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California Food Processing Industry Wastewater Demonstration Project: Phase I Final Report

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Abstract

Wastewater treatment is an energy-intensive process and electricity demand is especially high during the utilities' summer peak electricity demand periods. This makes wastewater treatment facilities prime candidates for demand response programs. However, wastewater treatment is often peripheral to food processing operations and its demand response opportunities have often been overlooked.

Phase I of this wastewater demonstration project monitored wastewater energy and environmental data at Bell-Carter Foods, Inc., California's largest olive processing plant. For this monitoring activity the project team used Green Energy Management System (GEMS) automated enterprise energy management (EEM) technologies. This report presents results from data collected by GEMS from September 15, 2008 through November 30, 2008, during the olive harvest season.

This project established and tested a methodology for (1) gathering baseline energy and environmental data at an industrial food-processing plant and (2) using the data to analyze energy efficiency, demand response, daily peak load management, and environmental management opportunities at the plant. The Phase I goals were to demonstrate the measurement and interrelationship of electricity demand, electricity usage, and water quality metrics and to estimate the associated CO_2 emissions.

Keywords: demand response, demand management, daily peak load management, automation, wastewater, food processing, olive, industrial

Executive Summary

California's municipal and industrial wastewater treatment facilities consumed 2,012 GWh of electricity in 2001. Wastewater treatment is an energy-intensive process and electricity demand is especially high during the utilities' summer peak electricity demand periods. This makes wastewater treatment facilities prime candidates for demand response programs. However, in the case of industrial wastewater treatment facilities the wastewater treatment is often peripheral to the industrial processing operations and its demand response opportunities have often been overlooked.

Demand response (DR) consists of actions taken to reduce electric loads when the balance of electricity supply and demand is in jeopardy due to conditions such as extreme weather, emergencies or congestion and/or market conditions occur that raise electric supply costs. DR programs are designed to improve the reliability of the electric grid and to lower the use of electricity during peak times to reduce total system costs. DR programs provide incentives to customers to curtail demand at these times, either manually or through automation.

Figure 1 shows the concepts of reducing consumption and load using energy efficiency, time-of-use and daily peak load management, day-ahead DR, and real-time DR. An explanation of this graph with definitions of terms may be found in the LBNL/DRRC report *Linking Continuous Energy Management and Open Automated Demand Response* on the DRRC website (Piette 2008).

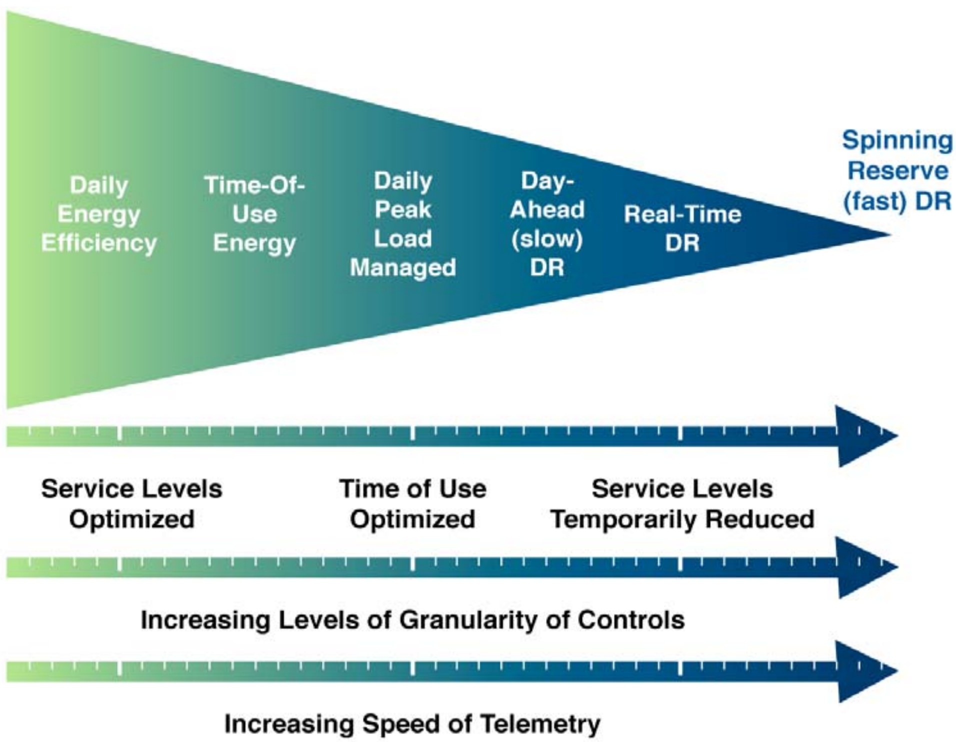

Figure 1. Energy Efficiency, Peak Load Management, and DR Diagram

Introduction

Phase I of this wastewater demonstration project monitored wastewater energy and environmental data at Bell-Carter Foods, Inc., California's largest olive processing plant. For this monitoring the project team used Green Energy Management System (GEMS) automated enterprise energy management (EEM) technologies. This report presents results from data collected by GEMS from September 15, 2008 through November 30, 2008.

Purpose

The purpose of this project is to introduce and test a methodology for (1) gathering baseline energy and environmental data at an industrial food-processing plant and (2) using the collected data to analyze energy efficiency, daily peak load management, and environmental opportunities at the plant. The Phase I goals were to demonstrate the measurement and interrelationship of electricity demand, electricity usage, and water quality metrics and to estimate the associated CO_2 emissions.

Project Objectives

Objective #1: To collect baseline data and develop correlations for Demand Response (DR), Demand Management (DM), Energy Efficiency (EE) and relate those to environmental management and associated regulatory compliance. The baseline information will be used for a Phase II costs-benefits assessment per Phase II as outlined below.

Objective #2: To illustrate by process example and measurement the potential energy supply chain and environmental management optimization of electricity generation, transmission, distribution and wastewater operations, CO_2 emissions management and forecasting.

Objective #3: To conduct a manual/Auto-DR, DM, and EE feasibility and cost assessment that incorporates and balances wastewater lagoon influent, dissolved oxygen, and associated aeration/aspiration energy and demand requirements.

Project Outcomes

During the 77-day seasonal wastewater assessment period GEMS measured and reported data for the majority of wastewater-related inputs, including demand (average, time-of-use,[1] and maximum), energy consumption (total and time-of-use), and dissolved oxygen (DO). Additional data such as flow and total suspended solids were integrated into GEMS from manual reporting. From these data the project team established baseline values for current plant operation parameters.

This report presents a method for calculating the existing (actual) demand (kW) vs. the demand required to meet DO levels. Results show that under the current on/off toggled operation of the wastewater plant's aerators and aspirators, during some time periods the aeration operates at higher demand than is needed to meet environmental requirements. During other times,

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[1] Time-of-use refers to electricity time periods in relation to the system peak demand, i.e. on-peak, partial-peak, and off-peak.

aeration operates at insufficient demand to meet desired DO levels. Also, during off- and partial-peak periods, aerators and aspirators turn on to *build DO* to ride through the subsequent on-peak period. Using EEM technologies to regulate aerator and aspirator operation allows more precise matching of energy use to environmental requirements, so that the actual demand matches the required demand. The analysis results showed that during the on-peak periods of the fall season a net 42 kW reduction (3 percent) in daily peak load could be realized by matching the aeration levels to the DO requirements. The resulting energy savings during this season's on-peak periods would be 8.7 MWh and the CO_2 emissions reduction would be 4 tons.

A cross correlation function for average demand and DO by time-of-use provides a tool to help the plant decide when to increase aeration to build DO and when to decrease aeration during on-peak periods. It also will allow plant operators to fine-tune this process using variable frequency drives (VFDs) installed on the plant aerator and aspirator motors.

Data analysis shows that the Bell-Carter plant experiences high intraday and interday demand (kW) variability, with an average interday demand variability of 22 percent for the period and 21 percent for the on-peak portion of the period.[2] This variability could be reduced by replacing some existing standard efficiency aeration and aspiration motors with VFD motors. In the scheme proposed for Phase II, the *base load*, representing a fixed level of aeration necessary to meet DO requirements, will be met with aerators and aspirators operating with new premium efficiency motors with constant speed drives. The remainder of the total demand, termed *variable load*, varies interday and by time-of-use (TOU) and will be met by aerators with new premium efficiency motors using VFDs integrated with GEMS. Both base load and variable load vary seasonally and will be adjusted based on monitored data for each season. The research team estimated that by using VFDs the on-peak period load variability could be reduced 50 percent (i.e. 10.5 percent) during the analysis period, resulting in a daily peak load reduction opportunity of 122 kW. The resulting energy savings during this season's on-peak periods would be 25.5 MWh and the CO_2 emissions reduction would be 11 tons.

In addition, savings in demand and energy from conversion of standard efficiency motors to premium efficiency motors are estimated as 3.3 percent or 32 kW. With load and consumption already reduced by the use of VFDs, the net energy savings for the analysis period are 59.2 MWh and the net CO_2 emissions savings would be 26 tons.

To analyze the demand response (DR) potential, the research team ran a multiple regression analysis of the relationships of data parameters (demand, DO, outside air temperature, and flow rate) relationships on data on a day with high outside air temperatures used to represent a peak day. The results indicate that there is a potential for DR at this site. Primarily, there is a positive correlation between aeration demand and effluent DO after controlling for other factors such as temperature and flow. This translates into the potential for using the EMS system and analysis tools to reduce demand during a DR event and predict the resulting amount of DO increase that will occur over the remainder of the day.

The results from the regression analysis were used to study three types of hypothetical scenarios of the impact of demand reduction on DO level. While these results from our model

[2] Intraday refers to variability within a day and interday refers to variability between days.

are preliminary, the potential for DR strategies is strongly supported by the data collected. Table 1 below shows the example scenarios with their assumptions and results.

Table 1. Summary of DR Impact Scenarios

Description	Demand Reduction Duration (hours)	DO Build Duration (hours)	Temperature	Flow	Demand Reduction (kW)	DO Reduction (mg/L)
Impulse Response (1)	One	NA	Constant	Constant	236	0.1
Impulse Response (2)	Six	NA	Actual on-peak	Constant	116	0.2
DR Event	Six	NA	Actual on-peak	Actual	See Figure 17	See Figure 18
DO Build with DR	Six	Eight	Actual on-peak	Actual	683	See Figure 20

(1) Impulse Response Functions. The results of the second scenario show that given an extreme temperature day and a 10 percent peak load reduction the reduction in DO does not exceed 0.2 mg/L. Also, the detrimental effect of the event is gone after about 8 hours.

(2) DR Event. Using the impulse response functions discussed above, a theoretical six-hour DR event was mapped on top of actual data collected for the site. Note that the requirement to maintain discharge DO levels above a regulatory minimum means that the DR potential of the site will vary depending on the initial DO readings at the beginning of the event.

(3) DO Build with DR Event. The research team simulated a theoretical DO build assuming 10 percent kW increase over observed levels on the peak temperature day for 8 hours followed by a DR event with 10 percent reduction in kW below actual observed levels for 6 hours. The results strongly suggest the possibility of using a DO build strategy to minimize the risk of discharging below the plant's regulatory limits. By the end of the simulated DR event, the levels of DO are nearly identical with the actual observed levels.

Conclusions

This section maps project conclusions onto the three project objectives to form the basis for the study recommendations.

Objective #1:

This project demonstrated the use of automated technologies for managing plant operations. The resulting energy-environmental data integration and correlations can provide baseline data for current operations. They can also provide a planning and decision-making foundation for continuous improvement in integrated energy-environmental management.

The baseline data gathered during this project form the basis for estimates of potential savings from daily peak load management, and associated energy efficiency and CO_2 reductions during Phase II, as discussed under Objective #3.

Objective #2:

The data integration gleaned from the wastewater project can provide sound information for integrated resource planning estimates and measurements. For example, the energy data are useful in demand response and time-of-use opportunity planning for utilities and California Independent System Operator (CAISO). In addition, the CO_2 emissions data correlated with energy consumption assist in reporting of CO_2 emissions impacts of wastewater–related air emissions, which is beneficial for upcoming AB 32 (California Global Warming Solutions Act of 2006) regulatory compliance and forecasting.

Objective #3:

The initial data analysis demonstrates a method for estimating the approximate daily peak load management opportunity from automating wastewater aeration and aspiration operations. As stated above, during the fall seasonal period the project team estimated an on-peak demand reduction potential of 3 – 10 percent. When a full year of data is analyzed, the DR opportunity may prove to be higher.

In Phase II savings from daily peak load management as well as potential manual DR/Auto-DR will arise from replacing some existing aerator motors with VFD motors that can automate and promptly adapt to changes in wastewater parameters. In addition, EE savings will result from retrofit of all existing aerator and aspirator motors to premium efficiency motors.

In Phase II, the research team will analyze wastewater energy and environmental parameters correlated with weather and tariff data from the summer peak period to predict DR/Auto-DR potential using a strategy of off-peak DO build to provide additional demand reduction during DR days.

<u>Recommendations</u>

1. Install 38 VFD-capable premium efficiency aerator and aspirator motors to achieve energy efficiency savings and CO_2 emissions reduction benefits (contingent on a wastewater electricity distribution system capacity assessment).
2. Install a minimum of six VFDs on the above aerator motors to accommodate wastewater variable load.
3. Replace PC-based DO monitoring system with a contemporary technology that integrates with GEMS.
4. Apply the National Weather Service ambient temperature and humidity data now integrated in GEMS to the wastewater control scheme.
5. Install pulse flow meters and adjacent DO sensors at Lagoon #1 influent and Lagoon #3 effluent points. Install total suspended solids and salinity probes in lagoon operations and integrate with GEMS.

Although not included in the original objectives, the research team developed the following recommendations during the course of Phase I and submits them for consideration for Phase II.

6. Conduct salinity and acetic acid research by the University of California-Davis, California Institute of Food and Agricultural Research/Food Science and Technology Department. For salinity, seek FDA food-grade sodium-based chemical replacement(s) for current sodium-based chemicals to balance food product sodium requirements

relative to wastewater energy and environmental requirements due to salinity levels. Conduct similar food science research for acetic acid replacements.

7. Once the project has optimized the water chemistry and energy operations of Lagoons #1, # 2 and #3, assess Lagoons #4, # 5, #6 and #7 to determine if water quality has improved enough to reduce energy-intensity through an alternative non-aeration system or reduction of aeration through VFDs, use of fewer motors, etc.
8. Explore additional wastewater technologies, including water and energy conservation strategies, for further energy-environmental improvement in wastewater operations (e.g. segregation of wastewater streams, reuse of washing water, recycling of final rinse water, fine-bubble aeration, solar-powered water circulators, etc.).
9. Perform research on real-time pricing using GEMS capability to evaluate the integration of a simulated price signal and Auto-DR signal.
10. Perform research on non-real time pricing using GEMS capability to evaluate Auto-DR signals.
11. Perform manual DR tests that duplicate the scenarios used in the simulations.

Although not included in the scope of this report, innovations in renewable energy (e.g. photovoltaics and methane capture for fuel cell application) for use at Bell-Carter and other wastewater plants have been identified for further review with the Energy Commission for a potential Phase III.

Benefits to California

The results of this integrated energy-environmental wastewater project could be beneficial to several California entities as follows.

For the California food processing industry, other industrial segments and municipal wastewater plants, the project results illustrate the integration of multiple variables for effective wastewater measurement and management that can achieve immediate wastewater cost savings. This integration can also provide predictive capability for ongoing cost and resource management for sustainable competitive advantage. Plants can gain the ability to effectively plan and incorporate both core and non-core plant operations in DR and Auto-DR programs while continuing to achieve strict environmental regulatory compliance. The project also provides the advancement of knowledge of wastewater chemistry impacts on energy use and environmental management.

The commercial buildings sector can apply many of the integrated energy-environmental aspects of this initiative for more TOU energy-environmental planning and impact; real-time, integrated energy-CO2 emissions tracking and reporting at asset levels; and improved ability to effectively plan and participate in energy programs such as DR, Auto-DR and EE.

This wastewater initiative can assist the Energy Commission's Industrial, Agriculture and Water program by providing a strategic, holistic approach to wastewater energy and environmental management coupled with measured results to apply statewide to program and incentive development.

California's utilities can use results of the wastewater initiative as a roadmap for collaborative work with customers from a resource optimization perspective. The results will assist utilities in wastewater operations-related electricity infrastructure and resource capacity planning, especially on a TOU basis.

CAISO can incorporate the results into an assessment of what percentage of wastewater treatment-related demand may be DR-applicable. In addition, improved wastewater electricity-related measurement that includes multiple variable integration will assist both in the measurement and verification of EE investments as well as effective DR planning, including the potential extension of Auto-DR to core operations.

California environmental regulatory entities can use results of this wastewater pilot initiative for current and future environmental policy and regulation of the direct and indirect environmental impacts of the electricity consumed by California wastewater treatment operations. For example, this project has illustrated real-time CO_2 emissions measurement integrated with energy management, allowing emissions tracking and reporting. From a wastewater quality perspective, it has provided a means to assist in forecasting approximate DO levels and BOD magnitude based upon an integration of multiple variables. From a solid waste management perspective, the issue of salinity and associated salt transportation and landfill disposal issues have been illuminated in the course of this wastewater project.

1.0 Introduction

1.1. Overview of Demand Response in Wastewater and Food Processing

California's municipal and industrial wastewater treatment facilities consumed 2,012 GWh of electricity in 2001 (CEC 2005). Wastewater treatment is an energy-intensive process, and electricity demand is especially high during the summer months, particularly in locations with high summer temperatures. This means that demand for treating and transporting wastewater is significant during utilities' peak electricity demand periods (NRDC 2004). These factors make wastewater treatment facilities prime candidates for demand response programs. However, for major electricity-using industries, wastewater treatment facilities are often peripheral. For example, in food processing plants the actual food-processing operations—which also culminate during the summer period—take precedence over wastewater treatment operations. Therefore the demand response opportunities of the wastewater treatment facilities in these plants have often been overlooked.

Demand response (DR) consists of actions taken to reduce electric loads when the balance of electricity supply and demand is in jeopardy due to conditions such as extreme weather, emergencies or grid congestion and/or market conditions occur that raise electric supply costs. DR programs are designed to improve the reliability of the electric grid and to lower the use of electricity during peak times to reduce the total system costs. DR programs provide incentives to customers to curtail demand during the utilities' peak electricity demand periods, either manually or through automation. Some load-shedding or load-shifting measures taken to reduce demand are performed only temporarily during DR periods. Other measures tested during pilot programs and implemented through automation can become part of plant operations and contribute toward energy efficiency (EE) and daily peak load management. Open Automated Demand Response (OpenADR) is a set of standard, continuous, open communication signals and systems sent to facilities over the Internet to allow them to automate their demand response.

A draft PIER report by Lawrence Berkeley National Laboratory's Demand Response Research Center (DRRC), *Opportunities for Energy Efficiency and Automated Demand Response in Wastewater Treatment Facilities in California: Phase I Report*, summarizes the status and potential for energy efficiency and demand response for California's wastewater treatment plants (LBNL 2009). Several plants have implemented energy efficiency and daily peak load management measures. A key finding from this report is the controls installed for energy efficiency and load management may enable these plants to successfully participate in demand response events. For example, variable frequency drives (VFDs) on pumps and aerator fans can be directly connected to a control system, allowing for capacity to be reduced during DR events without completely turning off equipment. Another key finding is that existing industrial controls, if DR-enabled, hold significant promise for integration into an OpenADR framework.

The PIER report *Strategies to Increase California Food Processing Industry Demand Response Participation: A Scoping Study (DRSS)* found that the industrial sector in general and food processing in particular face unique challenges for DR implementation not experienced by the commercial buildings sector (Lewis 2007). The feasibility of DR in food processing depends on plant operating schedules and supply chain needs, and plant operators have been reluctant to adjust production schedules where productivity and economics may suffer. However, the results of the scoping study indicated that significant potential for DR can be realized in this sector given coordination, tools and incentives planned from a perspective of plant operations.

Food processing is also a water-intensive operation. Fruit and vegetable processors in California consume about 30 billion gallons of water per year (Neenan 2008). According to a 1993 survey of the California food processing industry, 23% of this water was for fresh water supply and 77% was for wastewater disposal. Olive processing plants reported that they used an average of 7,250 gallons per ton of raw materials processed (Mannapperuma 1993). The production process requires water for cleaning, sanitizing, peeling, cooking, and cooling, and as a conveyor medium to transport food materials. Wastewater from food processing industries varies in composition and volume depending on the product, scale of operation, weather, and season. Upstream efforts to reduce the volume of water used in food processing results in lower wastewater treatment costs, including energy costs.

The Bibliography section provides references to prior work on food processing and wastewater treatment energy efficiency and demand response.

<u>Project Overview</u>

This project established and tested a methodology for (1) gathering baseline energy and environmental data at an industrial food-processing plant and (2) using the data to analyze energy efficiency, daily peak load management, and environmental opportunities at that plant. The site of this comprehensive wastewater pilot initiative was Bell-Carter Foods, Inc., California's largest olive processing plant, located in the northern California city of Corning in Tehama County. Bell-Carter sells and markets domestic olives, imported olives, and olive-related specialty products under the Lindsay and Bell brand names. Bell-Carter is the largest table olive producer in the U.S. and the second largest in the world. It produces and sells over half of all the California olives in the nation.

Data collection at the Bell-Carter plant began in mid-September 2008. This report presents results from September 15, 2008 through November 30, 2008. This time period provided an opportunity to assess energy usage related to environmental impacts during the summer-to-autumn shoulder months of the olive production season.

This phase of the project integrated, measured and correlated electricity demand, electricity usage, and wastewater environmental characteristics at Bell-Carter. By gathering and analyzing electricity consumption, electricity demand, dissolved oxygen (DO) data, and correlating them with weather data over a seasonal period, the project provided a tangible example of the measurement and actual interrelationships of energy use and wastewater quality characteristics. It also estimated the corresponding carbon dioxide (CO_2) emissions impacts. The resulting data provided a baseline from which the project team calculated energy-efficiency and demand response potential for this plant.

Several of the opportunities identified for Bell-Carter are applicable for daily plant operation and therefore are classified as daily peak load management. Incentives available for DR will not be applicable to these daily peak load management measures.

The results gleaned from this pilot project phase will be used in planning and implementing EE and DR at the Bell-Carter plant through integrated wastewater energy and environmental management. Data collection at Bell Carter is ongoing and will be incorporated in the planning of subsequent phases of this project. Due to plant confidentiality and competitiveness concerns, only energy and environmental improvements will be presented in this report without reference to actual realized cost savings associated with the improvements.

Project Objectives

Phase I goals are to demonstrate the measurement and interrelationship of electricity demand, electricity usage, and water quality metrics and to estimate the associated CO_2 emissions. The objectives are:

Objective #1: To collect baseline data and develop correlations for Demand Response (DR) Demand Management (DM), Energy Efficiency (EE) and relate those to environmental management and associated regulatory compliance. The baseline information will be used for a Phase II costs-benefits assessment per Phase II as outlined below.

Objective #2: To illustrate by process example and measurement the potential energy supply chain and environmental management optimization of electricity generation, transmission, distribution and wastewater operations, CO_2 emissions management and forecasting.

Objective #3: To conduct a manual/Auto-DR, DM, and EE feasibility and cost assessment that incorporates and balances wastewater lagoon influent, dissolved oxygen, and associated aeration/aspiration energy and demand requirements.

Potential Phase II activities are described in the Discussion section below.

1.2. Background

This section begins with a brief discussion of wastewater chemistry, followed by a description of the Bell-Carter plant and its operation, and concluding with discussion of existing water and energy efficiency measures that the plant has implemented or considered.

1.2.1. Wastewater Chemistry

From a wastewater chemistry standpoint, dissolved oxygen (DO) is the primary wastewater operations predictor for regulated biological oxygen demand (BOD) levels prior to discharge of the effluent into the Sacramento River. Meeting DO levels and subsequent BOD requirements are critical in mitigating both eutrophication and olfactory impacts to the river, the City of Corning and the surrounding environment. If untreated, high levels of organic pollutants can severely harm aquatic ecosystems by depleting DO, raising water temperature, reducing growth rates of plant life, and potentially causing death of fish and other aquatic organisms.

In wastewater operations there is an inverse relationship between DO, outdoor air temperature and wastewater temperature. Oxygen is only slightly soluble in water. High temperatures on summer days reduce DO saturation capacity in wastewater and increase aeration and aspiration demand requirements.

Biological oxygen demand (BOD), measured in mg/L, is significant in regulatory water quality compliance. Bacteria and organisms use organic substances for food and as they metabolize organic material they consume or "demand" oxygen. The organic substances are broken down into simpler compounds (e.g. CO_2, H_2O, N_2, etc.) as the microbes use the energy released from this compound breakdown. When this process occurs in water, the oxygen consumed affects the dissolved oxygen in the water. If oxygen is not continually replaced in the water by natural or artificial means, then the DO level will decrease as organic substances are decomposed by microbes. DO can be used as an estimated predictor of BOD. BOD cannot be effectively measured in real-time for regulatory compliance and requires a five-day laboratory test, whereas DO can be measured in real time (U.S. EPA 2004).

Solids in water are defined as any matter that remains as residue upon evaporation and drying at 103°C. Solids are separated into two classes, suspended and dissolved, contingent upon degree of filtering and laboratory analysis. For purposes of this wastewater project, total suspended solids (TSS) are considered of primary importance to the plant.

The paramount objective of aeration and aspiration is achieving the required DO saturation in lagoon wastewater to meet resulting BOD regulatory requirements for microbiological degradation of olive production waste. Hence, aeration electricity demand is inversely related to DO levels.

The U.S. Environmental Protection Agency (U.S. EPA) strictly regulates wastewater operations for BOD and TSS levels. Food processing wastewater can contain high levels of organic waste. In addition, Bell-Carter is regulated by the State of California Environmental Protection Agency, Department of Water Resources/Regional Water Quality Control Board as well as the California and Tehama County Air Resources Boards. The plant is covered by U.S. EPA National Pollution Discharge Elimination System (NPDES) regulation 40 CFR Part 407 for the Canned and Preserved Fruits and Vegetables Processing Point Source Category. In addition, NPDES regulations are used by the California Regional Water Quality Control Board. According to NPDES the regulated maximum values for olive processing wastewater BOD5 range from 2.39 kg/kg (lb/1000 lb) of raw material annual average to 5.44 kg/kg (lb/1000 lb) of raw material for one day. The TSS values for olive processing waste must be no higher than an annual average of 4.44 kg/kg of raw material or 9.79 kg/kg of raw material for one day.[3]

Bell-Carter harvests olives during the months of September through early November, releasing olive pieces and other organic material into the wastewater. During the rest of the year, the wastewater also requires treatment as olive processing and canning take place year-round. Before processing, ripe olives are stored in brine containing salt (sodium chloride), acetic acid, sodium benzoate, and calcium chloride. For black olives, ferrous gluconate is added to the brine to preserve color. All of these wastewater compounds require treatment.

During this study sodium and acetic acid have emerged as substances for which substitutes could reduce wastewater energy use. When substances such as salts are dissolved in a unit volume of water, there is less opportunity for oxygen to dissolve as oxygen is less soluble than most salts. Sodium significantly reduces DO solubility and transfer by nearly 50% and thus increases aeration energy requirements. In addition, the resulting salt precipitate removal from lagoons is a major operating cost and environmental issue.

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[3] http://cfpub.epa.gov/NPDES

Acetic acid, used as an olive storage preservative, is the largest contributor to BOD level in Bell-Carter wastewater. Research on replacements for both sodium and acetic acid is noted in the Recommendations section. Appendix D addresses the impacts of salinity on DO levels and wastewater treatment, Bell-Carter's prior salinity analysis, and the increased wastewater energy consumption, demand, and plant dredging costs resulting from excess salt precipitate.

1.2.2. Plant Description and Operation

The Bell-Carter plant uses a diffused coarse bubble aeration system that releases oxygen from aerators at the surface of the lagoons and disperses bubbles of air into the wastewater. Aspirators are used for convection of the wastewater and are located near the bottom of the lagoons. As shown in Table 2, current wastewater aerator and aspirator nominal motor capacity is significant at approximately 1.8 MW. Of this total, approximately 1.3 MW of capacity is in Lagoons #1, 2, and 3, which are the focus of this project.[4]

The data in this report cover the olive harvest period. The plant wastewater contains more organic material during harvest season and peak BOD loading is highest. Also, green ripe olives were being processed during the second half of September and the first half of October. Green ripe olives have higher BOD loading and are processed separately from black olives (whose water cannot be mixed into the green olives processing or it will discolor the green olives). Green ripe olives also have more sodium, which increases DO requirements and therefore increases wastewater energy demand. This is a critical season for plant operations and therefore load shifting or shedding for DR is subject to more operating constraints. In contrast, the Pacific Gas and Electric (PG&E) system peak period—when most Auto-DR events are called—is in the summer prior to the harvest, when black olives are being processed and conditions are more flexible for DR.

Table 2 describes the existing plant configuration and equipment (as of March 2008). There are seven lagoons totaling 27 acres in area. (Note that kW shown is nominal capacity based on motor horsepower.) Lagoon #1 has a capacity of 15 million gallons and Lagoons #2 and #3 each have a capacity of 8.5 million gallons. In 2008 the plant treated an average of 0.76 million gallons per month from September through November and an average of 0.53 million gallons during the other months.

Table 2. Bell-Carter Lagoon, Aerator and Aspirator Data

Lagoon #	Aerators			Aspirators			Totals	
	#	hp	kW*	#	hp	kW*	hp	kW*
1, 2, 3	28	50	1044	10	30	224	1,700	1,268
4,5,6,7	11	50	410	0			700	522
	6	25	112					
All	45			10			2,400	1,790

*Nominal kW for all aerators or aspirators in each row

[4] In addition to the 1.8 MW, the plant has incremental aeration capacity of approximately 300 kW, which is decommissioned due to maintenance required but could be recommissioned in the future based on an economic assessment. Since these aerators were not included in the Phase I monitoring, this report refers to their 300 kW capacity only when referring to the plant's e. 2.1 MW total capacity.

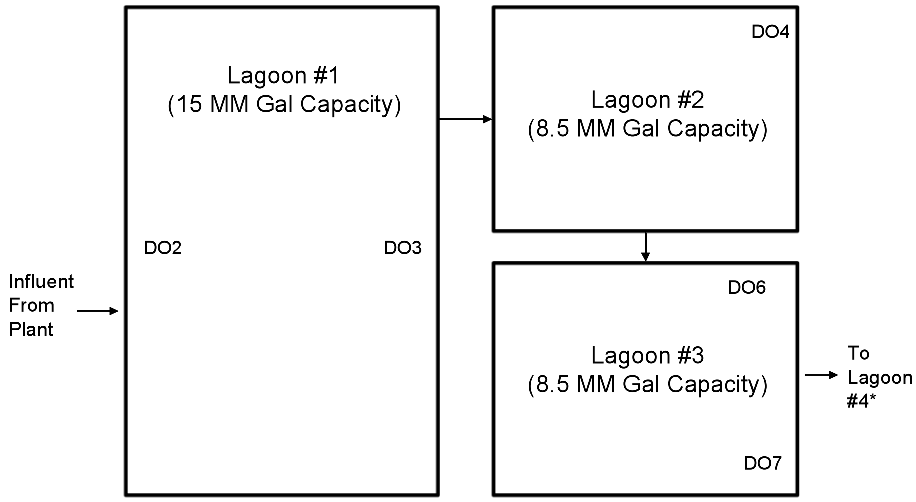
Figure 2 shows a satellite photo of the Bell-Carter plant's wastewater operations (which are five miles from the olive processing plant). The wastewater lagoons are within the red circle. As shown, the plant discharges treated wastewater into the Sacramento River via a series of seven wastewater treatment lagoons.

Figure 2. Satellite Photo of Bell-Carter Wastewater Operations

The Phase I focus was the "work horse" Lagoons #1, #2 and #3, which are the major wastewater treatment areas and account for approximately 71% of total aeration demand. As labeled, Lagoons #1, #2 and #3 are those to the lower left inside the circled area.

Figure 3 shows the flow arrangement of Lagoons 1, #2 and #3 and the locations of sensors operating during Phase I.

Treatment Lagoon Flow Diagram and DO Sensor Placement



*Additional treatment occurs in Lagoons #4 – #7.

Figure 3. Lagoon Flow Diagram with DO Sensor Placement

(Two additional sensors, #1 and #5, were not operational during Phase I.)

Currently, Bell-Carter aerators and aspirators operate throughout the year. A percentage of them are shut off during periods when sufficient DO levels are observed on a computer (desktop PC). This computer is a stand-alone, non-networked unit at a small building located at the lagoons, which are several miles from the actual plant. An operator needs to physically go to the building and read the DO information on the PC screen. In addition, the DO data can only be viewed; they do not print or export from the PC. Hence, rather than operating the aerators aspirators based on real-time data, plant operators rely on DO set point levels (with operator override option for emergencies) that are based on operator experience and judgment and vary by time-of-use.

Table 3 shows the set points of the DO sensors in operation during the study period. The set points by time-of-use are grouped into 3 categories: low, medium and high.

Table 3. Set Points by Time-of-Use (mg/L)

	Low	Medium	High
On-Peak	0.2	0.5	0.8
Partial-Peak	0.5	1.0	1.5
Off-Peak	0.8	1.5	1.8

If DO levels decrease below their set points, then aerators and their associated aspirators are turned back on to increase DO levels. Also, during off- and partial-peak periods, aerators and aspirators turn on to *build DO* to ride through the subsequent on-peak period. Without the feedback from readily accessible DO data, however, these processes are imprecise. Without applicable automated controls to better match aerator and aspirator operation to DO levels, to assure environmental regulatory compliance as well as operator convenience, the plant lacks optimal demand management planning and control.

1.2.3. Existing Energy Efficiency Measures

Prior to the start of this project the Bell-Carter plant had already taken some measures to reduce energy use in wastewater operations.

Energy Efficient Motors. The plant installed premium efficiency motors in Lagoon #4 in March 2008. Note that the energy consumption of Lagoon #4 is not part of this report's estimates. The Results section below presents estimates of savings from premium efficiency motors in Lagoons #1, #2 and #3.

Membrane Filtration. Membrane filtration technologies have been applied in many industries to clean wastewater prior to disposal and to recover water for recycling in various facility and process applications.

Bell-Carter installed a membrane filtration system in 2001-2002 for tertiary treatment of its effluent. Because of the seasonal variability in BOD and ammonia concentration, the membrane filtration system selectively draws from different lagoons depending on the season as a function of the ammonia concentration. In the summer months when the BOD level in Lagoons #1, #2 and #3 is well-controlled, while ammonia levels are often high in Lagoons #4, # 5, #6 and #7, the membrane filtration system draws from Lagoons #2 and #3. The reverse occurs in the cooler winter months with high BOD levels in Lagoons #1, #2 and #3 and low ammonia levels in Lagoons #4, # 5, #6 and #7, so the membrane filtration system draws from Lagoons #4, # 5, #6 and #7. The membranes form a physical barrier to suspended solids and colloidal material in the wastewater. The filtered water is collected and discharged into the Sacramento River without requiring additional treatment. By removing suspended solids, the system allows a shorter detention time in the lagoons in the winter months to remove TSS. It also protects the wastewater lagoons from overload conditions during winter storms. The membrane filtration system allowed Bell-Carter to increase its wastewater treatment capacity by nearly 50%. The effluent became so clean that Bell-Carter can blend the membrane effluent with effluent from Lagoons #4,# 5, #6 and #7 and still meet environmental discharge standards. This in turn eliminated the need to send excess wastewater to the municipal sewage treatment plant with corresponding cost savings (Novatchis 2006).

1.2.4. Other Potential EE and Water Conservation Measures

Research for this project revealed additional energy and water conservation strategies that merit feasibility studies to determine their future applicability for the Bell-Carter plant.

Advanced water treatment technologies that can potentially replace or reduce the aerator/aspirator combination have significant potential for reducing overall energy consumption. One example of an advanced technology that can replace or reduce the number of aerators (and subsequently reduce significant amount of electric energy) in a wastewater treatment plant is a solar powered water circulator technology.

The plant currently uses coarse-bubble aeration. Fine-bubble aeration, a more efficient strategy used in wastewater treatment plants, could save aeration energy and facilitate removal of fine particulates especially pertaining to sliced olives. However, this method has high chemical costs and requires higher maintenance than the current aeration method. This technology is included in the recommendations for further study in Phase II.

Wastewater treatment plants also use strategies to reduce wastewater volume and provide corresponding energy and cost savings. Some of these strategies, such as segregation of wastewater streams, reuse of washing water, and recycling of final rinse water, warrant cost/benefit and quality assurance analyses for possible future implementation and are included in the Phase II recommendations.

Any technologies or strategies that reduce peak load will also reduce the potential for the amount of DR savings. Nonetheless, exploration of energy and water conservation strategies is in the recommendations for Phase II.

1.3. Report Organization

This section provides an overview of demand response in wastewater treatment and food processing, a project overview, project objectives, and background information, including wastewater chemistry and description and operation of the Bell-Carter plant.

Section 3 describes the project methods.

Section 4 presents the project results.

Section 5 discusses the conclusions, recommendations, and benefits to California.

2.0 Project Approach/Methods

This section covers the methodology used for data collection and analysis for the project. It begins with definitions, followed by description of the monitoring equipment and monitoring points, discussion on incorporation of weather data, calculation of the CO_2 emissions factor, and presentation of the types of data collected.

Wastewater operations are core operations in manufacturing from both a water flow balance and an electricity demand perspective. All electricity demand discussed in this report is classified as 'essential demand,' which is demand directly associated with core manufacturing processes (e.g. production process-related demand, regulatory compliance, etc.). In contrast, non-essential demand is demand indirectly associated with core manufacturing operations but non-critical to manufacturing operations (e.g. office buildings, etc.)

During Phase I the plant implemented the Green Energy Management System (GEMS), an enterprise energy management (EEM) automated monitoring system for comprehensive water, air, gas, electricity and steam management.[5] See Appendix C for additional information on GEMS.

During the Phase I analysis period of September 15 through November 30, 2008, GEMS integrated real-time lagoon DO probe outputs and tracked and reported actual DO measurements to compare to wastewater regulatory requirements. At the same time, aerators and aspirators were integrated into GEMS to measure electricity demand and usage during manual operations.

The five Phase I DO monitoring points for Lagoons #1, #2 and #3 were as follows, as shown in Figure 3 above:

Lagoon #1: 2 DO sensors

Lagoon #2: 1 DO sensor

Lagoon #3: 2 DO sensors

The sensors are Hach LDO probes located approximately one foot from lagoon banks, measuring influent or effluent DO levels at a water depth of approximately 1.0 to 1.5 ft. Each probe is attached to a rotating boom gantry for cleaning and maintenance. It is impractical and not required to monitor DO in the center of lagoons. (Maintenance is an issue as the sensors need to be cleaned every day. The readings from the sensors near the shore are close enough to the average for environmental compliance goals.) Aerators and aspirators in the center of lagoons are accessible for maintenance via onsite boats.

Table 4 shows the data types that the project team collected during Phase 1. GEMS collects data at 15 minute intervals and can provide summaries on an hourly, daily, weekly, monthly, or periodic basis. GEMS can export either total data for all equipment and/or data for each specific wastewater aerator or aspirator. GEMS is structured to export data into standard comma separated values (CSV) file format, which the user can then import directly into Microsoft

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[5] Glen Lewis Group, http://www.glenlewisgroup.com/

Access or Microsoft Excel. The additional statistical data analysis software used in this project was Minitab 15, which also imports files in CSV format. The project team exported GEMS output data into Minitab to perform advanced statistical analysis.[6]

Table 4. Phase I Data Collected

GEMS Metered Data
Demand (kW)
Maximum Demand (kW): on-peak, mid-peak[7], off-peak
Time of Maximum Demand: on-peak, mid-peak, off-peak
Power Factor at Time of Maximum Demand
Maximum Reactive Demand (KVAR)
Load Factor
Dissolved Oxygen (mg/Liter)
Data Calculated by GEMS
Energy Use (kWh): total, weekday, weekend, on-peak, mid-peak, off-peak
CO_2 Emissions (tons)
Daily Costs per PG&E E20P Tariff ($)
National Weather Service Data
Outside Air Temperature (deg F)
Relative Humidity (%)
Data Added Manually
Influent Flow (million gallons)
Total Suspended Solids (mg/Liter)

Currently, influent wastewater flow is metered continuously at the inlet to Lagoon #1 and reported on a daily basis. TSS reporting is based on the plant's weekly random sample. These data are currently manually transcribed from plant records; these data could be automated and 15-minute interval data could be incorporated into GEMS monitoring.

GEMS currently receives hourly National Oceanic and Atmospheric Administration - National Weather Service (NWS) temperature and humidity input from the Red Bluff Municipal Airport, which is located approximately 19 miles from the wastewater operations as shown in Figure 4.

[6] Minitab Inc. www.minitab.com

[7] PG&E uses the term partial-peak while GEMS output refers to "mid-peak." The results in this report refer to "partial-peak" for consistency with PG&E.

GEMS Weather Data to Bell Carter Olive Wastewater Lagoon Operations
Distance from Red Bluff Municipal Airport (KRBL) "A" to Corning "B" = 19 Miles

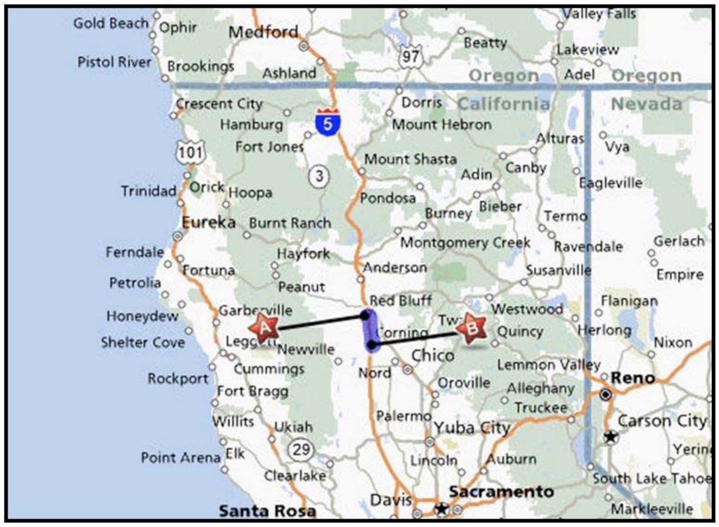

Figure 4. Weather Data Location Map

Although weather information is currently input real-time to GEMS, during Phase 1 it was not used in the course of routine wastewater operations. At the present time, wastewater aerators and aspirators operate independently of weather information and thus are not effectively correlated in a real-time, dynamic mode with ambient temperature and relative humidity conditions. In this project phase, weather data were imported in an 'offline' static mode for the statistical data analysis. However, this project has illuminated the need and justification of incorporating weather data into GEMS in a dynamic mode for ongoing operations. NWS weather data would be used in both manual and Auto-DR event forecasting and planning. Weather input would also be dynamically integrated to control VFDs to reduce electricity demand and usage in the outlined Phase II recommendations.

CO_2 Emissions Factor

The CO_2 emissions factor for aeration and aspiration is taken from the U.S. EPA eGRID annualized generation portfolio for Pacific Gas and Electric at Corning, CA (zip code 96021). This 2008 factor was used in this report for the data analysis period of September 15 – November 30, 2008. eGRID's updated value for 2009 will be used in subsequent data analysis as appropriate.[8]

The 2008 value is 0.879 lbs CO_2/kWh based on the following PG&E generation portfolio:

- 46% Natural Gas
- 15% Hydro Electric
- 14% Nuclear

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[8] http://www.epa.gov/cleanenergy/energy-resources/egrid/index.html

- 13% Coal
- 10% Non-Hydro Renewables (e.g. Photovoltaic, Geothermal, etc.)
- 1% Oil
- 1% Non-Reported Miscellaneous (e.g. distributed generation, etc.)

3.0 Project Outcomes/Results

The project team gathered data using GEMS to determine the relationship between aerator and aspirator operations and DO requirements. As discussed above, plant personnel currently operate each aerator and aspirator using automatic on/off toggle capability based upon a PC-based software program that controls the set points. GEMS has the capability to automate and refine aerator and aspirator operation based on current and predicted DO levels.

This section first shows the results of the monitored data analysis, then presents calculations of actual vs. required demand to meet desired DO levels, and finally outlines the proposed strategy to realize daily peak load management, EE and CO_2 emissions savings opportunities from automation of aerator/aspirator operations. The proposed strategy section contains calculations for replacement of existing motors.

GEMS tracked the PG&E E20P tariff invoice-accurate costs of aeration and aspiration on a real-time basis. Appendix A presents the details and statistical analysis of those data.

3.1. Monitored Data Analysis

Using the calculation methods described above, the project team used monitored data to calculate the following baseline conditions representing current plant operations.

- Demand Baseline
- Demand Variability Baseline
- Energy Consumption Baseline
- CO2 Emissions Baseline
- DO Sensor Composite Baseline
- DO vs. Temperature
- DO vs. kW

3.1.1. Demand Baseline

This section provides a demand baseline segmented by time-of-use (TOU) for the 77 day period. In addition, a histogram of the TOU data is provided that illustrates the demand distribution for each TOU period. The demand TOU baseline, segmentation and histogram information is as follows:

- On-Peak: 1,164 kW (12:00pm-6:00pm) = 25% of 24 hour period
- Partial Peak: 1,092 kW (8:30am-12:00pm; 6:00pm-9:30pm) = 29% of 24 hour period
- Off-Peak: 1,046 kW (9:30pm-8:30am) = 46% of 24 hour period
- Overall TOU: 1,089 kW

Figure 5 below provides a histogram summary of wastewater operations demand distribution by TOU for the study period. The statistical parameters (distribution pattern, skewness and kurtosis) are relatively uniform for all three TOU periods, essentially indicating consistent demand in wastewater operations independent of TOU. Such uniform demand will provide a steady baseline for planned continuous improvement phases of energy-environmental wastewater operations management.

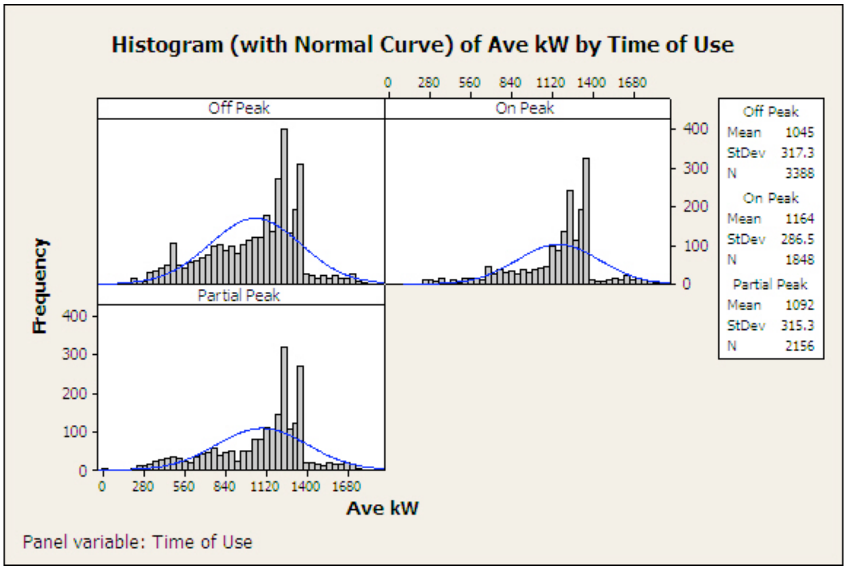


Figure 5. Average Demand by Time of Use

Source: GEMS reporting output and Minitab 15 statistical analysis

The GEMS output in Figure 6 provides the average daily (24-hour) profiles for weekday, weekend and peak day demand. As the graph indicates, there is significant intraday variability on the peak day, as discussed in the Demand Variability Baseline section below.

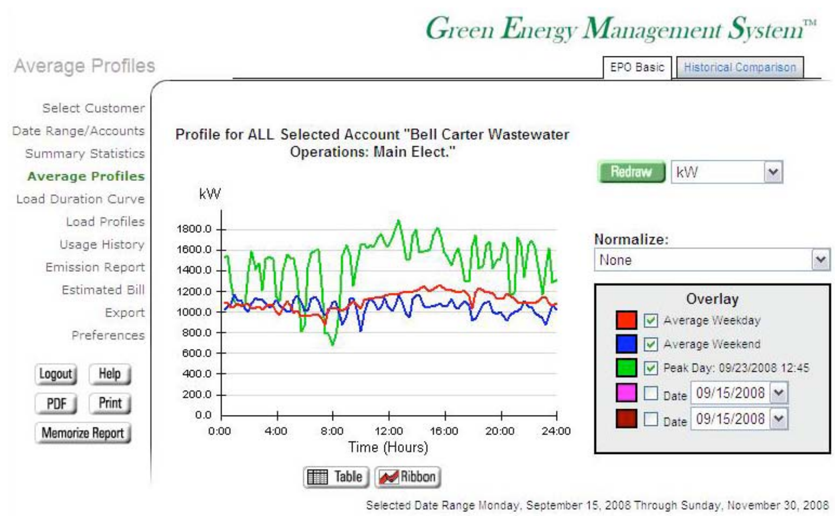


Figure 6. Daily Load Profiles

Source: GEMS reporting output

3.1.2. Demand Baseline Variability

Variability is a measure of the difference of data values from the mean for a specific period. As shown from the 15-minute kW values graphed in Figure 7, the plant experiences extreme interday and intraday demand variability due to on/off toggling of aerators and aspirators. Part of this variability arises from the plant's practice of providing DO build during off- and partial-peak periods to ride through on-peak periods.

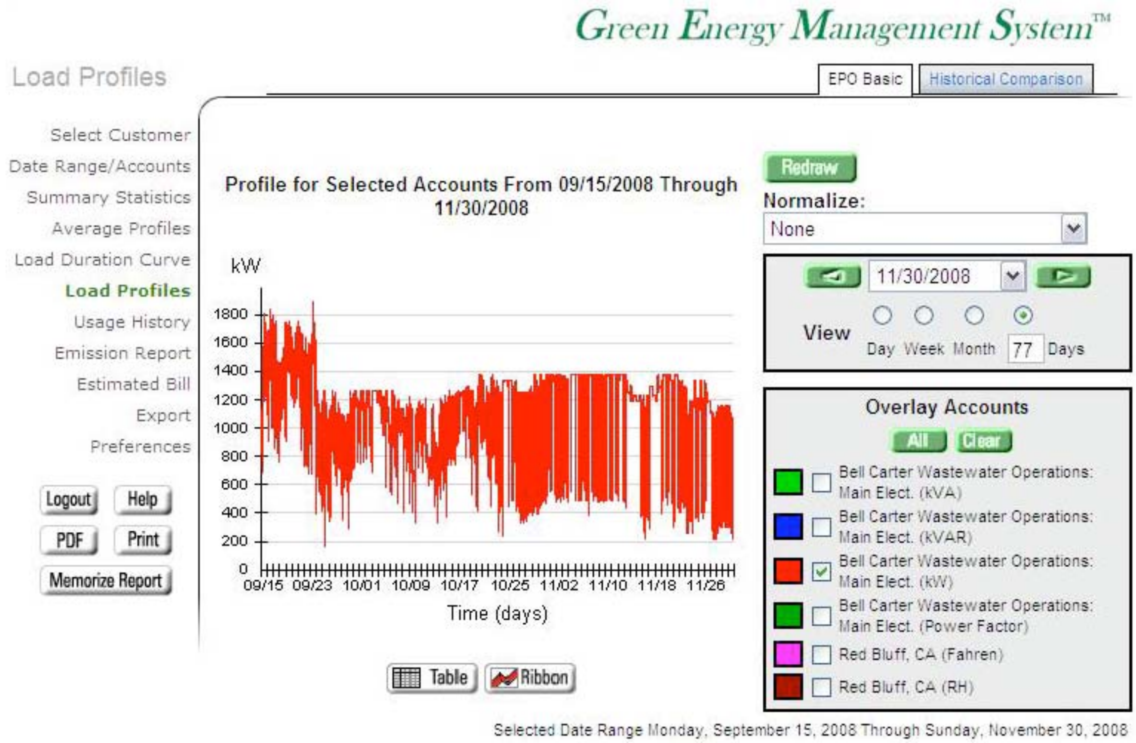


Figure 7. Interday and Intraday Variability

Figure 8 shows the variability of demand by hour of the day from 15-minute interval data for the analysis period. The average demand variability for the period is 22%; variability by time-of-use is shown in Table 5. The primary reason for demand variability is the current on/off toggled operation of wastewater aerators and aspirators to maintain the DO requirements.

Bell Carter kW Variability, September 15 through November 30, 2008

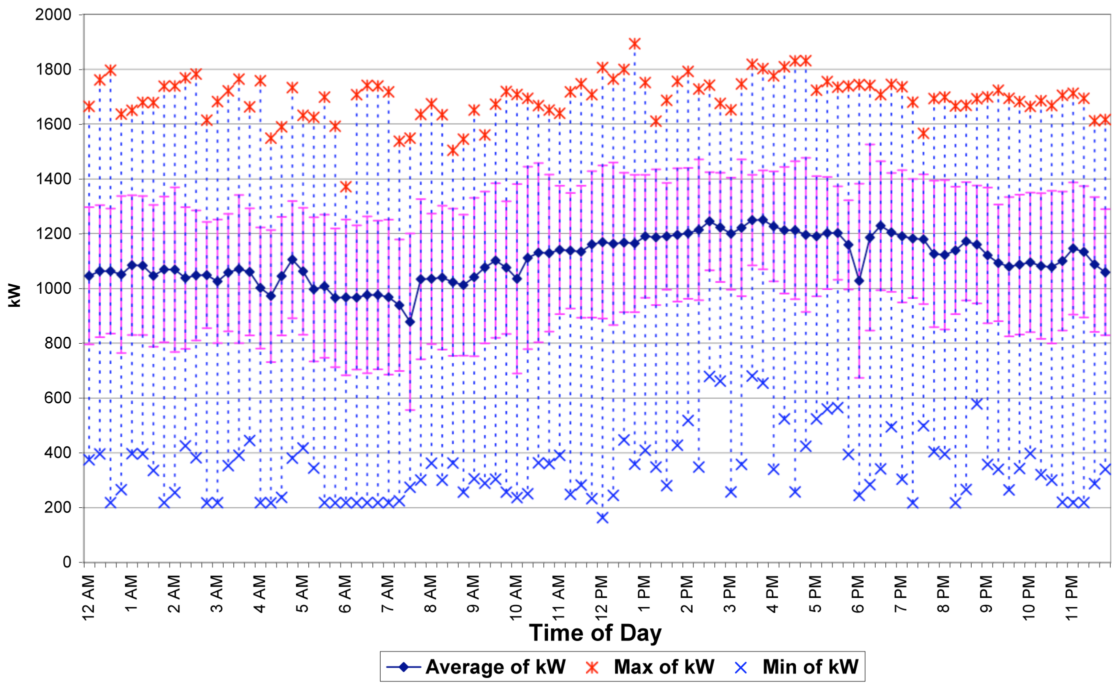


Figure 8. Variability Analysis by Hour

Sources: GEMS reporting, Lawrence Berkeley National Laboratory-Demand Response Research Center (LBNL-DRRC) Analysis. The pink lines are the standard deviations for each 15-min time point. The red and blue x's are the maximum and minimum demand, respectively

Table 5 shows the measured average and maximum demand data for the analysis period and the calculated variability based on 15-minute interval kW output data for the study period.

Table 5. Average Demand, Peak Demand, and Variability by Time-of-Use

	Average kW	Peak kW (Max)	Variability
On-Peak	1,164	1,893	21%
Partial-Peak	1,092	1,806	22%
Off-Peak	1,045	1,796	24%
Average of all TOU	1,089	1,832	22%

Sources: Average and Peak Demand from GEMS. Variability calculated by LBNL-DRRC.

As Table 5 indicates, the demand variability for the off-peak periods is slightly higher than variability in the other periods. As previously mentioned, there is an inverse relationship with temperature and DO. Lower night-time temperatures cause DO levels to rise and thus aerator/aspirator motors can be turned off during these off-peak periods.

3.1.3. Energy Baseline

Table 6 shows the total energy consumption, as well as consumption for the on-peak, partial-peak and off-peak periods, for the entire study period.

Table 6. Energy Consumption by Time-of-Use

On-Peak	242.8 MWh
Partial-Peak	550.9 MWh
Off-Peak	1,203.5 MWh
Total (all TOU)	1,997.2 MWh

Figure 9 displays the energy consumption (and demand) by week during September and October. Note that the highest consumption and load were during the first week, which represents the end of the summer season.

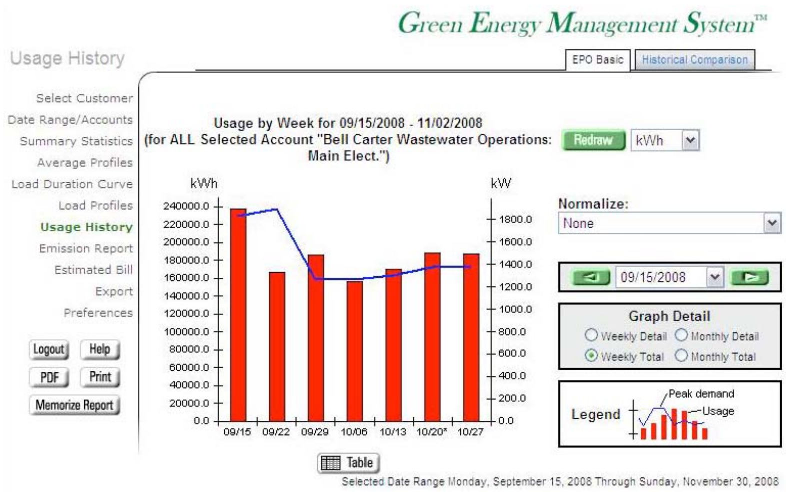
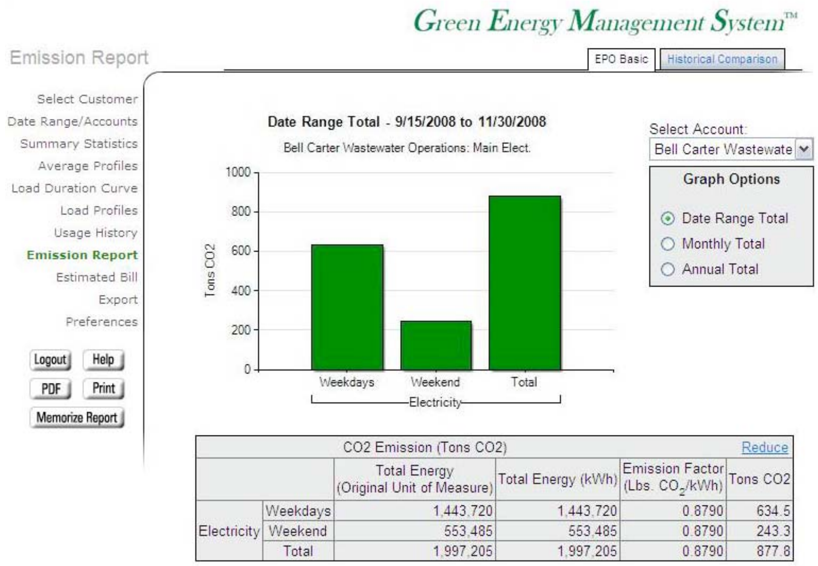


Figure 9. Weekly Energy Consumption and Peak Load

Source: GEMS reporting

3.1.4. CO_2 Emissions Baseline

Figure 10 shows the calculated CO_2 emissions for the analysis period, graphed by real-time-electricity use (kWh) for the total period, the weekdays during the period, and the weekend days during the period.



CO2 Emission (Tons CO2)		Total Energy (Original Unit of Measure)	Total Energy (kWh)	Emission Factor (Lbs. CO_2/kWh)	Tons CO2
Electricity	Weekdays	1,443,720	1,443,720	0.8790	634.5
	Weekend	553,485	553,485	0.8790	243.3
	Total	1,997,205	1,997,205	0.8790	877.8

Figure 10. CO_2 Emissions and Electricity Use

Source: GEMS reporting

The following CO_2 emissions are based upon measured kWh usage for the period September 15 – November 30, 2008 (77 operating days = 1,848 operating hours). GEMS derives the CO_2 emissions using the following equation:

$$1{,}997{,}200kWh * \frac{0.879lbsCO2}{kWh} = \frac{1756lbs}{\frac{2000lbs}{ton}} = 878 \text{ tons } CO_2 \qquad (1)$$

The U.S. EPA has recently announced that new federal greenhouse gas (GHG) emissions reporting requirements are forthcoming. Although CO_2 emissions are referenced in this report, all GHG can be reported and mapped in GEMS in either English or SI units once federal reporting requirements become effective.

3.1.5. DO Sensor Composite Baseline

Figure 11 is a histogram showing the frequency of number of occurrences of DO readings (in mg/L) averaged from all 5 sensors (defined as the DO sensor composite). It also shows the mean, the standard deviation, and number of data points (N) averaged from all 5 sensors for the analysis period.

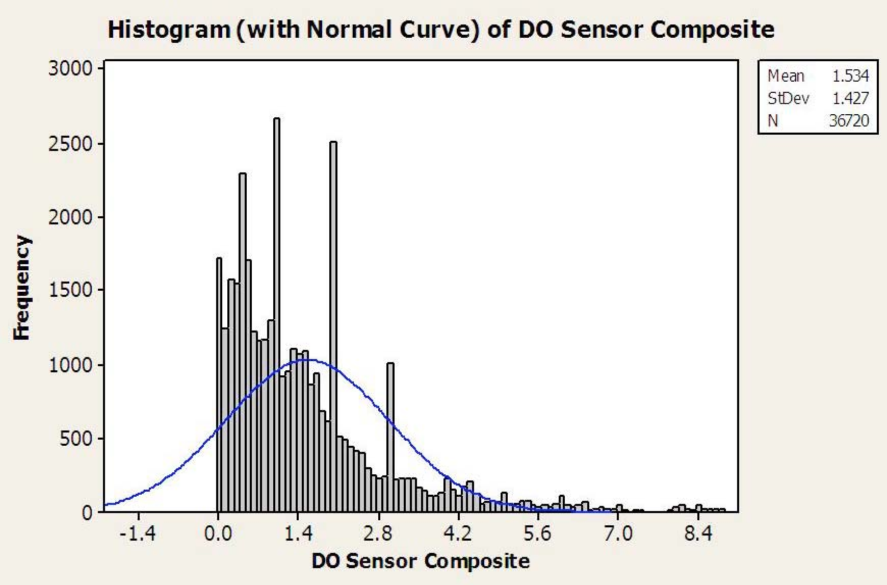


Figure 11. DO Sensor Composite

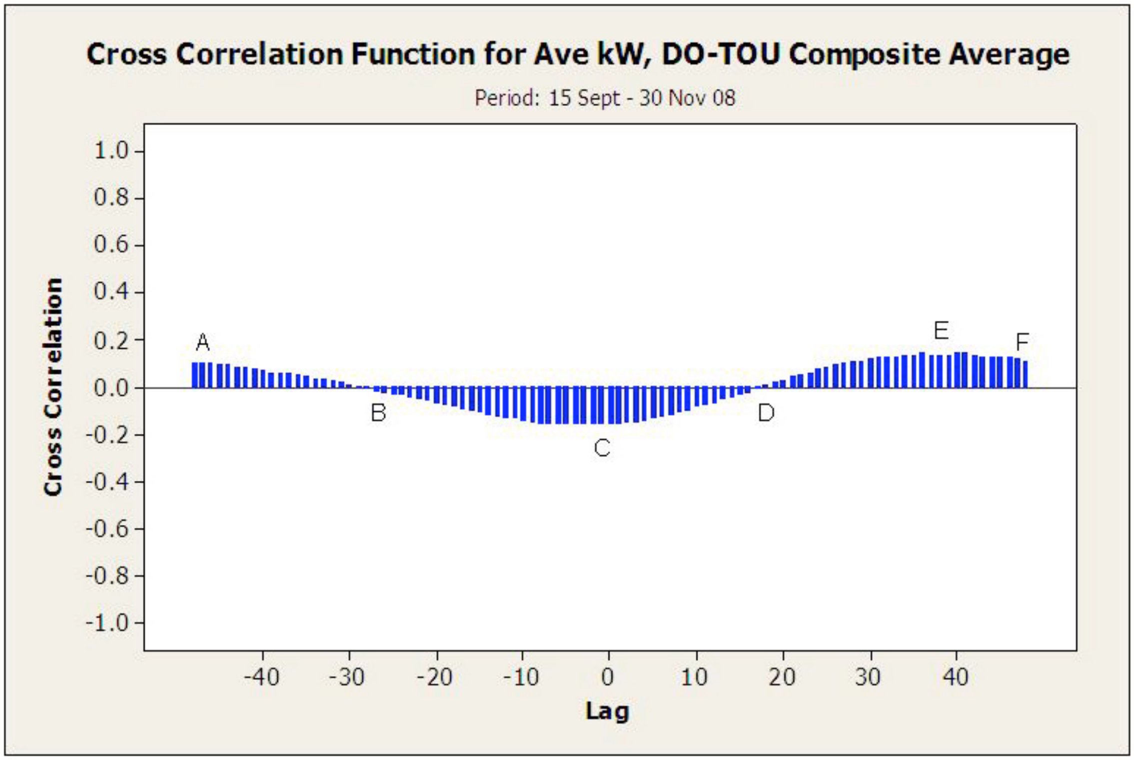
Source: GEMS reporting output and Minitab 15 statistical analysis

3.2. Cross Correlation Function

Through the cross correlation function (CCF) discussed in this section, a GEMS-VFD integration and control loop can be proactively structured to 'ramp up' or 'ramp down' the variable portion of wastewater operations contingent upon operating conditions. The Minitab software uses CCF to compute and plot the cross correlations between two time series, which can be useful in determining if a series of data leads or lags another series and by how many time periods.

As discussed in the Background section, the current wastewater operations management scheme attempts to build DO during off-peak and partial-peak periods to "ride out" on-peak periods at lower aeration and aspiration loads. The *DO build* practice historically has been experientially based and without effective measurement baselines. Phase II of this project will provide measurement and granularity to this practice to improve the current state demand-DO correlation and overall wastewater operations management.

Figure 12 shows the CCF for average kW and DO by TOU. For this cross correlation, the lag is a 15-minute interval. This function provides a tool to help describe how the plant operations as currently structured affect the overall level of DO in the discharge stream. Beginning at midnight on the left-hand side of the graph, the addition of more kW results in a measurably higher level of DO and therefore has a positive correlation. However, beginning at around 5 a.m. (point B), the operational characteristics of the plant and surrounding environment lead to lower DO levels regardless of the addition of more kW, and therefore there is a negative correlation factor. After point D is reached around 5 p.m. the aerators and aspirators once again are able to increase the DO levels faster than the other factors can affect them, resulting in a positive correlation at night.



Lag = 96, 15 Minute Intervals for 24 hour period
CCFC = Cross Correlation Function Coefficient

A: 12:15am (Lag-48;CCFC= 0.105288)
B: 5:00am (Lag-29;CCFC= 0.006068)
C: 12:15pm (Lag 0:CCFC= -0.153234)
D: 4:45pm (Lag 18;CCFC= 0.009040)
E: 10:30pm (Lag 41;CCFC= 0.144132)
F: 12:15am (Lag 48;CCFC= 0.112863)

Figure 12. Cross Correlation Function

The CCF provides an excellent kW-DO snapshot for understanding current wastewater operations. In Phase II the CCF information along with the regression results will be used to plan the DO build in alignment with shift scheduling and PG&E time-of-use tariffs. In addition, for future DR and EE planning the CCF will allow a clear understanding of effective timing and percent of demand available for a manual or Auto-DR event based upon relative DO levels, etc.).

3.3. Predictive Load Demand Reduction Estimates

Reduction in demand (as daily peak load management) and corresponding energy savings may be realized based upon streamlining of aeration operations using GEMS. As the examples below indicate, aerators are operating at higher kW levels than required during some periods as 'insurance' to meet environmental requirements. During other periods, kW may be insufficient to meet desired DO levels. Until this project, the plant has not had the energy efficiency management technologies available to effectively demonstrate, integrate and optimize the energy-environmental relationship to the greatest extent possible.

The load calculations in this study are based on data from the analysis period. They are intended to illustrate the method and equations used to estimate potential demand reduction during the on-peak period. The Annual DR potential to be estimated in Phase II will be based on data from the summer period when most DR events occur.

The examples below use both GEMS real-time measured data in addition to manual measurements of influent flow and TSS. The proposed Phase II plans to integrate all of these key variables using GEMS. In lieu of the direct integration of flow and TSS in Phase I, the multiple regression equations below statistically integrate them for approximate predictive on-peak demand needed in wastewater operations.

This section presents two estimates that use data for the periods indicated.

- The entire study period (September 15 – November 30, 2008)
- September 15 – September 23, 2008 (more representative of the summer season)

As discussed in the Background section above, the plant currently uses automatic on/off toggled operation of aerators and aspirators based on pre-determined set points. Part of this strategy includes providing *DO build* during partial-peak and off-peak period to ride through on-peak periods. (This is a similar in concept to the manufacturing plant practice of storage used in freezing and cooling operations.)

Appendix A provides additional information and detail on the regression analysis used in the following calculations.

3.3.1. Predictive Load for Total Study Period

Measured Average Conditions

- On-Peak Average kW: 1,164 kW
- On-Peak DO Composite Ave: 1.4 mg/L
- On-Peak Average Temperature: 23.9°C (75°F)
- Influent Daily Flow: 0.762 MM Gallons
- Total Suspended Solids (TSS) Ave: 1,677 mg/L

Calculation of Demand Required

Demand (kW) is dependent on temperature, DO saturation, flow and TSS according to the following equation, which uses coefficients derived by the Minitab software using conditions experienced during the period. This regression equation is applicable to partial-peak and off-peak periods as well as the on-peak period, as it incorporates and normalizes all TOU periods for the seasonal analysis.

> On-Peak Demand = 985 + 1.34 (75°F) – 128 (1.4 DO Ave mg/L) + 131 (0.762 MM Gal) + 0.0689 (1,677 TSS Ave mg/L)
>
> On-Peak Demand required to achieve 1.4 mg/L of DO = **1,122 kW**

Relative to the actual average on-peak demand of 1,164 kW, the actual demand required to achieve a DO level of 1.4 mg/L was 1,122 kW. In this example, aeration operated at approximately 3.6% more kW than required to achieve the desired DO level. This is a tangible example of a daily peak load management opportunity made possible when system variables are balanced using the automated GEMS system integrated with the proposed VFD configuration outlined below.

The on-peak demand savings are:

- On-Peak Demand (Actual): 1,164 kW
- On-Peak Demand (Required): 1,122 kW
- On-Peak Demand Savings: 42 kW

This represents a 3.6% kW savings, with corresponding energy savings from the on-peak energy consumption of 242.8 MWh of:

242.8 MWh * 0.036 = 8.7 MWh

The associated CO_2 emissions savings are:

8,700 kWh x 0.879 lbs CO2/kWh / 2,000 lbs/ton = 4 tons CO2

3.3.2. Representative Summer Week Period

The following example shows data from the third week of September 2008, the period with the highest demand, including the day with the maximum 15-minute peak (September 23rd). As Figure 14 below indicates there was a high average demand during that September week, making it most indicative of summer conditions, while demand became lower during the milder autumn months of the study period.

Measured Conditions

- On-Peak Average Demand: **1,437 kW**
- On-Peak DO Composite Ave: 1.1 mg/L
- On-Peak Average Temperature: 28.3°C (83°F)
- Influent Daily Flow: 0.780 MM Gallons
- Total Suspended Solids (TSS) Ave: 1,662 mg/L

Calculation of kW Required

On-Peak Demand = 3696 - 9.84 (83°F) - 358 (1.1 DO Sensor Composite Ave mg/L) + 96 (0.780 MM Gal) - 0.670 (1,662 TSS Ave mg/L)

Actual on-peak demand required to achieve 1.1 mg/L during September 15-23, 2008 = **1,447 kW**

Relative to the on-peak average actual demand of 1,437 kW, the demand required to achieve a DO level of 1.1 mg/L was 1,447 kW. This example illustrates a period when *less* electricity was used than was needed to provide the desired DO level. This indicates the importance of having the ability to define and integrate multiple operating variables to optimize environmental compliance. However, load and energy savings may not be possible during certain periods based on wastewater and environmental conditions.

3.4. Estimate of Demand Reduction Variability

In Phase II some existing standard efficiency aeration and aspiration motors would be replaced with VFD motors integrated with the EEM system. The purposes of this GEMS-VFD integration are to both mitigate demand variability swings and optimize the energy efficiency-DO balance to the greatest extent economically and operationally feasible. Hence this example shows potential demand reduction greater than the predictive load examples above, because it incorporates greater smoothing of variability fluctuations.

From a daily peak load management and DR perspective, the on-peak period is most important and is the basis for the proposed strategy and the following example. Additionally, on-peak consumption is the 'worst case' time period and demand scenario from both the plant operations and electricity infrastructure perspectives.

3.4.1. Estimation of Fixed and Variable Loads

The research team proposes to structure aeration and aspiration operations according to a *base load* and *variable load* configuration. The base load represents a fixed level of aeration necessary to meet DO requirements and will be met with aerators and aspirators operating with constant speed drives. The remainder of the total load, termed variable load, varies intraday and by TOU and will be met by aerators using motors controlled by VFDs. Both base load and variable load vary seasonally and will be adjusted based on monitoring data for each season, as described below.

Figure 13 graphs the metered average on-peak demand during the study period and shows the proposed demarcation line between the base load and the variable load. The following section discusses the method for derivation of the demarcation line.

The example shown below is an illustration for the fall period. As data for other seasons become available, the demarcation line between fixed and variable load will be calculated quarterly using the same calculation procedure illustrated below. The goal is to keep the base load aerators/aspirators adjusted to match each seasonal load. Results of monitoring data during the summer months during Phase II may indicate that more aerator motors will benefit from VFD controls.

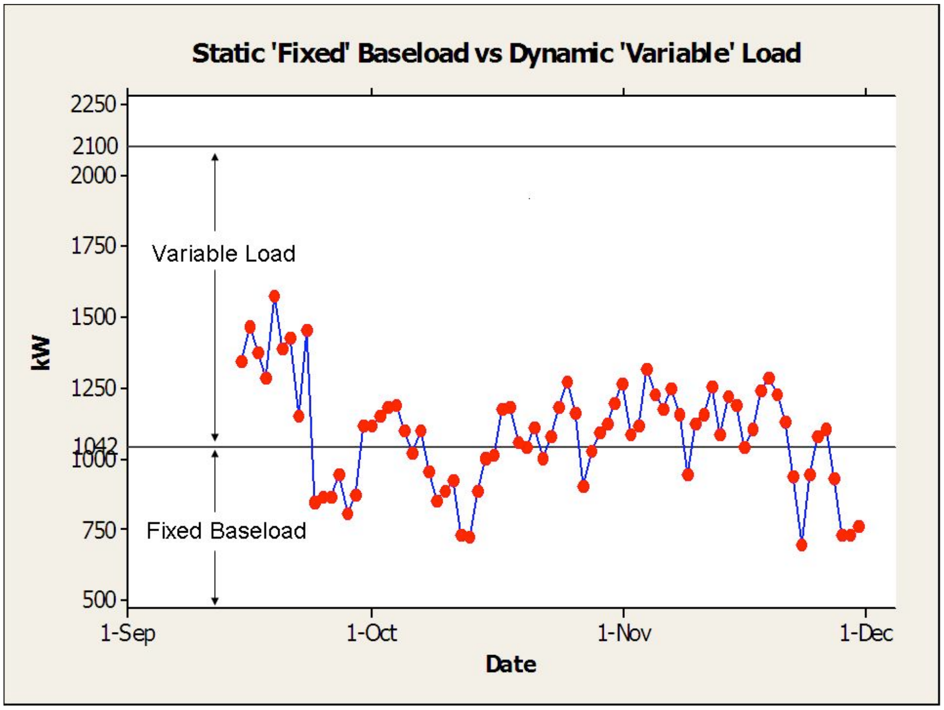


Figure 13. Base Load and Variable Load

For the lower end of the variable demand range, this method starts with the average annual on-peak demand *for the analysis period*, assuming that this is the minimum requirement for the fixed load. The project team then assumed that the on-peak variability of 21% (see above) can be reduced by half, providing a conservative estimate of a 10.5% reduction. The average annual on-peak value is thus lowered by the variability reduction amount and the results become the minimum requirement for the fixed load, as shown in the calculations below. Not choosing a lower value reduces investment in VFDs and ancillary equipment.

The fixed base load and variable load are calculated as follows. For the analysis period the maximum demand was 1,893 kW and occurred during the on-peak period. However, for the upper end of the variable load range, this calculation uses 2,100 kW to give a margin of safety for potential extreme conditions. (The aerators assigned to the variable load during Phase II will need to handle summer load conditions; the known historical upper limit for Bell-Carter's summer month wastewater operations is 2100 kW.[9]) Prior to VFD investment, further multi-year historical data analysis as well as incorporation of projected weather trends should be undertaken to ensure sufficient load capacity is available.

Following are the calculations of savings potential from reducing variability during the on-peak periods.

- Current Average On-Peak Average Demand Baseline[10]: 1,164 kW

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[9] Bell-Carter plant records from PG&E for 2005 – 2008

[10] Average on-peak demand for the period

- Demand Variability (On-Peak)[11]: 21%
- Demand Savings from Variability Reduction[12]: 1,164 kW * (1-0.105) = 122 kW
- Fixed Aeration/Aspiration Base Load: 1,164 kW– 122 kW = 1,042 kW
- Total Fixed-Variable Aeration/Aspiration Load: 2,100 kW
- Variable Aeration/Aspiration Load = 2,100 – 1,042: 1,058 kW

As discussed above and below, to accommodate the variable load, six aerator motors are proposed to be retrofit with premium energy efficient motors and VFDs. The remaining motors will be operated at constant speed but will be VFD-capable for potential future retrofit. Savings for the six proposed aerators will arise from their increased motor efficiency and their variable load operation**.**

Note that during Phase II annual data will become available, allowing the team to use a similar calculation method to estimate the seasonal and annual savings potentials.

3.4.2. Associated Energy and CO_2 Savings

The energy savings during the on-peak period based on 10.5% savings from the on-peak energy consumption are:

242.8 MWh * 0.105 = 25.5 MWh.

The CO_2 emissions savings for the on-peak period are:

25,500 kWh x 0.879 lbs CO_2/kWh / 2,000 lbs/ton = 11 tons CO_2.

3.4.3. Aeration and Aspiration Horsepower Requirements

Following are the calculations of aeration horsepower (50 hp/motor), aspiration horsepower (30 hp/motor), and the number of motors required to achieve the 1,042 kW fixed load and those to be used to meet the variable load.

Fixed Load

- 1,042 kW / 0.746 kW/hp = 1,397 hp for aeration and aspiration fixed load
- *Aspirator Requirement*
  - 10 aspirator motors @ 30 hp/motor = 300 hp
- *Aeration Requirement*
  - 1,397 hp for aeration and aspiration fixed load
  - <u>- 300</u> hp for aspiration fixed load

[11] Under current aeration operations, the demand variability is due to significant swings in both intraday and interday aeration operation. With the implementation of a fixed and variable load structure that can be seasonally adjusted, the seasonal and annualized variability will be dampened. This estimate uses a conservative 50% reduction of on-peak variability for illustration, but variability reduction could be higher with this baseload and variable load approach.

[12] Reducing demand variability by implementing the integrated baseload and variable load approach would yield a savings of approximately 122 kW during the fall seasonal period.

- 1,097 hp for aeration fixed load
- 1,097 hp / 50 hp per motor = 22 aeration motors for fixed load

Variable Load

Aerators: 300 hp (6-50 hp motors)

The variable load motors will be VFD-enabled and integrated with GEMS real-time weather, DO, TSS and flow measurements.

3.5. Energy Efficient Motor Replacement

Energy efficient motor replacement is required to achieve both energy savings and enable VFD installation. Existing aeration and aspiration motors are standard efficiency and very old. In addition, they are not VFD conversion-capable.

The research team assumed that in Phase II all motors, both those serving the fixed load and variable load, would be converted to premium efficiency motors. All of these motors would have VFD-retrofit capability. During Phase II, 6 of the aerator motors would be installed with VFDs to meet the variable load.

The following calculations show the demand and energy savings potential from retrofit of all of the existing standard-efficiency aerator and aspirator motors with premium efficiency motors. Table 7 shows the assumed motor efficiencies.

Table 7. Motor Efficiencies

Motor Type	50 hp	30 hp
Standard Efficiency (SE)	91.5	90.1
High Efficiency (HE)	93.8	93.1
Premium Efficiency (PE)	94.5	93.6

Sources: Standard and high efficiencies: Energy Efficient Motor Systems by Nadel, Shepard, Greenberg, Katz, and Almeida, Table 2-3 (Nadel 1992), average values (30 hp interpolated from 25 hp and 50 hp). Premium efficiencies: Consortium for Energy Efficiency (CEE) specifications, http://www.cee1.org/ind/motrs/Cee-nema.pdf

Assumptions: TEFC, 1800 rpm motors

The demand savings from conversion of standard efficiency motors to premium efficiency motors are calculated by this equation:

$$kW * (1 - \frac{SE}{PE}) \qquad (2)$$

The following calculations show the load and energy savings for conversion of all aerator and aspirator motors to premium efficiency motors**.** These calculations represent the savings for the 77-day study period.

The average aeration load for the entire period is 1089 kW. By using VFDs to meet the variable load, using the assumption discussed above of 50% variability reduction, the entire-period variability of 22% would be reduced to 11%. Hence the post-VFD aeration load would be:

1089 * 0.89 = 969 kW.

The measured energy consumption for the entire period was 1,997.2 MWh and the post-VFD energy consumption would be:

1,997.2 * 0.89 = 1,777.5 MWh

Per Table 7 above, there is a 3.2% kW savings between standard and premium efficiency 50 hp motors and a 3.7% kW savings between standard and premium efficiency 30 hp motors. Since average kW by motor is not available, the percentage savings is weight-averaged for 28 aerator motors and 10 aspirator motors at 3.33%. The period is 77 days * 24 hours/day = 1848 hours. Thus the demand savings from the aerator and aspirator motors are:

969 kW * .0333 = 32 kW.

The energy savings for the entire period from the efficient motors are:

1,777.5 MWh * 0.0333 = 59.2 MWh.

The associated CO_2 emissions savings are:

59,200 kWh x 0.879 lbs CO_2/kWh / 2,000 lbs/ton = 26 tons CO_2.

Annual savings may be recalculated from annual kW once data for the full year are available.

3.6. Multiple Regression Analysis

In preparation for estimating DR potential, the research team performed a multiple regression analysis to test the sensitivity of effluent DO (calculated as the average of DO measured by sensors #6 and #7) to multiple factors. The factors tested were:

- Prior hour DO from DO sensor #7 in Lagoon #3 (DO7(-1))
- DO influent from Lagoon #2 as measured by sensor #4 (DO4),
- Outside air temperature (TEMP),
- Current hour demand (kW) from aeration, and
- Prior hour demand (kW(-1) through kW(-5)).

An adjustment for flow rates was included using a ratio of the total lagoon volume to the average flow rate for the day (flowrat).

Table 8 shows the results of the multiple regression analysis. The software used was EViews 6.[13]

[13] http://www.eviews.com/eviews6/eviews6/overview/ev6over.html

Table 8. Multiple Regression Results

Current Dissolved Oxygen in Lagoon #3		
Variable	**Coefficient**	**Standard Error**
Prior Hour DO *	0.000605	6.55E-06
DO of Influent*	0.061978	0.01768
Outside Air Temperature*	-1.19E-05	7.85E-07
Current kW Demand	8.23E-08	7.12E-08
1 Hour Previous kW*	2.95E-07	7.48E-08
2 Hour Previous kW**	1.88E-07	7.70E-08
3 Hour Previous kW	9.36E-08	7.27E-08
4 Hour Previous kW***	1.21E-07	7.34E-08
5 Hour Previous kW	8.85E-08	6.78E-08
R-Squared	9.16E-01	
# of Observations	1.81E+03	

* Indicates significance at the 1% level

** Indicates significance at the 5% level

*** Indicates significance at the 10% level

The results in Table 8 indicate that there is at least some theoretical potential for DR at this site. Primarily, there is a positive correlation between aeration demand and effluent DO after controlling for all other factors. As shown below, this translates into the potential to reduce demand during a DR event and predict the resulting amount of DO increase that will occur over the remainder of the day.

Based on these results, the coefficients describe the sensitivity of the dependent variable (final DO at discharge) to changes in the independent variables. Three of the independent variables have no statistically significant change in DO: the current level of kW (with a 24.8% probability of being zero), kW used three hours ago (19.8% probability of zero) and kW used five hours ago (19.2% probability of zero). A practical interpretation of these results supports the idea that turning up the aeration is unlikely to have an immediate effect in a lagoon with over 20 million gallons of wastewater. The effects are more likely to be seen in the hours following the change in kW. The effect will trail off after some period of time, and unreported regression results with lags beyond five hours indicate that four hours is the longest period of aeration kW reduction for which there is significant change in DO levels. Based on this result, the low impact at three hours may be an anomaly that can be investigated by further real-world testing.

These results suggest that there is no more than a four hour window for having a direct effect on DO at the discharge of the lagoon, although the impulse response function results earlier in this report show that the indirect effects can linger for nearly 12 hours.

3.7. Demand Response Potential Estimates

DR potential is often difficult to determine, even given access to data and real world scenarios as in this study. The following estimates are based on the inferred relationships of DO, kW, influent flow rate, outside air temperature and hence are statistically supported by the entire data set from the analysis period. Multiple regression analysis of these relationships generated the coefficients shown in Table 8 above. These coefficients were used to run three hypothetical scenarios of the impact of kW reduction on DO level. Appendix B more fully explains the calculations of the DR potential presented in this section. While these results remain preliminary, the potential for DR strategies is strongly supported by the data collected.

3.7.1. Impulse Response Function Examples

Figure 14 shows a theoretical impulse response function for a 1-hour reduction of kW (through reduced use of aerators/aspirators) at the Bell-Carter wastewater treatment plant using the regression results from Table 8. The assumptions for this regression were a constant temperature during a 12-hour period and a constant influent flow rate. The results show that a reduction of 263 kW of aeration load would result in a maximum reduction of DO of 0.1 mg/L.

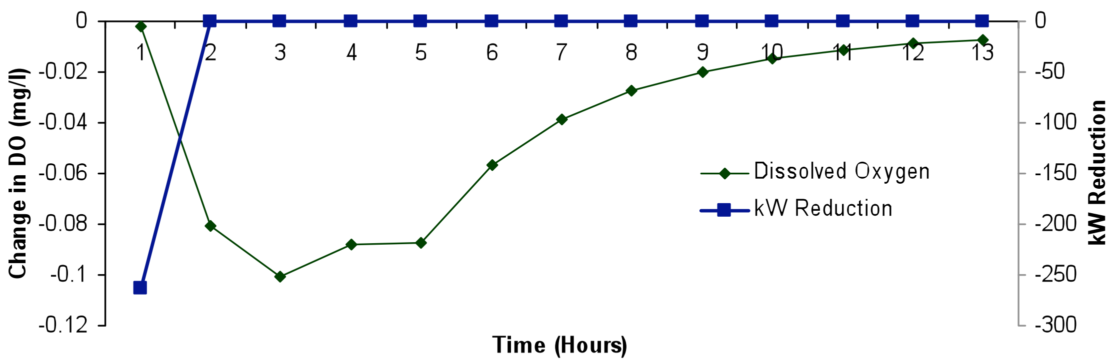

Figure 14. Impulse Response Function of DO to One-Hour kW Reduction with Constant Temperature

The reasoning behind measuring the demand reduction resulting in a 0.1 mg/L reduction in DO is based on the reality that plant conditions change on a daily basis. However, the requirement to maintain discharge DO levels above a regulatory minimum means that the DR potential of the site will vary depending on the initial DO readings at the beginning of the event.

A second analysis was performed using a slightly more realistic set of assumptions. The compounding factor of temperature was added to the regression using actual hourly temperature data from Chico, CA on August 31, 1998 during an intense heat storm. As discussed above, the average on-peak load for the analysis period was 1164 kW. A 10% reduction of this load represents a DR potential of 116 kW. Finally, the impulse demand reduction was assumed to last for the full six on-peak hours of this peak day. Figure 15 shows the impulse response function with resulting DO levels for this scenario.

The results show that given an extreme temperature day and a 10% peak load reduction the reduction in DO does not exceed 0.2 mg/L. Also, the detrimental effect of the event is gone after about eight hours.

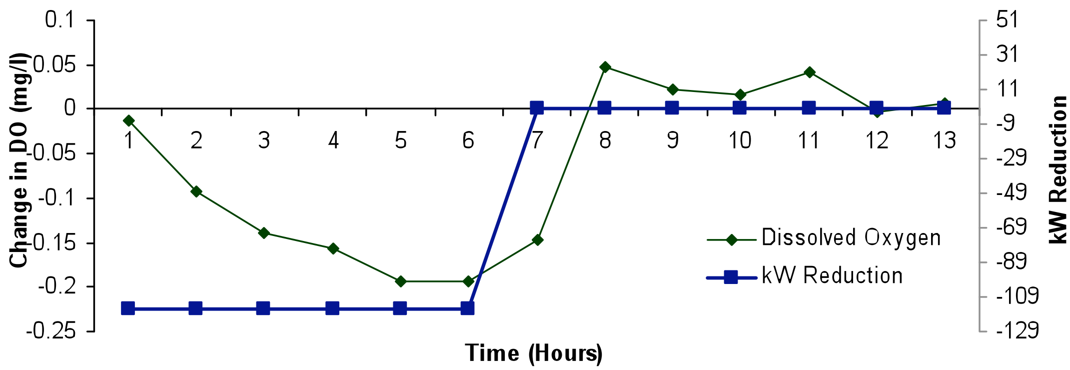

Figure 15. Impulse Response Function of DO to Six-Hour kW Reduction with Peak-Day Temperatures

The authors reemphasize caution in interpreting these results. These are both preliminary and theoretical results only. They do however indicate that additional real world tests of demand reductions could possibly lead to site savings from DR activities.

3.7.2. DR Event Example

In the next example, using the impulse response functions discussed above, a theoretical six-hour DR event is mapped on top of actual data collected for the site. This example illustrates the theoretical results of a 10% reduction in kW during the noon to 6pm period on September 28, 2008, the hottest day in the observed data set.

For background, Figure 16 shows the day's actual load shape plotted with actual DO (with no demand response). The graph also shows the site's PG&E DR baseline, which represents the average hourly kW for the three days with the highest on-peak kW (during the CPP period of noon–6 pm) of the ten non-CPP weekdays prior to the selected peak day of September 28, 2008. The figure shows that the DR baseline is considerably higher than the daily load shape. On an actual DR day (of which there were none during the analysis period) the difference between the DR baseline and the daily load shape would likely be lower. This illustrates again that variability in the baseline complicates the feasibility of DR and highlights the need for correlation of multiple parameters to inform DR control strategies. This variability occurs at many industrial sites.

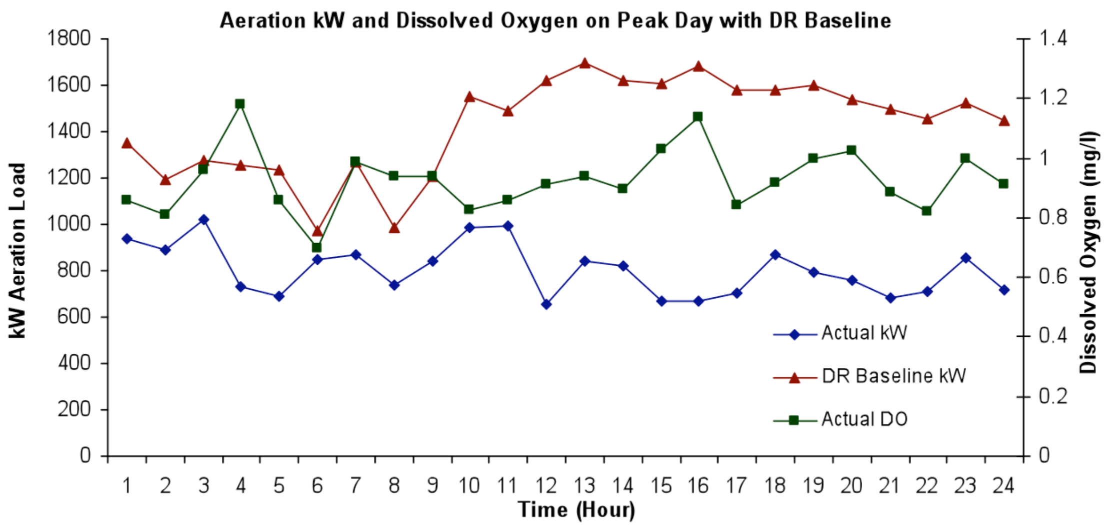

Figure 16. Load Shape for Actual kW and Actual DO on Peak Day

Figure 17 shows the day's load shapes from actual data (without DR) and with a 10% kW reduction during a DR event. Figure 18 shows the DO levels from the day's actual data and the DO levels resulting from the demand reduction during the theoretical DR event.

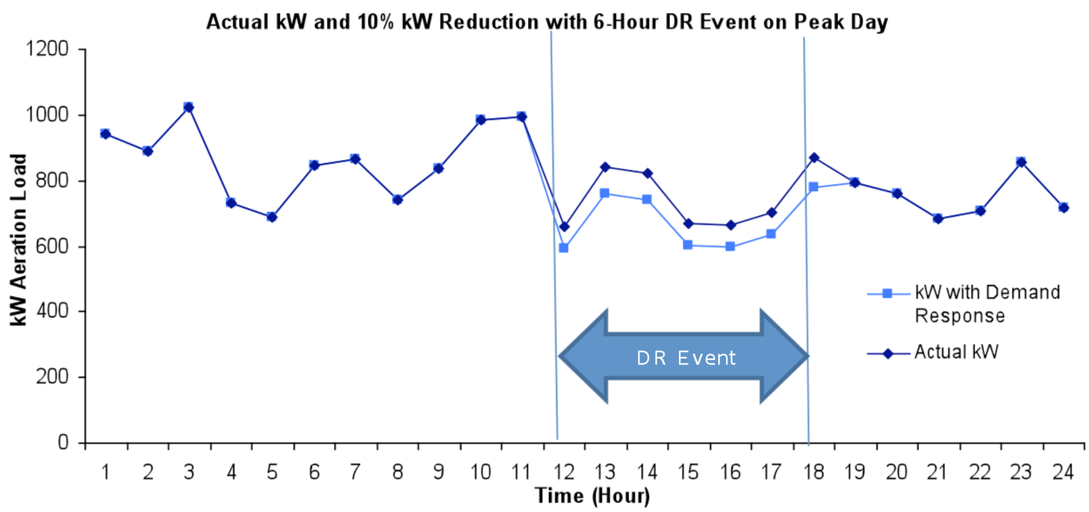

Figure 17. Theoretical vs. Actual Demand During Simulated 6-Hour DR Event

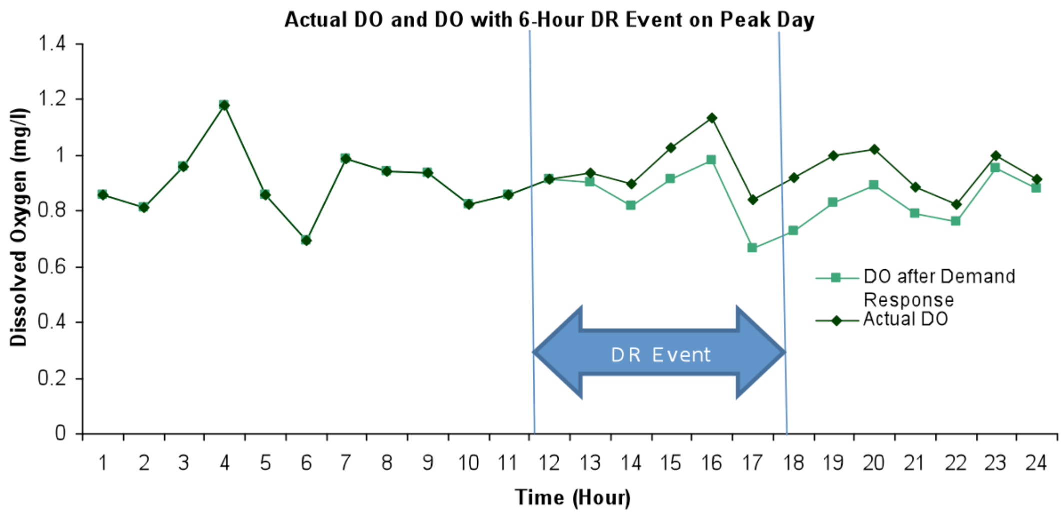

Figure 18. Theoretical vs. Actual DO with Simulated Six-Hour DR Event

3.7.3. DO Build Followed by DR Event Example

As discussed previously, the wastewater treatment facility currently operates on a DO build strategy whereby to compensate for being capacity constrained (as shown in the cross correlation function above) by attempting to increase DO levels prior to peak loading during the day. This suggests that the plant might be able to use a DO build strategy as part of their overall DR strategy. The research team simulated a theoretical DO build assuming 10% kW increase over observed levels on the peak temperature day of September 28, 2008 for eight hours followed by a DR event with 10% reduction in kW below actual observed levels for six hours. Figure 19 shows the actual demand on the peak day and the reduced demand during the theoretical DO build period.

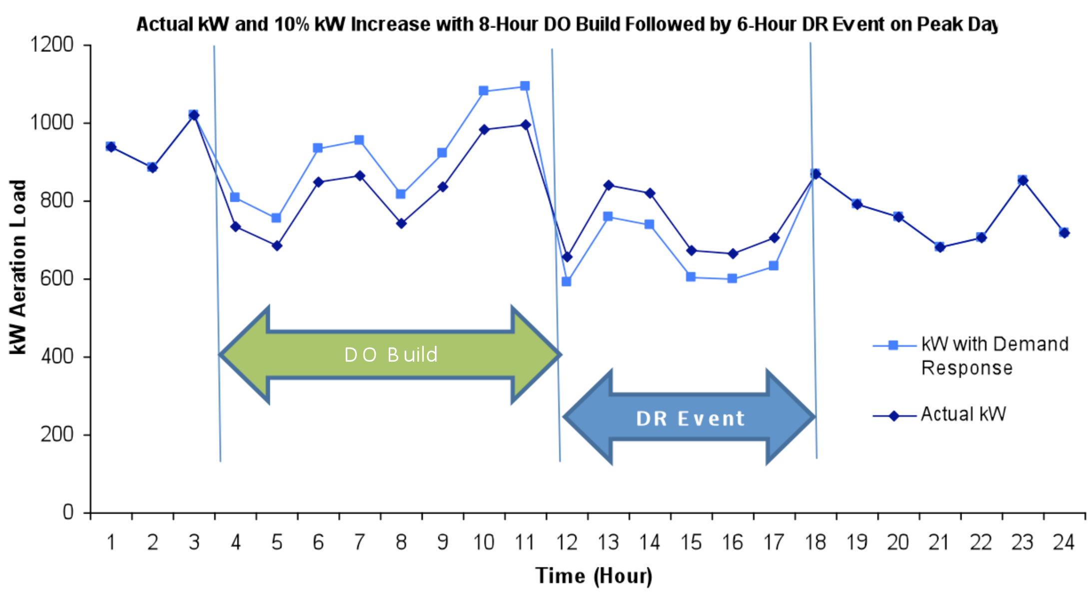

Figure 19. Demand with 8-Hour DO Build Followed by 6-Hour DR Event on Peak Day

Figure 20 shows both the actual observed DO for the selected day and the theoretical effects on DO of the DO build and DR event. It is important to note that this is a theoretical result. However, the results are strongly suggestive of the possibility of using a DO build strategy to minimize the risk of discharging below the plant's regulatory limits. By the end of the simulated DR event, the levels of DO are nearly identical with the actual observed levels, while having reduced consumption by 683 kWh during the DR event.

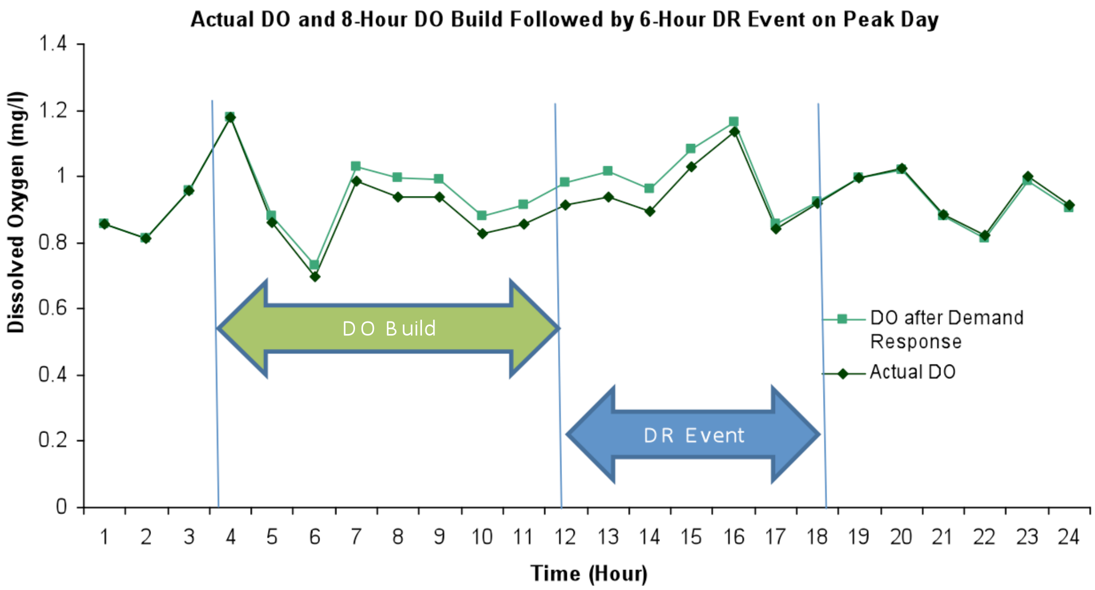

Figure 20. Dissolved Oxygen with 8-Hour DO Build Followed by 6-Hour DR Event on Peak Day

3.8. DR and Auto-DR Discussion

As discussed above, the research team estimates the relationship between kW and DO in theoretical DR events as well as daily peak load management savings from reducing demand variability using VFD motors with automated process control guided by DO and weather data integration. Additional Phase II data, especially from the summer season, are needed to estimate the actual DR potential. The primary component of this strategy will be DO build. Analysis of wastewater energy and environmental parameters, tariffs, and weather data from the summer peak period correlated by GEMS will provide estimates of the potential for additional off-peak DO build to provide on-peak demand reduction during DR days.

From an initial DR and subsequent Phase II Auto-DR perspective, the on-peak savings opportunity can provide a tangible example of how Auto-DR can eventually evolve to a future standard in core operations. In industrial plants core operations are where the primary demand is focused and have typically been 'off limits' for both manual and Auto-DR. In contrast, non-core support operations (e.g. office buildings, warehousing, etc.) generally provide small DR opportunities in industrial plants.

In Phase II post-VFD installation and the other associated investments needed for effective DR and Auto-DR, the plant could conduct Auto-DR for the on-peak demand. A practical and realistic Auto-DR approach would be as follows:

Assumptions

1. VFD and applicable infrastructure capacity investment (e.g. motors, electrical distribution, etc.) is in place.
2. VFD control loop integrating GEMS data for weather, DO, TSS and flow is in place.
3. GEMS DR and Real-Time Pricing modules are enabled and integrated with fixed and variable load requirements.

Non-Real-Time Pricing (Non-RTP) Approach: With the referenced assumptions in place, the GEMS DR module (which is also functional in the new OpenADR structure) is enabled to reduce 122 kW from specific aerators (and aspirators if required). Each specific aerator assigned for DR would receive a California Independent System Operator (CAISO) or LBNL-DRRC curtailment signal and automatic notification to the designated wastewater operations management. In addition, GEMS DR would track DR financial incentives (e.g. $X/kW, etc.) to report financial incentives payable per specific aerator and/or aspirator with a cumulative total for a specific DR event or multiple events.

RTP Approach: Similar to the Non-RTP approach but triggered by RTP signals and/or a DR curtailment signal. PG&E has announced that it will implement Peak Day Pricing (PDP) starting in 2010. Customers will be given a one-day notice of a PDP event to reduce or shift load. In Phase II, simulated research on RTP/PDP can be performed using GEMS capability to evaluate a simulated price signal for integration with Auto-DR.

To achieve expanded DR and Auto-DR, whether including non-RTP or RTP in food processing or other industrial segments, proactive energy supply chain operations planning needs to be in place on both the utility and customer-sides of the meter.

The 2007 DRSS report outlined the strategic planning approach for 'Red-Yellow-Green' (RYG) zones for each day of the summer months. In this approach, the allocation of a date to a zone depends on the probability that a DR day would be called on that date based on historical system demand, degree-days, and other statistical information. Each zone has a corresponding tariff incentive, with highest incentives for red zone days and lowest for green zone days. The zones would be on specific days, weeks or months during July through October such that plants could sign up for their dates in advance and could plan finished goods, capital projects, labor, railroads, trucking, raw materials and other supply chain resources. This RYG approach needs to be in place prior to the summer season for all energy supply chain entities to proactively plan DR based on enterprise resource planning finished goods inventory forecasts, engineering capital project completions, etc.

The plant master production schedule and/or operations asset assignment can be integrated and applied with RTP to automatically trigger DR participation on pre-defined RYG zone days based on schedule parameters. In addition, specific non-core plant assets, such as specific production lines with sufficient finished goods inventories to meet customer demand, warehousing areas, offices, etc. can be configured for specific Auto-DR enablement separately from core assets in plant operations. As previously mentioned, Phase II will incorporate intraday RYG and simulated RTP signals.

A final point in the discussion of DR in industrial settings is the difference between DR and daily peak load management (permanent load shifting). One of the key lessons learned in this and other industrial demand response studies is that DR activities sometimes prove appropriate for everyday use and become permanent shifts in load. This occurs because DR is seen as having a risk/reward tradeoff. Production processes are altered in response to a financial incentive to take a risk and deviate from activities that have proven reliable. In some cases industrial plant operators find that they can tolerate the small level of increased risk without increased incentives and make what began as a DR strategy into a permanent practice.

The wastewater process studied at Bell-Carter presents itself as a candidate for continued DR activities because the risk portion of the risk/reward payoff will not likely ever fall to a level low enough to allow the plant to operate continuously with little or no aeration. The data have shown that the plant currently operates at times with an excess DO “buffer” that will be an excellent candidate for a permanent shift in load. There will remain, however, some operating margin that produces a confidence level for operations that could, with the right financial incentive, be called upon to produce a short-term demand reduction. In summary, this plant will remain a candidate for DR even after permanent load reductions are accomplished.

4.0 Conclusions and Recommendations

4.1. Conclusions

During the 77-day seasonal wastewater assessment period, the project team established baselines for current plant operations. The team effectively measured, analyzed and reported data provided by GEMS integration of the majority of all wastewater inputs. Using these baseline data from the seasonal period, this report demonstrates a methodology for estimating potential savings for daily peak load management and the associated EE for Phase II. Besides quantifying and documenting decades-long methods and practices at the plant, the automated and manual data integration and analysis gleaned from this initiative has illuminated new opportunities in wastewater operations. The baseline information has been sufficient to prepare Phase II cost-benefits assessment.

This section maps project conclusions onto the original three objectives to form the basis for the subsequent recommendations.

Objective #1: To collect baseline data and develop correlations for Demand Response (DR), Demand Management (DM), Energy Efficiency (EE) and relate those to environmental management and associated regulatory compliance. The baseline information will be used for a Phase II cost-benefits assessment per Phase II as outlined below.

This project demonstrated the use of automated EEM technology for managing plant operations. The resulting energy-environmental data integration and correlations can provide baseline data for current operations. They can also provide a planning and decision-making foundation for continuous improvement in integrated energy-environmental management.

The baseline data gathered during this project form the basis for estimates of potential savings from daily peak load management, energy efficiency and CO_2 reduction during Phase II, as discussed under Objective #3.

Objective #2: To illustrate by process example and measurement the potential energy supply chain and environmental management optimization of electricity generation, transmission, distribution and wastewater operations, CO_2 emissions management and forecasting.

The data integration gleaned from the wastewater project can provide sound information for integrated resource planning estimates and measurements. For example, the energy data are useful in demand response and time-of-use opportunity planning for utilities and CAISO. In addition, the CO_2 emissions data correlated with energy consumption assists in reporting of CO_2 emissions impacts of wastewater–related air emissions, which is beneficial for upcoming AB 32 (California Global Warming Solutions Act of 2006) regulatory compliance and forecasting.

Objective #3: To conduct a manual/Auto-DR, DM, and EE feasibility and cost assessment that incorporates and balances wastewater lagoon influent, dissolved oxygen, and associated aeration/aspiration energy and demand requirements.

Preliminary analysis of DR potential using multiple regression analysis to develop coefficients statistically supported by the data from the study period shows theoretical impact of demand reduction on DO levels. In a scenario with ten percent kW reduction on a peak day, impact on

DO level may be modest and recede in less than a day. Further tests of demand reduction based on actual data could demonstrate DR savings potential.

The initial data analysis for Phase I shows a method for estimating the approximate daily peak load management opportunity from automating wastewater aeration and aspiration operations. As stated above, during the fall seasonal period the project team estimated an on-peak kW reduction potential of 3 – 10% percent.

Phase II savings from daily peak load management as well as DR/Auto-DR will arise from replacing some existing aerator motors with VFD motors that can automate and promptly adapt to changes in wastewater parameters. Savings are relative to the current on/off operation of aerators with resulting missed opportunities for both energy and environmental management. EE savings will also result from retrofit of all existing aerator and aspirator motors to premium efficiency motors.

In Phase II, the research team will analyze wastewater energy and environmental parameters correlated with weather and tariff data from the summer peak period to predict DR/Auto-DR potential using a strategy of off-peak DO build to provide additional demand reduction during DR days.

4.2. Discussion

This project has illuminated potential opportunities at the plant for daily peak load management, energy efficiency (EE), water quality environmental management, and carbon dioxide (CO_2) emissions savings. It has established the basis for calculating demand response (DR) opportunities in Phase II. Data collection at Bell Carter is ongoing and the calculation methodology presented in this report will be applied to future data. Changes to plant operations, as well as planning for Auto-DR opportunities, will therefore be dynamic and seasonally adjusted. In addition, data analysis will become more robust as three years of historical 15-minute wastewater kW and kWh data from PG&E that have been input into GEMS.

Proactive water chemistry management and forecasting can be realized due to the new technology enablers and structure to address key energy-environmental issues. For example, Phase I has ascertained the impact of salinity in wastewater, which significantly impedes DO solubility and results in significantly greater demand than required for wastewater operations. Effectively addressing salinity can provide further daily peak load management and demand response opportunities. Salinity is an excellent example of an integrated energy-environmental issue. It is also a health issue that applies to many industry segments where sodium-based inputs to wastewater are commonplace. Relative to other industrial segments, the food and pharmaceutical industries are subject to the most stringent FDA requirements. Thus further salinity research is warranted from energy, environmental and health perspectives.

This project demonstrates an approach and methodology that California food processors can use to automate their operations for energy efficiency, demand management, and demand response. Many food processing industries, particularly fruit processing (including tomatoes),[14]

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[14] SIC code 2033/NAICS 311421

generate wastewater similar to this olive processing plant, so that they would have similar discharge requirements and conditions. The quality of wastewater from other food processing plants, as well as site location and method of treated water discharge, would determine the type of permit and applicable regulated discharge levels. Therefore, EE/DR potential and strategies would need to be designed based on these site-specific conditions.

This study was performed for a wastewater treatment operation that utilizes aerators and aspirators. Not all wastewater treatment plants utilize this type of technology. The Auto-DR potential for plants that utilize other type of equipment will be different and is out of the scope of this report. For more information on wastewater treatment types, see *Opportunities for Energy Efficiency and Automated Demand Response in Wastewater Treatment Facilities in California: Phase I Report* (LBNL 2009).

Other industrial and commercial segments without major wastewater operations can selectively apply the initiative's processes and methodologies to their operations to improve DR, daily peak load management, EE, CO_2 emissions data integration, environmental management and reporting.

4.3. Recommendations

Based upon the wastewater project conclusions, the following are the recommendations for Phase II.

Install 38 VFD-capable premium efficiency aerator and aspirator motors to achieve energy efficiency savings and CO_2 emissions reduction benefits (contingent on a wastewater electricity distribution system capacity assessment).

1. Install a minimum of six VFDs on aerator motors to accommodate wastewater variable load.
2. Replace PC-based DO monitoring system with a contemporary technology that integrates with GEMS.
3. Apply the National Weather Service ambient temperature and humidity data now integrated into GEMS to the wastewater control scheme.
4. Install pulse flow meters and adjacent DO sensors at Lagoon #1 influent and Lagoon #3 effluent points. Install total suspended solids and salinity probes in lagoon operations and integrate with GEMS.

Although not included in the original objectives, the research team developed the following recommendations during the course of Phase I and submits them for consideration for Phase II.

5. Conduct salinity and acetic acid research by the University of California-Davis, California Institute of Food and Agricultural Research/Food Science and Technology Department. For salinity, seek FDA food-grade sodium-based chemical replacement(s) for current sodium-based chemicals to balance food product sodium requirements relative to wastewater energy and environmental requirements due to salinity levels. Conduct similar food science research for acetic acid replacements.
6. Once the project has optimized the water chemistry and energy operations of Lagoons #1, #2 and #3, assess Lagoons #4, #5, #6 and #7 to see if water quality has improved

enough to reduce energy-intensity through an alternative non-aeration system or reduction of aeration through VFDs, use of fewer motors, etc.

7. Explore additional wastewater technologies, including water and energy conservation strategies, for further energy-environmental improvement in wastewater operations (e.g. segregation of wastewater streams, reuse of washing water, recycling of final rinse water, fine-bubble aeration, solar-powered water circulators, etc.).
8. Perform research on real-time pricing using GEMS capability to evaluate the integration of a simulated price signal and Auto-DR signal using Red/Yellow/Green zones.
9. Perform research on non-real time pricing using GEMS capability to evaluate Auto-DR signals using Red/Yellow/Green zones.
10. Perform manual DR tests that duplicate the scenarios used in the simulations.

Although not included in the scope of this report, innovations in renewable energy (e.g. photovoltaics and methane capture for fuel cell application) for use at Bell-Carter and other wastewater plants have been identified for further review with the Energy Commission for a potential Phase III.

4.4. Benefits to California

Project results indicate that the use of automated technology to integrate aeration energy with environmental requirements would be beneficial on 'both sides of the meter.' Wastewater operations such as those at Bell-Carter would realize economic benefits and more precise environmental compliance. The state utility electricity infrastructure and supply chain would experience demand and consumption savings.

The results of this integrated energy-environmental wastewater project could be beneficial to the California food processing industry in addition to other California entities as follows.

4.4.1. California Food Processing Industry, Other Industrial Segments and Municipal Wastewater Operations

The integrated energy-environmental project results illustrate an interrelationship of multiple variables that need to be included and effectively measured in major wastewater operations. The result of this holistic approach is effective wastewater measurement and management that can achieve:

- initial wastewater cost savings plus ongoing cost and resource management for sustainable competitive advantage for wastewater plants;
- predictive energy and environmental resource management;
- ability to effectively plan and participate both core and non-core plant operations in DR and Auto-DR programs while continuing to achieve strict environmental regulatory compliance;
- advancement of knowledge of wastewater chemistry impacts on energy use and environmental management.

4.4.2. California Commercial Industry Segments

The commercial buildings sector can apply many of the integrated energy-environmental aspects of this initiative, such as application of the cross correlation function (CCF) for more

TOU energy-environmental planning and impact; real-time, integrated energy-CO_2 emissions tracking and reporting at asset levels (e.g. chillers, HVAC, lighting, etc.) with total building rollup; and improved ability to effectively plan and participate in energy programs such as DR, Auto-DR and EE.

4.4.3. California Energy Commission

This wastewater initiative can assist the Energy Commission's Industrial, Agriculture and Water program by providing a strategic, holistic approach to wastewater energy and environmental management coupled with measured results to apply statewide to program and incentive development. In addition, this approach will assist the Commission in its integrated resource planning with regard to California wastewater operations.

4.4.4. California Electric Utilities and CAISO

California's utilities can use results of the wastewater initiative as a "roadmap" for collaborative work with customers from a resource optimization perspective. The results will assist utilities in wastewater operations-related electricity infrastructure and resource capacity planning, especially on a TOU basis.

CAISO can incorporate the results into an assessment of what percentage of wastewater treatment-related demand may be DR-applicable. In addition, improved wastewater electricity-related measurement that includes integration of multiple variables will assist both in the measurement and verification of EE investments as well as effective DR planning, including the potential extension of Auto-DR to core operations.

4.4.5. California Environmental Policy and Regulatory Entities

California environmental regulatory entities can use results of this wastewater pilot initiative for current and future environmental policy and regulation of the direct and indirect environmental impacts of the electricity consumed by California wastewater treatment operations. For example, this project has illustrated real-time CO_2 emissions measurement integrated with energy management, allowing emissions tracking and reporting. From a wastewater quality perspective, it has provided a means to assist in forecasting approximate DO levels and BOD magnitude based upon an integration of multiple variables. From a solid waste management perspective, the issue of salinity and associated salt transportation and landfill disposal issues have been illuminated in the course of this wastewater project.

Figure 21. Osprey with Fish

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6.0 Glossary

CAISO	California Independent System Operator
CCF	Cross Correlation Function
DR	Demand Response
DRRC	Demand Response Research Center
DO	Dissolved Oxygen
BOD	Biological Oxygen Demand
CO_2	Carbon Dioxide
EE	Energy Efficiency
EEM	Enterprise Energy Management
FDA	Food and Drug Administration
GEMS	Green Energy Management System
GHG	Greenhouse Gas
kW	Kilowatt
kWh	Kilowatt-hour
KVAR	Kilovolt-Ampere Reactive
LBNL	Lawrence Berkeley National Laboratory
mg/L	milligrams/liter
NOAA-NWS	National Oceanographic and Atmospheric Administration-National Weather Service
NPDES	National Pollution Discharge Elimination System
OpenADR	Open Automated Demand Response
PDP	Peak Day Pricing
PG&E	Pacific Gas and Electric
RD&D	Research, development and demonstration
RTP	Real Time Pricing
TSS	Total Suspended Solids
TOU	Time-of-Use
U.S. EPA	United States Environmental Protection Agency
VFD	Variable Frequency Drive

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Appendix A. Supporting Data and Statistical Analysis

Dissolved Oxygen (DO) Target Ranges (mg/L) Per BC Plant Operations

	Low	Medium	High
Peak:	0.2	0.5	0.8
Partial Peak:	0.5	1.0	1.5
Off Peak:	0.8	1.5	1.8

Descriptive Statistics: Summary

Variable	N	N*	Mean	StDev	Minimum	Median	Maximum
Ave kW	77	0	1089.1	189.8	701.4	1109.3	1575.8
Ave Degree F	77	0	62.293	7.973	47.263	62.806	79.119
DO Composite Ave	77	0	1.5256	0.7085	0.3056	1.4057	4.1506
BOD-mg/L	77	0	5740	3766	2185	4848	18240
Influent-MM Gal	77	0	0.7622	0.2561	0.1210	0.8420	1.4580
TSS-mg/L	77	0	1676.6	753.6	682.0	1773.0	2965.0

Descriptive Statistics: Time of Use (TOU)

Variable	Time of Use	N	N*	Mean	StDev	Minimum
Ave kW	Off Peak	3388	0	1044.5	317.3	217.8
	On Peak	1848	0	1163.6	286.5	164.0
	Partial Peak	2156	0	1091.8	315.3	0.00
Deg F	Off Peak	3388	0	54.900	7.447	37.000
	On Peak	1848	0	73.542	11.602	50.000
	Partial Peak	2156	0	64.252	10.099	42.800
DO-TOU Composite Average	Off Peak	3388	0	1.6207	0.000000	1.6207
	On Peak	1848	0	1.3613	0.000000	1.3613
	Partial Peak	2156	0	1.5170	0.000000	1.5170

Variable	Time of Use	Median	Maximum
Ave kW	Off Peak	1135.2	1796.0
	On Peak	1247.1	1893.0
	Partial Peak	1188.6	1747.0
Deg F	Off Peak	53.600	75.200
	On Peak	75.200	100.400
	Partial Peak	62.600	96.800
DO-TOU Composite Average	Off Peak	1.6207	1.6207
	On Peak	1.3613	1.3613
	Partial Peak	1.5170	1.5170

Correlations: Ave kW, Deg F, DO-TOU Composite Ave, BOD, Influent, TSS

	Ave kW	Deg F	DO-TOU Composite Ave
Deg F	0.140		
	0.000		
DO-TOU Composite Ave	-0.153	-0.624	
	0.000	0.000	
BOD - mg/L	-0.079	-0.297	0.000
	0.000	0.000	0.972
Influent - MM Gal	0.071	0.006	0.006
	0.000	0.600	0.613

TSS - mg/L	0.119	0.041	0.000
	0.000	0.000	0.987

	BOD - mg/L	Influent - MM Gal
Influent - MM Gal	-0.072	
	0.000	
TSS - mg/L	0.473	0.105
	0.000	0.000

Hypothesis Test of DO Less than or Greater than Mean of 1.5256 mg/L

Note: An alpha of 0.05 was used for the DO hypothesis test.

1. Test of mu = 1.5256 vs. > 1.5256

Variable	N	Mean	StDev	SE Mean	95% Lower Bound	T
DO-TOU Composite Average	7392	1.52560	0.10448	0.00122	1.52360	0.00

Variable	P
DO-TOU Composite Average	0.499

2. Test of mu = 1.5256 vs. < 1.5256

Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T
DO-TOU Composite Average	7392	1.52560	0.10448	0.00122	1.52760	0.00

Variable	P
DO-TOU Composite Average	0.501

Hypothesis Test of Ave kW Less than or Greater than Mean of 1088.08 kW

Note: An alpha of 0.05 was used for the kW hypothesis test.

1. Test of mu = 1088.08 vs. < 1088.08

Variable	N	Mean	StDev	SE Mean	95% Upper Bound	T	P
Ave kW	7392	1088.08	312.93	3.64	1094.06	-0.00	0.500

2. Test of mu = 1088.08 vs. > 1088.08

Variable	N	Mean	StDev	SE Mean	95% Lower Bound	T	P
Ave kW	7392	1088.08	312.93	3.64	1082.09	-0.00	0.500

Best Subsets Regression: Ave kW vs. Temperature; DO Composite Average;

Influent Flow; Total Suspended Solids *1

Response is Ave kW

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ave Degree F	DO Composite Ave	Influent-MM Gal	TSS-mg/L
1	27.4	26.4	11.8	162.81		X		
1	17.4	16.3	23.4	173.59			X	
2	35.5	33.8	4.2	154.43		X		X
2	30.5	28.7	10.0	160.26		X	X	
3	38.0	35.4	3.4	152.49		X	X	X
3	36.0	33.3	5.7	154.93	X	X		X
4	38.3	34.9	5.0	153.15	X	X	X	X

*1: Although the Best Subsets Regression variable analysis indicated the highest R-squared (adj) and lowest Mallows Cp score, from a practical and experiential basis the option with all four independent variables was selected to include temperature in the regression model.

Best Subsets Regression: DO Composite Average vs. Ave kW, Temperature; Influent Flow; Total Suspended Solids *2

Response is DO Composite Ave

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ave kW	Ave Degree F	Influent-MM Gal	TSS-mg/L
1	27.4	26.4	18.7	0.60790	X			
1	25.2	24.2	21.3	0.61666			X	
2	37.1	35.4	8.3	0.56932	X		X	
2	34.7	33.0	11.3	0.58004	X			X
3	42.8	40.5	3.1	0.54656	X		X	X
3	37.3	34.7	10.1	0.57236	X	X	X	
4	42.9	39.8	5.0	0.54988	X	X	X	X

*2: Although the Best Subsets Regression variable analysis indicated the highest R-squared (adj) and lowest Mallows Cp score, from a practical and experiential basis the option with all four independent variables was selected to include temperature in the regression model.

Best Subsets Regression: BOD-mg/L vs. Ave kW; Temperature; DO Composite Average; Influent Flow; Total Suspended Solids *3

Response is BOD-mg/L

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	Ave kW	Ave Degree F	DO Composite Ave	Influent-MM Gal	TSS-mg/L
1	22.5	21.5	69.1	3337.2			X		
1	22.4	21.3	69.4	3340.1					X
2	45.7	44.3	28.5	2811.2		X			X
2	42.0	40.4	35.3	2906.1		X	X		
3	60.6	59.0	3.2	2411.0		X	X		X
3	51.8	49.9	19.3	2666.4		X		X	X
4	61.0	58.8	4.5	2416.5		X	X	X	X
4	60.8	58.6	4.9	2422.4	X	X	X		X
5	61.3	58.6	6.0	2424.4	X	X	X	X	X

*3: Although the Best Subsets Regression variable analysis indicated the highest R-squared (adj) and lowest Mallows Cp score, from a practical and experiential basis the option with all five independent variables was selected.

Regression Analysis: Ave kW

The regression equation is

Ave kW = 985 + 1.34 Ave Degree F - 128 DO Composite Ave + 131 Influent-MM Gal + 0.0689 TSS-mg/L

Predictor	Coef	SE Coef	T	P
Constant	985.4	162.1	6.08	0.000
Ave Degree F	1.338	2.216	0.60	0.548
DO Composite Ave	-127.91	29.16	-4.39	0.000
Influent-MM Gal	131.17	79.82	1.64	0.105
TSS-mg/L	0.06890	0.02375	2.90	0.005

S = 153.153   R-Sq = 38.3%   R-Sq(adj) = 34.9%

99% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	985.403	556.497	1414.31
2	Ave Degree F	1.338	-4.524	7.20
3	DO Composite Ave	-127.913	-205.060	-50.77
4	Influent-MM Gal	131.171	-80.023	342.37
5	TSS-mg/L	0.069	0.006	0.13

95% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	985.403	662.252	1308.55
2	Ave Degree F	1.338	-3.078	5.76

3	DO Composite Ave	-127.913	-186.038	-69.79
4	Influent-MM Gal	131.171	-27.949	290.29
5	TSS-mg/L	0.069	0.022	0.12

90% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	985.403	715.288	1255.52
2	Ave Degree F	1.338	-2.353	5.03
3	DO Composite Ave	-127.913	-176.498	-79.33
4	Influent-MM Gal	131.171	-1.834	264.18
5	TSS-mg/L	0.069	0.029	0.11

Regression Analysis: DO Composite

The regression equation is

DO Composite Ave = 3.43 - 0.00165 Ave kW + 0.00278 Ave Degree F
- 0.877 Influent-MM Gal + 0.000229 TSS-mg/L

Predictor	Coef	SE Coef	T	P
Constant	3.4327	0.5907	5.81	0.000
Ave kW	-0.0016489	0.0003759	-4.39	0.000
Ave Degree F	0.002778	0.007968	0.35	0.728
Influent-MM Gal	-0.8765	0.2730	-3.21	0.002
TSS-mg/L	0.00022899	0.00008598	2.66	0.010

S = 0.549878   R-Sq = 42.9%   R-Sq(adj) = 39.8%

99% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	3.43267	1.86973	4.99560

Row	Predictor	Coeff	Lower	Upper
2	Influent-MM Gal	-0.87655	-1.59893	-0.15417
3	TSS-mg/L	0.00023	0.00000	0.00046
4	Ave kW	-0.00165	-0.00264	-0.00065
5	Ave Degree F	0.00278	-0.01831	0.02386

95% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	3.43267	2.25510	4.61023
2	Influent-MM Gal	-0.87655	-1.42081	-0.33229
3	TSS-mg/L	0.00023	0.00006	0.00040
4	Ave kW	-0.00165	-0.00240	-0.00090
5	Ave Degree F	0.00278	-0.01311	0.01866

90% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	3.43267	2.44837	4.41696
2	Influent-MM Gal	-0.87655	-1.33149	-0.42161
3	TSS-mg/L	0.00023	0.00009	0.00037
4	Ave kW	-0.00165	-0.00228	-0.00102
5	Ave Degree F	0.00278	-0.01050	0.01606

Regression Analysis: BOD-mg/L

The regression equation is

BOD-mg/L = 12309 + 1.36 Ave kW - 222 Ave Degree F + 2065 DO Composite Ave

- 1209 Influent-MM Gal + 2.12 TSS-mg/L

Predictor	Coef	SE Coef	T	P
Constant	12309	3157	3.90	0.000
Ave kW	1.365	1.866	0.73	0.467
Ave Degree F	-222.11	35.16	-6.32	0.000
DO Composite Ave	2064.6	519.6	3.97	0.000

Influent-MM Gal	-1209	1287	-0.94	0.351
TSS-mg/L	2.1189	0.3973	5.33	0.000

S = 2424.37   R-Sq = 61.3%   R-Sq(adj) = 58.6%

99% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	12308.9	3953.83	20664.0
2	Ave kW	1.4	-3.57	6.3
3	Ave Degree F	-222.1	-315.18	-129.0
4	DO Composite Ave	2064.6	689.26	3439.9
5	Influent-MM Gal	-1208.5	-4615.09	2198.0
6	TSS-mg/L	2.1	1.07	3.2

95% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	12308.9	6014.84	18603.0
2	Ave kW	1.4	-2.36	5.1
3	Ave Degree F	-222.1	-292.22	-152.0
4	DO Composite Ave	2064.6	1028.51	3100.6
5	Influent-MM Gal	-1208.5	-3774.77	1357.7
6	TSS-mg/L	2.1	1.33	2.9

90% Individual Confidence Intervals

Row	Predictor	Coeff	Lower	Upper
1	Constant	12308.9	7048.14	17569.7
2	Ave kW	1.4	-1.74	4.5
3	Ave Degree F	-222.1	-280.71	-163.5
4	DO Composite Ave	2064.6	1198.60	2930.5
5	Influent-MM Gal	-1208.5	-3353.47	936.4
6	TSS-mg/L	2.1	1.46	2.8

Appendix B. Multiple Regression Analysis

The empirical methodology for disaggregating the effects of increased aeration (as measured by increased kW), temperature, and flow rates is based on a standard water chemistry concentration and dilution model modified to accommodate the data input limitations of the test site. The initial concentration dilution equation is represented in equation B-1.

$$C_f V_f = C_o V_o + C_a V_a + C_{kw} V_{kw} - C_d V_d \qquad \text{(B-1)}$$

Where:

C_f & V_f : Concentration and Volume in final retention pond

C_o & V_o: Concentration and Volume initial

C_a & V_a: Concentration and Volume added via influent

C_{kw} & V_{kw}: Concentration and Volume aerated

C_d & V_d: Concentration and Volume discharged

Since the variable of interest in this scenario is the concentration of dissolved oxygen (DO) in the discharge stream, this equation is rearranged to solve for the concentrations in question. Also, because the concentration added due to aeration is an unspecified function of temperature and kW, equation B-1 can be expanded to explicitly capture both terms. Finally, the volumes used over the course of this investigation are assumed to reach remain relatively constant (mass balance), therefore V_a=V_d and V_o=V_f. These substitutions can be accomplished and equation B-1 rewritten as equation B-2 below.

$$C_d = \left(\frac{V_f}{V_d}\right) C_o + C_a - \left(\frac{V_f}{V_d}\right) C_f + \left(\frac{V_f}{V_d}\right) f(kw, temp) \qquad \text{(B-2)}$$

Finally, since the regression analysis measures the sensitivity of the dependent variable to changes in the independent variables, the final representation of the regression results requires taking the total differential of equation 2 and solving for the effects of changes in total kW on the discharge concentration (C_d). This solution is represented in equation B-3 below.

$$dC_d = \left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial C_o} dC_o + \frac{\partial C_d}{\partial C_a} dC_a - \left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial C_f} dC_f + \left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial kW} dkW + \left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial temp} dtemp \qquad \text{(B-3)}$$

Equation 3 reveals one key aspect of managing water chemistry with constant influent and effluent streams. The relationship of the volume added to the total volume in the retention facility must be accommodated as part of the investigation. The ratio of total volume to daily flow rate is a multiplier that was included explicitly in the regression analysis. The regression results are then mapped to the terms in equation B-3 as shown in Table 9.

Table 9. Regression Equation Terms and Their Relationship to Equation B-3

Regression Equation Shorthand	Description of Regressor	Relationship to Equation (B-3)
DO7(-1)*FLOWRAT	The initial state of Lagoon #3 as measured at sensor #7 multiplied by the ratio of total lagoon volume to average hourly flow rate	$\left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial C_o}$
DO4	The current state of Lagoon (#2) feeding Lagoon #3 as measured at sensor #4	$\frac{\partial C_d}{\partial C_a}$
TEMP*FLOWRAT	Current outside air temperature multiplied by the ratio of total lagoon volume to average hourly flow rate	$\left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial temp}$
kW*FLOWRAT	Current kW for aeration operation multiplied by the ratio of total lagoon volume to average hourly flow rate	$\left(\frac{V_f}{V_d}\right)\frac{\partial C_d}{\partial kW}$
kW(-1)*FLOWRAT	Level of kW for aeration one hour ago multiplied by the ratio of total lagoon volume to average hourly flow rate	Same as above for previous hour kW
kW(-2)*FLOWRAT	Level of kW for aeration two hours ago multiplied by the ratio of total lagoon volume to average hourly flow rate	Same as above for kW two hours prior
kW(-3)*FLOWRAT	Level of kW for aeration three hours ago multiplied by the ratio of total lagoon volume to average hourly flow rate	Same as above for kW three hours prior
kW(-4)*FLOWRAT	Level of kW for aeration four hours ago multiplied by the ratio of total lagoon volume to average hourly flow rate	Same as above for kW four hours prior
kW(-5)*FLOWRAT	Level of kW for aeration five hours ago multiplied by the ratio of total lagoon volume to average hourly flow rate	Same as above for kW five hours prior

The regression equation results are shown in Table 10. (Table 8 above contains a summary of these results.)

Table 10. Multiple Regression Background Results

Dependent Variable: DOFINAL				
Method: Least Squares				
Date: 04/16/09 Time: 10:37				
Sample (adjusted): 6 1848				
Included observations: 1811 after adjustments				
White Heteroskedasticity-Consistent Standard Errors & Covariance				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
DO7(-1)*FLOWRAT	0.000605	6.55E-06	92.38393	0
DO4	0.061978	0.01768	3.505609	0.0005
TEMP*FLOWRAT	-1.19E-05	7.85E-07	-15.11021	0
kW*FLOWRAT	8.23E-08	7.12E-08	1.154783	0.2483
kW(-1)*FLOWRAT	2.95E-07	7.48E-08	3.939213	0.0001
kW(-2)*FLOWRAT	1.88E-07	7.70E-08	2.443106	0.0147
kW(-3)*FLOWRAT	9.36E-08	7.27E-08	1.286444	0.1985
kW(-4)*FLOWRAT	1.21E-07	7.34E-08	1.6505E+00	0.099
kW(-5)*FLOWRAT	8.85E-08	6.78E-08	1.30E+00	0.1922
R-squared	0.916005	Mean dependent var		1.659965
Adjusted R-squared	0.915632	S.D. dependent var		1.604785
S.E. of regression	0.466128	Akaike info criterion		1.316244
Sum squared resid	391.5301	Schwarz criterion		1.343585
Log likelihood	-1182.86	Hannan-Quinn criter.		1.326334
Durbin-Watson stat	0.323966			

Based on these results, the coefficients describe the sensitivity of the dependent variable (final DO at discharge) to changes in the independent variables. Three of the independent variables have no statistically significant change in DO: the current level of kW (with only a 24.8% probability of being zero), kW used three hours ago (19.8% probability of zero) and kW used five hours ago (19.2% probability of zero). A practical interpretation of these results supports the idea that turning up the aeration is unlikely to have an immediate effect in a lagoon with over 20 million gallons of wastewater. The effects are more likely to be seen in the hours following the change in kW. The effect will trail off after some period of time, and unreported regression results with lags beyond five hours indicate that four hours is the longest period of aeration kW reduction for which there is significant change in DO levels. Based on this result, the low impact at three hours may be an anomaly that can be investigated by further real-world testing in the future.

These results suggest that there is no more than a four hour window for having a direct effect on DO at the discharge of the lagoon, although the impulse response function results earlier in this report show that the indirect effects can linger for nearly 12 hours.

Appendix C. GEMS Overview

The Green Energy Management System (GEMS) consists of world-class enterprise energy management technologies for competitively managing all facets of water, air, gas, electricity, steam (WAGES) energy and environmental resources including energy cost and usage scenario modeling and forecasting plus integration of CO_2 emissions management reporting based upon actual energy demand and usage.

- All water, air, gas, electricity and steam (WAGES) information standardized in one common system for effective operations, cost management, budgeting, forecasting, capital project planning, environmental and regulatory management and reporting.
- Credible data integrity and real-time information for sustainability initiatives. On a daily, monthly and annual basis as needed, tangibly track and report electricity, natural gas and propane usage and direct correlation of CO_2 emissions impact (e.g. lbs or kg CO_2/kWh, lbs or kg CO_2/BTU, etc.) based upon annualized utility electricity generation portfolio (e.g. X% coal, hydroelectric, natural gas, non-hydro renewables, etc.), facility natural gas and propane usage.
- Integrate renewable investments into GEMS (e.g. photovoltaic, energy storage, etc.) to measure, directly correlate and report fossil fuel energy vs. renewable energy usage and relative environmental impact.
- Can start GEMS with importing several years of actual facility manufacturing, warehousing and distribution operations location baseline electric, gas and water utility digital data from multiple utilities. Know your WAGES usage and cost baselines from GEMS Day One in operations.
- No IT resources and maintenance is required for GEMS. 100% hosted with minimal investment.
- Advanced technology options in benchmarking, demand response, real-time electricity pricing, water/wastewater chemistry-energy correlations and analysis, scenario modeling and forecasting of WAGES usage and costs versus budget, weather normalization and sensitivity.
- WAGES utility invoice-accurate costs are resident in GEMS. Not necessary to manually input or import detailed energy information. Operating and financial reports can be automatically normalized by units of production, square footage and hours of operation. Operating and financial reports can be automatically emailed on user-defined time and frequency in addition to conventional system queries (e.g. date ranges, etc.).
- Open systems architecture to integrate with existing plant production systems, financial systems, asset management systems, etc.

Appendix D. Salinity Impacts on Electricity Demand and Use

Salts and salt-based chemicals are common elements with energy and environmental impact across the spectrum of industrial and commercial wastewater operations. The impact of salinity is a critical issue in wastewater operations requiring further research. Salinity significantly reduces DO solubility and transfer by nearly 50% and requires additional energy use for aeration to overcome this constraint. In addition, the resulting salt precipitate removal from lagoon operations is a major operating cost and environmental issue.

When substances such as salts are dissolved in a unit volume of water, there is less opportunity for oxygen to dissolve since oxygen is less soluble than most salts. Table 11 shows the relationship of dissolved oxygen (mg/L) to temperature (degrees Celsius) and salinity (parts per thousand).

Table 11. Dissolved Oxygen Saturation Based on Temperature and Salinity

Oxygen Saturation (mg/L) Based on Temperature and Salinity						
Temp (deg C)	Salinity (ppt)					
	0 ppt	9 ppt	18.1 ppt	27.1 ppt	36.1 ppt	45.2 ppt
0	14.62 mg/L	13.73	12.89	12.10	11.36	10.66
10	11.29	10.66	10.06	9.49	8.96	8.45
20	9.09	8.62	8.17	7.75	7.35	6.96
25	8.26	7.85	7.46	7.08	6.72	6.39
30	7.56	7.19	6.85	6.51	6.20	5.90
40	6.41	6.12	5.84	5.58	5.32	5.08

Source: http://www.sensorex.com/support/education/DO_education.html

The average temperature during the September 15-30, 2008 period was 30°C (86°F) and during the November 15-30, 2008 period it was 24°C (76°F). From Table 11 there appears to be an opportunity to improve DO saturation by approximately 8-10%.

Several years ago, the Bell-Carter plant had a salinity assessment conducted in wastewater operations. The net findings were that DO transfer levels were nearly 50% lower than they should have been based on aerator design ratings with one of the primary contributors of this inefficiency being wastewater salinity conditions. The aerator design rating for DO transfer is 3.2 mg/L. The actual DO transfer rate due to wastewater quality and salinity during the salinity assessment was 1.8 mg/L, which is relatively close to the composite 1.5 mg/L DO level measured during this wastewater project.

As noted in the Conclusions and Recommendations section above, the salinity issue should be addressed by a food science approach investigating possible U.S. FDA-approved sodium substitutes in the plant production process to achieve the following key benefits:

a. Significantly reduce incremental kW/kWh aeration and aspiration requirements associated with salinity.
b. Significantly reduce or eliminate the need for annual lagoon salt dredging, transportation, disposal and associated costs.
c. Significantly reduce or eliminate plant finished goods levels of sodium for customer physiological and health benefits.