Technical Analysis

Debbie Meyer Swim Center Pool Pump Replacement

Prepared by:

Davis Energy Group

On behalf of the:

Foundation for Pool & Spa Industry Education (FPSIE)

Prepared for:

The Sacramento Municipal Utility District

Sacramento, CA

October 2012

Contributors: Michael Orr (FPSIE)
Elizabeth Weitzel (DEG)
David Springer (DEG)

Table of Contents

1. Background & Objectives

1.1. Project Objective

The primary objective of this project is to test the hypothesis that reduced flow rates can maintain water quality to a similar standard as would result from filtration required by current codes, and to identify the energy savings potential of a reduced flow regime. The Debbie Meyer Swim Center in Sacramento volunteered to have their existing pump replaced with a new variable speed pump, and to allow the installation of equipment to measure pump energy and water quality. Information presented in this report will be useful for identifying new pool pump control strategies, to support potential code revisions, and for development or modification of utility programs.

1.2. Pool Pump Energy Consumption

Swimming pool pumps consume a significant amount of energy in California. According to the 2009 Residential Appliance Efficiency Standards (RASS), residential swimming pool pumps consume more energy than any other end use (averaging over 3500 kWh/year). Most residential pool pumps are only operated about 8 hours per day, but pumps used in public pools are required to be operated continuously while the pool is in use, and therefore stand to benefit from efficiency improvements to a much greater extent than residential systems.

1.3. Regulations Affecting Swimming Pool Operation

California Title 20 regulations established efficiency standards for residential pool pumps in 2009. These include development of test criteria, preventing the sale of split phase or capacitor start motors, and pumps and motors that do not have two or more speeds (CEC-400-2009-013). No similar standards have been developed for public pools.

Water quality is a key factor in determining the run schedule and consequently the energy consumption of swimming pool filtration equipment. Section 9032 of the California Title 24 California Administrative Code states that systems must be sized no greater than the rate required to pass the entire volume of the pool through the filter in 6 hours (6 hour "turnover") or 36GPM, whichever is greater. Title 22 California code pertaining to public pools states that the variation in flow during a filtration cycle shall be such as to not reduce the flow below 65 percent of the rate required in Section 9032 of Title 24 (Title 22 Section 65525). This code requirement would typically result in 3 to 4 turnovers per day, which would guarantee at least 98% of all the pool water would pass through the filter at least 1 time in a 24 hour period. This filtration model was developed in the 1970's and is still used today, however new technology has changed the landscape of the swimming pool system components which the current regulations do not address. This project was conceived to demonstrate that with new technology in equipment and different flow and timing schedules, one can maintain a high standard of water quality while using 75-80% less energy. The California Title 24 Building Code has completed its update and the Title 22 code of Regulations along with Health and Safety codes are currently under review by the CDPH, which can possibly change the requirements for circulation/filtration timing based on technology installed at any given facility.

1.4. Swimming Pool Water Quality Principles and Definitions

Water quality is affected by particulate matter suspended in the water and organic compounds dissolved in the water. These are controlled by:

- Filtration to remove particulates
- Chemical treatments to oxidize organic compounds
- Restricting the entry of contaminants into the pool

The amount of particulates and organic materials in swimming pool water affects its clarity, and the metric used for clarity is "turbidity." Turbidity is measured on a scale called, "Jackson or Nephlometric Turbidity Units" (NTU's). For swimming pool applications this scale typically ranges from 0 to 1. Swimming pool water is said to be very clear when the turbidity is at or below 0.2 NTU's (the drinking water standard) and unacceptable for swimming when it exceeds 0.5 NTU's. The primary methods of keeping water in the "very clear" range of <0.2 NTU's is circulating the pool water through filter media. Filters types include fiber cartridges, sand, or diatomaceous earth or other media. The rate at which water is run through the filter media and the area of the filter media affect filtration effectiveness. The lower the velocity at which water moves through the media, the more effective the media becomes at removing debris from the water. The metric used for filter velocity is gallons per minute per square foot of filter surface area (gpm/ft^2).

Turbidity can be measured using various methods, the simplest being a visual observation of the main drain of the pool or the use of a Secchi disk[1] placed on the bottom of the pool. A more exact approach is to use a Nephlometer that measures the diffusion of light by matter in the water. Nephalometers require frequent calibration and cleaning to insure accuracy.

Chlorine is typically used to oxidize organics in swimming pool water, and the chlorine concentration dictates the "oxidation reduction potential", or ORP, of the water. Cyanuric acid is also used as a stabilizer (at about 30 ppm) to protect chlorine from UV degradation so that the concentration can be kept at optimal levels. If chlorine levels are below 2 ppm, almost no oxidation takes place. The pH of the water is a factor in the ability of chlorine is to both sanitize and oxidize. The lower the pH the greater the oxidation potential of the chlorine. The pH must be maintained between 7.2 and 7.8 for both bather comfort and effective use of chlorine (7.4-7.6 is ideal).

Maintenance and supervision are key factors in maintaining water quality. The introduction and removal of swimming pool contaminants can be facilitated by insuring bathers shower before entering the pool, applying a pool cover after closing each day, and keeping the deck around the

---

[1] A Secchi disk is a circular disk with an alternating color pattern that is used to measure transparency in bodies of water. The depth at which the pattern on the disk is no longer visible is taken as a measure of transparency.

pool clean. Bottom cleaners and skimmers must be kept in good working order. Filters must be periodically cleaned or backwashed, and chlorination equipment, flow meters, pressure gauges, and other equipment must be maintained. Frequent water tests using reagents to measure chlorine, pH, ORP, total dissolved solids, and cyanuric acid, are required.

2. Pool Facility and Equipment Description

The Debbie Meyer Swim Center, pictured in Figure 1, is located at 4840 Marconi Ave., Carmichael, California. The center provides swimming instruction for all ages, and is typically opened from March through September each year. It includes both a covered and an uncovered pool. The covered pool, which is about 22,000 gallons, is maintained at temperatures around 90°F while in use, and is the pool which was monitored in this study.

Figure 1: The Debbie Meyer Swim Center

Table 1 lists the original equipment, and the equipment that was used to upgrade the system. The original single speed pump with capacitor start motor was replaced with a new Hayward Ecostar pump that utilizes a brushless permanent magnet motor, advanced hydraulic design, and an integrated safety vacuum release system that helps prevent suction entrapment. The new Hayward pump controller monitors flow rate, temperature, oxidation-reduction potential (ORP) and pH.

Table 1: Original and Replacement Pool Equipment

Equipment	Original	Retrofit
Filtration Pump	StaRite ¾ Hp	Hayward Ecostar SVRS
Pump Controller	Mechanical TC off/on	Hayward CAT5000
Cartridge Filter	Sta Rite 2 ea. 300 ft2	Hayward HCF7030C
Pool Heater	Raypak -250Kbtu	Hayward H250HDN
UV Filter	n/a	Delta UV ELP28HO

3. Test and Analysis Methods

3.1. Monitoring Equipment

Since the new Hayward pump and controller includes remote monitoring capabilities, it was used to measure and report pool water temperature, pH, water flow, and ORP via a web interface. A Data Electronics DT-50 logger was used to monitor the system power, environmental temperature, turbidity and gas consumption. The power and gas consumption were measured via the digital channels that read pulsed inputs, while the temperature and turbidity sensors were single-ended analog sensors (referenced to ground). The logger utilizes a battery backup, has an external memory card, and RS232 communications. The datalogger was connected to a telephone modem that also allowed remote access to data. Datalogger specifications are as follows:

Manufacturer: Data Electronics (DataTaker)
Model: DT50
Analog Inputs: Up to 10 single ended, 5 double-ended
Digital Inputs: 5 bi-directional (10hz) digital, 3 high speed (1khz) counters
Analog Accuracy: 4-20ma, 0.25% at 25°C
Memory: 500kB onboard RAM, 2mb SRAM pc card

3.2. Data Points and Frequency of Measurement

Table 2 lists the data points monitored, and Table 3 provides information on sensor characteristics. Information on the accuracy of the Hayward sensors was not available.

Table 2: Schedule of Data Points

Point	**Purpose**	**Location**	**Datalogger**
Outdoor Temperature	Reference	North roof of support building	Datataker
Turbidity	Water Quality	In-line	Datataker
Filter Pressure	Filtration Effectiveness	In-line	Datataker
Gas Usage	Energy Consumption	Heater	Datataker
Lighting Energy	Energy Consumption	At breaker	Datataker
Pool Filtration Energy	Energy Consumption	At breaker	Datataker
PH	Sanitation	In-line	Hayward
ORP	Sanitation	In-line	Hayward
Supply Temperature	Reference	In-line	Hayward
Flow Meter	Pump Efficiency	In-line	Hayward

Table 3: Sensor Characteristics

Point	Sensor Type	Mfg/Model	Span	Accuracy
Outdoor Temperature	4-20mA	GE MRHT3	32 - 132°F	±1.5%
Turbidity	4-20mA	Cole Parmer	0.02 – 10 NTU	2% of reading
Filter Pressure	4-20mA	Cole Parmer	0-50 psi	±0.5%
Gas Usage	Digital pulsed output	IMAC/ Rockwell	250SCFM	±1ft^3
Lighting Energy	Digital pulsed output	Rochester	0.25 wh/pulse	
Pool Filtration Energy	Digital pulsed output	Rochester	0.25 wh/pulse	
PH	4-20mA	Hayward		
ORP	4-20mA	Hayward		
Supply Temperature	Immersion Thermocouple	Hayward		
Flow Meter	Digital pulsed output	Hayward		

3.3. Pool Use and Monitoring Schedule

The pool equipment was replaced in June 2011. Due to contract delays, monitoring equipment was not installed and commissioned until October 2011. Problems with the Hayward data acquisition system further delayed the formal initiation of monitoring until late October. Data reported here was taken beginning October 29, 2011 and continued to October 15, 2012. Monitored temperatures and gas use indicate that the pool was heated and likely in use until about November 2, 2011. Usage resumed on March 1, 2012 and continued into October 2012. Operation of the heater was sporadic, sometimes maintaining the pool in the 88°F to 90°F range from 5 or 6 AM to 5 to 5 PM, or starting in the late afternoon or evening and running until 3 to 4 AM. The replacement pump was operated continuously during the monitoring period and cycled from low speed (about 32 gpm) to high speed (about 60 gpm) for a minimum of 4 hours of every day.

3.4. Data Analysis Methods

Baseline Pump Energy Use

The project schedule precluded power measurements or monitoring of the original pump. However, a full year of utility bill data for the original and replacement pumps were available for comparison, along with a description of the operation schedule. This data contains energy use for the entire facility, so the bills were disaggregated using post-retrofit utility bills and monitoring data to determine baseline pumping energy usage.

Fifteen minute interval data obtained from the datalogger were converted to hourly data and aligned with data from the Hayward system. Data from the DT-50 logger was of good quality, however, substantial cleaning of the Hayward data was necessary to eliminate duplicate records and records that occurred in between the hourly records. Also, multiple interruptions of the data stream from the Hayward system lasting up to two and a half days limited the data available for analysis. To allow proper alignment of data it was necessary to eliminate the extraneous Hayward data. No efforts were made to fill in missing data.

Intermittent out-of-range errors were seen with the turbidity sensor, most likely as a result of air introduced into the lines by the chemical feeder, which is immediately upstream of the sensor. Readings would periodically spike, then return to expected levels. Readings of greater than 0.2 NTU (typical drinking water quality) were observed typically during chemical feed alarms, and were filtered out. Good pool clarity was observed throughout the test period. The nephelometer was also periodically cleaned to maintain accuracy.

Since the focus of this research is the relationship between filtration rate and pool water quality, valid data sets of turbidity and ORP were averaged and plotted against average flow rate. Averaged data sets were typically daily periods when flow rates were consistent (either high or low). For example, if a daily period included four hours of high speed pump operation and 20 hours of low speed operation, averages were developed for each period. As indicated, data sets where there were chemical feed alarms were not included.

Much of the data obtained, including gas use, lighting energy, and outdoor temperature were not used in this analysis other than determining baselines as they have little or no bearing on the results, however, they may be useful for further study.

In addition to data measurements completed at the site, meter data was downloaded to compare pre-replacement and post-replacement energy use. Since the meter includes other end uses besides the pump, other uses can be expected to affect this comparison.

4. Results

Baseline Pumping Power and Energy

The baseline prescriptive flow rate for the covered pool was 61GPM, and the smaller outside pool was 54GPM. The typical operation schedule was only during occupancy, as an effort by the owners to reduce energy usage. One time power measurements were taken of both filtration pumps, revealing 1.7kW for the covered pool and 1.6kW for the smaller outside pool. The smaller pool was occupied for only half days, and as such, the pump was operated less often as the larger pool. Table 1 shows the estimated pumping and total site energy usage based on the reported occupational schedule. The average daily site energy usage includes all auxillary loads including lighting, building, computers, security etc, evaluated as an average based on post-retrofit monitored data and utility bills.

Table 4 – Estimated Pre Retrofit Pumping and Site Energy Usage

Occupied Season 3/1/2010 11/12/2010

Schedule	Runtime (Hrs)	Combined Pump Power (kW)	Annual Pumping Energy (kWh)	Average Daily Site Energy Use (kWh)	Total Energy Use (kWh)
Weekends	6	2.54	1,084	14	2,044
Weekdays	12	2.54	5,643	20	9,364
Off Season	6	2.54	1,664	14	3,137
Lighting	240	1.2			288
	Estimated Annual Pumping Energy (kWh):		**8,390**	**Total Estimated Site Energy (kWh):**	**14,833**
				Billed 2010 (kWh)	**15,678**

Measured Pumping Power – New Pump

As an initial exercise, pump power was plotted against flow rate to identify this relationship. These data, and the second order polynomial trend line, are presented in Figure 2. Pump affinity laws indicate that power should increase with the cube of the water flow, assuming there is no change in the system that would affect pressure drop (i.e. the “system curve). The trend line in Figure 2 is relatively flat, and has far less inflection than would a cubic relationship between power and flow.

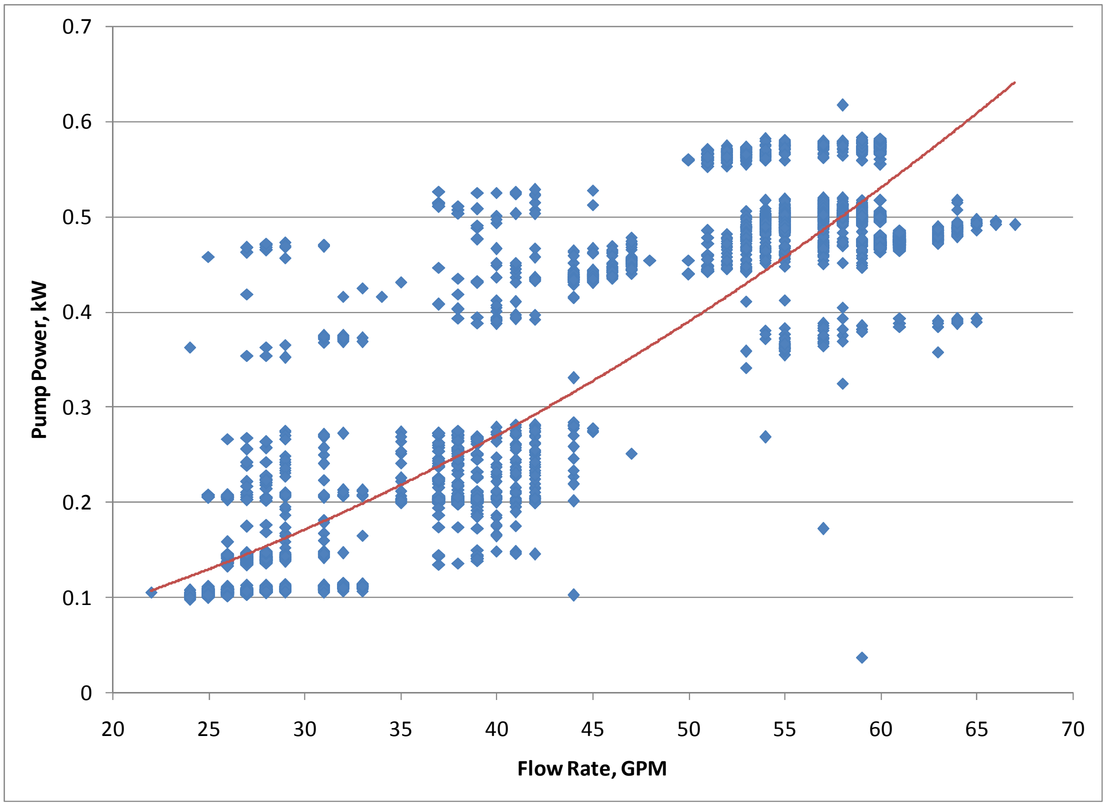

Figure 2: Pump Flow vs. Power

The reason for this is that the system curve changes. The heater incorporates a pressure-operated bypass valve that shunts a percentage of the water around the heat exchanger. As the flow increases, the effect of the valve is to flatten out the system curve, reducing the pressure seen by the pump, and reducing its power requirement.

To account for changes in pressure the measured pressure and flow were used to calculate the water horsepower of the pump. Figure 3 shows the pump performance curves (flow vs filter pressure) at various power draws. The scatter of the data is due to the effects of dirt on the filter element and measurement error.

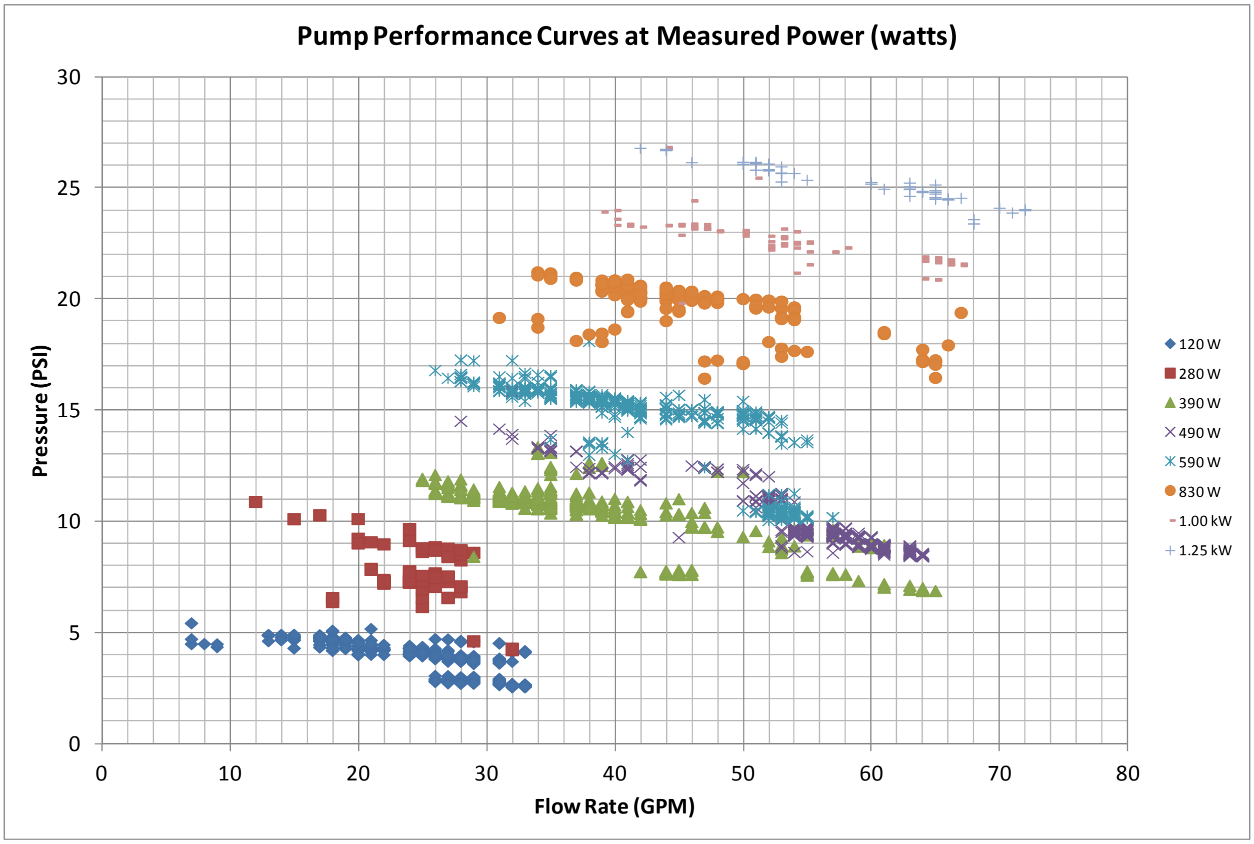

Figure 3: Pump Performance Curves

Energy Savings

Due to a number of variances in behavior during the monitoring period, a period of performance where the optimal schedule was adhered to was used for determining energy savings. During the monitored period there were a number of tests to evaluate jet performance, bacteriological inoculation tests that were started and left unfinished, and many issues with the chemical feed alarm system causing the operators to modify pumping schedules. Even during the occupied period, the operators increased the filtration rates in concern for issues with the chemical balancing system. In addition, a 24x7 internet connected security system was added to observe the pumping equipment and pool areas. These changes resulted in higher than expected energy demands.

Table 5 - Post-Retrofit Pumping and Site Energy Usage

Nominal Schedule

	Low Speed		High Speed				
Schedule	**Runtime** (Hrs)	**Combined Pump Power** (kW)	**Runtime** (Hrs)	**Combined Pump Power** (kW)	**Annual Pumping Energy** (kWh)	**Average Daily Site Energy Use** (kWh)	**Total Energy Use** (kWh)
Weekends	18	0.205	6	0.698	559	14	1,519
Weekdays	15	0.283	9	0.750	2,034	20	5,755
Off Season	20	0.250	4	0.698	751	14	2,225
Lighting	240	0.205					60
			Estimated Annual Pumping Energy (kWh):		**3,344**	**Estimated Site Energy (kWh):**	**9,559**
			Total Annual Pumping Energy (kWh):		**5,506**	Billed, 2011-2012:	**12,764**

The nominal pumping schedule is such that during occupancy, the pool is run at a higher speed (60 GPM), while the rest of the time it is operated at a low enough speed to satisfy pumping requirements and pool heating operation (32 GPM). During non-occupied times, the high speed is scheduled only for pool sweep operation and was observed to be only 4 hours per day. These rates account for approximately 3 turnovers/day during active season and 2 turnovers/day during idle season.

By operating on this nominal schedule, the pumping savings are 60%, while the total utility savings are 36%. Due to the variances in operation related to testing and controller issues, the realized pumping savings were 34% and utility bills were 19%.

Table 6 - Energy Savings

	Pumping Energy (kWh)		Site Energy (kWh)	
Estimated Annual Savings	5,046	60%	5,274	36%
Realized Savings	2,884	34%	2,914	19%

Pool Water Quality Impacts

Using the methods described to isolate valid data, both ORP and NTU were plotted against water flow rate to determine whether there was any correlation between flow and these two determinants of water quality. The correlation coefficient for flow vs. ORP is 0.094, and for flow vs. turbidity (NTU) is 0.007. Given the low correlation coefficients and large number of points, the probability that the correlations were not obtained by chance is greater than 10%. The PH and ORP sensors were used by the controller to adjust the chemical feed rates, and as they were control variables, the only time they varied out of the control range was during feed errors. Since the observed range was very narrow, it was difficult to extrapolate a better correlation.

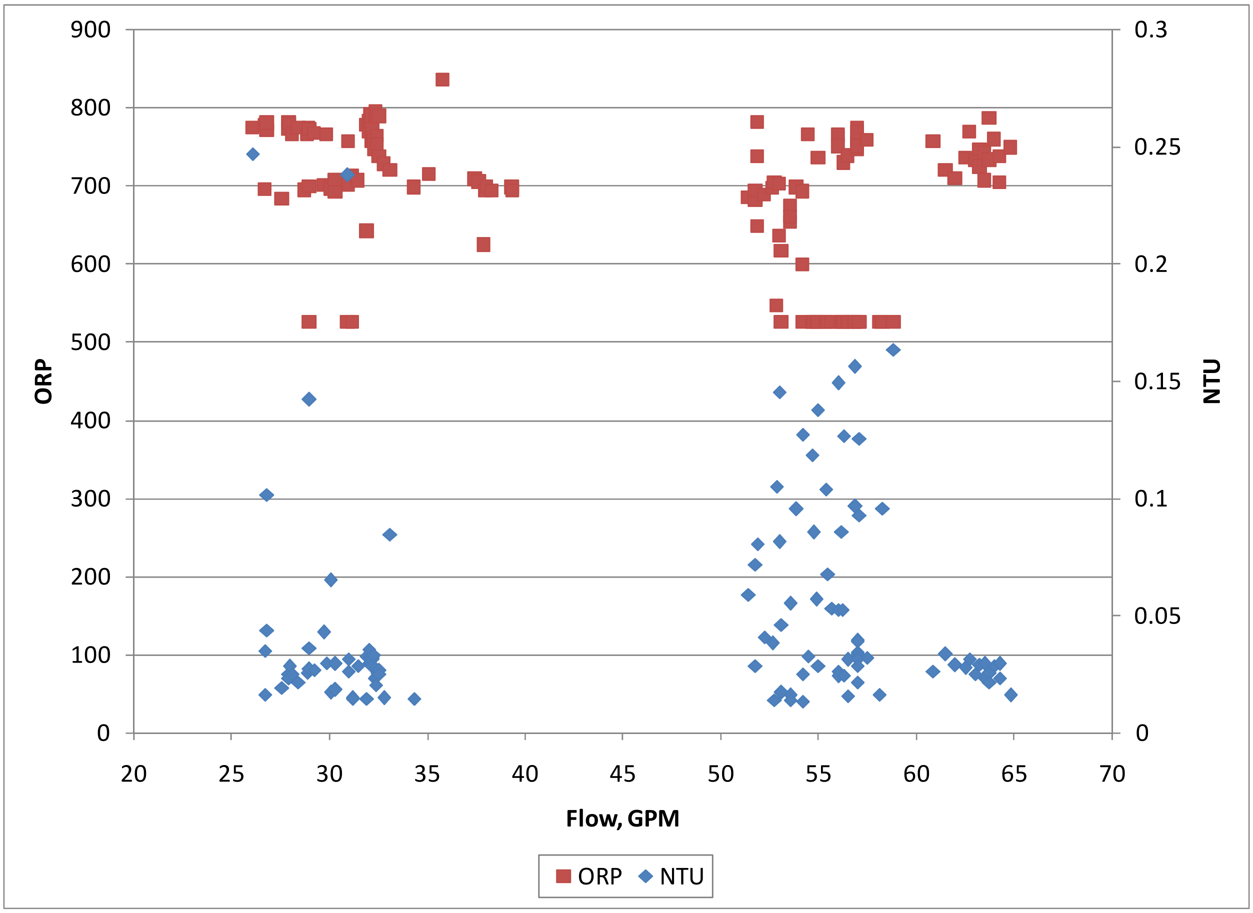

Figure 4: Flow Rate vs. Oxidation Reduction Potential and Turbidity

While the correlation between ORP and Turbidity was very low, indicating that the ORP sensor is a poor indicator of water clarity, the turbidity did show the filtration effectiveness over time that was unaccounted for with either metrics (PH, ORP). In Figure 5, the turbidity is shown during a sample week timescale, against filter pressure. The pressure varies between 2.7 and 8.7 PSI during low and high speed filtration rates. The turbidity is shown to slowly creep higher during low speed filtration rates, and quickly return to baseline during high speed operation. This schedule of 4 hours high speed and 20 hours low speed was seen to be the “sweet spot”, whereas the water clarity remained fairly consistent and within acceptable range.

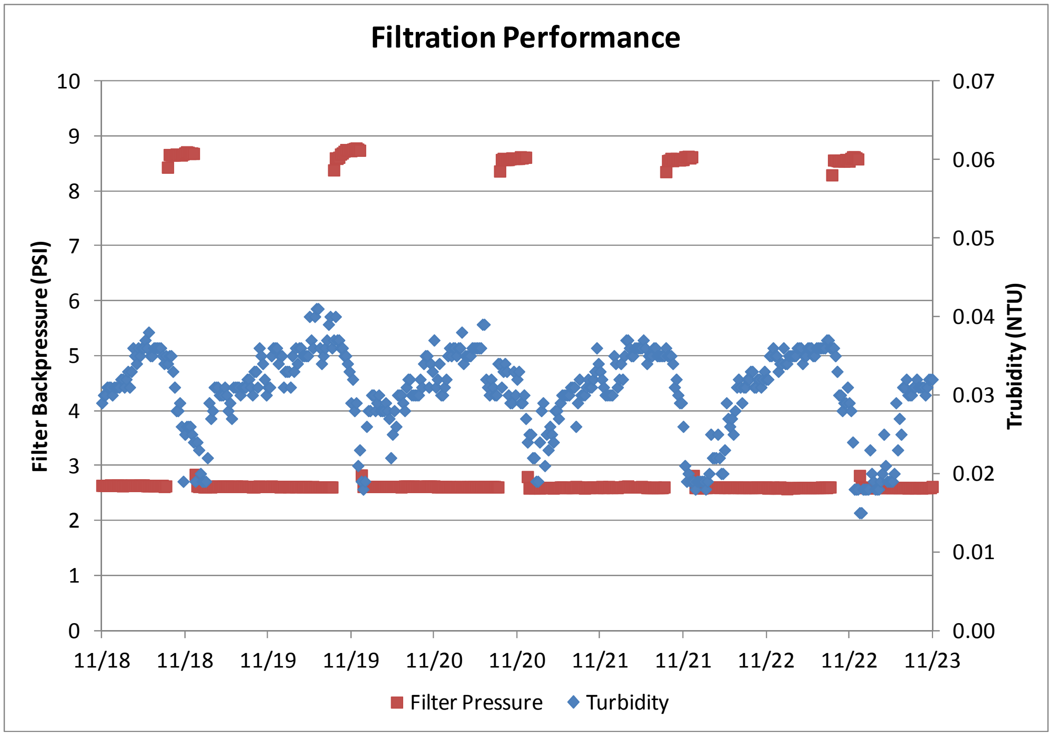

Figure 5: Steady State Filtration Effectiveness

Utility Cost Savings

Annual cost savings were estimated using the utility bill data and current off-peak and on-peak utility rates for SMUD Schedule GS. Results, listed in Table 4, show the Debbie Meyer Swim Center is saving $625 per year in electricity costs. During the pre-retrofit period, the pump was shut off during the off season, whereas it was just run at a lower rate during the monitored period, resulting in negative realized savings during that period. In the pre-retrofit case, the pool would have to be re-commissioned at the start of each season, which means higher pumping energy for a few days prior to occupancy while the pool is shocked with large amounts of chlorine. Features of the system controls that automate the maintenance of chlorine levels and pH also reduce maintenance costs and insure that the pool is continuously safe for swimming and available for use.

Table 7 - Estimated Monthly Utility Savings Attributed to Pool Pump Replacement

Month	Realized Savings	Average Rate	Estimated Savings
January	-$16.42	0.124	$33.22
February	-$7.88	0.124	$30.11
March	$139.88	0.124	$59.04
April	$129.35	0.124	$57.20
May	$64.84	0.124	$59.62
June	$90.48	0.139	$66.83
July	$85.38	0.139	$65.15
August	$65.90	0.139	$67.86
September	$33.77	0.139	$66.83
October	$48.86	0.124	$59.04
November	-$1.45	0.124	$29.07
December	-$17.40	0.124	$31.15
TOTAL	$615.31		$625.12

5. Conclusions and Recommendations

This study provides evidence that high efficiency variable speed pumps can yield significant energy savings without negatively affecting the health and safety of the pool users, or risking pool shutdown due to unsanitary conditions that would affect operational revenues. Continued monitoring is recommended to verify the long term reliability of systems. Additional field tests are recommended to develop pre- and post-replacement data to support changes in Title 22 and Title 24 codes that will bring them up to date with the capabilities of the new pump systems. Code changes are probably not essential to facilitate utility programs that can yield cost-effective investments for consumers.

Variable speed pumps in public pool facilities may also offer a demand response opportunity for utilities. With the ability to remotely access pump settings, “soft” schedules that are programmed into the pump control may be varied to shift loads to off-peak periods. Manufacturers should be encouraged to pursue this opportunity by providing schedules that would allow facility operators to set fixed filtration rates during use periods, and flexible filtration rates during non-use periods that would still produce the required number of daily turnovers.

Facility managers may also benefit from technology that would adjust filtration rates based on measured turbidity and ORP. However, improvements in reliability of nephelometers and code changes, would be needed to allow this mode of operation.