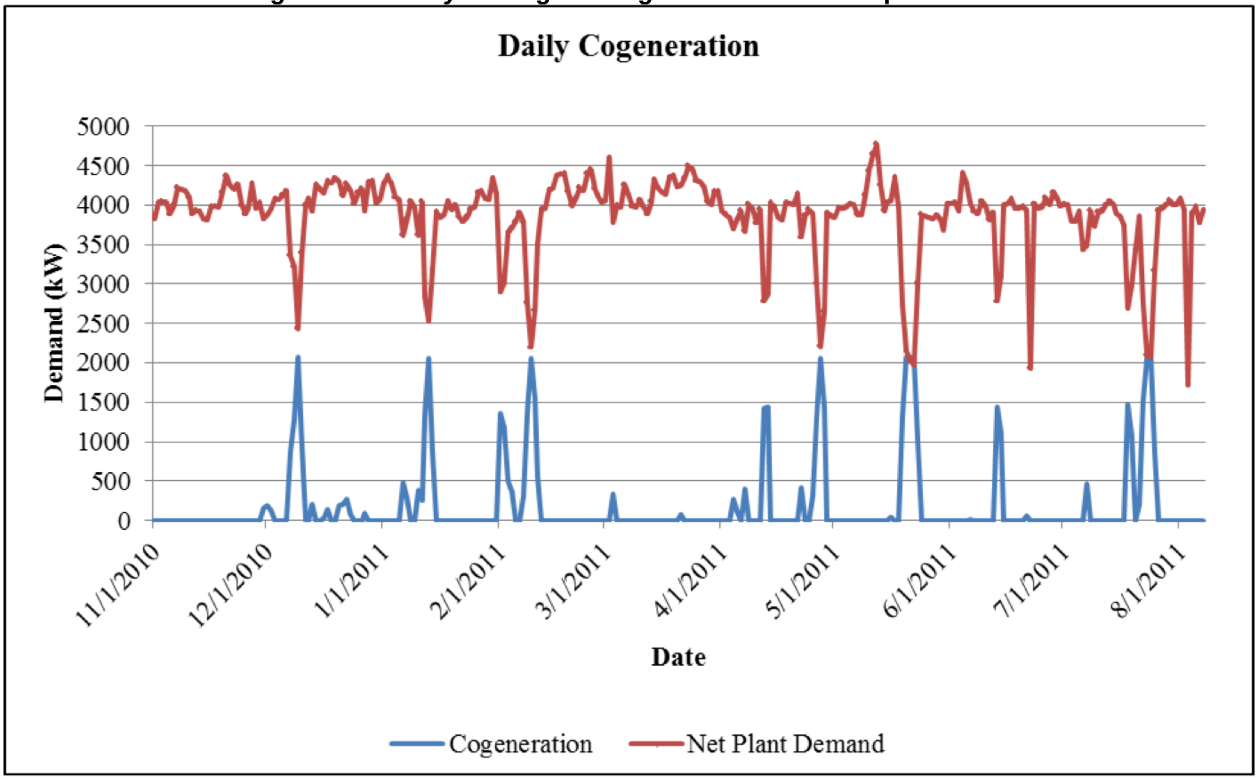


Figure A-7: Correlation between precipitation and influent flow

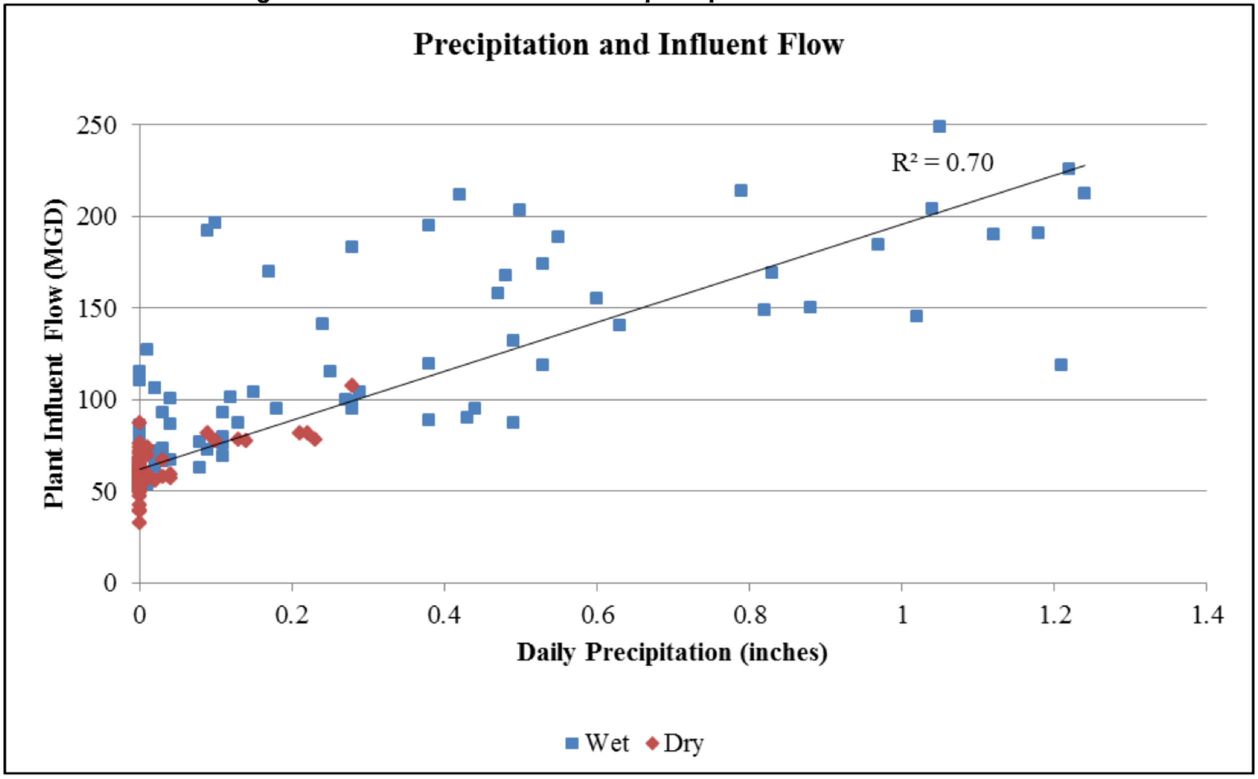


Figure A-8: Correlation between temperature and influent flow

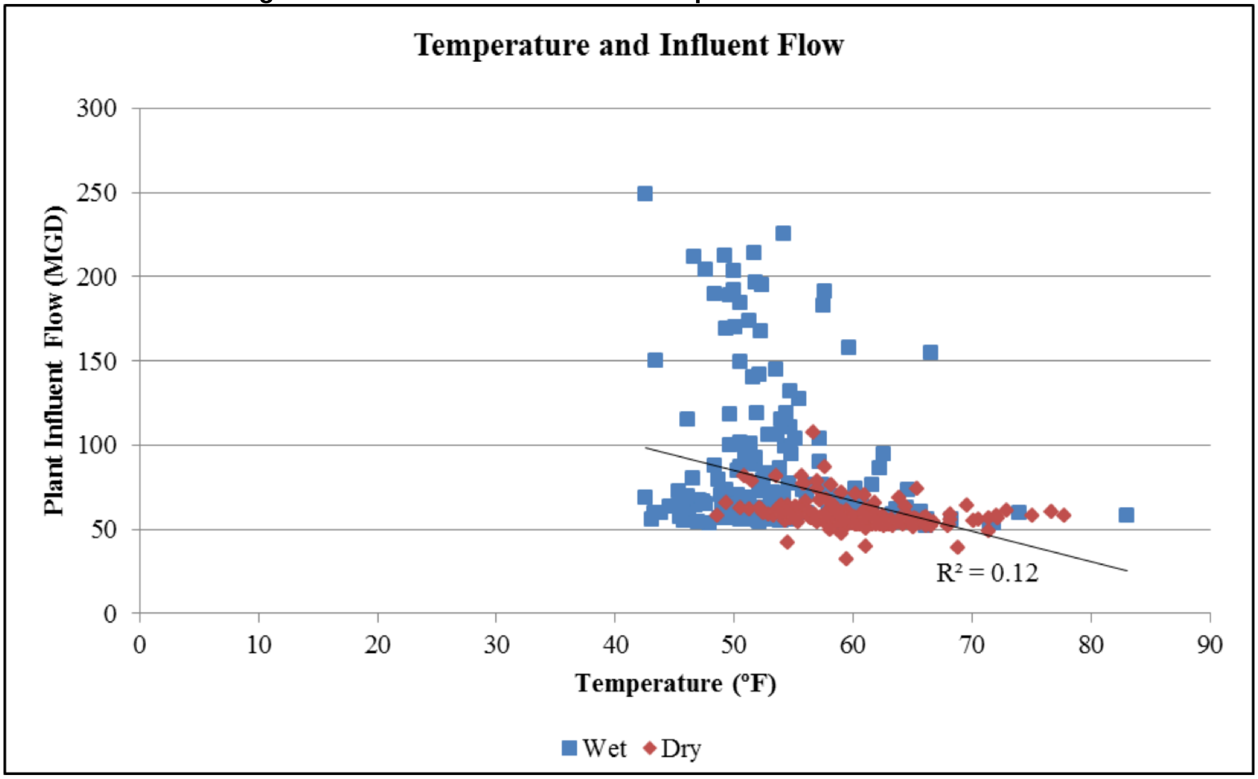


Figure A-9: Average load profile for six submetered centrifuges

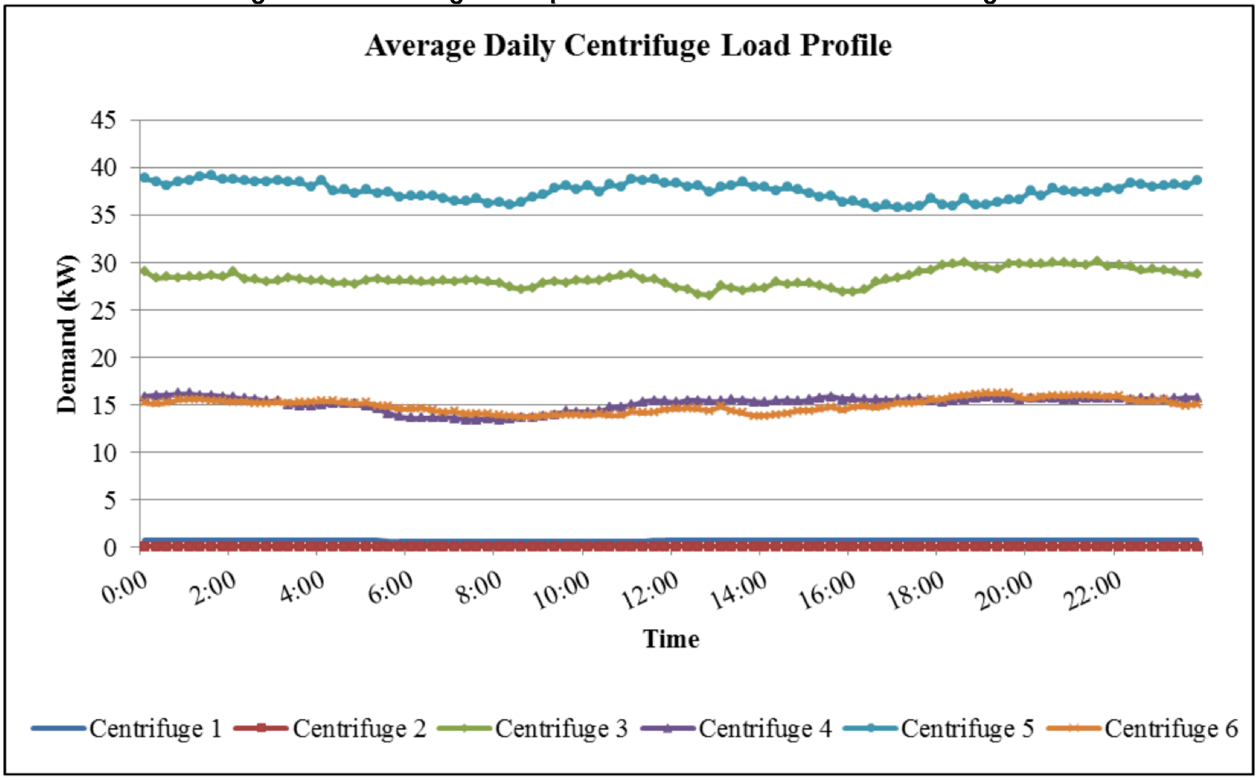


Figure A-10: Load curves for six submetered centrifuges

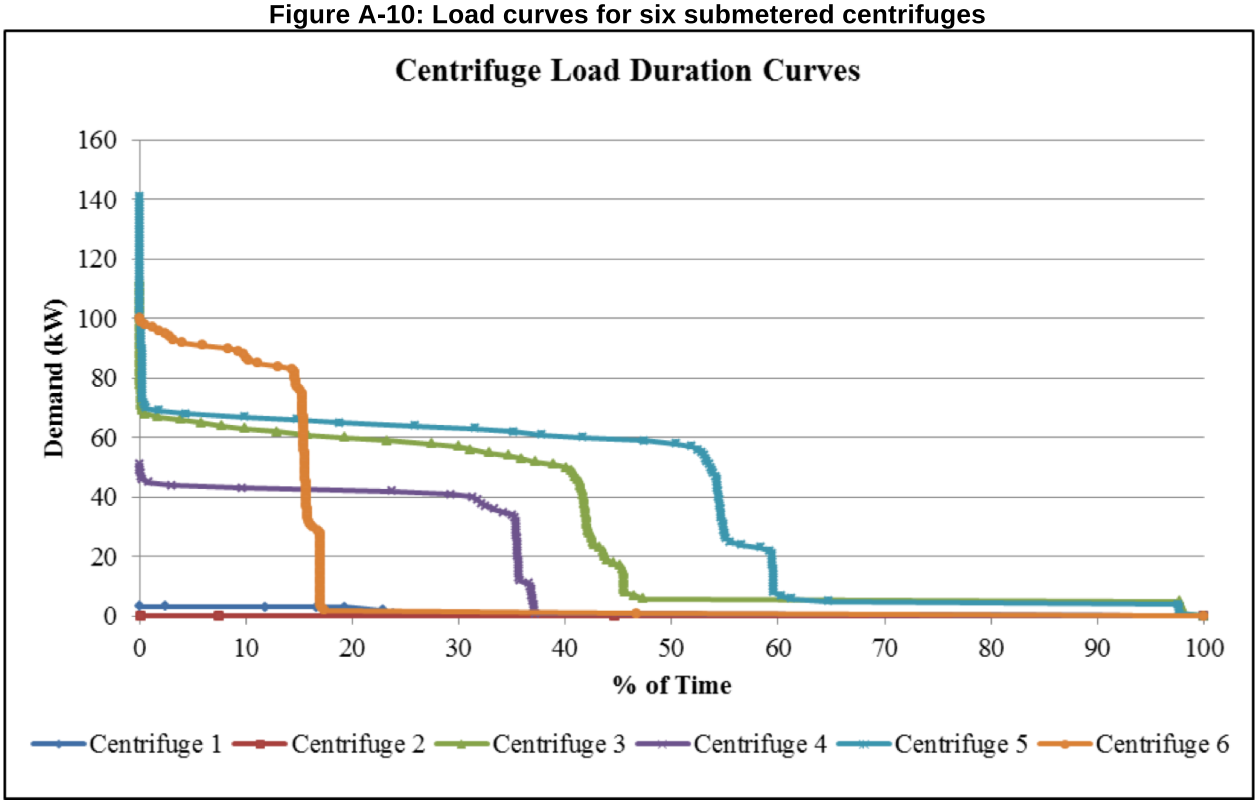


Figure A-11: Correlation between influent flow and centrifuge demand

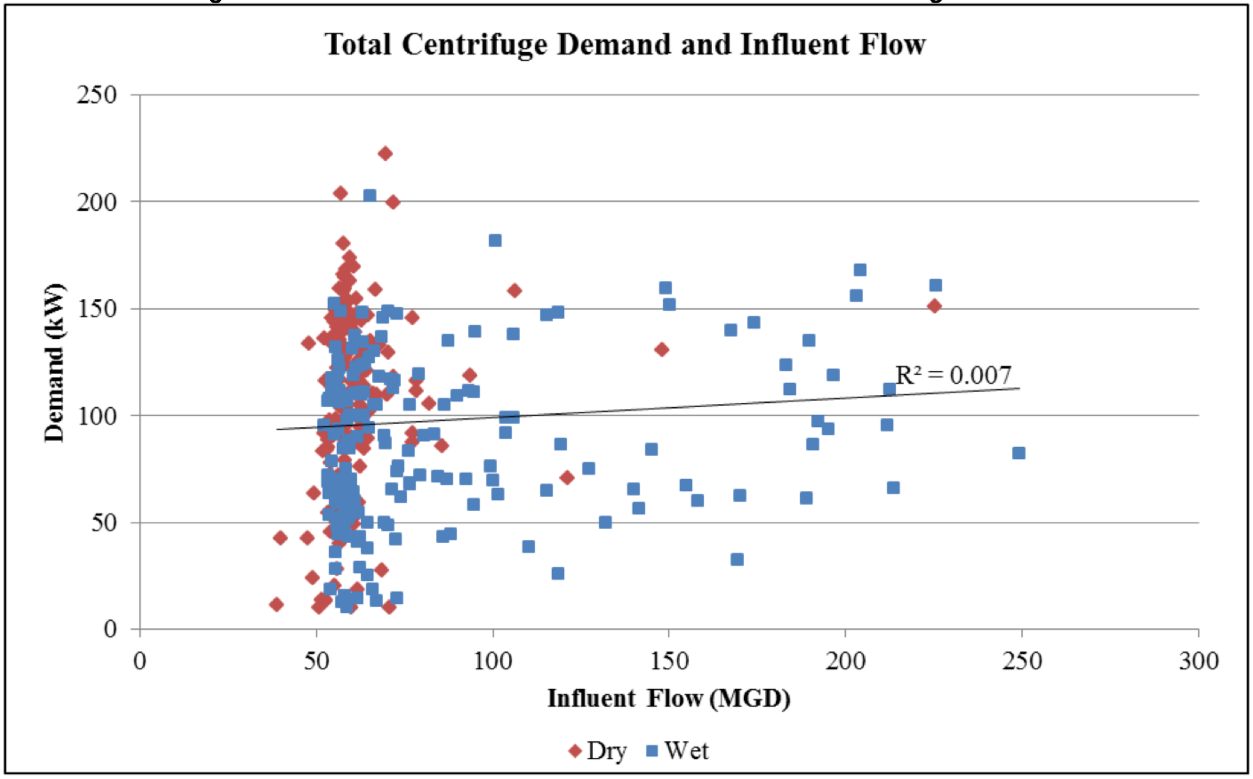


Figure A-12: Average load profile for four submetered lift pumps

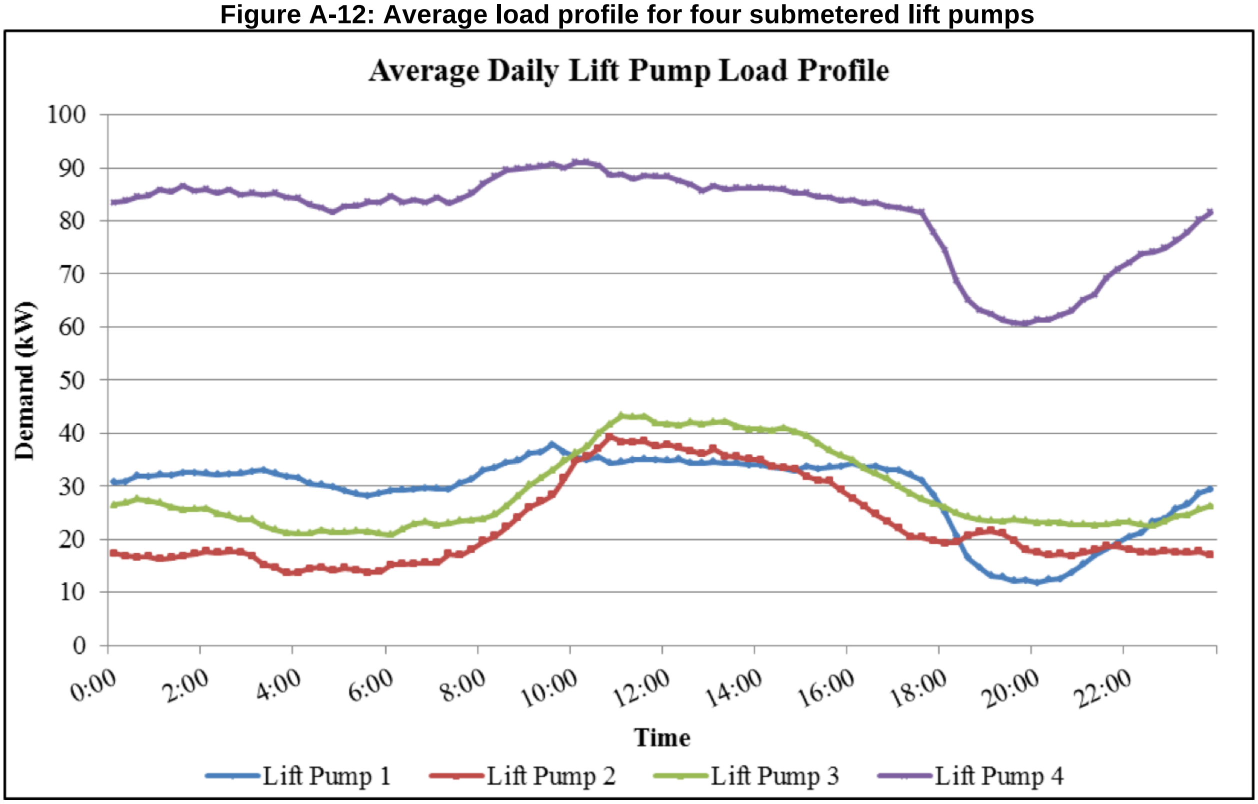


Figure A-13: Load curves for four submetered lift pumps

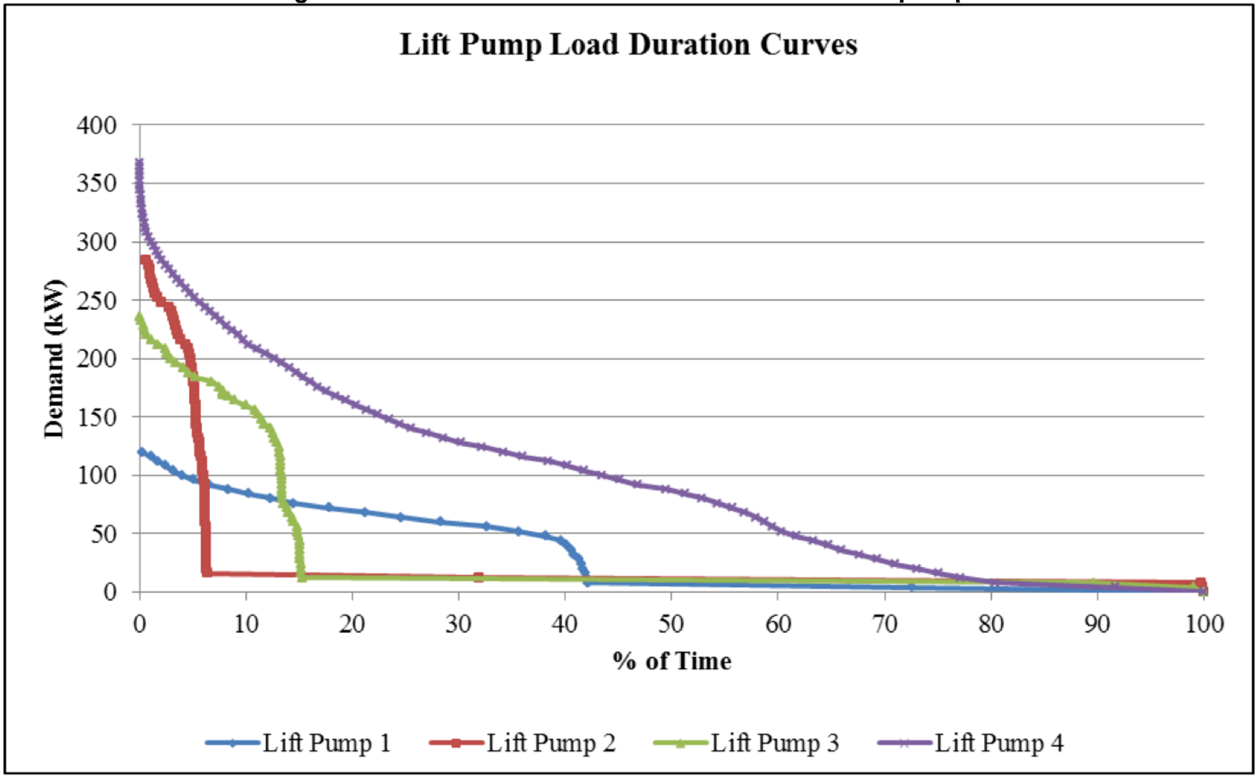


Figure A-14: Correlation between influent flow and lift pump demand

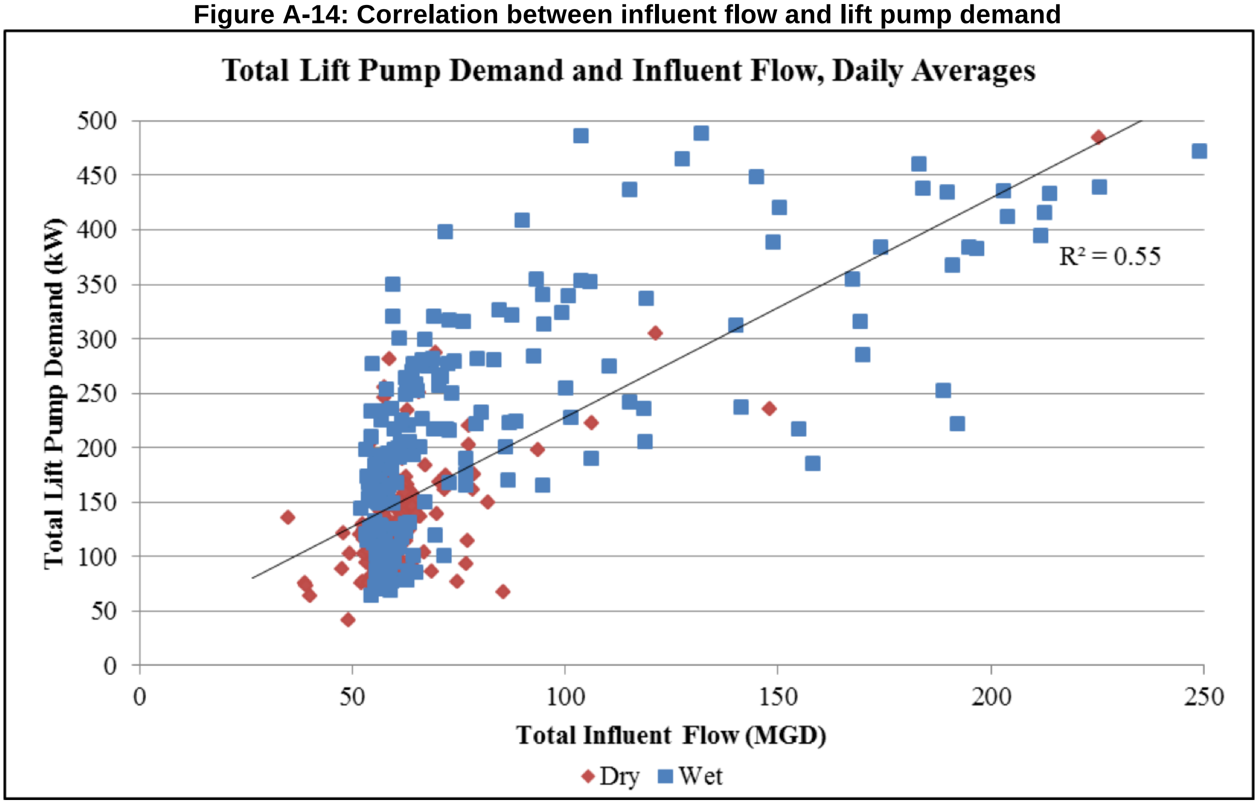


Figure A-15: Reductions in lift pump and centrifuge demand during partial-day plant shutdowns

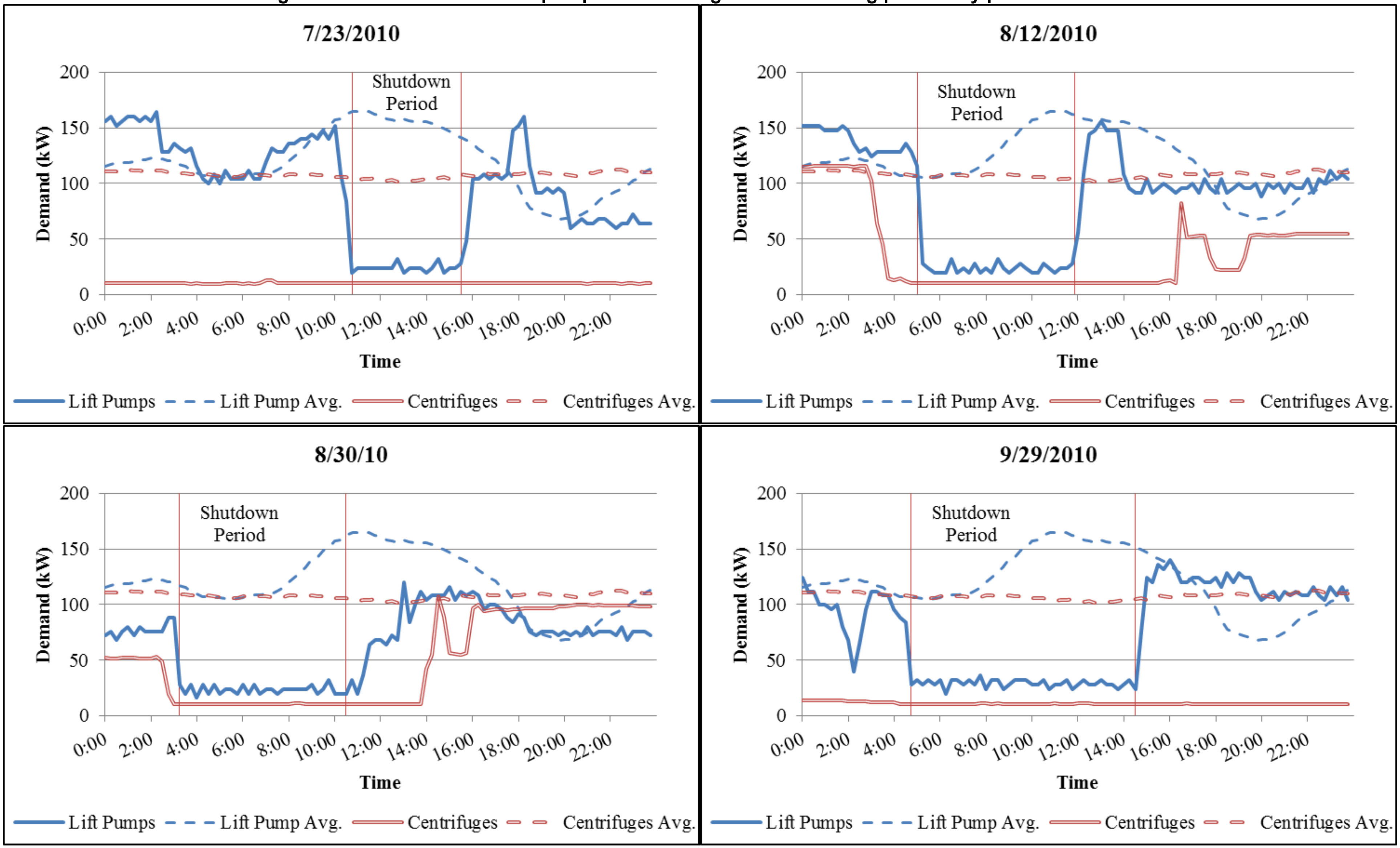
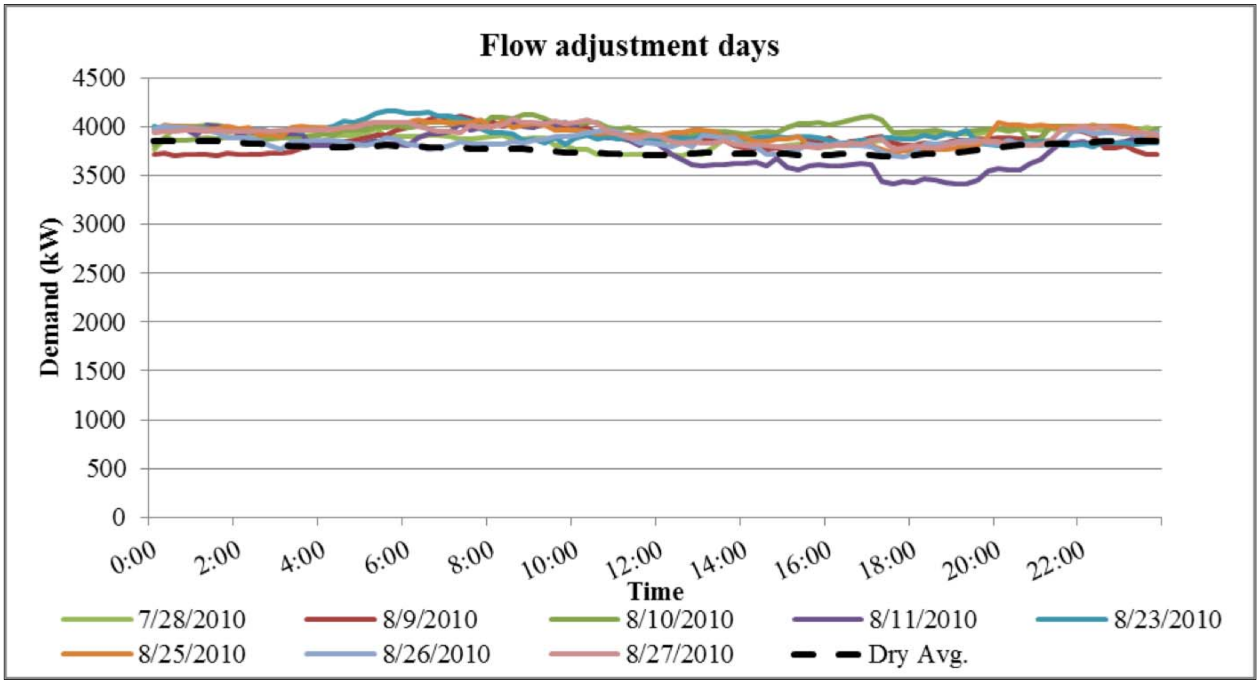


Figure A-16: Plant demand on flow adjustment days



Appendix B: Details of Reported Plant Maintenance Days

Table B-1: Details of plant maintenance days, as reported by plant personnel

Date	Event details
7/16/2010	From about 10 am Aeration train #6 off-line including 6 mixers Secondary clarifiers 9, 10, 12, 13, 14 and 16 offline
7/17/2010	Aeration train #6 off-line including 6 mixers Aeration train #8 off-line including 6 mixers from about 10 am Secondary clarifiers 9, 10, 12, 13, 14 and 16 offline
7/18/2010	Aeration train #6 & 8 off-line including 6 mixers Secondary clarifiers 9, 10, 12, 13, 14 and 16 offline
7/19/2010	Aeration train #6 & 8 off-line including 6 mixers Aeration train #7 off-line including 6 mixers from about 2 am Secondary clarifiers 9, 10, 12, 13, 14 and 16 offline Secondary clarifiers 11 and 15 offline 2 am
7/20/2010	Aeration train #6, 7 & 8 off-line including 6 mixers Secondary clarifier's 9 - 16 offline
7/21/2010	Aeration train #6, 7 & 8 off-line including 6 mixers Secondary clarifier's 9 - 16 offline GBT off-line 1100 to 0800 the next day All centrifuges off-line from 1400 to 0600 the next day
7/22/2010	Aeration train #6, 7 & 8 off-line including 6 mixers Secondary clarifier's 9 - 16 offline GBT off line All centrifuges off-line from 1300
7/23/2010	Complete plant shutdown from 1030 to 1530 All centrifuges off-line GBT off line at 1030
7/24/2010	All centrifuges off-line GBT off line
7/25/2010	All centrifuges off-line until 1400 GBT off line
7/26/2010	All centrifuges off-line GBT off line until 1400
7/28/2010	Channel pump station shutdown went off-line 0630 to 1330 Flynn pump station went on-line 0630 to 1350
7/30/2010	Aeration pair #2, train’s #3 & #4 off-line including 12 mixers went off-line 1000 to 1800
8/9/2010	Shutdown NSS [North Shore Pump Station] dry weather pumps from 1200 to 1800

8/10/2010	Shutdown NSS [North Shore Pump Station] dry weather pumps from 1400 to 1800
8/11/2010	Maintain a flow of 25 MGD from CHS [Channel Pump Station] from 1200 to 1800
8/12/2010	SEP plant shutdown for 6 to 8 hours 0500 to 1200
8/23/2010	Shutdown NSS [North Shore Pump Station] dry weather pumps from 1200 to 1800
8/25/2010	Local 011 average flow was 10 MGD 1400 to 1800, no flow from 1800 to 2000
8/26/2010	011 no flow from 1800 to 2230
8/27/2010	Local 011 average flow was 10 MGD from 1200 to 1800 no flow from 1800 to 2200
8/30-9/1/2010	North side secondary shutdown 8 clarifiers and 3 aeration trains off line.
9/29/2010	14 to 16 hour plant wide shutdown for inspection of discharge pipe/diffusers.