ABSTRACT

Title of Thesis: ANALYSIS AND SIMULATION OF ENERGY USE AND COST AT A MUNICIPAL WASTEWATER TREATMENT PLANT

Yilu Feng, Master of Science, 2011

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The cost of electricity, a major operating cost of municipal wastewater treatment plants, is related to influent flow rate, power price, and power load. With knowledge of inflow and price patterns, plant operators can manage processes to reduce electricity costs. Records of influent flow, power price, and load are evaluated for Blue Plains Advanced Wastewater Treatment Plant. Diurnal and seasonal trends are analyzed. Power usage is broken down among treatment processes.

A simulation model of influent pumping, a large power user, is developed. It predicts pump discharge and power usage based on wet-well level. Individual pump characteristics are tested in the plant. The model accurately simulates plant inflow and power use for two pumping stations [R^2 = 0.68, 0.93 (inflow), R^2 =0.94, 0.91(power)]. Wet-well stage-storage relationship is estimated from data. Time-varying wet-well level is added to the model. A synthetic example demonstrates application in managing pumps to reduce electricity cost.

ANALYSIS AND SIMULATION OF ENERGY USE AND COST AT A MUNICIPAL WASTEWATER TREATMENT PLANT

By

Yilu Feng

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Chapter 1. Introduction

1.1 Problem Statement

Municipal wastewater treatment plants are large power consumers. Four percent of the electrical power of United States is consumed by water/wastewater delivery and treatment (EPRI, 2003). The power bill accounts for 25% to 40% of the operating cost of a wastewater treatment facility (PG&E, 2003).

Power usage (load) of a municipal wastewater treatment plant is closely related to influent flow rate, while power cost is related to both power load and power price. Most wastewater characteristics fluctuate throughout the day based on the living and working patterns of the community. An evaluation of diurnal flow trend and corresponding power usage pattern helps to understand the energy distribution and the potential energy and cost saving opportunities.

The influent pumping station, which is located at the end of the wastewater collection system and the beginning of the treatment process, is one of the largest in-plant power users. The Environmental Protection Agency estimates that 85% to 95% of the operation and maintenance costs of pumping station are power costs, which are directly proportional to the unit cost of power and the actual power used by the pumps (EPA, 2000).

Centrifugal pumps in the wastewater pumping station may remain in service for decades. For example, Raw Wastewater Pump Station 1 (RWWPS1) in District of

Columbia Water and Sewer Authority (DC WATER) Blue Plains facility was constructed in 1938 and upgraded in the early 1980s (DCWASA, 2002). Because of wearing and other factors, the original pump characteristic curves, including the Head-Discharge and Efficiency-Discharge curves, no longer represent these relationships. The designed pumping rate and other characteristics tend to be misleading for current operation. New pump tests are necessary to interpret the pump performance. New analyses of the relationship among power usage, pumping rates, efficiency, and pumping head will be important for operation, maintenance, and other decision making.

1.2 Research Goal and Objectives

The goal of this research project was to provide a preliminary study for power saving opportunities with a focus on influent pumping. The study used historical data for trend and performance analysis. The Process Control System (PCS) at the Blue Plains Advanced Wastewater Treatment Plant provided access to the records of power usage, pump operation status, flow rate, level of wet-wells, etc.

This research project had two phases:

Objectives of Phase I: Energy Load and Cost Analysis

- Analyze the diurnal and seasonal trend of unit power price and total power load of Blue Plains.
- Break down the energy usage to major treatment processes.

Objectives of Phase II: Simulation Model of Influent Pumping Station

- Run pump performance tests with the aid of PCS system.

- Develop algorithm to represent Discharge-Head curve for each raw wastewater pump.
- Develop a simulation model for predicting pump discharge/ primary inflow based on wet-well level, pumps on service and pump speed.
- Evaluate pump performance characteristics including pump discharge, power consumption and wire-to-water efficiency.
- Develop a simulation model for predicting power consumption of influent pumping based on pumps on service.
- Estimate the influent wet-well storage based on data obtained from power outage or influent pumping outage.
- Provide examples of inefficient pumping, e.g., pumping without a good priming condition.

1.3 Study Area

Blue Plains Advanced Wastewater Treatment Plant is located on the east bank of the Potomac River in Washington, D.C. It serves as a wastewater collection and treatment facility for the District of Columbia and surrounding areas including parts of suburban Virginia and Maryland (Total service area around 725 square miles). The service area and population is illustrated in Fig. 1-1 and Table 1-1 (Metropolitan Washington Council of Governments, 2003). Blue Plains' wastewater collection system comprises both combined and separate sewers. About one-third of the District is served by combined sewer (approximately 12,955 acres) and two-thirds is served by separate sewer (DCWASA, 2002). The process flow diagram is shown in Fig.1-2.

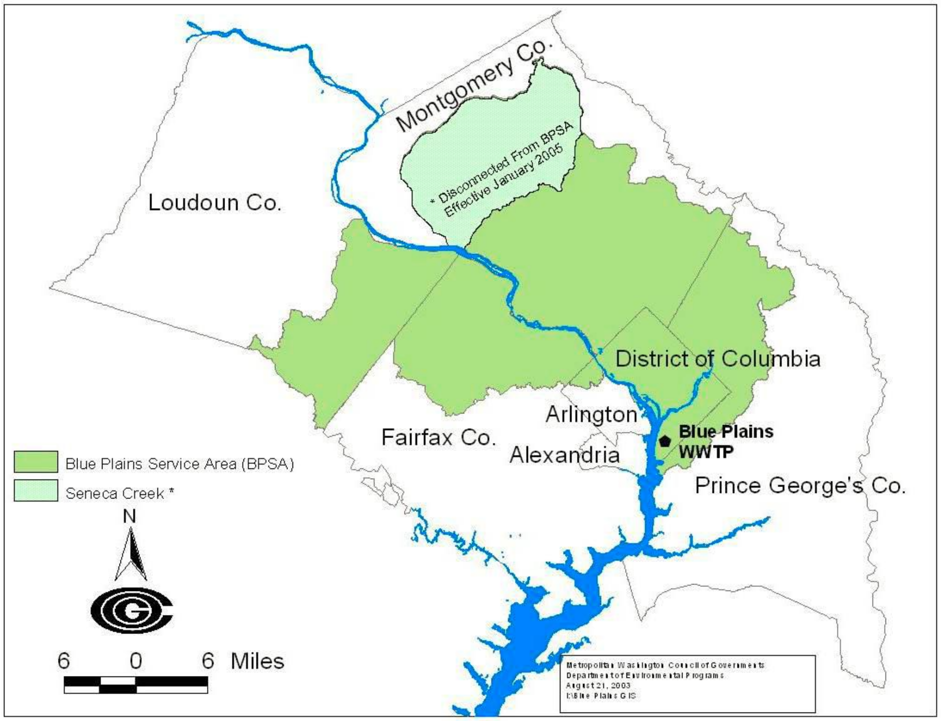


Figure 1-1. Blue Plains service area (Metropolitan Washington Council of Governments, 2003)

Table 1-1. Service population of Blue Plains (Metropolitan Washington Council of Governments,2003)

State	County	% of population served
District of Columbia		100%
Virginia	Fairfax County	27%
	Arlington County	8%
	Loudoun County	60%
	Dulles Airport	100%
	the Town of Vienna	100%
Maryland	Prince George's County	49%
	Montgomery County	77%
	National Park Service (NPS)	100%
	Naval Ship Research and Development (NSR&D)	100%

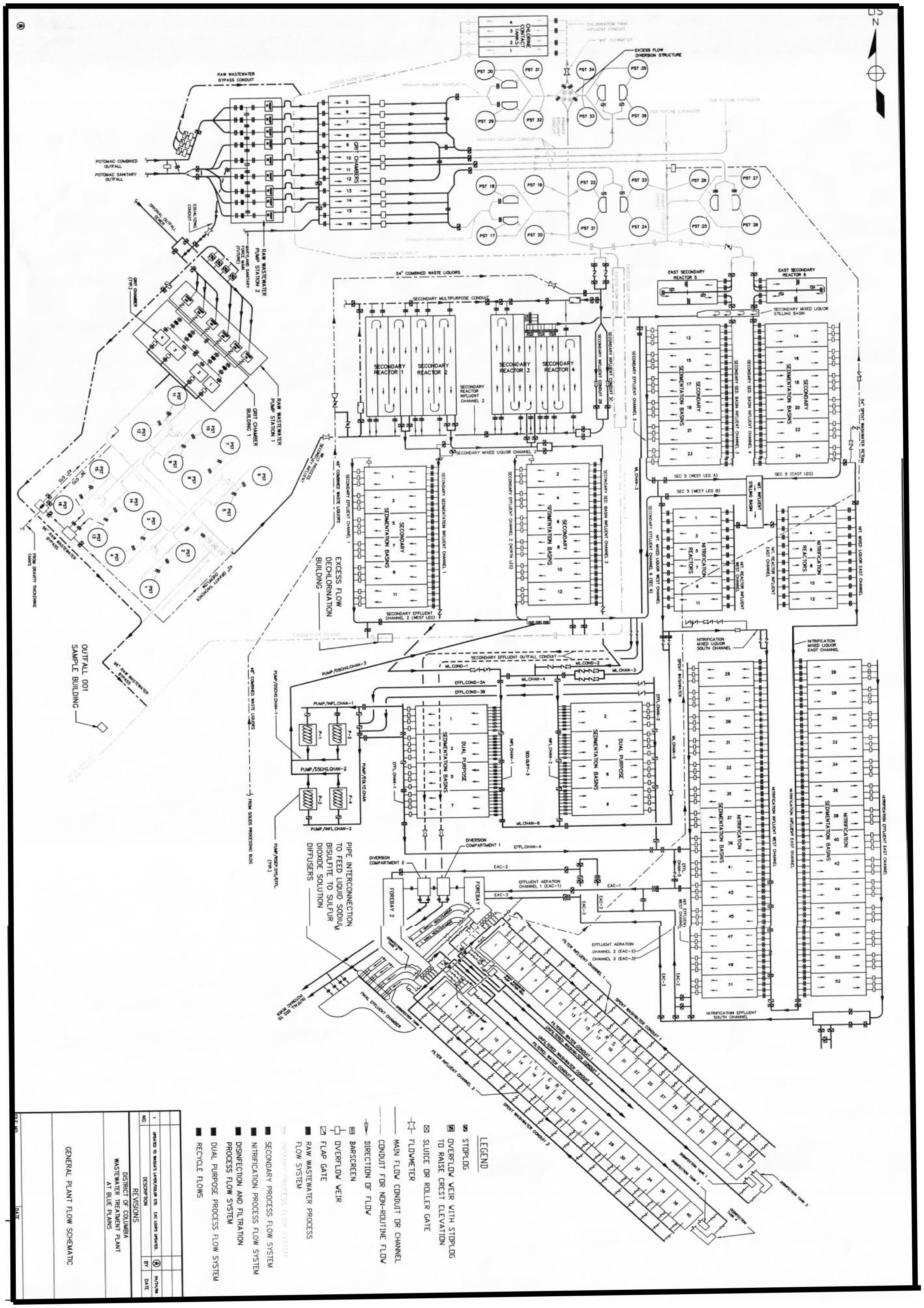


Figure 1-2. Blue Plains process flow diagram (Michael Tucker, 1996)

Blue Plains is designed for an average daily flow of 370 MGD and a peak plant wet weather flow of 1076 MGD, which could provide wastewater treatment for the service area until 2030. During wet weather events, the treatment capacity depends on the storm duration. Flows up to 740 MGD can receive treatment for up to 4 hours. In order to protect the biological process, the treatment capacity is reduced to 511 MGD for the next 20 hours and additional flows of up to 336 MGD receive excess flow treatment before discharge to the Potomac River, which consists of screening, grit removal, primary treatment and disinfection. After 24 hours, the maximum flow treated by the plant would be 450 MGD. The treatment capacity is recommended to be expanded to a plan that would provide zero overflows/bypass (untreated wastewater discharged to a water body when incoming wastewater exceeds the treatment capacity due to heavy rainfall, etc.) in the three analysis years or to a plan that would provide zero overflows during a 5-year 24-hour design storm (Metcalf & Eddy and Greeley & Hansen LLC, 2007).

The Raw Wastewater Pump Stations, RWWPS1 (West) and RWWPS2 (East), are located at the end of the collection system (Fig.1-3). Both combined sewer and separate sanitary sewer flows arrive at the plant by gravity and are collected and temporarily stored in two wet-wells, one for West (Fig.1-4) and one for East. The two wet-wells are connected by an equalizing conduit (Fig.1-5) and the water levels of the two wet-wells are considered hydraulically the same. Fig. 1-6 illustrates the flow diagram of influent pumping to Blue Plains. On the west side, the pumps in RWWPS1 deliver the wastewater from a concrete wet-well to the screen influent channel (Fig.1-7). On the east side, the screened wastewater is lifted by the pumps in

RWWPS2 from the wet-well to the crest of the discharge siphon (Fig.1-8), then flows by gravity to the aerated grit chamber. During current operation, the discharge siphon is always open. How the wastewater is split between the two sides depends on the pumping rates of each pumping station. The desired flow ratio is 40% (West, RWWPS1) to 60% (East, RWWPS2). The wet-well level of RWWPS1&2 is normally operated between -2 to +2 feet (dry weather), although sometimes it is drawn down to -3ft or lower to accommodate anticipated wet-weather flow. The decision is made by the operators according to the current wet-well level and weather conditions.

Pumps with variable speed drive provide the operator with more flexibility to maintain the wet-well level according to the flow variation. If the wet-well level rises significantly, the speed of the variable speed pumps will be increased. If no variable speed pump is on or if it has already been adjusted to full speed, one additional constant speed pump can be brought on to control the well level. The goal is to prevent hydraulic overloads to downstream processes and avoid bypass to the Potomac River during the storm event. The wet-well should not be drawn down below a certain minimum elevation, because of (a) the energy required to pump from the low elevation, and (b) the potential release of hydrogen sulfide to the buildings.

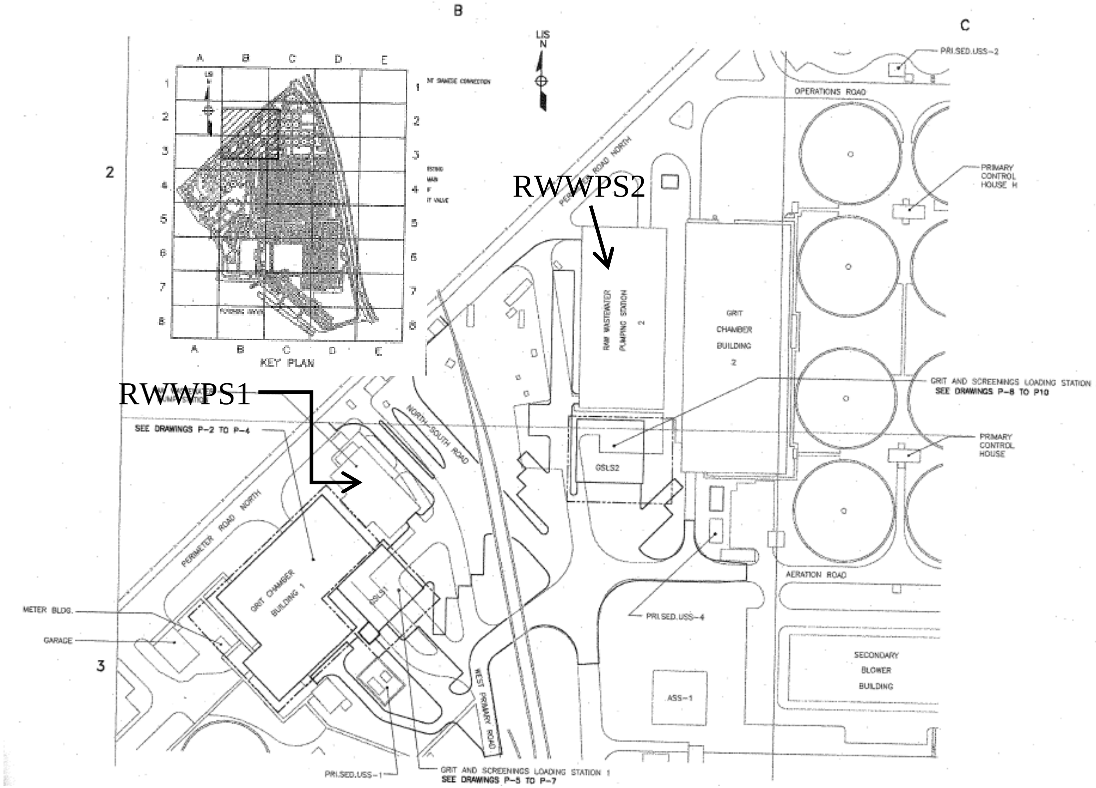


Figure 1-3. Location of RWWPS1&2 in Blue Plains (DCWASA, 2002)

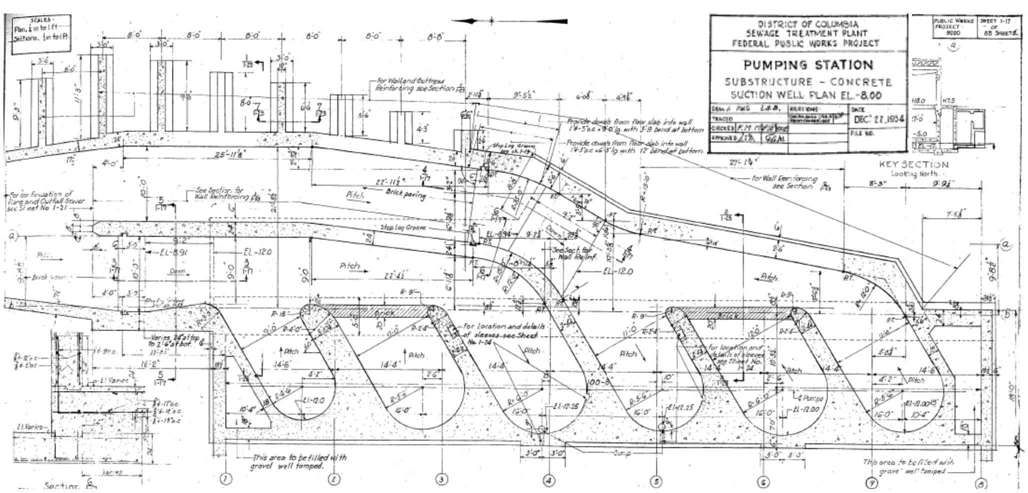


Figure 1-4. Wet-well of RWWPS1 (DCWASA, 2006)

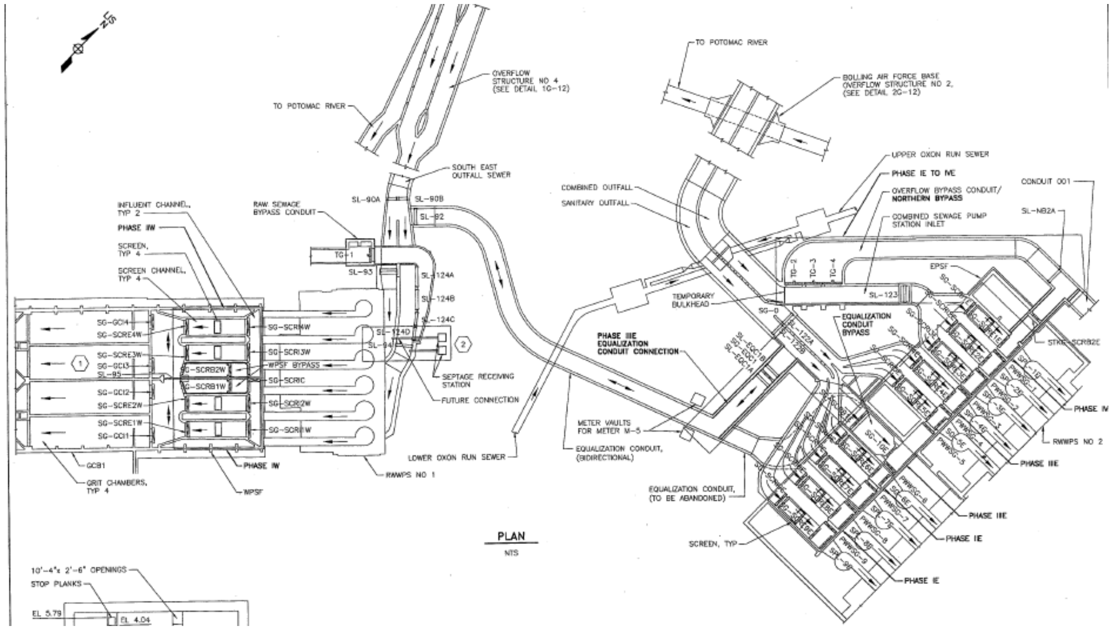


Figure 1-5. Equalizing conduit connecting RWWPS 1&2(DCWASA, 2006)

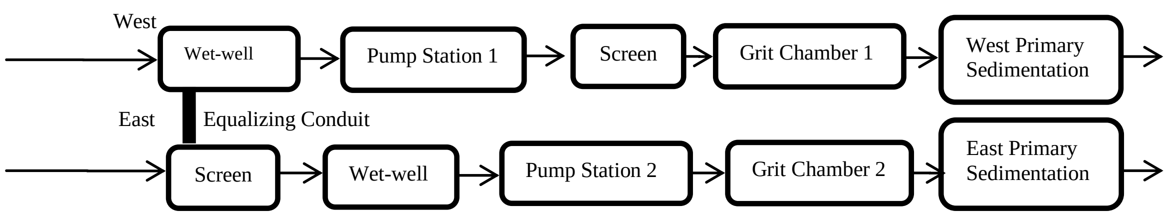


Figure 1-6. Flow diagram of influent pumping

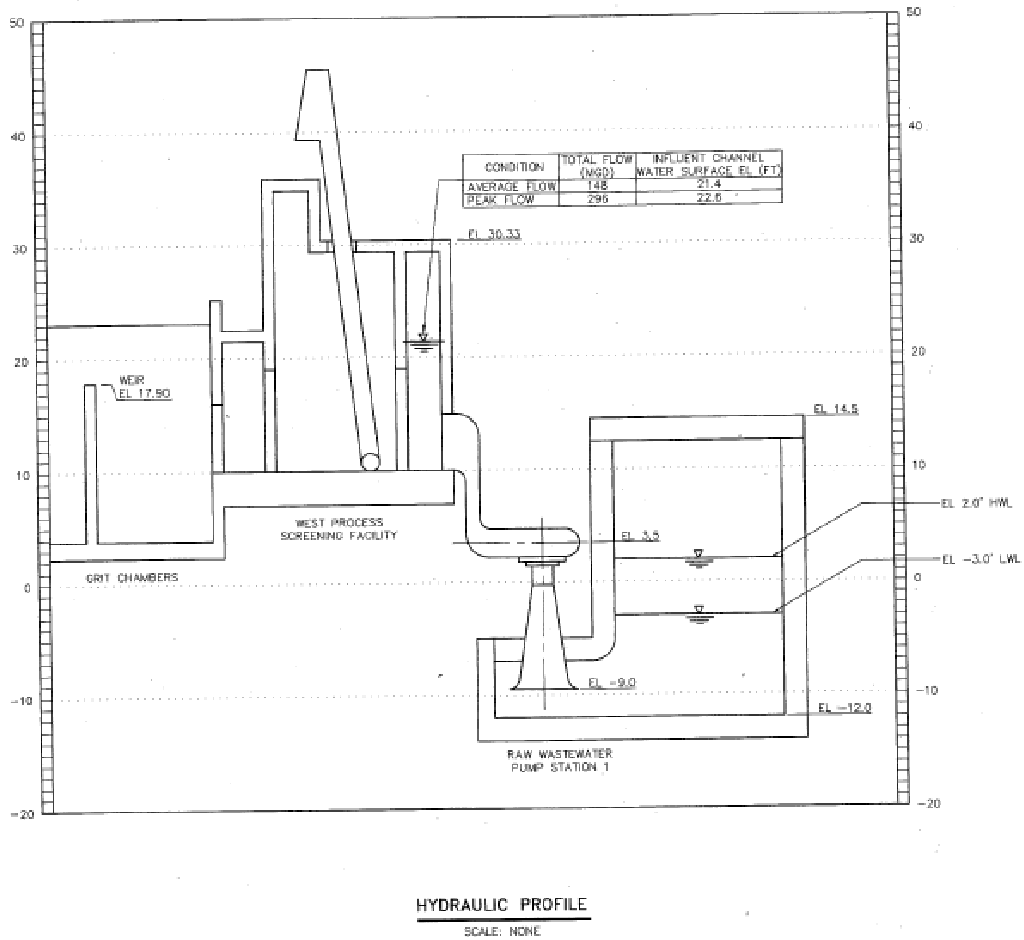


Figure 1-7. Hydraulic profile of RWWPS1(DCWASA, 2006)

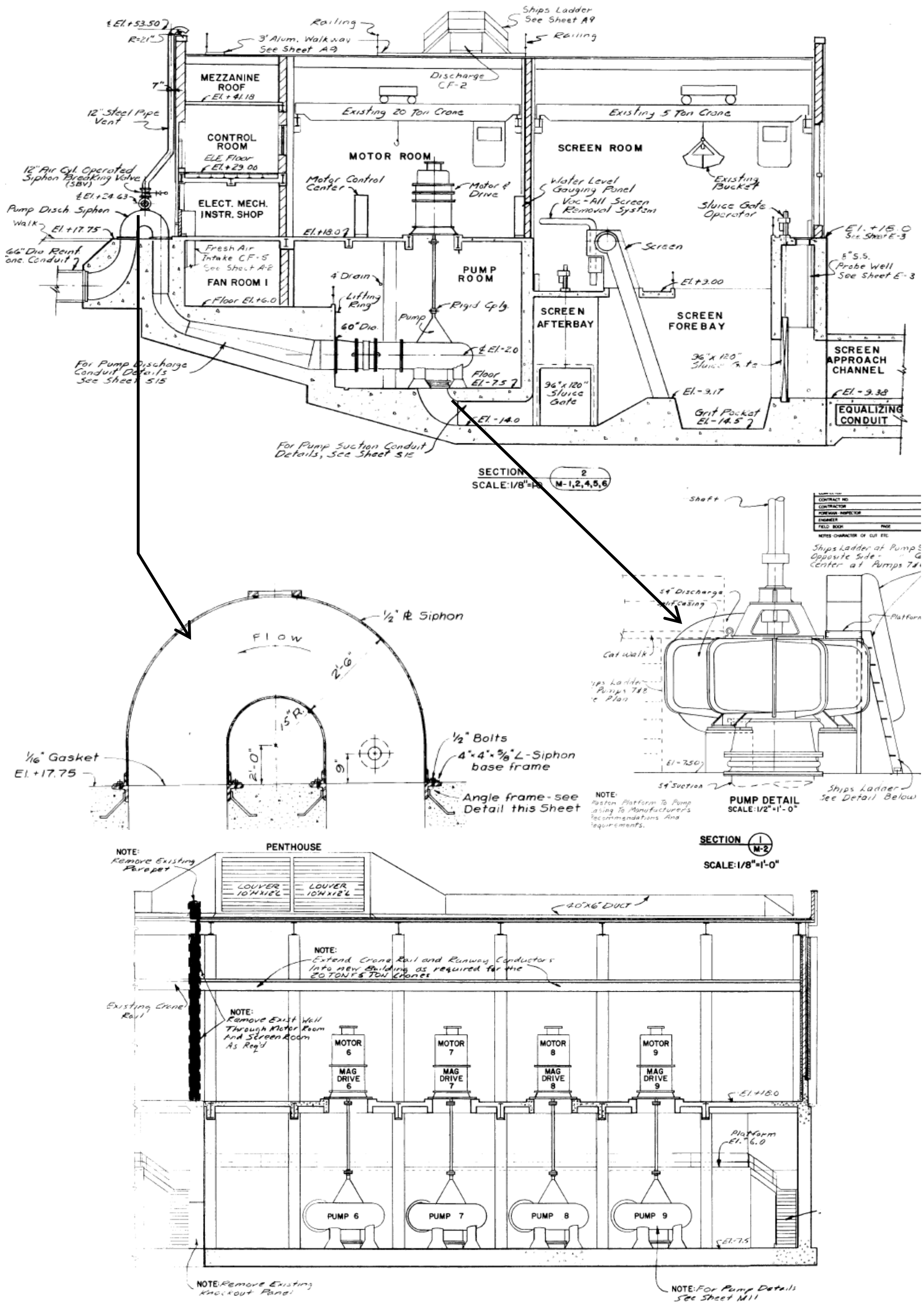


Figure 1-8. Pumping facilities of RWWPS2 (DCWASA, 1974)

There are six centrifugal pumps in RWWPS1: four constant speed pumps and two with adjustable speed magnetic drive. In RWWPS2, four of the nine centrifugal pumps are installed with adjustable speed magnetic drive. The unit information of the centrifugal pumps in RWWPS1 and RWWPS2 are listed in Table 1-2 and Table 1-3, respectively.

Table 1-2. Pump and drive unit information (West, RWWPS1)

	Pump			Motor				
	Manufacturer	Pump Capacity	Model	Manufacturer	Adjustable speed magnetic drive	HP	Volts	RPM
RWWP-1W, 3W	Worthington	41700GPM (60MGD) @22TDH	42 MS-1, 2-Vane	Electric Machinery		300	4160	300
RWWP-2W, 5W	Worthington	55600GPM (80MGD) @22TDH	48 MS-1, 2-Vane	Electric Machinery	X	400	4160	257
RWWP-4W	Worthington	55600GPM (80MGD) @22TDH	48 MS-1, 2-Vane	Electric Machinery		400	4160	257
RWWP-6W	Flowserve	27800GPM (40MGD) @22TDH	36 MS-1, 2-Vane	Electric Machinery		250	4160	360

Note: 6W is the new pump installed in 2010.

(DCWASA 2008)

Table 1-3. Pump and drive unit information (East, RWWPS2)

	Pump			Motor				
	Manufacturer	Pump Capacity	Model	Manufacturer	Adjustable speed magnetic drive	HP	Volts	RPM
RWWP-1E,2E,3E	Worthington	69500GPM (100MGD) @24TDH	5411CU-1	IDEAL ELECTRIC		500	4160	225
RWWP-4E, 5E	Worthington	69500GPM (100MGD) @24TDH	5411CU-1	WESTINGHOUSE		500	4160	225
RWWP-6E, 7E,8E,9E	ALLIS-CHALMERS	69500GPM (100MGD) @24TDH	112-312-533	Electric Machinery	X	560@ 97% speed	4160	233

(DCWASA 2008)

Chapter 2. Literature Review

2.1 Introduction

In this chapter, energy consumption patterns of municipal wastewater treatment plant are discussed, with an emphasis on the power consumption of influent pumping. Wet well and its water level control will be introduced. The relationships among pump characteristics (capacity, efficiency, etc.) and system characteristics (Total Dynamic Head, head loss, etc.) are illustrated by their graphical solution. Possible reasons of unstable pumping are listed in order to understand the potential pumping failure. Numerical modeling and goodness-of-fit statistics are also discussed in this Chapter.

2.2 Energy Consumption of Municipal Wastewater Treatment Plant and Energy Saving Opportunities

According to 2004 Clean Watersheds Needs Survey (CWNS), there are 16,676 municipal wastewater treatment facilities in service in the United States (EPA, 2007). Wastewater treatment consumes approximately 1.5% of total US electric power (PG&E, 2003).

A report by the Electric Power Research institute (EPRI, 2007) illustrates the power consumption of a typical advanced wastewater treatment facility with a treatment capacity of 10 MGD (Fig. 2-1). According to this report, diffused aeration/nitrification, flotation thickening, anaerobic digestion and raw wastewater pumping are the top energy consumers in advanced wastewater treatment process.

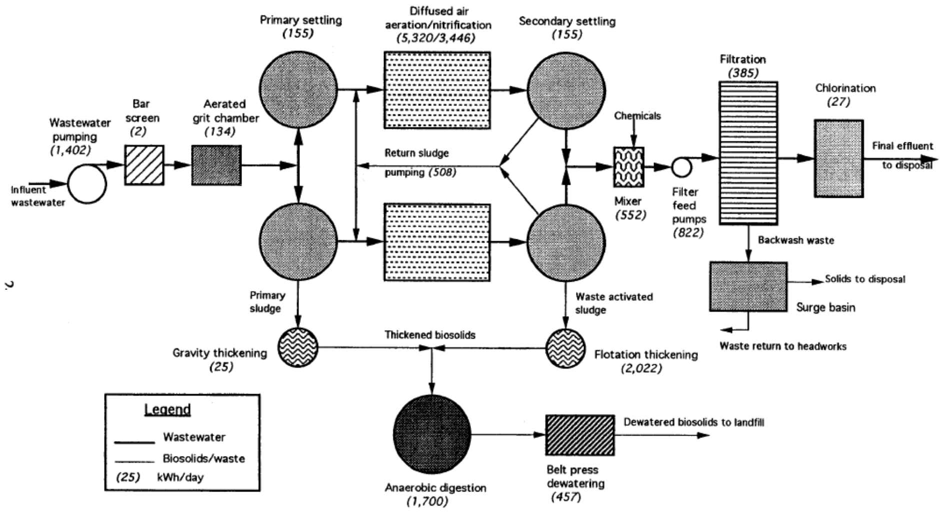
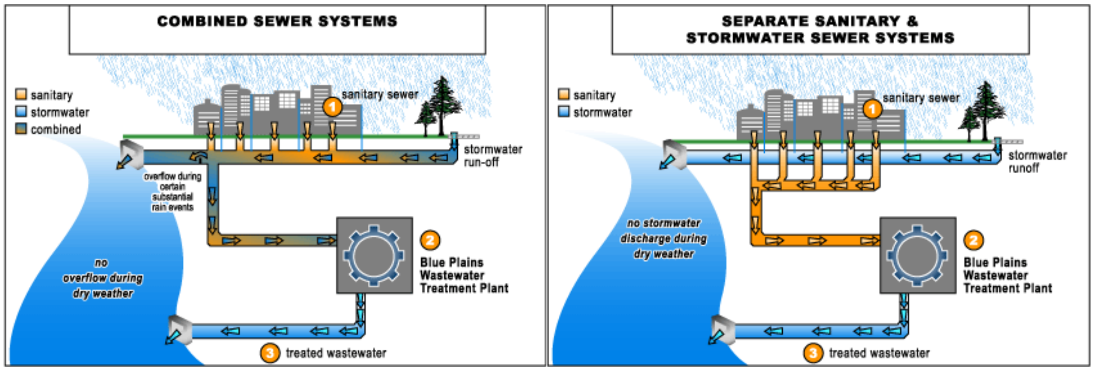


Figure 2-1. Example 10MGD advanced wastewater treatment facility with typical daily electricity consumption (EPRI, 2007)

Energy savings could be achieved (1) from the source, (2) from operations and (3) from renewable energy utilization. Various examples of each approach can be found in the literature.

(1) Savings from the source

Although no combined sewer system has been built in United States after the 1960s, most of the sewer systems in old cities are combined sewer system (Haestad Methods, 2004). For example, approximately one-third of the District of Columbia is served by combined sewer system [Fig. 2-2(a)], built before 1900 (Metcalf & Eddy and Greeley & Hansen LLC, 2007). Another two-thirds is served by separate systems [Fig. 2-2(b)]. Separate systems consist of one system for sanitary sewage (sewage from homes and businesses) and one system for storm water.



(a) (b)

Figure 2-2. Sewer system
(a) Combined sewer systems
(b)Separate sanitary and storm water sewer systems

(DC Water, 2011)

The construction of a separate sewer system provides energy saving opportunities. Influent flow to the WWTP can be decreased dramatically and energy is saved from the source. Rain leaders could be disconnected from the combined sewer system and the storm runoff could be diverted to a dry well, a retention basin, etc. Fig. 2-3 illustrates three types of separation, from the most basic one to the more desirable one. Sewage is diverted to wastewater treatment plant, and storm water is treated with simple process and release separately. By either constructing a new storm water system or a new sanitary wastewater system, partial separation could be achieved by separating the combined sewer in the streets. For complete separation, storm water runoff from rooftops of residence houses, buildings and parking lots is also separated (DCWASA, 2002).

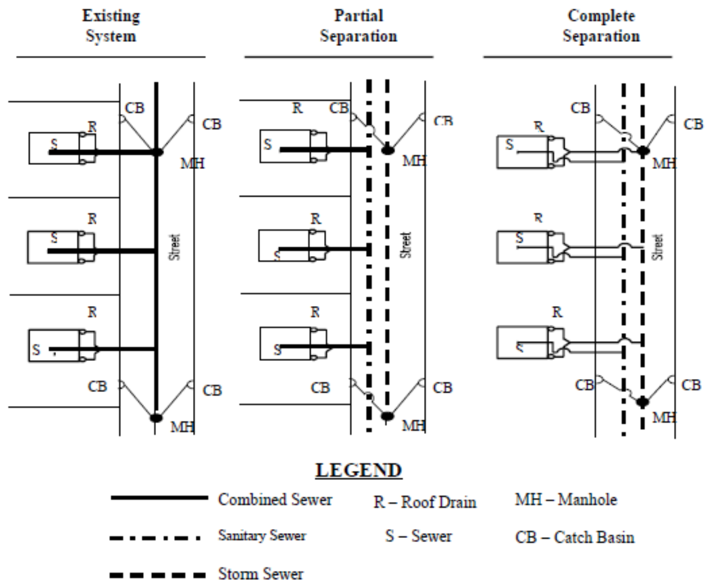


Figure 2-3. Sewer separation alternatives (DCWASA, 2002)

(2) Savings in operation

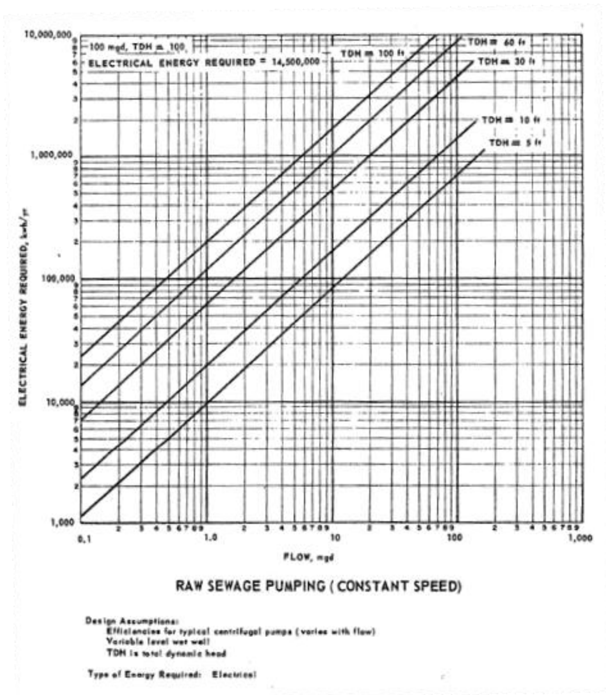
Large energy consumers in wastewater treatment plant have potential energy saving opportunities, such as aeration for activated sludge, nitrification processes and influent pumping. Possible choices for energy savings include: use of high efficiency blowers, fine bubble diffusers, efficient motors, and pumps with variable speed drives.

(3) Savings from renewable energy utilization

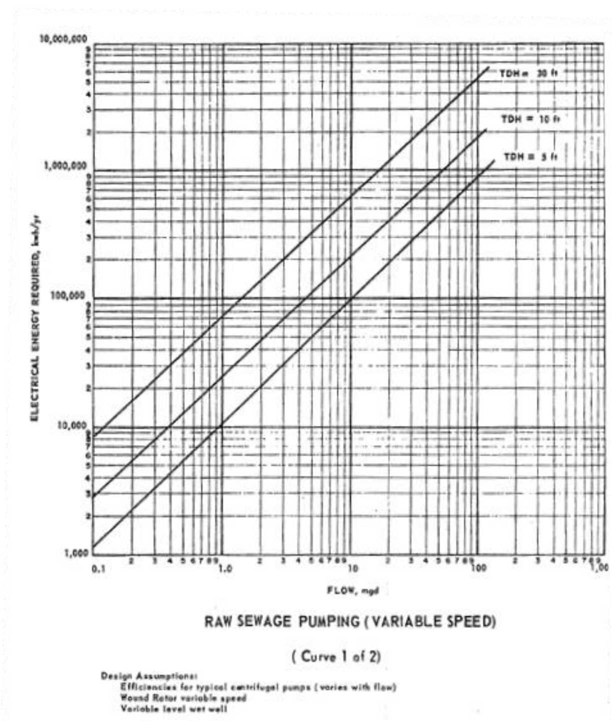
Renewable energy is another energy saving opportunity; municipal wastewater treatment plants can use they waste they treat as a fuel source to produce energy for plant use. The U.S. Environmental Protection Agency (EPA) Combined Heat and Power (CHP) Partnership reported the cost-effective option for utilizing biogas, which contains approximately 60% methane, for heating or electricity generation. This is applicable for Wastewater treatment plant with anaerobic digesters. The biogas can produce approximately 100 KW electricity for each 4.5

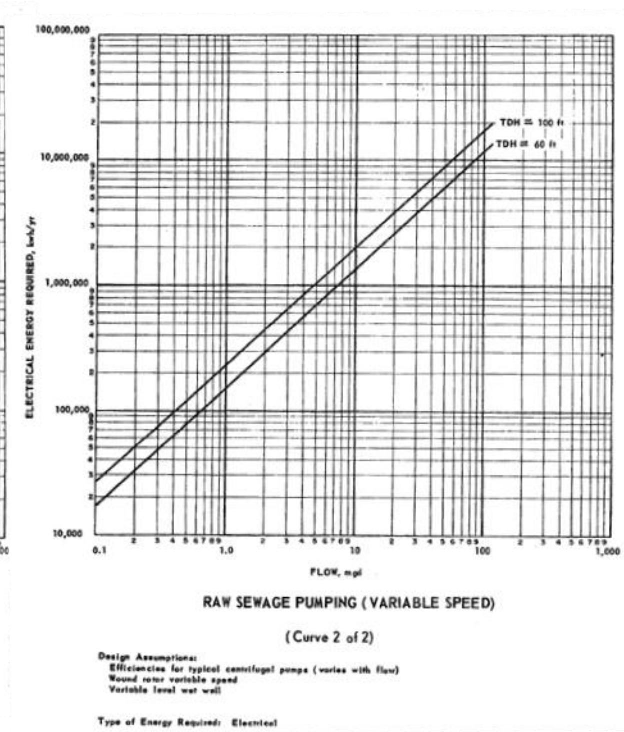
MGD processed by a wastewater treatment facility with anaerobic digestion. In United States, 544 out of 1066 wastewater treatment facilities with flow rates greater than 5 MGD operate anaerobic digesters. Only 106 of them use the biogas as renewable energy for plant use. The potential market is large (CWNS, 2004).

USEPA (1978) conducted a survey about the energy consumption of wastewater treatment processes. According to the technical report of energy conservation of municipal wastewater treatment, an influent pump station with a Total Dynamic Head (TDH) of 22ft like Blue Plains Advanced Wastewater Treatment Plant may consume more than 10,000,000 KWH/yr for constant speed pumping or variable speed pumping (Fig. 2-4).



(a)

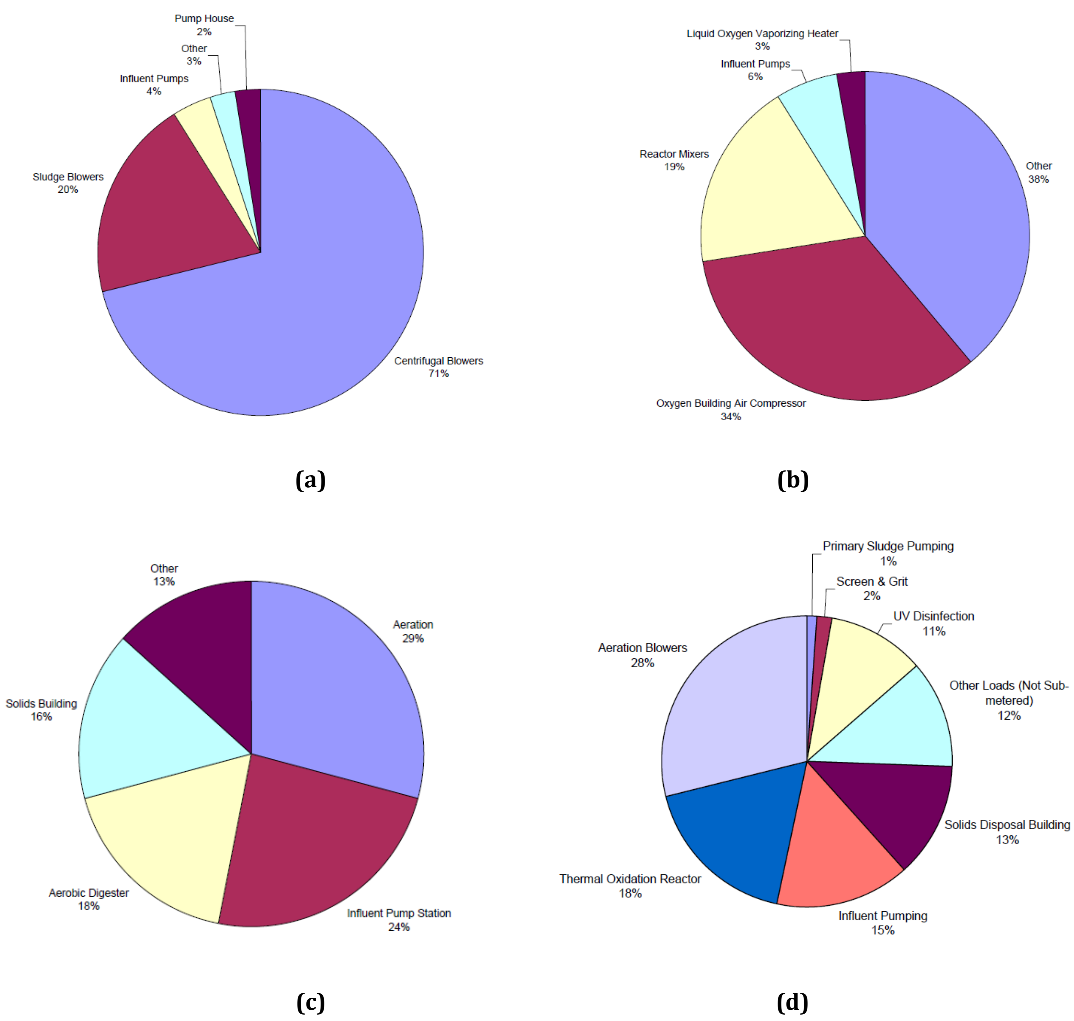




(b) **(c)**

Figure 2-4. (a) Electrical power consumption of constant speed raw sewage pumping (b) Electrical power consumption of variable speed Raw Sewage pumping, curve 1 of 2 (c) Electrical power consumption of variable speed raw sewage pumping, curve 2 of 2 (EPA, 1978)

New York State Energy Research and Development Authority (NYSERDA, 2006) provides the energy consumption breakdown by treatment processes of eleven wastewater treatment facilities, five of which are summarized in Fig. 2-5. Energy consumption of influent pumping at the five WWTPs has an average of 12% of the total plant consumption and a standard deviation of 7.2%. The percentage varies with plant size, plant treatment process, pumping head, piping characteristics, etc. Centrifugal blowers/aeration is the largest power consumer for these plants.



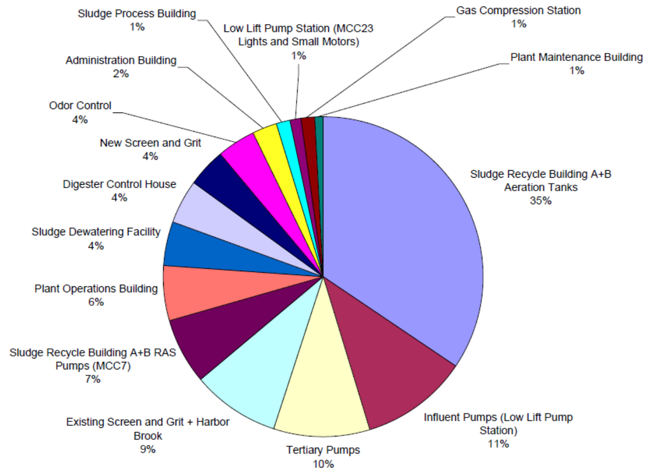


Figure 2-5. Wastewater treatment plant energy use breakdown (a) Village of Heuvelton (b) Town of Grand Island (c) Erie County Big Sister Creek (d) Saratoga Sewer District #1 (e) Onondaga County (Lampman, 2006)

Cost for power usage of influent pumping facility can be saved by installation of Variable Frequency Drive (VFD) and/or replacement of aged or oversized equipment. Variable frequency drive allows the pumping rates to match the flow rate, which leads to the reduction of pump start/shutdown frequency and mechanical wear. Because of less wet-well level fluctuation, the required wet-well size of pump stations with variable frequency drive is smaller, thus reducing the construction and operation cost.

Some wastewater treatment plants are designed in consideration of future flow increment. These wastewater treatment plants may have oversized pump motor. Efficient motor and other equipment sized for current utilization would be another factor for energy saving.

2.3 Raw Wastewater Influent Flow Patterns

2.3.1 Dry Weather Flow Patterns

Raw wastewater influent is made up of four components: residential flow, commercial flow, industrial wastewater flow and storm water. Influent flow patterns vary with region, time of the day, weather, etc. During dry weather, Residential flow, Commercial flow, and Industrial wastewater flow are dominant. Empirical equations, and survey data of water use are often used for the flow estimation of raw wastewater influent.

Unit Load Factors are based on the survey data of water use or wastewater generation rate per capita. They help the engineer to get a general idea of water consumption and discharge in a specific region. Average residential flow rate in the USA is approximately 100 gallons per capita per day (gpcd) (Haestad Methods, 2004). Usually, unit load factors in developing countries are lower than that in developed countries.

Indoor water usage per household can be estimated as a linear function of number of people per household .For example, Haested Methods (2004) gives the following:

$$Y=37.2X+69.2(\text{gpd}) \qquad (2\text{-}1)$$

where

Y=Indoor water use per household (gpd)

X=Number of people per household

Commercial and industrial wastewater flows differ from site to site. Historical data of a specific site or facility should be analyzed to estimate the regional flow rate.

Peaking Factors are used to estimate the peak flow based on the average flow rate, which is commonly used for the wastewater treatment facility design.

$$Q_{peak}=Q_{avg}\times PF \tag{2-2}$$

where

Q_{peak}=peak hourly flow rate (gpd)

Q_{avg}=average daily flow rate (gpd)

PF=peaking factor (dimensionless, greater than or equal to 1)

Peaking factor can be obtained by peaking factor curves (PF vs population or flow rate) and empirical equations. U.S. codes and guidelines specify peaking factors for engineers to estimate peak flows. Equation 2-3, 2-4 and 2-5 are the commonly used estimation methods.

(1) Peaking factor as a function of population

$$PF=\frac{5.0}{\left(\frac{P}{1000}\right)^{0.2}} \quad \text{(Babbitt et al., 1958)} \tag{2-3}$$

$$PF=\frac{\frac{P}{1000}+18}{\frac{P}{1000}+4} \quad \text{(Harmon et al., 1918)} \tag{2-4}$$

where

P=population

(2) Peaking factor as a function of average flow

$$PF=C(Qavg)^{-m} \tag{2-5}$$

where

C=empirical coefficient

Qavg=average flow rate(ft3/s)

m=exponent

(Haestad Methods, 2004)

The diurnal flow factors of Blue Plains estimated from the variations of dry weather flows for flows from the major boundary points as well as the District are listed in Fig. 2-6. These flows contribute to the diurnal trend of the total influent flow rate of Blue Plain. The range of wet weather peaking factors are summarized in Table 2-1.

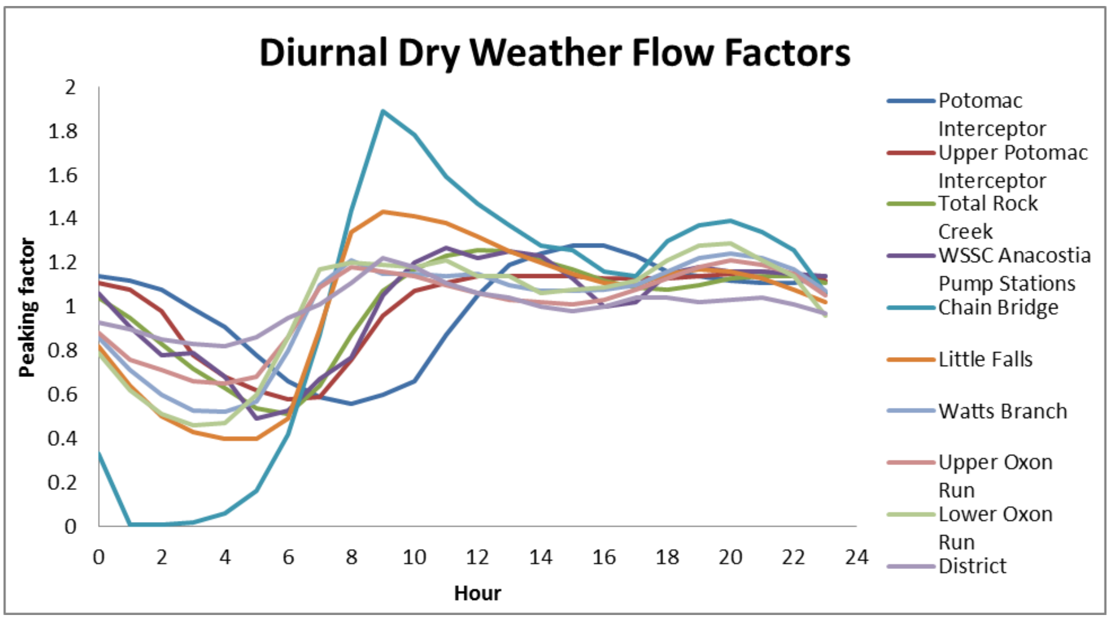


Figure 2-6. Diurnal dry weather flow factors(Metcalf & Eddy and Greeley & Hansen LLC, 2002)

Table 2-1. Range of wet weather peaking factors (Metcalf & Eddy and Greeley and Hansen LLC, 2002)

Location	*Range of Wet Weather Peaking Factors for Dry Weather Flow*[1]
Potomac Interceptor	1.04 to 1.32
Upper Potomac Interceptor	1.34
Total Rock Creek	1.03 to 1.29
Total WSSC Anacostia Pump Station	1.03 to 1.63
Chain Bridge	1.26 to 1.92
Little Falls	1.01 to 1.37
Watts Branch	1.01 to 1.90
Upper Oxon Run	1.01 to 1.74
Lower Oxon Run	1.49 to 2.08
District	1.25

Notes: 1. Flow Rate as a function of time = annual average dry weather flow x wet weather peaking factor x diurnal peaking factor.

In order to understand the diurnal variation of raw wastewater influent, diurnal curves and load duration curves can be developed for a specific region or a specific wastewater treatment facility. For each time step, demands could be expressed by multiplying baseline demand by a dimensionless demand pattern factor (equation 2-6). Fig. 2-7 illustrates the dimensionless diurnal flow pattern using multiplier (Haestad Methods, 2004).

$$Mult_i = Q_i/Q_{base} \qquad (2\text{-}6)$$

where

$Mult_i$ = demand multiplier at the i^{th} time step

Q_i=demand in i^{th} time step(gpm)

Q_{base}=base demand(gpm)

(Haestad Methods, 2007)

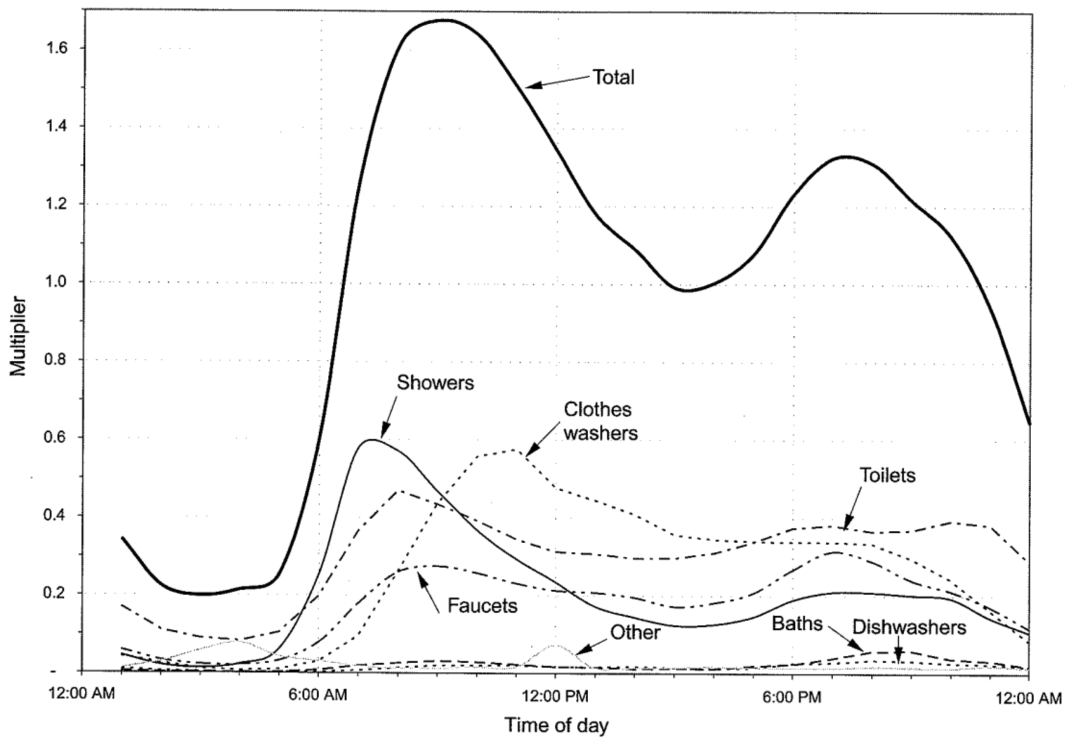


Figure 2-7. Diurnal wastewater flow pattern from a residential area (Haestad Methods, 2004)

Diurnal curves can also be developed by plotting actual flow rates versus time. It should be noted that the length of the time step is directly related to the precision of the curve. For example, if time step of one hour is used to develop the diurnal curve (Fig. 2-8), the true peak might not be detected if the actual peak occurs between 7am and 8am.

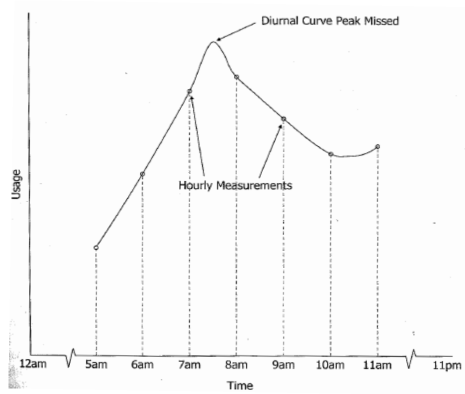


Figure 2-8. A typical diurnal curve and its missing peak due to model time step (Haestad Methods, 2007)

2.3.2 Wet Weather Flow Patterns

During wet weather, flow pattern will be affected by precipitation and water distribution (e.g. infiltration, base flow). Fig. 2-9 is a typical wastewater hydrograph for modeling purposes, introduced by Haestad Methods (2004). The hydrograph can be separated into Groundwater Infiltration (GWI), Base Wastewater Flow (BWF) and Rainfall-derived Infiltration and Inflow (RDII).

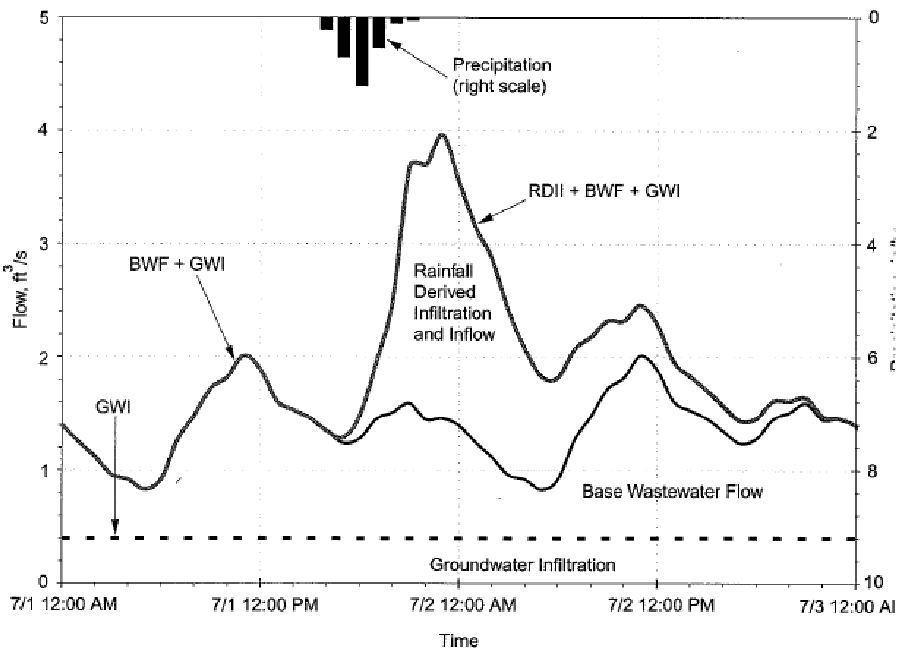


Figure 2-9. Typical wastewater hydrograph (Haestad Methods, 2004)

Historical and annual average rainfall conditions within the District are summarized in Table 2-2. Typically, storm and combined sewer systems in the United States are designed to accommodate the 5-, 10- or 15-year storms.

Table 2-2. Annual average rainfall conditions in the District

Statistic	*1988*	*1989*	*1990*	*Average of 1988-1990*	*Long Term Average*[1]
Annual Rainfall (inches)	31.74	50.32	40.84	40.97	38.95
No. Events > 0.05 inches[2]	61	79	74	71	74
Average Storm Duration (Hours)[2]	9.6	11.2	9.6	10.1	9.9
Average Maximum Intensity (in/hr)	0.15	0.18	0.15	0.16	0.15
Maximum Intensity (in/hr)	1.32	1.31	1.25	1.29	1.30
Percentile[3]	14th	90th	68th	68th	

Notes: 1. Ronald Reagan National Airport hourly data, 1949-1998

2. Individual events separated by a minimum of 6 hours with no rain. A threshold of 0.05" was selected since rainfall less than this produces minimal, if any, runoff.

3. Percentile is based on total annual rainfall.

Metcalf & Eddy and Greeley & Hansen LLC (2007) analyzed the monthly influent flow of Blue Plain from 2002 to 2004. The relationships between precipitation, groundwater level and flow rate are shown in Fig. 2-10, using rainfall data collected at Washington Reagan National Airport and groundwater levels measured in Fairland, MD at USGS well 390434076573002 MO Eh 20.

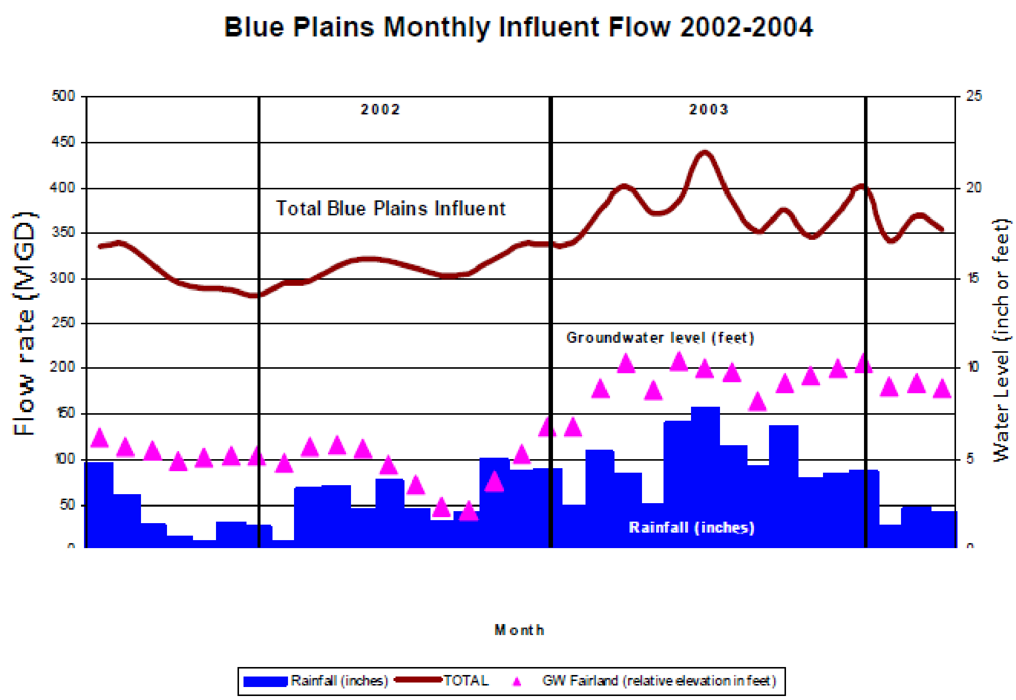


Figure 2-10. Blue Plains monthly influent flow pattern (Metcalf & Eddy and Greeley & Hansen LLC, 2007)

2.4 Raw Wastewater Pumping Facilities

2.4.1 In Plant Pumping Station

Gravity flow is always desirable in the design of water distribution and collection system. When the destination elevation is higher than the source, pumping is required to lift the water/sewage. Centrifugal pumps are commonly used for raw wastewater pumping. Energy is transferred from a motor shaft to the water by a rotating impeller.

The design of a pumping station is based on required capacity, cost, easy access of operation, maintenance and aesthetic considerations. Dry pit/Dry well pump station is often used for raw sewage pumping because of potential clogging and corrosion. Dry well allows for easy access of inspection and maintenance. Relatively higher construction cost and larger spaces are needed for the dry well pumping station. In the dry well influent pumping station at Blue Plains Advanced Wastewater Treatment Plant, motors are installed in the motor room above ground (Fig. 2-11) and pumps are installed in the dry well underground (Fig. 2-12).

Figure 2-11. **(a) Motor in RWWPS1** **(b) Motor in RWWPS2**

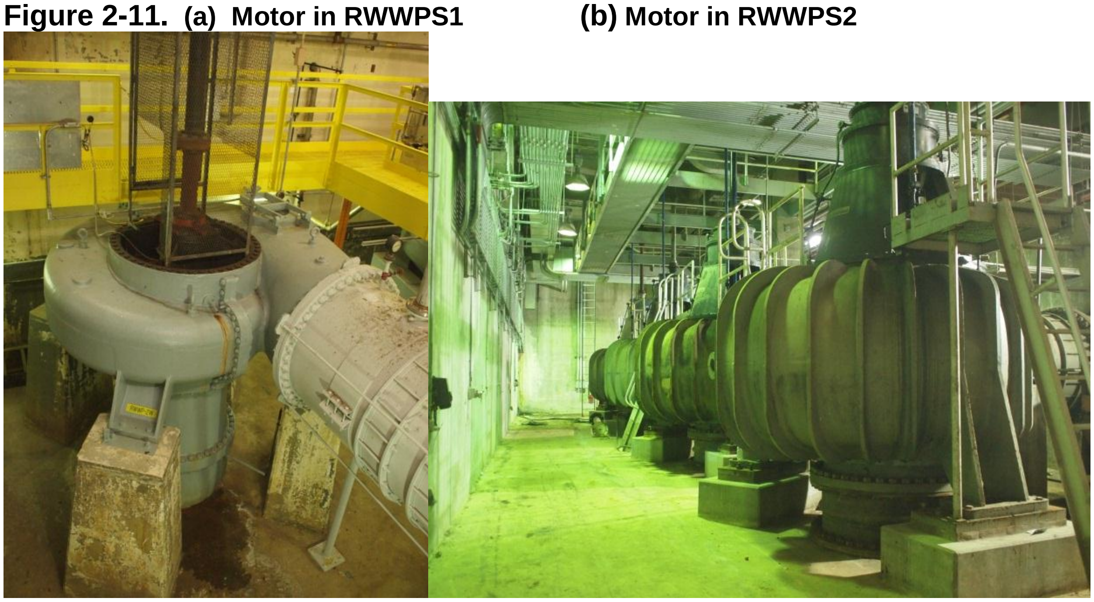


Figure 2-12. (a)Pump in dry well(RWWPS1) (b) Pump in dry well (RWWPS2)

2.4.2 **Wet-well and Pump Control**

The pump control logic is to sequence the pumps with different sizes to match the incoming flow as closely as possible. But even in the 21st century, when automatic control can be realized by computer program, it is not very practical to exactly match the influent flow rate. Each pump has its starting and shut off period and it is not desirable to start or shut down too frequently.

Two types of pump control schemes used in water pumping are described by American Association of State Highway and Transportation Officials (AASHTO, 1991). As depicted in Fig. 2-13, in the Common Off Elevation Scheme, pumps start at successively higher water level elevations and stop simultaneously at the same elevation. In the Successive Start/Stop Scheme, for each water elevation level, one pump is stopped while another is brought online. The advantage of the Common Off Elevation Scheme would be the limit of solids settling time. The advantage of the Successive Start/Stop Scheme is that no unnecessary pump is on service when the water surface drops in the reservoir of suction side (Haestad Methods, 2007).

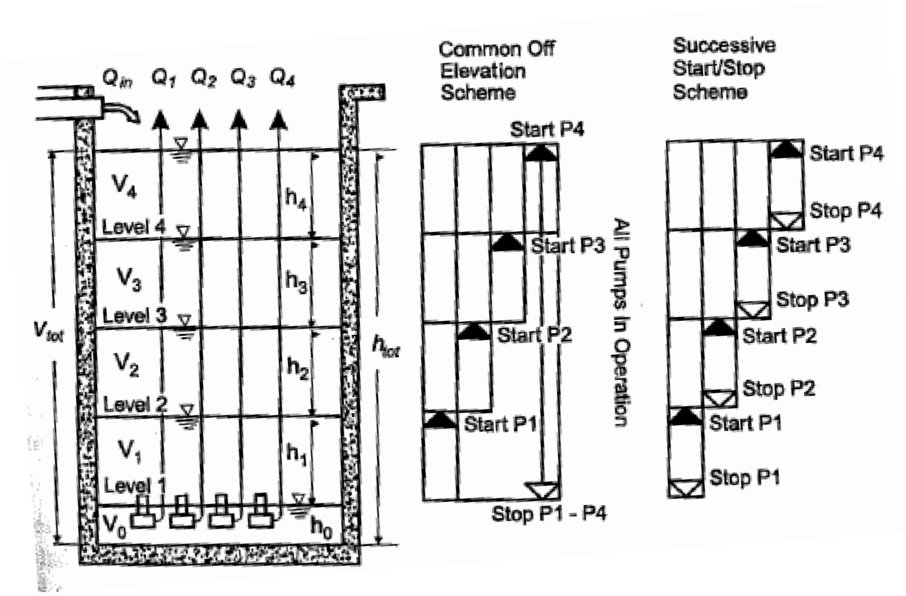


Figure 2-13. Multiple-pump control schemes (Haestad Methods, 2007)

A wet-well should be designed large enough to serve as a temporary storage and balance reservoir for influent wastewater and prevent rapid pump cycling. The wet-well should also be designed small enough to prevent a long detention time and associated odor release. The maximum detention time of wet-well for constant-speed pumping is typically 20 to 30 minutes. The use of variable frequency drives for pump speed control can reduce wet-well detention time to 5 to 15 minutes (EPA, 2000).

2.5 Pump Performance Characteristics

2.5.1 **Conservation of Energy**

Pump is a device to add energy to the system in order to overcome static head and head losses. Considering the flow to be steady and incompressible, the principle of conservative of energy can be expressed by Bernoulli's equation and energy added by the pump would be

$$hp = \left(\frac{p2}{\gamma} - \frac{p1}{\gamma}\right) + (Z_2\text{-}Z_1) + \left(\frac{\alpha 2V2^2}{2g} - \frac{\alpha 1V1^2}{2g}\right) + h_L \qquad (2\text{-}7)$$

where

p=Fluid pressure (lb/in^2)

γ=Specific weight of the fluid ($lb/ft^{3,}$ N/m^3)

Z=Elevation above an arbitrary datum plane (ft, m)

α=Velocity distribution coefficient

V=Fluid velocity, averaged over a cross section (ft/s, m/s)

g=Gravitational acceleration constant (ft/s^2, m/s^2)

h_L=Energy loss between cross sections 1 and 2 (ft, m)

h_P=Fluid energy supplied by a pump between cross sections 1 and 2 (ft,m)

In Equation (2-7), the pressure head term p/ϒ represents the internal energy due to fluid pressure. The static head term Z represents potential energy due to elevation of the fluid. $\frac{\alpha V^2}{2g}$ is the velocity head term that represents the kinetic energy.

The summation of pressure head and elevation head is called piezometric head.

2.5.2 Total Dynamic Head

Total Dynamic Head (TDH) is a combination of pressure head, static head and velocity head. The energy added by the pump should be the energy difference between pump inlet and outlet. If the pump lifts fluid (wastewater) from one open reservoir to another (both at atmospheric pressure), Total Dynamic Head (TDH) added by the pump can be computed as the combination of velocity head, static head and head losses, which includes friction loss and minor loss(equation 2-8)

$$TDH = z_d - z_s + \frac{Vd^2 - Vs^2}{2g} + h_L \quad (2\text{-}8)$$

where

z_d—Water surface elevation of the reservoir (discharge side)

z_s—Water surface elevation of the reservoir (suction side)

V_d—Water velocity of the discharge side, averaged over a cross section

V_s—Water velocity of the suction side, averaged over a cross section

h_L—Head loss, including friction loss and minor loss.

If the difference of the pipe diameter is small enough to neglect (that is, the two velocities are approximately equal),

$$TDH = z_d - z_s + h_L \quad (2\text{-}9)$$

In equation (2-9), TDH added by the pump is only related to the difference of the water surface of reservoirs on both side and the head loss.

The energy added by pumping can also be explained by Hydraulic Grade Line (HGL) or Energy Grade Line (EGL). The HGL is a plot of peizometric head along a flow line and EGL is a plot of the TDH along a flow line. If velocity head is negligible, EGL and HGL overlap each other. Fig. 2-14 is a sketch of HGL of a pumping system.

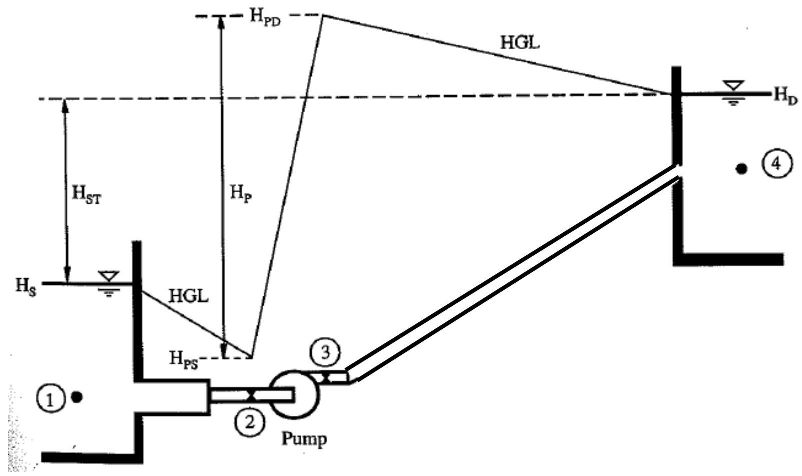


Figure 2-14. Sketch of Hydraulic grade line (Mays, 1999)

The energy relationship between point 1 and 2 can be described by equation (2-10):

$$H_S = H_{PS} + h_{Ls} \qquad (2\text{-}10)$$

where

H_S= head of suction reservoir

H_{PS}= total head at the suction flange of the pump

H_{Ls}= head losses in the suction line

The energy relationship between points 3 and 4 can be described by equation (2-11):

$$H_{PD} = H_D + h_{Ld} \qquad (2\text{-}11)$$

H_{PD}= total head at the discharge flange of the pump

H_D= head of discharge reservoir

H_{Ld}= head losses in the discharge line

By rearranging equation 2-10and 2-11, the energy added by pump (H_{add}) is described by equation (2-12)

$$H_{add} = H_{PD} - H_{PS} = H_D + h_{Ld} - (H_S - h_{Ls}) = H_{ST} + H_L \qquad (2\text{-}12)$$

H_{ST} =total static lift

H_L=total head losses

2.5.3 Head Loss

Head losses of the pumping system are caused by pipe friction and also occur at pipe connections or appurtenances, such as valves, tees, bends, union, elbow, contraction, expansion, manholes, etc. The former is called friction loss and the latter are called minor losses. Head loss is the sum of Friction Loss and Minor Loss.

(1) Friction Loss

Friction loss refers to the portion of head loss caused by shear stresses when fluid is moving through a pipe. Friction loss depends on the properties of pipe, such as length, diameter, and internal roughness, which is usually related to pipe material and age. Friction loss is also related to fluid properties, including density, viscosity, velocity, etc.

The most commonly used equations to compute friction loss are the Darcy-Weisbach equation, Hazen-Williams Equation and Manning Equation.

(1) Darcy-Weisbach Equation

$$h_L = f\frac{LV^2}{D2g} = \frac{8fLQ^2}{gD^5\pi^2} \qquad (2\text{-}13)$$

where

f=Darcy-Weisbach friction factor

g=gravitational acceleration (32.2ft/s2, 9.81m/s2)

Q=pipeline flow rate (ft3/s, m3/s)

Darcy-Weisbach equation for pipe flow calculation is convenient in computation since explicit mathematical form is provided by Colebrook-White equation (2-14) or Swamee-Jain Equation (2-15). Colebrook-White equation and Swamee-Jain Equation relate friction factor (f) to Reynolds number (Re) and relative roughness. Trial-and-error solution is required for Colebrook-White equation since f appears on both side of the equation. Swamee-Jain equation, which is an explicit approximation to Colebrook-White equation, is developed for convenient calculation.

Colebrook-White equation

$$\frac{1}{\sqrt{f}} = -0.86\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{Re\sqrt{f}}\right) \qquad (2\text{-}14)$$

Swamee-Jain Equation

$$f = \frac{1.325}{\left[\ln\left(\frac{\varepsilon}{3.7D + \frac{5.74}{Re^{0.9}}}\right)\right]^2} \qquad (2\text{-}15)$$

where

Ɛ=pipe roughness factor (equivalent sand grain roughness)

D=pipe diameter

Pipe roughness factor (Ɛ) is in the unit of length, it varies with pipe materials (Table 2-3)

Table 2-3. Pipe roughness factor (Haestad Methods, 2004)

Material	Equivalent sand grain roughness, Ɛ(ft)
Uncoated cast iron	7.4 x10-4
Coated cast iron	3.3 x10-4
Uncoated steel	9.2 x10-5
Coated steel	1.8 x10-4
Concrete	10-3-10-2
Cement	1.3 x10-3-4 x10-3
PVC	5 x10-6

(2) Hazen-Williams Equation

The Hazen-Williams method calculates friction head loss as follows,

$$H_L = \frac{C_f L}{D^{4.87}} \left(\frac{Q}{C}\right)^{1.852} \quad (2\text{-}16)$$

where

H_L=Pipe friction head loss (ft, m)

L=Pipe length (ft, m)

C=Hazen-Williams C- factor

D=Diameter (ft, m)

Q= Flow rate (ft3/s, m3/s)

C_f=Unit conversion factor (4.73 for US customary units, 10.7 for SI)

The Hazen-Williams C factor is related to pipe material and pipe diameter (Table 2-4).

Table 2-4. Hazen-Williams C Factor as a function of pipe material and diameter (Haestad Methods, 2004)

Type of Pipe	Discrete Pipe Diameter, in.				
	3	6	12	24	48
Uncoated cast iron, smooth and new	121	125	130	132	134
Coated cast iron, smooth and new	129	133	138	140	141
Uncoated steel, smooth and new	142	145	147	150	150
Coated steel, smooth and new	137	142	145	148	148
PVC wavy, clean	142	145	147	150	150
Prestressed concrete pipes-clean			147	150	150

(3) Manning Equation

The Manning equation for a pipe flowing full is expressed as

$$h_L = \frac{CfL(nQ)^2}{D^{5.33}} \quad (2\text{-}17)$$

where

n=Manning roughness coefficient

C_f=Unit conversion factor (4.66 for customary units, 5.29 SI)

D= Pipe diameter

(Haestad Methods, 2004)

Darcy-Weisbach equation is theoretically based. It is generally claimed to be more accurate than Hazen-Williams equation and Manning equation, since they are empirically based. Hazen-Williams equation is frequently used for water distribution design (Haestad Methods, 2007).

(2) Minor Loss

Minor loss within the piping systems are the energy depletion that occurs at expansions, contractions, valves, manholes, bends and other components along the pipeline. Minor loss varies with the number and property of the additional components. It is expressed for a single component by equation (2-18):

$$h_m = K_L\frac{V^2}{2g} = K_L\frac{Q^2}{2gA^2} \quad (2\text{-}18)$$

where

h_m=Minor head loss(ft, m)

K_L=Minor loss coefficient

V^2=Average fluid velocity (ft/s, m/s)

g=Gravitational acceleration constant (ft/s^2, m/s^2)

Q=Pipeline flow rate(ft^3/s,m^3/s)

A=Cross-sectional area of pipe (ft^2,m^2)

Minor loss coefficients for some commonly used fittings are listed in Table 2-5.

Table 2-5. Minor loss coefficient

Fitting	K_L
Pipe Entrance	
Bellmouth	0.03-0.05
Rounded	0.12-0.25
Sharp Edged	0.5
Projecting	0.8
Expansion-Conical	
D2/D1=0.8	0.03
D2/D1=0.5	0.08
D2/D1=0.2	0.13
Mitered Bend	
è=15º	0.05
è=30º	0.1
è=45º	0.2
è=60º	0.35
è=90º	0.8
Valves	
Gate, fully open	0.15
Gate, closed	0.26
Gate, closed	2.1
Gate, closed	17

2.5.4 Pump Capacity and Pump Characteristic Curves

Pump capacity is the volume of fluid (wastewater) that the pump can move per unit of time. It is measured by the unit of flow rate, e.g. MGD or GPM. The designed capacity is usually available from the manufacturer, but the actual capacity depends on the system in which the pump is running. For example, the capacity varies with the system head, fluid specific gravity, etc.

Pump characteristic curves, including TDH-discharge curves, power-discharge curves, and efficiency-discharge curves, are usually provided by the manufacturer to depict the behavior of the pump. Sometimes the manufacturer will also provide the system curves. System curve is usually obtained by tests in the pump operation system. Pump will be operated at the point that the system curve and pump head-discharge curve intercepts. Pump capacity depends on the interception point, as illustrated in Fig. 2-15. Pump performance varies with the size of the pump.

As illustrated in Fig. 2-16, if two pumps are installed in parallel and energy heads produced by the pumps are equal, the total discharge of two pumps will be Q=Q1+Q2 (Q1 is the discharge of pump1 and Q2 is the discharge of pump 2). If identical pumps are installed in parallel with a single discharge piping system, the increment of discharge produced by the second pump is less than the discharge produced by one pump in the system because of the increased friction loss and minor loss in response to the increased flow rate in the piping system (Fig. 2-17).

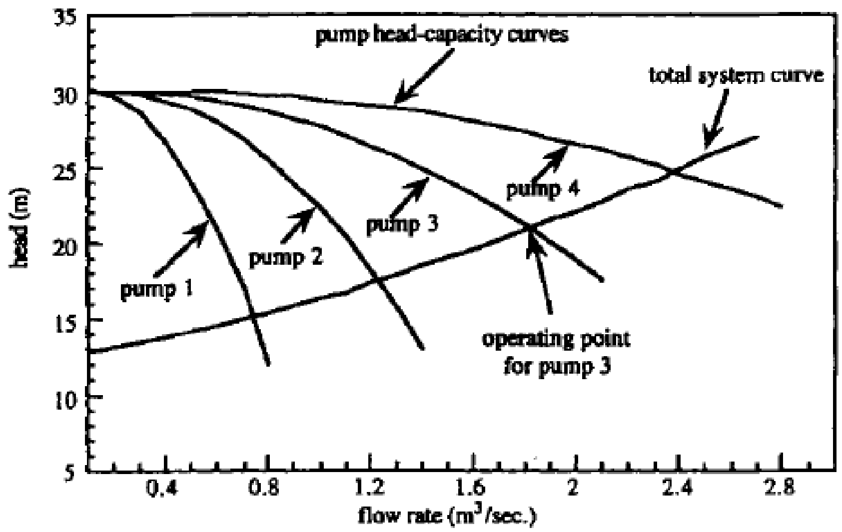


Figure 2-15. Pump Head-Discharge Curve and Operating points

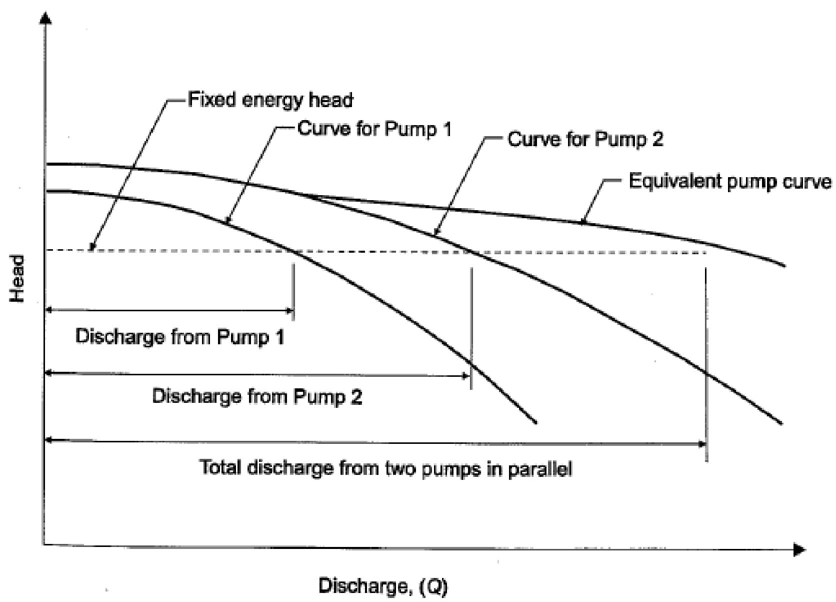


Figure 2-16. Equivalent pump curve for a system of two pumps in parallel (Haestad Methods, 2007)

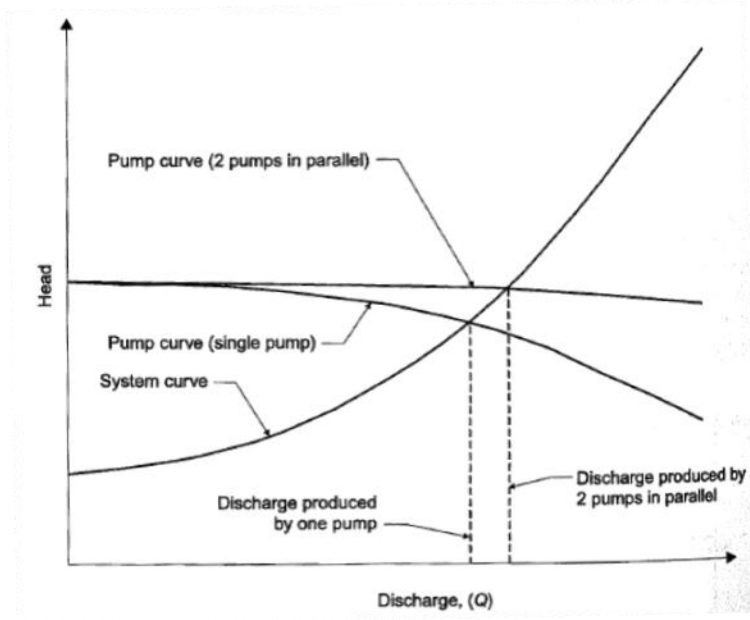


Figure 2-17. Comparison of performance of single pump and pumps in parallel (Haestad Methods, 2007)

A pump head-discharge curves are generated by running the pump under controlled conditions where Q and TDH can both be measured. Empirical equations can be used to fit the pump head-discharge curves generated by experiment. A power model (equation 2-19) is one of the reasonable functions to describe the head-discharge relationship.

$$h_p=h_0-cQ_p^m \qquad (2\text{-}19)$$

where

h_p=pump head(ft,m)

h_0=shutoff head(ft,m),

Q_p=pump discharge (ft^3/s, m^3/s)

c,m=power regression coefficients

A polynomial model (equation 2-20) is another flexible function form.

Modeler need to be careful about the potential polynomial swing (sign change of the polynomial coefficients lead to sign change of the curve slope).

$$h_p=a_0+ a_1Q_p + a_2Q_p^2 + a_3Q_p^3 \quad (2\text{-}20)$$

a_0, a_1, a_2, a_3=polynomial regression coefficients

(Haestad Methods, 2004)

2.5.5 Power and Efficiency

Water horsepower (WHP) is a measure of work that pump does to lift water to a certain height in a specific amount of time. It is also called hydraulic horsepower. 1 horsepower is the power required to lift 33000 pounds by one foot in one minute.

$$WHP=\frac{W(work)}{T(time)}$$

$$=\frac{F(force)\times d(distance)}{T(time)}$$

$$= Q(gpm)\times \gamma(\frac{lb}{gal})\times H(ft)$$

$$=\frac{Q(gpm)\times\gamma(lb/gal)\times H(ft)}{\frac{33000ft-lb/min}{hp}}$$

$$=\frac{8.34QH}{33000}$$

$$=\frac{QH}{3960} \quad (2\text{-}21)$$

where

Q—pump discharge (GPM)

H—total head (ft)

1hp=33000 ft-lb/min

ϒ=8.34 lb/gal

33000/8.34 is often rounded to 3960.

(Spellman, 2010)

Brake horsepower (BHP) is the amount of work generated by the motor to drive the pump. It is the horsepower at the output shaft of the motor.

Electrical power is the total electrical energy input, which is transferred by an electric circuit.

Power required to overcome friction within the engine is termed **friction horsepower**. Friction horsepower=Electrical horsepower-brake horse power.

The relationship between Electrical power, Brake horsepower and water horsepower is illustrated by Fig. 2-18.

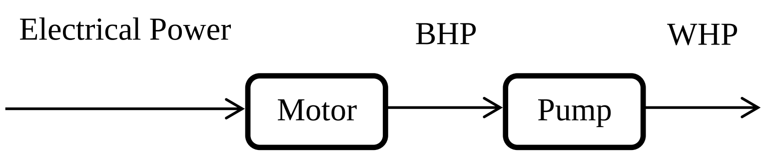


Figure 2-18. Relationship of Electrical power, Brake horsepower and water horsepower

Some of the electrical energy provided by the power supply and kinetic energy provided by the motor is lost in the pumping process. Pump efficiency is a measure of the degree of hydraulic and mechanical perfection (Bankston, 1994). The efficiency can be explained by equation 2-22 to 2-24. The manufacturer usually provides the pump efficiency curves obtained from shop tests. Field tests are also necessary to understand the pump performance in the operation system.

Pump efficiency (η_p) = $\frac{WHP}{BHP}$ (2-22)

Motor efficiency (η_m) = $\frac{BHP}{Electrical\ power}$ (2-23)

Wire-to water efficiency(η) = $\frac{WHP}{Electrical\ power}$ (2-24)

(Haested Methods, 2004)

2.5.6 Affinity Law for Variable Speed Pumping

Affinity law expresses the effect of pump speed and impeller diameter on pump performance. For a given impeller diameter and pump rotational speed, a centrifugal pump characteristic curve is fixed. The affinity law is applied to modify the curve for different speed or diameter.

If the impeller diameter is fixed, and speed is variable,

$Q_1/Q_2=n_1/n_2$ (2-25)

$H_1/H_2=(n_1/n_2)^2$ (2-26)

$P_1/P_2=(n_1/n_2)^3$ (2-27)

where n1 and n2 are pumping speed

If rotational speed is fixed, and impeller diameter is variable

$Q_1/Q_2=D_1/D_2$ (2-28)

$H_1/H_2=(D_1/D_2)^2$ (2-29)

$P_1/P_2=(D_1/D_2)^3$ (2-30)

where D1 and D2 are Impeller diameter

(Haestad Methods, 2004)

Fig. 2-19 illustrates the pump head-discharge modification for different speeds, according to affinity law when the impeller diameter is fixed. The full speed curve is shifted down by affinity law to represent lower speed. Affinity laws assume that pump efficiency remains constant. Change of interaction between pump and system is not counted in affinity law.

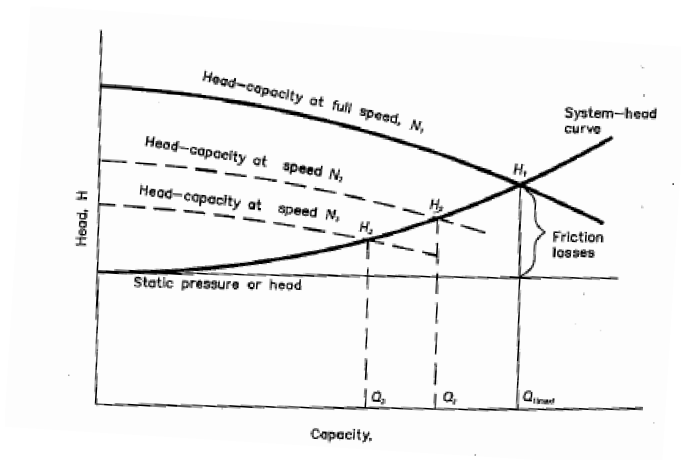


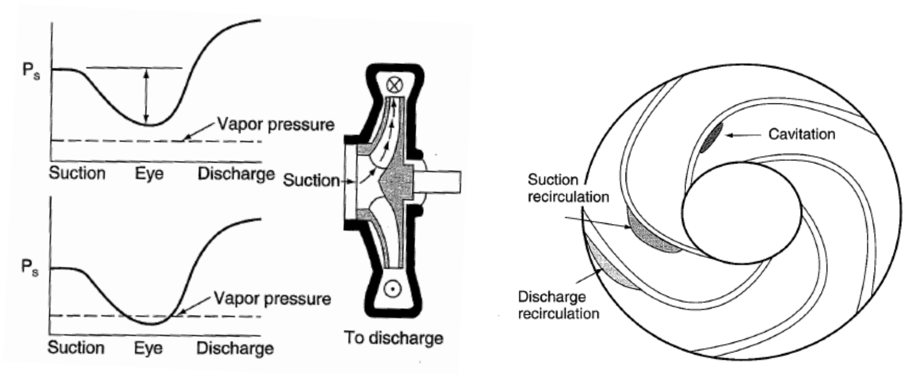
Figure 2-19. Typical discharge curves for a variable speed pump (Haestad Methods, 2007)

2.6 Instability of Influent Pumping

Unstable pump performance or pump failure often occurs during pump operation. The possible causes of instability are

(1) Cavitation/Excessive air entrapped in liquid

As most people know from experience, when a soda bottle is opened, the pressure is reduced and the dissolved gas forms bubbles in the liquid. Similarly, when liquid is delivered by the pump, the pressure drops near the suction inlet and reaches the lowest point at the impeller eye. As a result, the reduced pressure approaches the vapor pressure of the liquid and the liquid may start to vaporize [Fig. 2-20 (a)], forming bubbles. The bubbles collapse when the fluid moves further down to the region with higher pressure. This phenomenon is termed cavitation. Cavitation results in the damage of pump internals, especially low pressure side of the impeller vane as shown in Fig. 2-20 (b).



(a) (b)

Figure 2-20. Cavitation (Girdhar, 2005)

(2) Pump not primed or prime lost

Before the pump is started, the pump casing must be filled with liquid (primed); otherwise the impeller will be gas-bounded and the pressure increment created by the pump may not be sufficient to lift the liquid to a certain height. In order to prevent cavitation or loss of suction, the vacuum priming system is installed for RWWPS1 (Blue Plains). The system provides a pressure difference from the pump suction bell up to the pump discharge valve by continuously maintaining a positive suction head (primed), or in the other words, creating a vacuum on each of the non-operating pumps and the raw wastewater pump discharge pipes. Raw wastewater is pulled into the well above the elevation of the pump volute.

(3) Transient period

During fluid transient period (changing inflow rates and wet-well water surface elevation), pumping system characteristics may change rapidly. It is a big challenge for the engineer to understand the causes of the flow change since varying condition may lead to uncertainties affecting control decisions. For example, changes in reservoir level, changes in valve settings, unstable device characteristics, starting or stopping of pumps, transitions from open channel to pressure flow such as during storm events in the sewer, air releasing, accumulating, entrainment may cause disturbances, resulting in unstable flow (Mays, 1999).

Al-Khomairi (2003) studied the use of steady-state pump head-discharge curve for unsteady pipe flow applications. A multistage vertical centrifugal pump was installed in the experiment system with a 2.54 cm diameter, 300 m long copper pipe (Fig. 2-21). Pump head was computed by measurements from pressure sensors upstream and downstream. A steady-state pump discharge curve was developed for comparison to the transient flow conditions. Thousands of readings of each discharge value were averaged to compute the head-discharge characteristic curve. Different degrees of transient (unsteady-state) conditions were compared with the steady-state condition. The difference varied with the degree of transient severity [Fig. 2-22(a),(b)]. Closing/opening of a downstream valve in 20s results in a small deviation between the transient pump head and its corresponding steady-state value [Fig 22(c)]. Obvious deviation is observed for faster transients [Fig. 22(d)].

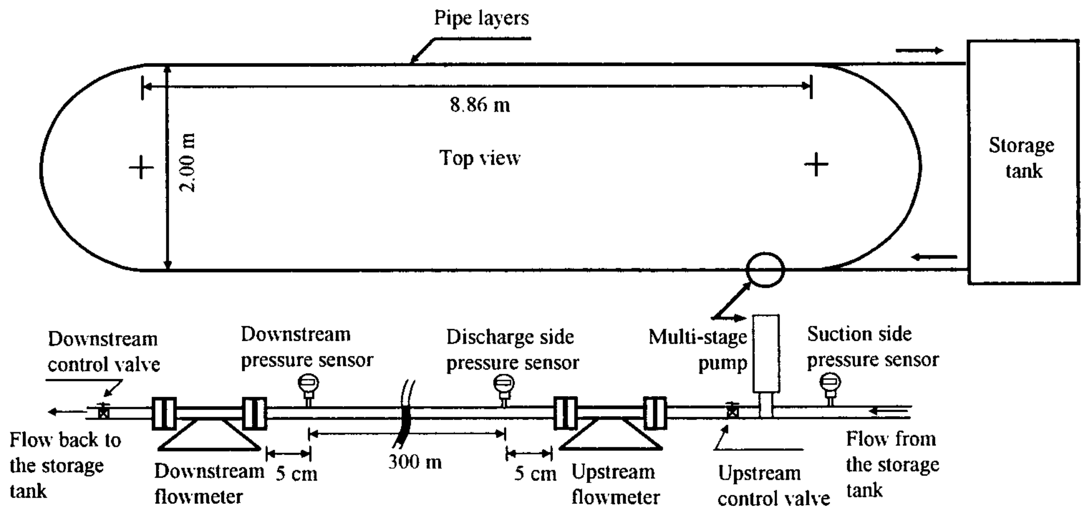


Figure 2-21. Schematic diagram of the experimental setup (Al-Khomairi ,2003)

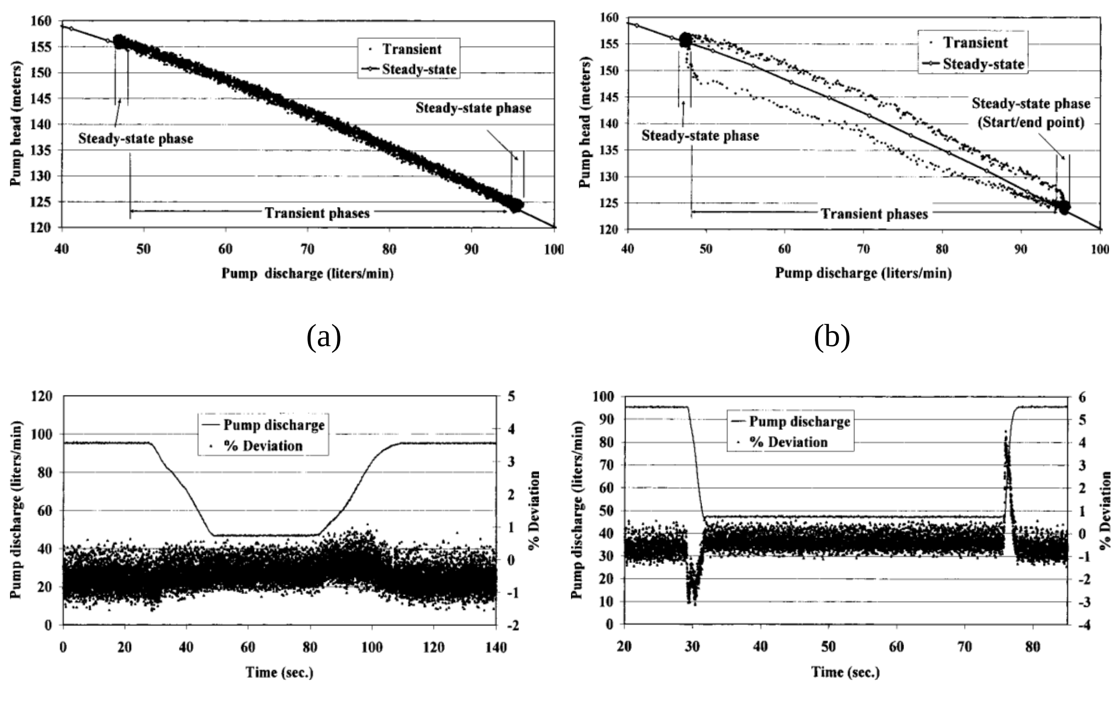


Figure 2-22. Comparison of steady-state pump head-discharge curve with unsteady-state pump head-discharge condition (Al-Khomairi,2003)

(a) Pump head versus discharge for 20-s valve closure/opening

(b) Pump head versus discharge for 2-s valve closure/opening

(c) Pump discharge and percent of head deviation for 20-s valve closure/opening

(d) Pump discharge and percent of head deviation for 2-s valve closure/opening

(4) Insufficient Net Positive Suction Head (NPSH) available

Higher velocity of flow leads to low pressure and low pressure may lead to cavitation. Net Positive Suction Head required by the pump in order to prevent the inception of cavitation is termed NPSH-r. Net Positive Suction Head available by the pump suction system is termed NPSH-a. It could be expressed by equation 2-31

$$NPSH\text{-}a = H_{bar} + H_s - H_{vap} - H_L \qquad (2\text{-}31)$$

where

NPSH-a=net positive suction head available (ft)

H_{bar}=barometric pressure at the elevation of the pump (ft)

H_s=static head (ft)

H_{vap}=vapor pressure of water (ft)

H_L=head loss between the wet-well and pump (ft)

(Haestad Methods, 2004)

The Hydraulic Institute defines NPSH-r of a pump as the net positive suction head that causes the total head to be reduced by 3%.The net positive suction head at incipient cavitation can be from 2-20 times the 3% NPSH-r value depending on pump design (Girdhar, 2005).

(5) Operating in unstable region of the pump curve

Stepanoff (1992) and Nelik (2011) explained the unstable head-capacity characteristics of centrifugal pumps. For stable pump curves [Fig. 2-23(a)], a unique interception point of head-discharge curve and system curve always exists. For unstable pump curves [Fig. 2-23(b)], multiple interception points can be found, which indicates that two possible discharges could occur with the same head condition.

Actual test curves of low specific speed pumps ($n_s \approx 1000$) approach the unstable pump curve (Stepanoff ,1992).

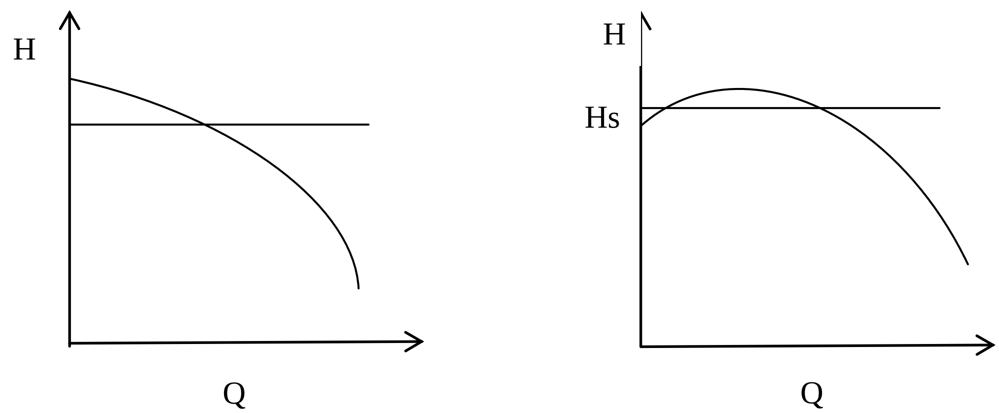


Figure 2-23. Stable (a) and unstable (b) pump head-capacity curves(Nelik, 2011)

Assume a system that two pumps A and B are installed in parallel and discharge to a common header. Suppose that Pump A is on service in the unstable region (Fig. 2-24, point A) and Pump B is ready to be brought on. Pump usually starts near the shutoff point B to minimize pump load. The system head H_A is higher than the shutoff head H_B and the check valve will not open.

Assume another pump in parallel system with several pumps running in point C (Fig. 2-24) and several pumps running in point D (Common head H). Suppose that the system curve is flat (Friction loss and minor loss are small enough to be ignored). If the head decreases from H to H’, the operation point of pumps working in point D will shift to D’ while the operation point of the pumps working in point C will shift to C’. The stronger pump may finally take over the weaker pump, thus causing pump failure (Nelik, 2011)

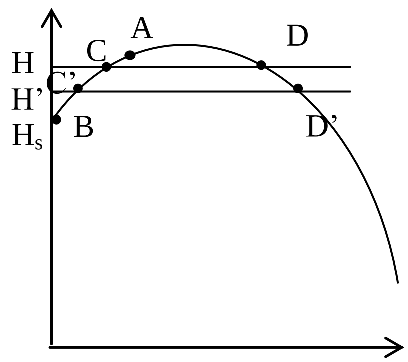


Figure 2-24. Unstable pump head-capacity curve(Nelik, 2011)

(6) Speed (rpm) too low

For variable speed pumping, speed lower than the recommended operation range may result in pump failure.

(7) Broken impeller or other parts/Impeller clogged/Severe impeller wearing

Severe impeller wearing will cause pump failure or reduce pumping efficiency. Fig. 2-25 shows the effect of impeller wearing on pump head-capacity curve. Pump curve is shift down due to impeller wearing, thus causing lower capacity or efficiency.

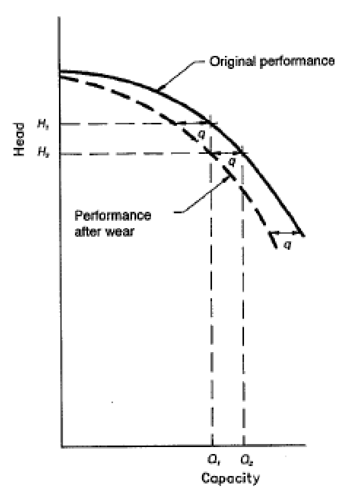


Figure 2-25. Effect of impeller wearing (Mays, 1999)

2.7 Numerical Modeling

2.7.1 Modeling Procedure

A model is a properly developed representation of a real system that provides a rational explanation of the system and can accurately mimic the functioning of the system. Modeling is a way to forecast future actual system response or to predict a future value based on knowledge of one or more related independent variables. Empirical models are derived from observation and guided by practical experience rather than theory. Conceptual models are based on thought or consideration of theory. They represent human intentions.

McCuen (2011) identifies the phases of modeling as follows:

- Conceptualization
- Formulation
- Calibration
- Verification

Conceptualization is a process to identify processes and variables that are important in transforming system inputs into the system outputs that are needed to make decisions about the problem. It is applicable to empirical models. In this phase, the modeler need to identify the problem type, criterion variable, relevant physical processes, available inputs and simplify the theory to match problem statement, inputs and outputs.

Formulation is the process to assembling an algorithmic, conceptual, or physical representation of the conceptualize framework. In this phase, modelers need to collect data, do graphical-statistical analysis to check outliers and then identify alternative functions and consider types of coefficients needed. If new computer code is required, the code needs to be tested to ensure that is solving the model equations correctly.

Calibration is for qualifying the model so that it can provide quantitative (or qualitative) forecasts or predictions of system behavior. It is the process of assigning values to model parameters to make the general conceptual equation specific to the system under study, so that the model predicts that specific system's behavior as accurately as possible. For empirical models, modelers need to set the objective function (e.g., least squares), assess goodness of fit to calibrate the data, and get the best parameter values.

Verification is for establishing the rationality of the calibrated model in both its predictions and its measure of effects that will enable the placement of bounds on its applicability. Independent data, not used in Calibration, is needed for this phase. (McCuen, 2011).

Chapra (1996) includes a "Preliminary Application" phase between Formulation and Calibration. This phase is for testing whether the proposed model can be applied successfully to the system in question, and determining additional data needs before Calibration is attempted.

Chapra (1996) prefers the term "Confirmation" for what McCuen (2011) calls "Verification," stating that the word verification implies the model's truthfulness has been established, which is not really the case. Other modelers use the expression "Validation" to describe the stage of testing the model on other data sets not used in calibration, and speak of the “Cal/Val” process for the combination of these two processes in model development (e.g., CEOS, date unknown). In practice, the terms Verification, Confirmation, and Validation are all used to describe the process of testing a model on data not used in Calibration.

2.7.2 Numerical Optimization and Goodness-of-Fit Statistics

Numerical optimization is a class of optimization techniques in which the gradient of the objective function is evaluated using the numerical approximation of the derivative(s). A solution is found iteratively. Sometimes constraints are set to place limits on the possible values of the unknowns. In model calibration, the unknowns are the model parameters or coefficients.

Regression is a technique for developing a prediction equation of estimating criterion variable when predictor variable is given. Predictor variable is a quantity that is associated with and is known or believed to cause change in the criterion variable. Criterion variable is the variable representing the response of the system. The criterion variable is expressed as a linear or nonlinear function of one or more predictor variables.

The objective function is a mathematical function that describes the best fit between model predictions and observed data. Some widely-used objective functions are

(1) Least Squares (Minimize the sum of the squared errors, which leads to the model coefficients that minimize the unexplained variance).

$$F = \min \Sigma\, (Y' - Y)^2 \qquad (2\text{-}32)$$

where Y'= Predicted value

Y= Observed value

(2) Unbiasedness. (i.e., Σe=0) where e = error = Y'-Y

(3) The minimum/maximum value of a function

(4) Minimize the maximum error.

Goodness of fit statistics describes how well a model fits a set of observations. The following statistics indicates the goodness of fit of a model.

(1) Correlation coefficient (R): -1 < R < 1.

Correlation is the measurement of the degree of linear association between the elements of two sets of data. Correlation coefficient (R) indicates the strength of the relationship. The sign of it indicates the direction of the relationship.

The coefficient of determination, R^2, is mathematically the square of the correlation coefficient. It also quantifies the extent to which the model explains variation in the data.

$$R^2=EV/TV=\frac{\Sigma(Y'-Y\ bar)\text{^}2}{\Sigma(Y-Y\ bar)\text{^}2} \tag{2-33}$$

where

EV: Explained variance, variation of predicted values about mean of observed values. $EV=\Sigma\ (Y'-Y\ bar)^2$

TV: Total variance, variation of measured points about the mean of measured points. $TV=\Sigma\ (Y-Y\ bar)^2$

Y bar: Mean value of a set of observed values

R^2 greater than 0.7 or R greater than 0.5 indicates good model accuracy.

(2) Standard error of estimate (Se) and Standard error ratio (Se/Sy).

Standard error of estimate (Se) reflects both systematic and nonsystematic errors. It has the same units as the criterion variable. If Se/Sy is close to 1 (Se close to Sy), it suggests that the model is not significantly better than prediction by the mean. If one set of data has smaller sample size than the other, the larger Se value may not suggest better accuracy.

$$\text{Se} = \sqrt{\frac{UV}{\nu}} = \sqrt{\frac{\sum (Y' - Y)^2}{n - p}} \qquad (2\text{-}34)$$

where

UV= Σ (Y'-Y) ^{2} (unexplained variance)

ν: Degrees of freedom

n: Number of observations

p: Number of unknowns

$$\text{Sy} = \sqrt{\frac{\text{TV}}{n-1}} = \sqrt{\frac{\Sigma\,(\text{Y}-\text{Y bar})\,\text{^}2}{n-1}} \qquad (2\text{-}35)$$

Standard error ratio, Se/Sy indicates the accuracy of the model relative to the accuracy of predictions of y when using the mean value of y. Se/Sy is dimensionless, which allows comparison between models with different sample sizes. Degree of freedom is considered in the computation of Se/Sy. A value greater than 0.6-0.8 usually suggests a poor model and a value under 0.3-0.5 suggests a good one.

(3) Residuals and model bias.

The residual, or error, e, is defined as the difference between the model prediction and its corresponding observation,

$$e=Y'-Y \tag{2-36}$$

Model bias is the mean of the errors. e bar=1/n*$\sum_{i=1}^{n}(Y' - Y)$. A positive value indicates over prediction and a negative value indicates under prediction. Relative bias, e bar/ y bar indicates the amount by which a model predicted value will be consistently in error. It is a dimensionless value and could be compared with other studies when dimensional magnitudes are different. A relative bias of more than 10% is generally considered to be significant.

A model may be biased only for some ranges of data. The regional error is called local bias. Local bias should be checked even if the overall bias is zero (McCuen, 2011).

Chapter 3. Methods

3.1 Diurnal Trend Analysis for Influent Flow Rate, Power Price and Power Load

3.1.1 Influent Flow Rate

Data from the Process Control System (PCS) for 1/1/2008 to 12/31/2010 are analyzed to evaluate the diurnal variation of influent flow rate. The PCS flow data are based on the measurement of venturi flow meters, located downstream of the Raw Wastewater Pumping Stations (Fig. 3-1). Making the assumption that there is no storage –or negligible residence time-- in the screen, raw wastewater pump station, grit chamber and primary clarifier, the influent flow rate can be estimated by equation 3-1 to equation 3-3 based on mass balance.

$$Q_{total}= Q_{in\ east}+ Q_{in\ west} \qquad (3\text{-}1)$$

$$Q_{in\ west} = Q(M8) \qquad (3\text{-}2)$$

$$Q_{in\ east} = Q(M1)+Q(M3)+Q(M17)+Q(M18)+Q(M3) -Q(M6)-Q(M11) \qquad (3\text{-}3)$$

Note that Q(M6) and Q(M11) are subtracted from the total in Eq. (3-3), because they represent internal return flows to RWWPS2.

Diurnal trend of influent flow rate are plotted to compare with the trend of power load. Each curve consists of 24 data points and each point is based on an hourly average. For example, hour 1 stands for 12:00:00am-1:00:00am. Influent flow rate is grouped into four seasons. Weekday flow and weekend flow are plotted separately.

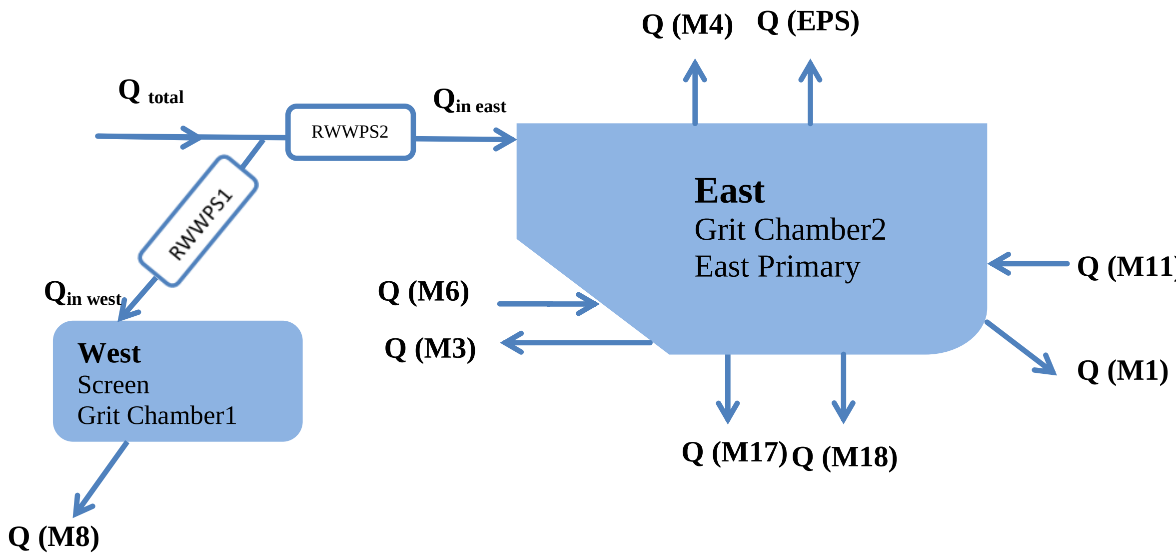


Figure 3-1. Sketch of flow measurements (Kharkar, Personal communication, June, 2011)

Notes: **Q_{total}—Total influent flow rate**
$Q_{in\ west}$—West influent flow rate
$Q_{in\ east}$—East influent flow rate
Q (EPS)—East primary sludge flow
M1—Meter101 (East primary effluent to secondary reactor 5&6)
M3—Meter103 (East primary effluent to north side of secondary reactor 3&4)
M4—Meter104 (Outfall 001 flow)
M6—Meter101 (Combined waste liquors from Solids Processing Building(SPB))
M8—Meter108 (West primary influent from Grit Chamber 1)
M11—Meter111 (Spent Wash Water return flow)
M17—Meter117 (East primary effluent to south side of secondary reactor 3&4)
M18—Meter118 (East primary effluent to south side of secondary reactor 3&4)

Data point named PLANT INF FLOW (FI_PLTINF) in [MGD] is downloaded from PCS for total influent flow rate analysis (Table 3-1). Flow is calculated by PCS system based on equation 3-1, 3-2 and 3-3. It should be noted that the influent flow rate analyzed in this study is the influent to the primary treatment processes instead of the plant influent flow before influent pumping. The plant inflow is not measured; in this study, the total inflow is estimated by assuming negligible residence time in the processes upstream of primary treatment, as explained above.

Table 3-1 Flow point information and corresponding flow meter

	Flow	PCS point information	Corresponding flow meter
Q_{total}	PLANT INF FLOW	FI_PLTINF	M1,M2,M4,M6, M8, M11,M17,M18
$Q_{in\ east}$	EAST INF FLOW	FI_EASTINF	M1,M2,M4,M6,M11,M17,M18
$Q_{in\ west}$	WEST INFLUENT FLOW	FI_WESTINF	M8

3.1.2 Unit Power Price and Total Power Load

Analysis of power price is based on the monthly utility billing data for three years (2008-2010). Power price in the unit of $/MWh of each hour is obtained from the plant's Potomac Electric Power Company (PEPCO) bill. For diurnal trend analysis, the average price for each hour of the day is computed. Monthly, yearly, and seasonal variation of the power price is illustrated by graphical analysis. Unit power cost is computed by equation 3-4.

Unit power price [$/MWh] = total power cost ($) / (total power load (KWh) *1000) (3-4)

For the diurnal trend of total power load of Blue Plains, the summation of power load of four area substations (ASS1 through ASS4) is computed to compare with the PEPCO billing data. For each substation, three power lines contribute to the total load, as listed in Table 3-2.

Table 3-2 Electrical Lines to ASS1, 3, 4, 5

ASS1			
Line	MAIN SS FDR BRKR A7 KW	MAIN SS FDR BRKR B11 KW	MAIN SS FDR BRKR C20 KW
Point	JWI82046	JWI82052	JWI82062
ASS3			
Line	MAIN SS FDR BRKR A3 KW	MAIN SS FDR BRKR B10 KW	MAIN SS FDR BRKR C21 KW
Point	JWI82042	JWI82051	JWI82063
ASS4			
Line	MAIN SS FDR BRKR A6 KW	MAIN SS FDR BRKR B16 KW	MAIN SS FDR BRKR C22 KW
Point	JWI82045	JWI82056	JWI82064
ASS5			
Line	MAIN SS FDR BRKR A4 KW	MAIN SS FDR BRKR B13 KW	MAIN SS FDR BRKR C23 KW
Point	JWI82043	JWI82054	JWI82065

Power consumption (KWh) of each hour by PEPCO bill is used to analyze the diurnal trend and the yearly/seasonal variation. Monthly total electricity expenditures, including the cost for energy (power), ancillaries, RPM Capacity, Transmission, Fixed Price Adder and block settlement are summed up to evaluate the overall monthly power cost. An example PEPCO bill summary is listed in Table 3-3. All trend analysis is based on hourly average.

Table 3-3 Example PEPCO bill summary (12/22/2010-1/24/2011)

Billing Parameters			
UCAP Requirement 2009/10		34,276.2	kW
UCAP Requirement 2010/11		34,138.1	kW
Trans Tag		29,608.3	kW
Loss Factor		1.028	%
PJM RPM Capacity Rate 2009/10	$	224.75	$/MW-Day
PJM RPM Capacity Rate 2010/11	$	182.88	$/MW-Day
PJM NITS Rate	$	13,229.00	$/MW-Year
Transmission Rate	$	1,102.42	$/MW-Month
	Real Time Energy		
Volume - kwh		20,514,247	
Energy Cost	$	1,248,906.25	
Ancillaries	$	78,298.49	
RPM Capacity 2009/10	$	-	
RPM Capacity 2010/11	$	213,126.45	
Transmission	$	32,640.73	
Fixed Price Adder	$	8,189.88	
Block Settlement	$	(233,254.70)	
TOTAL		**$1,347,907.10**	
Billing Rate		**$0.065706**	

3.2 Power Consumption Breakdown

The energy breakdown analysis is grouped by four area substations, ASS1, ASS3, ASS4 and ASS5, as illustrated by the main substation overview obtained from the PCS Graphic (Fig. 3-2). The location of area substations is illustrated in Fig. 3-3 and the treatment processes fed by each area substation are listed in Table 3-4. ASS1 supplies power to both Raw Wastewater Pump Stations 1 and 2.

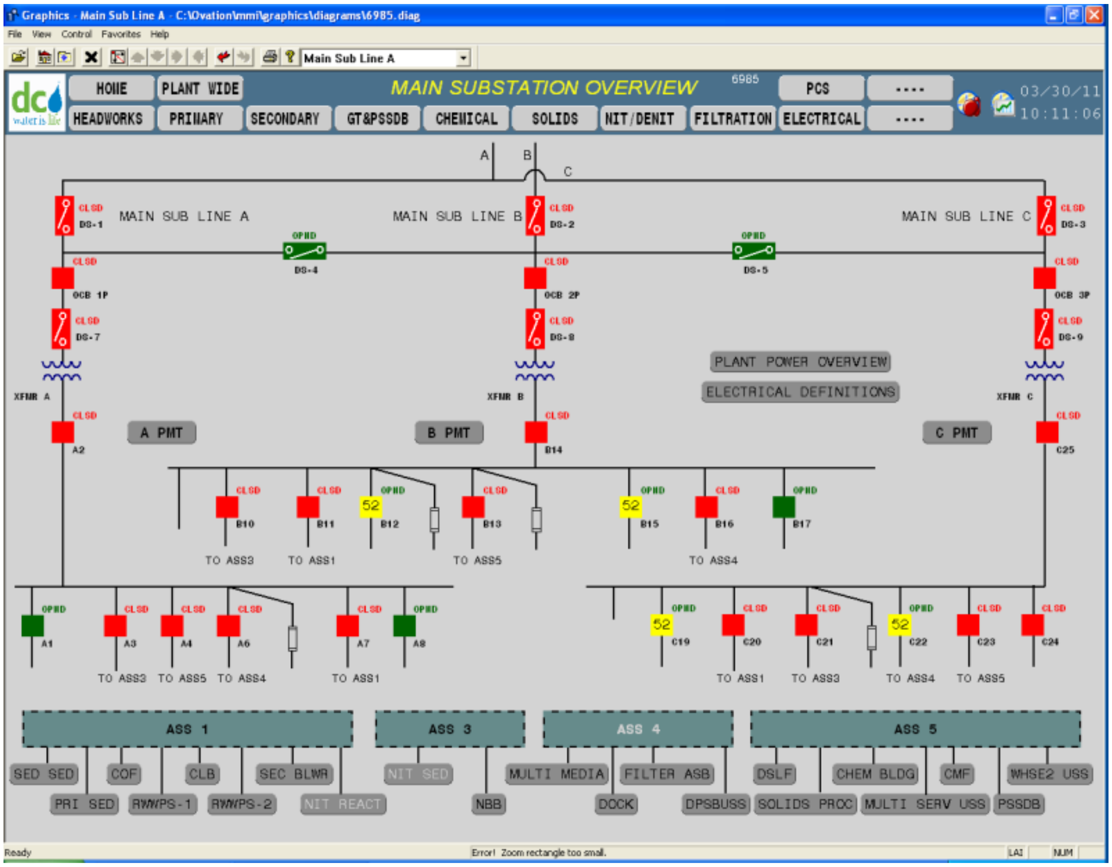


Figure 3-2. Main substation overview

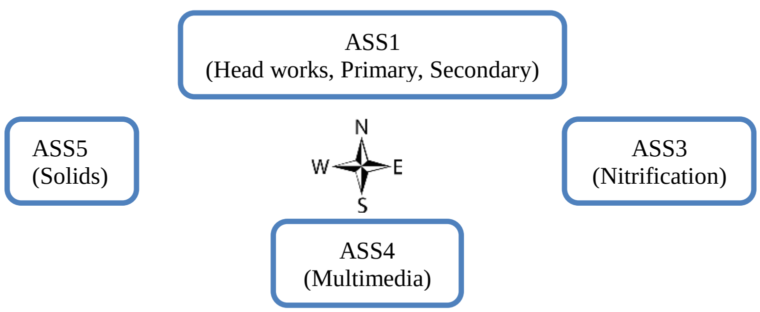


Figure 3-3. Location of area substations in Blue Plains

Table 3-4 Area substations and corresponding treatment processes

Area Substation	Treatment Processes
ASS1	Secondary sedimentation (SEC SED) Primary Sedimentation (PRI SED) COF Raw Wastewater Pump Station1 (RWWPS-1) Chlorine Building (CLB) Raw Wastewater Pump Station 2 (RWWPS-2) Secondary Blower (SEC BLWR)
ASS3	Nitrification Blower Building (NIT-BLWR) Nitrification Sedimentation (NIT-SED)
ASS4	Multi Media(including SPWP, WWP, Fips, HPRFEP) Docking facility(DOCK) Filter Air Scour Blower(FILTER ASB) Due Purpose Sedimentation Basin Unit Substation(DPSBUSS)
ASS5	Dewatering Sludge Loading Facility (DSLF) Solids processing (SOLIDS PROC) Chemical Building(CHEM BLDG) Multi Service Unit Substation(MULTI SERV USS) Central Maintenance Facility(CMF) Primary Sludge Screening Degritting Building(PSSDB)

Hourly average power use data from 1/1/2009 to 4/30/2011 are retrieved from PCS for the energy breakdown analysis. Since the reliable data period of each sub-line is different, the analysis period may vary. If two years of data are available, analysis period is separated into two independent years for comparison, 5/1/2009-4/30/2010 and 5/1/2010-4/30/2011. If only one year data is available, analysis is limited to one year's hourly average (5/1/2010-4/30/2011). Generally, trend detection is more reliable if independent data of two periods (one year for each period) indicate the same trend. (Note: Data collection is ongoing; future data will be needed to confirm the trend observed by one year data.) Hourly average data are grouped by season to detect diurnal or seasonal trends (**Winter**: Dec, Jan, Feb. **Spring**: Mar, Apr, May. **Summer**: June, July, Aug. **Fall**: Sept, Oct, Nov.).

Diurnal trend of each substation and raw wastewater influent pumping are illustrated in Chapter 4.2.2 and that of the other 21 treatment processes fed by ASS1, ASS3, ASS4 and ASS5 are listed in Appendices 1, 2, 3, and 4, respectively. Only end power usage is included in this analysis. Other power loads, for example XFMR or TIE, are ignored in the breakdown analysis. So the summation of the analyzed power load would be slightly lower than the power load of the whole plant. Energy breakdown pie charts are plotted based on hourly average data from 5/1/2010 to 4/30/2011, since this is the available period that all the components share.

3.3 Raw Wastewater Pump Station 1 & 2 Pump Performance Evaluation

3.3.1 Introduction of Modeling Approach

The raw wastewater wet-well is treated as an open reservoir. The change of storage in the reservoir is described by the mass balance equation (3-5),

$$\frac{dS}{dt} = Q_{in} - \sum_{i=1}^{n} Q_i \qquad (3\text{-}5)$$

where S is storage in the wet-well, Q_{in} is inflow of wastewater from the collection system to the wet-well, Q_i is the discharge by pump *i*, and n is the number of pumps.

The pump discharge is a function of pumping head (and, for the variable-speed pumps, pump speed). The functional relationship is given by the pump characteristic curve, which is unique to a given pump (Section 2.5.4).

Ultimately, the goal of the simulation model is plan the time sequence of pumping (which pumps are on service, and speed for the variable-speed pumps) in order to minimize energy costs, in response to a predicted time sequence of Q_{in}. Under those conditions, wet-well elevation would be unknown, and would need to be simulated as a function of S, using a stage-storage curve. In this thesis, a first step toward that goal is developed: using measured values of wet-well elevation, estimated pump characteristic curves are used to predict the Q_i. These flows are summed and can be compared to measured plant influent, as a test of this part of the model.

In order to predict wet-well yield, power usage, and efficiency according to the wet-well level and pump combination on service, the model is separated into two tasks:

Task 1. Predicting wet-well yield (total pump station discharge) based on wet-well level and combination of pumps on service.

Task 2. Estimating power consumption [KW/ MGD] by the raw wastewater pumping stations, as a time series, and as a function of wet-well level.

The following is the input and output for Task 1.

Input:

- Reservoir water free-surface level of pump suction (Wet-well) and discharge reservoir
- Combination of pumps on service and (for variable speed pumps) operation speed

Output:

- Wet-well yield (Summation of the discharge of each pump)

For Task 2, historical data from 1/1/2009 to 4/30/2011 are analyzed to evaluate power use. The temporal patterns of power consumption and the effect of wet-well level may provide information that can reduce the energy costs of this particular operation.

In order to obtain the data needed for the model, pump performance characteristics including discharge rate at different pumping head values (pump characteristic curve) and power usage (KW) were physically tested in the operation system in RWWPS1 and RWWPS2. The detailed test procedure will be introduced in Section 3.3.3.

3.3.2 Model Assumptions

The three main assumptions for this model are as follows:

1. Assume negligible storage in screen influent channel and aerated grit chamber for RWWPS1. Assume negligible storage in aerated grit chamber and east primary clarifiers for RWWPS2. So the flow rate illustrated in Fig. 3-1 in section 3.1.1 reflects the pump discharge. It would be more prudent to say that this model is for predicting the primary influent rate associated with influent pumping.
2. Assume minor loss and friction loss could be ignored.
3. If multiple tests of same pump lead to different results, the test with best wire-to-water efficiency would be chosen for model prediction.

The reason for these assumptions will be introduced below.

Assumption 1

For RWWPS 1, the pump discharges are combined in an open channel (the grit screen inflow channel), then the combined flow passes through the screen and aerated grit chamber (Fig. 3-4) before being measured by the Venturi flow meter located at the entrance of the primary influent conduit (Fig. 3-5). The detention time of grit chamber building 1 (West) is approximately 4.3 min; it is assumed that change in storage is negligible in RWWPS1 grit chamber; that is inflow and outflow are equal, and that the flow measured at the entrance to influent conduit approximates the total flow delivered by the pumps to the grit chamber. Similar zero storage assumption is applied to RWWPS2.

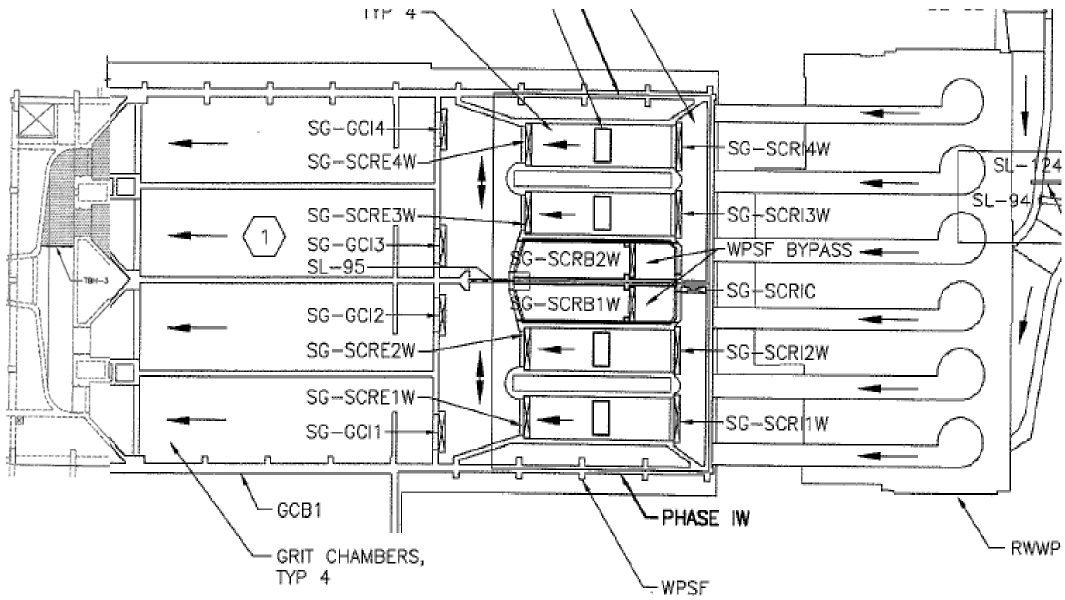


Figure 3-4. RWWPS1, Screen and Grit Chamber

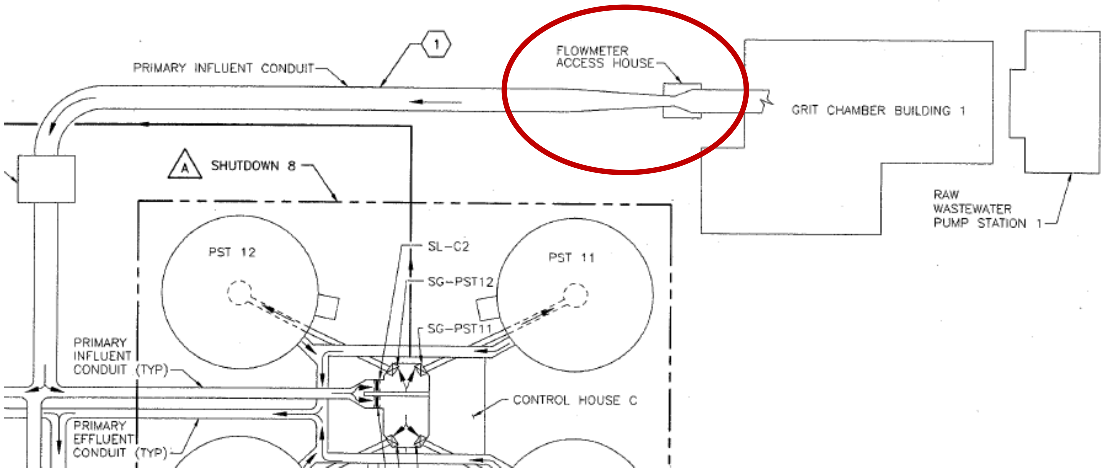


Figure 3-5. Location of flow meter 108

Assumption 2

Pumps are installed in parallel and pump discharge pipeline of RWWPS1 is illustrated as an example (Fig. 3-6 – Fig. 3-8). Since pumps in RWWPS1 and 2 share the common suction and discharge reservoir with free surface, each pump can be considered a single system, without interaction with other pumps on service. For each pump, friction loss and minor loss are only related to the flow rate through its own pipeline. Therefore the relationship between pumping head and flow rate can be analyzed individually for each pump, and it is not necessary to develop a combined pump curve, as discussed in Section 2.5.4. To justify the neglect of minor losses in the model, graphical solution of operation points of Pump 3W is illustrated as an example in Fig. 3-9. Static head-discharge curve for pump 3W is obtained by experiment. The question would be whether we could use Static head-discharge relationship (curve) to express pump performance instead of using TDH-discharge relationship (curve). If we ignore minor loss, pump H_{static}-Q curve AB is developed by plotting each test data pair (H_{static}, Q). If head loss is taken into account, TDH-Q curve is developed by adding head losses to H_{static} for corresponding discharge, which is illustrated as A'B'. Since head loss is a function of pump discharge Q, the difference between the head discharge curve would be A'A for static head 21ft and B'B when for static head 18ft, which represents the head losses. The higher the Q, the greater the head loss, that is, B'B > A'A.

Assume that both H_{static}-Q model (Curve AB) and TDH-Q model (Curve A'B') are available and let's try the prediction. If static head is known as 18ft, the H_{static}-Q system curve intercepts point B and the corresponding discharge Q_B would be the predicted. For TDH-Q model, the head loss calculation also includes minor and friction losses and the system curve to intercept curve A'B' at Q_B as well.

It should be noted that only in the system where each pump has its own suction and discharge pipeline do the two models give the same prediction. For multiple pumps operated in parallel and discharging to the same pipeline, as illustrated by Fig. 3-10 and Fig. 3-11, if additional pump is brought on service, the system curve gets steeper because of the additional head loss. The system curve with additional pump operating (red curve) intercepts the pump TDH-Q curve at point C instead of point B', resulting in a lower discharge value Qc. In this case, static head-discharge model will not accurately predict head-discharge relationship because the change of head loss. For this research project, H_{static}-Q model will be chosen since discharge of each pump only goes through its own pipe line and creates its own head loss, and the same head loss applies to the system curve, as shown above.

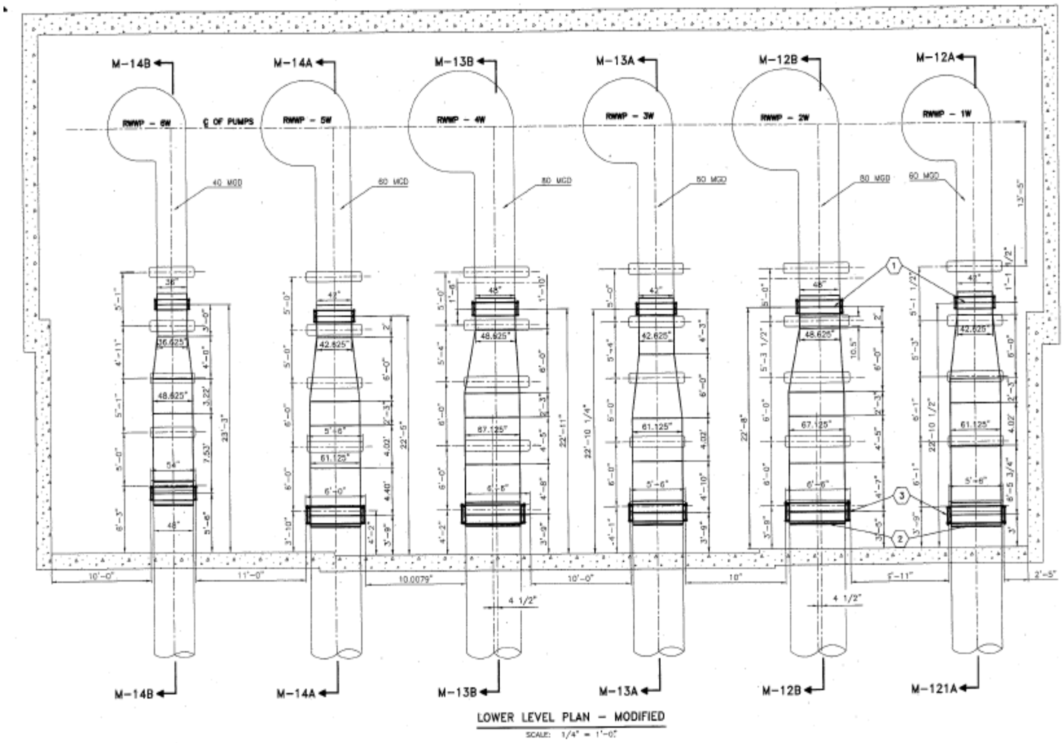


Figure 3-6. Pump pipeline in RWWPS1 (DCWASA, 2006)

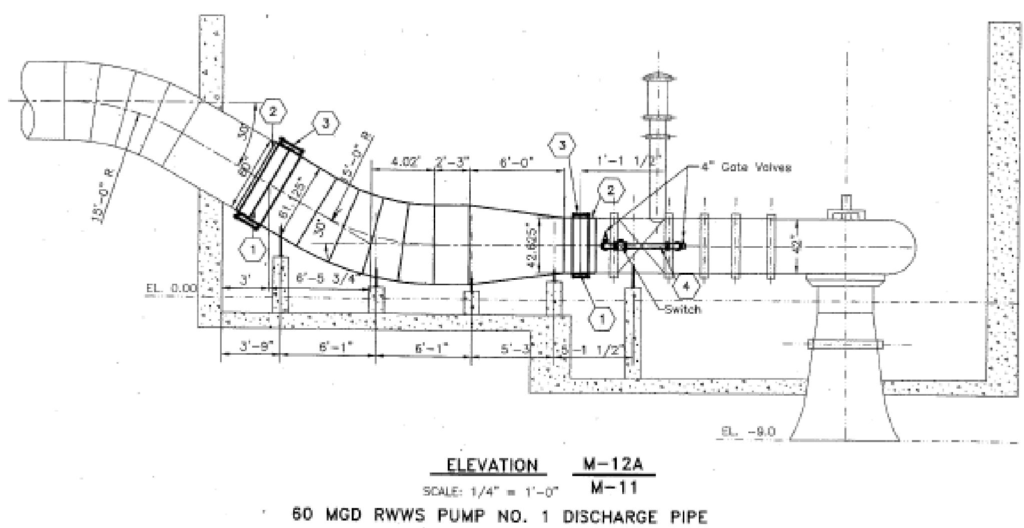


Figure 3-7. Pump 1W (DCWASA, 2006)

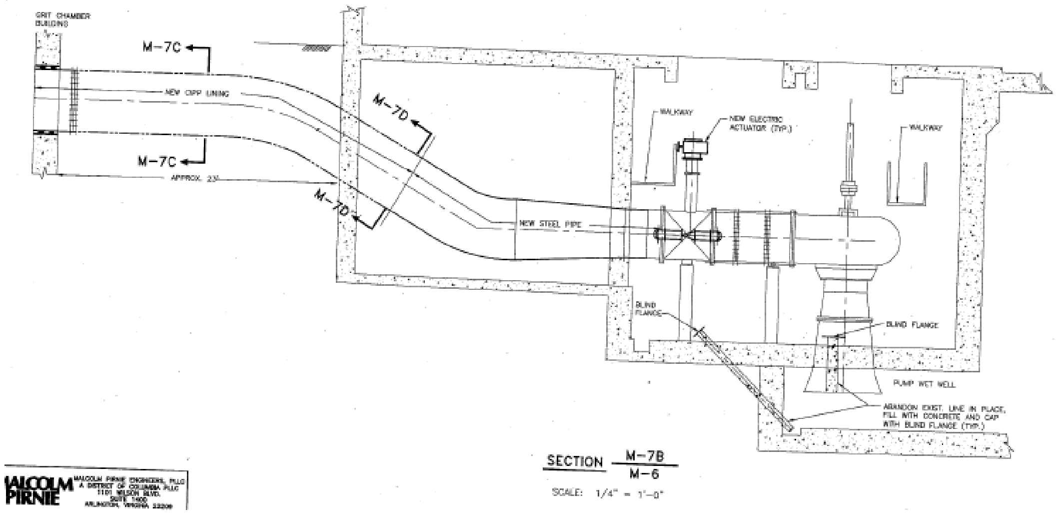


Figure 3-8. Pump discharge pipeline (DCWASA, 2006)

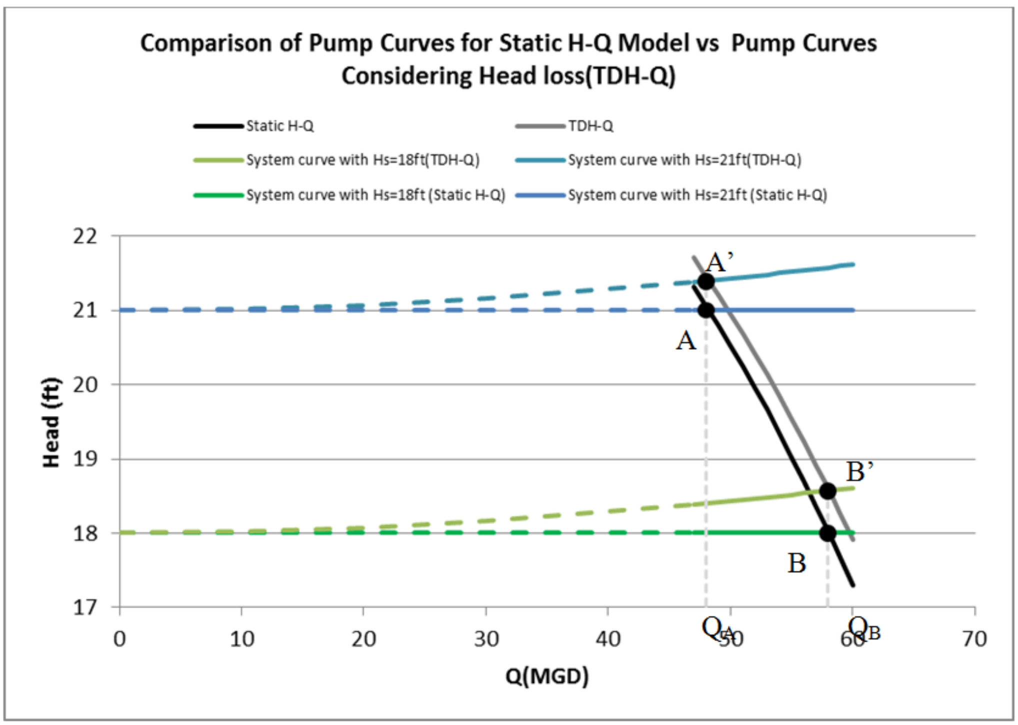


Figure 3-9. Comparison of pump curves for static H-Q model vs pump curves considering head loss (3W)

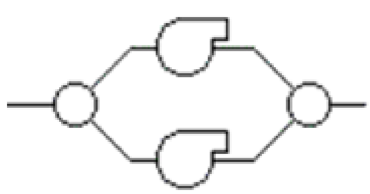


Figure 3-10. Pumps in parallel sharing the discharge pipeline

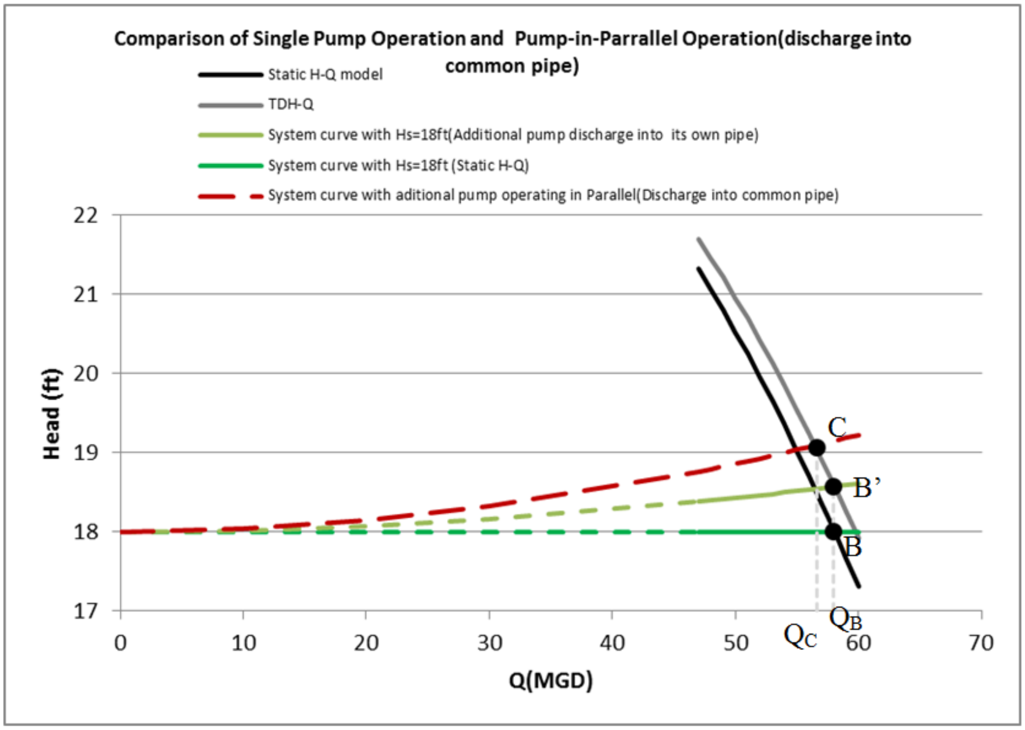


Figure 3-11. Comparison of single pump operation and pump-in-parallel operation (discharge into common pipe)

Another reason for neglecting the friction loss and minor loss is that they are approximately 3% of the total designed dynamic head. The small head loss-TDH ratio results from a large pipe diameter-length ratio (D/L=4.8ft/46ft=10%). A sample calculation for RWWPS1 is provided in Table 3-5. The red number indicates the head loss at design capacity.

Table 3-5 Estimated head losses of pump pipelines of RWWPS1

	Q(MGD)	Hf	Hm(ft)	Hf+m	TDH
1W,3W	0.00	0.00	0.00	0.00	22.00
	20.00	0.03	0.04	0.07	22.07
	40.00	0.10	0.17	0.27	22.27
	60.00	0.22	0.37	0.59	22.59
	80.00	0.37	0.66	1.03	23.03
	100.00	0.55	1.03	1.59	23.59
2W,5W	0.00	0.00	0.00	0.00	22.00
	20.00	0.02	0.03	0.04	22.04
	40.00	0.06	0.10	0.16	22.16
	60.00	0.12	0.23	0.34	22.34
	80.00	0.20	0.40	0.60	22.60
	100.00	0.30	0.63	0.93	22.93
4W	0.00	0.00	0.00	0.00	22.00
	20.00	0.02	0.03	0.04	22.04
	40.00	0.06	0.10	0.16	22.16
	60.00	0.12	0.23	0.34	22.34
	80.00	0.20	0.40	0.60	22.60
	100.00	0.30	0.63	0.93	22.93

Assumption 3

The pump curves provided by the manufacturers when the raw wastewater pumps were installed cannot be assumed to apply to the pumps today. An accurate pump curve can only be obtained by testing each pump individually over a range of pumping head values. As a contribution to this study, Blue Plains personnel conducted a number of pump tests, but the tests are limited by practical considerations. Pump tests can be run in the Blue Plains raw wastewater pumping system only if the following conditions are all satisfied:

- No storm is expected during the test period. Weather forecast should be checked in advance.
- No antecedent storm event has occurred to cause possible increment of influent flow. Usually, test will not be run if there was a severe storm event within 24 hour.

- No construction project/ operation and maintenance event request inside or outside the plant required that wet-well level remain fixed. The wet-wells of RWWPS1 and RWWPS2 are hydraulically connected to other pump stations or storage reservoirs; communication with these facilities are necessary to ensure a safe test.

If multiple tests are performed for one pump and the test results do not duplicate each other, the test result with best wire-to-water efficiency will be chosen for model use; an inferior efficiency is interpreted as indication that the pump is not functioning at capacity because of unidentified problems. Finally, the pump curve developed for one pump may be shared for another identical pump if the test result of the latter is not reliable.

3.3.3 Pump Test Experiment Design

The experiment is designed for obtaining the static head-discharge relationship for each pump. The test procedure is introduced below.

- Run more than one pump to decrease wet-well level.
- Test is started when wet-well elevation is around -1.5 ft.
- All other pumps are shut down. With the target pump running alone, the wet-well level will rise because the inflow is greater than the discharge of one pump.
- Testing is stopped when the wet-well elevation is approximately +1.5ft. Another pump is then brought on for normal operation.

Most tests are done in the morning because the flow is lower in the morning than in the afternoon. The tests for RWWPS1 and 2 are listed in Table 3-6, excluding the failed tests. For example, while testing Pump 6W (12/16/2010), the flow reading is much less than the designed capacity, which is considered a failed test and discussed in Appendix 7.

During the tests, the flow measured by the Venturi meter accounts for only one pump and can be directly used in developing the Q-H curve. The static pumping head is calculated from the wet-well elevation and the known water surface elevation for the pump discharge.

Table 3-6 Pump tests for RWWPS1&2

RWWPS1			
	Test pump	Speed	Test Duration
Constant Speed	1W	Constant	12/15/2010 08:00:00 am-- 12/15/2010 10:09:00 am
	3W	Constant	12/14/2010 08:19:00 am -- 12/14/2010 10:14:00 am
	4W	Constant	02/04/2011 07:43:00 am --02/04/2011 10:33:00 am
	6W	Constant	01/14/2011 09:29:00 am --01/14/2011 11:47:00 am
Variable Speed	2W	Full Speed	12/17/2010 8:40:00 am -- 12/17/2010 11:27:00 am
		85% of full speed	12/21/2010 08:19:00 am -- 12/21/2010 10:18:00 am
		75% of full speed	12/20/2010 8:23:00 am -- 12/20/2010 9:02:00 am
	5W	Full speed	02/17/2011 12:56:00 pm -- 02/17/2011 15:52:00 pm
RWWPS2			
	Test pump	Speed	Test Duration
Constant Speed	1E	Constant	01/12/2011 08:28:00 am-- 01/12/2011 11:48:00 am
	2E	Constant	01/03/2011 09:34:00 am -- 01/03/2011 11:54:00 am
	3E	Constant	01/13/2011 07:43:00 am-- 01/13/2011 10:54:00 am
	4E	Constant	04/10/2011 07:20:00 am -- 04/10/2011 12:07:00 pm
	5E	Constant	04/30/2011 07:21:00 am -- 04/30/2011 12:12:00 pm
Variable Speed	6E	Full Speed	06/07/2011 08:18:00 am-- 06/07/2011 11:19:00 am
		85% of full speed	05/07/2011 08:11:00 am --05/07/2011 11:42:00 am
		75% of full speed	07/02/2011 09:37:00 am--07/02/2011 12:08:00 pm
	8E	Full Speed	04/26/2011 07:45:00 am-- 04/26/2011 10:38:00 am
		85% of full speed	06/18/2011 13:50:00 pm --06/18/2011 15:31:00 pm
		75% of full speed	06/25/2011 10:33:00 am -- 06/25/2011 12:05:00 pm
	9E	Full Speed	04/15/2011 08:56:00 am --04/15/2011 11:00:00 am
		85% of full speed	06/11/2011 11:38:00 am --06/11/2011 13:07:00 pm
		75% of full speed	05/21/2011 09:08:00 am --05/21/2011 10:59:00 am

Note: 85% and 75% speed test for 5W are not available due to feedback failure. 7E is out of service during the research period.

3.3.4 **Data Collection**

All of the time series used in model development are downloaded from Process Control System (PCS). The PCS is designed for monitoring, controlling and automation of plant processes at Blue Plain. Data point of one-minute time average is downloaded for pump curve generation. Time series of hourly average is downloaded for model validation part, which will be introduced in Section 3.3.6. The point information is listed in the Table 3-7. Point information of flow is listed in Table 3-1.

3.3.5 **Discharge-Head Curve Formulation**

Pump experiment data are graphed as (Q, H) and fit by empirical equation to express the Static head – Discharge relationship. For constant speed pumps, pump experimental data are fit by equation (3-6) because this equation is a general flexible equation with rational extrapolation for wet-well elevation.

Table 3-7 Data point information

RWWPS1		
Point Name		Description
WPSF COMMON INF CHAN 1 LVL	LI05210	Pump discharge side water surface elevation (ft) for pump 1W, 2W, 3W
WPSF COMMON INF CHAN 2 LVL	LI05211	Pump discharge side water surface elevation(ft) for pump 4W, 5W, 6W
RWWPS1 WETWELL 1 LVL	LI0501	Pump suction side wet-well level (ft) for pump 1W, 2W, 3W
RWWPS1 WETWELL 2 LVL	LI0502	Pump suction side wet-well level (ft) for pump 4W, 5W, 6W
RWWPS1 1W PMP RUNSTAT	MN0511	1—Pump 1W is on; 0—pump 1W is off
RWWPS1 2W PMP RUNSTAT	MN0512	1—Pump 2W is on; 0—pump 2W is off
RWWPS1 3W PMP RUNSTAT	MN0513	1—Pump 3W is on; 0—pump 3W is off
RWWPS1 4W PMP RUNSTAT	MN0514	1—Pump 4W is on; 0—pump 4W is off
RWWPS1 5W PMP RUNSTAT	MN0515	1—Pump 5W is on; 0—pump 5W is off
RWWPS1 6W PMP RUNSTAT	MN0516	1—Pump 6W is on; 0—pump 6W is off
RWWPS1 2W PMP SPEED	PCT- SI0512	% of the full speed of pump 2W
RWWPS1 5W PMP SPEED	PCT-SI0515	% of the full speed of pump 5W
RWWPS1 1W PMP REAL PWR	JWI81222	Electricity consumption of pump 1W(KW)
RWWPS1 2W PMP REAL PWR	JWI81223	Electricity consumption of pump 2W(KW)
RWWPS1 3W PMP REAL PWR	JWI81224	Electricity consumption of pump 3W(KW)
RWWPS1 4W PMP REAL PWR	JWI81227	Electricity consumption of pump 4W(KW)
RWWPS1 5W PMP REAL PWR	JWI81228	Electricity consumption of pump 5W(KW)
RWWPS1 6W PMP REAL PWR	JWI81229	Electricity consumption of pump 6W(KW)
RWWPS2		
Point Name		Description
EPSF SCRN 1 EFF CHAN LVL	LI06314	Pump 1E suction side wet-well level (ft)
EPSF SCRN 2 EFF CHAN LVL	LI06324	Pump 2E suction side wet-well level (ft)
EPSF SCRN 3 EFF CHAN LVL	LI06334	Pump 3E suction side wet-well level (ft)
EPSF SCRN 4 EFF CHAN LVL	LI06344	Pump 4E suction side wet-well level (ft)
EPSF SCRN 5 EFF CHAN LVL	LI06354	Pump 5E suction side wet-well level (ft)
EPSF SCRN 6 EFF CHAN LVL	LI06364	Pump 6E suction side wet-well level (ft)
EPSF SCRN 7 EFF CHAN LVL	LI06374	Pump 7E suction side wet-well level (ft)
EPSF SCRN 8 EFF CHAN LVL	LI06384	Pump 8E suction side wet-well level (ft)
EPSF SCRN 9 EFF CHAN LVL	LI06394	Pump 9E suction side wet-well level (ft)
RWWPS2 1E RUNSTAT	MN0611	1—Pump 1E is on; 0—pump 1E is off
RWWPS2 2E RUNSTAT	MN0612	1—Pump 2E is on; 0—pump 2E is off
RWWPS2 3E RUNSTAT	MN0613	1—Pump 3E is on; 0—pump 3E is off
RWWPS2 4E RUNSTAT	MN0614	1—Pump 4E is on; 0—pump 4E is off
RWWPS2 5E RUNSTAT	MN0615	1—Pump 5E is on; 0—pump 5E is off
RWWPS2 6E RUNSTAT	MN0616	1—Pump 6E is on; 0—pump 6E is off
RWWPS2 6E SPEED	SI0616	% of the full speed of pump 6E
RWWPS2 7E RUNSTAT	MN0617	1—Pump 7E is on; 0—pump 7E is off
RWWPS2 7E SPEED	SI0617	% of the full speed of pump 7E
RWWPS2 8E RUNSTAT	MN0618	1—Pump 8E is on; 0—pump 8E is off
RWWPS2 8E SPEED	SI0618	% of the full speed of pump 8E
RWWPS2 9E RUNSTAT	MN0619	1—Pump 9E is on; 0—pump 9E is off
RWWPS2 9E SPEED	SI0619	% of the full speed of pump 9E
RWWPS2 FDR BRKR A1 REAL PWR	JWI81151	Electricity consumption of pump 1E(KW)
RWWPS2 FDR BRKR A2 REAL PWR	JWI81152	Electricity consumption of pump 2E(KW)
RWWPS2 FDR BRKR C13 REAL PWR	JWI81163	Electricity consumption of pump 3E(KW)
RWWPS2 FDR BRKR A5 REAL PWR	JWI81155	Electricity consumption of pump 4E(KW)
RWWPS2 FDR BRKR C12 REAL PWR	JWI81162	Electricity consumption of pump 5E(KW)
RWWPS2 FDR BRKR A3 REAL PWR	JWI81153	Electricity consumption of pump 6E(KW)
RWWPS2 FDR BRKR A4 REAL PWR	JWI81154	Electricity consumption of pump 7E(KW)
RWWPS2 FDR BRKR C14 REAL PWR	JWI81164	Electricity consumption of pump 8E(KW)
RWWPS2 FDR BRKR C15 REAL PWR	JWI81165	Electricity consumption of pump 9E(KW)

$$Q = \frac{K}{1+\exp(b(H-a))} + c \qquad (3\text{-}6)$$

Q=Pump discharge (MGD).

H=Static head (ft)

K, a, b, c = curve-fitting coefficients

For RWWPS1 (Variables defined in Table 3-7),

H(1W,2W,3W) = (WPSF COMMON INF CHAN 1 LVL)

- (RWWPS1 WETWELL 1 LVL) (3-7)

H(4W,5W,6W) = (WPSF COMMON INF CHAN 2 LVL)

- (RWWPS1 WETWELL 2 LVL) (3-8)

For RWWPS2 (Variables defined in Table 3-7),

H (iE) = 22.25ft - (EPSF SCRN i EFF CHAN LVL) (3-9)

where i= Pump number, e.g., i=1, iE=pump 1E, and 22.25 is the elevation of discharge siphon, which is always open during normal operation.

The criterion for the Q-H curve fitting is least-squares optimization. MS Excel Solver function is used for fitting the coefficients K, a, b, and c.

For variable-speed pumps, the test procedure gives data points in different H ranges for the different speeds because the speeds were tested on different dates (Table 3-6). Equation 3-6 is modified by affinity law to obtain a full-speed pump curve with wider range.

According to the Affinity law,

$$Q_1/Q_f = n_1/n_f = n_1 \qquad (3\text{-}10)$$

$$H_1/H_f = (n_1/n_f)^2 = n_1^2 \qquad (3\text{-}11)$$

where Q is pump discharge, H is pumping head, and subscripts f and 1 represent full speed (100%) and lower speed, respectively.

Therefore, equivalent-full speed flow rates can be estimated

$$Q_f=Q_1/ n_1 \quad (3\text{-}12)$$

$$H_f= H_1/ n_1^2 \quad (3\text{-}13)$$

For example, pump test of full speed, 85% of full speed and 75% of full speed are run for pump 2W. The speed feedback is slightly different from the pump's set point; 98% is the feedback for the 100% set point, and the feedback reports 75.12 to 77.85% for the 75% set point. The actual speed feedback (rather than the set point) is used for the pump curve generation. For each data pair (H_1, Q_1) obtained from the pump test, Q_1 is shifted up by equation 3-12 to get Q_f , while H_1 is shift up by equation 3-13 to get H_f. A new effective full-speed curve is formed by shifting these data pairs from each test (Fig. 3-12, circled) and fit by equation 3-6.

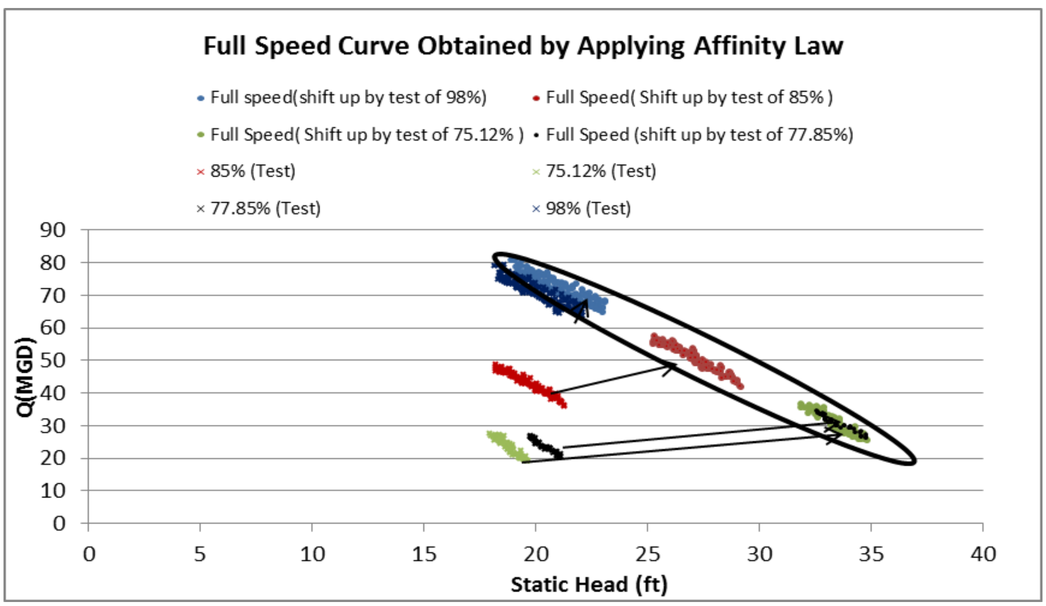


Figure 3-12. Effective full-speed pump performance curve obtained by shifting observed head and discharge according to pump affinity law.

3.3.6 **Simulation Model Algorithm**

The simulation model is programmed in MS Excel. The input to the model is the time series of wet-well elevation, and for RWWPS1, the elevation of the discharge channel.

At each time step (1 hour) static head is calculated by equation 3-7, 3-8 for RWWPS1 and equation 3-9 for RWWPS2. The corresponding discharge of each pump on service is predicted by the Q-H curve formulated for each pump as described in Section 3.3.5.

For constant speed pumping, the discharge of each pump is a function of static head only, Q=f(H). For each hourly time step, the following equation is used to calculate flow for each pump:

$$Q_i = \left(\frac{K}{1+\exp(b(H-a))} + c\right) *MNi \qquad (3\text{-}14)$$

MNi is a variable indicating whether pump i is on service or not: RWWPS1 PMP RUNSTAT (Table 3-7). A value of 1 indicates on, 0 indicates off, and a value between 0 and 1 means that pump is on service less than one hour during the time step of one hour.

For variable speed pumping, pump discharge is a function of both static head and speed. By applying the affinity law [Eqs. (3-10), (3-11), (3-14)],

$$Q_1 = \left(\frac{K}{1+\exp(b(H/n1^{\wedge}2-a))} + c\right) *n_1 *MNi \qquad (3\text{-}15)$$

The total discharge for the time step is $Q_{predicted}$, which is the summation of the discharge of all the pumps on service during the time step.

3.3.7 **Model Evaluation**

In order to verify the performance of model flow prediction, the discharge data from 4/1/2009 - 4/30/2011 are retrieved from PCS system for RWWPS1 and 4/21/2009 - 4/31/2011 for RWWPS2. These time series represent the longest available data period for each influent pump station. Each data point is the time average of one hour. Observed flow rates $Q_{observed}$ (RWWPS2) or $Q_{real\ time}$(RWWPS1), which are the total discharge rates of pumps on service, are plotted together with the respective modeled flow, $Q_{predicted}$. Time series of WEST INFLUENT FLOW (FI_WESTINF) is plotted for RWWPS1 and EAST INF FLOW (FI_EASTINF) for RWWPS2.

Graphically, the model is considered good if the two curves overlap or are close to each other. Goodness-of-fit statistics including R, R2, Se/Sy, mean error and relative error were calculated.

3.3.8 **Data Issues**

Hydraulically, the two reported wet-well levels for RWWPS1 (RWWPS1 WETWELL 1 LVL and RWWPS1 WETWELL 2 LVL) represent the same water surface elevation, and the two reported grit chamber influent channel elevations (WPSF COMMON INF CHAN 1 LVL and WPSF COMMON INF CHAN 2 LVL) represent the same water surface elevation. The data downloaded from PCS, however, show slight differences due to meter error or the water level fluctuation. Sometimes irrational numbers are found in the time series (Table 3-8), to list a few.

Table 3-8 Time period of irrational data(Wet-well level of RWWPS1)

Data point		Time Period	Problem Description
RWWPS1 WETWELL 1 LVL	LI0501	12/22/2009 14:00:00 -- 01/26/2010 07:00:00	Stuck at -7.00ft
		06/09/2009 06:00:00 -- 06/09/2009 10:00:00	Missing data
RWWPS1 WETWELL 2 LVL	LI0502	02/12/2009 17:00:00 -- 02/13/2009 08:00:00	Stuck at +2.00ft
		02/13/2009 09:00:00 -- 06/09/2009 05:00:00	Stuck at -5.00ft
		06/09/2009 23:00:00 -- 12/21/2009 10:00:00	Stuck at 0.00 ft
		06/09/2009 06:00:00 -- 06/09/2009 10:00:00	Missing data
WPSF COMMON INF CHAN 1 LVL	LI05210	06/09/2009 06:00:00 -- 06/09/2009 10:00:00	Missing data
WPSF COMMON INF CHAN 2 LVL	LI05211	10/04/2010 11:00:00 -- 10/08/2010 12:00:00	Stuck at 25.4 ft
		12/07/2010 10:00:00 -- 12/10/2010 14:00:00	Stuck at 16.9 ft
		01/10/2011 11:00:00 -- 01/11/2011 06:00:00	Stuck at 16.9 ft
		06/09/2009 06:00:00 -- 06/09/2009 10:00:00	Missing data

For RWWPS1, if meter RWWPS1 WETWELL 1 LVL gives irrational number (e.g., stuck in the same number for more than 5 hours), data from RWWPS1 WETWELL 2 LVL is used instead of RWWPS1 WETWELL 1 LVL, and vice versa. Similarly, if meter WPSF COMMON INF CHAN 1 LVL gives irrational number (e.g., stuck in the same number for more than 5 hours), data from WPSF COMMON INF CHAN 2 LVL is used instead of WPSF COMMON INF CHAN 1 LVL, and vice versa. For RWWPS2, if wet-well level before the target pump gives irrational number, the average of other 8 wet-well levels will be used instead.

3.3.9 Power Consumption and Wire-to-Water Efficiency

Since only one test is available for each pump in RWWPS1 and 2, it would be inaccurate to use only power data obtained from the test. Random variation and data dead band problem may mask the actual power consumption trend. Data from 1/1/2009 to 4/30/2011 based on hourly average will be used for power consumption analysis. Linear regression of KW/MGD vs Wet-well Level will be provided to estimate power saving by raising wet-well level.

Wire-to-Water efficiency is calculated by equation 3-16.

$$\text{Wire to water efficiency } (\eta) = \frac{\text{WHP}}{\text{Electrical power}} = \frac{QH}{3960 \times KW} \qquad (3\text{-}16)$$

Q: Pump discharge in GPM

H: Static head [ft].

KW: Power Consumption (KWh)

Note: The actual WHP would be slightly higher than WHP calculated because Static head is used instead of TDH. As a result, this method underestimates the actual wire-to-water efficiency slightly.

3.4 Influent Wet-well Storage Estimation

Using the model to predict wet-well elevation, as well as flow rates, will require a stage-storage curve for the wet-well. The wet-wells are complex in shape (Fig.1-4) and connected to the conduits from outside of the plant. Existing drawings are not sufficiently detailed in three dimensions to obtain the geometric quantities required. However, the measured data provide an opportunity to estimate this relationship. Influent wet-well storage is estimated based on data obtained during an influent pumping outage on 6/27/2011, assuming a constant inflow rate to the wet-well during the pump shutdown period. A second influent outage due to power outage on 3/13/2011 serves as an independent data set to verify the estimation. The detailed assumption and results are provided in Section 4.6.

3.5 Preliminary Application of Model to Power Cost Prediction

With the rough estimate of the wet-well stage-storage relationship as introduced in Section 3.4, a full simulation of pump flow and wet-well elevation can be performed with the following as input:

(1) A real or synthetic wastewater inflow hydrograph.

(2) A real or synthetic pump operation strategy (selection of pumps, timing, speed).

Based on the time series of wet-well elevation produced by this simulation, power use can be estimated using the results of regressing power use on wet-well elevation. Finally, based on empirical curves for the time variation of energy cost, the cost of pumping for the simulated time period can be estimated. This cost can be compared to the costs that result from alternative pump operation strategies. Although some of the inputs to the simulation model are fairly coarse estimates at this point, this exercise can nonetheless demonstrate the potential use of the simulation model in short-term operation planning of the Raw Wastewater Pump Stations at Blue Plains. It will also give an indication of next-step priorities for improving the input functions and regressions.

Chapter 4. Results

4.1 Flow Rate, Power Price, Power Load and Energy Breakdown Analysis

4.1.1 Diurnal Trend of Influent Flow Rate

Three years of data (2008-2010) were available for the diurnal total influent flow rate analysis. Similar trends were found for all three years. The influent flow rate starts increasing at 8 am and reaches a peak around 5-6 pm, followed by a slight drop from 6 pm to 12 am. A significant decrease occurs during the night from 12am to 8pm (Fig. 4-1). The daily average influent flow rate ranges from 223 MGD to 347 MGD, with an average of 302 MGD based on the data from 1/1/2008 to 12/31/2010. The influent flow rate during 2009 was slightly larger than that for 2008.

In order to evaluate the seasonal variation, flow rate data for two years (1/1/2009-12/31/2010) were grouped into seasons (Fig. 4-2). The weekday and weekend flows are plotted separately. It is observed that the rising limb of weekend flow has a one-hour lag behind the weekday flow for all seasons. This may be attributed to residents' water consumption and discharge pattern. For the winter and fall seasons, the weekend flow for the period 4-8pm (16:00-20:00) is greater than the weekday flow for that period [Fig. 4-2 (a), (d)].

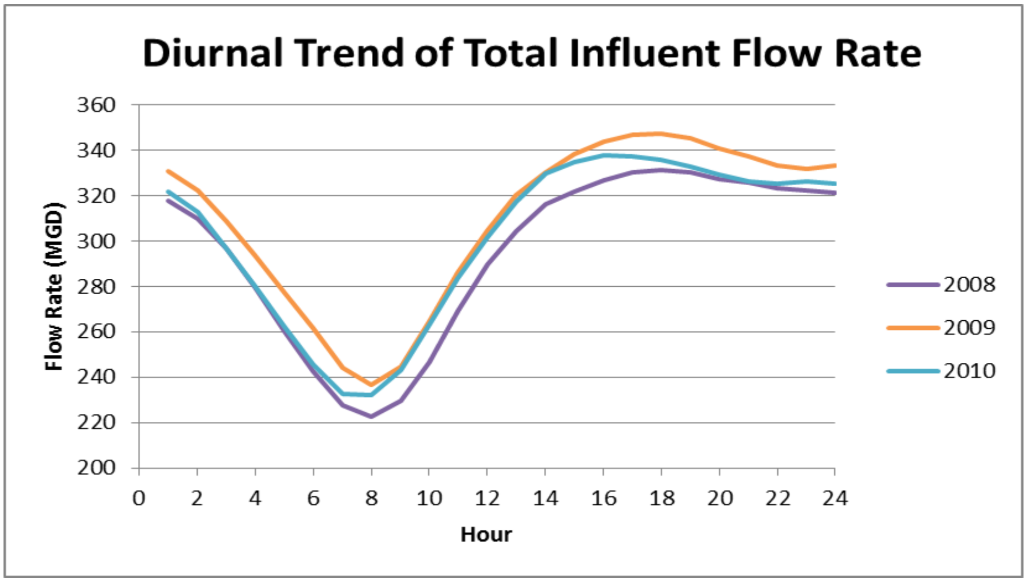


Figure 4-1. Diurnal trend of influent flow rate

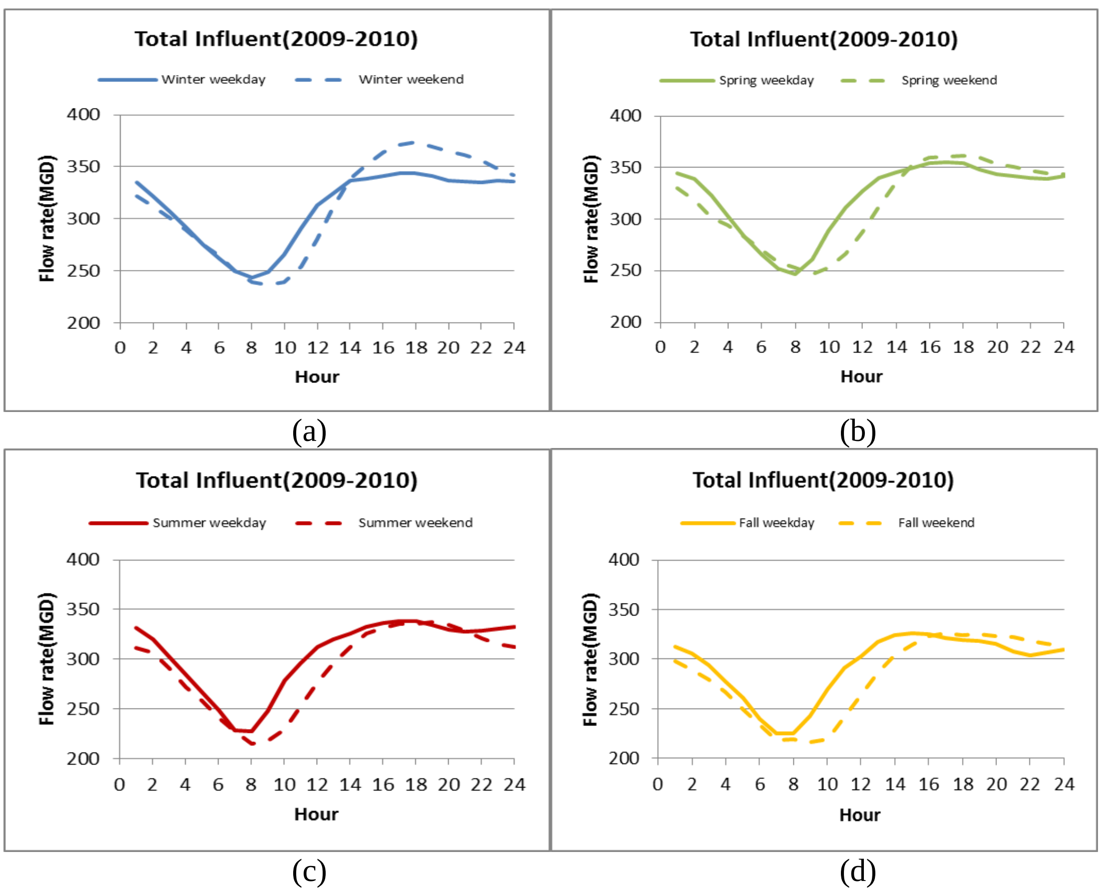


Figure 4-2. Total influent flow rate (comparison of weekday and weekend, 2009-2010) (a)Winter, (b)Spring, (c)Summer, (d)Fall

4.1.2 **Diurnal Trend of Power Price**

The diurnal trend of power price was computed based on the hourly average data for 2008, 2009, and 2010. Each of the 24 points on the curve represents the mean value of the power price ($/MWh) for that hour of the day, averaged over 365 days for each year. It is observed from Fig. 4-3 that the mean unit power price follows a similar trend for the three years. The first peak is observed at 7am and the highest power cost occurs at 7-9 pm. The lowest price occurs in the early morning. As illustrated in the box-and-whisker plot of power price (Fig. 4-4), the power price variation during the daytime working hours is larger than during the night time.

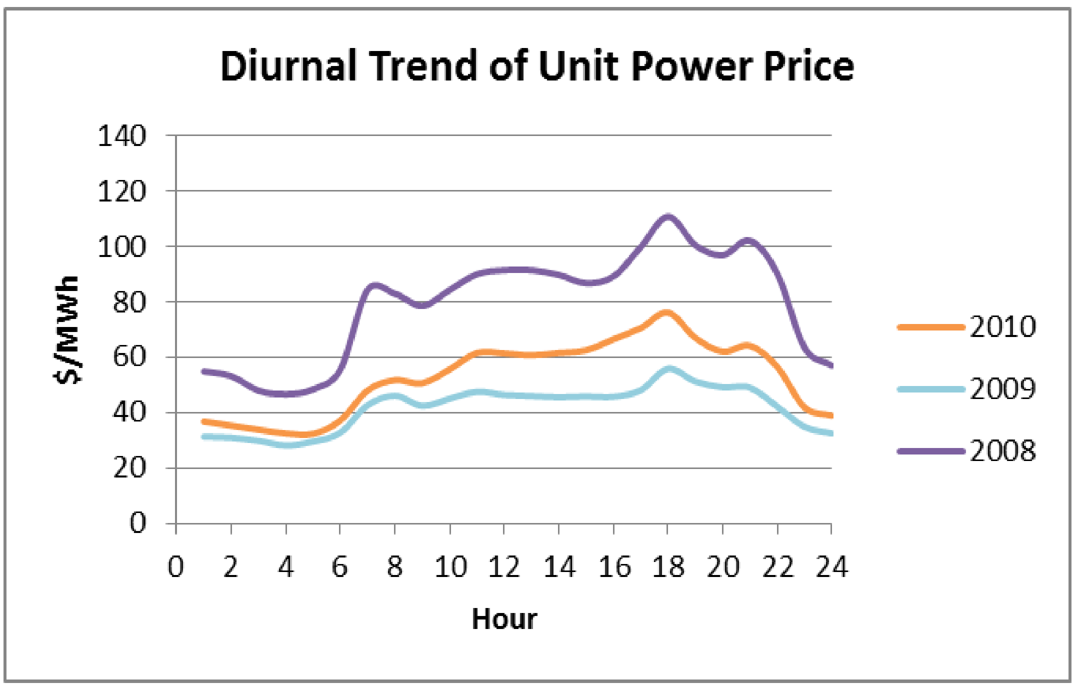


Figure 4-3. Diurnal trend of unit power price for 2008, 2009 and 2010

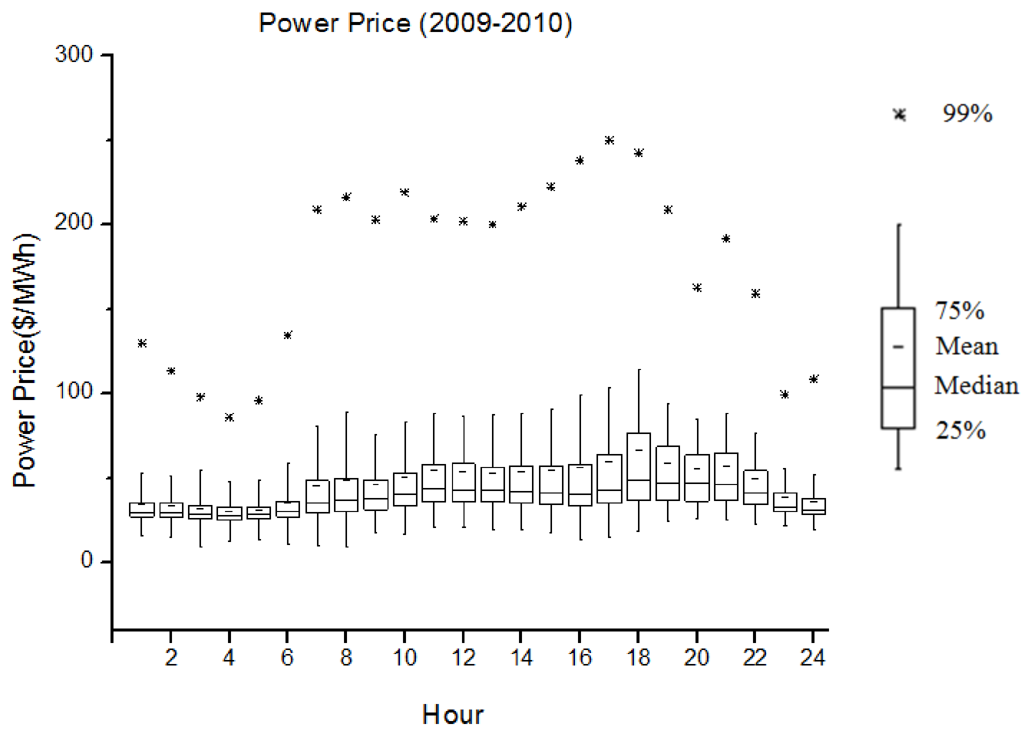


Figure 4-4. Box-and-whisker plot for power price (2009-2010)

Note: Whisker: One Standard Deviation from mean; 75%: The value that 75% of the sample are less than or equal. Similar for 99%, 25%. Sample size = 730

Data from 1/1/2009 to 12/31/2010 (730 days) were also used for seasonal power price evaluations. As depicted in Fig. 4-5, the diurnal trend is different for each season. The trend for winter is similar to that for fall, while the summer is closer to that for the spring. For the winter and fall seasons, two peaks are observed, one around 6-8 am and the other at 6-8 pm. For summer and spring, one peak occurs around 5 pm. A higher peak is observed in summer than in spring. Seasonal variation is confirmed for each season by plotting the hourly average of each monthly billing period (Fig. 4-6 to Fig. 4-9). Unit power cost for each season is illustrated in Fig. 4-10. Average unit power cost decreases during the three years.

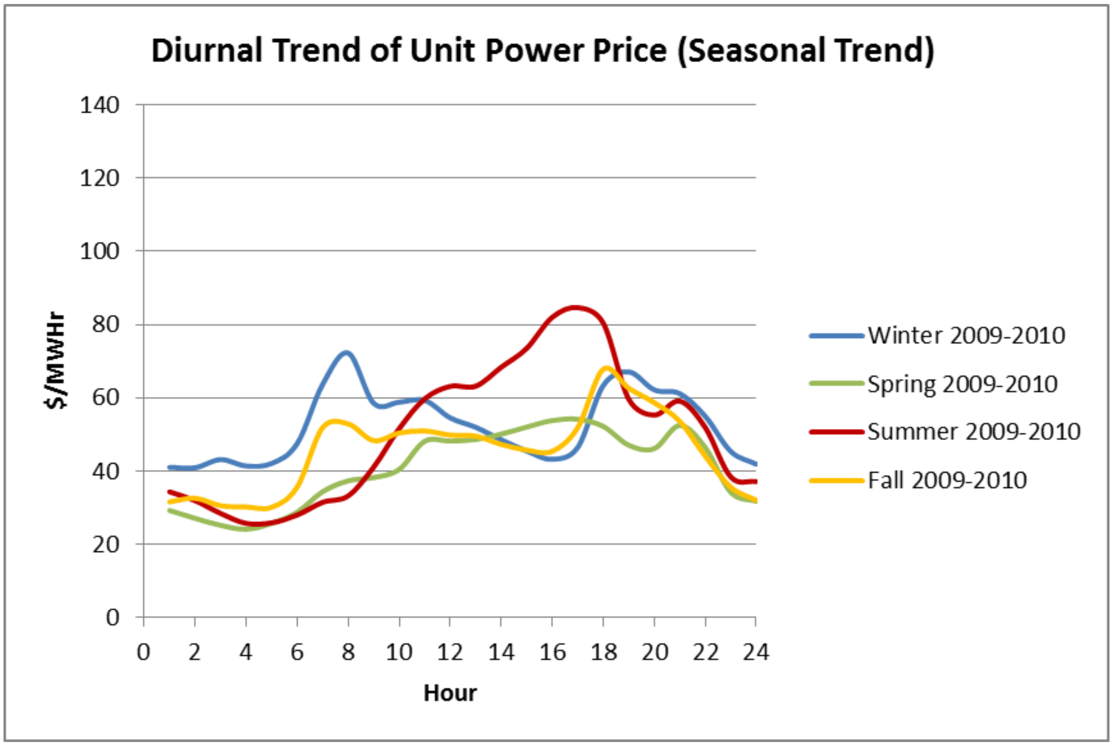


Figure 4-5. Diurnal trend of unit power price by season

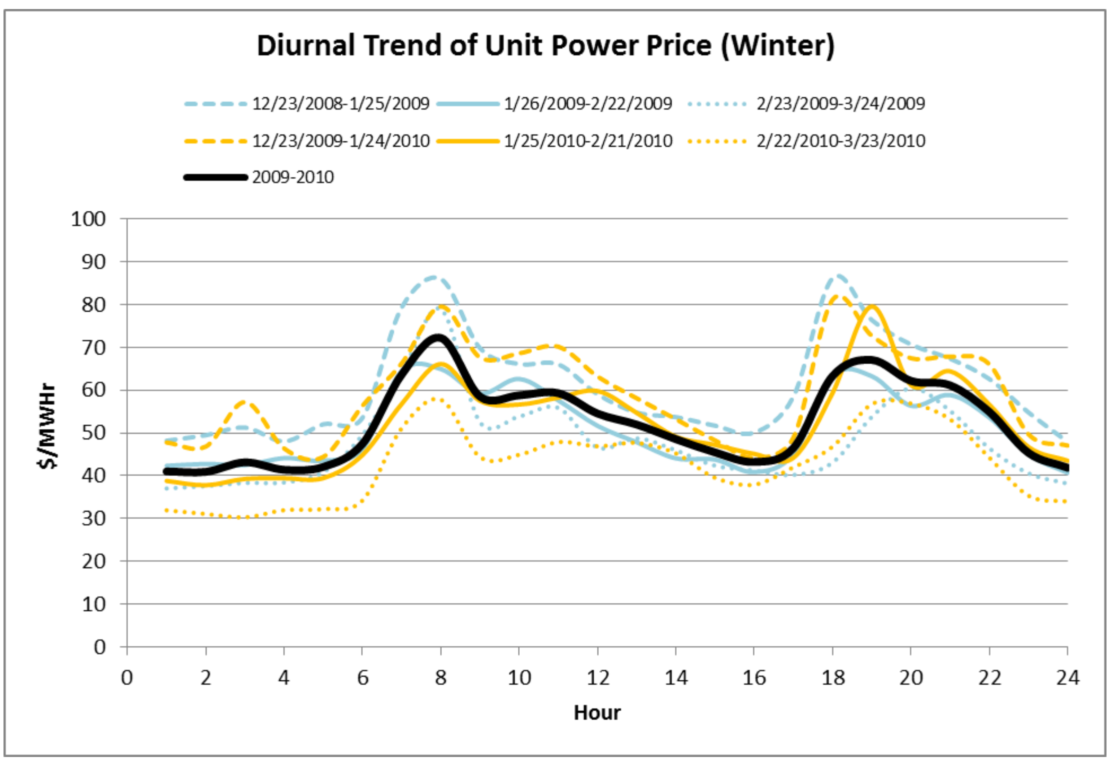


Figure 4-6. Diurnal trend of unit power price by billing period (Winter)

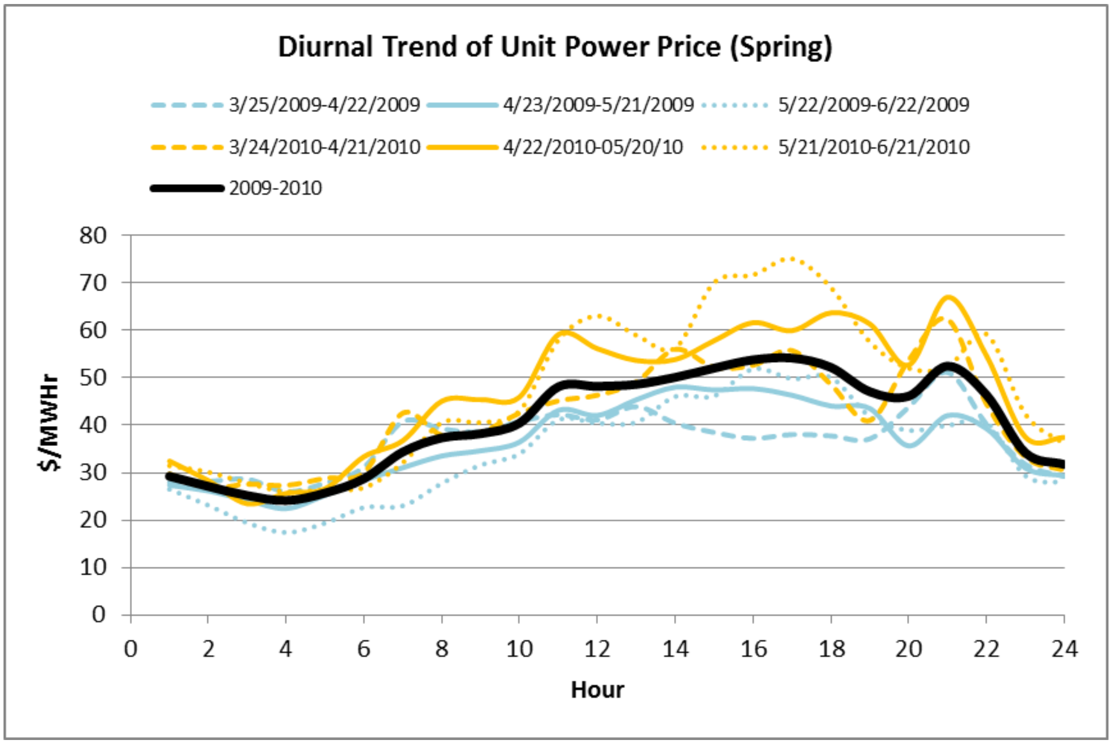


Figure 4-7. Diurnal trend of unit power price by billing period (Spring)

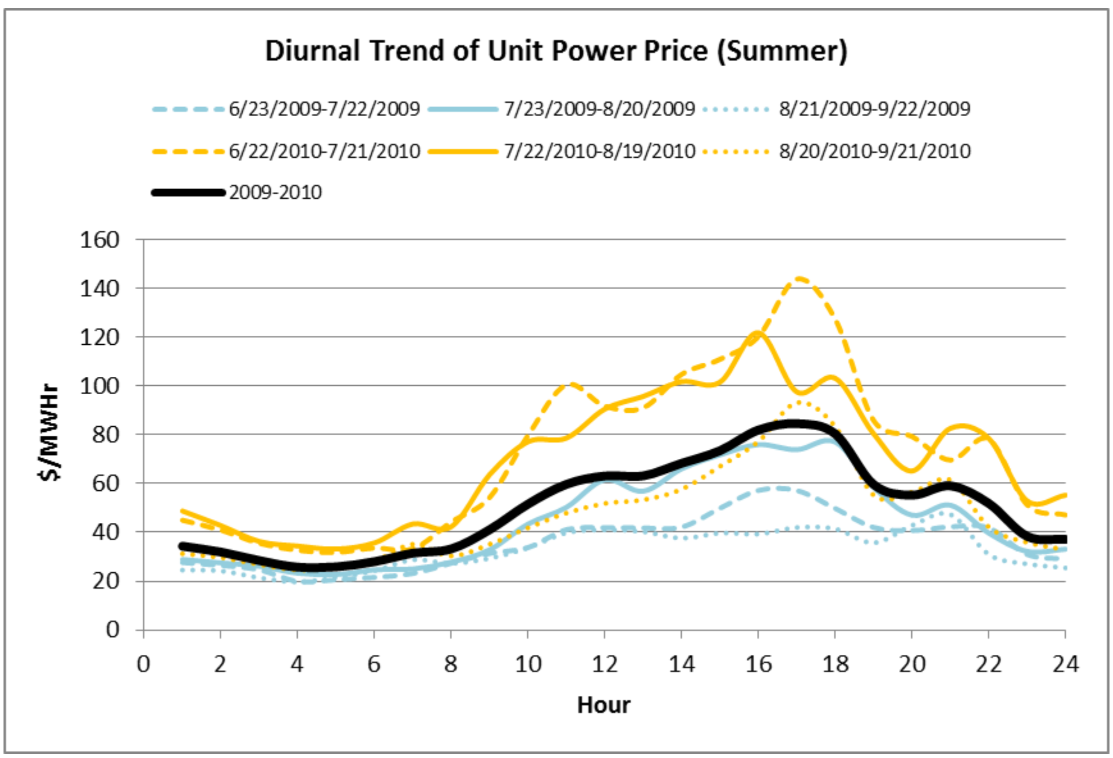


Figure 4-8. Diurnal trend of unit power price by billing period (Summer)

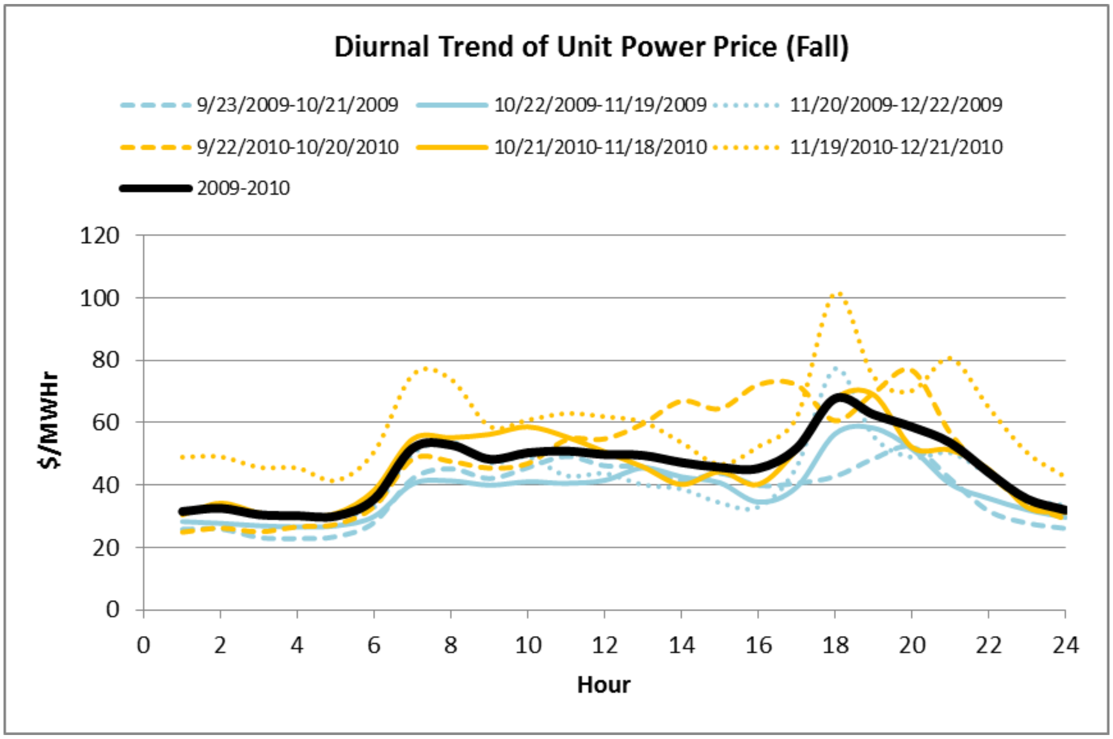


Figure 4-9. Diurnal trend of unit power price by billing period (Fall)

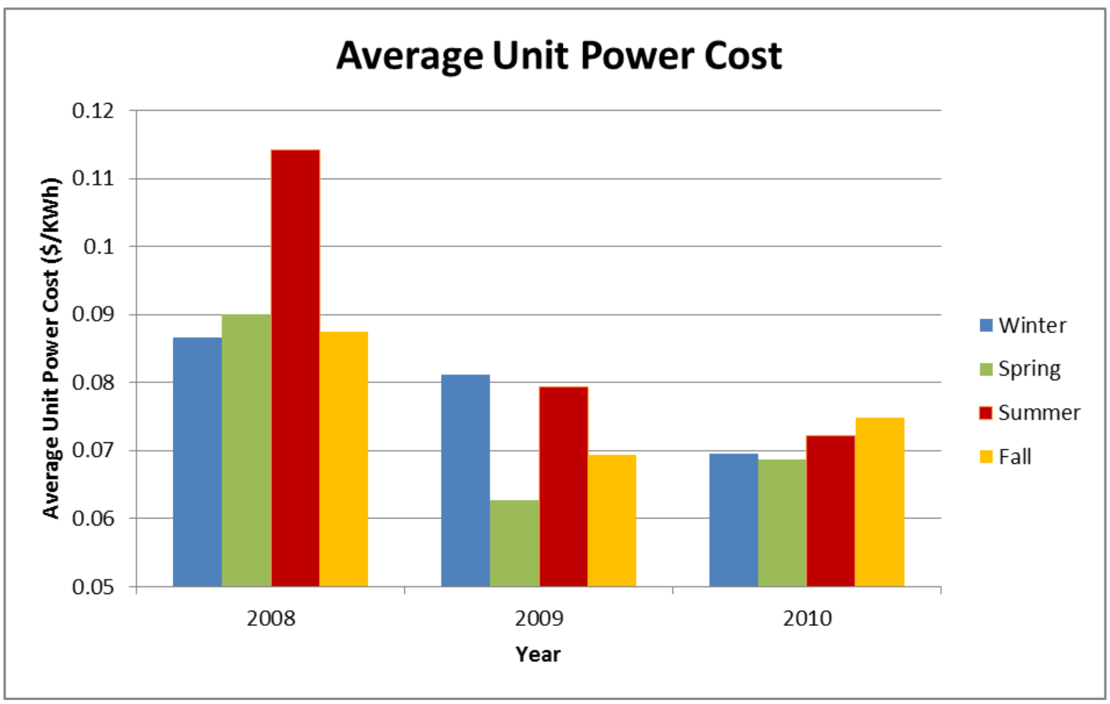


Figure 4-10. Average unit power cost ($/KWh)

4.1.3 **Diurnal Trend of Total Power Load of the Whole Plant**

Power use data from PEPCO bill (solid lines) and in-plant sub-meter (dashed lines) indicates the similar trend and magnitude for the four seasons (Fig. 4-11). Total power load is higher in spring and winter than in summer and fall for 2009-2010, with an average difference of around 1120KWh.

Based on the three years of hourly data obtained from PEPCO monthly bill (Fig. 4-12), total power load of the whole plant gradually decreases during the three years. Significant power saving is observed based on hourly average load, with a drop of 10.6 % (3170KWh) achieved in 2009 compared to 2008 and 2.4% (640KWh) in 2010 compared to 2009. The total power load follows the same diurnal trend as total influent flow rate. As listed in Table 4-1, the saving of the power cost is result from the drop of both power consumption and unit power price over the three years.

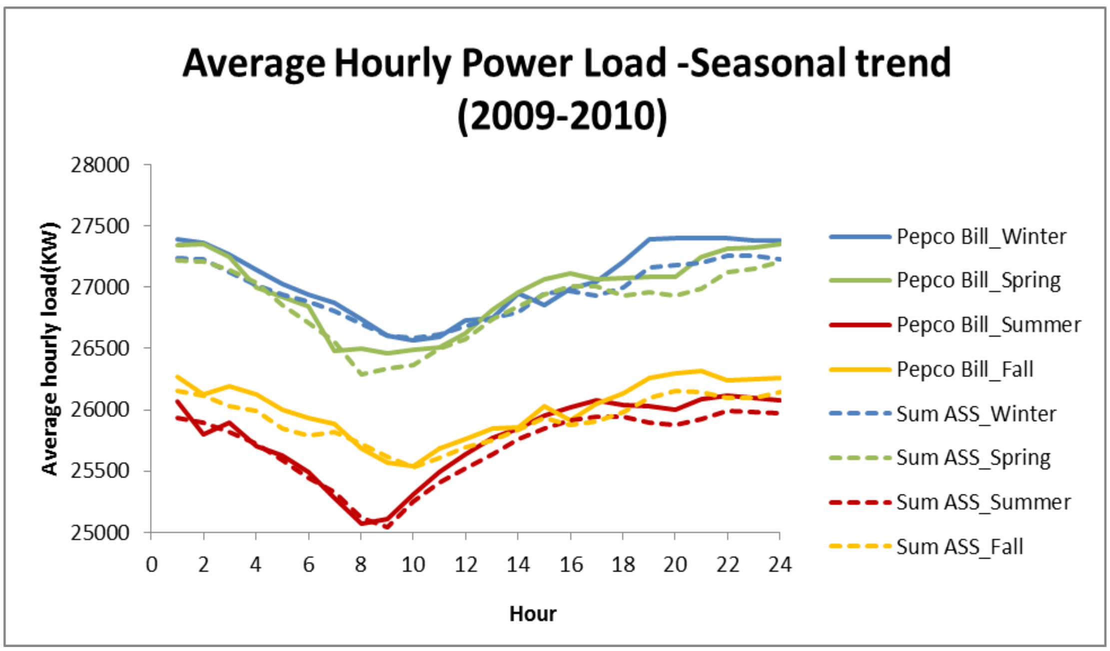


Figure 4-11. Diurnal trend of total power load of Blue Plains by season (2009 - 2010), according to power bill and in-plant meters.

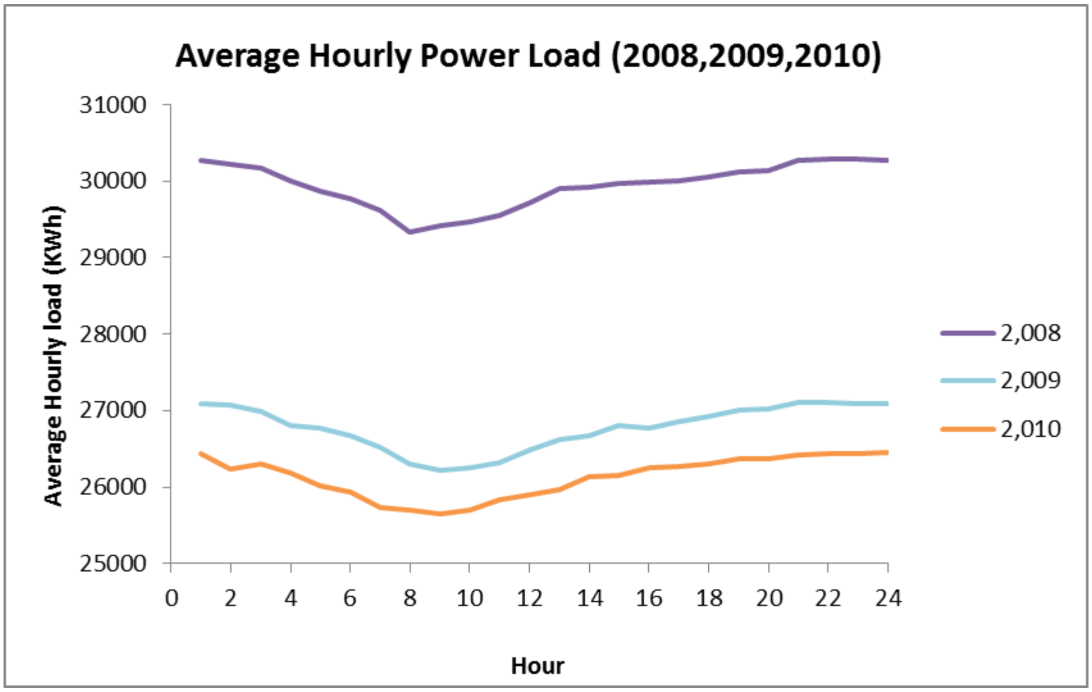


Figure 4-12. Diurnal trend of total power load of Blue Plains (2008, 2009 and 2010)

Table 4-1 Power load and power cost of 2008, 2009, and 2010

	Total Load (MWh)	Total Cost	Average Monthly Load (MWh)	Average Monthly Total Cost	Average Unit Cost ($/KWh)
2008	264,550	$25,031,938	22,046	$2,085,995	0.095
2009	234,555	$17,161,202	19,546	$1,430,100	0.073
2010	228,222	$16,281,371	19,018	$1,356,781	0.071
Saving (2009)	29,996	$7,870,736	2,500	$655,895	0.0214
Saving (2010)	6,333	$879,830	528	$73,319	0.0019
Percent Saving (2009)	11.34%	31.44%	11.34%	31.44%	22.65%
Percent Saving (2010)	2.70%	5.13%	2.70%	5.13%	2.62%

Note: Saving is calculated by comparing to the previous year

4.2 Energy Breakdown Analysis

4.2.1 Energy Breakdown of Major Treatment Processes of Blue Plains

The five major energy users of Blue Plains are: Nitrification blower, secondary blower, secondary sedimentation, solids processing, and the two Raw Wastewater Pump Stations (Fig. 4-13). The nitrification blower is the largest power consumer inside Blue Plains, with a demand of 4830 KWh or 21% of total power load. The secondary blower is the second largest power consumer, representing around 18% of the total power consumption, followed by secondary sedimentation, solids processing and RWWPS1&2 with 9.3%, 8.9%, and 6.7%, respectively. This does not include power losses in the motor control center or other power transmission process. It is evident that aeration processes are the most power consuming treatment processes. Nitrification blower and secondary blower together consume about 9000KWh, which is about 39% of the electricity load of wastewater treatment of Blue Plains. It should be noted that data are not available for the breakdown of grit chamber, primary sedimentation and control houses, all included in the power consumption of primary sedimentation.

Area Substation 1 (ASS1) is by far the largest area substation, distributing 42% of the plant's electrical power ASS3, ASS4 and ASS5 distribute 25%, 17%, and 16% of the electricity of the whole plant, respectively (Fig. 4-14). Area substation 6 will be constructed for future upgrade, and will not be included in this analysis.

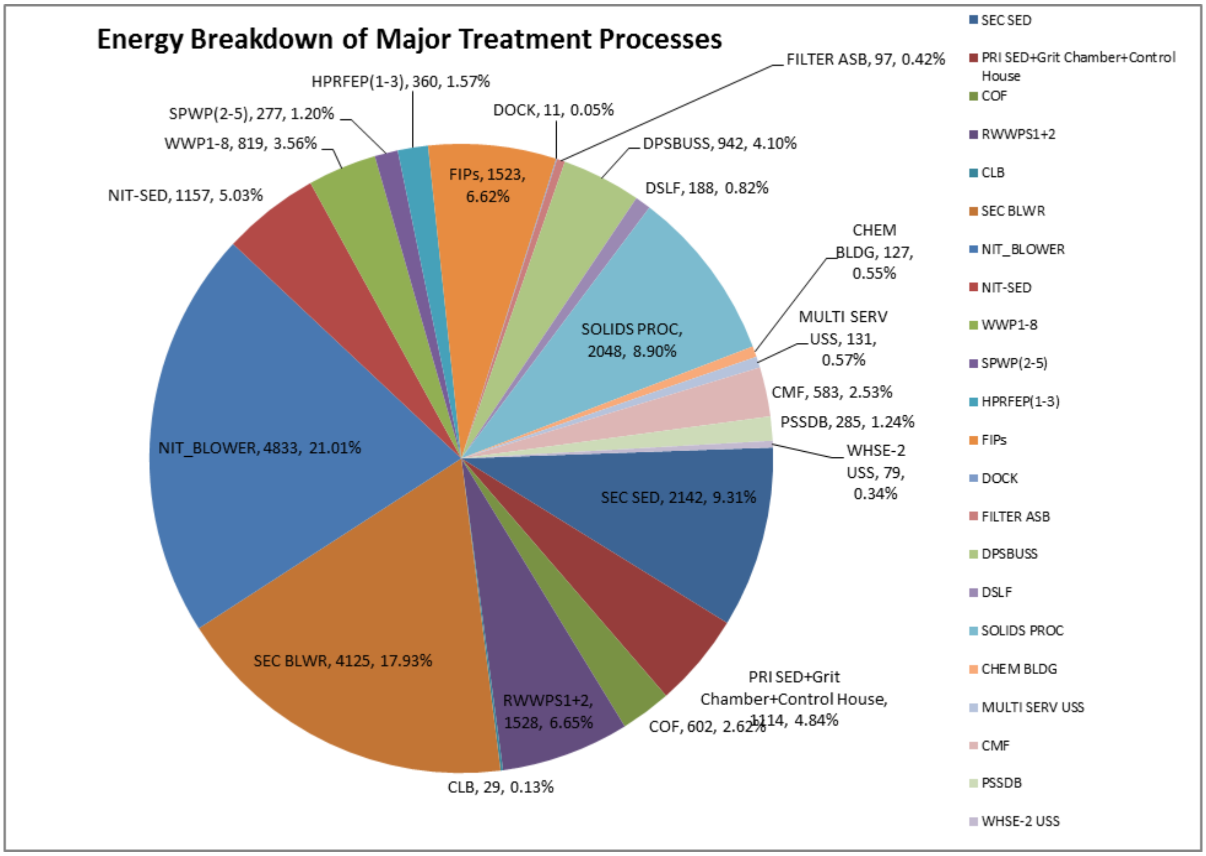


Figure 4-13. Energy breakdown of major treatment processes in Blue Plains (5/1/2010-4/30/2011)

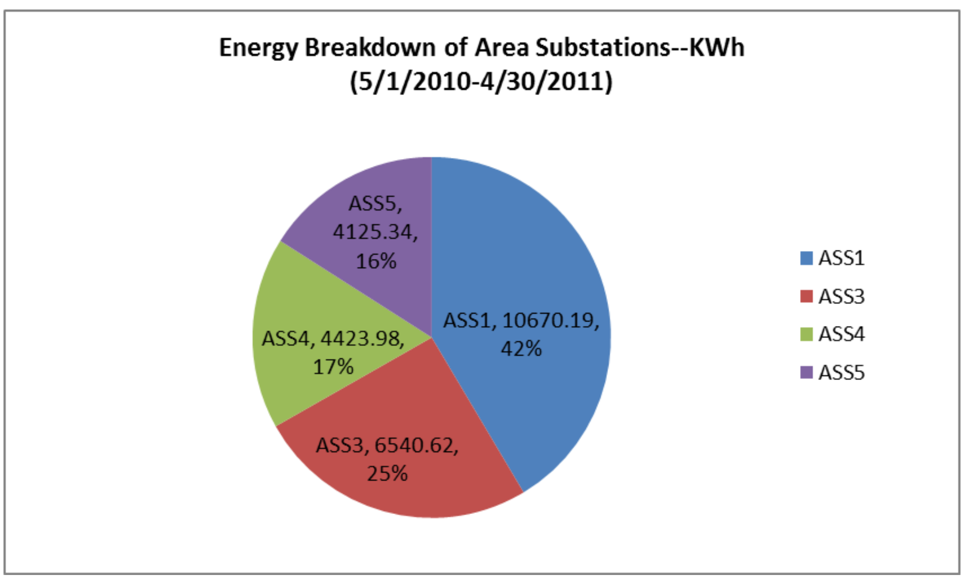


Figure 4-14. Energy breakdown of area substations (5/1/2010-4/30/2011)

4.2.2 **Diurnal and Seasonal Trend of Area Substations and Major Treatment Processes**

The loads distributed by ASS1 and ASS4 [Fig. 4-15(a) and (c)] follow the trend of influent flow rate (Fig. 4-1), which accounts for the 1000 KWh difference between peak and minimum in total power load. Lowest power load of ASS3 is observed around 5-7pm and the peak is observed around 5-8am [Fig. 4-15(b)]. ASS5 peaks during working hours on weekdays [Fig. 4-15(d)]. It is the only substation shows significant difference between weekdays and weekend. It is also observed in Fig. 4-15(d) that power load of winter is much higher than the other seasons for ASS5.

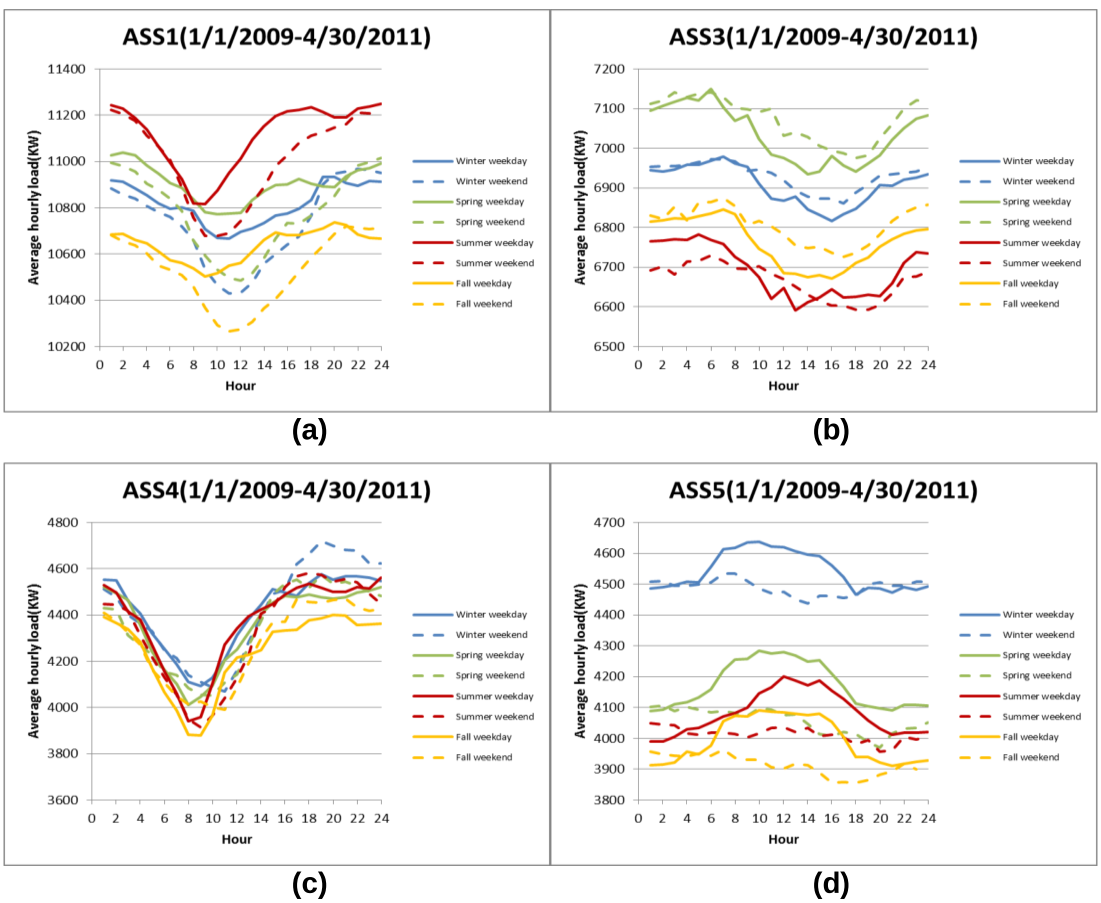


Figure 4-15. Diurnal trend of power load for area substations 1, 3, 4, and 5.

Diurnal trend of raw wastewater pumping (Fig. 4-16) follows the same trend as influent flow rate (Fig. 4-1), confirmed by independent data for all four seasons. The operators set the pumping combination by following the influent flow rate, which results in this flow- matching trend. Diurnal and seasonal trends of the other major treatment processes are reported in Appendix 1 to Appendix 4 for ASS1, ASS3, ASS4, ASS5, respectively.

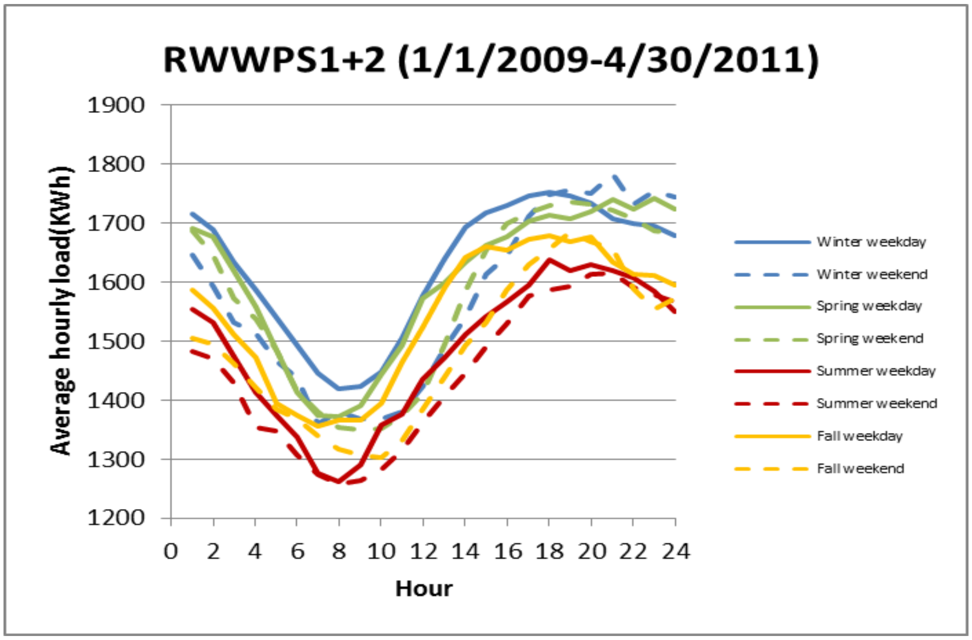


Figure 4-16. Diurnal trend of power load - RWWPS1&2 (1/1/2009 - 4/30/2011)

4.3 Pump Performance Characteristics and Discharge-Static Head Curve Formulation

All the pump characteristic curves obtained by pump testing are attached in Appendix 5. For each pump test, pump discharge-static head (Q-H) curve is plotted compared to the designed point, which is the designed capacity under TDH. The designed static head would be slightly lower than TDH. Power consumption, wet-well level and corresponding pump discharge are also graphed in Appendix 5.

Pump discharge-static curve fit by equation 3-4 are plotted with test results for each pump (Fig. 4-17 through 4-29). Typically, pump characteristic curves are presented with H (head) as a function of Q (discharge). In this study, Q is predicted as a function of H, because pump discharge is to be calculated from wet-well and grit chamber influent channel (RWWPS1) or discharge siphon (RWWPS2) elevation. Values of the curve fitting coefficients K, a, b, c for RWWPS1 and RWWPS2 by least-squares optimization are listed in Table 4-2. For simulation, the curve fitting coefficient is modified in Table 4-3 based on calibration. All curve fitting are based on one test. In this research, it is believed that if one test result, for example, test curve of 1W doesn't work well in calibration, test curve of identical pump 3W could be used instead. During the research period, speed feedback of 5W is not available. Pump 7E is out of service.

Table 4-2 Discharge-head curve fitting coefficient for RWWPS1&2 pump tests

	Pump	k	a	b	c
RWWPS1	1W	64.4294	22.1601	0.2061	11.6788
	3W	14.4948	20.0067	1.2277	47.9299
	4W	85.0423	-0.4946	-0.6189	0.6172
	6W	39.9987	7.769	0.1124	26.6095
	2W	84.0411	25.8762	0.1759	13.2208
	5W	NA	NA	NA	NA
RWWPS2	1E	60.5611	24.9475	0.3234	49.5345
	2E	69.7628	20.4057	0.1628	74.2736
	3E	552.9704	33.4949	0.3694	-449.771
	4E	77.5344	26.56	0.5043	28.0908
	5E	86.5415	27.6257	0.249	37.1956
	6E	61.9582	32.6709	0.2984	59.8673
	7E	NA	NA	NA	NA
	8E	46.7172	32.8897	0.3976	64.7101
	9E	45.766	28.6238	0.2654	65.8885

Table 4-3 Discharge-head curve fitting coefficient for RWWPS1&2 simulation

	Pump	k	a	b	c
RWWPS1	1W(3W)	14.4948	20.0067	1.2277	47.9299
	3W	14.4948	20.0067	1.2277	47.9299
	4W	72.0434	23.494	0.1889	12.1781
	6W	39.9987	7.769	0.1124	26.6095
	2W	84.0411	25.8762	0.1759	13.2208
	5W(2W)	84.0411	25.8762	0.1759	13.2208
RWWPS2	1E	60.5611	24.9475	0.3234	49.5345
	2E(4E)	77.5344	26.56	0.5043	28.0908
	3E	552.9704	33.4949	0.3694	-449.771
	4E	77.5344	26.56	0.5043	28.0908
	5E	86.5415	27.6257	0.249	37.1956
	6E	61.9582	32.6709	0.2984	59.8673
	7E(8E)	46.7172	32.8897	0.3976	64.7101
	8E	46.7172	32.8897	0.3976	64.7101
	9E	45.766	28.6238	0.2654	65.8885

Note: 1W (3W) indicates that test curve of pump 3W is used for pump 1W.

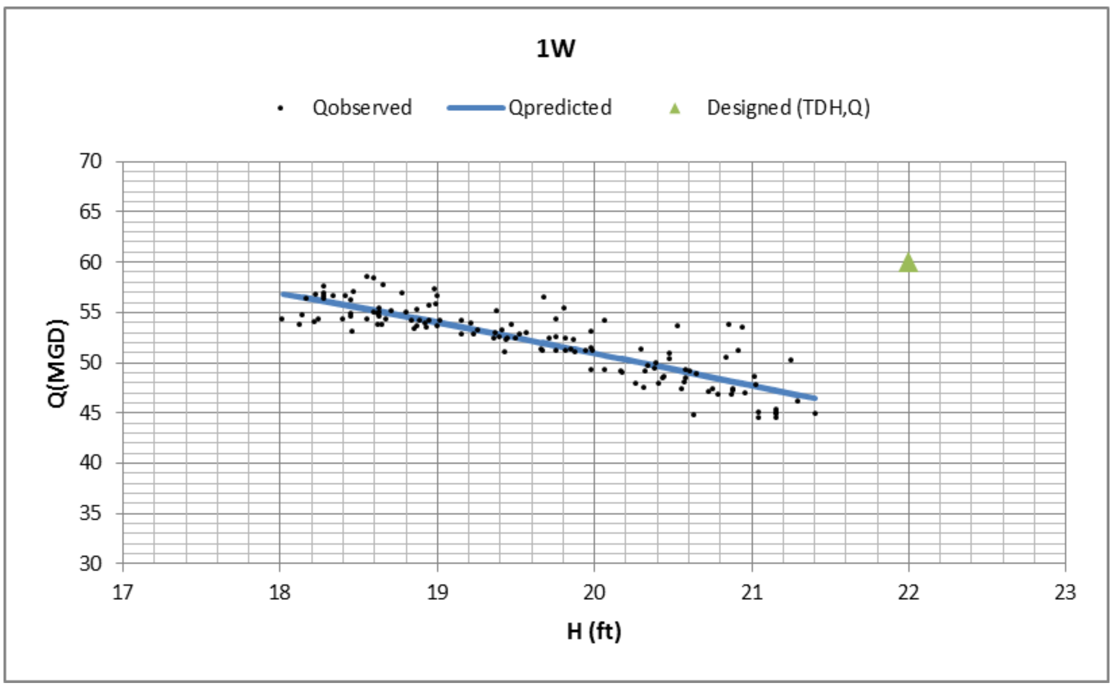


Figure 4-17. Discharge-static head curve for pump 1W

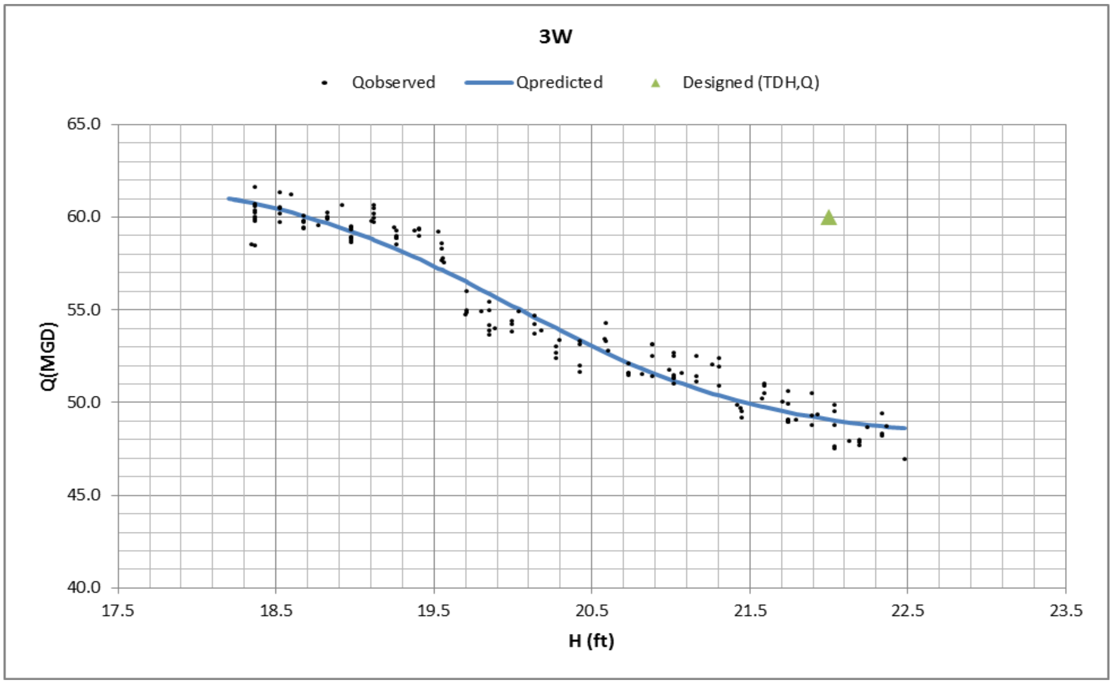


Figure 4-18. Discharge-static head curve for pump 3W

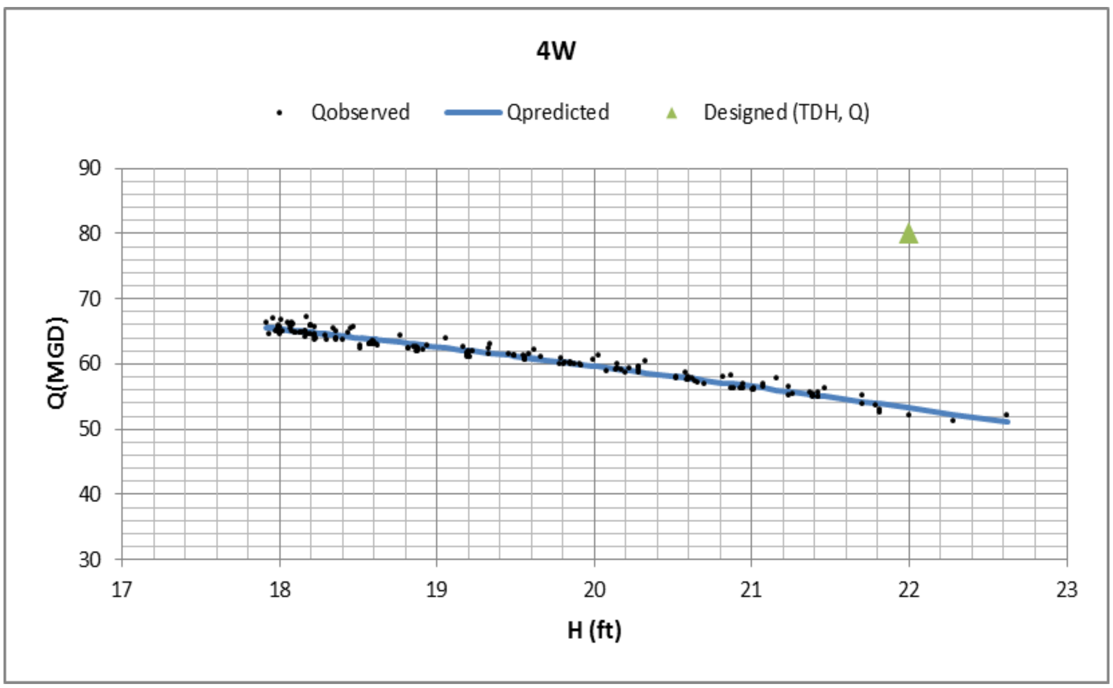


Figure 4-19. Discharge-static head curve for pump 4W

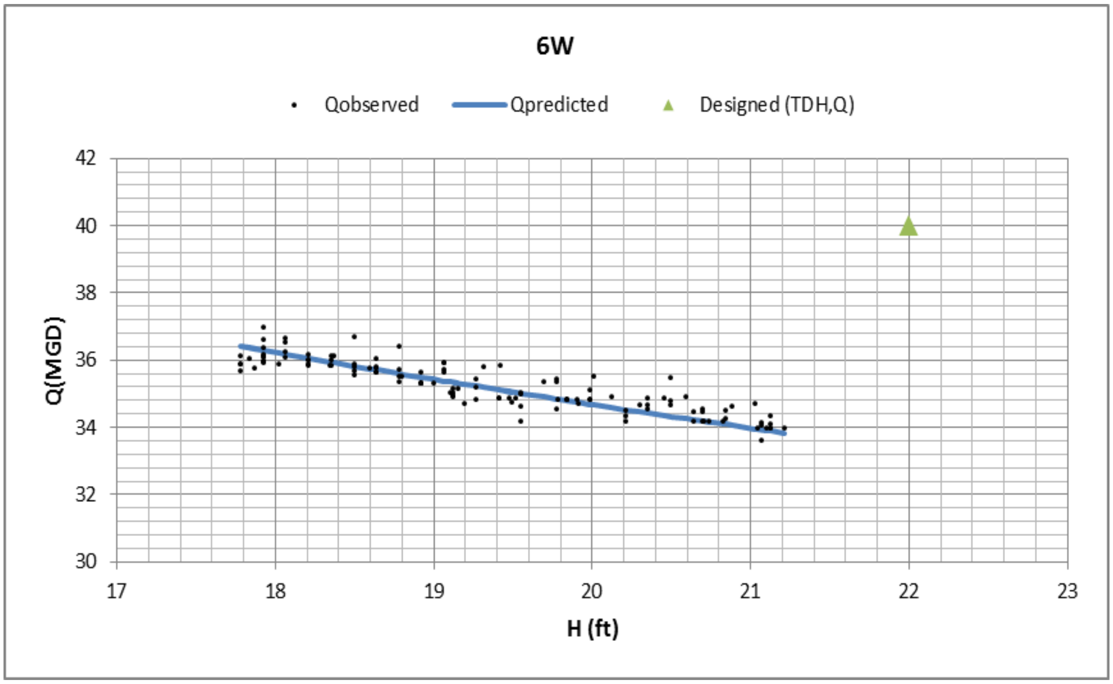


Figure 4-20. Discharge-static head curve for pump 6W

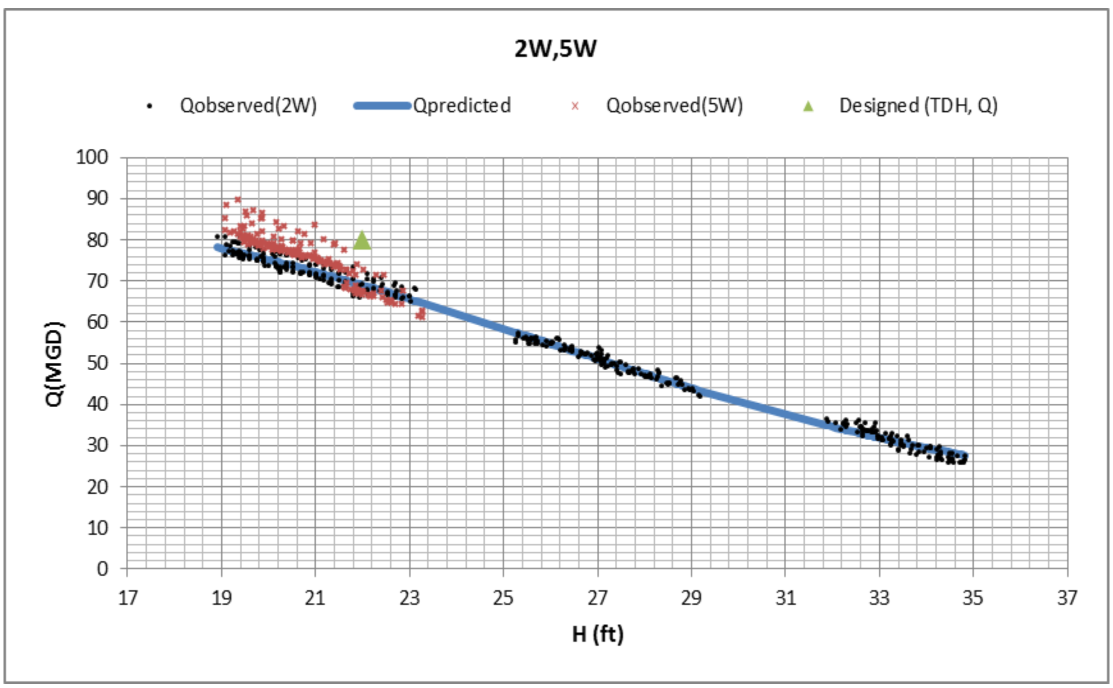


Figure 4-21. Full-speed discharge-static head curve for pump 2W,5W

Note: Only full speed test is done for 5W (Speed feedback is not available for 5W during the research period). 5W and 2W are identical and full speed capacity is observed similar. Same curve is fit for 2W and 5W. Partial speed test measurements are scaled to equivalent full speed using pump affinity law, as described in section 3.3.5.

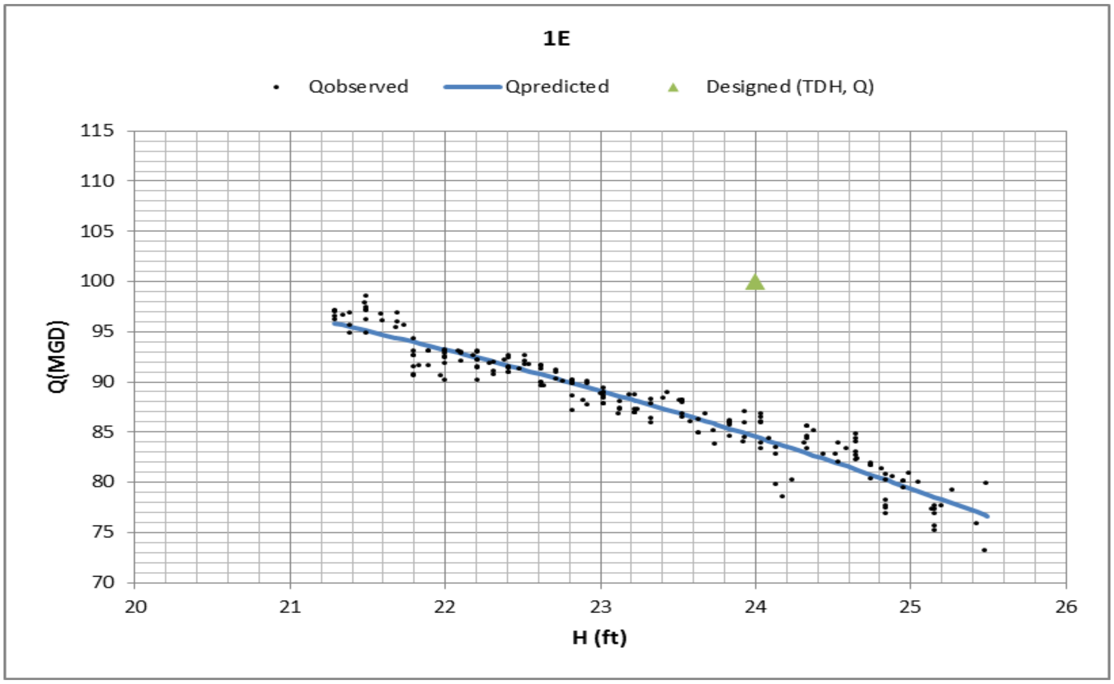


Figure 4-22. Discharge-static head curve for pump 1E

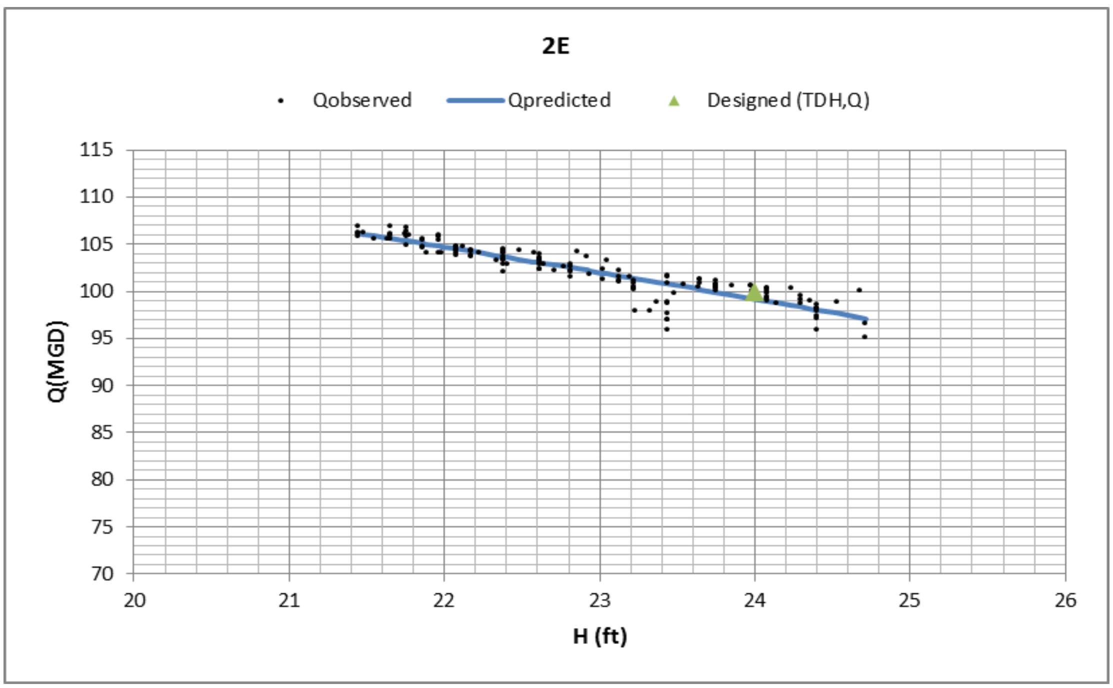


Figure 4-23. Discharge-static head curve for pump 2E

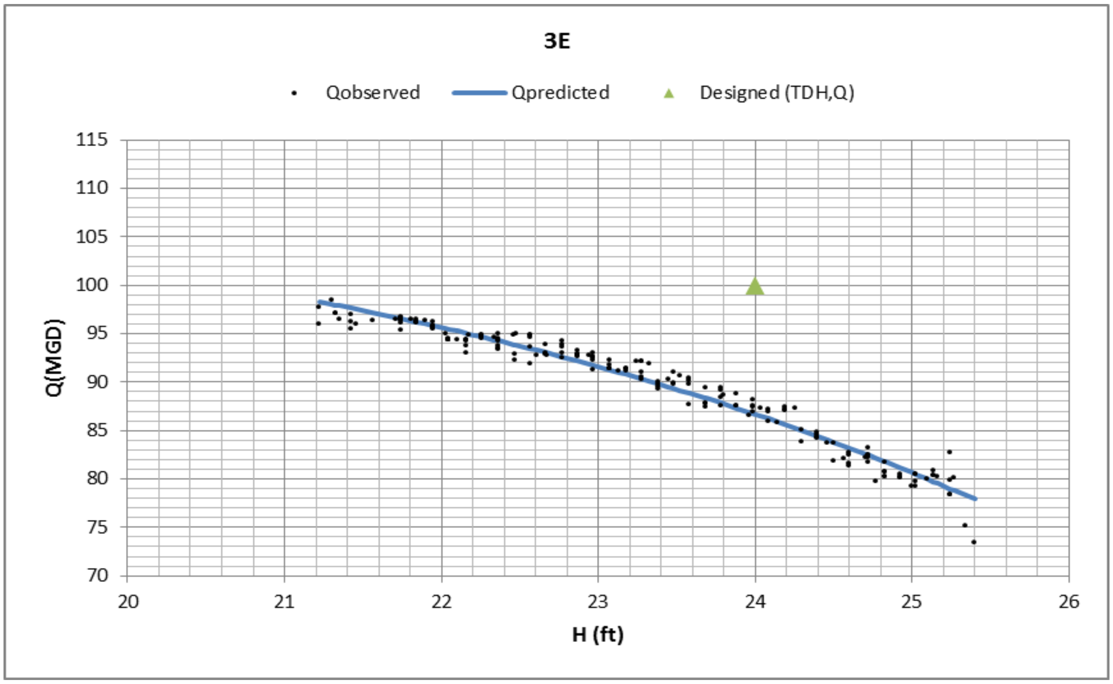


Figure 4-24. Discharge-static head curve for pump 3E

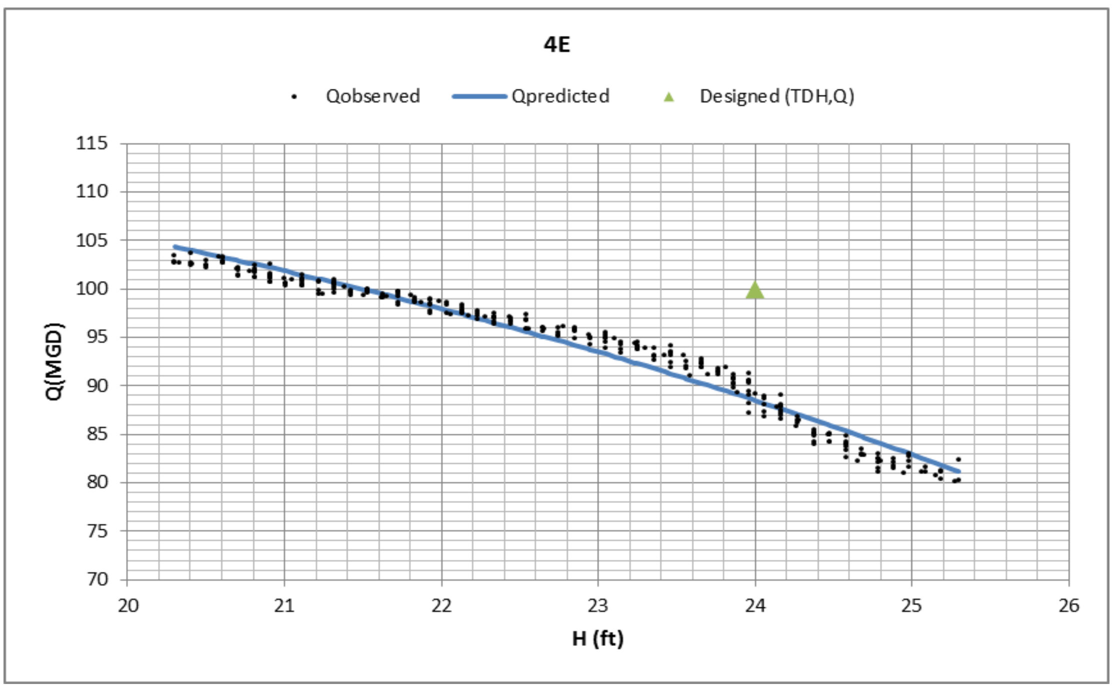


Figure 4-25. Discharge-static head curve for pump 4E

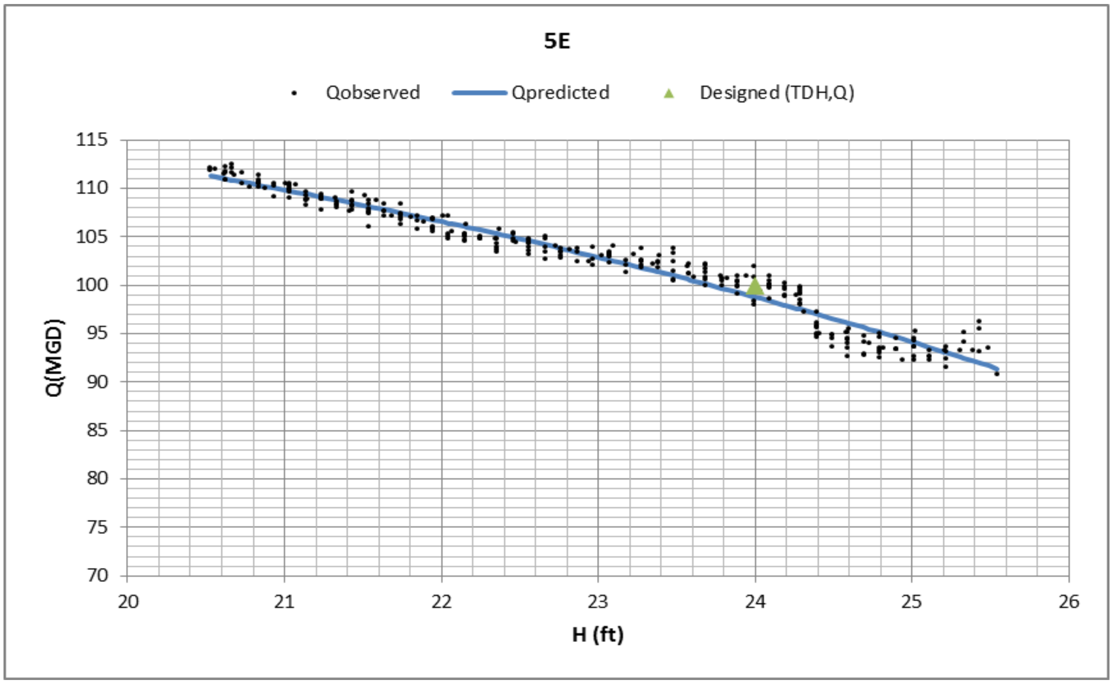


Figure 4-26. Discharge-static head curve for pump 5E

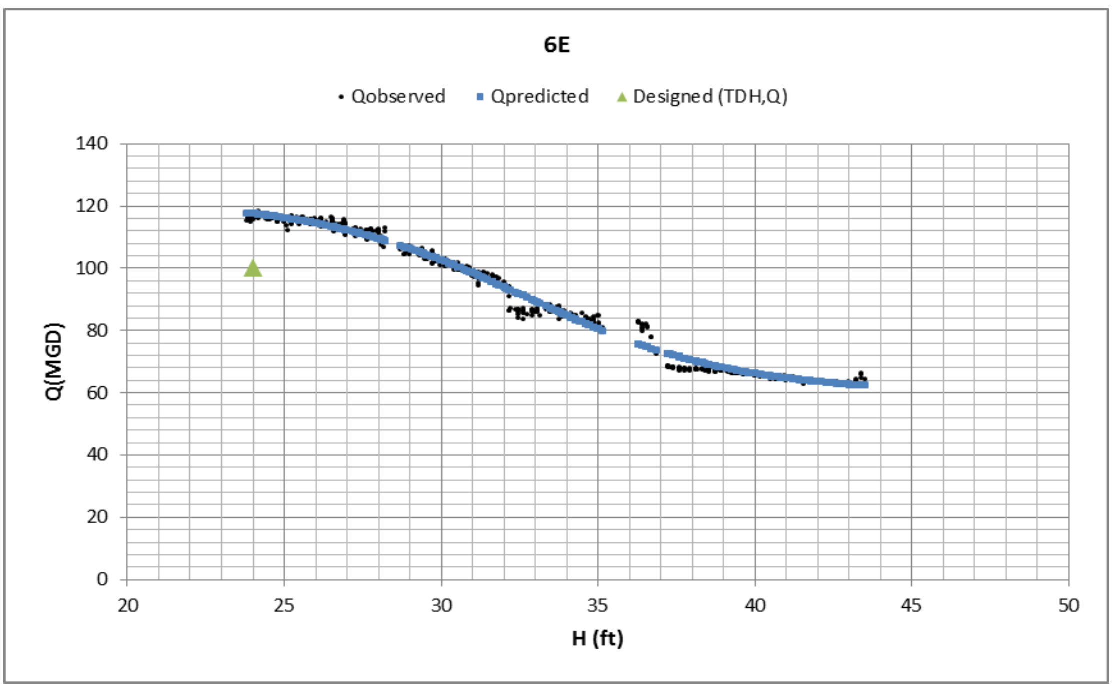


Figure 4-27. Discharge-static head curve for pump 6E

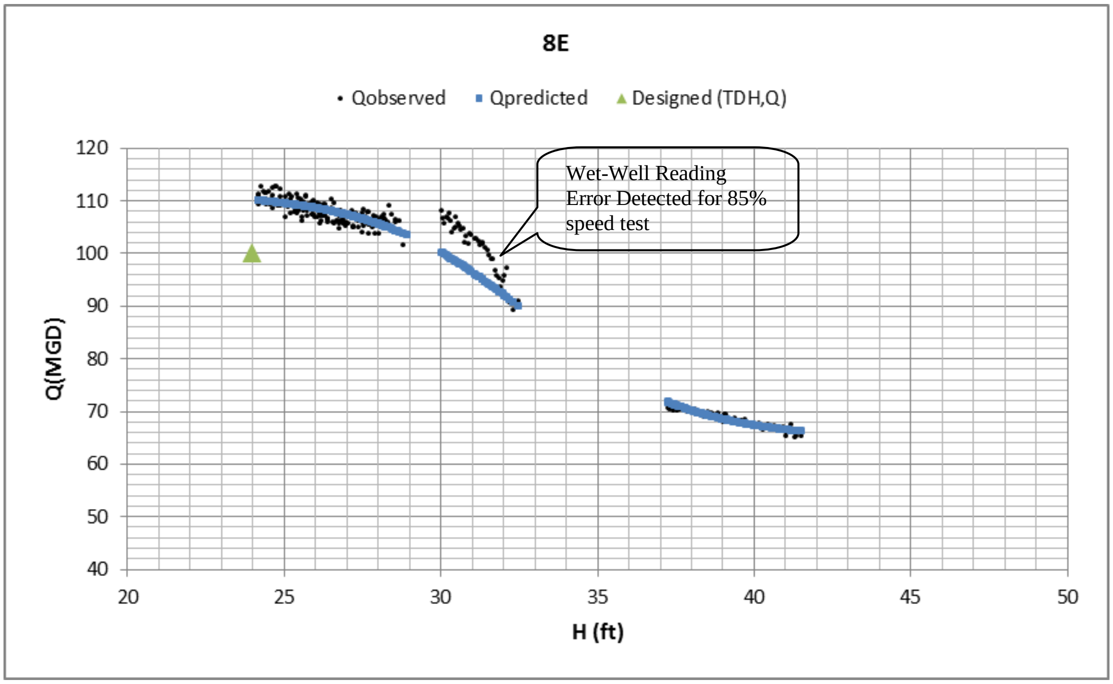


Figure 4-28. Full-speed discharge-static head curve for pump 8E

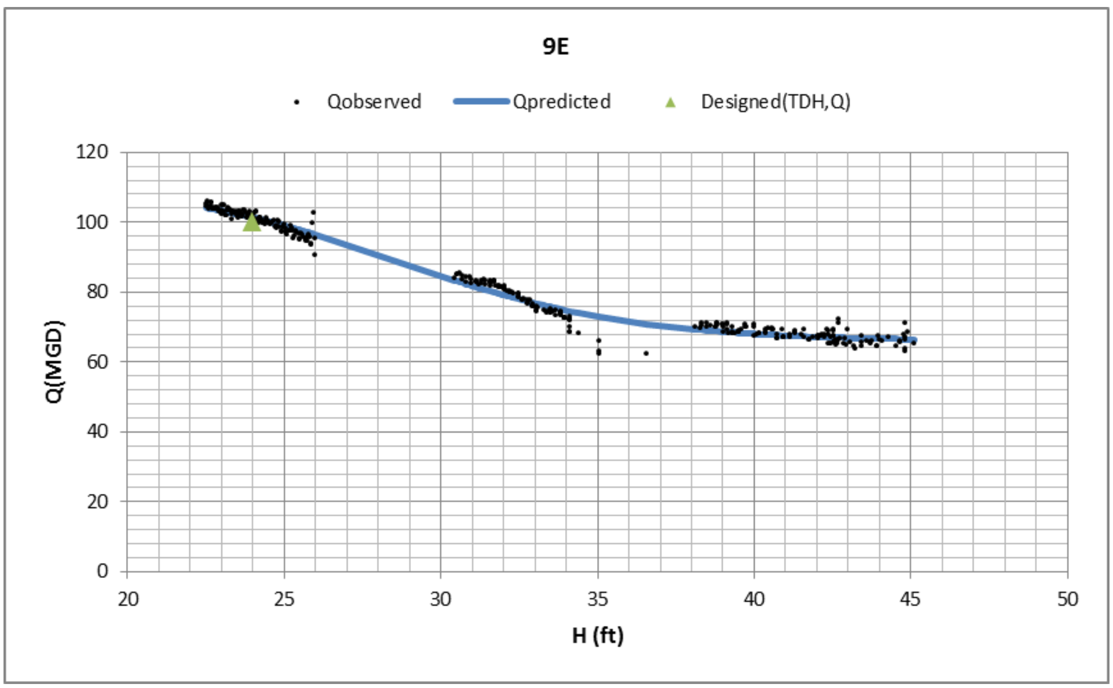


Figure 4-29. Full-speed discharge-static head curve for pump 9E

4.4 Application and Verification of Pumping Model

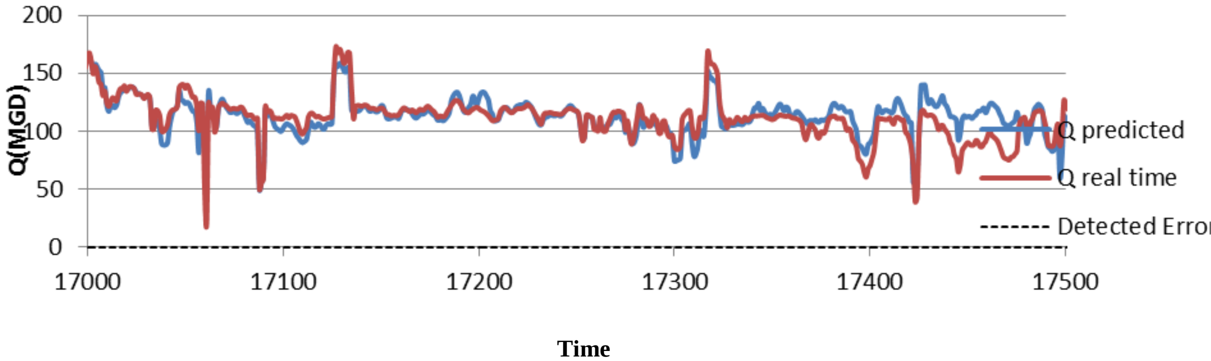
The complete time series of model verification results is attached in Appendix 6. In this section, time series of 500 hours picked from RWWPS1 and RWWPS2 are illustrated in Fig. 4-30 and Fig. 4-31 as examples. In Fig. 4-30(a) and Fig. 4-31(a), red curve represents the real time flow data obtained from PCS system and the blue curve represents the model prediction. If the dash line named detected error appears at the top of the graph, it means that error of original data is detected for the specific period and the simulation results are not reliable. Reliable simulation period is indicated by dashed line lies at 0. No data error is detected for this simulation period of RWWPS1 while the data problem detected for RWWPS2 is listed in Table 4-4. Pump on service based on MN point, speed of pumps with variable speed drive and wet-well level is illustrated in Fig. 4-30(b)-(d) and Fig. 4-31(b)-(d). Other detected data error for simulation includes

- Wet-well level stuck at -8ft (RWWPS1)
- Wet-well level stuck at -6ft (RWWPS2)
- Pump MN point shows 1 but no power consumption is observed
- Pump MN point shows 0 but power consumption is observed
- Pump MN point shows 1 for a variable speed pump but speed feedback is not available

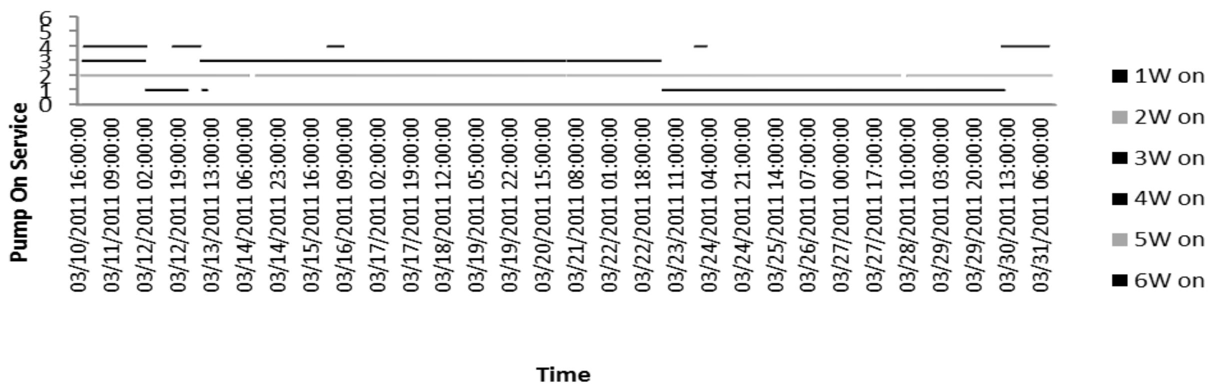
For the complete time series, the time period with detected error is listed in the table in Appendix 7. It should be noted that if no data error is detected, it doesn't necessarily mean that there is no problem of the flow prediction. For example, the flow measured by meter is lower than 100MGD during the period 3/29/2011 3:00:00-3/30/2011 13:00:00 for RWWPS1 [Fig. 4-30(a), (b)], which is much lower than usual if pump 1W and 2W(close to full speed) is operating. This may due to priming problem or other undetected error.

Table 4-4 Detected data error(RWWPS2)

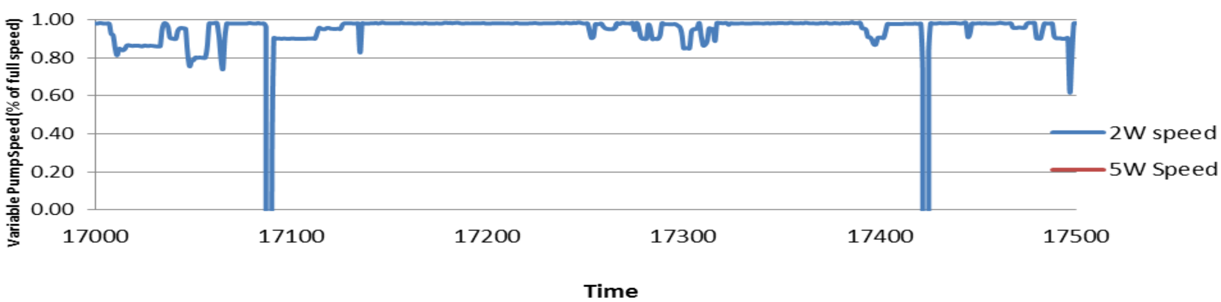
Data Error Period	Problem Description
6/23/2009 9:00:00 -06/27/2009 07:00:00	6E speed feedback
06/27/2009 19:00:00 -06/28/2009 02:00:00	6E speed feedback
06/28/2009 14:00:00 -06/29/2009 03:00:00	5E MN point
06/30/2009 16:00:00 -07/01/2009 01:00:00	5E MN point
06/30/2009 18:00:00 -06/30/2009 19:00:00	EPSF SCRN 1,4 ,7 EFF CHAN LVL stuck at -6ft



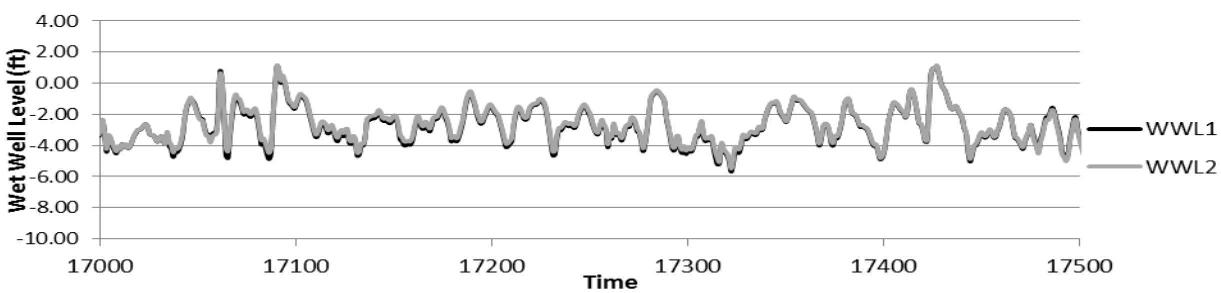
(a)



(b)

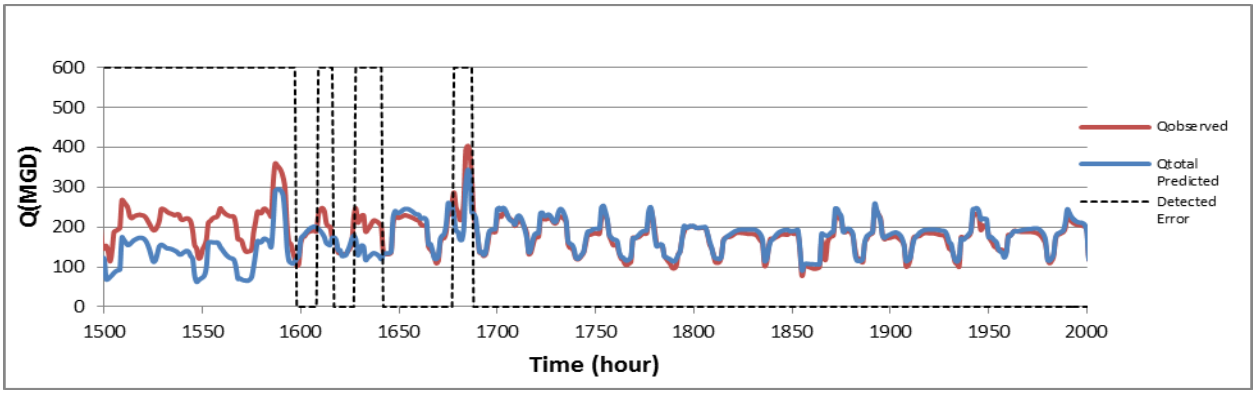


(c)

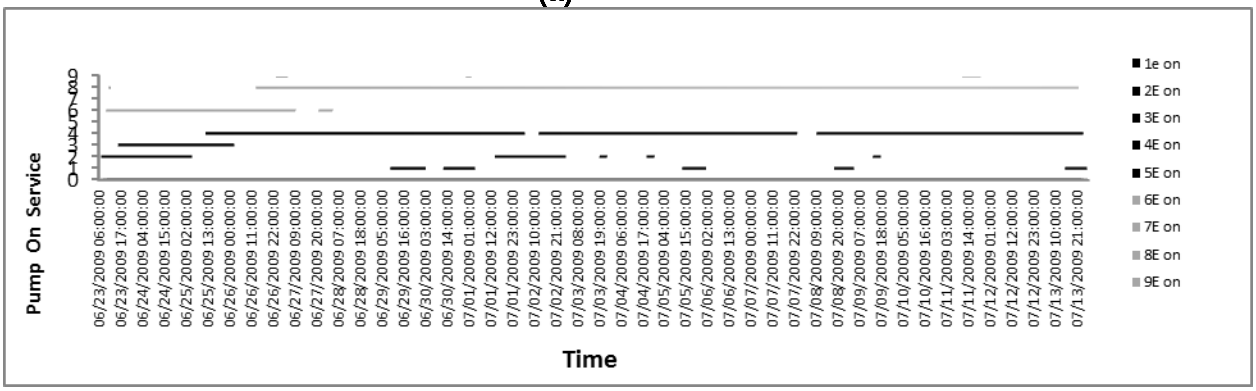


(d)

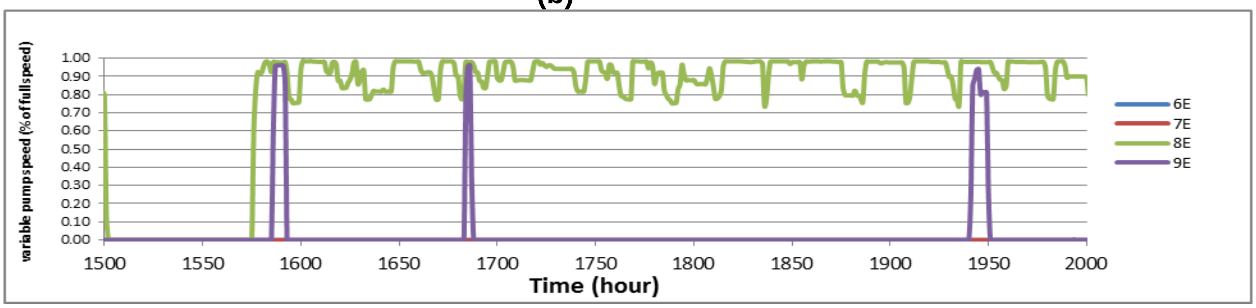
Figure 4-30. Example verification results for model predicting pump discharge based on static head (wet-well elevation) (RWWPS1)



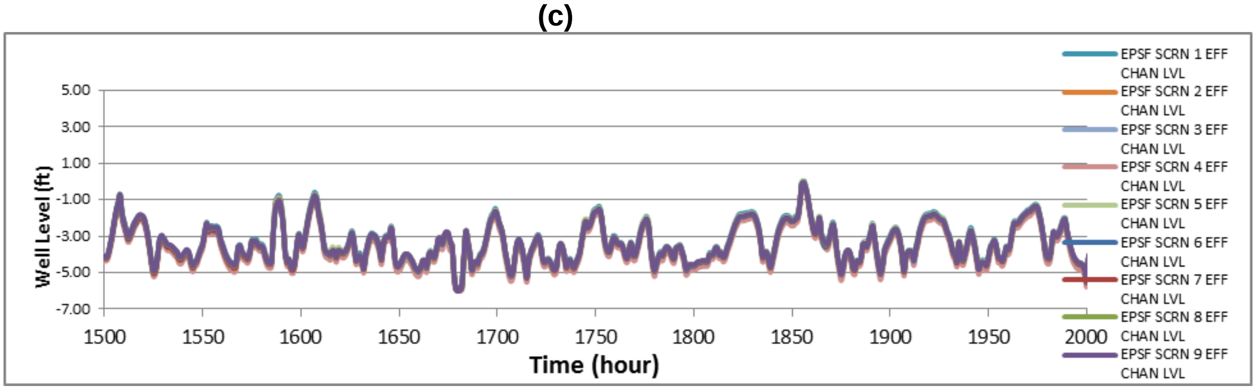
(a)



(b)



(c)



(d)

Figure 4-31. Example verification results for model predicting pump discharge based on static head (wet-well elevation) (RWWPS2)

Goodness of fit statistics based on the complete simulation period are reported in Table 4-5 for RWWPS1 &2. Excluding the time periods with detected error, the statistics are calculated for 18143 and 13944 hours for the RWWPS1 and 2 simulations, respectively. Correlation coefficient (R) and standard error ratio (Se/Sy) indicate good accuracy for both RWWPS1 and RWWPS2. Based on average error ratio, simulation results in under-prediction for RWWPS1by 2% and over-prediction for RWWPS2 by 8%. The possible reasons would be

- Instrument problem, including meter inaccuracy, PCS data dead band.
- Data random variation or undetected problematic data / outliers due to limited pump test and data length
- Model bias, including inaccuracy of curve fitting coefficient, neglecting storage between pump discharge and flow measurement, applying point measurement of wet-well elevation to calculate flow rate for entire hour.

Table 4-5 Goodness of fit statistics for RWWPS1&2 flow simulation

	R	R^2	Se	Sy	Se/Sy	Average Error	Average Error Ratio
RWWPS1	0.8217	0.6752	12.8259	20.3383	0.6306	-2.3785	-0.0217
RWWPS2	0.9637	0.9286	23.9873	52.4316	0.4575	15.7574	0.0809

4.5 Power Consumption Analysis

Based on the data from 1/1/2009 to 4/30/2011, it is observed that power consumption per MGD influent sewer pumped (KW/MGD) has a linear relationship with wet-well level, regardless of how many pumps are on service (Figs. 4-32 and 4-33). According to linear regression in Fig. 4-34, the power saving by raising wet-well level by one foot could be estimated for each pump station. Approximately

$ 58,640 / year could be saved by raising one foot of wet-well level for influent pumping.

RWWPS1:

Power saving $=0.2765\frac{KW}{MGD*ft} * 24\frac{hr}{day}*110\ MGD*365\frac{day}{yr} * \$0.07/KWh$

$= \$18,650/(yr*ft)$

110MGD: Average influent pumping flow rate of RWWPS1based on analysis period of 1/1/2009-4/30/2011

$0.07/KWh: Average power price based on 2010 PEPCO bill

RWWPS2:

Power saving $=0.3327\frac{KW}{MGD*ft} * 24\frac{hr}{day}*196\ MGD*365\frac{day}{yr} * \$0.07/KWh$

$= \$39,990/(yr*ft)$

196MGD: Average influent pumping flow rate of RWWPS2 based on analysis period of 1/1/2009-4/30/2011

Total saving per year by raising one foot of wet-well level

=$18,650/(yr*ft) + $39,990/(yr*ft) = $ 58,640 /(yr*ft)

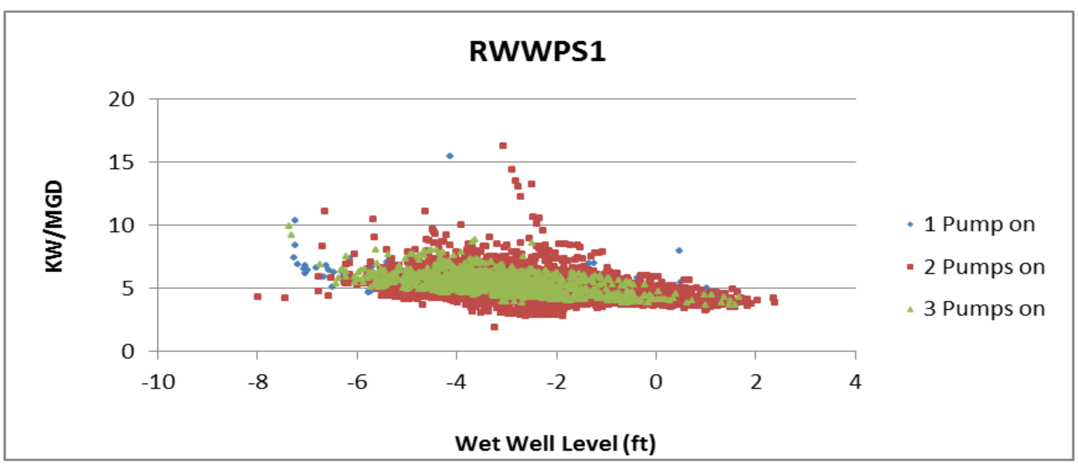


Figure 4-32. Power consumption per MGD influent pumped based on wet-well level(exclude transient period)-RWWPS1(1/1/2009-4/30/2011)

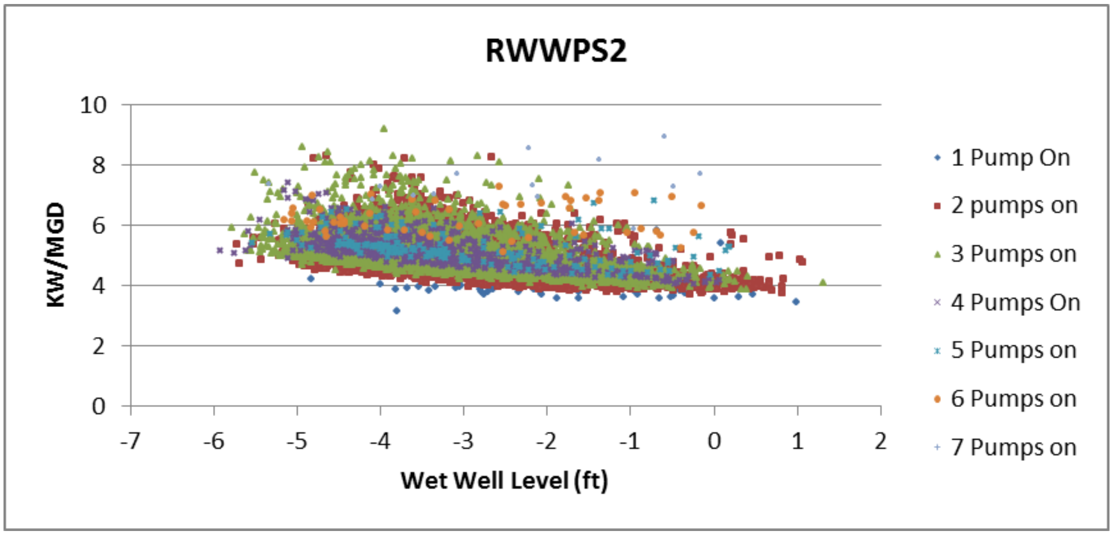


Figure 4-33. Power consumption per MGD influent pumped based on wet-well level(exclude transient period)-RWWPS2(1/1/2009-4/30/2011)

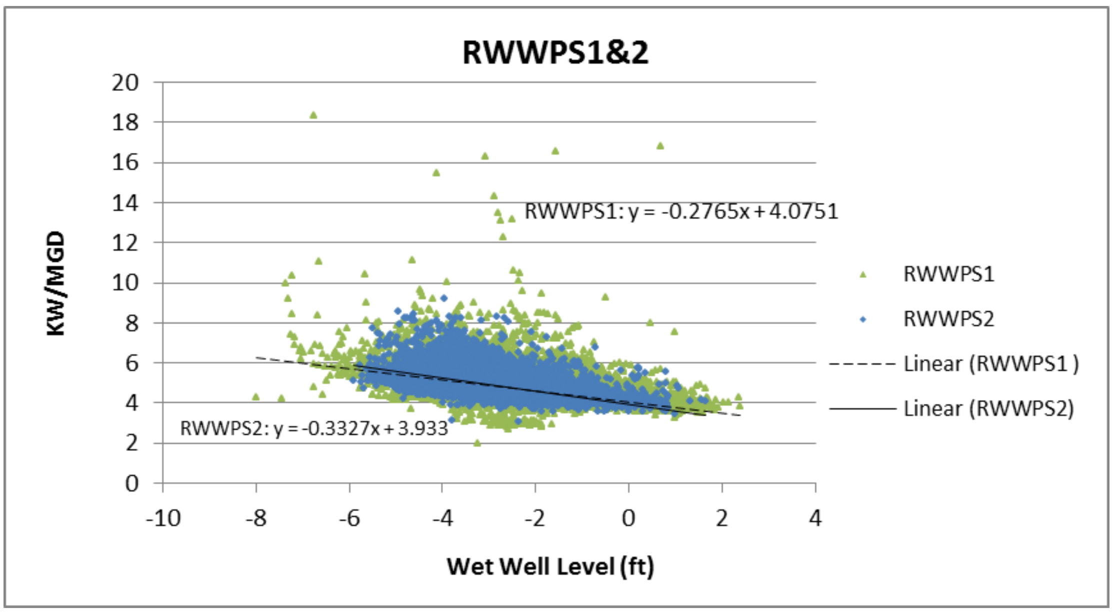


Figure 4-34. Linear regression -- RWWPS1&2 (1/1/2009-4/30/2011)

4.6 Influent Wet-Well Storage Estimation

4.6.1 Rate of Wet-Well Rise during Influent Pumping Outage

In order to cooperate with maintenance of the downstream filter influent forebay, influent pumping was shut down from 6:08:00 am to 8:23:00 am on 6/27/2011. The wet-well level rose from -5.5ft to 1.8ft within 2 hour and 15minutes (Fig. 4-35). Assuming a constant inflow during this period allows an estimation of the change in wet-well storage as the water surface rises, and from this, an estimate of the stage-storage curve for the wet-well. Influent flow rate is assumed to be 187MGD during the pumping outage based on total influent curve and WWL1 in Fig. 4-35. It should be noted that 47MGD flow rate reading is observed for east influent, which is believed to be meter lower range error since all pumps are shut down. Duration of wet-well rise and estimated storage according to wet-well level are illustrated in Fig. 4-36 and Fig. 4-37. The average storage from -5 ft to 2ft is around 2.6 MG/ft. The estimated storage increases with the wet-well elevation (Fig. 4-37).

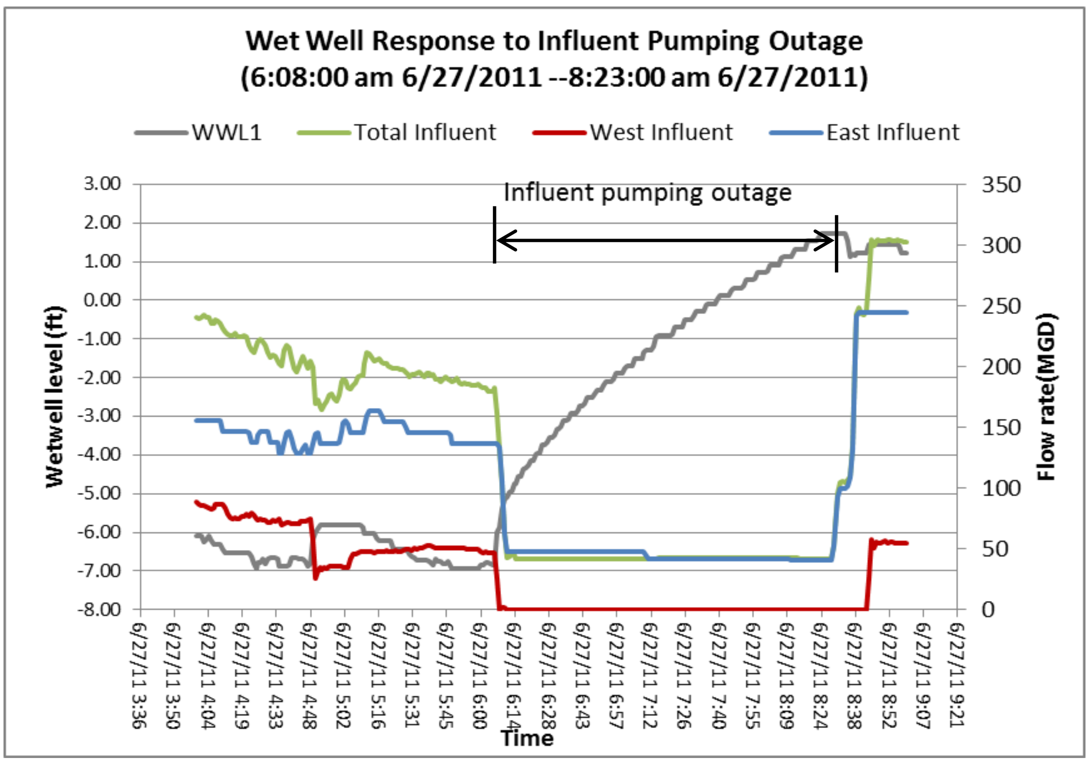


Figure 4-35. Wet-well response to influent outage (6/27/2011)

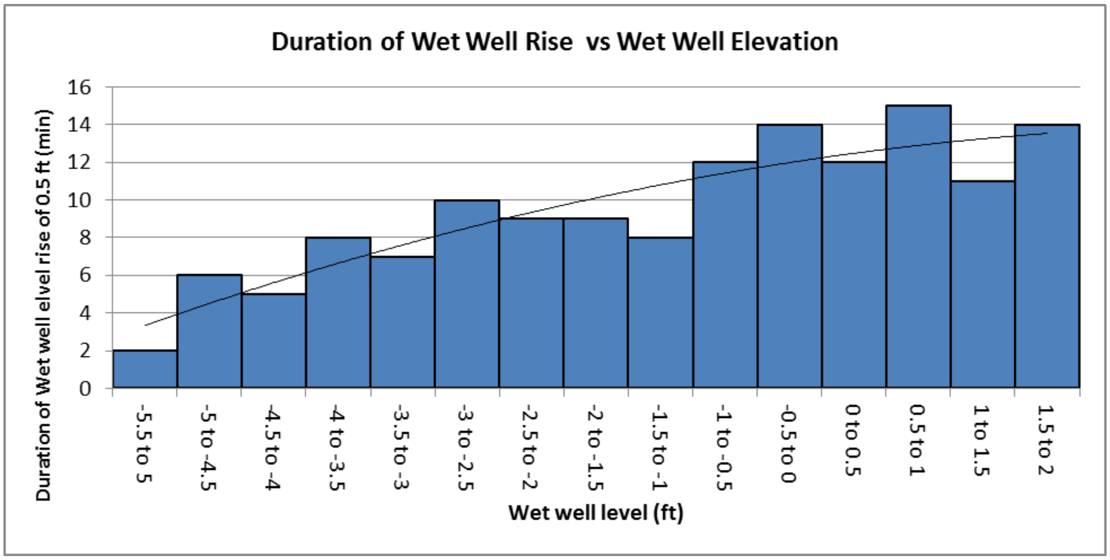


Figure 4-36. Duration of wet-well rise (6/27/2011)

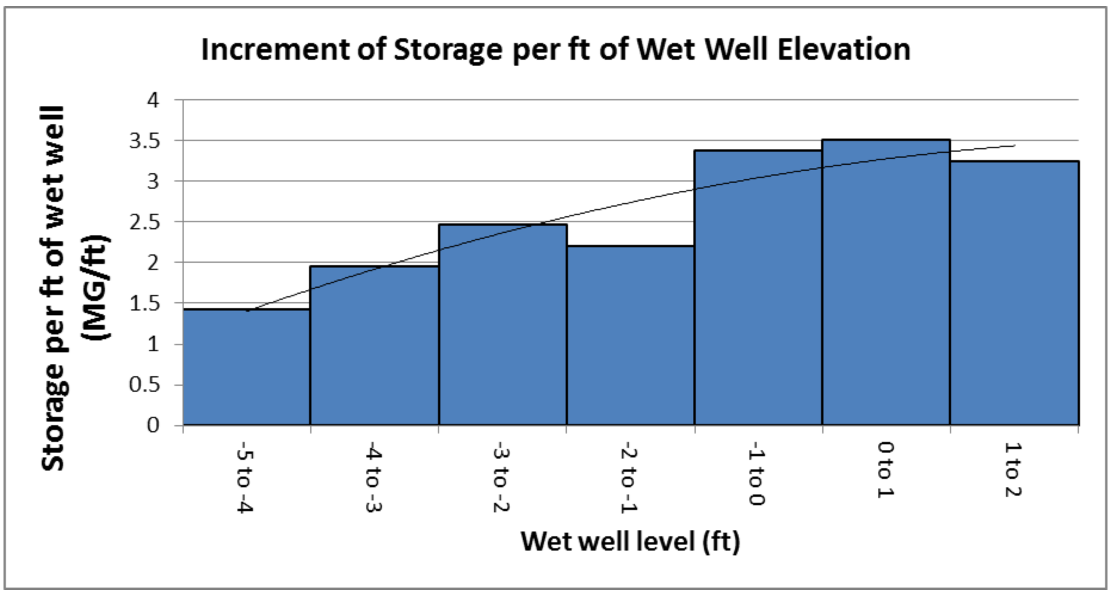


Figure 4-37. Increment of storage per ft of wet-well elevation (6/27/2011)

4.6.2 **Rate of Wet-Well Rise during Power Outage**

During an unexpected power outage of RWWPS1 on 3/13/ 2011, the wet-well level rose from -1.4ft to 1.3ft from 5:29:00 am to 6:42:00 am (Fig. 4-38), providing an opportunity to confirm the estimates described above. Because no significant wet-well level change is observed for about 160 min before the power outage, it is assumed that total influent rate is equal to the pumping rate, which is 285MGD. During the power outage, pump discharge of RWWPS2 (East) was about 96 MGD. It is equivalent to a net addition of 189 MGD (no outflow) to the wet-well during this period. The wet-well responded to a net inflow rate of 189 MGD by rising 2.7 feet within 73 minutes. In order to verify the estimation of storage in Section 4.6.1, duration, rate of rise and estimated storage based on influent pumping outage of 3/13/2011 and 6/27/2011 are compared in Fig. 4-39- Fig. 4-41. A storage of 3.5 MG/ft is estimated for wet-well level between -1 ft and +1 ft for both observation (Table 4-6).

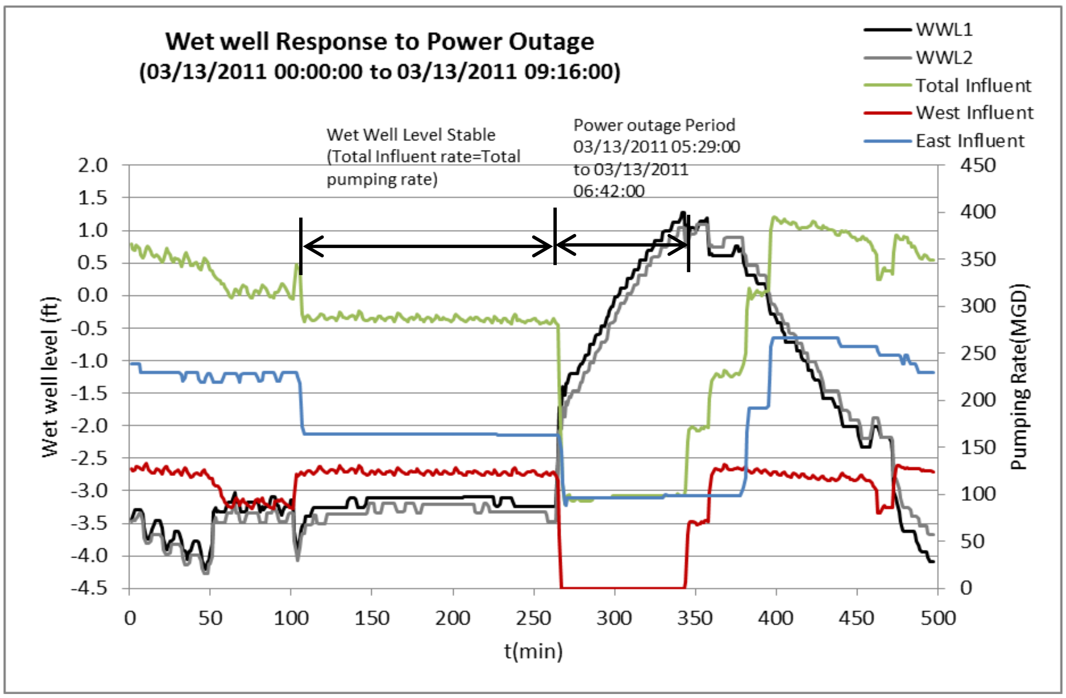


Figure 4-38. Wet-well response to a power outage (3/13/2011)

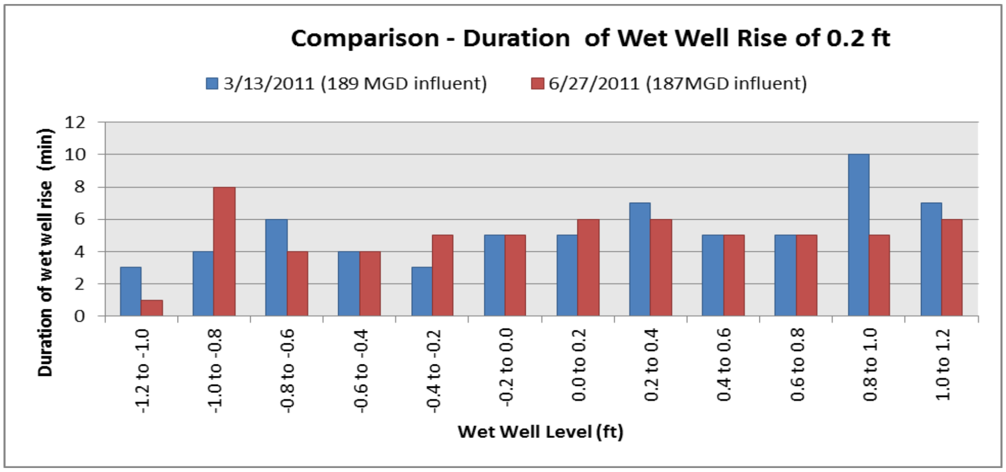


Figure 4-39. Comparison of duration of wet-well rise

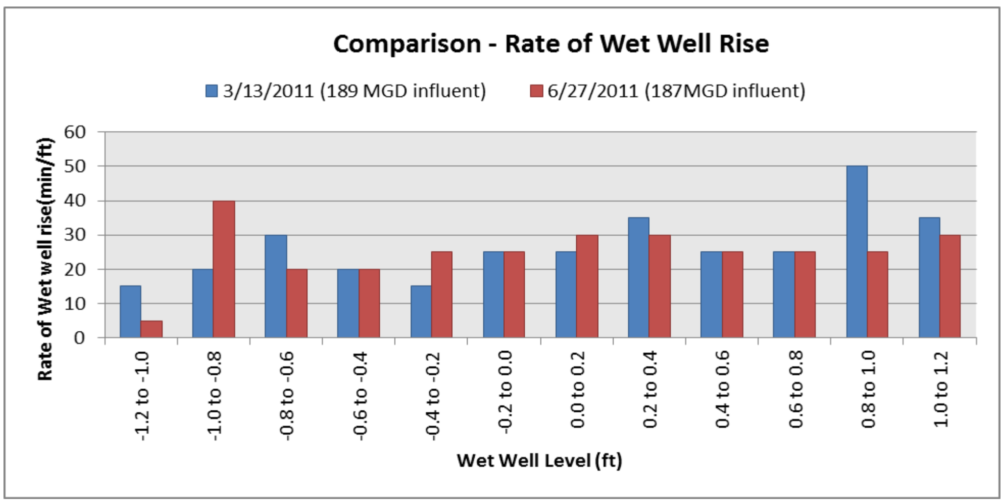


Figure 4-40. Comparison of rate of wet-well rise

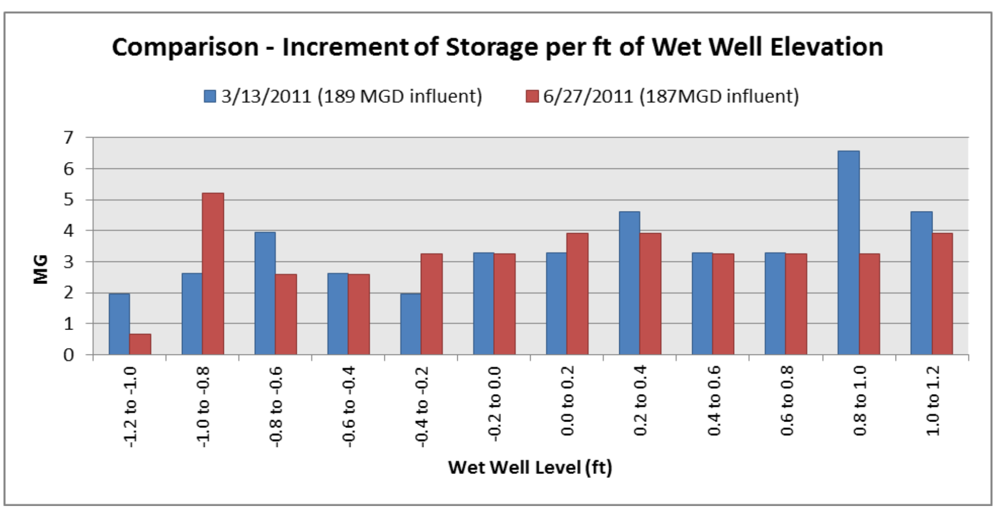


Figure 4-41. Comparison of increment of storage per ft of wet-well elevation

Table 4-6 Comparison of storage estimation

	Average Storage per ft (MG/ft)	
Wet-well Level (ft)	3/13/2011 (189 MGD influent)	6/27/2011 (187MGD influent)
-1 to 0	2.89	3.38
0 to 1	4.20	3.51
-1 to 1	3.54	3.44

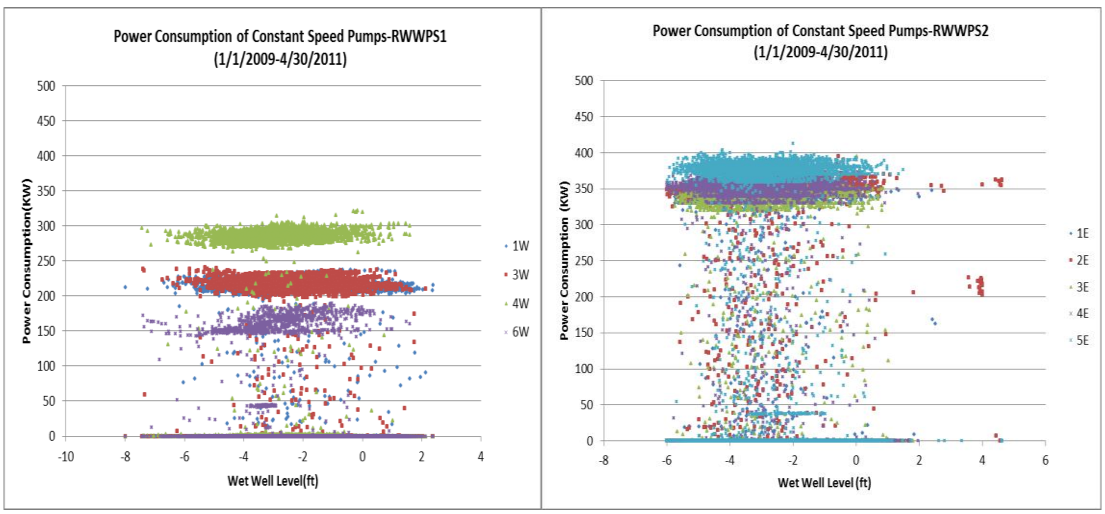
4.6.3 Power Consumption Prediction for Raw Wastewater Pumping

As observed in Fig. 4-42, power consumption of constant speed pumps could be represented by an average value regardless of wet-well level; these values are listed in Table 4-7. In Fig. 4-42(a), most scatters lower than 140KW result from the trensient period. For example, if pump is on for half an hour during the time step of one hour, power consumption would be an average of zero and the actual on-service KW value. The same reasoning applies to the power consumption value lower than 310KW in Fig. 4-42(b). Neglecting this transient scatter, the range from lowest to highest power consumption for each constant speed pump is around 40KW for both RWWPS1&2.

For variable speed pumps, power consumption shows a linear relationship with speed (Fig. 4-43). For normal operation, pump speed would be set for over 60% of the full speed. For example, it is observed in the pump test of RWWPS1 that flow drop to zero when pump 2W is operated at 50% of its full speed. In order to get a better accuracy for the normal operation range, non-zero intercept equation KW=a*n+b is fit to only the data with relative speed greater than 50% (Fig. 4-44, Table 4-7). Users must be careful not to apply the equations outside of this range.

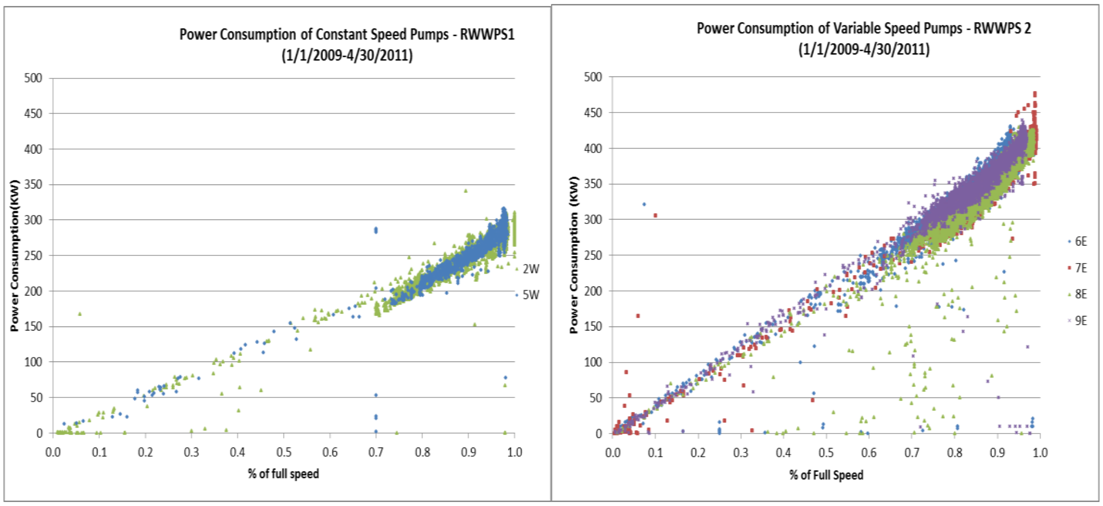
Power prediction graphical analysis is illustrated in Fig. 4-45(RWWPS1) and

Fig. 4-46(RWWPS2), compared with the real time data from PCS system. In this case, power consumption is calculated from flow rate for each pump, based on the estimated average power consumption (for fixed speed pumps) and consumption as a linear function of speed (for variable speed pumps). Similar to flow prediction, the time periods with detected error are listed in Table 4-8; these periods are not counted in the Goodness-of-Fit statistics reported in Table 4-9. Based on graphical analysis and Goodness-of -Fit statistics, good prediction accuracy is observed for both RWWPS1 and RWWPS2.



(a) (b)

Figure 4-42. Power consumption of constant speed pumps



(a) (b)

Figure 4-43. Power consumption of variable speed pumps

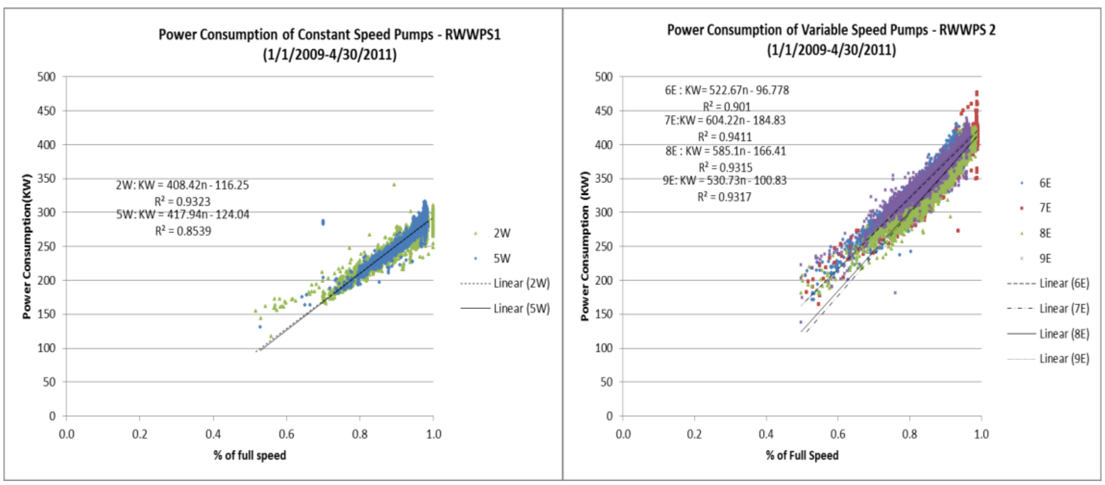
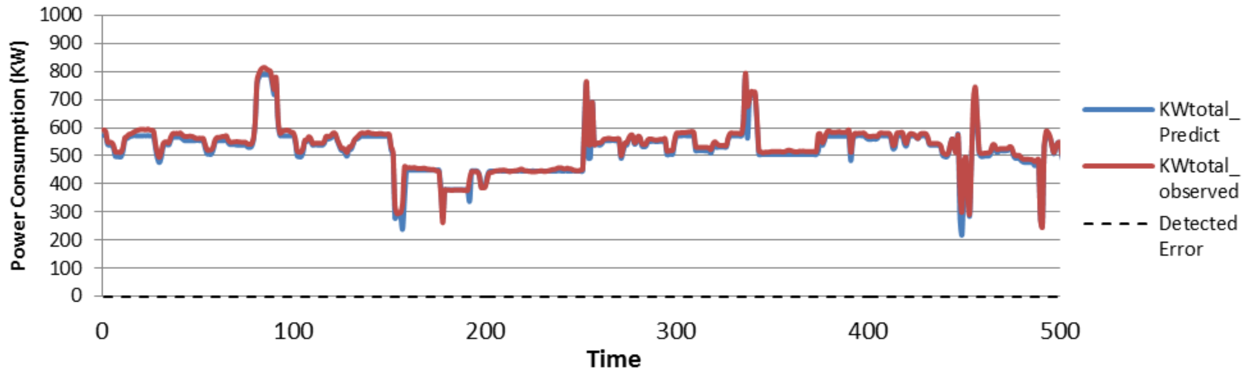


Figure 4-44. Linear regression of power consumption for variable speed pumps

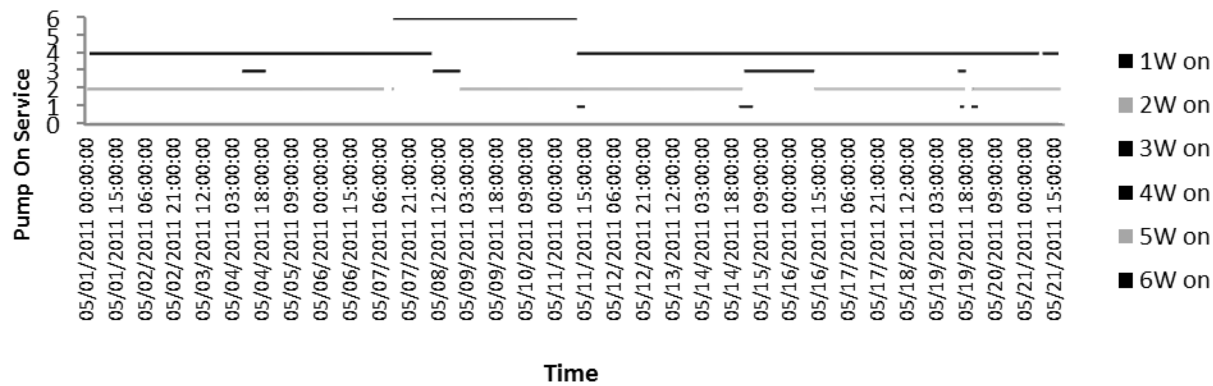
Table 4-7 Power prediction

	RWWPS1		RWWPS2	
Constant	1W	212.62	1E	338.12
	3W	217.58	2E	352.39
	4W	287.04	3E	338.69
	6W	161.75	4E	350.41
			5E	375.49
Variable	2W	KW= 408.42(n-0.5)+87.96	6E	KW = 552.67(n-0.5) +179.56
	5W	KW=417.94(n-0.5) + 84.93	7E	KW= 604.22(n-0.5) +117.28
			8E	KW= 585.1(n-0.5) +126.14
			9E	KW= 530.73(n-0.5)+ 164.54

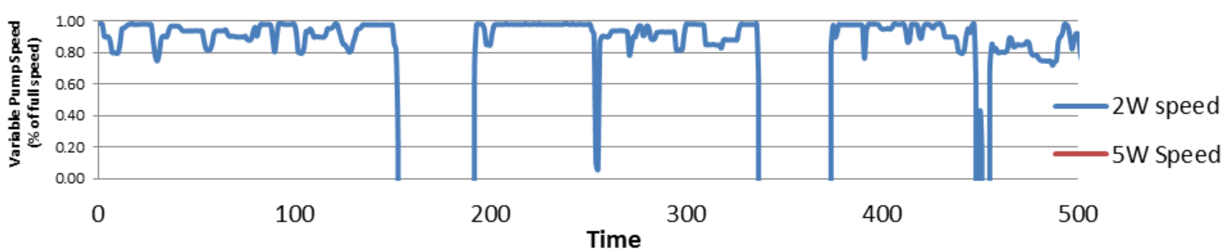
Note: Variable-speed power use equations apply only for relative speed greater than or equal to 0.5.



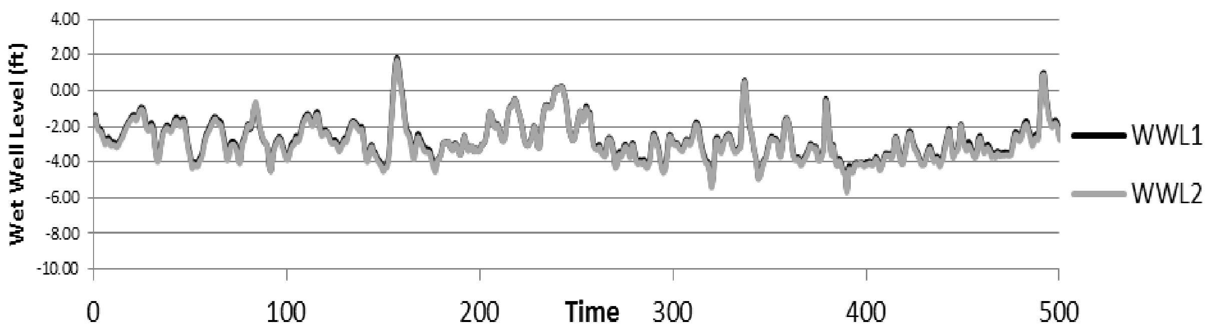
Power Consumption (KW)
1000
900
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
Time
KWtotal_Predict
KWtotal_observed
Detected Error



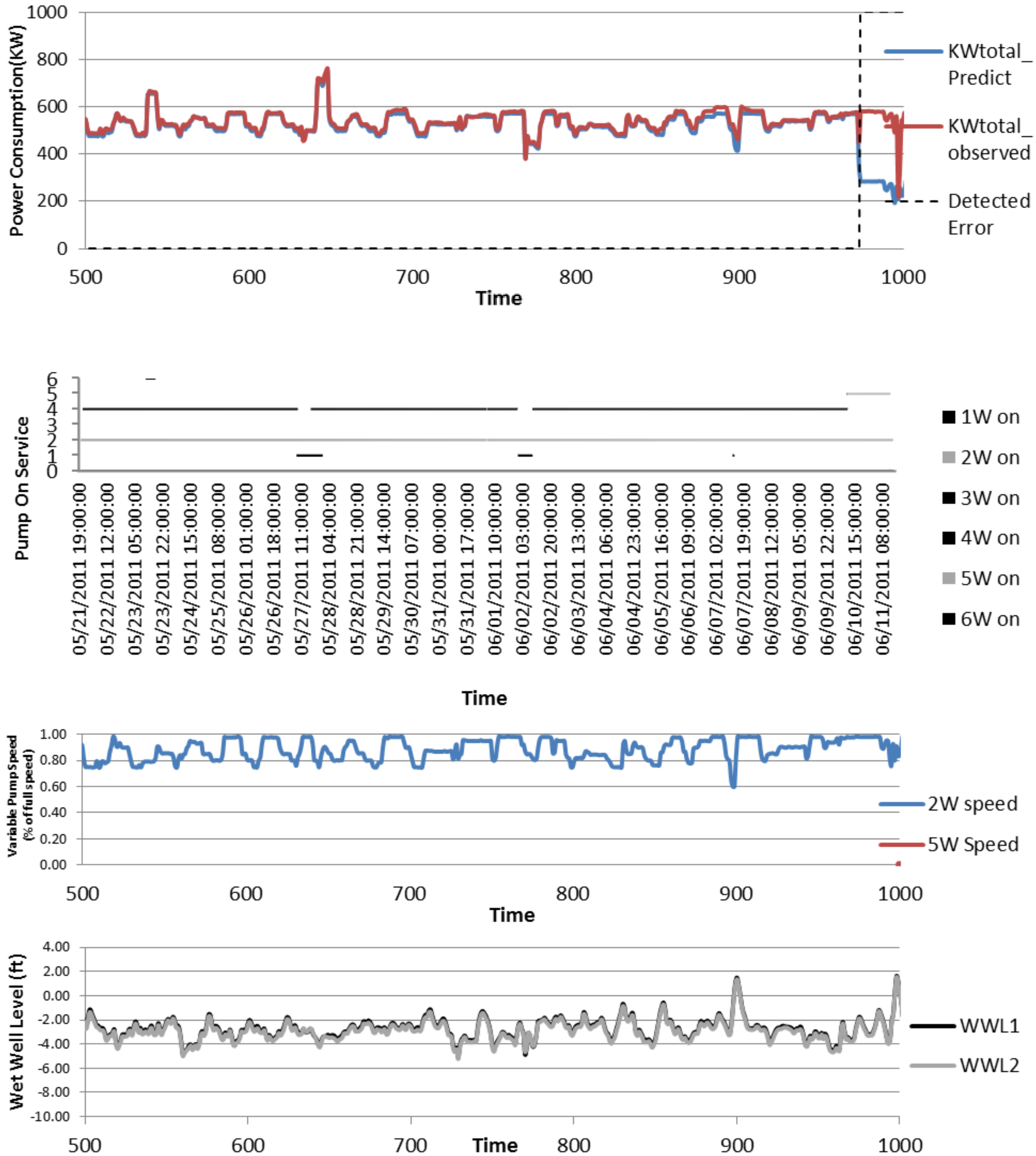
Pump On Service
6
5
4
3
2
1
0
05/01/2011 00:00:00
05/01/2011 15:00:00
05/02/2011 06:00:00
05/02/2011 21:00:00
05/03/2011 12:00:00
05/04/2011 03:00:00
05/04/2011 18:00:00
05/05/2011 09:00:00
05/06/2011 00:00:00
05/06/2011 15:00:00
05/07/2011 06:00:00
05/07/2011 21:00:00
05/08/2011 12:00:00
05/09/2011 03:00:00
05/09/2011 18:00:00
05/10/2011 09:00:00
05/11/2011 00:00:00
05/11/2011 15:00:00
05/12/2011 06:00:00
05/12/2011 21:00:00
05/13/2011 12:00:00
05/14/2011 03:00:00
05/14/2011 18:00:00
05/15/2011 09:00:00
05/16/2011 00:00:00
05/16/2011 15:00:00
05/17/2011 06:00:00
05/17/2011 21:00:00
05/18/2011 12:00:00
05/19/2011 03:00:00
05/19/2011 18:00:00
05/20/2011 09:00:00
05/21/2011 00:00:00
05/21/2011 15:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on



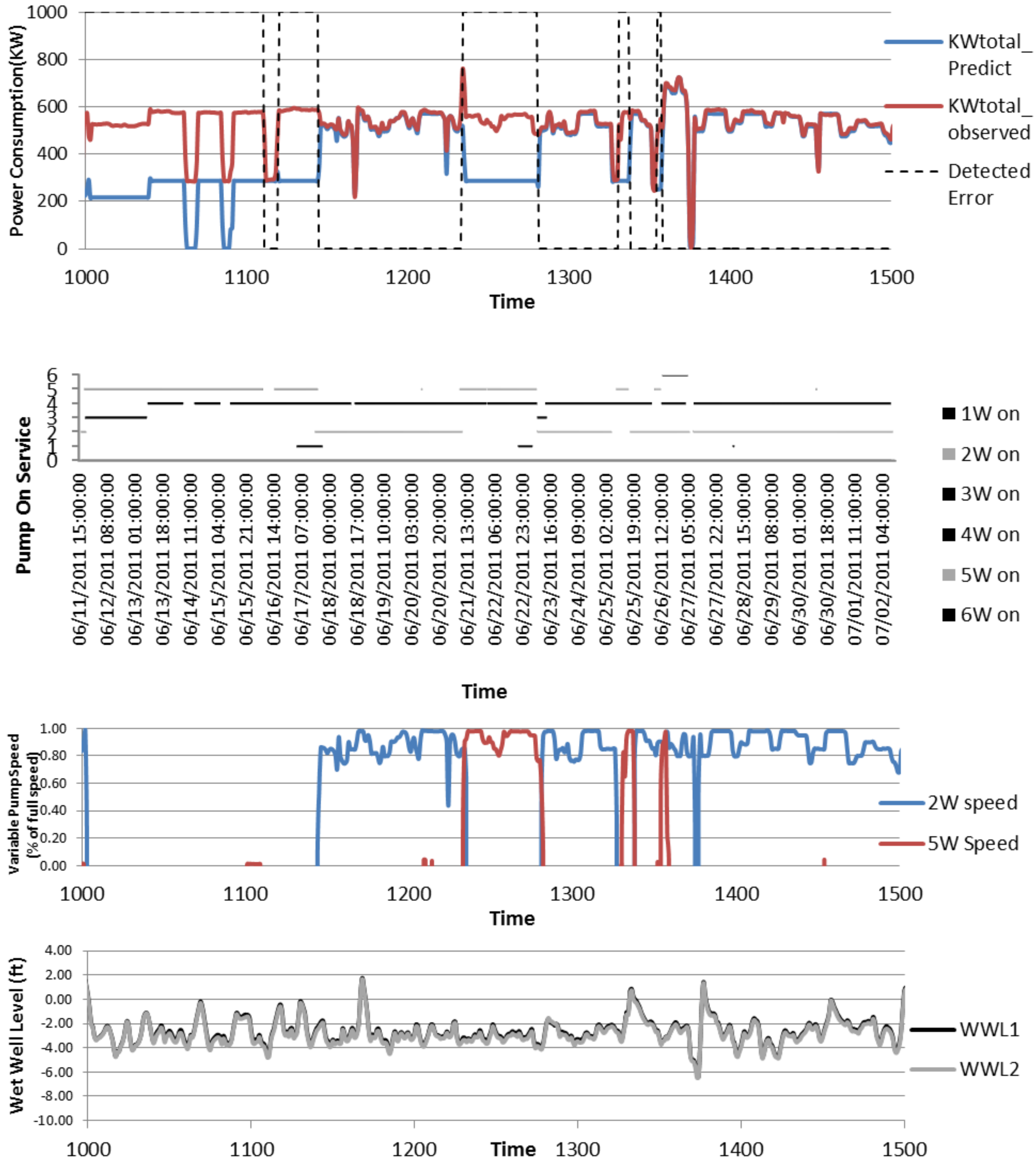
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
0
100
200
300
400
500
Time
2W speed
5W Speed



Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
0
100
200
Time
300
400
500
WWL1
WWL2



Power Consumption(KW)
1000
800
600
400
200
0
500
600
700
800
900
1000
Time
KWtotal_Predict
KWtotal_observed
Detected Error
Pump On Service
6
5
4
3
2
1
0
05/21/2011 19:00:00
05/22/2011 12:00:00
05/23/2011 05:00:00
05/23/2011 22:00:00
05/24/2011 15:00:00
05/25/2011 08:00:00
05/26/2011 01:00:00
05/26/2011 18:00:00
05/27/2011 11:00:00
05/28/2011 04:00:00
05/28/2011 21:00:00
05/29/2011 14:00:00
05/30/2011 07:00:00
05/31/2011 00:00:00
05/31/2011 17:00:00
06/01/2011 10:00:00
06/02/2011 03:00:00
06/02/2011 20:00:00
06/03/2011 13:00:00
06/04/2011 06:00:00
06/04/2011 23:00:00
06/05/2011 16:00:00
06/06/2011 09:00:00
06/07/2011 02:00:00
06/07/2011 19:00:00
06/08/2011 12:00:00
06/09/2011 05:00:00
06/09/2011 22:00:00
06/10/2011 15:00:00
06/11/2011 08:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
500
600
700
800
900
1000
Time
2W speed
5W Speed
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
500
600
700
Time
800
900
1000
WWL1
WWL2


Power Consumption(KW)
1000
800
600
400
200
0
1000
1100
1200
1300
1400
1500
Time
KWtotal_ Predict
KWtotal_ observed
Detected Error
Pump On Service
6
5
4
3
2
1
0
06/11/2011 15:00:00
06/12/2011 08:00:00
06/13/2011 01:00:00
06/13/2011 18:00:00
06/14/2011 11:00:00
06/15/2011 04:00:00
06/15/2011 21:00:00
06/16/2011 14:00:00
06/17/2011 07:00:00
06/18/2011 00:00:00
06/18/2011 17:00:00
06/19/2011 10:00:00
06/20/2011 03:00:00
06/20/2011 20:00:00
06/21/2011 13:00:00
06/22/2011 06:00:00
06/22/2011 23:00:00
06/23/2011 16:00:00
06/24/2011 09:00:00
06/25/2011 02:00:00
06/25/2011 19:00:00
06/26/2011 12:00:00
06/27/2011 05:00:00
06/27/2011 22:00:00
06/28/2011 15:00:00
06/29/2011 08:00:00
06/30/2011 01:00:00
06/30/2011 18:00:00
07/01/2011 11:00:00
07/02/2011 04:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on
Variable PumpSpeed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
1000
1100
1200
1300
1400
1500
Time
2W speed
5W Speed
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
1000
1100
1200
Time
1300
1400
1500
WWL1
WWL2

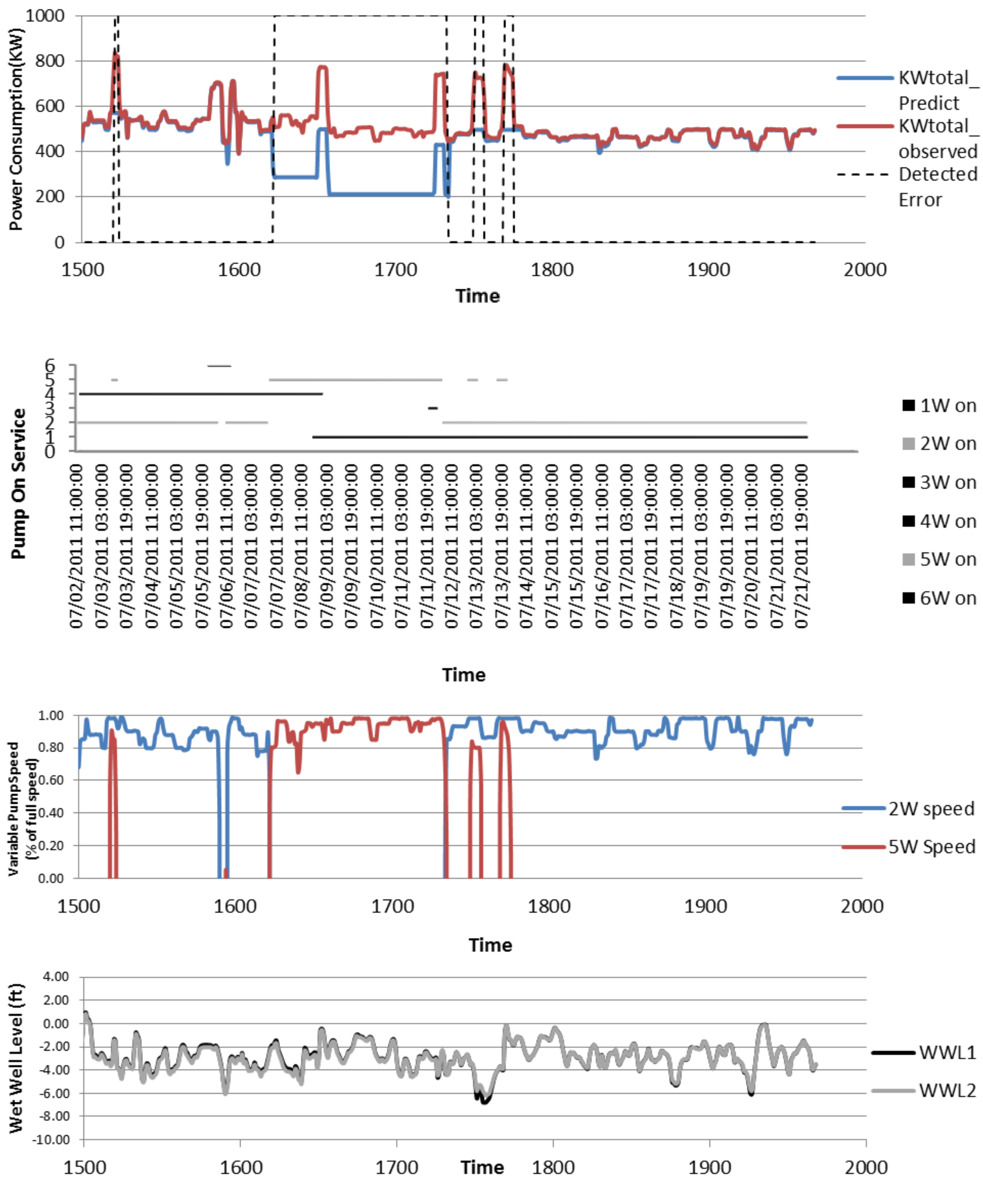
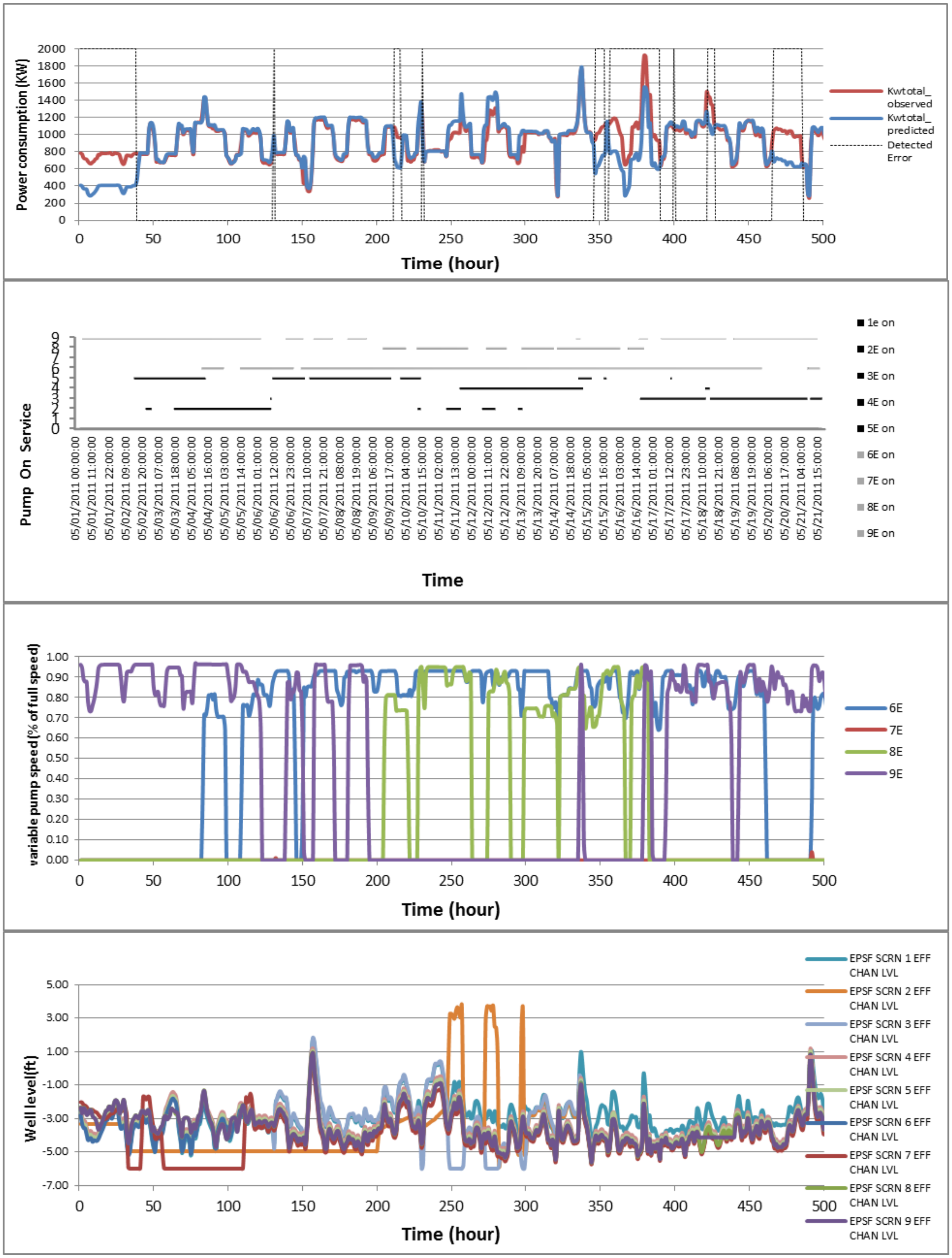
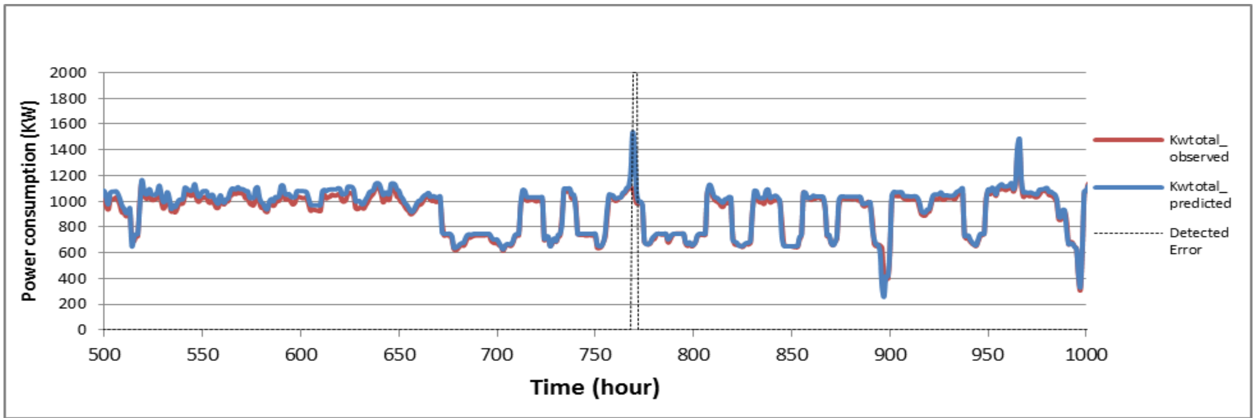
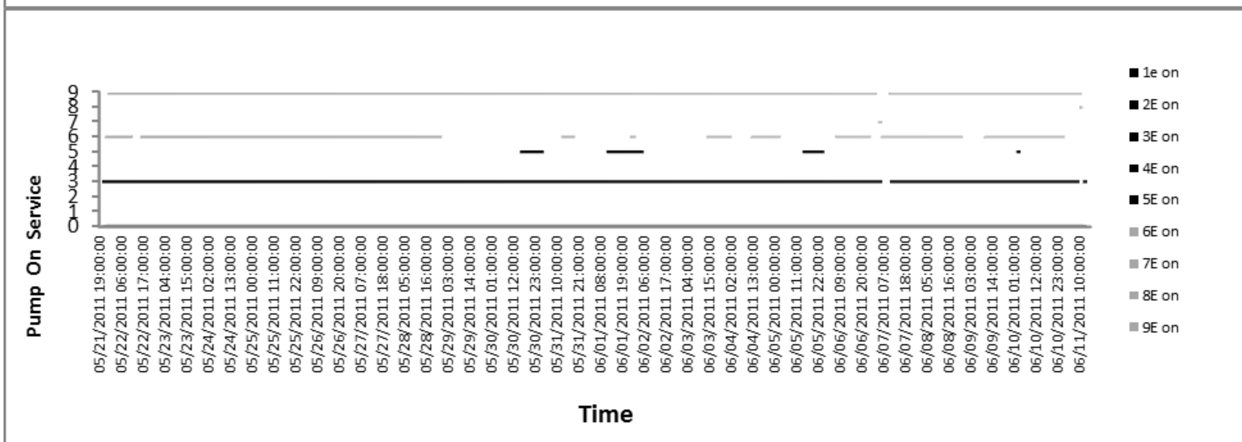
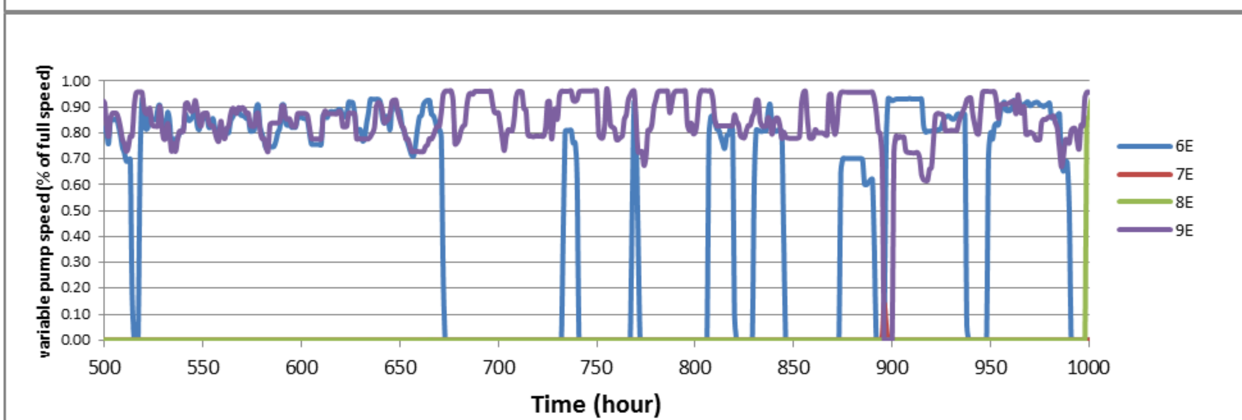


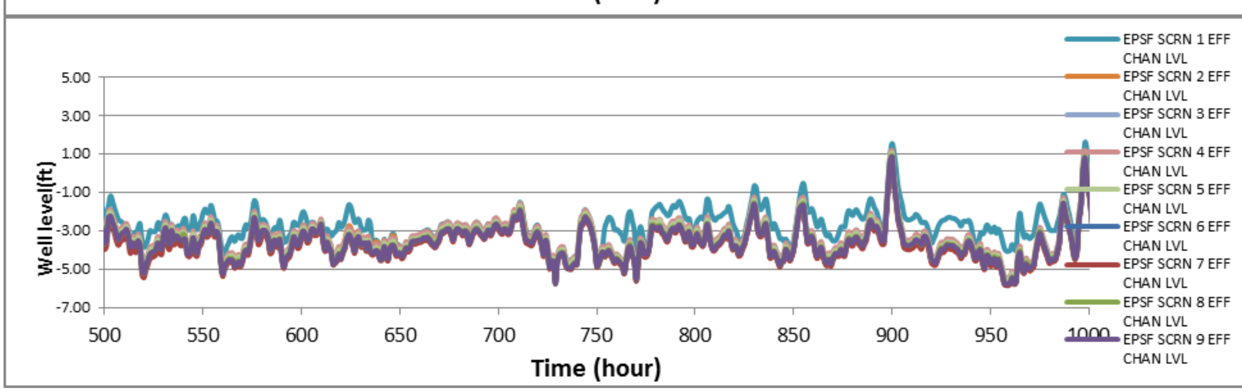
Figure 4-45. Graphical analysis of power prediction (RWWPS1)

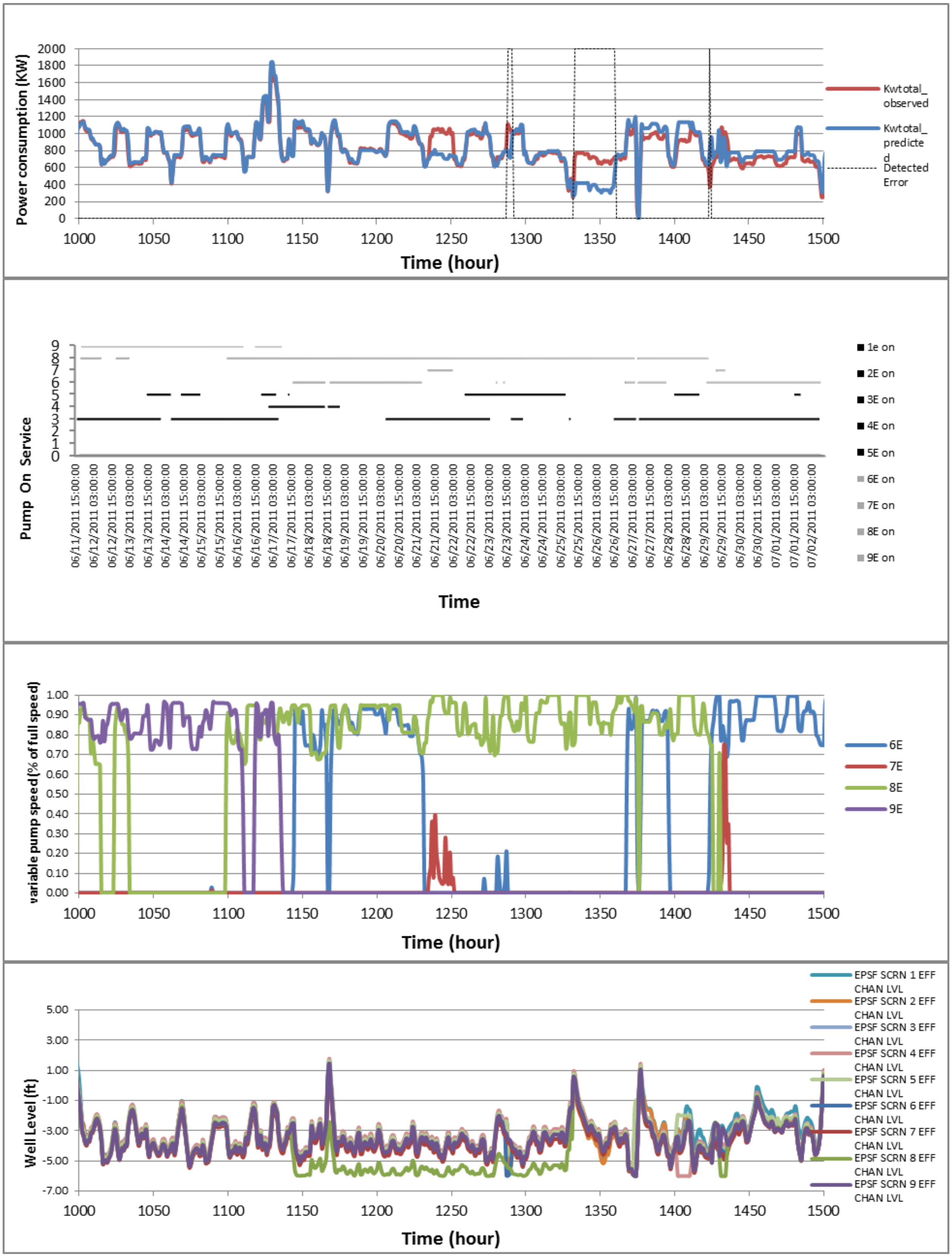

Power consumption (KW)
Time (hour)
Kwtotal_observed
Kwtotal_predicted
Detected Error
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Well level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Power consumption (KW)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
500
550
600
650
700
750
800
850
900
950
1000
Time (hour)
Kwtotal_ observed
Kwtotal_ predicted
Detected Error


Pump On Service
9
8
7
6
5
4
3
2
1
0
05/21/2011 19:00:00
05/22/2011 06:00:00
05/22/2011 17:00:00
05/23/2011 04:00:00
05/23/2011 15:00:00
05/24/2011 02:00:00
05/24/2011 13:00:00
05/25/2011 00:00:00
05/25/2011 11:00:00
05/25/2011 22:00:00
05/26/2011 09:00:00
05/26/2011 20:00:00
05/27/2011 07:00:00
05/27/2011 18:00:00
05/28/2011 05:00:00
05/28/2011 16:00:00
05/29/2011 03:00:00
05/29/2011 14:00:00
05/30/2011 01:00:00
05/30/2011 12:00:00
05/30/2011 23:00:00
05/31/2011 10:00:00
05/31/2011 21:00:00
06/01/2011 08:00:00
06/01/2011 19:00:00
06/02/2011 06:00:00
06/02/2011 17:00:00
06/03/2011 04:00:00
06/03/2011 15:00:00
06/04/2011 02:00:00
06/04/2011 13:00:00
06/05/2011 00:00:00
06/05/2011 11:00:00
06/05/2011 22:00:00
06/06/2011 09:00:00
06/06/2011 20:00:00
06/07/2011 07:00:00
06/07/2011 18:00:00
06/08/2011 05:00:00
06/08/2011 16:00:00
06/09/2011 03:00:00
06/09/2011 14:00:00
06/10/2011 01:00:00
06/10/2011 12:00:00
06/10/2011 23:00:00
06/11/2011 10:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on


variable pump speed(% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
500
550
600
650
700
750
800
850
900
950
1000
Time (hour)
6E
7E
8E
9E


Well level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
500
550
600
650
700
750
800
850
900
950
1000
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Power consumption (KW)
Time (hour)
Kwtotal_observed
Kwtotal_predicted
Detected Error
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Well Level (ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

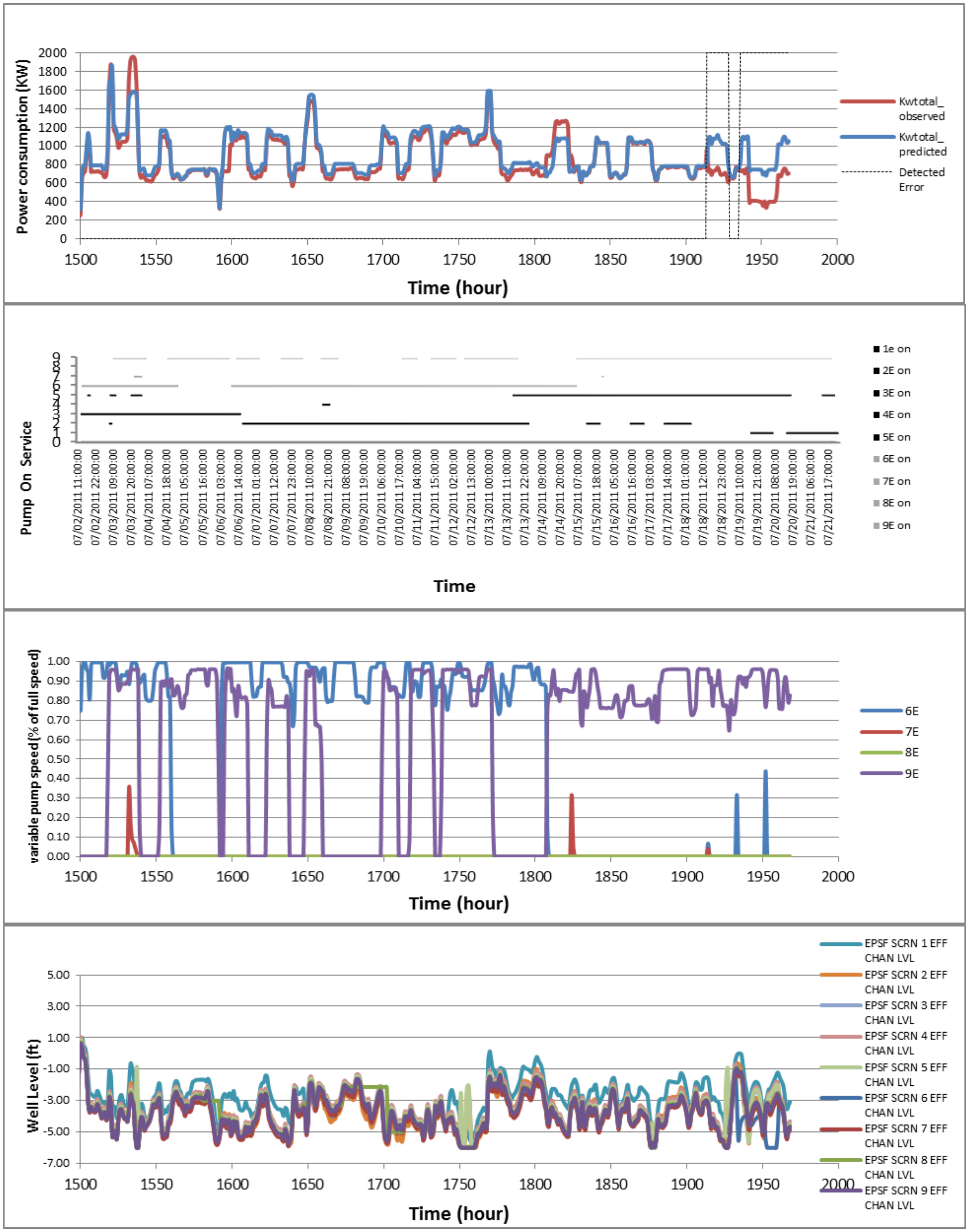


Figure 4-46. Graphical analysis of power prediction (RWWPS2)

Table 4-8 Time period with detected error for power prediction (5/1/2011-7/21/2011)

	Data Error Period	Problem Description
RWWPS1	06/10/2011 13:00:00 -06/16/2011 05:00:00	5W is on but no speed feedback
	06/16/2011 15:00:00 -06/17/2011 15:00:00	5W is on but no speed feedback
	06/21/2011 09:00:00 - 06/23/2011 07:00:00	5W is on but no speed feedback
	06/25/2011 10:00:00 -06/25/2011 16:00:00	5W is on but no speed feedback
	06/26/2011 10:00:00 - 06/26/2011 12:00:00	5W is on but no speed feedback
	07/03/2011 08:00:00 -07/03/2011 10:00:00	5W is on but no speed feedback
	07/07/2011 14:00:00 -07/12/2011 04:00:00	5W is on but no speed feedback
	07/12/2011 22:00:00 -07/13/2011 03:00:00	5W is on but no speed feedback
	07/13/2011 17:00:00 -07/13/2011 22:00:00	5W is on but no speed feedback
RWWPS2	05/01/2011 00:00:00 -05/02/2011 13:00:00	5E MN no feedback but consume power
	05/06/2011 10:00:00	5E MN no feedback but consume power
	05/09/2011 19:00:00 -05/09/2011 23:00:00	5E MN no feedback but consume power
	05/10/2011 14:00:00	5E MN no feedback but consume power
	05/15/2011 10:00:00 -05/15/2011 16:00:00	5E MN no feedback but consume power
	05/15/2011 20:00:00 -05/17/2011 05:00:00	5E MN no feedback but consume power
	05/17/2011 15:00:00	5E MN no feedback but consume power
	5/18/2011 2:00:00 PM -5/18/2011 6:00:00 PM	5E MN no feedback but consume power
	05/20/2011 10:00:00 -05/21/2011 05:00:00	5E MN no feedback but consume power
	06/02/2011 00:00:00 -06/02/2011 02:00:00	6E no power feed back
	06/23/2011 15:00:00 -06/23/2011 18:00:00	2E MN no feedback but consume power
	06/25/2011 12:00:00 -06/26/2011 15:00:00	2E MN no feedback but consume power
	6/29/2011 7:00	6E no power feedback
	07/19/2011 17:00:00 -07/20/2011 07:00:00	1E MN on but no power feedback
	07/20/2011 15:00:00 -07/21/2011 23:00:00	1E MN on but no power feedback

Table 4-9 Goodness-of-fit statistics for power prediction

	R	R^2	Se (KW)	Sy (KW)	Se/Sy	Average Error (KW)	Average KW	Average Error Ratio
RWWPS1	0.97	0.94	20.53	68.96	0.30	-10.00	527.90	-0.02
RWWPS2	0.95	0.91	70.10	209.68	0.33	25.33	894.18	0.03

Note: The time periods with error detected in Table 4-9 are not included in the computation of Goodness-of-Fit

4.6.4 Power Consumption Prediction Based on KW/MGD

Power consumption in the unit of KW/MGD could be predicted based on the combination of power prediction (Table 4-7) and flow prediction (Table 4-3).

For constant speed pumps, KW/MGD is a function of KW(mean), K,a,b,c,H. For variable speed pumps, KW/MGD is a function of speed n, K, a, b, c, H. If a prediction based on wet-well level is preferred, static head in Eqs. 3-14 and 3-15 could be modified by the following relationship.

RWWPS1:

H=Hscreen influent channel-WWL=19.85-WWL

where

19.85 =average screen influent channel water free-surface level -1/1/2009-4/30/2011(ft)

WWL=Wet-well level 1 and 2(West)

RWWPS2:

H=22.25-WWL

where

22.25=elevation of the crest of discharge siphon

WWL= screen effluent channel level (East)

To summarize, the equations for KW/MGD prediction are listed in Table 4-10. In order to give a general idea about KW/MGD estimation, Lookup tables for constant and variable speed pumping are developed (Table 4-11 and Table 4-12) based on equations in Table 4-10. It is observed in table 4-11 that the minimum KW/MGD for each constant speed pump occurs at the highest wet-well level. For variable speed pumping (Table 4-12), lower KW/MGD (highlighted red) for each pump usually occurs with higher speed, which means higher speed is more efficient than lower speed.

Table 4-10 KW/MGD prediction equation(RWWPS1&2)

Equation for constant pumps_West (1W, 3W, 4W, 6W)	$$\frac{KWconstant}{\frac{K}{1+\exp(b(19.85-WWL-a))}+c}$$
Equation for constant pumps_East (1E, 2E, 3E, 4E, 5E)	$$\frac{KWconstant}{\frac{K}{1+\exp(b(22.25-WWL-a))}+c}$$
Equation for variable speed pumps_West (2W, 5W)	$$\frac{d*n-e}{\left(\frac{K}{1+\exp\left(b\left(\frac{19.85-WWL}{n^2}-a\right)\right)}+c\right)*n}$$
Equation for variable speed pumps_East (6E, 7E, 8E, 9E)	$$\frac{d*n-e}{\left(\frac{K}{1+\exp\left(b\left(\frac{22.25-WWL}{n^2}-a\right)\right)}+c\right)*n}$$

		k	a	b	c	KW constant	d	e
RWWPS 1	1W	14.49	20.01	1.23	47.93	212.62		
	2W	84.04	25.88	0.18	13.22		408.42	116.25
	3W	14.49	20.01	1.23	47.93	217.58		
	4W	72.04	23.49	0.19	12.18	287.04		
	5W	84.04	25.88	0.18	13.22		417.94	124.04
	6W	40.00	7.77	0.11	26.61	161.75		
RWWPS 2	1E	60.56	24.95	0.32	49.53	338.12		
	2E	77.53	26.56	0.50	28.09	352.39		
	3E	552.97	33.49	0.37	449.77	338.69		
	4E	77.53	26.56	0.50	28.09	350.41		
	5E	86.54	27.63	0.25	37.20	375.49		
	6E	61.96	32.67	0.30	59.87		552.67	96.78
	7E	46.72	32.89	0.40	64.71		604.22	184.83
	8E	46.72	32.89	0.40	64.71		585.10	166.41
	9E	45.77	28.62	0.27	65.89		530.73	100.83

Note: WWL=wet-well level (RWWPS1)
WWL=Screen effluent channel level(RWWPS2)
Variable-speed power use equations apply only for relative speed greater than or equal to 0.5.

Table 4-11 KW/MGD estimation of constant speed pumping

RWWPS1												
	1W			3W			4W			6W		
WWL	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD
-2	49.30	212.62	4.31	49.30	217.58	4.41	53.75	287.04	5.34	33.43	161.75	4.84
-1.5	50.27	212.62	4.23	50.27	217.58	4.33	55.40	287.04	5.18	33.75	161.75	4.79
-1	51.73	212.62	4.11	51.73	217.58	4.21	57.01	287.04	5.03	34.09	161.75	4.75
-0.5	53.67	212.62	3.96	53.67	217.58	4.05	58.59	287.04	4.90	34.43	161.75	4.70
0	55.87	212.62	3.81	55.87	217.58	3.89	60.13	287.04	4.77	34.79	161.75	4.65
0.5	57.95	212.62	3.67	57.95	217.58	3.75	61.62	287.04	4.66	35.16	161.75	4.60
1	59.60	212.62	3.57	59.60	217.58	3.65	63.06	287.04	4.55	35.55	161.75	4.55
1.5	60.75	212.62	3.50	60.75	217.58	3.58	64.44	287.04	4.45	35.94	161.75	4.50
2	61.47	212.62	3.46	61.47	217.58	3.54	65.77	287.04	4.36	36.35	161.75	4.45

RWWPS2															
	1E			2E			3E			4E			5E		
WWL	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD	ow Rate (MGI	KW	KW/MGD
-2	83.22	338.12	4.06	87.19	352.39	4.04	85.60	338.69	3.96	87.19	350.41	4.02	97.65	375.49	3.85
-1.5	85.61	338.12	3.95	90.50	352.39	3.89	88.49	338.69	3.83	90.50	350.41	3.87	99.86	375.49	3.76
-1	87.92	338.12	3.85	93.33	352.39	3.78	90.91	338.69	3.73	93.33	350.41	3.75	101.95	375.49	3.68
-0.5	90.14	338.12	3.75	95.72	352.39	3.68	92.95	338.69	3.64	95.72	350.41	3.66	103.92	375.49	3.61
0	92.24	338.12	3.67	97.70	352.39	3.61	94.65	338.69	3.58	97.70	350.41	3.59	105.76	375.49	3.55
0.5	94.21	338.12	3.59	99.33	352.39	3.55	96.07	338.69	3.53	99.33	350.41	3.53	107.47	375.49	3.49
1	96.03	338.12	3.52	100.64	352.39	3.50	97.26	338.69	3.48	100.64	350.41	3.48	109.05	375.49	3.44
1.5	97.70	338.12	3.46	101.69	352.39	3.47	98.25	338.69	3.45	101.69	350.41	3.45	110.51	375.49	3.40
2	99.22	338.12	3.41	102.54	352.39	3.44	99.08	338.69	3.42	102.54	350.41	3.42	111.84	375.49	3.36

Table 4-12 KW/MGD estimation of variable speed pumping

		RWWPS1						RWWPS2											
		2W			5W			6E			7E			8E			9E		
WWL	Speed (% o	Flow Rate (MGD	KW	KW/MGD	Flow Rate (MGD	KW	KW/MGD	Flow Rate (MGD)	KW	KW/MGD	Flow Rate (MGD	KW	KW/MGD	Flow Rate (MGD	KW	KW/MGD	Flow Rate (MGD	KW	KW/MGD
-2	1	69.53	292.17	4.20	69.53	293.90	4.23	117.18	455.89	3.89	109.97	419.39	3.81	109.97	418.69	3.81	100.74	429.90	4.27
-2	1	71.14	292.17	4.11	71.14	293.90	4.13	117.78	455.89	3.87	110.23	419.39	3.80	110.23	418.69	3.80	101.80	429.90	4.22
-1	1	72.69	292.17	4.02	72.69	293.90	4.04	118.31	455.89	3.85	110.44	419.39	3.80	110.44	418.69	3.79	102.79	429.90	4.18
-1	1	74.20	292.17	3.94	74.20	293.90	3.96	118.77	455.89	3.84	110.61	419.39	3.79	110.61	418.69	3.79	103.70	429.90	4.15
0	1	75.64	292.17	3.86	75.64	293.90	3.89	119.18	455.89	3.83	110.76	419.39	3.79	110.76	418.69	3.78	104.53	429.90	4.11
1	1	77.02	292.17	3.79	77.02	293.90	3.82	119.53	455.89	3.81	110.88	419.39	3.78	110.88	418.69	3.78	105.30	429.90	4.08
1	1	78.34	292.17	3.73	78.34	293.90	3.75	119.84	455.89	3.80	110.98	419.39	3.78	110.98	418.69	3.77	105.99	429.90	4.06
2	1	79.60	292.17	3.67	79.60	293.90	3.69	120.11	455.89	3.80	111.06	419.39	3.78	111.06	418.69	3.77	106.62	429.90	4.03
2	1	80.79	292.17	3.62	80.79	293.90	3.64	120.34	455.89	3.79	111.12	419.39	3.77	111.12	418.69	3.77	107.18	429.90	4.01
-2	0.9	46.07	251.33	5.46	46.07	252.11	5.47	92.54	400.63	4.33	90.35	358.97	3.97	90.35	360.18	3.99	76.34	376.83	4.94
-2	0.9	48.12	251.33	5.22	48.12	252.11	5.24	94.64	400.63	4.23	92.09	358.97	3.90	92.09	360.18	3.91	77.99	376.83	4.83
-1	0.9	50.17	251.33	5.01	50.17	252.11	5.03	96.57	400.63	4.15	93.59	358.97	3.84	93.59	360.18	3.85	79.68	376.83	4.73
-1	0.9	52.22	251.33	4.81	52.22	252.11	4.83	98.33	400.63	4.07	94.86	358.97	3.78	94.86	360.18	3.80	81.36	376.83	4.63
0	0.9	54.25	251.33	4.63	54.25	252.11	4.65	99.90	400.63	4.01	95.92	358.97	3.74	95.92	360.18	3.76	83.03	376.83	4.54
1	0.9	56.26	251.33	4.47	56.26	252.11	4.48	101.29	400.63	3.96	96.79	358.97	3.71	96.79	360.18	3.72	84.65	376.83	4.45
1	0.9	58.23	251.33	4.32	58.23	252.11	4.33	102.52	400.63	3.91	97.50	358.97	3.68	97.50	360.18	3.69	86.21	376.83	4.37
2	0.9	60.16	251.33	4.18	60.16	252.11	4.19	103.59	400.63	3.87	98.07	358.97	3.66	98.07	360.18	3.67	87.70	376.83	4.30
2	0.9	62.02	251.33	4.05	62.02	252.11	4.06	104.51	400.63	3.83	98.54	358.97	3.64	98.54	360.18	3.66	89.10	376.83	4.23
-2	0.85	33.88	230.91	6.82	33.88	231.21	6.83	73.73	372.99	5.06	72.21	328.76	4.55	72.21	330.93	4.58	64.26	350.29	5.45
-2	0.85	35.80	230.91	6.45	35.80	231.21	6.46	76.43	372.99	4.88	74.93	328.76	4.39	74.93	330.93	4.42	65.52	350.29	5.35
-1	0.85	37.80	230.91	6.11	37.80	231.21	6.12	79.14	372.99	4.71	77.64	328.76	4.23	77.64	330.93	4.26	66.90	350.29	5.24
-1	0.85	39.86	230.91	5.79	39.86	231.21	5.80	81.82	372.99	4.56	80.25	328.76	4.10	80.25	330.93	4.12	68.40	350.29	5.12
0	0.85	41.97	230.91	5.50	41.97	231.21	5.51	84.40	372.99	4.42	82.68	328.76	3.98	82.68	330.93	4.00	70.00	350.29	5.00
1	0.85	44.12	230.91	5.23	44.12	231.21	5.24	86.84	372.99	4.30	84.85	328.76	3.87	84.85	330.93	3.90	71.68	350.29	4.89
1	0.85	46.28	230.91	4.99	46.28	231.21	5.00	89.10	372.99	4.19	86.75	328.76	3.79	86.75	330.93	3.81	73.43	350.29	4.77
2	0.85	48.46	230.91	4.77	48.46	231.21	4.77	91.16	372.99	4.09	88.36	328.76	3.72	88.36	330.93	3.75	75.21	350.29	4.66
2	0.85	50.62	230.91	4.56	50.62	231.21	4.57	93.01	372.99	4.01	89.69	328.76	3.67	89.69	330.93	3.69	76.99	350.29	4.55
-2	0.75	15.76	190.07	12.06	15.76	189.42	12.02	46.87	317.72	6.78	49.12	268.34	5.46	49.12	272.42	5.55	50.13	297.22	5.93
-2	0.75	16.64	190.07	11.42	16.64	189.42	11.38	47.44	317.72	6.70	49.37	268.34	5.44	49.37	272.42	5.52	50.32	297.22	5.91
-1	0.75	17.64	190.07	10.77	17.64	189.42	10.74	48.16	317.72	6.60	49.71	268.34	5.40	49.71	272.42	5.48	50.55	297.22	5.88
-1	0.75	18.76	190.07	10.13	18.76	189.42	10.09	49.06	317.72	6.48	50.19	268.34	5.35	50.19	272.42	5.43	50.84	297.22	5.85
0	0.75	20.02	190.07	9.49	20.02	189.42	9.46	50.18	317.72	6.33	50.84	268.34	5.28	50.84	272.42	5.36	51.20	297.22	5.80
1	0.75	21.42	190.07	8.87	21.42	189.42	8.84	51.55	317.72	6.16	51.73	268.34	5.19	51.73	272.42	5.27	51.65	297.22	5.75
1	0.75	22.96	190.07	8.28	22.96	189.42	8.25	53.21	317.72	5.97	52.92	268.34	5.07	52.92	272.42	5.15	52.19	297.22	5.69
2	0.75	24.66	190.07	7.71	24.66	189.42	7.68	55.18	317.72	5.76	54.47	268.34	4.93	54.47	272.42	5.00	52.86	297.22	5.62
2	0.75	26.49	190.07	7.17	26.49	189.42	7.15	57.46	317.72	5.53	56.42	268.34	4.76	56.42	272.42	4.83	53.66	297.22	5.54
-2	0.65	9.17	149.22	16.28	9.17	147.62	16.10	38.94	262.46	6.74	42.06	207.91	4.94	42.06	213.91	5.09	42.84	244.14	5.70
-2	0.65	9.30	149.22	16.05	9.30	147.62	15.88	38.95	262.46	6.74	42.06	207.91	4.94	42.06	213.91	5.09	42.85	244.14	5.70
-1	0.65	9.46	149.22	15.78	9.46	147.62	15.61	38.96	262.46	6.74	42.07	207.91	4.94	42.07	213.91	5.08	42.85	244.14	5.70
-1	0.65	9.66	149.22	15.45	9.66	147.62	15.29	38.99	262.46	6.73	42.07	207.91	4.94	42.07	213.91	5.08	42.86	244.14	5.70
0	0.65	9.90	149.22	15.08	9.90	147.62	14.92	39.02	262.46	6.73	42.07	207.91	4.94	42.07	213.91	5.08	42.88	244.14	5.69
1	0.65	10.19	149.22	14.65	10.19	147.62	14.49	39.06	262.46	6.72	42.08	207.91	4.94	42.08	213.91	5.08	42.90	244.14	5.69
1	0.65	10.54	149.22	14.15	10.54	147.62	14.00	39.12	262.46	6.71	42.09	207.91	4.94	42.09	213.91	5.08	42.92	244.14	5.69
2	0.65	10.98	149.22	13.60	10.98	147.62	13.45	39.21	262.46	6.69	42.11	207.91	4.94	42.11	213.91	5.08	42.96	244.14	5.68
2	0.65	11.50	149.22	12.98	11.50	147.62	12.84	39.33	262.46	6.67	42.14	207.91	4.93	42.14	213.91	5.08	43.00	244.14	5.68

4.7 Simulation of Wet-Well Response and Power Consumption to a Synthetic Operation Condition

In order to illustrate the impact of the pump combination on power cost, a numerical experiment was performed using the version of the simulation model that predicts wet-well elevation. The external forcing function is the inflow to the wet well. The wet-well response depends on which pumps are operating and, for the variable speed pumps, at what speed. A synthetic operating condition was created with the following assumptions:

- The summer average weekday inflow pattern of 2009 and 2010 [Fig. 4-2(c)] serves as the diurnal inflow variation (Fig. 4-47)
- The summer average power price pattern of 2009 and 2010 (Fig. 4-5) reflects the diurnal power price variation (Fig. 4-47)
- The wet-well equivalent storage is assumed to be the same as that illustrated in Fig. 4-37.
- Two pump operation schemes are assumed:

  Scheme 1: 2W + 2E+5E+8E

  Speed of variable speed pumps are set at 12:00:00am

  2W@82%(00:00:00-24:00:00),8E@72%(00:00:00-24:00:00)

  Scheme 2: 2W + 3W+ 2E+8E

  Speed of variable speed pumps are set at 12:00:00am and reset at 12:00:00pm

  2W@86%(00:00:00-12:00:00), 2W@88%(12:00:00-

24:00:00),8E@85%(00:00:00-12:00:00), 8E@90%(12:00:00-24:00:00)

- Assume the wet-well level of RWWPS1 is equal to the screen effluent channel level of RWWPS2, although in reality they usually are slightly different.

The synthetic simulation model input and output for Schemes 1 and 2 are illustrated in Figs. 4-47 and 4-48, respectively. For this synthetic model, pumping Scheme 2 is better than Scheme 1 in that the power price is reduced by $114/day. But Scheme 1 is better than Scheme 2 in that it keeps the wet-well lower. By drawing down the wet-well level, pump Scheme 1 does a better job in preventing potential wet weather bypass. The decision making would be based on the tradeoff of power price and risk of bypass.

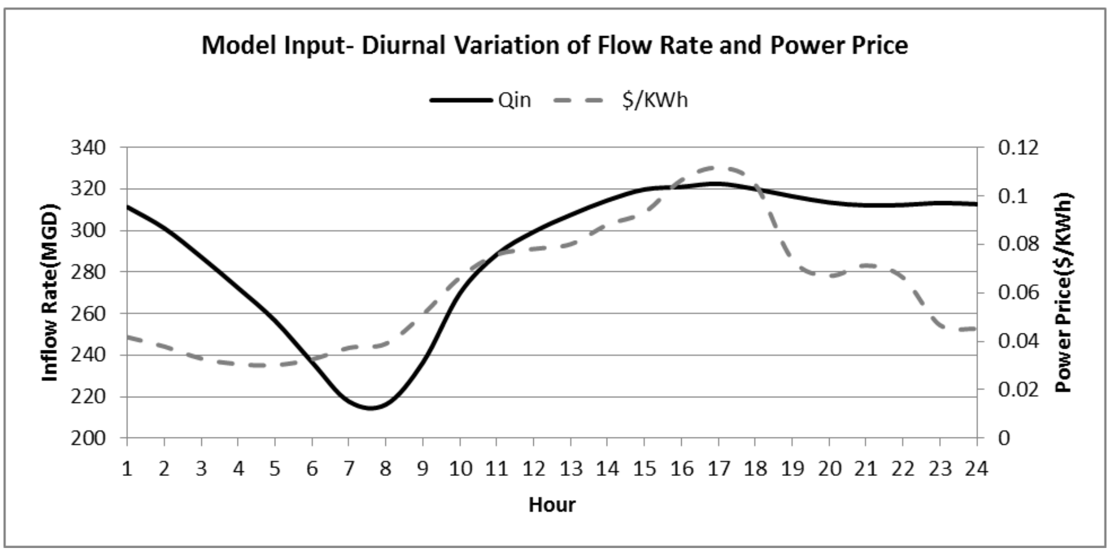


Figure 4-47. Model input--diurnal flow rate and power price
Note:Inflow rate variation same as Fig. 4-2(c) weekday inflow. Power price variation same as Fig. 4-8 summer pattern.

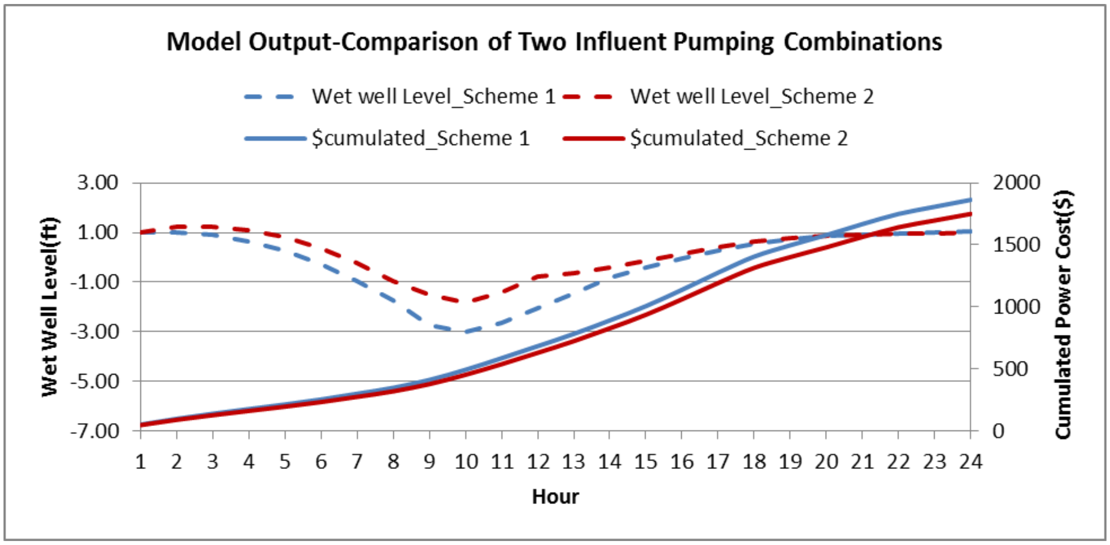


Figure 4-48. Model output--Wet-well level change and cumulated power cost

Chapter 5. Conclusions and Future Study

5.1 Influent Flow Rate

The influent flow rate shows a systematic diurnal trend. A similar trend, but with a one-hour lag was detected for weekend flow compared to weekday flow. The lowest flow was observed at 7-9 am and the peak flow was observed 4pm-1am.

The total influent flow rate analyzed in this research is the primary influent associated with influent pumping instead of plant raw wastewater influent. The actual influent flow trend could be masked by the setting of influent pumping. In order to understand the diurnal trend of plant influent, it is recommended to take a close look into the historical data to obtain the period that the wet-well level is not changing. For these periods, plant raw wastewater influent could be assumed to be equal to the primary influent. Diurnal trend observed from these periods would be more reliable to serve as a reference for decision making based on plant inflow rate.

5.2 Unit Power Price

Power price shows systematic diurnal and seasonal trend. The diurnal trend varies with season (Table 5-2). Unit power price ($/KWh) of 2008 was about two cents higher than that of 2009 and 2010.

In the future, combined heat and power generated in plant would be another choice to feed the treatment processes. In order to save power cost, the combined heat and power generated in plant could be used in the higher price period and PEPCO load could be shift to the lower price period according to the diurnal trend if possible.

In order to understand how to distribute self-generated power and PEPCO power, an understanding of storage and distribution of combined head and power is necessary for future study.

5.3 Power Consumption Breakdown

According to the power consumption breakdown analysis from 5/1/2010 to 4/30/2011, the power load of major treatment processes are listed in order of magnitude (Table 5-1). Nitrification blower, secondary blower, secondary sedimentation, solids processing and raw wastewater pumping are the five largest power consumers in Blue Plains. Aeration consumed approximately 40% of the total power load.

Large energy saving opportunity lies in the large consumers. In order to save power cost, studies on energy saving method of the major power consumers could be conducted in the future.

5.4 Diurnal Trend Analysis

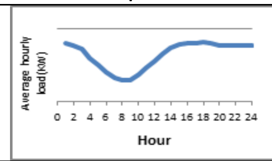
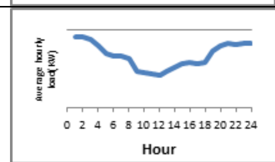
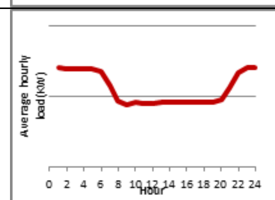
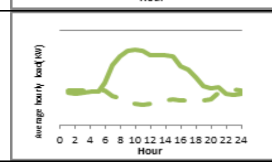
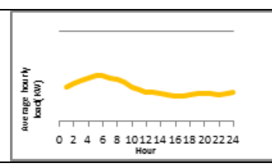
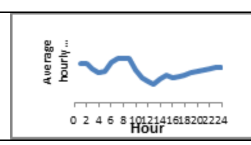
Diurnal trends of 22 treatment processes are illustrated in Appendix 1-4 for ASS1, ASS3, ASS4 and ASS5, respectively. The diurnal trends found in this research project are summarized in Tables 5-1 and 5-2. For the treatment processes for which only one year of data is available, future study is needed to confirm the trend. Diurnal trend of treatment processes is summarized in Table 5-1. For NIT-SED (ASS3), NIT-BLWR (ASS3), DOCK (ASS4), FILTER ASB (ASS4), DPSBUSS (ASS4) and DSLF (ASS5), longer analysis period is required to detect the diurnal trend. In future upgrade, ASS6 will be added into the system and power line fed by each substation may vary.

Determining the reasons that cause the diurnal trend is out of the scope of this research project. If this could be studied in the future, we could investigate whether high power demand activity could be shifted to low power cost periods. If this is allowed for some major power consumption treatment processes, significant power savings may be achieved. The treatment processes with large value of variation in Table 5-2 may have more opportunity of power saving by shift the high load period.

Table 5-1. Average power load of major treatment processes

Treatment Process	Average Power Load(KWh)	Percent of Total Load	Area Substations
NIT_BLOWER	4833	21.01%	ASS3
SEC BLWR	4125	17.93%	ASS1
SEC SED	2142	9.31%	ASS1
SOLIDS PROC	2048	8.90%	ASS5
RWWPS1+2	1528	6.65%	ASS1
FIPs	1523	6.62%	ASS4
NIT-SED	1157	5.03%	ASS3
PRI SED+Grit Chamber+Control House	1114	4.84%	ASS1
DPSBUSS	942	4.10%	ASS4
WWP1-8	819	3.56%	ASS4
COF	602	2.62%	ASS1
CMF	583	2.53%	ASS5
HPRFEP(1-3)	360	1.57%	ASS4
PSSDB	285	1.24%	ASS5
SPWP(2-5)	277	1.20%	ASS4
DSLF	188	0.82%	ASS5
MULTI SERV USS	131	0.57%	ASS5
CHEM BLDG	127	0.55%	ASS5
FILTER ASB	97	0.42%	ASS4
WHSE-2 USS	79	0.34%	ASS5
CLB	29	0.13%	ASS1
DOCK	11	0.05%	ASS4

Table 5-2. Summary of diurnal trend

	Trend Description	Curve shape	Treatment Processes
Trend 1	Closely Follow the trend of influent flow rate		ASS4, RWWPS1&2(ASS1), Fips(ASS4)
Trend 2	Follow the trend of influent flow rate with lag		ASS1, PSSDB(ASS5)
Trend 3	Abrupt change between two value, low load during daytime working hour		SEC SED(ASS1), CLB(ASS1)
Trend 4	Peak at working hour on weekdays		ASS5, COF(ASS1), Multi Service USS(ASS5), CMF(ASS5)
Trend 5	Higher load in winter		SEC SED(ASS1), COF(ASS1), SOLIDS PROC(ASS5),CHEM BLDG(ASS5),MULTI SERVICE USS(ASS5),WHSE-2(ASS5),PSSDB(ASS5)
Trend 6	Lower load in Winter		SEC BLWR (ASS1)
Trend 7	Higher load in Summer		CMF(ASS5)
Trend 8	Peak load at 5-7am, lowest load at 1-4pm		ASS3, SEC BLWR(ASS1), CHEM BLDG(ASS5)
Trend 9	No obvious diurnal trend, uniform during the day	Flat line	PRI SED(ASS1), WWP1-8(ASS4), SPWP2-5(ASS4), HPRFEP1-3(ASS4), , SOLIDS PROC(ASS5)
Trend 10	Peak at 6-10am		WHSE-2(ASS5)
Trend not detected	Trend not obvious due to limited data period and large data variation		NIT-SED(ASS3), NIT-BLWR(ASS3),DOCK(ASS4), FILTER ASB(ASS4), DPSBUSS(ASS4), DSLF(ASS5)

5.5 Flow and Power Consumption Prediction

In this research, raw wastewater inflow was simulated using individual pump curves and total power consumption of raw wastewater influent pumping was simulated using individual pump power equations.

Although the overall flow prediction is good, it was observed that the prediction is not very accurate for some periods. It was observed in the simulation that the possible inaccuracy may result from underprediction of pump 4W and lower speed of pump 2W.The flow prediction of this research project is based on discharge-static head curves obtained by pump tests. Only one test for each pump is not enough to lead to an accurate prediction. Multiple tests for each pump are needed for RWWPS1 & 2 for comparison. Longer analysis period is also necessary to separate each pump combination for model evaluation and calibration.

Based on the KW/MGD prediction, it was found that for each constant speed pumps, efficiency (low KW/MGD) is determined by the denominator, flow rate, which is increased by operating at a higher wet-well level. For variable speed pumps, running in higher speed would be more efficient than lower speed.

The possible application of the equation developed by this research is that modeler/programmer may be able to predict flow based on wet-well level and pump combination. This prediction could be shown on the screen of PCS system to compare with the measurement by Venturi meter. For example, if the predicted value is much higher than the measured value, operator need to be aware of the potential priming problem—one pump may not be functioning well but still consuming energy. If the predicted value is much lower than the measured one, it may indicate that PCS data, e.g. MN point or speed feedback is lost or stuck in some value.

Comparing Table 4-5 with Table 4-7, and figures with Appendix 6, it was observed that power prediction is more accurate than flow prediction. If pumps with different designed capacity are operated together, the power real-time data could also serve as alarm about priming problem.

It was found in the simulation that the reliability of the different point data follows this relationship:

KW > MN > Speed

The power feedback seldom has problem for every pump in RWWPS1 &2, which indicates that simulation programming based on KW will be more accurate.

Power prediction is a function of pump combination and pump speed, while flow prediction is also related to wet-well level. If more pump tests could be done in the future to get a better prediction of pump discharge, more accurate pump characteristic curves could be developed, thus more accurate optimization could be achieved for minimizing power cost. As implied by this comparison of two pump combinations, it is also possible to set a desired destination wet-well elevation and choose best pump combination (power saving + lower wet-well level) by numerical modeling. In this thesis, optimization is not the task due to limitation of accurate pump tests and research time; however, the brief experiment in Section 4.7 shows how the model could be useful in plant operations.

5.6 Wet-Well Storage Estimation

The duration of wet-well rise based on influent pumping outage and wet-well storage estimation could be served as a reference for future prediction of wet-well response. It is observed in influent pumping outage on 6/27/2011 that flow rate reading is observed from PCS system for east influent even though no pump was run. It is believed to be the Venturi meter lower range problem because pressure change was still detected by Venturi meter. This may remind operators that low flow rate readings are not always reliable.

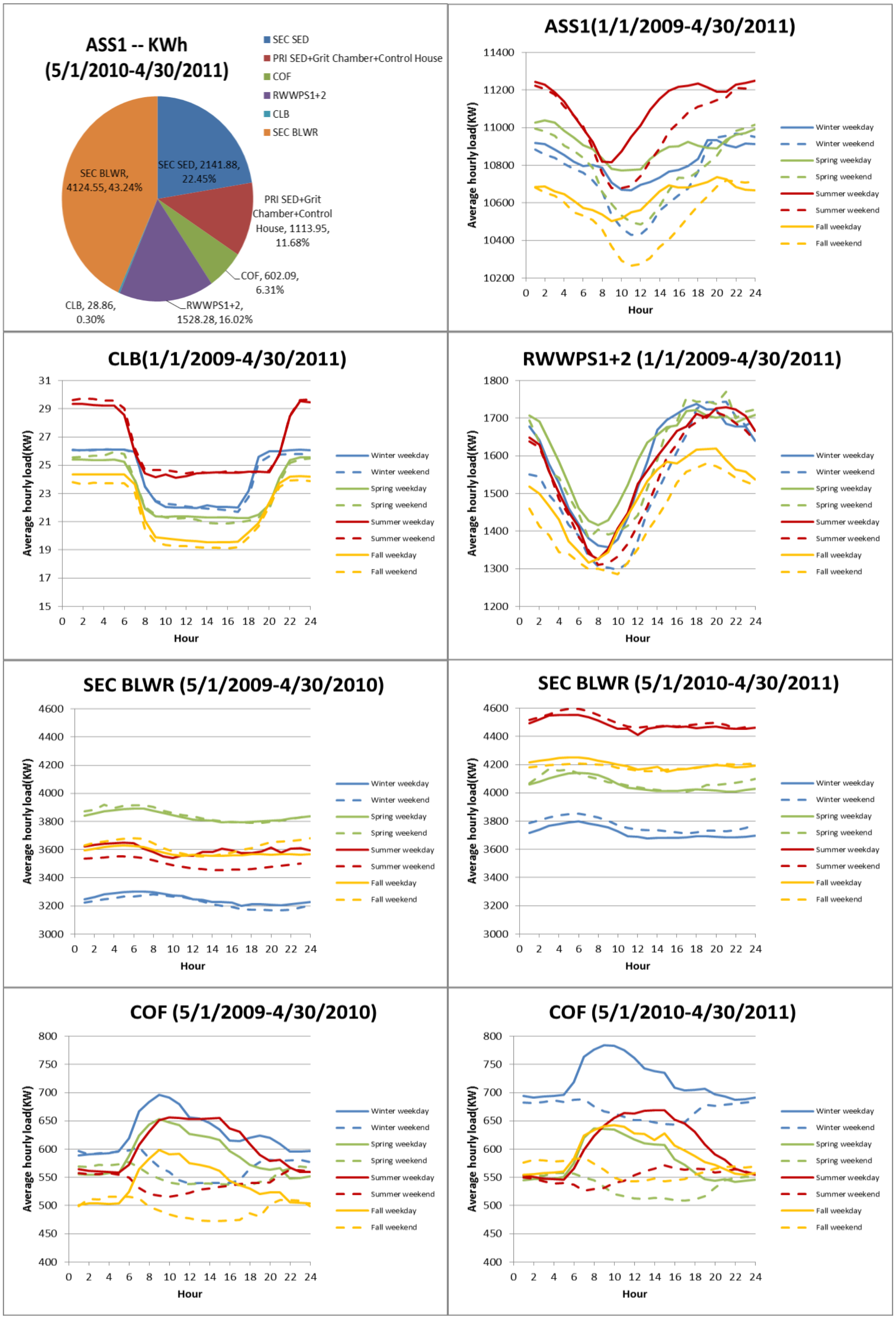
Total influent to the raw wastewater pumping stations is not currently measured. If the equivalent wet-well storage is believed to be accurate, with the time series of raw wastewater pump station effluent flow rate measurements and wet-well level readings, modeler could develop a model to calculate the actual influent flow rate into the raw wastewater pump stations.

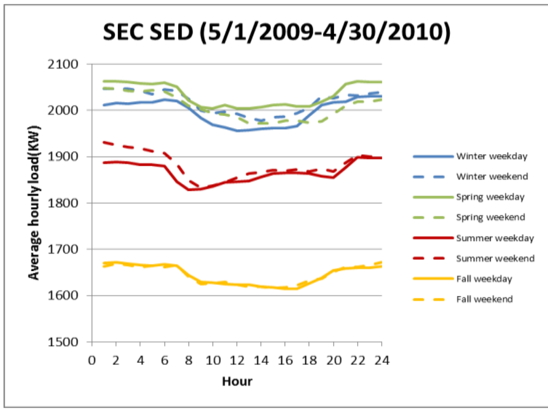
The geometry of the wet well is complex; detailed 3-D drawings from a stage-storage curve could be derived are not available, and the structure itself is not accessible for in-situ measurement. If future work with the simulation model shows that results are sensitive to this input data, methods will need to be developed.

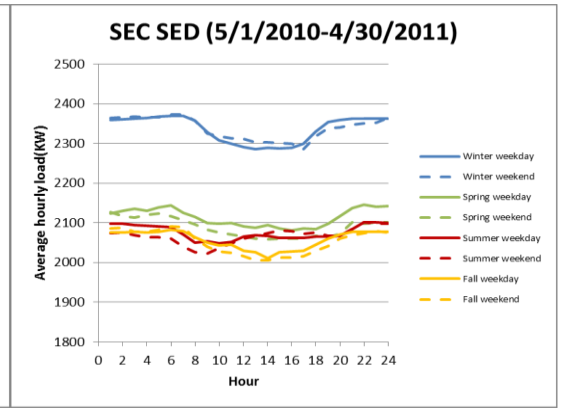
5.7 Power Saving by Raising Influent Wet-well Level

It was discussed in Section 4.5 that $58,640/year could be saved by raising one foot of wet well during normal operation. The question we need to answer by future study is whether the Raw Wastewater Pumping Stations should save power by raising wet-well level and which elevation range is safe. This is the problem of tradeoff between cost and risk. If we trust the weather prediction, operator may be able to set well level high for certain period. But even if the weather prediction is reliable, operator may not be able to suddenly start a large number of pumps to accommodate potential wet weather flow. A high rate of influent pumping results in high load to downstream treatment processes. Treatment detention time may not be able to keep up and biomass may be washed out. Understanding of downstream treatment process is necessary for this decision.

Appendix 1. Diurnal and Seasonal Trend of Power Load (ASS1)







Findings:

(1) Diurnal Trend

- Match the flow—RWWPS1&2
- Abrupt Change Between Two Rates—SEC SED, CLB
- Peak at Working Hour/ Weekday and Weekend Difference—COF
- Peak Load at 5-7 am / Minimum Load at 1-4pm—SEC BLWR

(2) Seasonal Trend

- Lowest Load in Winter—SEC BLWR
- Highest Load in Winter—COF, SEC SED
- Peak Load Lasts Longer in Summer—COF

Data available is not sufficient to detect the trend of primary sedimentation / Grit Chamber / Control House. Future analysis is needed to understand the diurnal and seasonal variation.

Table 1. Electrical Lines Fed by ASS1
(*indicates the point is used for diurnal trend analysis or energy breakdown computation, same for Table 2 and Table 6)

SEC SED						
Line	SSUSS1 SEC LINE B REAL PWR *	SSUSS1 SEC LINE C REAL PWR*	SSUSS2 LINE A REAL PWR*	SSUSS2 LINE B REAL PWR*	SSUSS3 SEC LINE A REAL PWR*	SSUSS3 SEC LINE B REAL PWR*
Point	JWI81384	JWI81387	JWI81194	JWI81196	JWI81206	JWI81208
Reliable data period	1	1	1	1	1	1
PRI SED						
Line	PSUSS1 LINE A REAL POWER*	PSUSS1 LINE C REAL POWER*	PSUSS2 SEC LINE B REAL PWR	PSUSS3 SEC LINE REAL POWER*	PSUSS4 SEC LINE C REAL PWR*	PSUSS5 REAL POWER*
Point	JWI81234	JWI81237	JWI81364	JWI81374	JWI81424	JWI81444
Reliable data period	3	3	3	1	1	1
COF						
Line	COBUSS LINE A REAL POWER*	COBUSS LINE B REAL POWER*				
Point	JWI81171	JWI81176				
Reliable data period	1	1				
RWWPS-1						
Line	RWWPS1 IN LINE A REAL PWR*	RWWPS1 IN LINE C REAL PWR*	RWWPS1 1W PMP REAL PWR	RWWPS1 2W PMP REAL PWR	RWWPS1 3W PMP REAL PWR	RWWPS1 4W PMP REAL PWR
Point	JWI81220	JWI81225	JWI81222	JWI81223	JWI81224	JWI81227
Reliable data period	1	1	1	1	1	1
Line	RWWPS1 5W PMP REAL PWR	RWWPS1 6W PMP REAL PWR	RWWPS1 FDR BRKR 5A KW	RWWPS1 FDR BRKR C12 KW		
Point	JWI81228	JWI81229	JWI81218	JWI81219		
Reliable data period	1	1	3	3		
CLB						
Line	CLBUSS SEC LINE REAL POWER*	CLBUSS SEC LINE C PHA REAL PWR*				
Point	JWI81341	JWI81343				
Reliable data period	2	2				

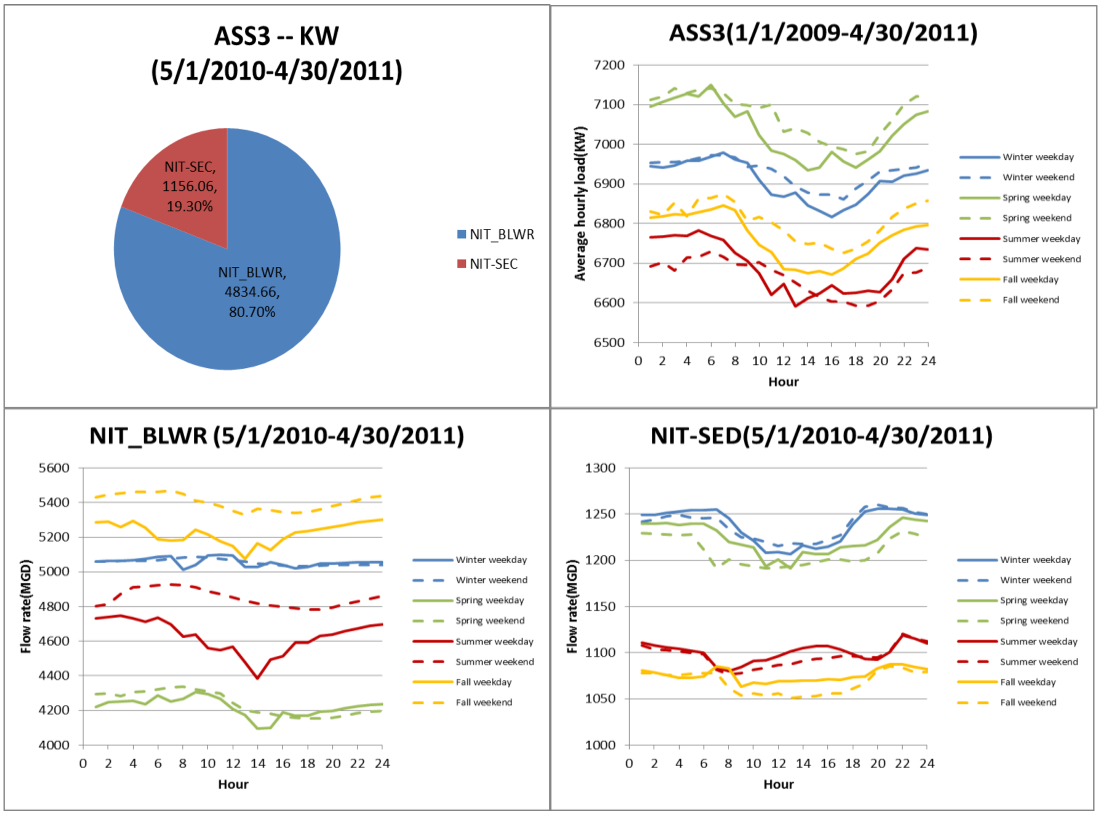
Table 1 Continue

Continue Table 1

RWWPS-2						
Line	RWWPS2 FDR BRKR A1 REAL PWR	RWWPS2 FDR BRKR A2 REAL PWR	RWWPS2 FDR BRKR C13 REAL PWR	RWWPS2 FDR BRKR A5 REAL PWR	RWWPS2 FDR BRKR C12 REAL PWR	RWWPS2 FDR BRKR A3 REAL PWR
Point	JWI81151	JWI81152	JWI81163	JWI81155	JWI81162	JWI81153
Reliable data period	1	1	1	1	1	1
Line	RWWPS2 FDR BRKR A4 REAL PWR	RWWPS2 FDR BRKR C14 REAL PWR	RWWPS2 FDR BRKR C15 REAL PWR	RWWPS2 BRKR A7 REAL PWR*	RWWPS2 BRKR C10 REAL PWR*	RWWPS2 FDR BRKR A6 REAL PWR
Point	JWI81154	JWI81164	JWI81165	JWI81150	JWI81160	JWI81156
Reliable data period	1	1	1	1	1	1
Line	RWWPS2 FDR BRKR C11 REAL PWR	RWWPS2 SEC FDR BRKR LINE A REA	RWWPS2 SEC FDR BRKR LINE C REA			
Point	JWI81161	JWI81158	JWI81167			
Reliable data period	1	1	1			
SEC BLWR						
Line	SBB BLWR 1 REAL PWR	SBB BLWR 2 REAL PWR	SBB BLWR 3 REAL PWR	SBB BLWR 4 REAL PWR	SBB BLWR 5 REAL PWR	SBB BLWR 6 REAL PWR
Point	JWI81131	JWI81123	JWI81112	JWI81132	JWI81111	JWI81122
Reliable data period	1	1	1	1	1	1
Line	SBB LINE A REAL PWR*	SBB LINE B REAL PWR*	SBB LINE C REAL PWR*	SBB STN SERV XFMR B REAL PWR	SBB STN SERV XFMR C REAL PWR	SBB SPARE C15 REAL PWR
Point	JWI81110	JWI81120	JWI81130	JWI81121	JWI81134	JWI81133
Reliable data period	1	1	1	1	1	1

Note: reliable data period
1: 1/1/2009-present
2: 5/1/2009- present
3: 5/1/2010-present

Appendix 2. Diurnal and Seasonal Trend of Power Load (ASS3)



Findings:

Data period available for ASS3 is one year (2010.5-2011.5), which is short compared to ASS1. No obvious diurnal trend is observed for nitrification blowers and nitrification secondary sedimentation. Longer data period is expected to arrive at a more precise evaluation.

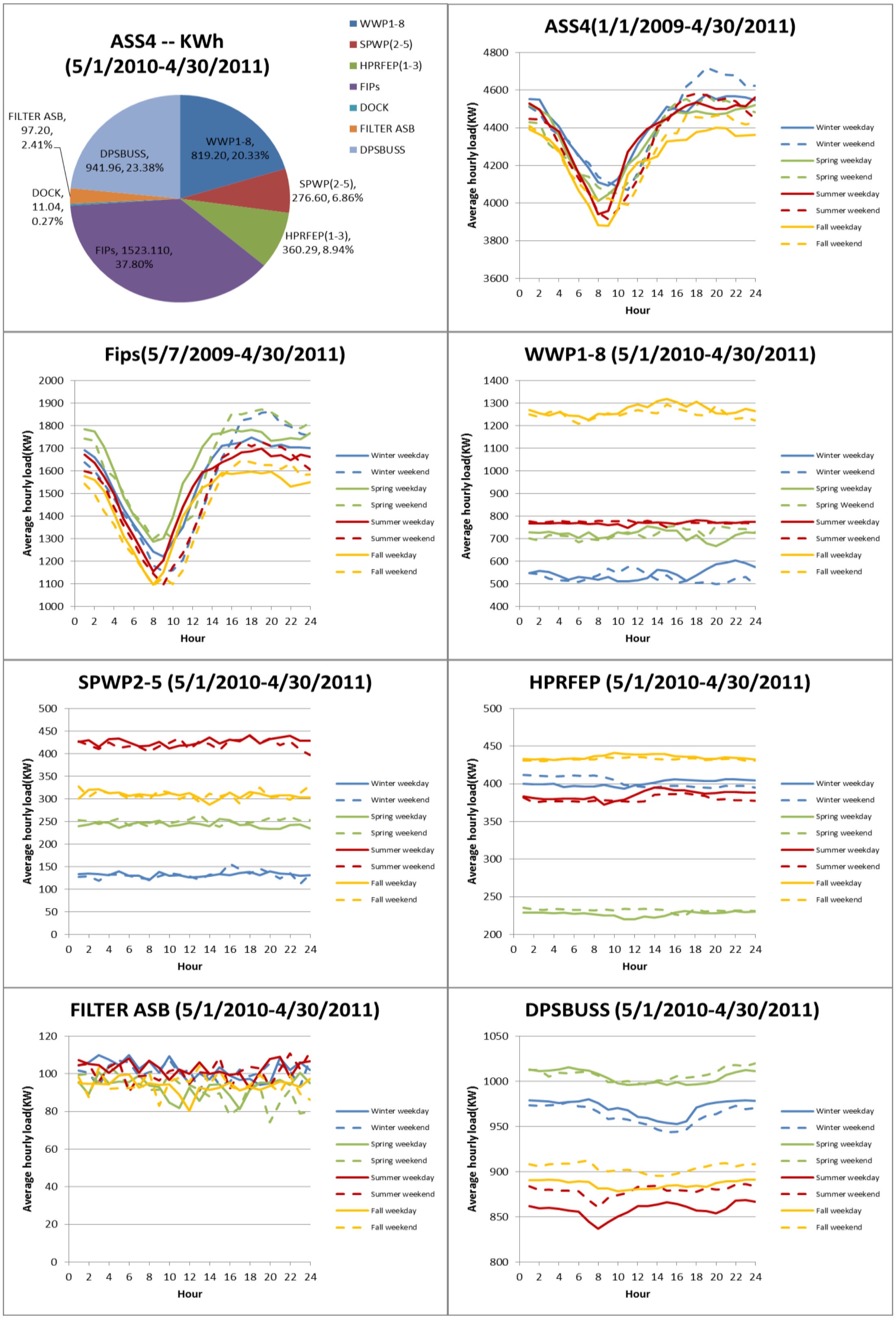
Nitrification blowers would be expected to follow a pattern similar to the secondary blower; they have the same control logic, and dissolved oxygen (DO) control is employed for both. The weekend curve for each season suggests this similar pattern.

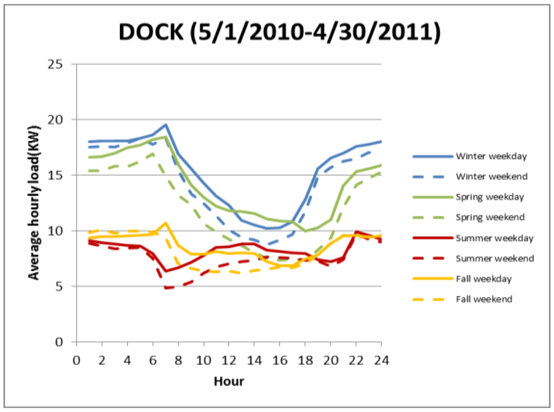
Table 2. Electrical Lines Fed by ASS3

NIT-Blower								
Line	NBB 5KV INC LINE A KW	NBB 5KV INC LINE B KW	NBB 5KV INC LINE C KW	NBB 5KV SWGR BLWR 1 KW*	NBB 5KV SWGR BLWR 2 KW*	NBB 5 KV SWGR BLWR3 KW*	NBB 5 KV SWGR BLWR 4 KW*	NBB 5 KV SWGR BLWR 5 KW*
Point	JWI83040	JWI83050	JWI83060	JWI83042	JWI83043	JWI83053	JWI83054	JWI83062
Reliable data period	3	3	3	3	3	3	3	3
NIT-SED								
Line	NBB 5KV FDR XMFR B7 KW	NBB 5KV FDR XFR B8 KW	NBB 5KV FDRXFT-HV1 KW	NBB 5KV FDR NSUSS KW*	NBB 5KV LINE C FDR NSUSS KW*	NBB 5KV TIE LINE A KW	NBB 5KV TIE BRKR LINE B KW	NBB 5KV TIE BRKR LINE C KW
Point	JWI83041	JWI83052	JWI83061	JWI83051	JWI83063	JWI83044	JWI83055	JWI83064
Reliable data period	3	3	3	3	3	3	3	3

Note: reliable data period
1: 1/1/2009-present
2: 5/1/2009- present
3: 5/1/2010-present

Appendix 3. Diurnal and Seasonal Trend of Power Load (ASS4)





Findings:

Diurnal Trend

- Match the flow—FIPs
- Uniform throughout the Day—WWP, SPWP, HPRFEP, FILTER ASB

No diurnal trend is detected for docking facilities (DOCK) and Dual Purpose sedimentation basin (DPSBUSS). The diurnal trend of these treatment processes are believed to be masked by data variation and the limitation of data period; and more data is required for future analysis.

Table 3. Electrical Lines Fed by ASS4

MULTI MEDIA								
Line	FDSWGR 1 REAL PWR (WWP 7)*	FDSWGR 1 REAL PWR (WWP 5)*	FDSWGR 1 REAL PWR (WWP 3)*	FDSWGR 1 REAL PWR (WWP 1)*	FDSWGR 2 KW (WWP 2)*	FDSWGR 2 KW (WWP 4)*	FDSWGR2 KW (WWP 6)*	FDSWGR2 KW (WWP 8)*
Point	JWI84231	JWI84232	JWI84233	JWI84234	JWI84151	JWI84152	JWI84153	JWI84154
Reliable data period	2	2	2	2	2	2	2	2
Line	FDSWGR 1 REAL PWR (HPRFEP 3)*	FDSWGR 1 REAL PWR (HPRFEP 2)*	FDSWGR 2 KW (HPRFEP 1)*	FDSWGR 1 REAL PWR (SPWP 5)*	FDSWGR 1 REAL PWR (SPWP 4)*	FDSWGR 2 KW (SPWP 3)*	FDSWGR2 KW (SPWP 2)*	
Point	JWI84237	JWI84238	JWI84148	JWI84235	JWI84236	JWI84149	JWI84150	
Reliable data period	2	2	2	2	2	2	2	
Line	FDSWGR 1 KW FIP 3*	FDSWGR 1 KW FIP 5*	FDSWGR 1 KW FIP 7*	FDSWGR 1 KW FIP 9*	FDSWGR 1 KW FIP 11*	FDSWGR 2 KW FIP 2*	FDSWGR2 KW FIP 4*	FDSWGR2 KW FIP 6*
Point	JWI84242	JWI84243	JWI84244	JWI84245	JWI84247	JWI84146	JWI84145	JWI84144
Reliable data period	2	2	2	2	2	2	2	2
Line	FDSWGR 2 KW FIP 8*	FDSWGR 2 KW FIP 10*	FDSWGR 2 KW (FIP 12)*	FDSWGR 1 4.16KV INC KW	FDSWGR 2 INCOMING KW	FDSWGR 1 REAL PWR XFMR C	FDSWGR2 XFMR B REAL PWR	
Point	JWI84143	JWI84142	JWI84155	JWI84230	JWI84140	JWI84261	JWI84161	
Reliable data period	2	2	2	3	2	2	2	
DOCK								
Line	DOCKING FAC USS REAL PWR*							
Point	JWI84101							
Reliable data period	3							
FILTER ASB								
Line	DOCKING FAC USS REAL PWR*	4160 BLWR BLDG LINE B REAL PWR*	AS BLWR 1 REAL PWR	AS BLWR 5 REAL PWR	AS BLWR 3 REAL PWR	AS BLWR 4 REAL PWR	AS BLWR 2 REAL PWR	AS BLWR 6 REAL PWR
Point	JWI84101	JWI84280	JWI84271	JWI84272	JWI84273	JWI84281	JWI84282	JWI84283
Reliable data period	3	3	3	3	3	3	3	3

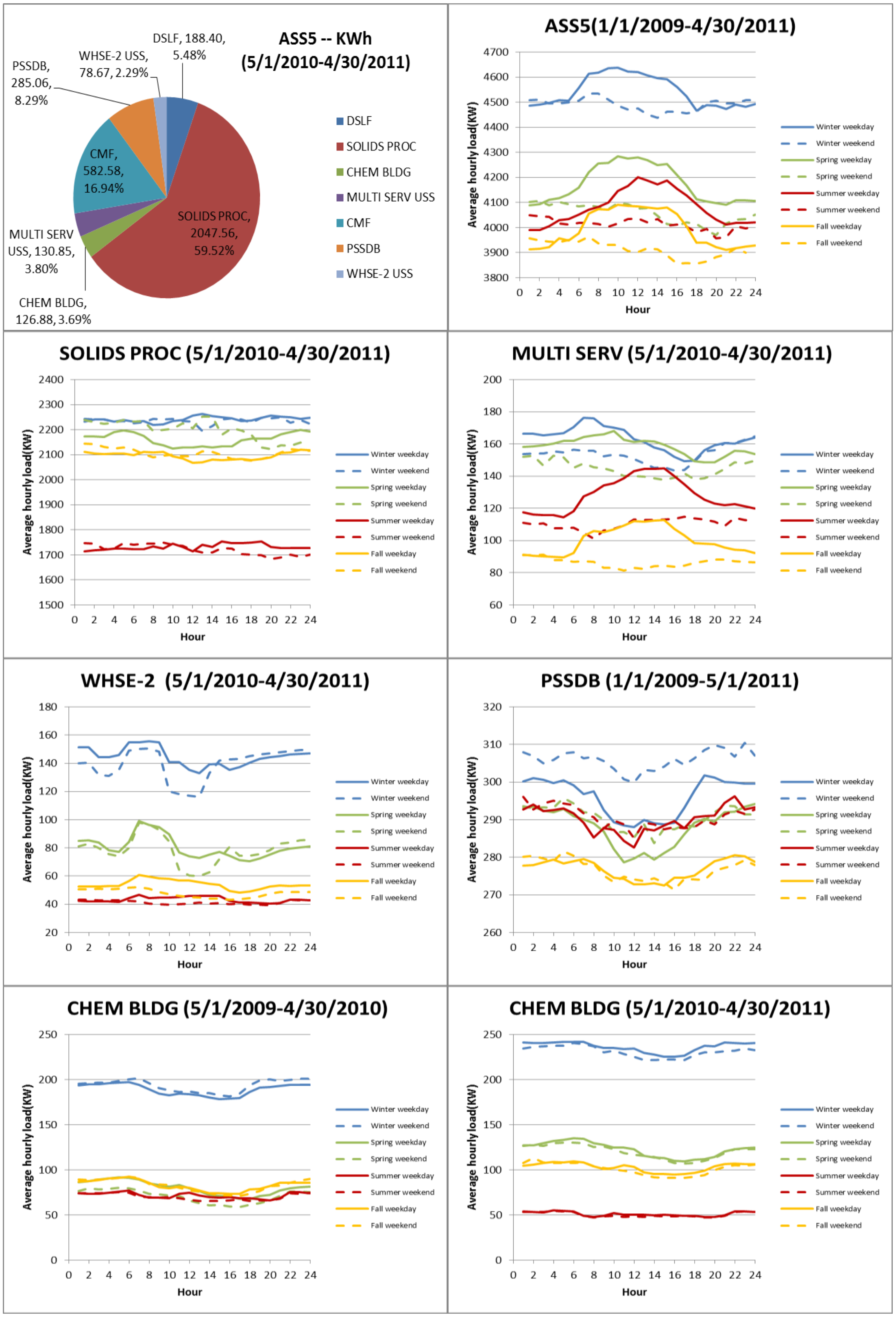
Table 2 Continue

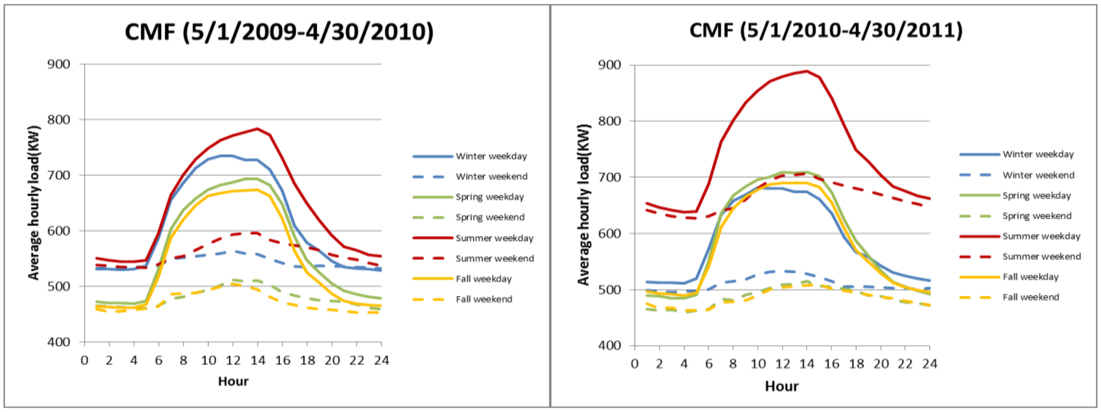
Continue Table 2

DPSBUSS								
Line	DPSBUSS 1 LINE A REAL PWR	DPSBUSS 1 LINE B REAL PWR	DPSBUSS2 LINE A REAL PWR	DPSBUSS 2 LINE B REAL PWR				
Point	JWI84194	JWI84195	JWI84204	JWI84205				
Reliable data period	3	3	3	3				

Note: reliable data period
1: 1/1/2009-present
2: 5/1/2009- present
3: 5/1/2010-present

Appendix 4. Diurnal and Seasonal Trend of Power Load (ASS5)





Findings:

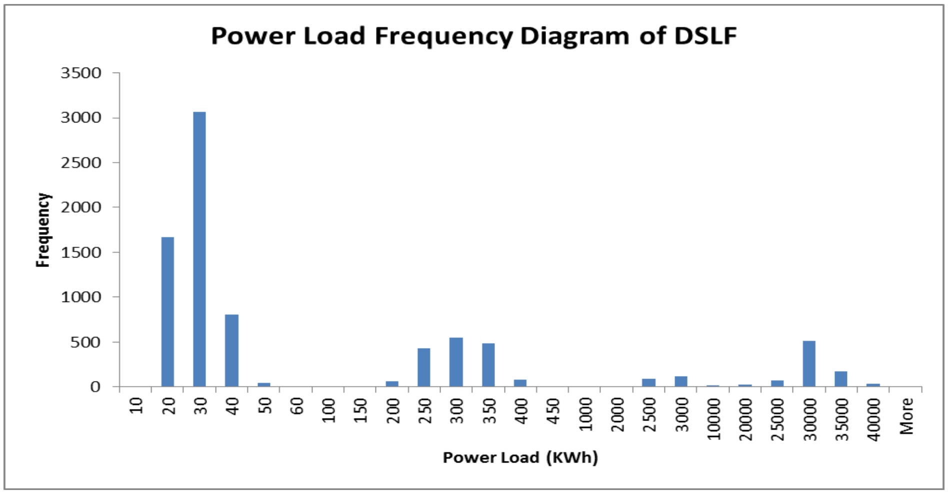
(1) Diurnal Trend

- Peak at Working Hour/ Weekday and Weekend Difference—CMF, MULTI SERV
- Uniform throughout the Day—SOLIDS PROC, CHEM BLDG
- Peak Load at 6-10am—WHSE-2

(2) Seasonal Trend

- Highest Load in Winter—CHEM BLDG, SOLIDS PROC, MULTI SERV, WHSE-2, PSSDB
- Highest Load in Summer—CMF

For the Dewatering Sludge loading facility (DSLF), diurnal trend and seasonal trend is not detected, due to large data variation. This may due to a power line shift since three fairly distinct groups of data magnitude are observed, ranging approximately 30KWh, 300KWh to 30000KWh.



Power load frequency diagram of DSLF(01/21/2010-4/30/2011)
Sample size: 8282

Table 4. Electrical Lines Fed by ASS5

DSLF					
Line	DSLFUSS PMT 1 PWR*	DSLFUSS PMT 2 PWR*			
Point	JWI85185	JWI85187			
Reliable data period	3	3			
SOLIDS PROC					
Line	SPBUSS5 LINE A REAL PWR*	SPBUSS5 LINE B REAL PWR*	SPBUSS4 LINE B REAL PWR*	SPBUSS4 LINE C REAL PWR*	SPBUSS3 LINE A REAL PWR*
Point	JWI85164	JWI85165	JWI85154	JWI85155	JWI85194
Reliable data period	3	3	3	3	3
Line	SPBUSS3 LINE B REAL PWR*	USS 12-MAIN BUS B - PWR KW*	USS 11-MAIN BUS A-PWR KW*	USS 11-MAIN BUS B - PWR KW*	
Point	JWI85195	JWI85126	JWI85105	JWI85106	
Reliable data period	3	3	3	3	
CHEM BLDG					
Line	CHBUSS SEC LINE B REAL POWER*	CHBUSS SEC LINE C REAL POWER*			
Point	JWI85304	JWI85307			
Reliable data period	1	1			
MULTI SERV USS					
Line	MSUSS SEC LINE B KW*	MSUSS SEC LINE C KW*			
Point	JWI85375	JWI85377			
Reliable data period	3	3			
CMF					
Line	CMBUSS1 REAL POWER*	CMBUSS2 REAL POWER*	CMBUSS3 REAL POWER*		
Point	JWI85331	JWI85336	JWI85341		
Reliable data period	1	1	1		
PSSDB					
Line	DEGUSS SEC LINE B REAL PWR*	DEGUSS SEC LINE C REAL PWR*			
Point	JWI85394	JWI85397			
Reliable data period	1	1			
WHSE2 USS					
Line	WHSE-2 USS KW*				
Point	JWI85411				
Reliable data period	3				

Note: reliable data period
1: 1/1/2009-present
2: 5/1/2009- present
3: 5/1/2010-present

Appendix 5. Pump Performance Curves

RWWPS1

(1)Constant Speed Pumps

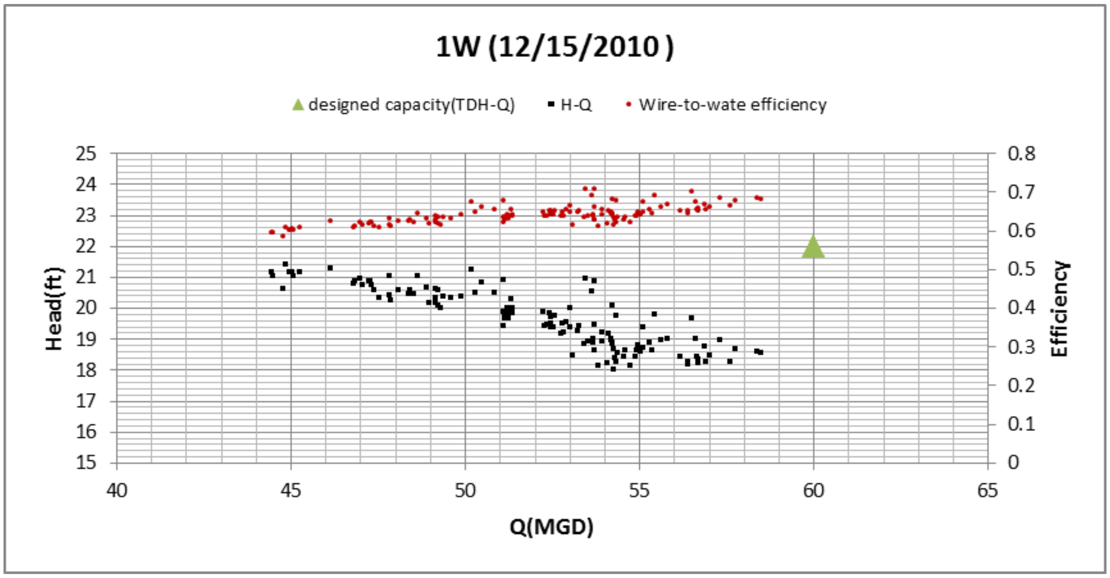


Figure 1 Static head-discharge curve and efficiency-discharge curve(1W)

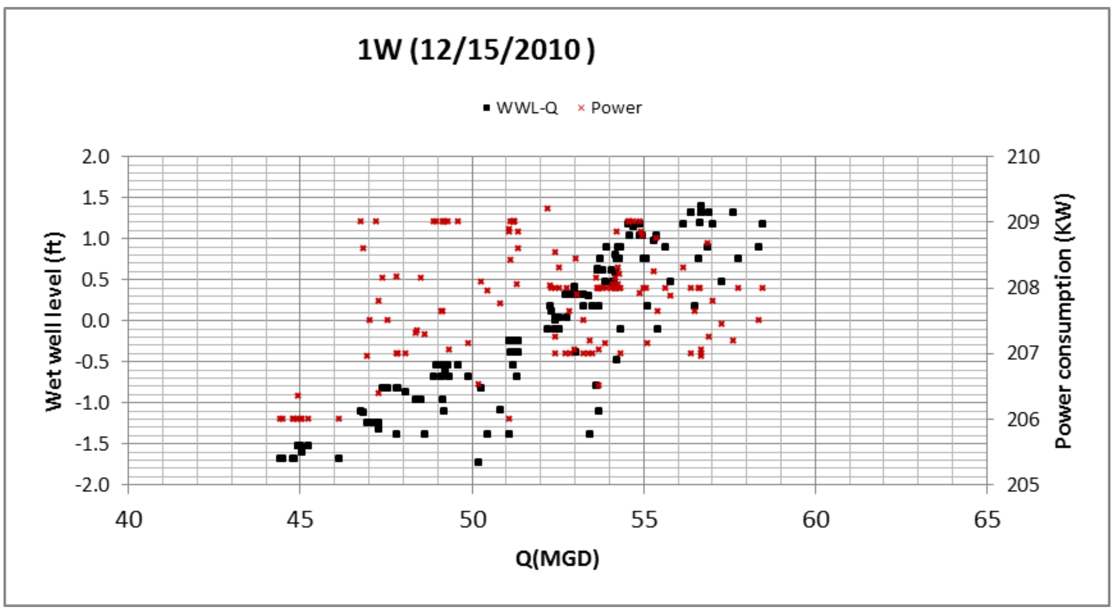


Figure 2 Wet-well level-discharge curve and power-discharge curve (1W)

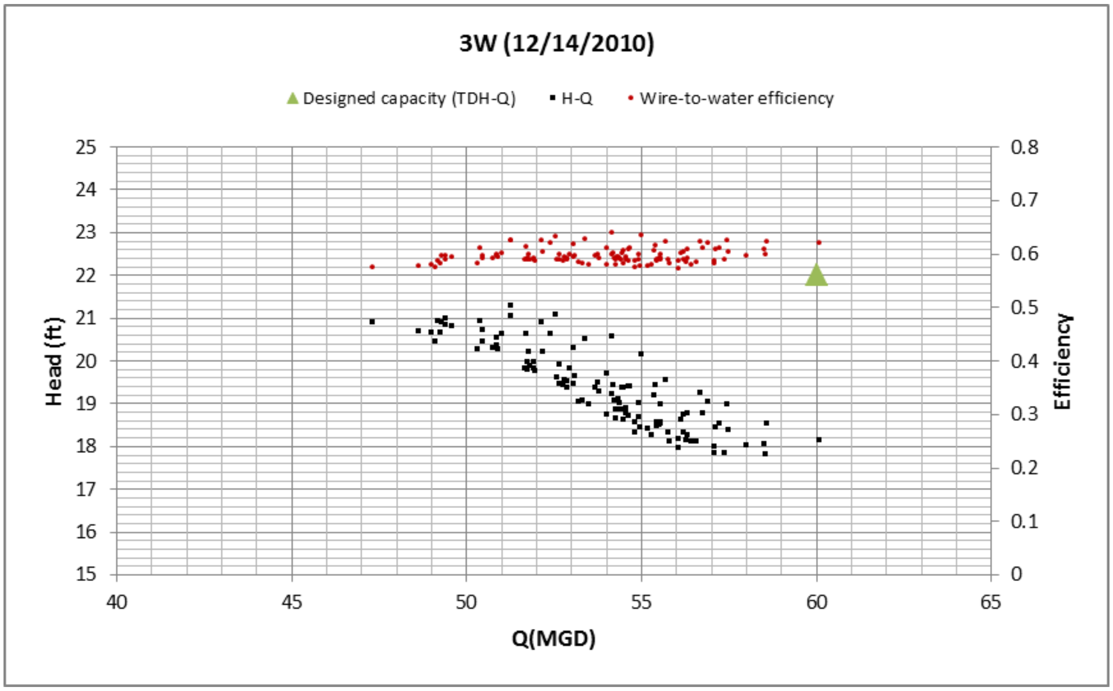


Figure 3 Static head-discharge curve and efficiency-discharge curve (3W)

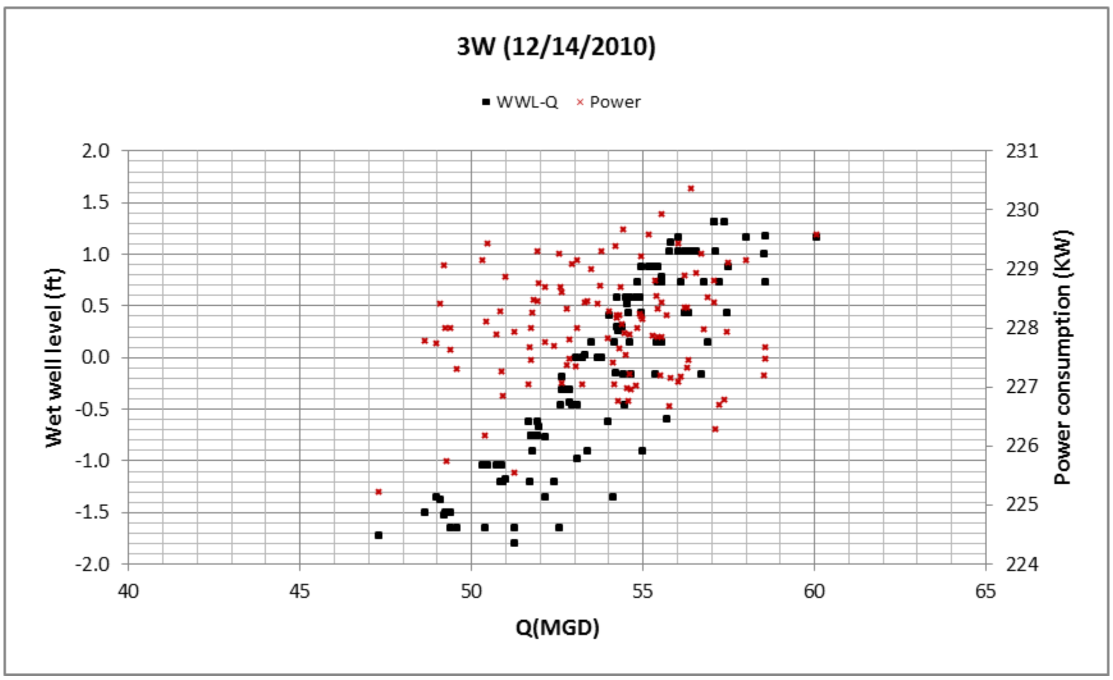


Figure 4 Wet-well level-discharge curve and power-discharge curve (3W)

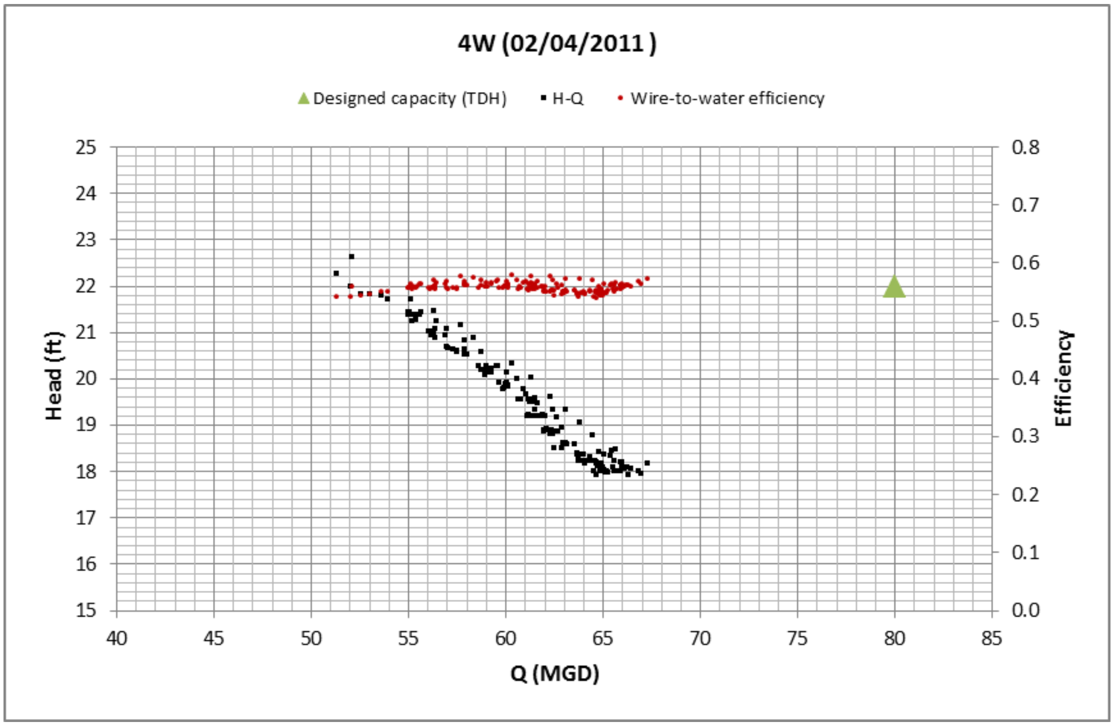


Figure 5 Static head-discharge curve and efficiency-discharge curve (4W)

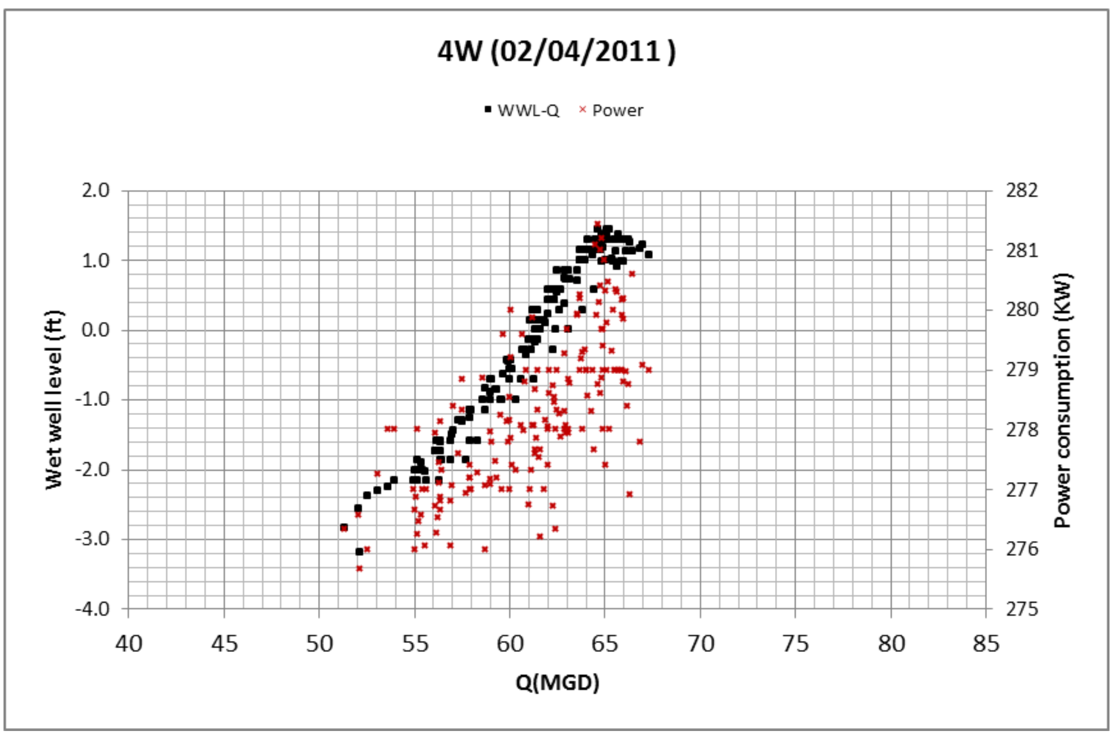


Figure 6 Wet-well level-discharge curve and power-discharge curve (4W)

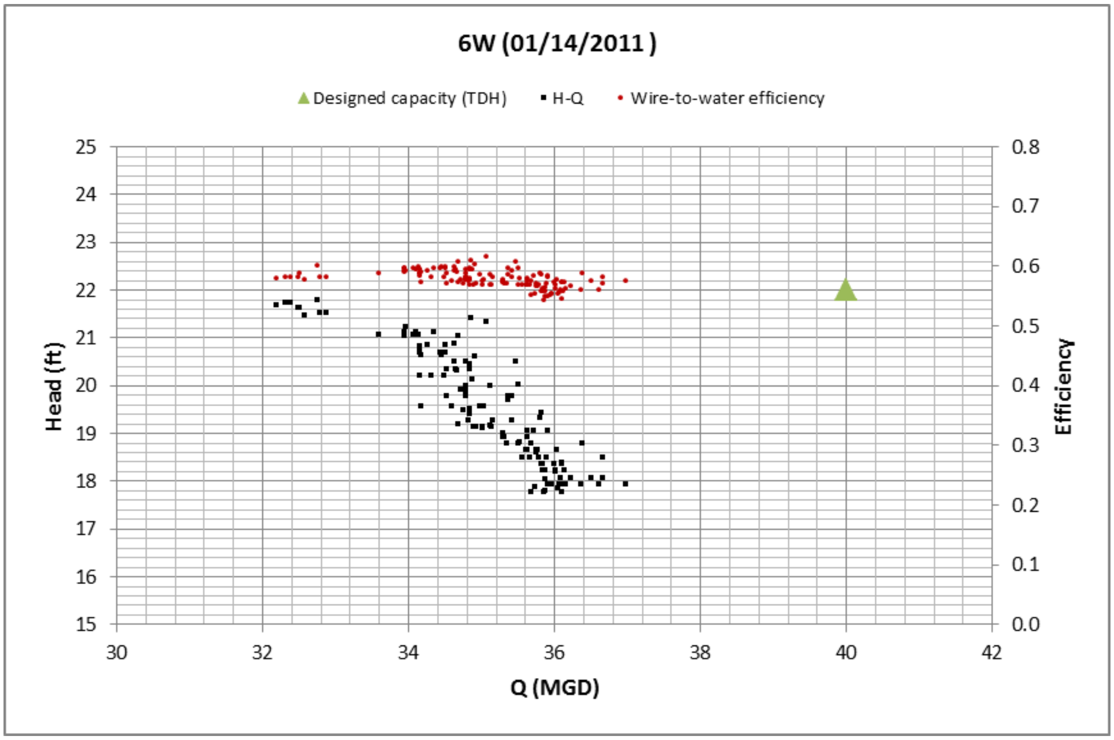


Figure 7 Static head-discharge curve and efficiency-discharge curve (6W)

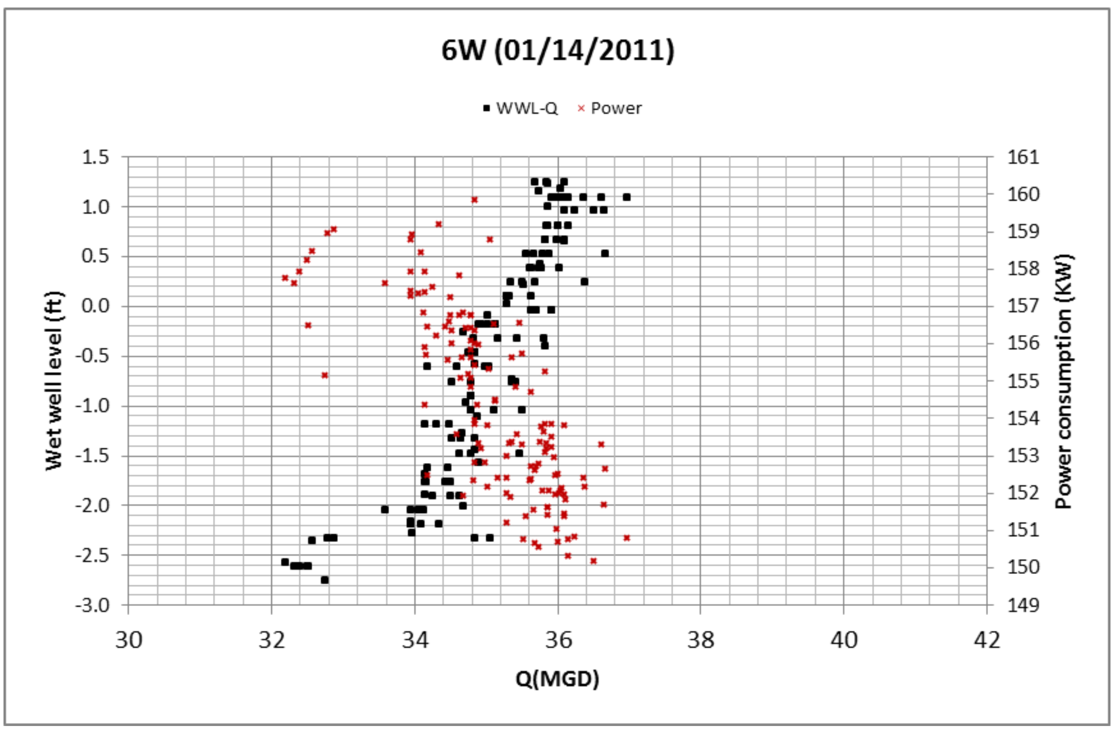


Figure 8 Wet-well level-discharge curve and power-discharge curve (6W)

(2)Variable Speed Pumps

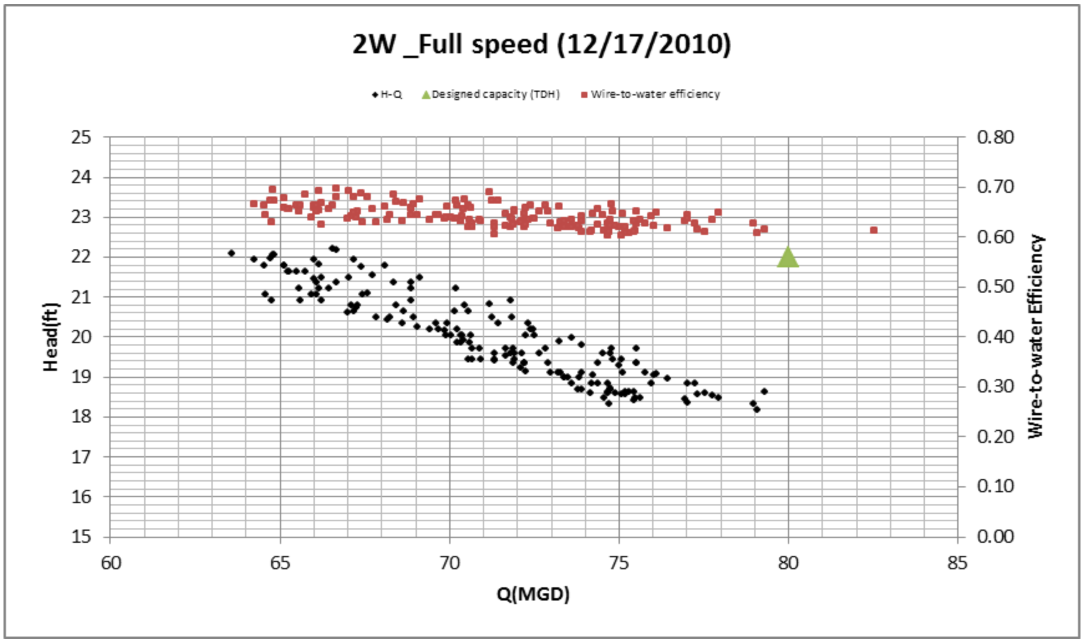


Figure 9 Static head-discharge curve and efficiency-discharge curve (2W_Full speed)

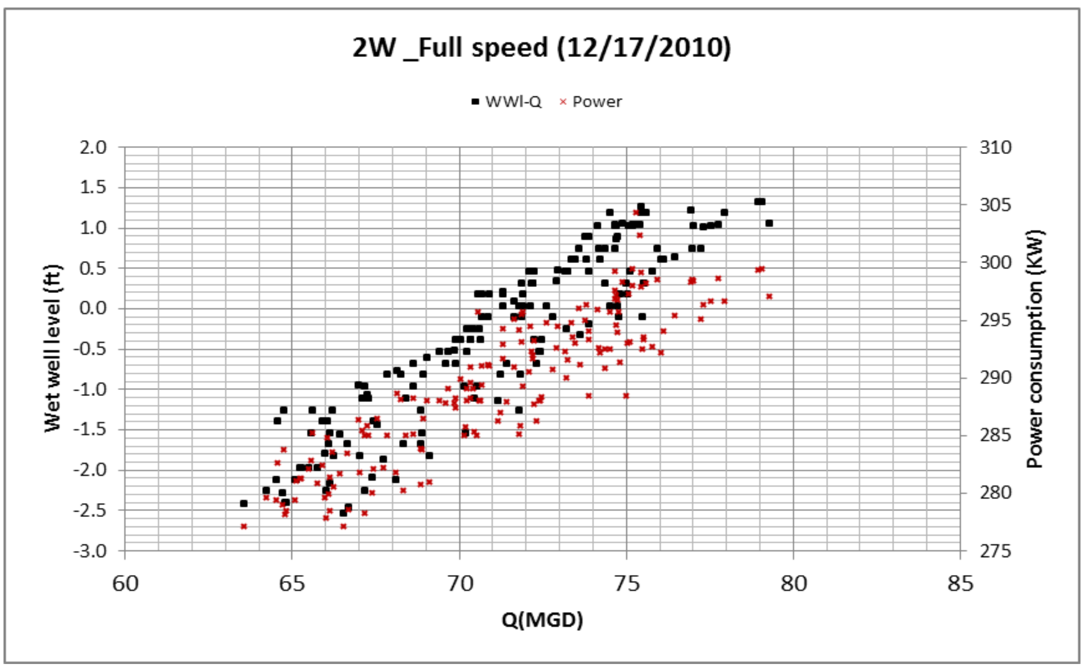


Figure 10 Wet-well level-discharge curve and power-discharge curve (2W_Full speed)

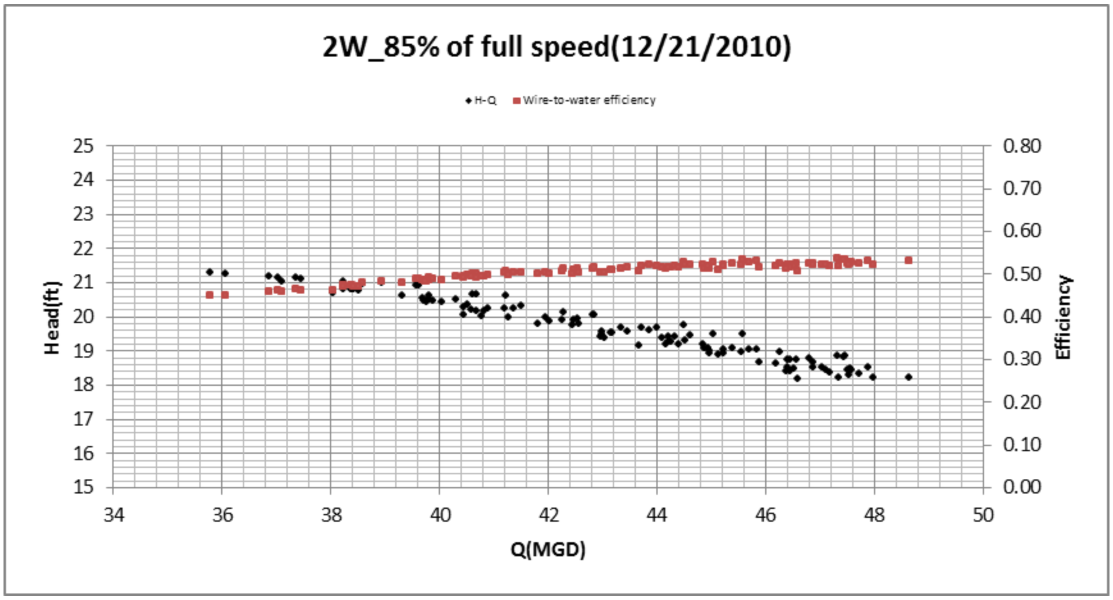


Figure 11 Static head-discharge curve and efficiency-discharge curve (2W_85% of full speed)

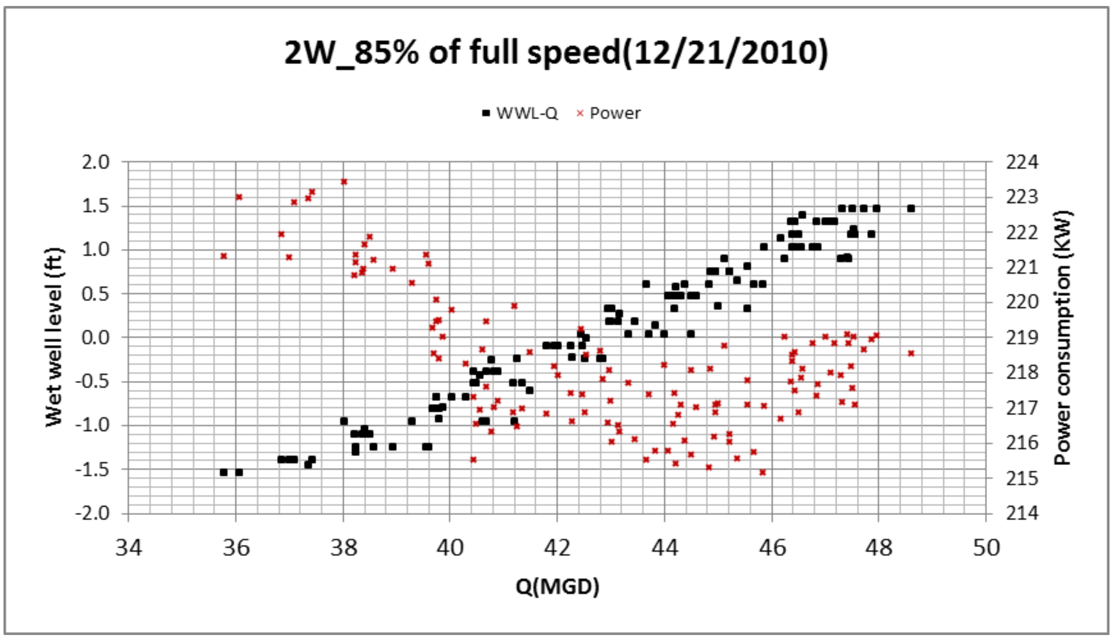


Figure 12 Wet-well level-discharge curve and power-discharge curve (2W_85% of full speed)

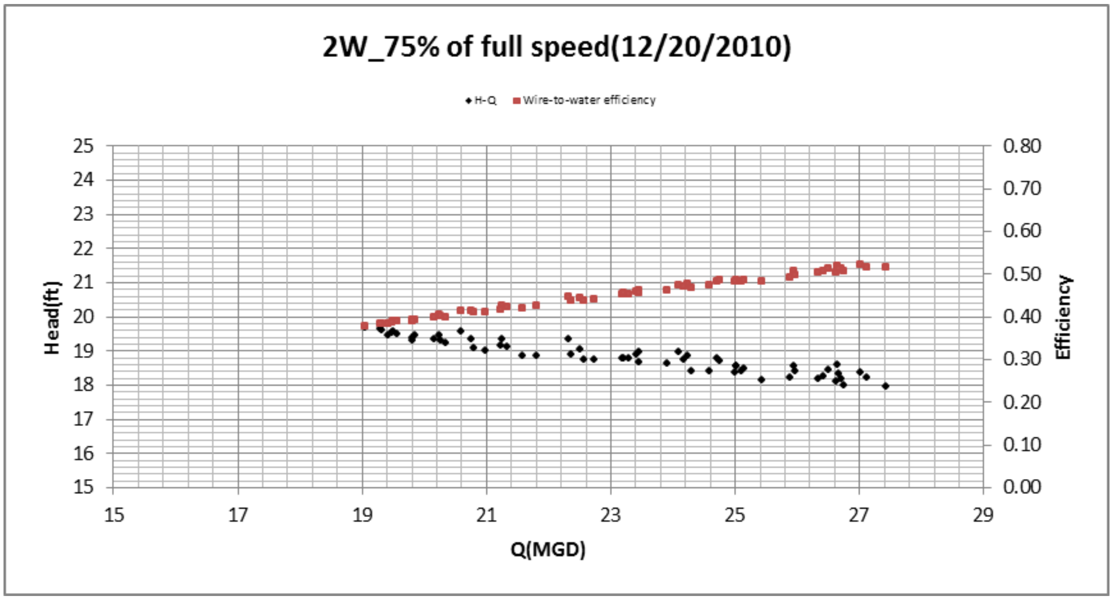


Figure 13 Static head-discharge curve and efficiency-discharge curve (2W_75% of full speed)

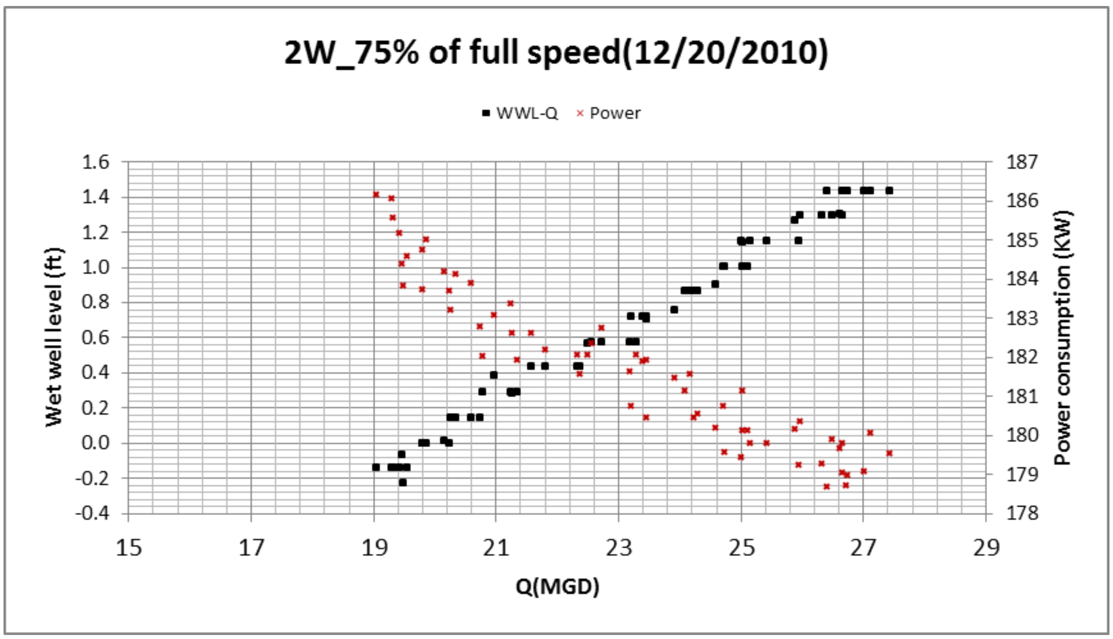


Figure 14 Wet-well level-discharge curve and power-discharge curve (2W_75% of full speed)

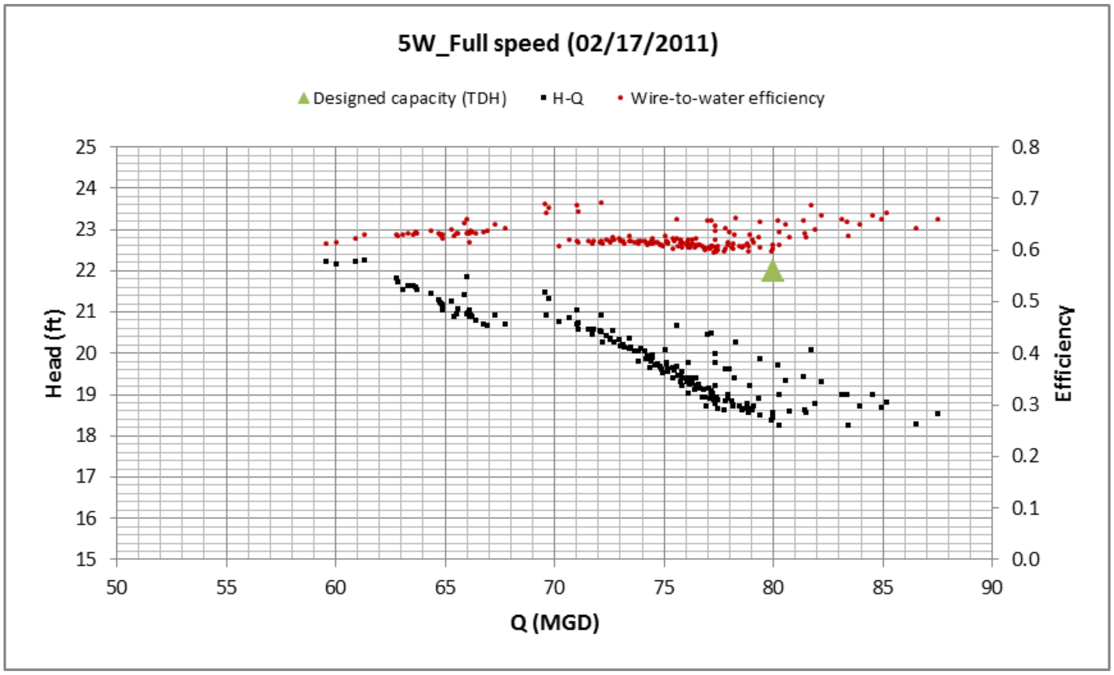


Figure 15 Static head-discharge curve and efficiency-discharge curve (5W_Full speed)

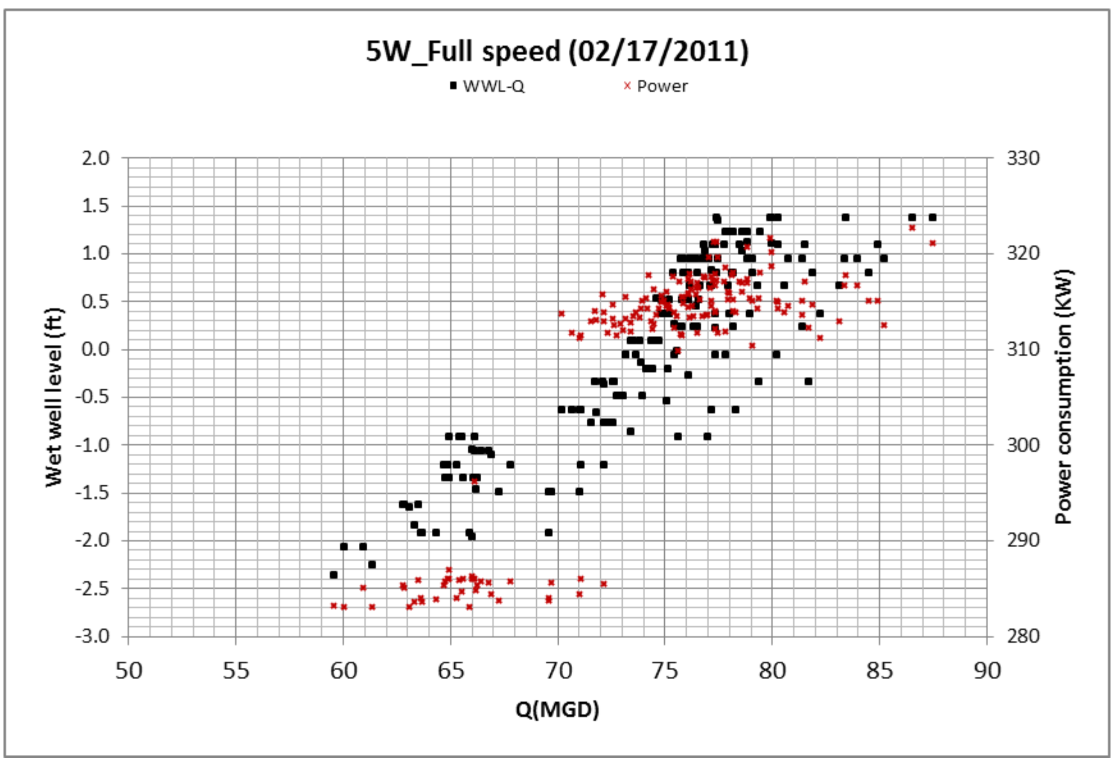


Figure 16 Wet-well level-discharge curve and power-discharge curve (5W_Full speed)

RWWPS2

(1)Constant Speed Pumps

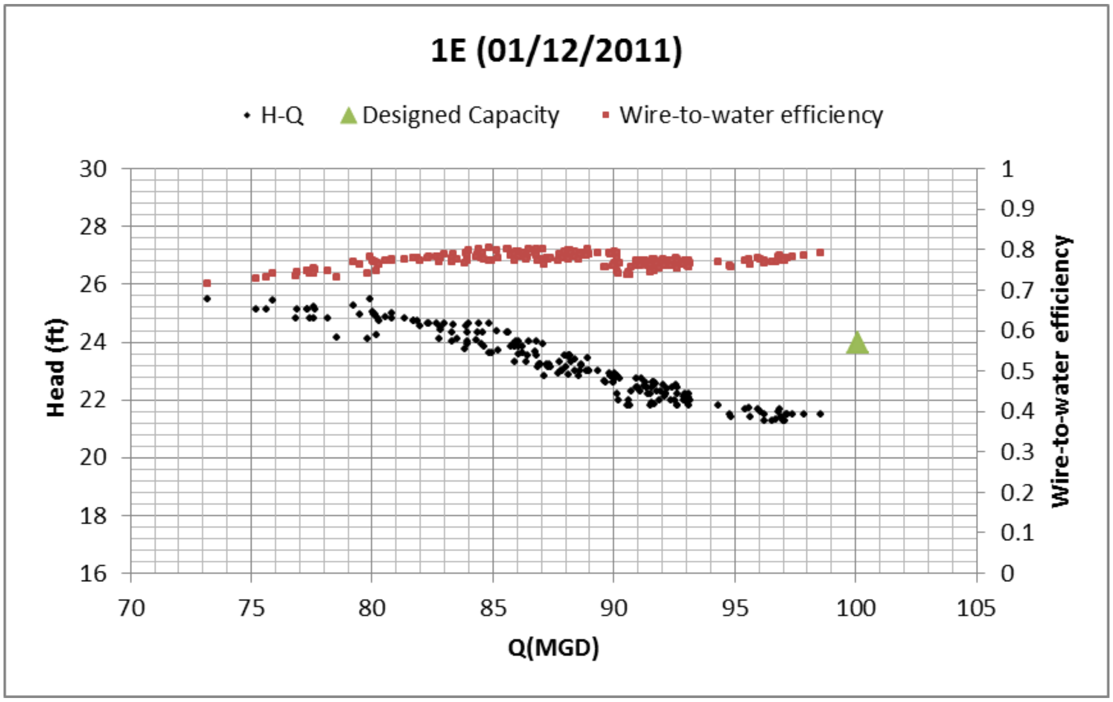


Figure 17 Static head-discharge curve and efficiency-discharge curve (1E)

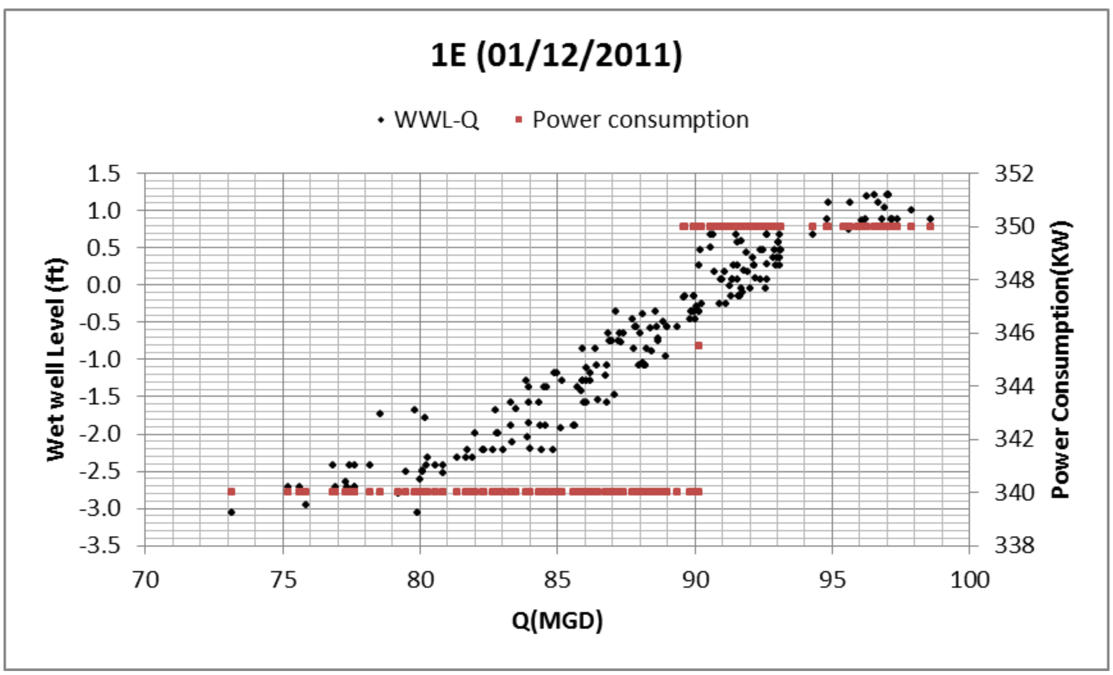


Figure 18 Wet-well level-discharge curve and power-discharge curve (1E)

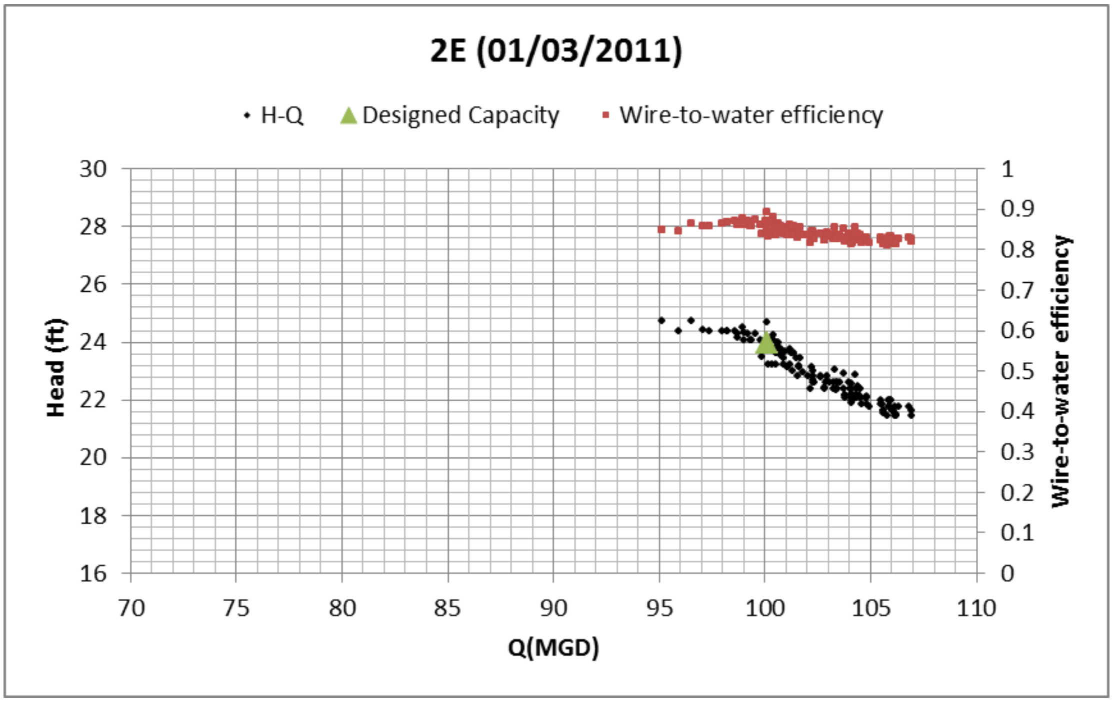


Figure 19 Static head-discharge curve and efficiency-discharge curve (2E)

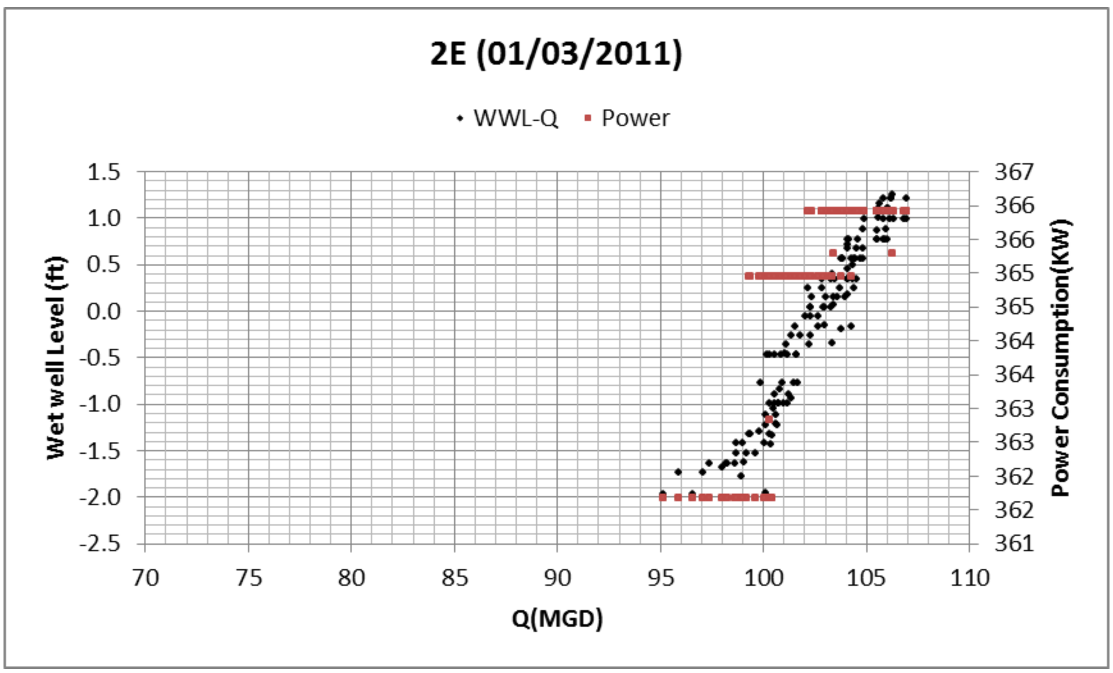


Figure 20 Wet-well level-discharge curve and power-discharge curve (2E)

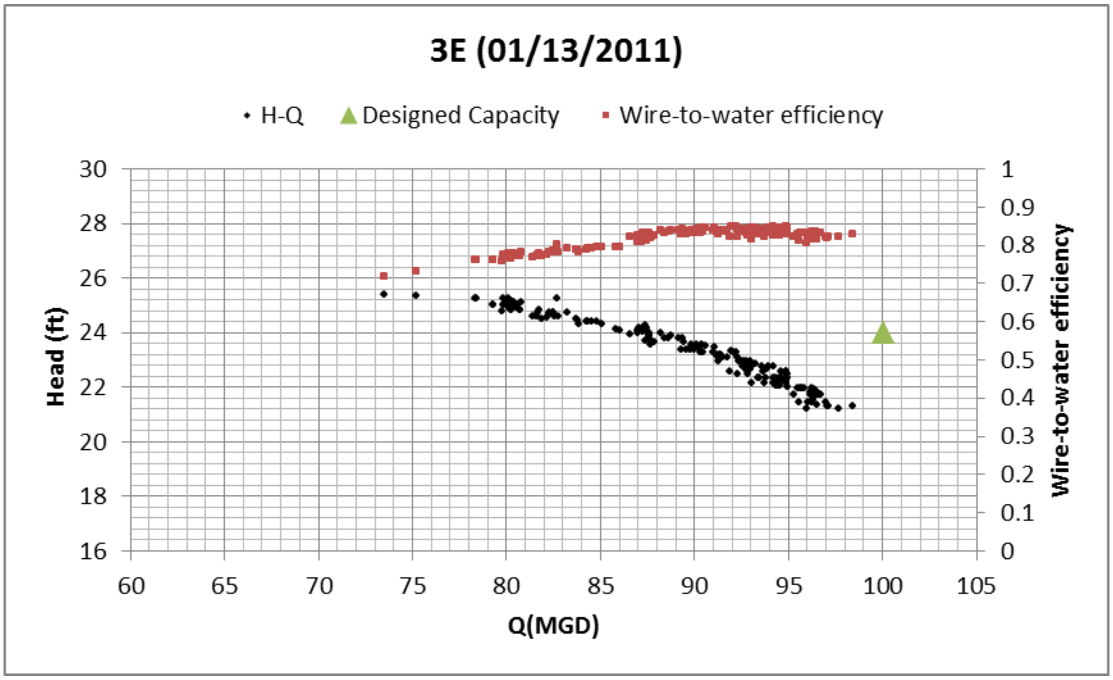


Figure 21 Static head-discharge curve and efficiency-discharge curve (3E)

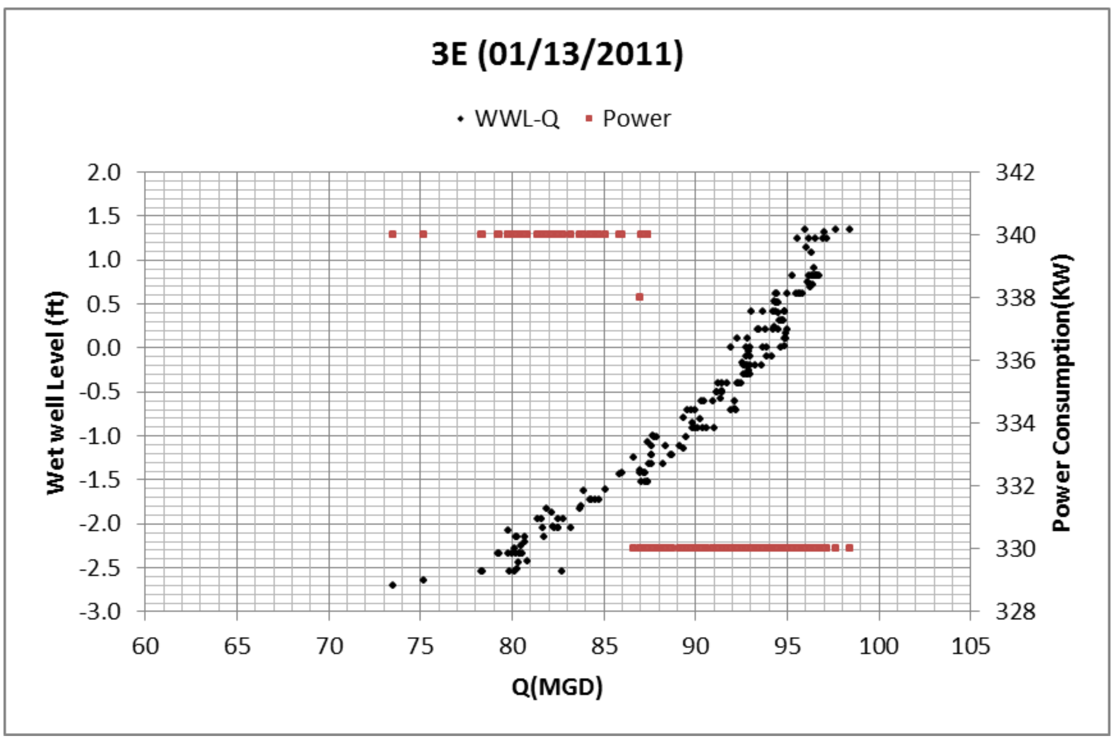


Figure 22 Wet-well level-discharge curve and power-discharge curve (3E)

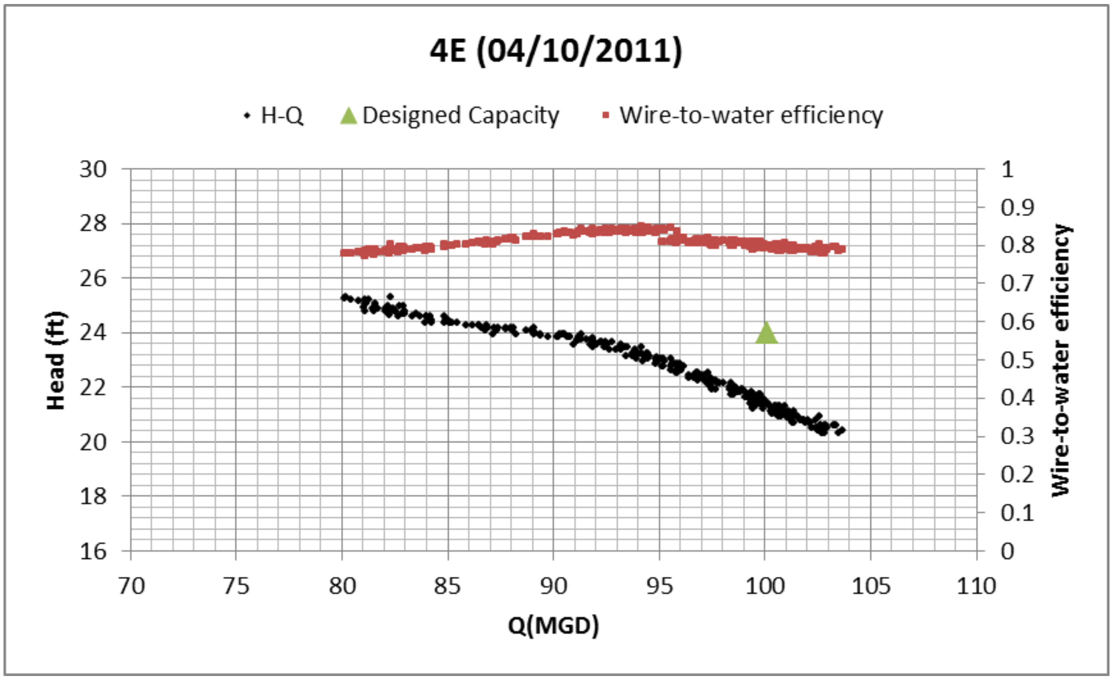


Figure 23 Static head-discharge curve and efficiency-discharge curve (4E)

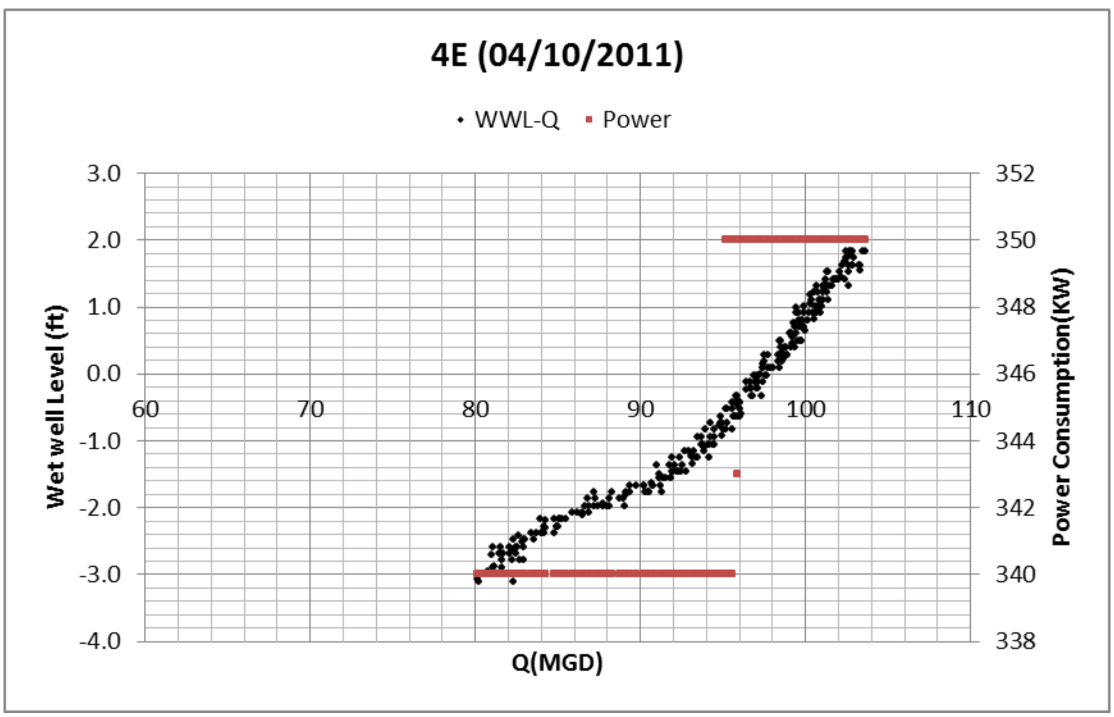


Figure 24 Wet-well level-discharge curve and power-discharge curve (4E)

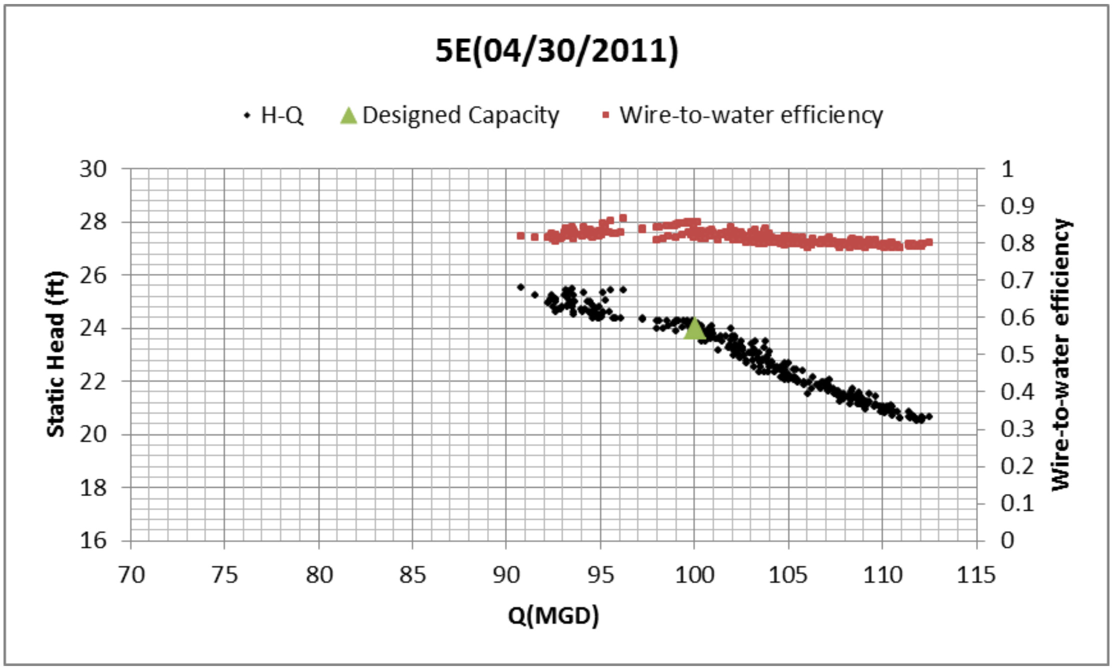


Figure 25 Static head-discharge curve and efficiency-discharge curve (5E)

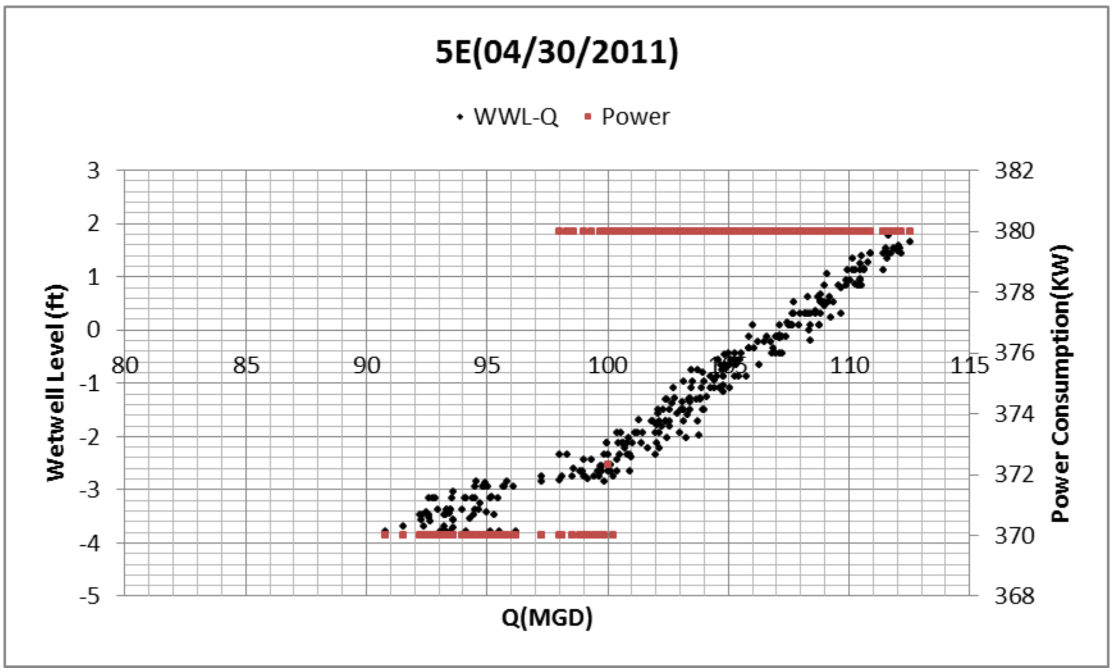


Figure 26 Wet-well level-discharge curve and power-discharge curve (5E)

(2)Variable Speed Pumps

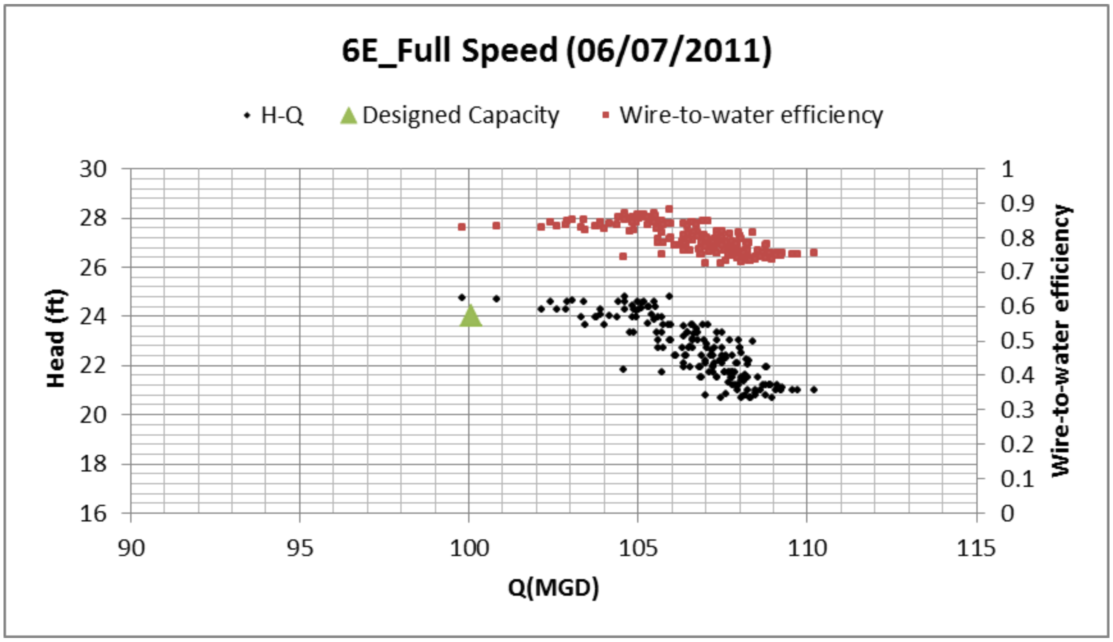


Figure 27 Static head-discharge curve and efficiency-discharge curve (6E_full speed)

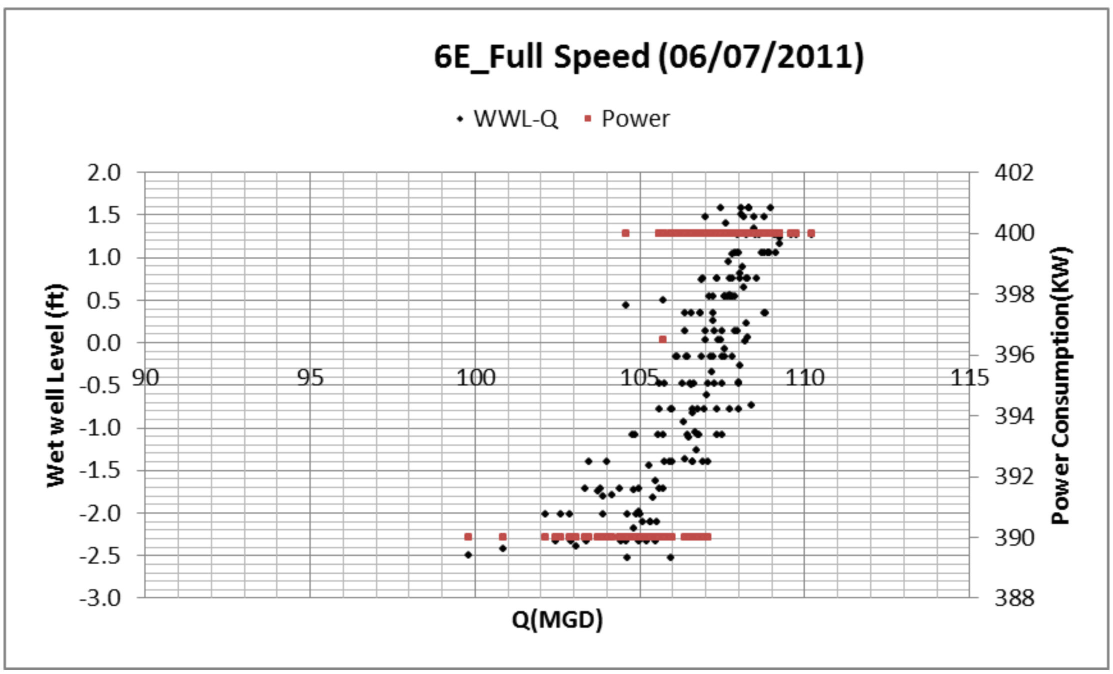


Figure 28 Wet-well level-discharge curve and power-discharge curve (6E_Full speed)

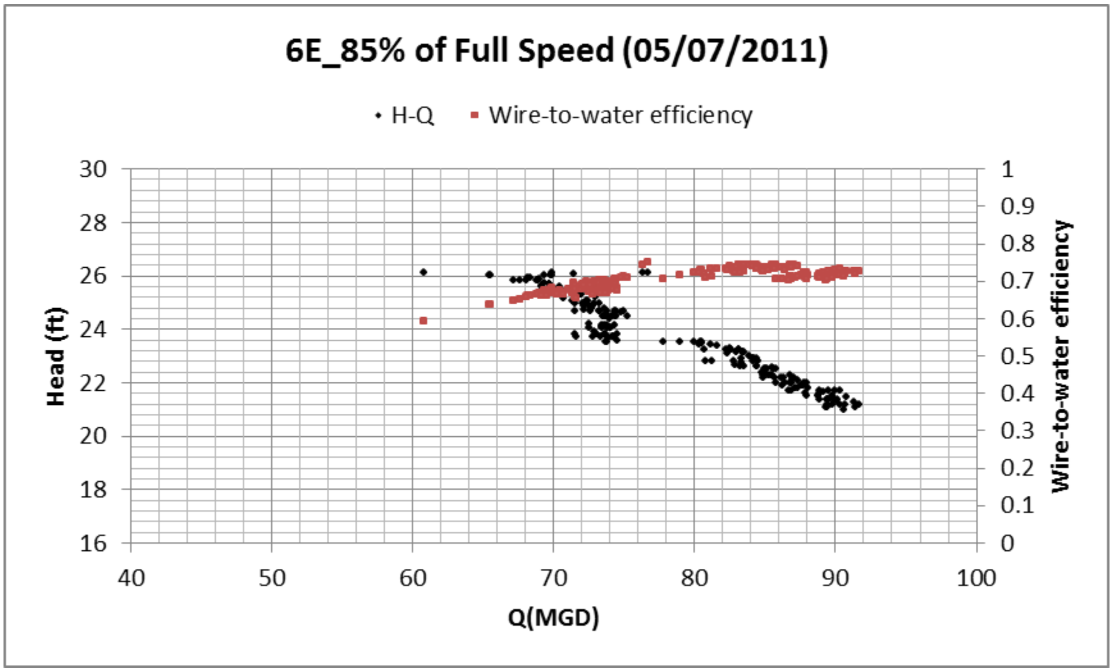


Figure 29 Static head-discharge curve and efficiency-discharge curve (6E_85% of full speed)

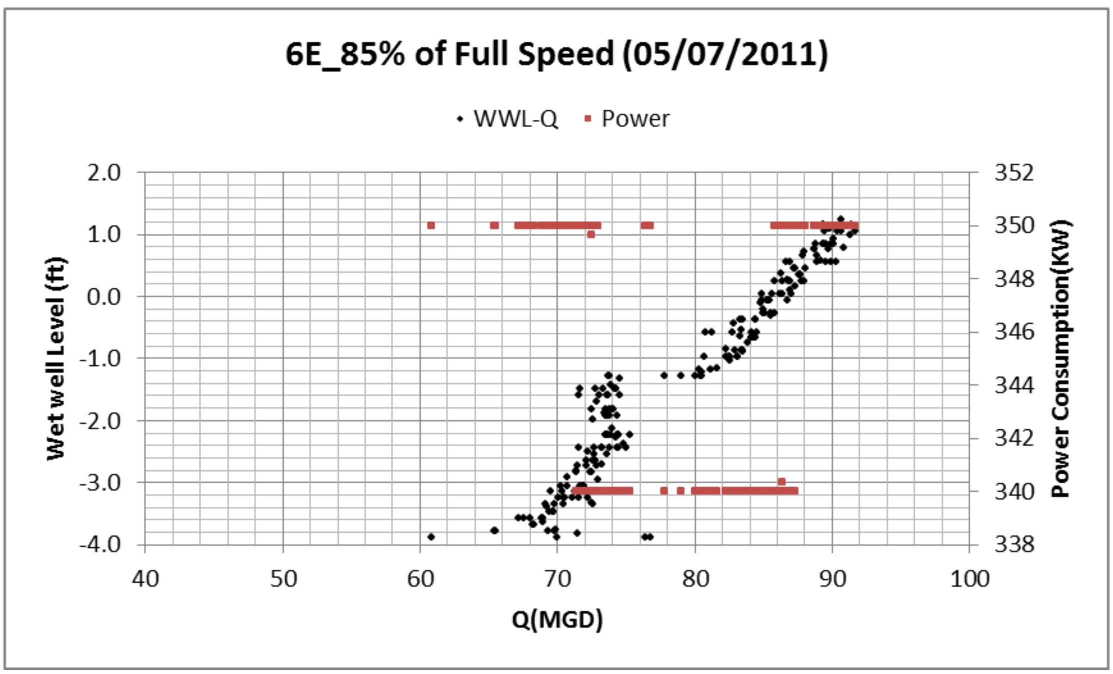


Figure 30 Wet-well level-discharge curve and power-discharge curve (6E_85% of full speed)

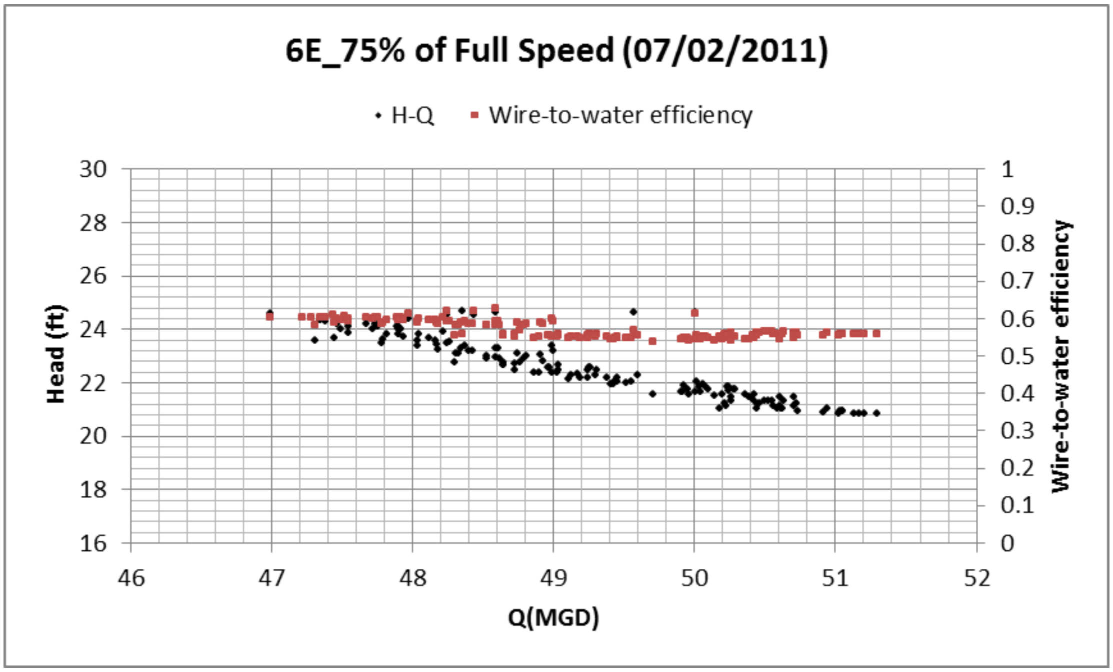


Figure 31 Static head-discharge curve and efficiency-discharge curve (6E_75% of full speed)

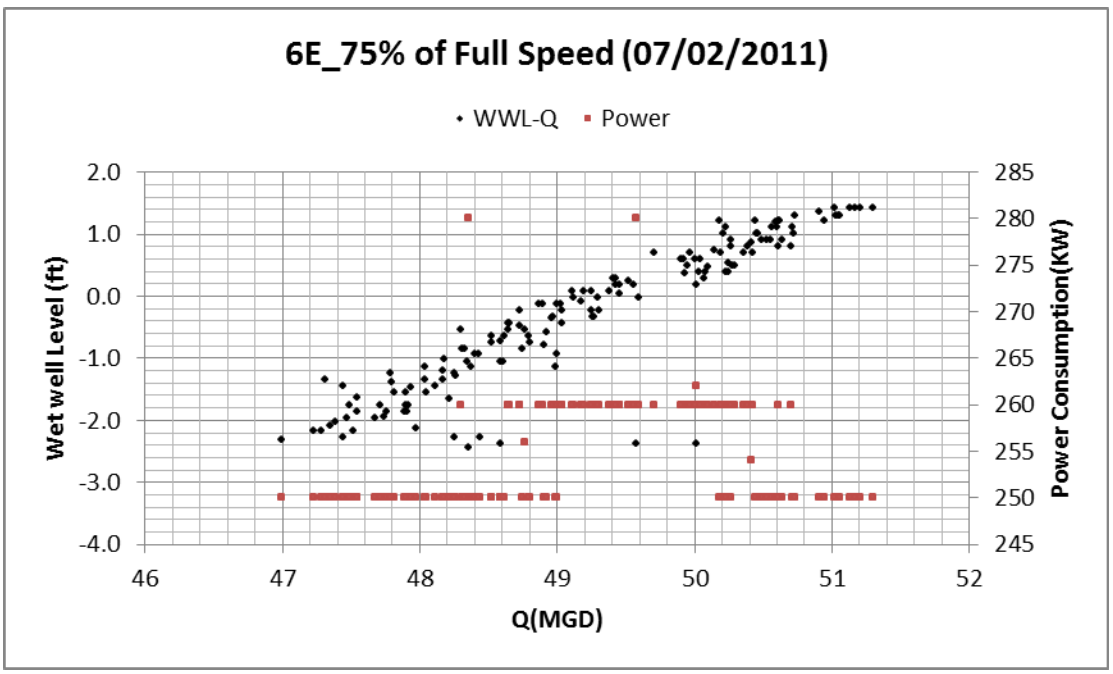


Figure 32 Wet-well level-discharge curve and power-discharge curve (6E_75% of full speed)

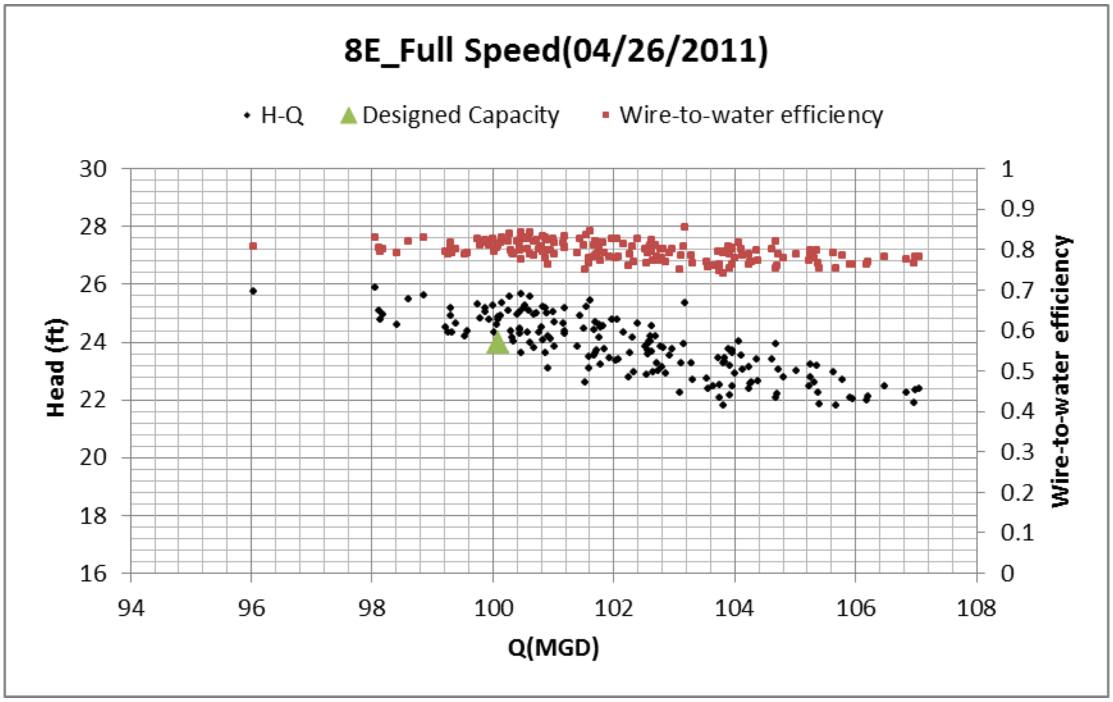


Figure 33 Static head-discharge curve and efficiency-discharge curve (8E_full speed)

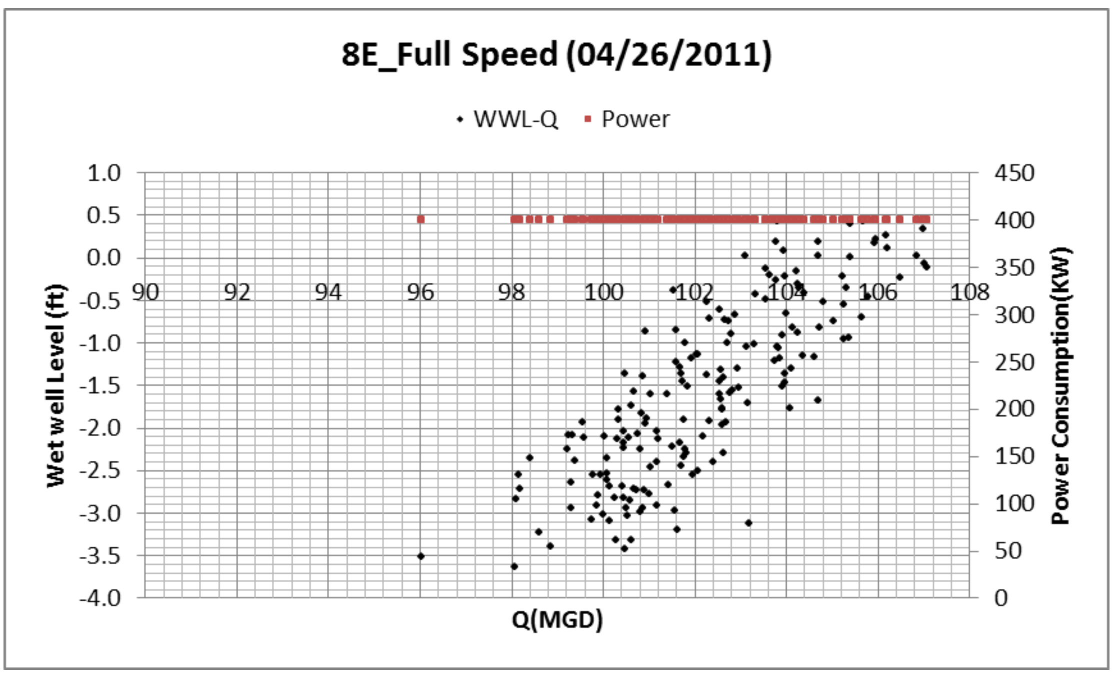


Figure 34 Wet-well level-discharge curve and power-discharge curve (8E_Full speed)

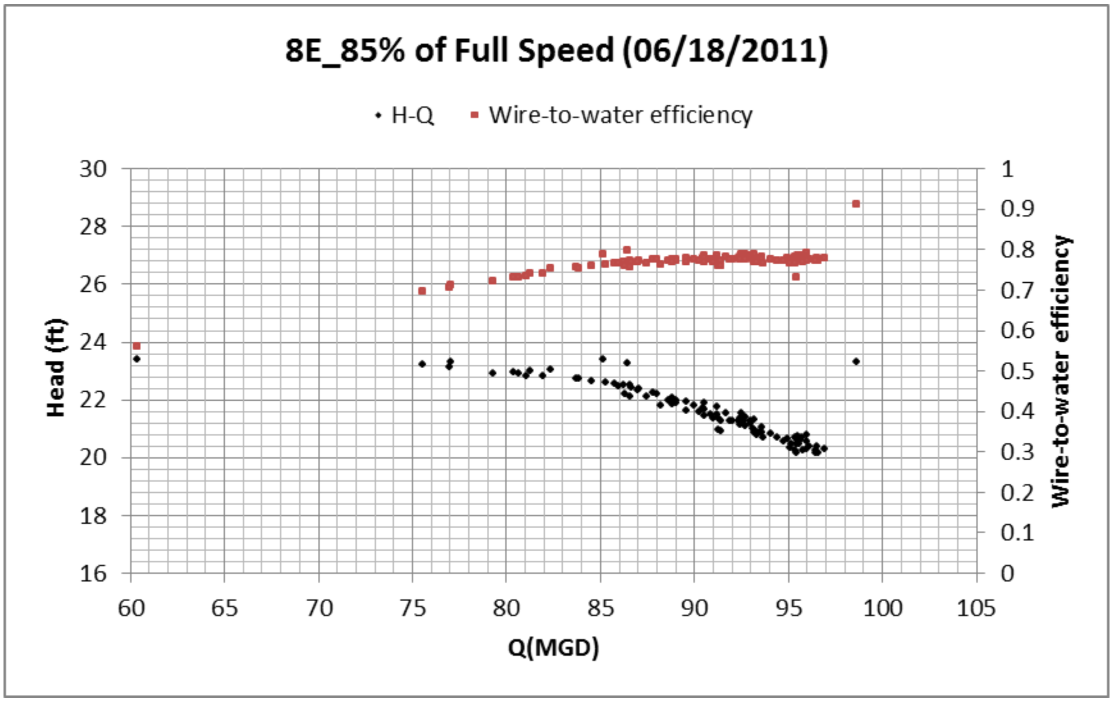


Figure 35 Static head-discharge curve and efficiency-discharge curve (8E_85% of full speed)

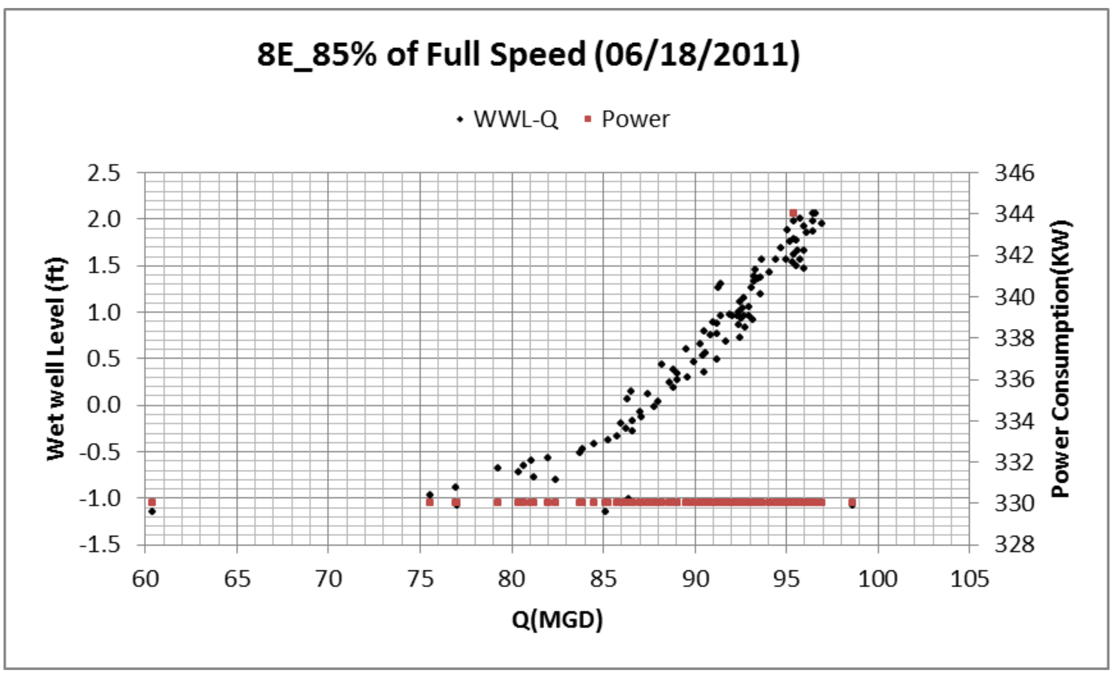


Figure 36 Wet-well level-discharge curve and power-discharge curve (8E_85% of full speed)

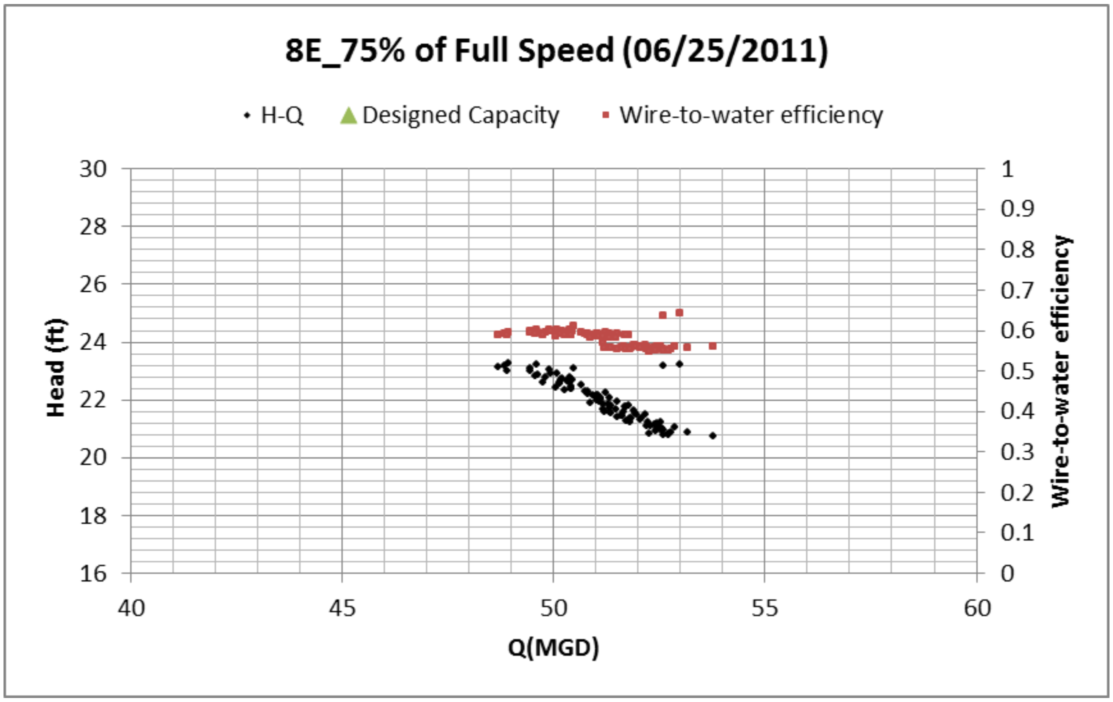


Figure 37 Static head-discharge curve and efficiency-discharge curve (8E_75% of full speed)

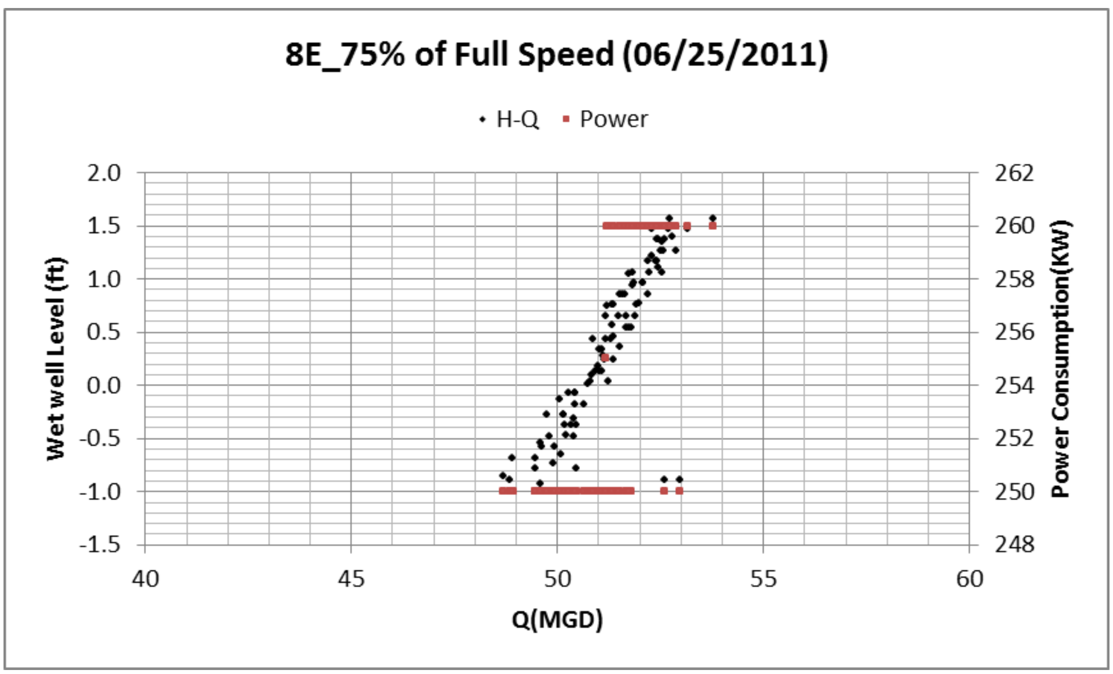


Figure 38 Wet-well level-discharge curve and power-discharge curve (8E_75% of full speed)

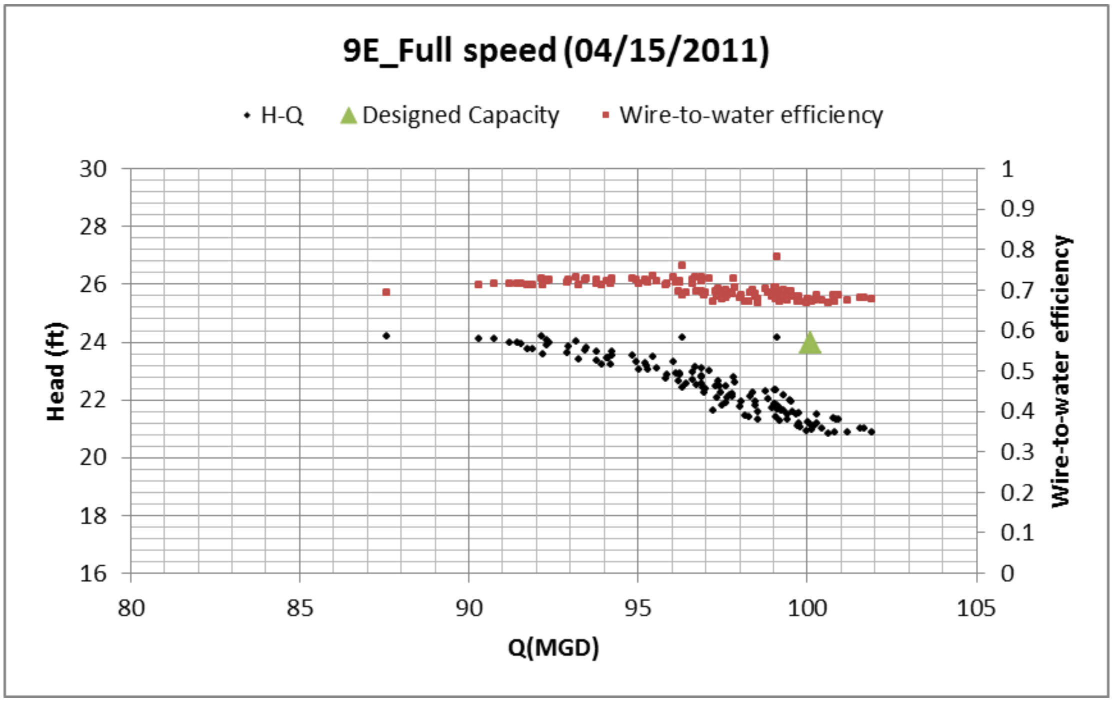


Figure 39 Static head-discharge curve and efficiency-discharge curve (9E_full speed)

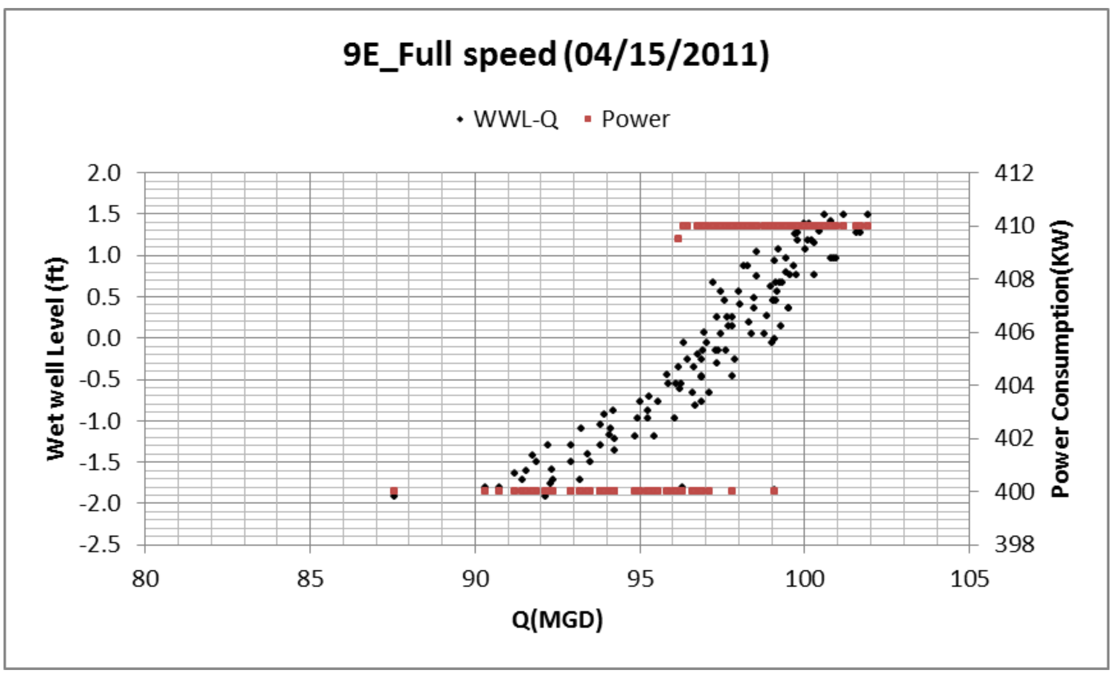


Figure 40 Wet-well level-discharge curve and power-discharge curve (9E_ full speed)

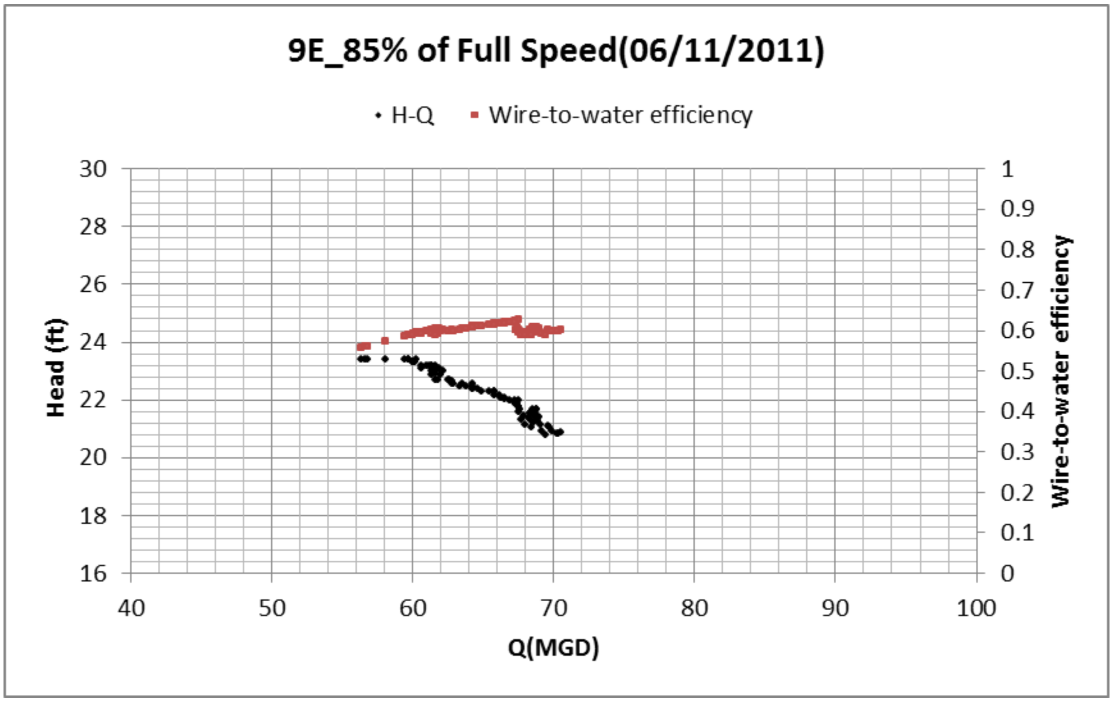


Figure 41 Static head-discharge curve and efficiency-discharge curve (9E_85% of full speed)

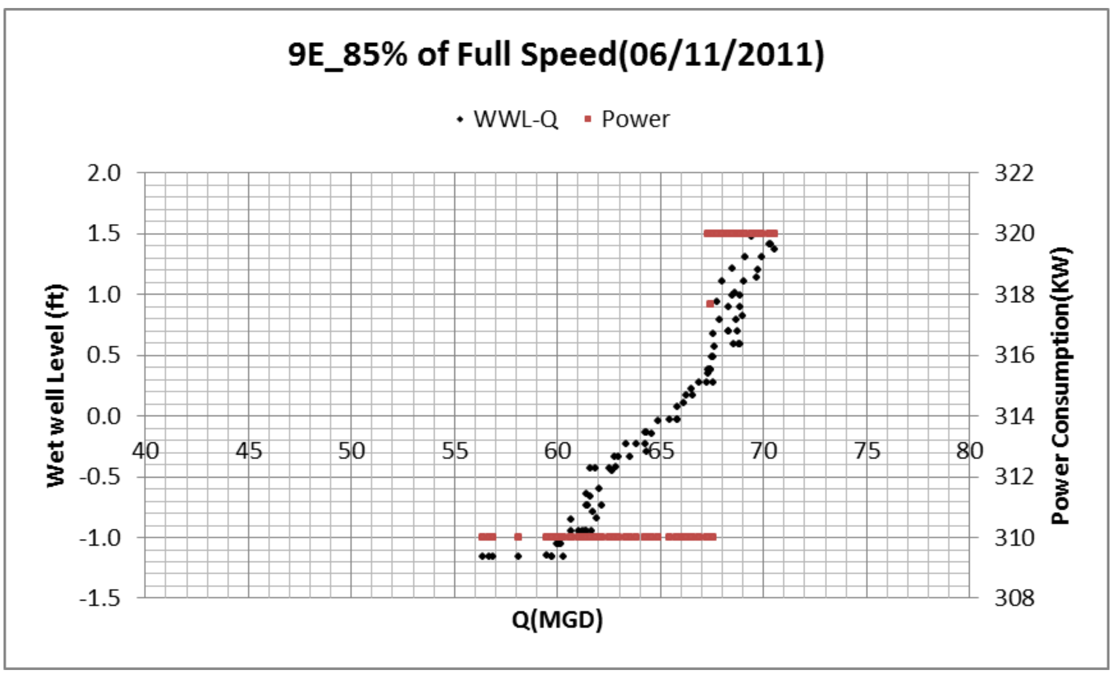


Figure 42 Wet-well level-discharge curve and power-discharge curve (9E_85% of full speed)

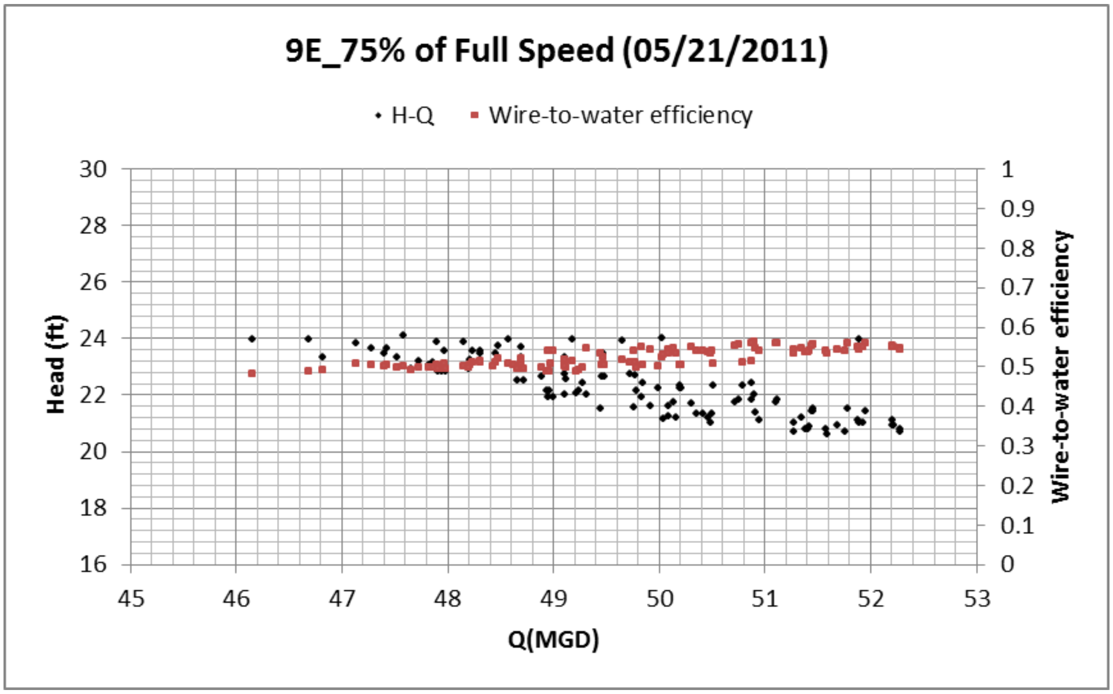


Figure 43 Static head-discharge curve and efficiency-discharge curve (9E_75% of full speed)

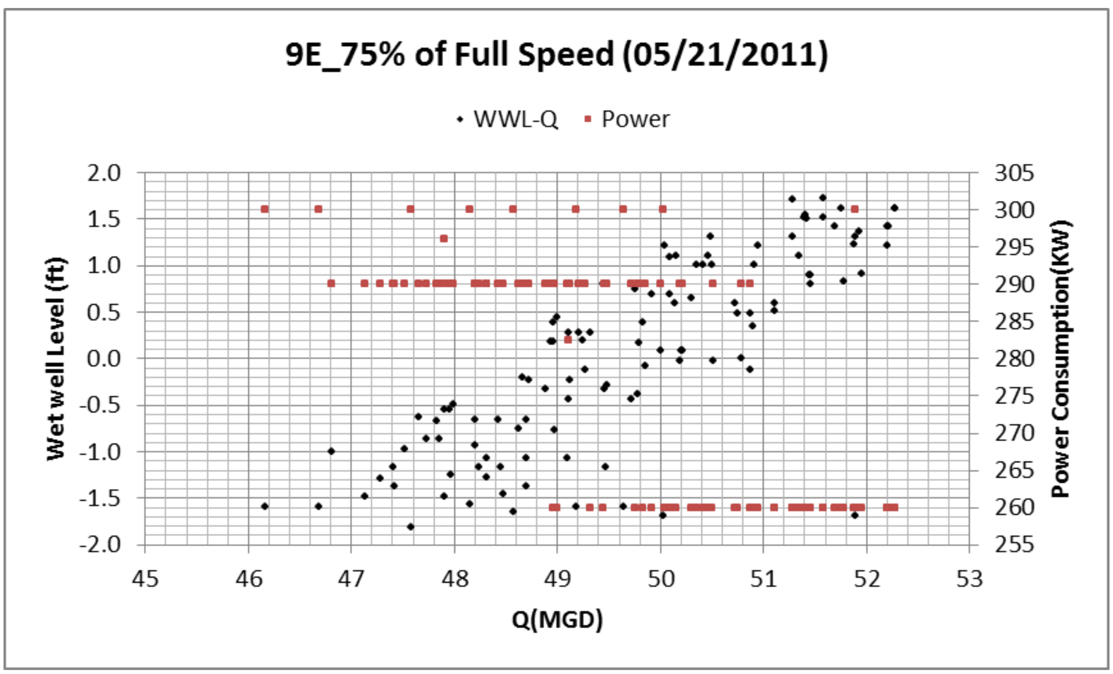
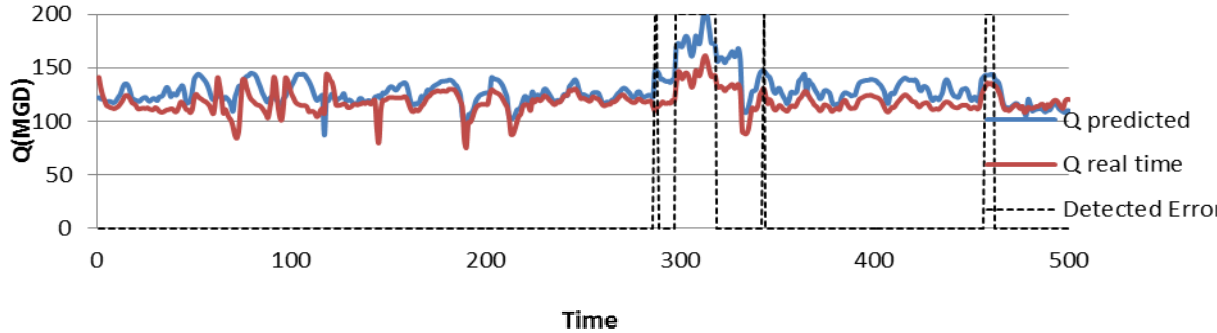
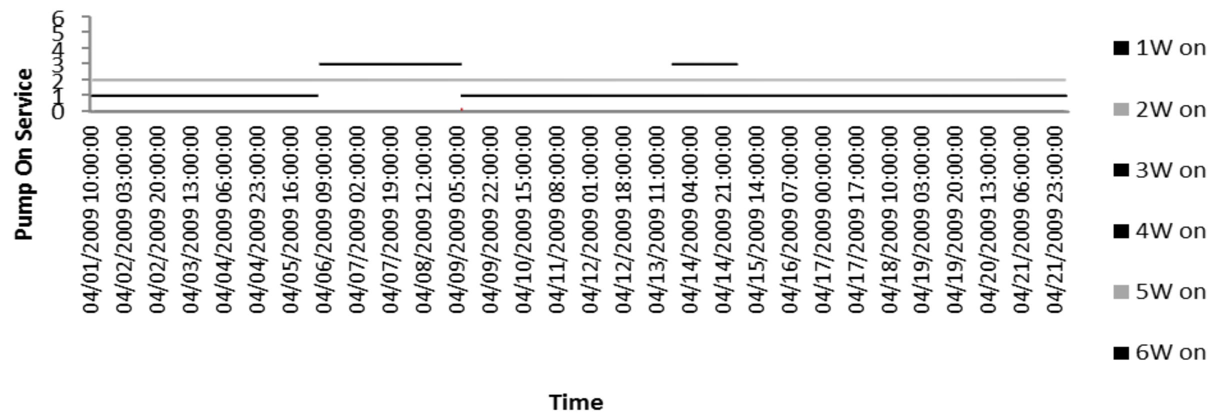


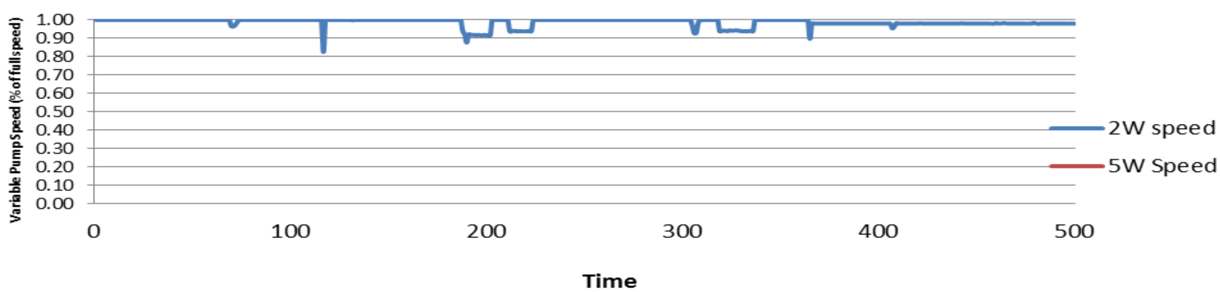
Figure 44 Wet-well level-discharge curve and power-discharge curve (9E_75% of full speed)

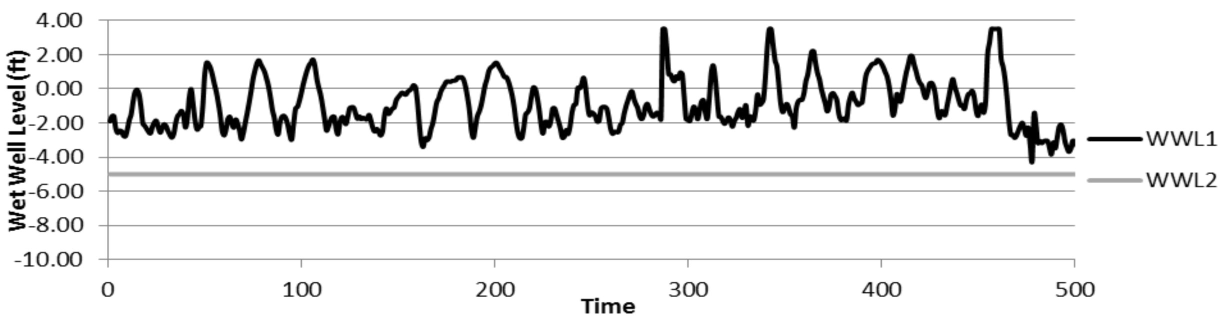
Appendix 6. Influent Flow Rate Simulation

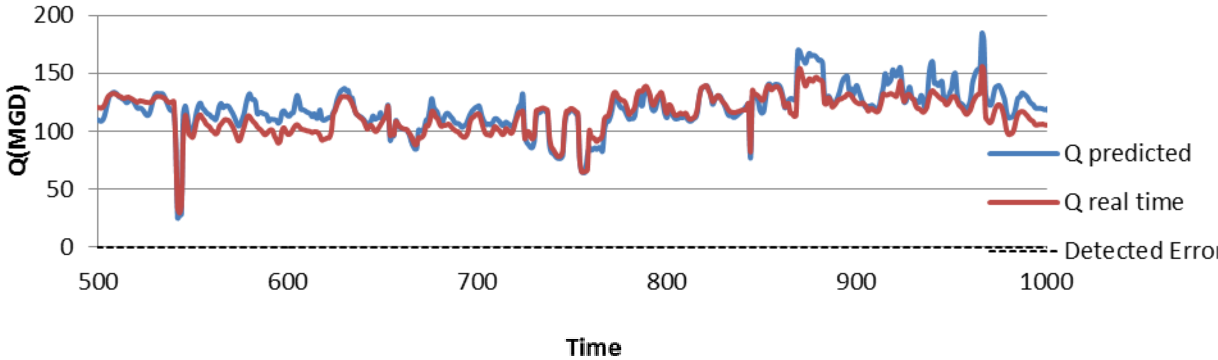
(1) RWWPS1

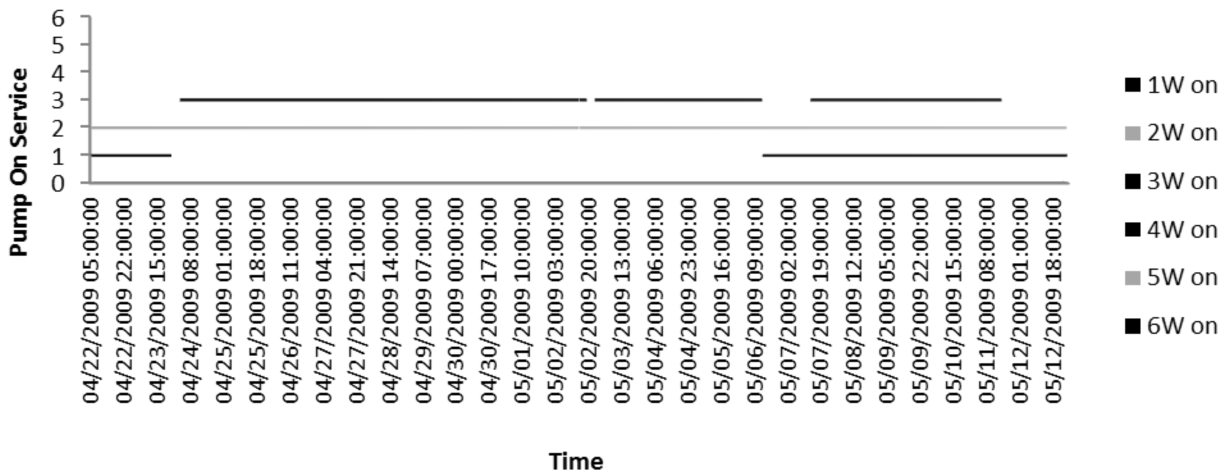


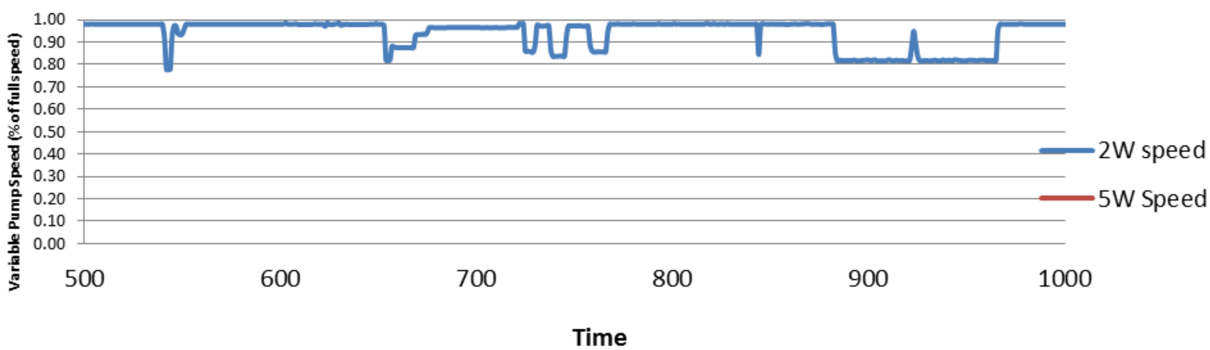


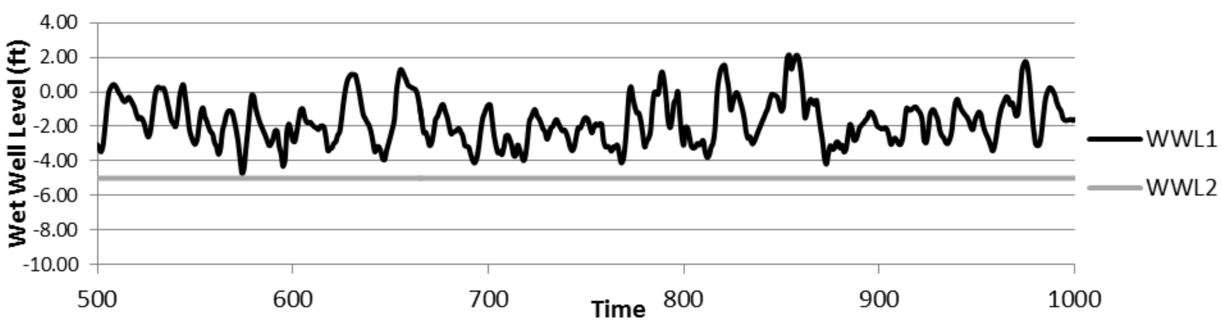


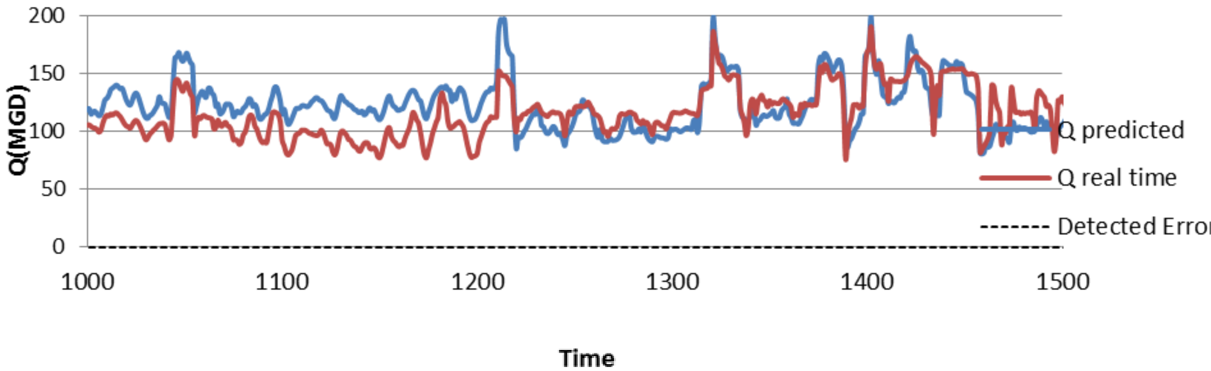


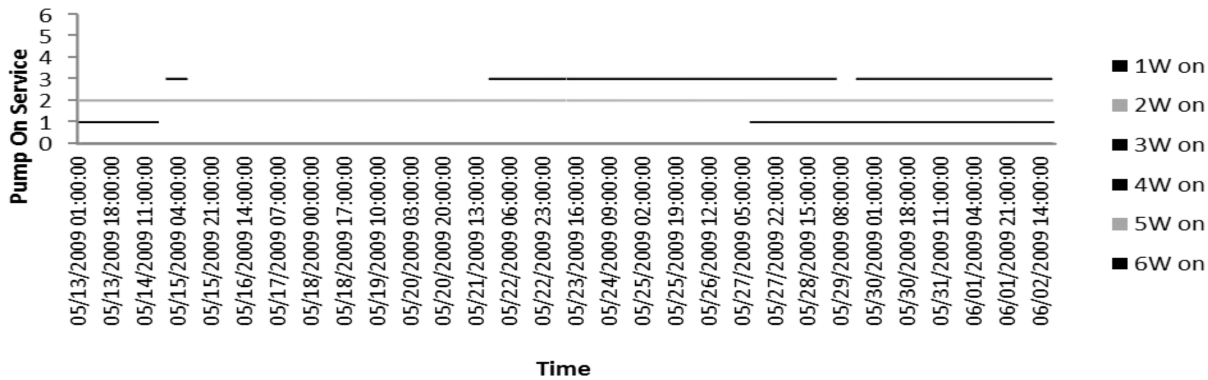

Q(MGD)
200
150
100
50
0
500
600
700
800
900
1000
Time
Q predicted
Q real time
Detected Error

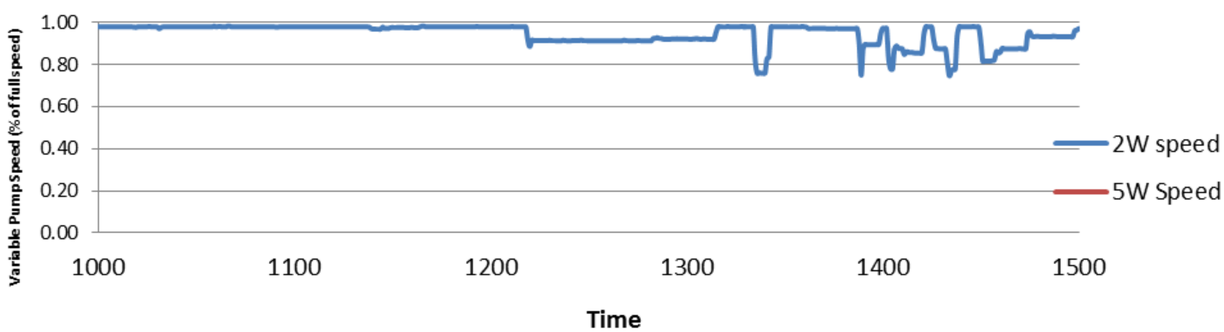

Pump On Service
6
5
4
3
2
1
0
04/22/2009 05:00:00
04/22/2009 22:00:00
04/23/2009 15:00:00
04/24/2009 08:00:00
04/25/2009 01:00:00
04/25/2009 18:00:00
04/26/2009 11:00:00
04/27/2009 04:00:00
04/27/2009 21:00:00
04/28/2009 14:00:00
04/29/2009 07:00:00
04/30/2009 00:00:00
04/30/2009 17:00:00
05/01/2009 10:00:00
05/02/2009 03:00:00
05/02/2009 20:00:00
05/03/2009 13:00:00
05/04/2009 06:00:00
05/04/2009 23:00:00
05/05/2009 16:00:00
05/06/2009 09:00:00
05/07/2009 02:00:00
05/07/2009 19:00:00
05/08/2009 12:00:00
05/09/2009 05:00:00
05/09/2009 22:00:00
05/10/2009 15:00:00
05/11/2009 08:00:00
05/12/2009 01:00:00
05/12/2009 18:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

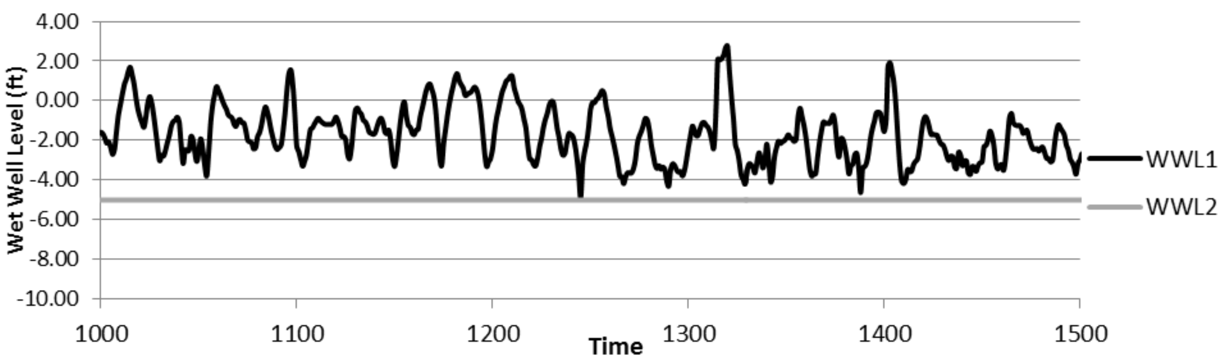

Variable Pump Speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
500
600
700
800
900
1000
Time
2W speed
5W Speed

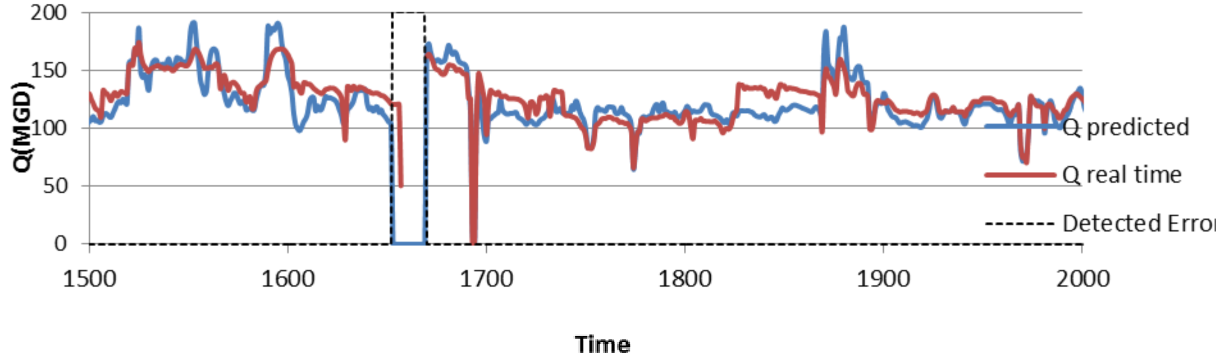

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
500
600
700
Time
800
900
1000
WWL1
WWL2

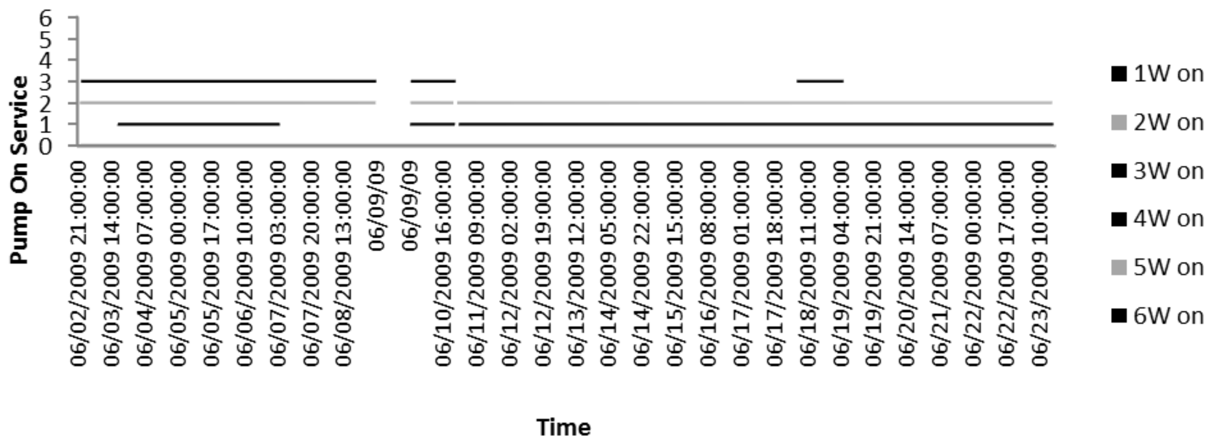

Q(MGD)
200
150
100
50
0
1000
1100
1200
1300
1400
1500
Time
Q predicted
Q real time
Detected Error

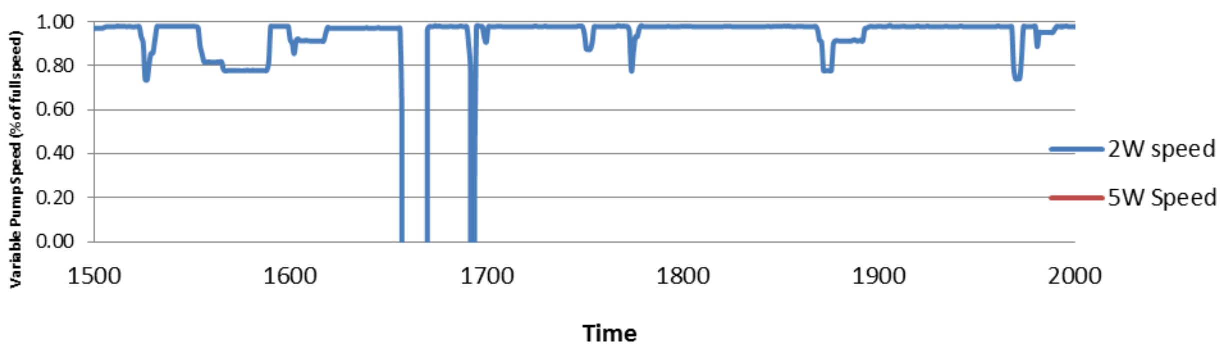

Pump On Service
6
5
4
3
2
1
0
05/13/2009 01:00:00
05/13/2009 18:00:00
05/14/2009 11:00:00
05/15/2009 04:00:00
05/15/2009 21:00:00
05/16/2009 14:00:00
05/17/2009 07:00:00
05/18/2009 00:00:00
05/18/2009 17:00:00
05/19/2009 10:00:00
05/20/2009 03:00:00
05/20/2009 20:00:00
05/21/2009 13:00:00
05/22/2009 06:00:00
05/22/2009 23:00:00
05/23/2009 16:00:00
05/24/2009 09:00:00
05/25/2009 02:00:00
05/25/2009 19:00:00
05/26/2009 12:00:00
05/27/2009 05:00:00
05/27/2009 22:00:00
05/28/2009 15:00:00
05/29/2009 08:00:00
05/30/2009 01:00:00
05/30/2009 18:00:00
05/31/2009 11:00:00
06/01/2009 04:00:00
06/01/2009 21:00:00
06/02/2009 14:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

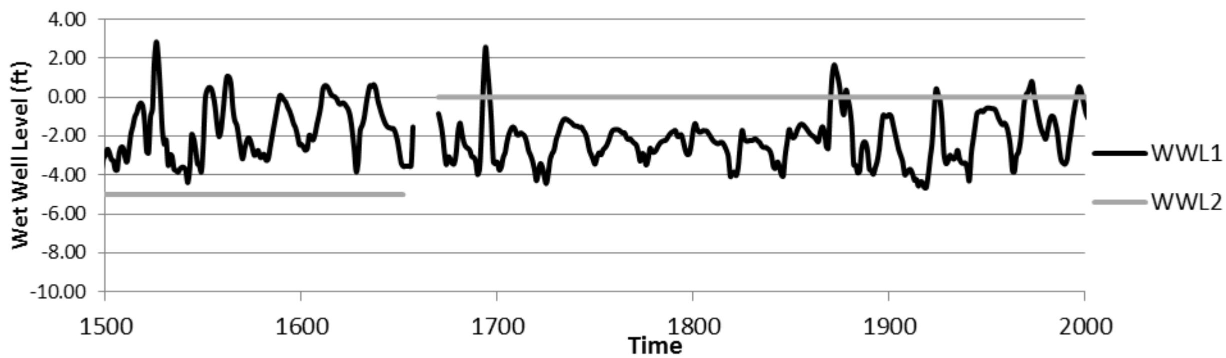

Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
1000
1100
1200
1300
1400
1500
Time
2W speed
5W Speed

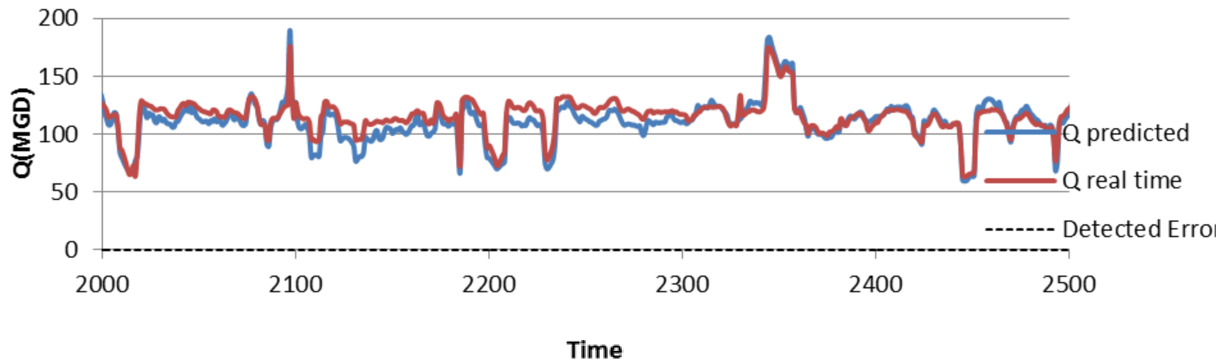

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
1000
1100
1200
1300
1400
1500
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
1500
1600
1700
1800
1900
2000
Time
Q predicted
Q real time
Detected Error

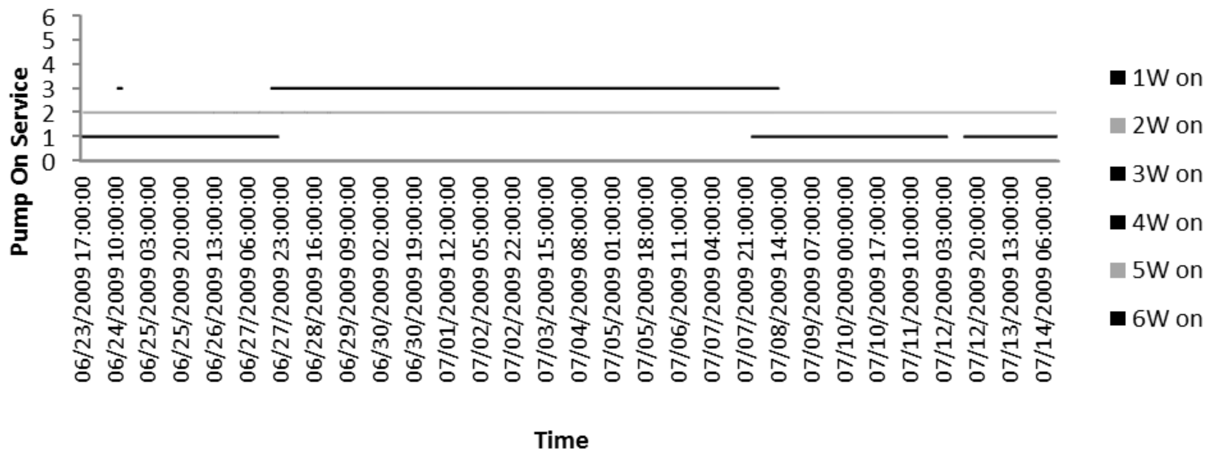

Pump On Service
6
5
4
3
2
1
0
06/02/2009 21:00:00
06/03/2009 14:00:00
06/04/2009 07:00:00
06/05/2009 00:00:00
06/05/2009 17:00:00
06/06/2009 10:00:00
06/07/2009 03:00:00
06/07/2009 20:00:00
06/08/2009 13:00:00
06/09/09
06/09/09
06/10/2009 16:00:00
06/11/2009 09:00:00
06/12/2009 02:00:00
06/12/2009 19:00:00
06/13/2009 12:00:00
06/14/2009 05:00:00
06/14/2009 22:00:00
06/15/2009 15:00:00
06/16/2009 08:00:00
06/17/2009 01:00:00
06/17/2009 18:00:00
06/18/2009 11:00:00
06/19/2009 04:00:00
06/19/2009 21:00:00
06/20/2009 14:00:00
06/21/2009 07:00:00
06/22/2009 00:00:00
06/22/2009 17:00:00
06/23/2009 10:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
1500
1600
1700
1800
1900
2000
Time
2W speed
5W Speed

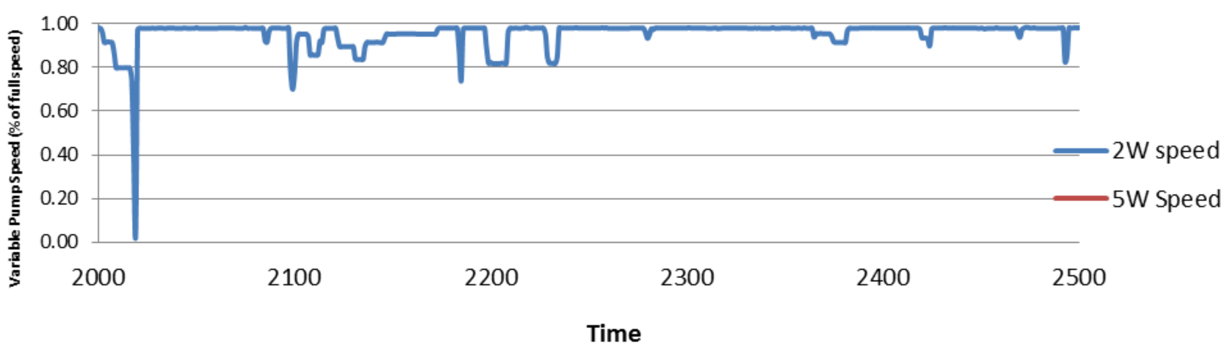

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
1500
1600
1700
1800
1900
2000
Time
WWL1
WWL2



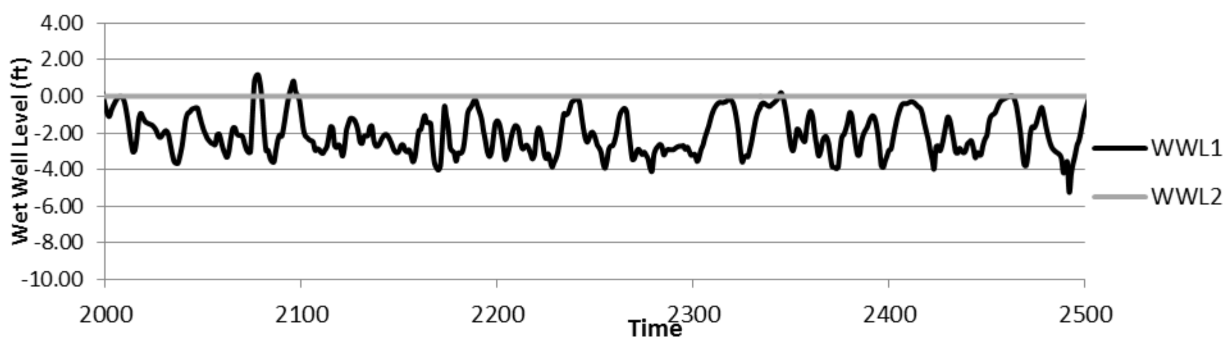
Q(MGD)
200
150
100
50
0
2000
2100
2200
2300
2400
2500
Time
Q predicted
Q real time
Detected Error



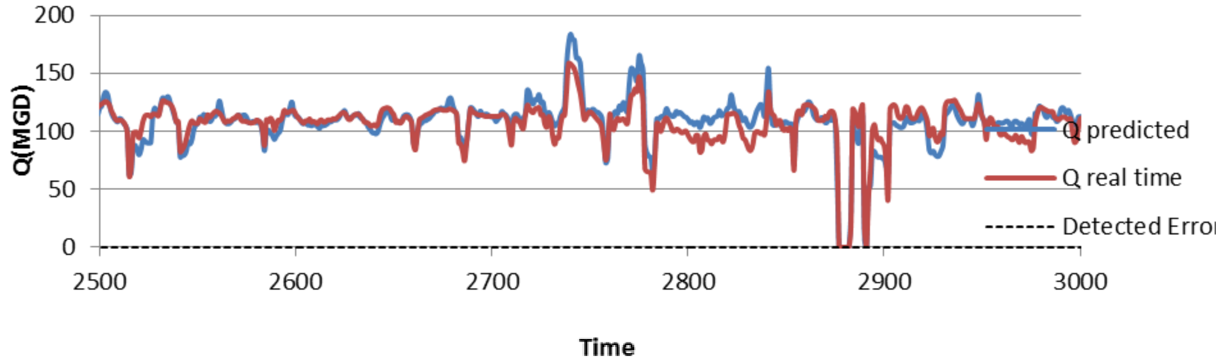
Pump On Service
6
5
4
3
2
1
0
06/23/2009 17:00:00
06/24/2009 10:00:00
06/25/2009 03:00:00
06/25/2009 20:00:00
06/26/2009 13:00:00
06/27/2009 06:00:00
06/27/2009 23:00:00
06/28/2009 16:00:00
06/29/2009 09:00:00
06/30/2009 02:00:00
06/30/2009 19:00:00
07/01/2009 12:00:00
07/02/2009 05:00:00
07/02/2009 22:00:00
07/03/2009 15:00:00
07/04/2009 08:00:00
07/05/2009 01:00:00
07/05/2009 18:00:00
07/06/2009 11:00:00
07/07/2009 04:00:00
07/07/2009 21:00:00
07/08/2009 14:00:00
07/09/2009 07:00:00
07/10/2009 00:00:00
07/10/2009 17:00:00
07/11/2009 10:00:00
07/12/2009 03:00:00
07/12/2009 20:00:00
07/13/2009 13:00:00
07/14/2009 06:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on



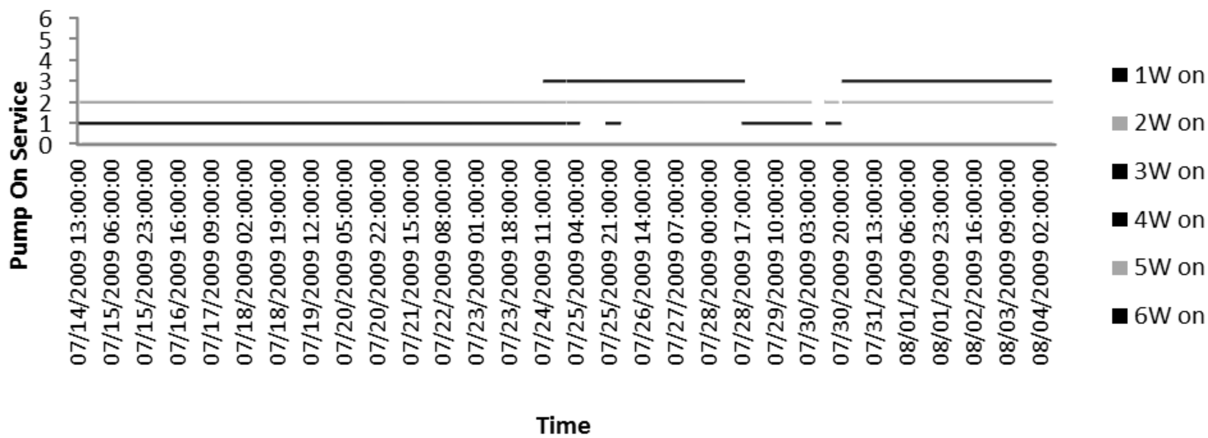
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
2000
2100
2200
2300
2400
2500
Time
2W speed
5W Speed



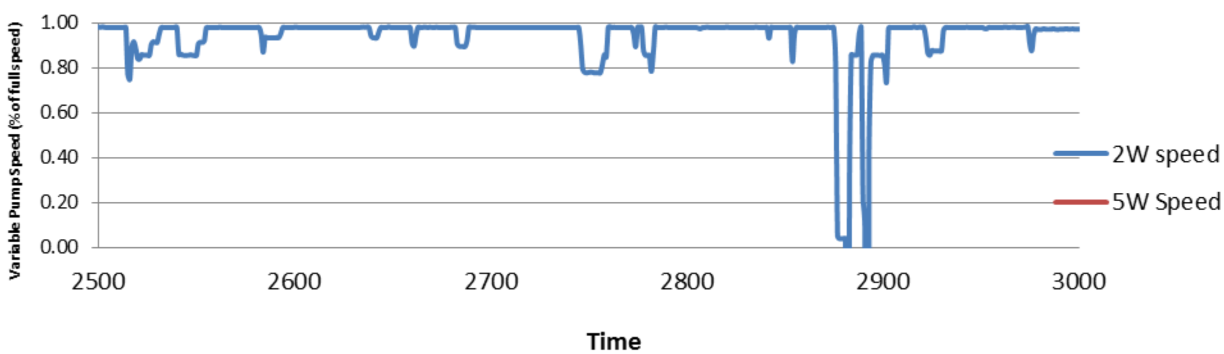
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
2000
2100
2200
2300
2400
2500
Time
WWL1
WWL2



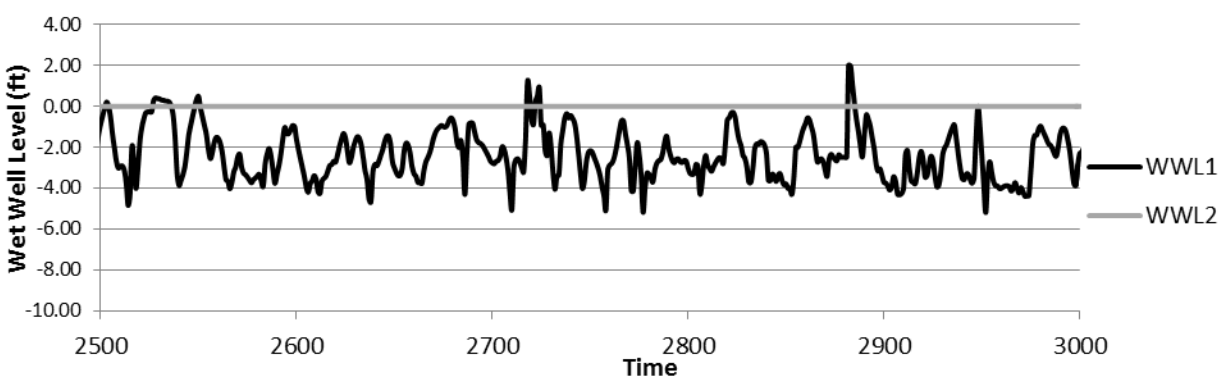
Q(MGD)
200
150
100
50
0
2500
2600
2700
2800
2900
3000
Time
Q predicted
Q real time
Detected Error



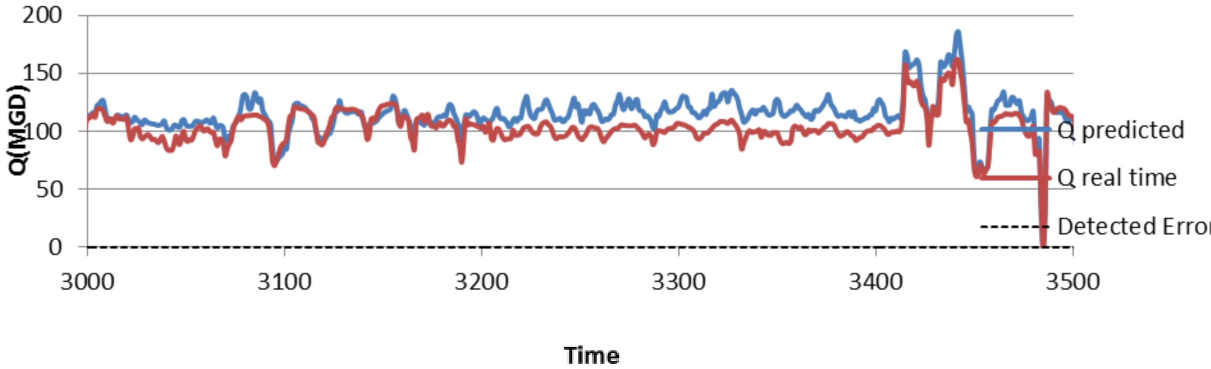
Pump On Service
6
5
4
3
2
1
0
07/14/2009 13:00:00
07/15/2009 06:00:00
07/15/2009 23:00:00
07/16/2009 16:00:00
07/17/2009 09:00:00
07/18/2009 02:00:00
07/18/2009 19:00:00
07/19/2009 12:00:00
07/20/2009 05:00:00
07/20/2009 22:00:00
07/21/2009 15:00:00
07/22/2009 08:00:00
07/23/2009 01:00:00
07/23/2009 18:00:00
07/24/2009 11:00:00
07/25/2009 04:00:00
07/25/2009 21:00:00
07/26/2009 14:00:00
07/27/2009 07:00:00
07/28/2009 00:00:00
07/28/2009 17:00:00
07/29/2009 10:00:00
07/30/2009 03:00:00
07/30/2009 20:00:00
07/31/2009 13:00:00
08/01/2009 06:00:00
08/01/2009 23:00:00
08/02/2009 16:00:00
08/03/2009 09:00:00
08/04/2009 02:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

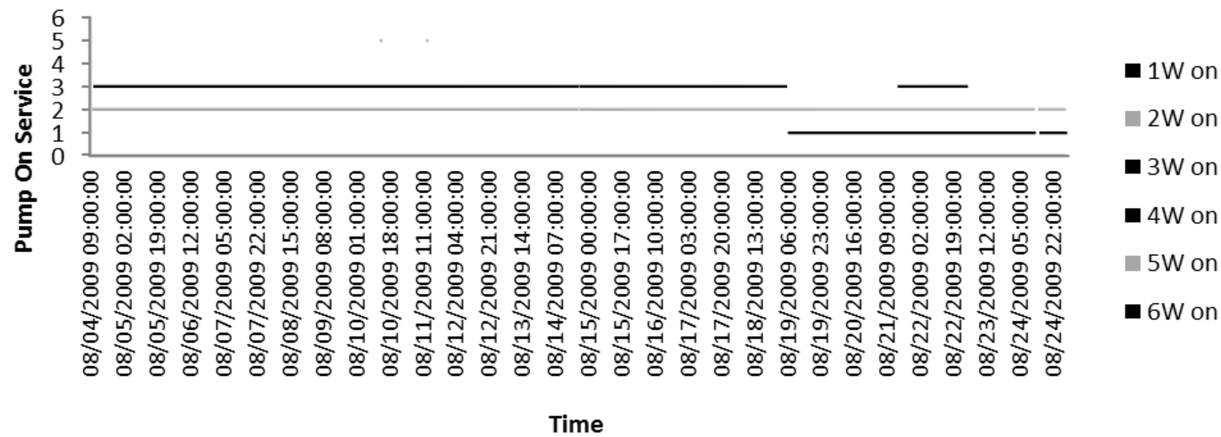


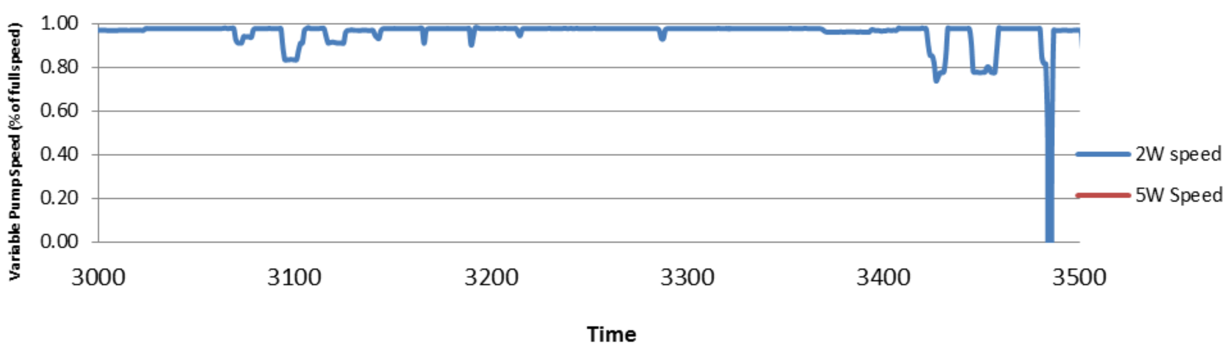
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
2500
2600
2700
2800
2900
3000
Time
2W speed
5W Speed

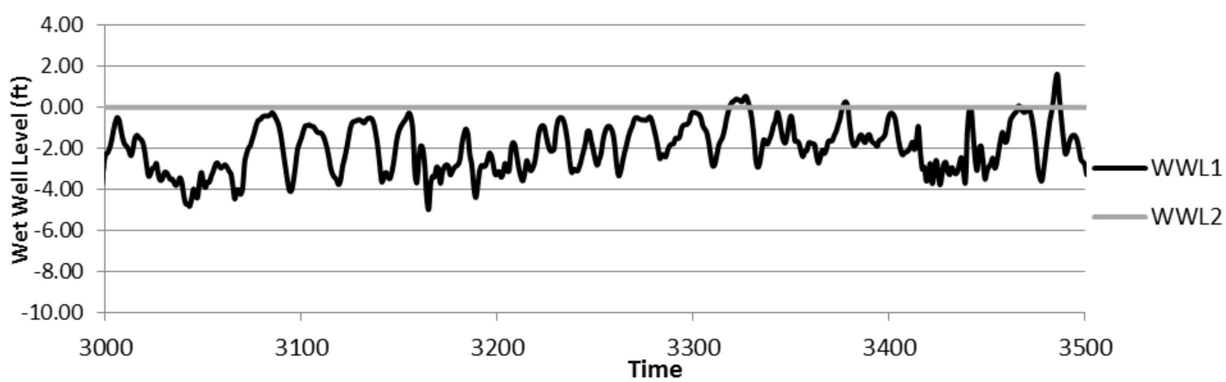


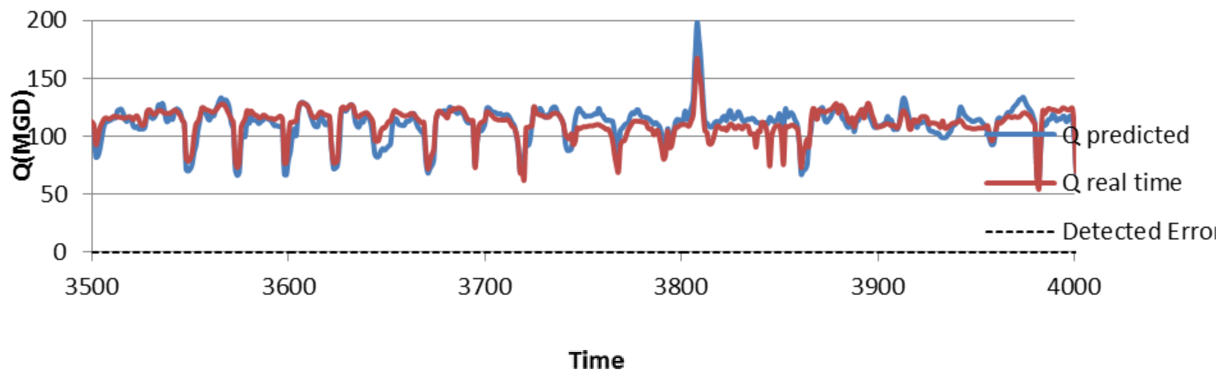
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
2500
2600
2700
2800
2900
3000
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
3000
3100
3200
3300
3400
3500
Time
Q predicted
Q real time
Detected Error

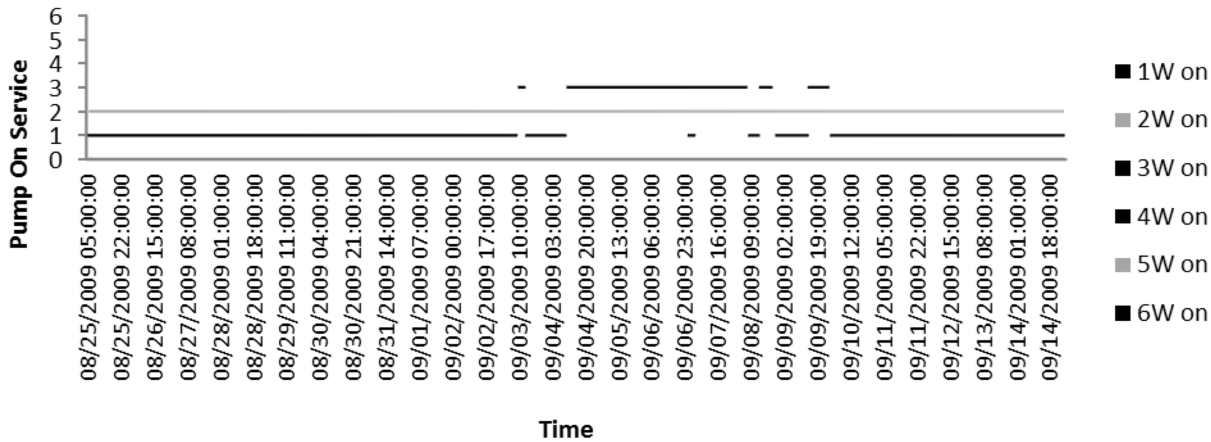

Pump On Service
6
5
4
3
2
1
0
08/04/2009 09:00:00
08/05/2009 02:00:00
08/05/2009 19:00:00
08/06/2009 12:00:00
08/07/2009 05:00:00
08/07/2009 22:00:00
08/08/2009 15:00:00
08/09/2009 08:00:00
08/10/2009 01:00:00
08/10/2009 18:00:00
08/11/2009 11:00:00
08/12/2009 04:00:00
08/12/2009 21:00:00
08/13/2009 14:00:00
08/14/2009 07:00:00
08/15/2009 00:00:00
08/15/2009 17:00:00
08/16/2009 10:00:00
08/17/2009 03:00:00
08/17/2009 20:00:00
08/18/2009 13:00:00
08/19/2009 06:00:00
08/19/2009 23:00:00
08/20/2009 16:00:00
08/21/2009 09:00:00
08/22/2009 02:00:00
08/22/2009 19:00:00
08/23/2009 12:00:00
08/24/2009 05:00:00
08/24/2009 22:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
3000
3100
3200
3300
3400
3500
Time
2W speed
5W Speed

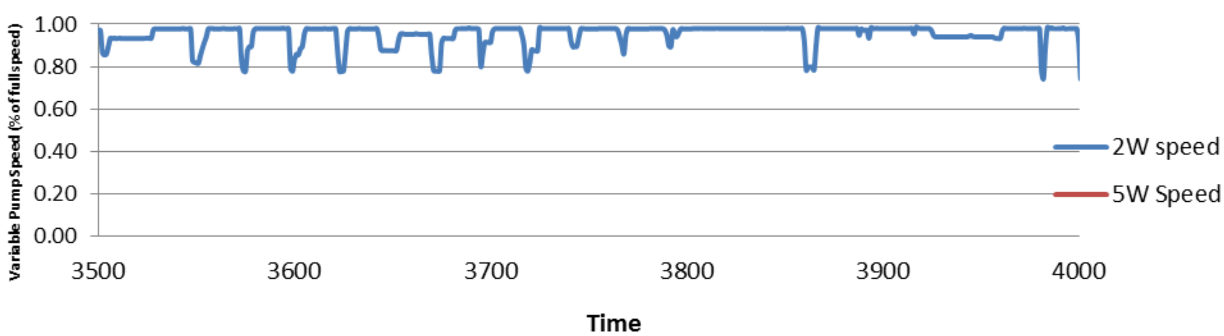

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
3000
3100
3200
3300
3400
3500
Time
WWL1
WWL2



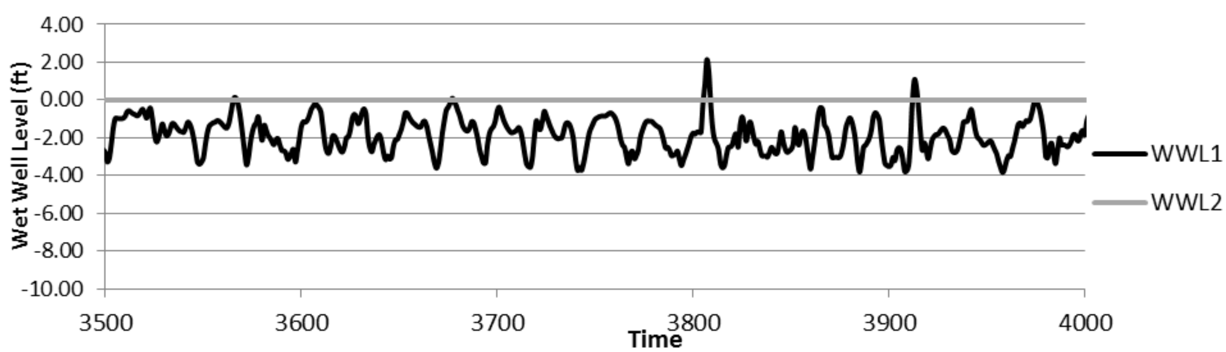
Q(MGD)
200
150
100
50
0
3500
3600
3700
3800
3900
4000
Time
Q predicted
Q real time
Detected Error



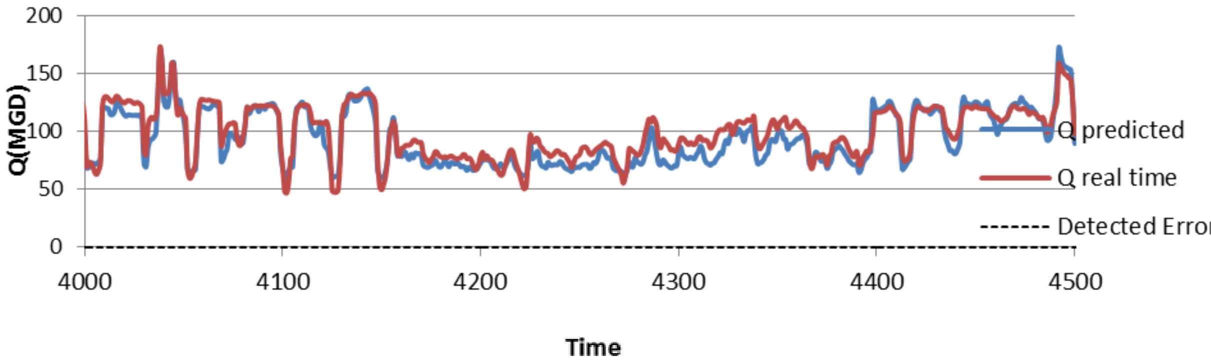
Pump On Service
6
5
4
3
2
1
0
08/25/2009 05:00:00
08/25/2009 22:00:00
08/26/2009 15:00:00
08/27/2009 08:00:00
08/28/2009 01:00:00
08/28/2009 18:00:00
08/29/2009 11:00:00
08/30/2009 04:00:00
08/30/2009 21:00:00
08/31/2009 14:00:00
09/01/2009 07:00:00
09/02/2009 00:00:00
09/02/2009 17:00:00
09/03/2009 10:00:00
09/04/2009 03:00:00
09/04/2009 20:00:00
09/05/2009 13:00:00
09/06/2009 06:00:00
09/06/2009 23:00:00
09/07/2009 16:00:00
09/08/2009 09:00:00
09/09/2009 02:00:00
09/09/2009 19:00:00
09/10/2009 12:00:00
09/11/2009 05:00:00
09/11/2009 22:00:00
09/12/2009 15:00:00
09/13/2009 08:00:00
09/14/2009 01:00:00
09/14/2009 18:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on



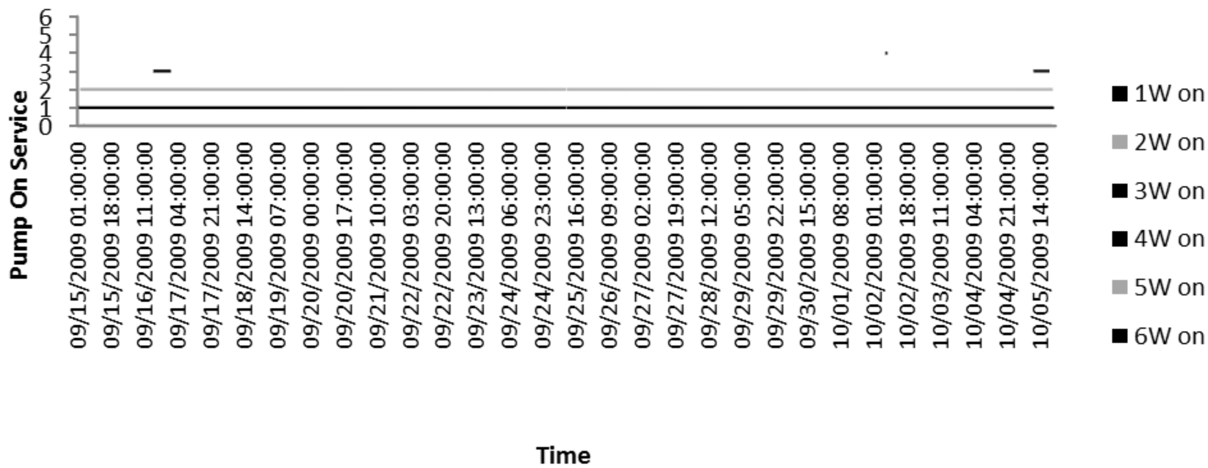
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
3500
3600
3700
3800
3900
4000
Time
2W speed
5W Speed



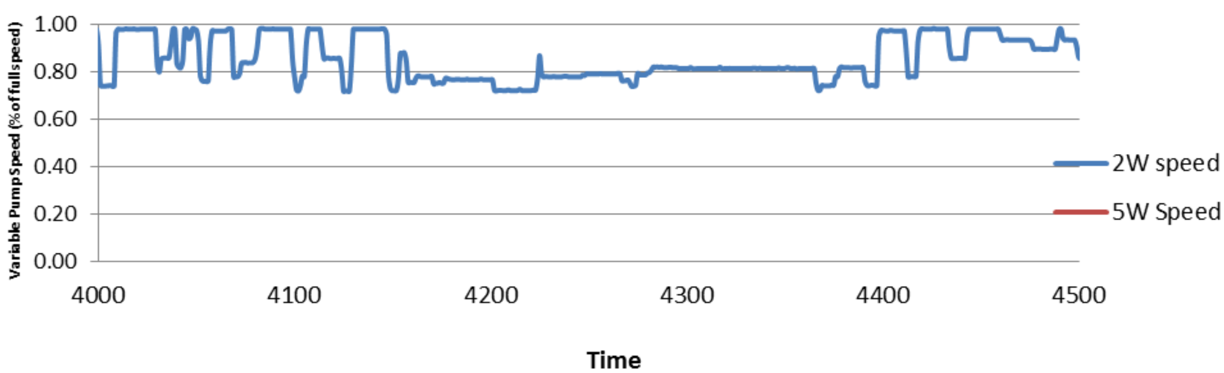
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
3500
3600
3700
3800
3900
4000
Time
WWL1
WWL2



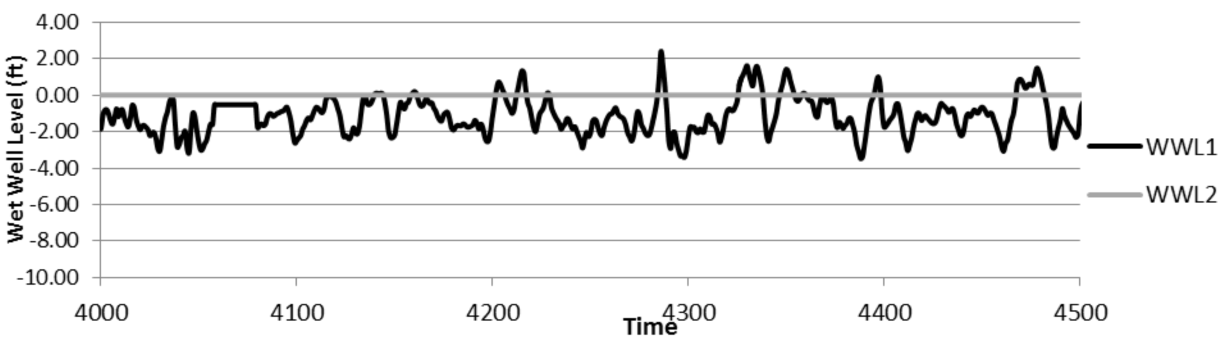
Q(MGD)
200
150
100
50
0
4000
4100
4200
4300
4400
4500
Time
Q predicted
Q real time
Detected Error



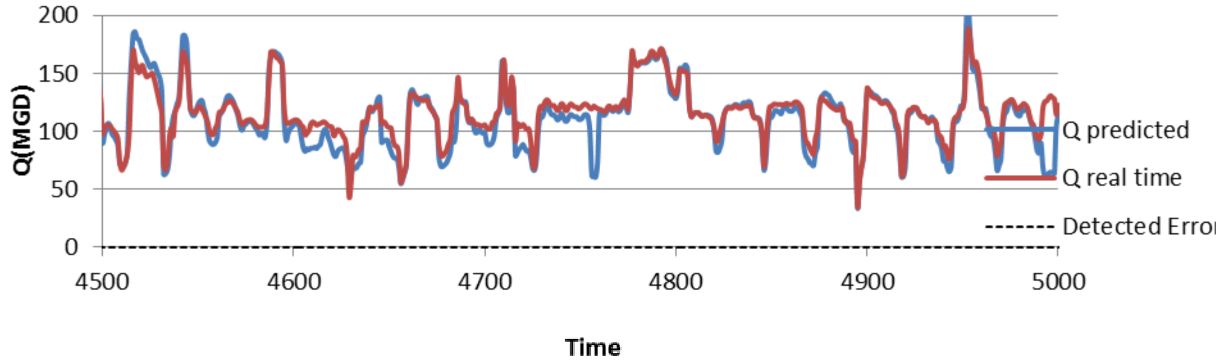
Pump On Service
6
5
4
3
2
1
0
09/15/2009 01:00:00
09/15/2009 18:00:00
09/16/2009 11:00:00
09/17/2009 04:00:00
09/17/2009 21:00:00
09/18/2009 14:00:00
09/19/2009 07:00:00
09/20/2009 00:00:00
09/20/2009 17:00:00
09/21/2009 10:00:00
09/22/2009 03:00:00
09/22/2009 20:00:00
09/23/2009 13:00:00
09/24/2009 06:00:00
09/24/2009 23:00:00
09/25/2009 16:00:00
09/26/2009 09:00:00
09/27/2009 02:00:00
09/27/2009 19:00:00
09/28/2009 12:00:00
09/29/2009 05:00:00
09/29/2009 22:00:00
09/30/2009 15:00:00
10/01/2009 08:00:00
10/02/2009 01:00:00
10/02/2009 18:00:00
10/03/2009 11:00:00
10/04/2009 04:00:00
10/04/2009 21:00:00
10/05/2009 14:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

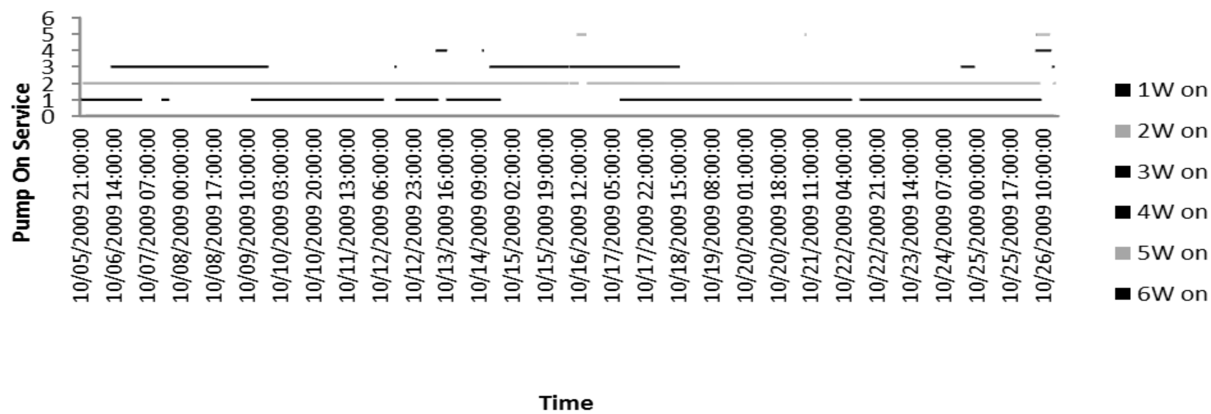


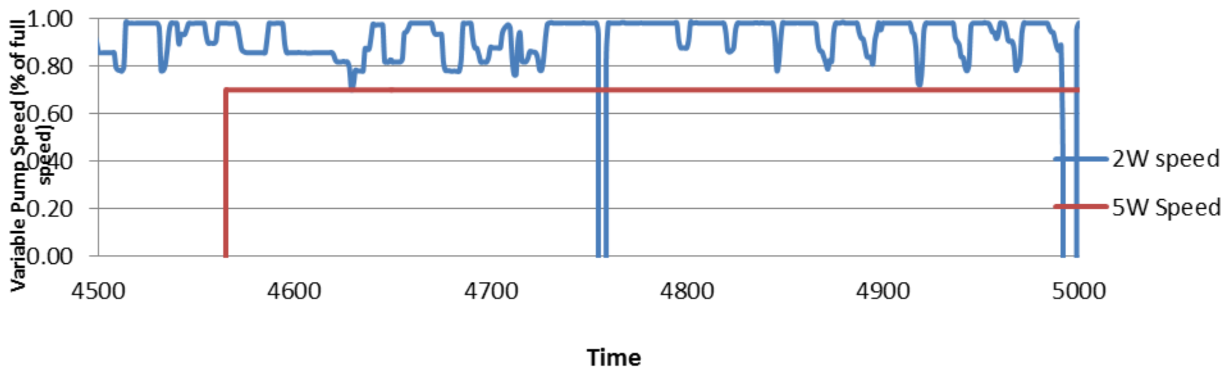
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
4000
4100
4200
4300
4400
4500
Time
2W speed
5W Speed

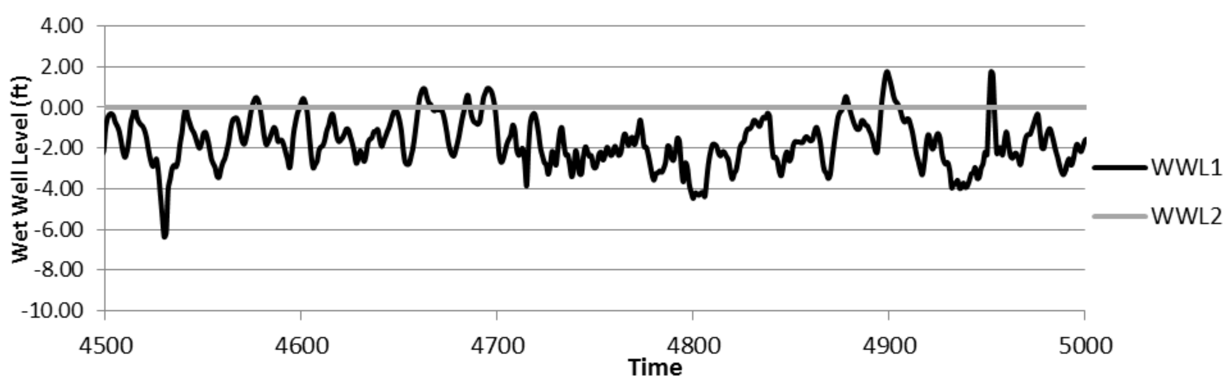


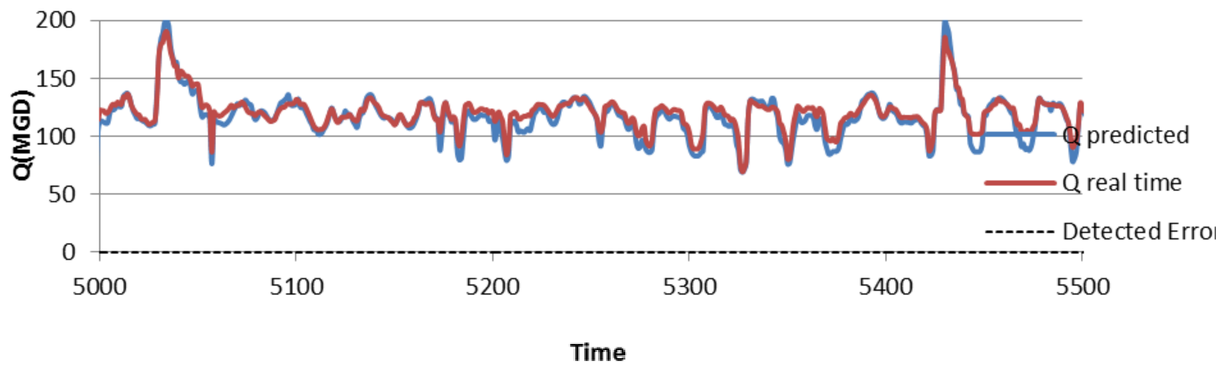
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
4000
4100
4200
4300
4400
4500
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
4500
4600
4700
4800
4900
5000
Time
Q predicted
Q real time
Detected Error

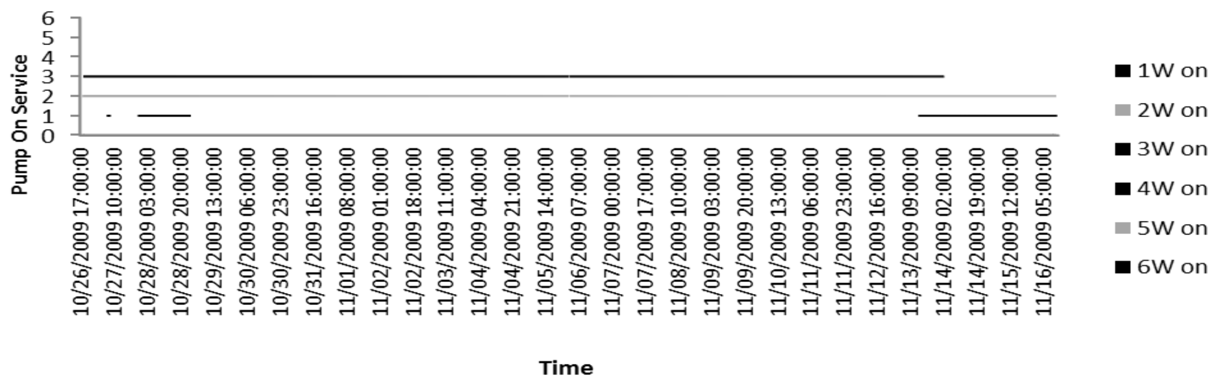

Pump On Service
6
5
4
3
2
1
0
10/05/2009 21:00:00
10/06/2009 14:00:00
10/07/2009 07:00:00
10/08/2009 00:00:00
10/08/2009 17:00:00
10/09/2009 10:00:00
10/10/2009 03:00:00
10/10/2009 20:00:00
10/11/2009 13:00:00
10/12/2009 06:00:00
10/12/2009 23:00:00
10/13/2009 16:00:00
10/14/2009 09:00:00
10/15/2009 02:00:00
10/15/2009 19:00:00
10/16/2009 12:00:00
10/17/2009 05:00:00
10/17/2009 22:00:00
10/18/2009 15:00:00
10/19/2009 08:00:00
10/20/2009 01:00:00
10/20/2009 18:00:00
10/21/2009 11:00:00
10/22/2009 04:00:00
10/22/2009 21:00:00
10/23/2009 14:00:00
10/24/2009 07:00:00
10/25/2009 00:00:00
10/25/2009 17:00:00
10/26/2009 10:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
4500
4600
4700
4800
4900
5000
Time
2W speed
5W Speed

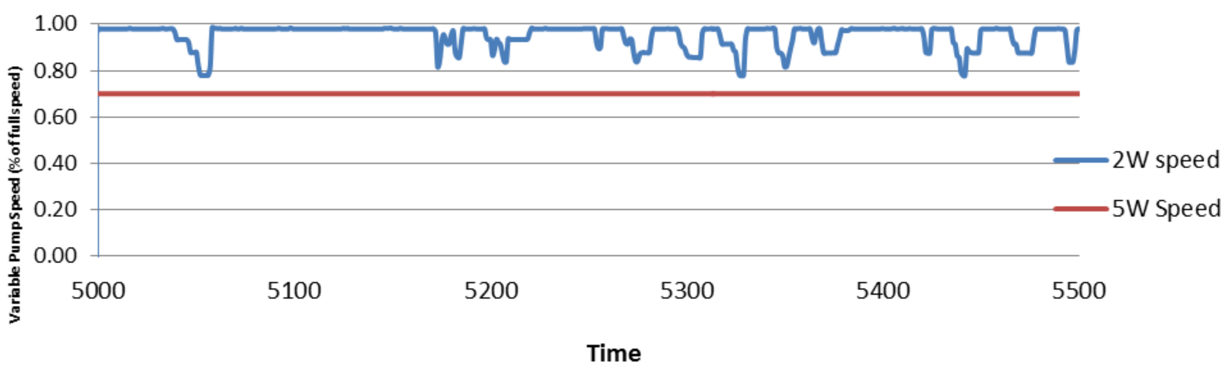

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
4500
4600
4700
4800
4900
5000
Time
WWL1
WWL2



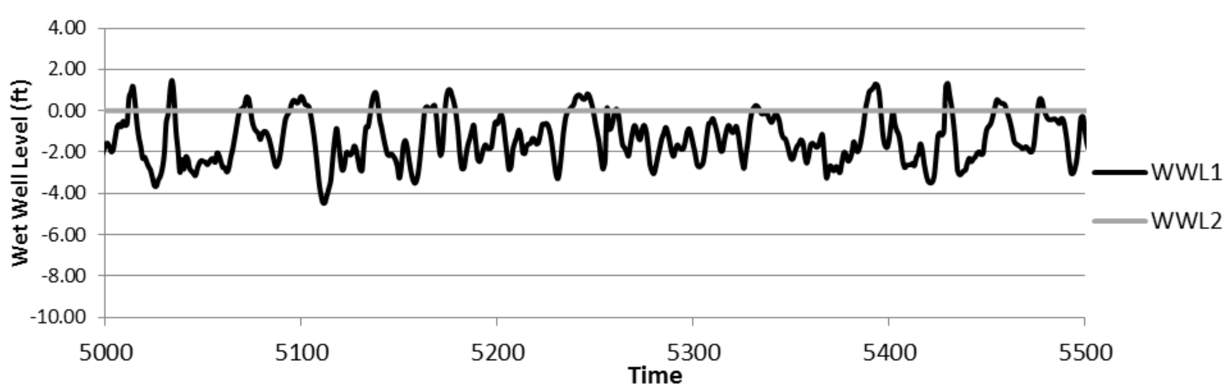
Q(MGD)
200
150
100
50
0
5000
5100
5200
5300
5400
5500
Time
Q predicted
Q real time
Detected Error



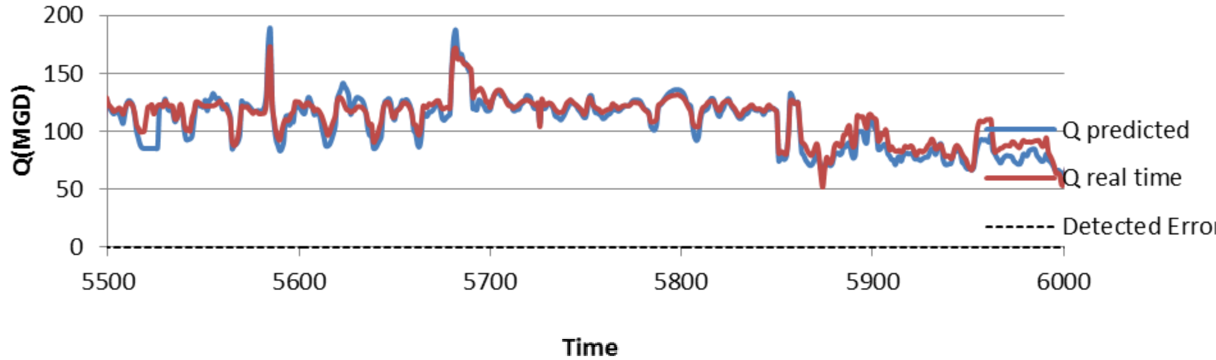
Pump On Service
6
5
4
3
2
1
0
10/26/2009 17:00:00
10/27/2009 10:00:00
10/28/2009 03:00:00
10/28/2009 20:00:00
10/29/2009 13:00:00
10/30/2009 06:00:00
10/30/2009 23:00:00
10/31/2009 16:00:00
11/01/2009 08:00:00
11/02/2009 01:00:00
11/02/2009 18:00:00
11/03/2009 11:00:00
11/04/2009 04:00:00
11/04/2009 21:00:00
11/05/2009 14:00:00
11/06/2009 07:00:00
11/07/2009 00:00:00
11/07/2009 17:00:00
11/08/2009 10:00:00
11/09/2009 03:00:00
11/09/2009 20:00:00
11/10/2009 13:00:00
11/11/2009 06:00:00
11/11/2009 23:00:00
11/12/2009 16:00:00
11/13/2009 09:00:00
11/14/2009 02:00:00
11/14/2009 19:00:00
11/15/2009 12:00:00
11/16/2009 05:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

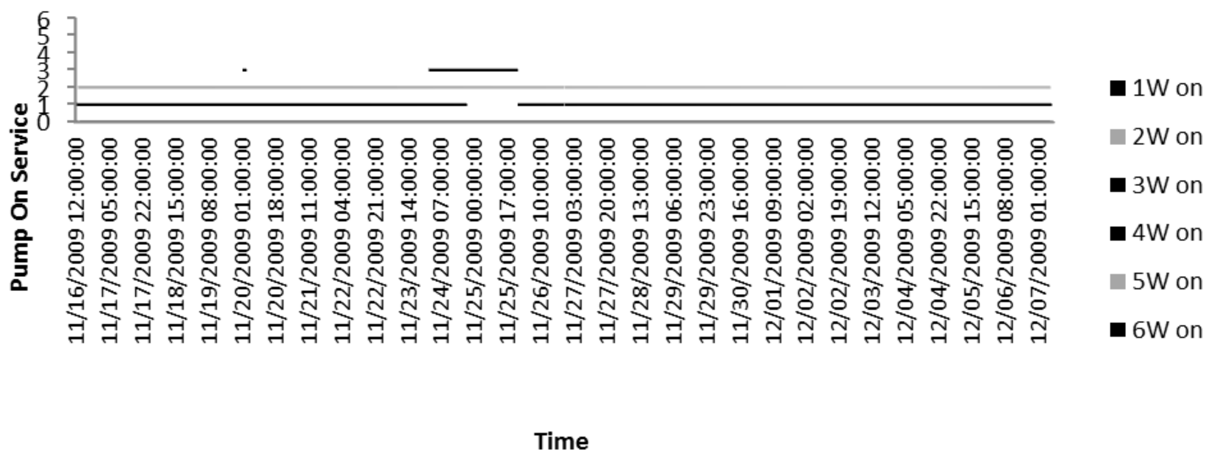


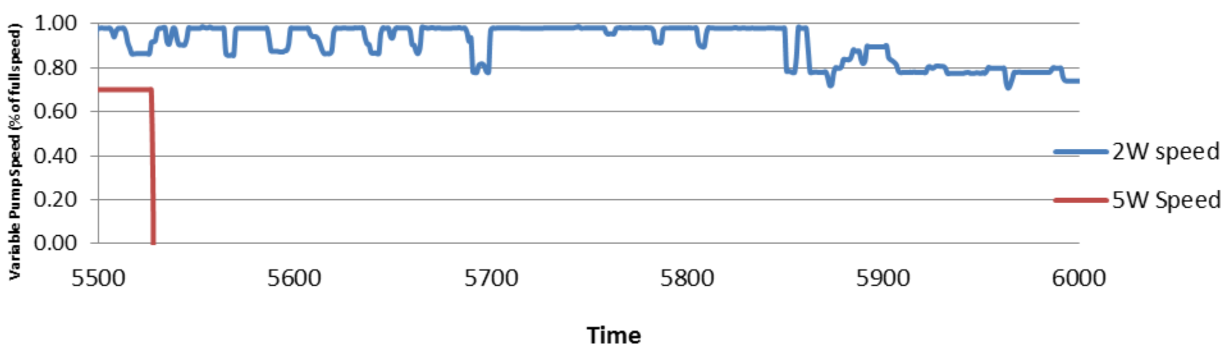
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
5000
5100
5200
5300
5400
5500
Time
2W speed
5W Speed

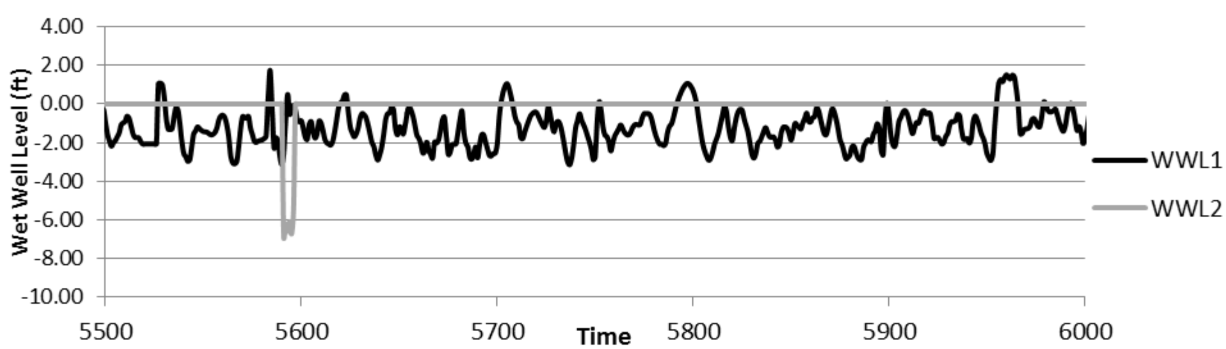


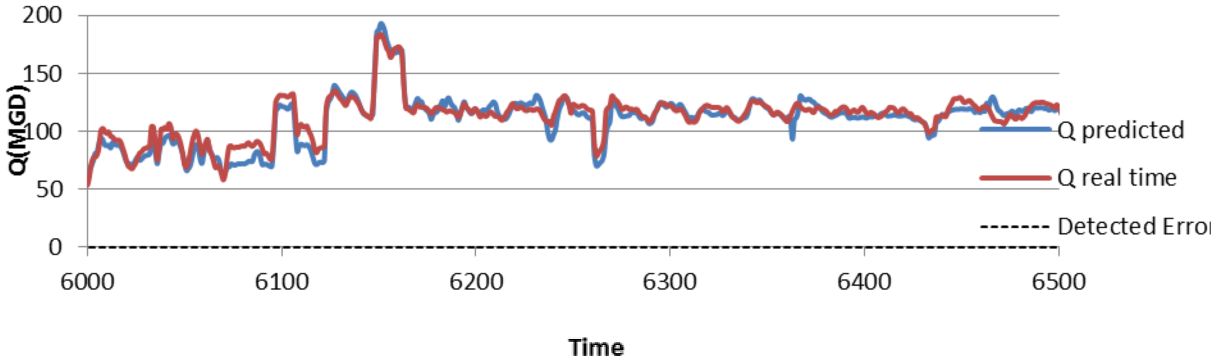
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
5000
5100
5200
5300
5400
5500
Time
WWL1
WWL2


200
150
100
50
0
Q(MGD)
5500
5600
5700
5800
5900
6000
Time
Q predicted
Q real time
Detected Error

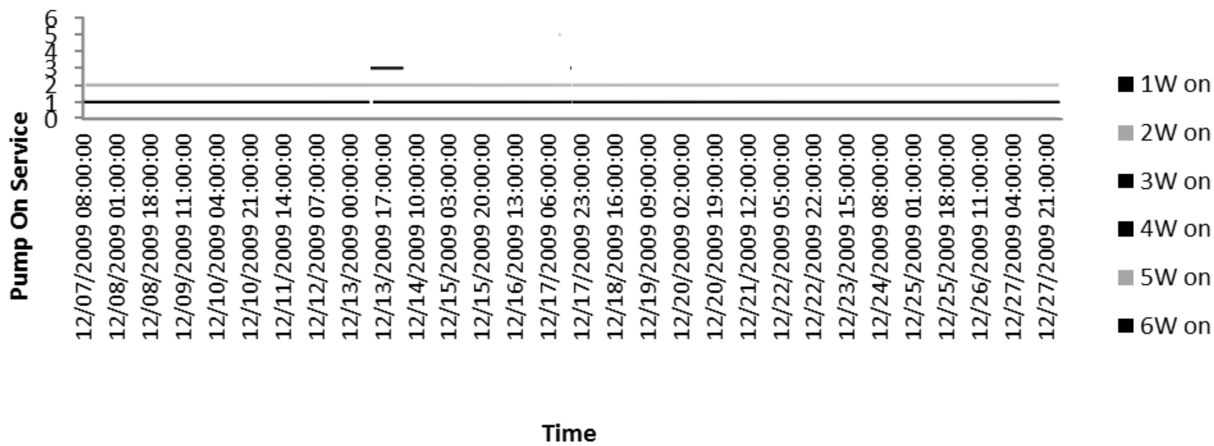

6
5
4
3
2
1
0
Pump On Service
11/16/2009 12:00:00
11/17/2009 05:00:00
11/17/2009 22:00:00
11/18/2009 15:00:00
11/19/2009 08:00:00
11/20/2009 01:00:00
11/20/2009 18:00:00
11/21/2009 11:00:00
11/22/2009 04:00:00
11/22/2009 21:00:00
11/23/2009 14:00:00
11/24/2009 07:00:00
11/25/2009 00:00:00
11/25/2009 17:00:00
11/26/2009 10:00:00
11/27/2009 03:00:00
11/27/2009 20:00:00
11/28/2009 13:00:00
11/29/2009 06:00:00
11/29/2009 23:00:00
11/30/2009 16:00:00
12/01/2009 09:00:00
12/02/2009 02:00:00
12/02/2009 19:00:00
12/03/2009 12:00:00
12/04/2009 05:00:00
12/04/2009 22:00:00
12/05/2009 15:00:00
12/06/2009 08:00:00
12/07/2009 01:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
5500
5600
5700
5800
5900
6000
Time
2W speed
5W Speed

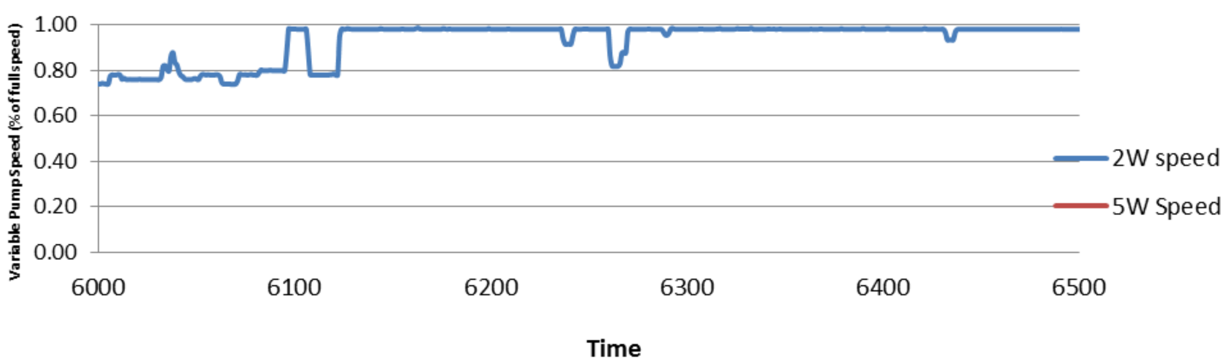

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
5500
5600
5700
5800
5900
6000
Time
WWL1
WWL2



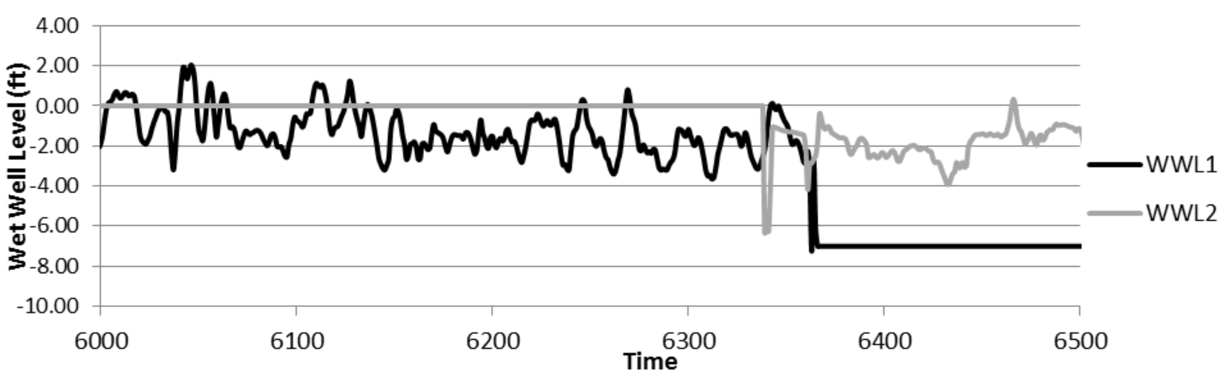
Q(MGD)
200
150
100
50
0
6000
6100
6200
6300
6400
6500
Time
Q predicted
Q real time
Detected Error



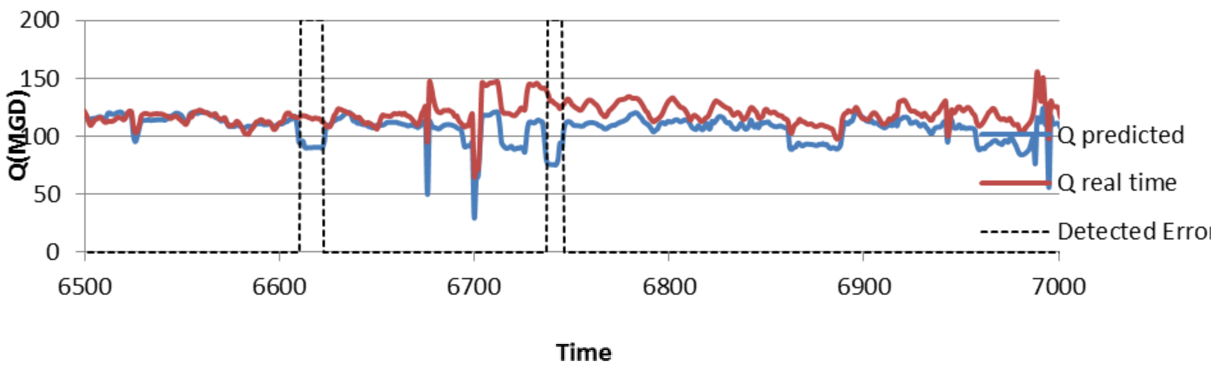
Pump On Service
6
5
4
3
2
1
0
12/07/2009 08:00:00
12/08/2009 01:00:00
12/08/2009 18:00:00
12/09/2009 11:00:00
12/10/2009 04:00:00
12/10/2009 21:00:00
12/11/2009 14:00:00
12/12/2009 07:00:00
12/13/2009 00:00:00
12/13/2009 17:00:00
12/14/2009 10:00:00
12/15/2009 03:00:00
12/15/2009 20:00:00
12/16/2009 13:00:00
12/17/2009 06:00:00
12/17/2009 23:00:00
12/18/2009 16:00:00
12/19/2009 09:00:00
12/20/2009 02:00:00
12/20/2009 19:00:00
12/21/2009 12:00:00
12/22/2009 05:00:00
12/22/2009 22:00:00
12/23/2009 15:00:00
12/24/2009 08:00:00
12/25/2009 01:00:00
12/25/2009 18:00:00
12/26/2009 11:00:00
12/27/2009 04:00:00
12/27/2009 21:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on



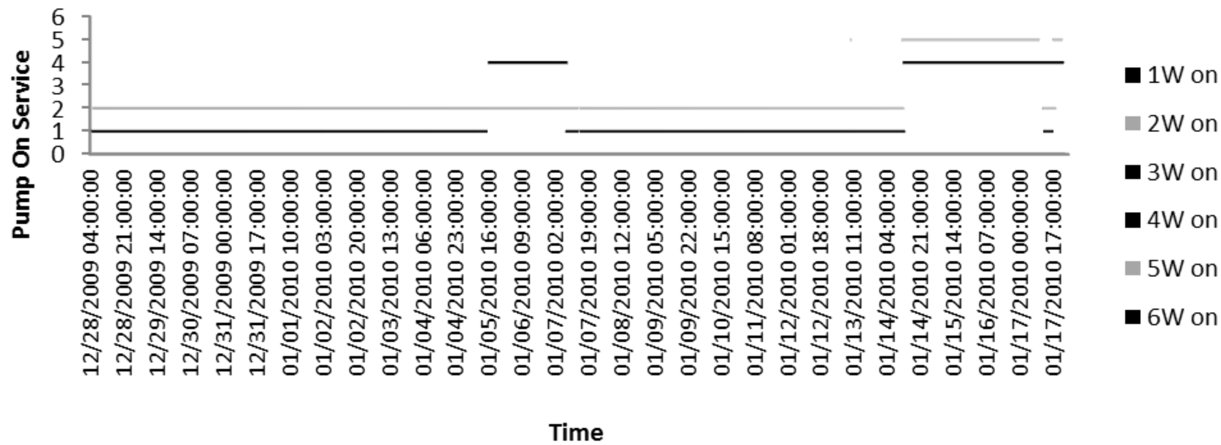
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
6000
6100
6200
6300
6400
6500
Time
2W speed
5W Speed



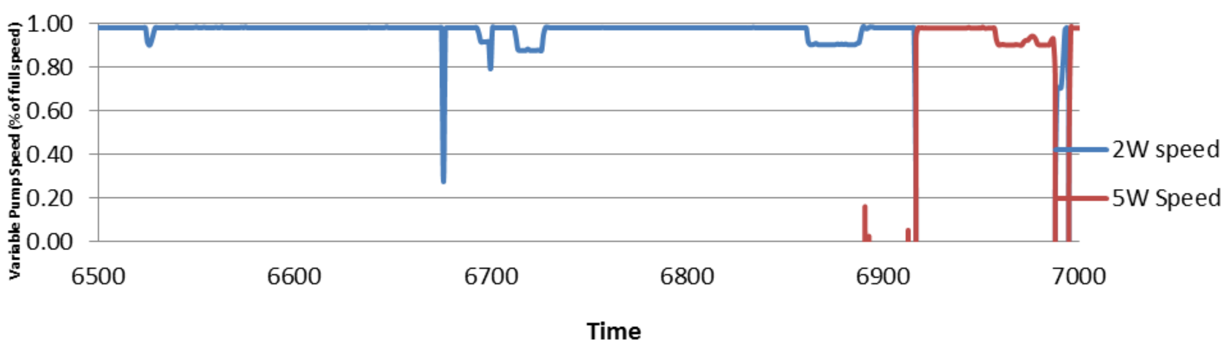
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
6000
6100
6200
6300
6400
6500
Time
WWL1
WWL2



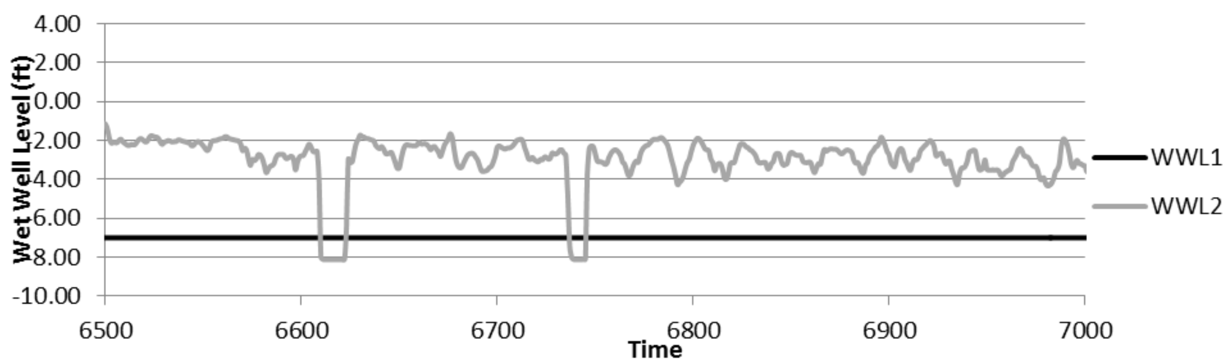
Q(MGD)
200
150
100
50
0
6500
6600
6700
6800
6900
7000
Time
Q predicted
Q real time
Detected Error



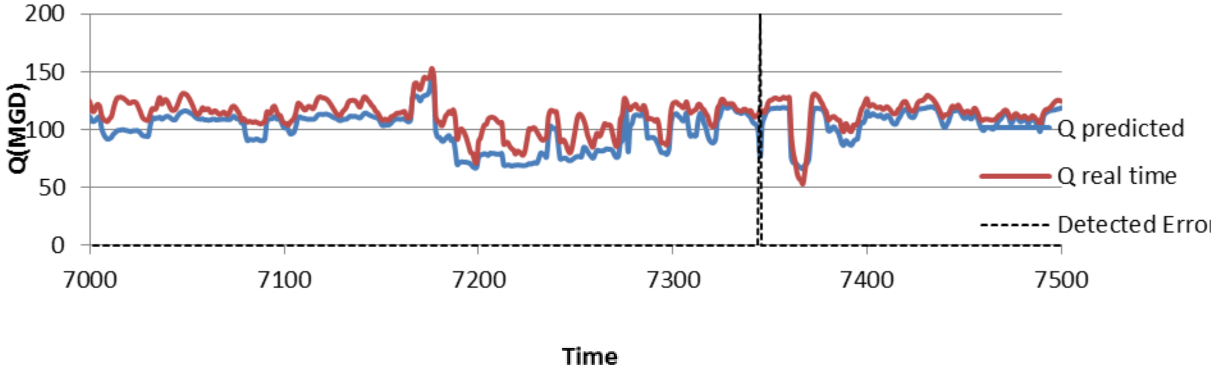
Pump On Service
6
5
4
3
2
1
0
12/28/2009 04:00:00
12/28/2009 21:00:00
12/29/2009 14:00:00
12/30/2009 07:00:00
12/31/2009 00:00:00
12/31/2009 17:00:00
01/01/2010 10:00:00
01/02/2010 03:00:00
01/02/2010 20:00:00
01/03/2010 13:00:00
01/04/2010 06:00:00
01/04/2010 23:00:00
01/05/2010 16:00:00
01/06/2010 09:00:00
01/07/2010 02:00:00
01/07/2010 19:00:00
01/08/2010 12:00:00
01/09/2010 05:00:00
01/09/2010 22:00:00
01/10/2010 15:00:00
01/11/2010 08:00:00
01/12/2010 01:00:00
01/12/2010 18:00:00
01/13/2010 11:00:00
01/14/2010 04:00:00
01/14/2010 21:00:00
01/15/2010 14:00:00
01/16/2010 07:00:00
01/17/2010 00:00:00
01/17/2010 17:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on



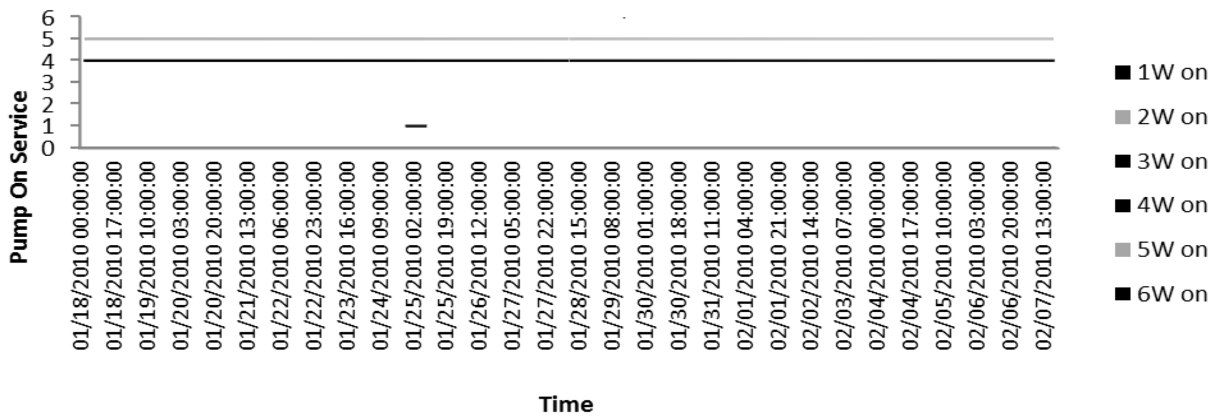
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
6500
6600
6700
6800
6900
7000
Time
2W speed
5W Speed



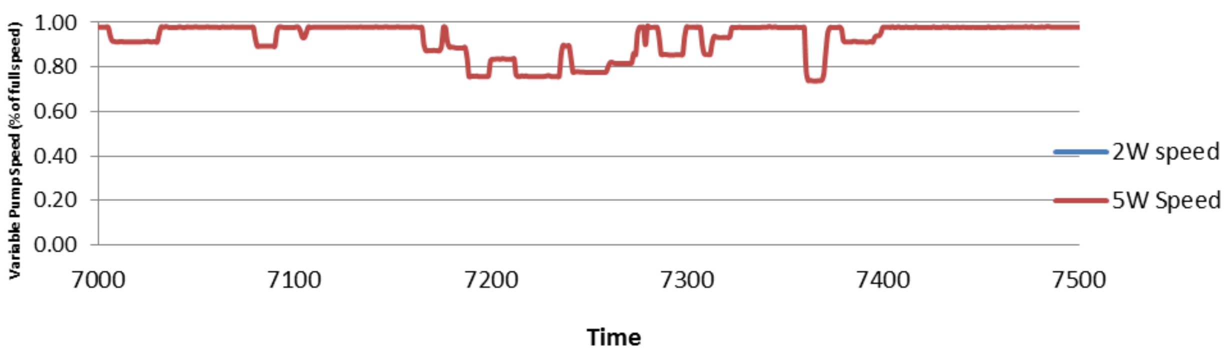
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
6500
6600
6700
6800
6900
7000
Time
WWL1
WWL2



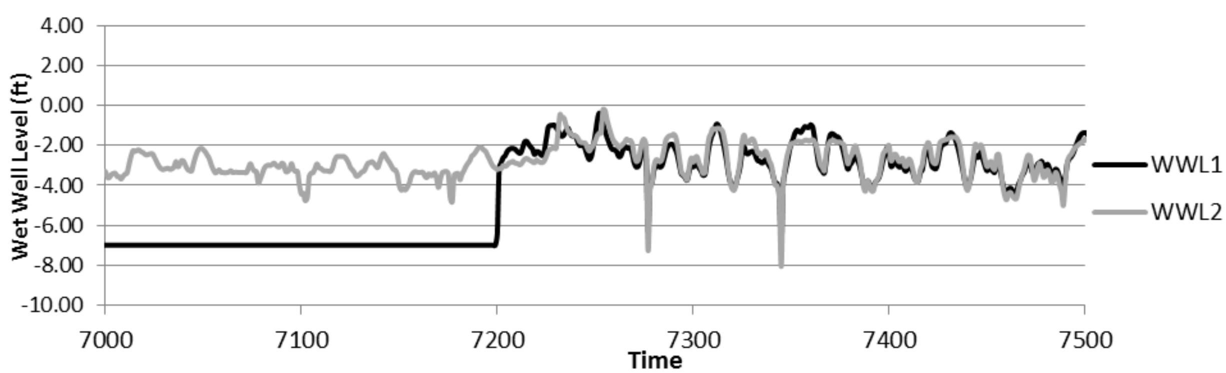
Q(MGD)
200
150
100
50
0
7000
7100
7200
7300
7400
7500
Q predicted
Q real time
Detected Error
Time



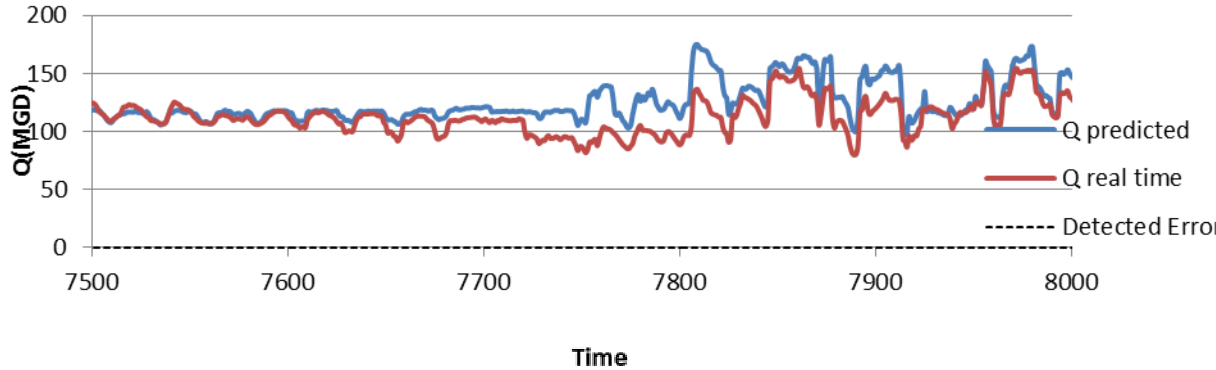
Pump On Service
6
5
4
3
2
1
0
1W on
2W on
3W on
4W on
5W on
6W on
Time

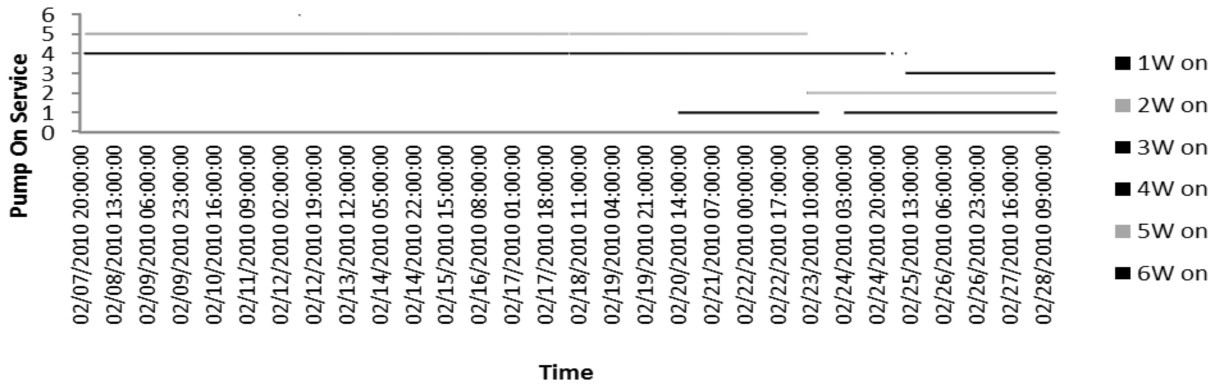


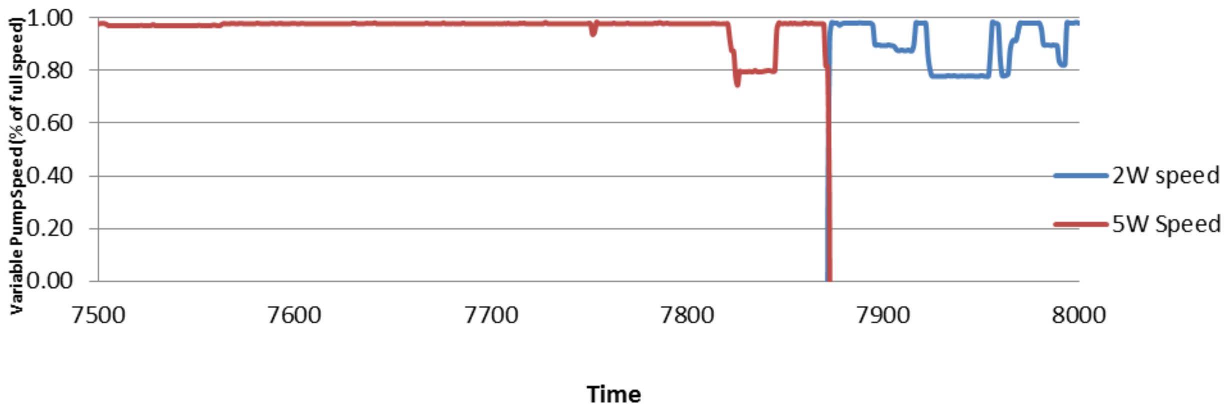
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
7000
7100
7200
7300
7400
7500
2W speed
5W Speed
Time

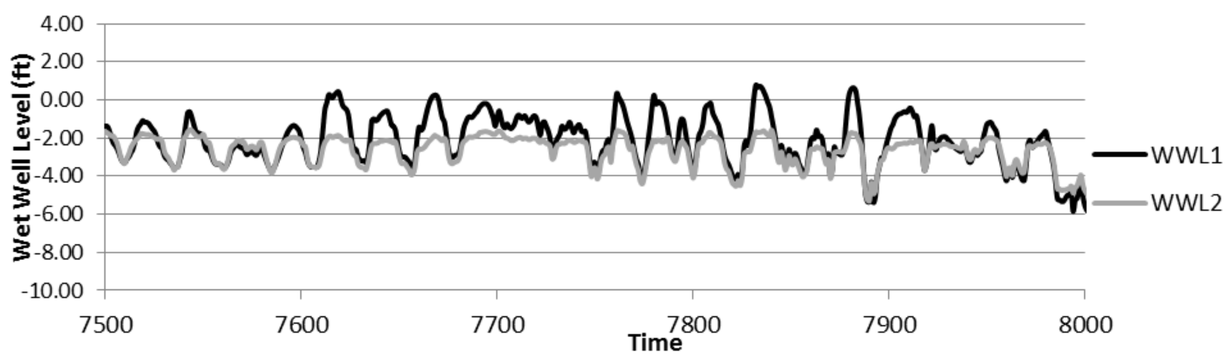


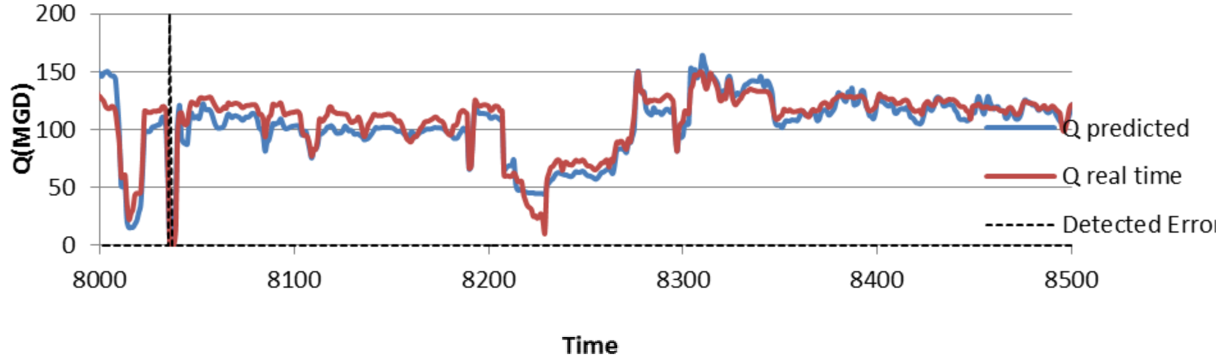
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
7000
7100
7200
7300
7400
7500
WWL1
WWL2
Time

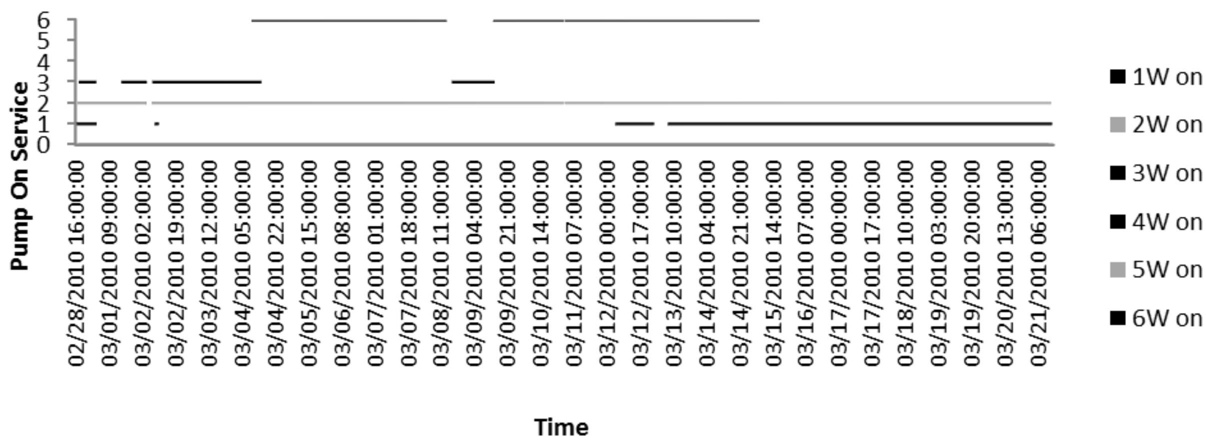

Q(MGD)
200
150
100
50
0
7500
7600
7700
7800
7900
8000
Time
Q predicted
Q real time
Detected Error

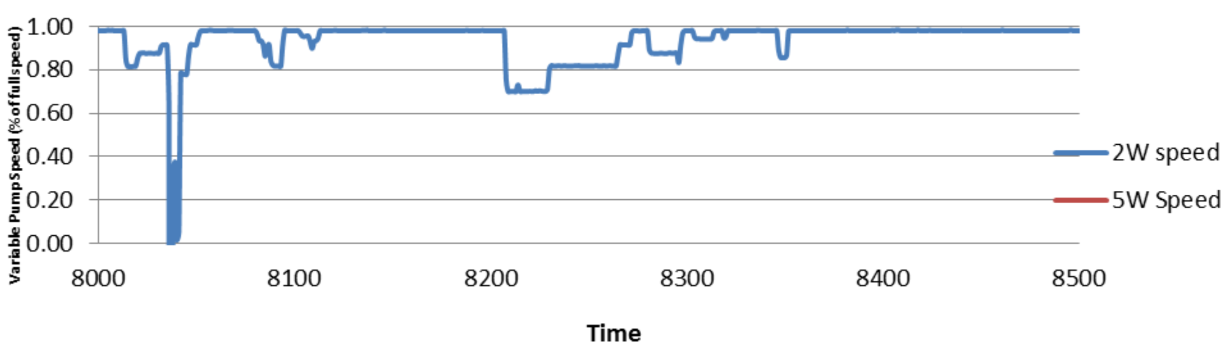

Pump On Service
6
5
4
3
2
1
0
02/07/2010 20:00:00
02/08/2010 13:00:00
02/09/2010 06:00:00
02/09/2010 23:00:00
02/10/2010 16:00:00
02/11/2010 09:00:00
02/12/2010 02:00:00
02/12/2010 19:00:00
02/13/2010 12:00:00
02/14/2010 05:00:00
02/14/2010 22:00:00
02/15/2010 15:00:00
02/16/2010 08:00:00
02/17/2010 01:00:00
02/17/2010 18:00:00
02/18/2010 11:00:00
02/19/2010 04:00:00
02/19/2010 21:00:00
02/20/2010 14:00:00
02/21/2010 07:00:00
02/22/2010 00:00:00
02/22/2010 17:00:00
02/23/2010 10:00:00
02/24/2010 03:00:00
02/24/2010 20:00:00
02/25/2010 13:00:00
02/26/2010 06:00:00
02/26/2010 23:00:00
02/27/2010 16:00:00
02/28/2010 09:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

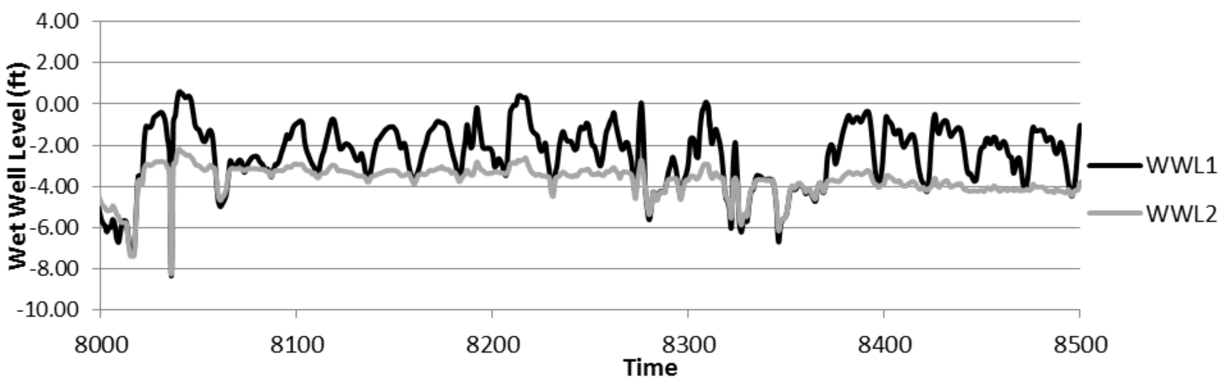

Variable PumpSpeed(% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
7500
7600
7700
7800
7900
8000
Time
2W speed
5W Speed

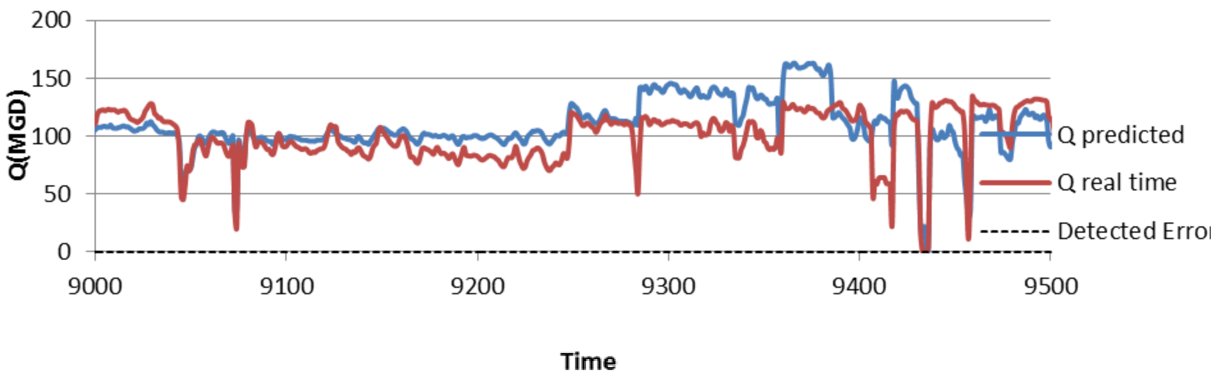

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
7500
7600
7700
7800
7900
8000
Time
WWL1
WWL2

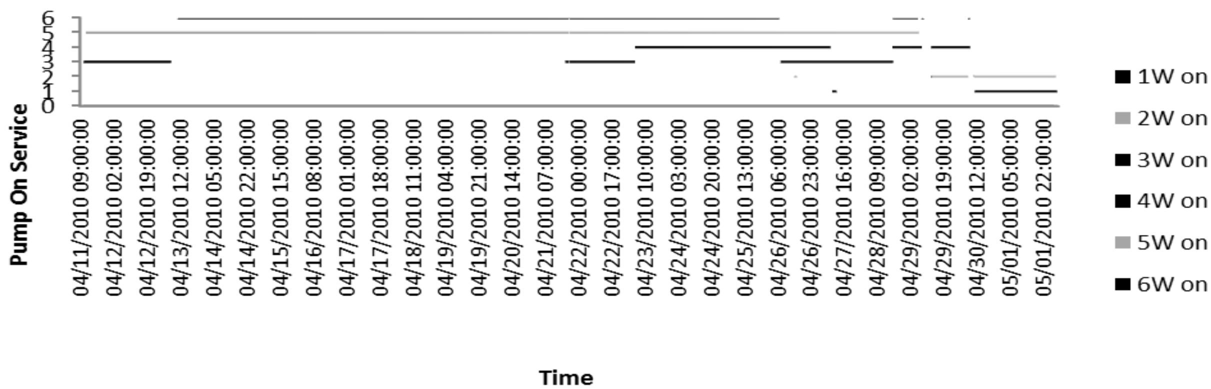

200
150
100
50
0
Q(MGD)
8000
8100
8200
8300
8400
8500
Time
Q predicted
Q real time
Detected Error

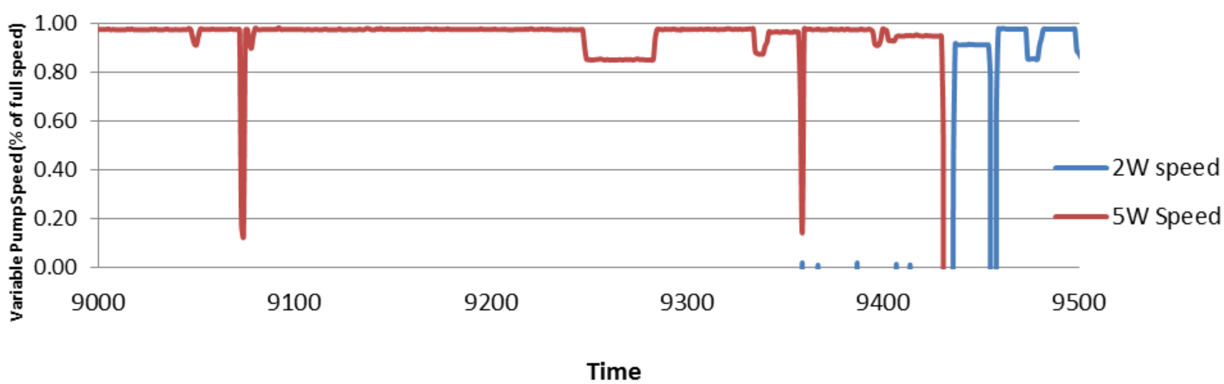

6
5
4
3
2
1
0
Pump On Service
02/28/2010 16:00:00
03/01/2010 09:00:00
03/02/2010 02:00:00
03/02/2010 19:00:00
03/03/2010 12:00:00
03/04/2010 05:00:00
03/04/2010 22:00:00
03/05/2010 15:00:00
03/06/2010 08:00:00
03/07/2010 01:00:00
03/07/2010 18:00:00
03/08/2010 11:00:00
03/09/2010 04:00:00
03/09/2010 21:00:00
03/10/2010 14:00:00
03/11/2010 07:00:00
03/12/2010 00:00:00
03/12/2010 17:00:00
03/13/2010 10:00:00
03/14/2010 04:00:00
03/14/2010 21:00:00
03/15/2010 14:00:00
03/16/2010 07:00:00
03/17/2010 00:00:00
03/17/2010 17:00:00
03/18/2010 10:00:00
03/19/2010 03:00:00
03/19/2010 20:00:00
03/20/2010 13:00:00
03/21/2010 06:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

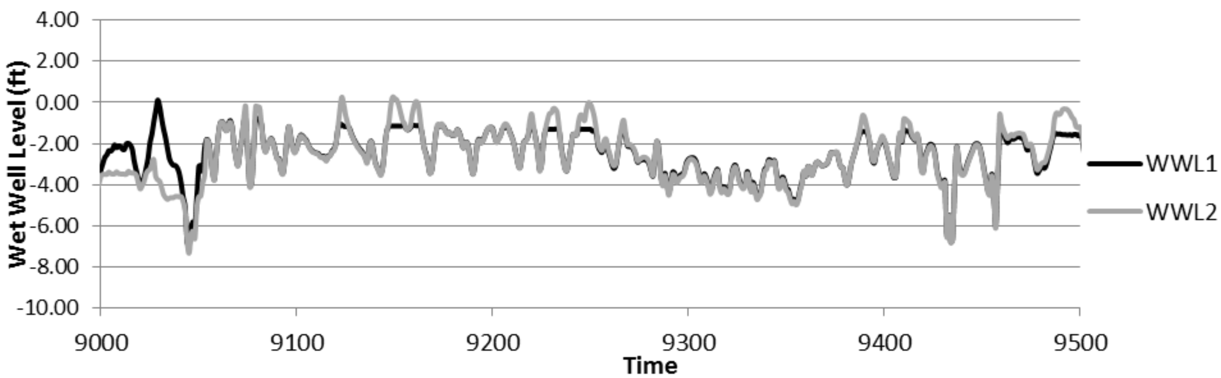

1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
8000
8100
8200
8300
8400
8500
Time
2W speed
5W Speed

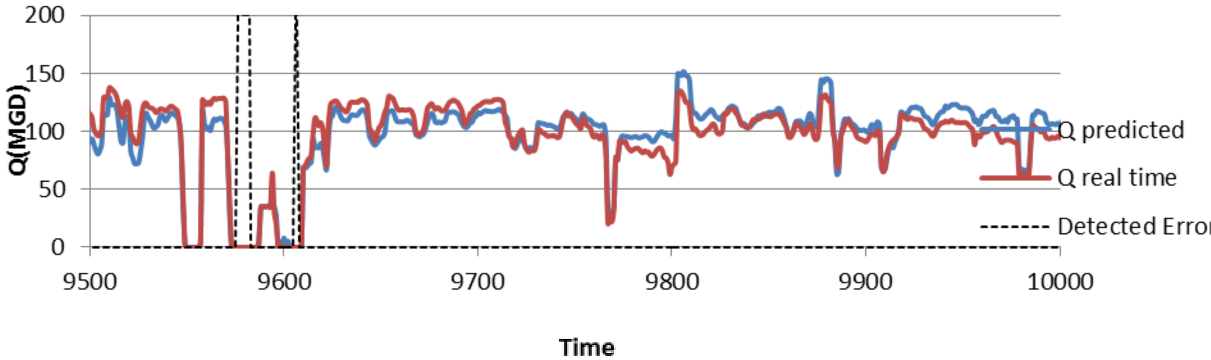

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
8000
8100
8200
8300
8400
8500
Time
WWL1
WWL2

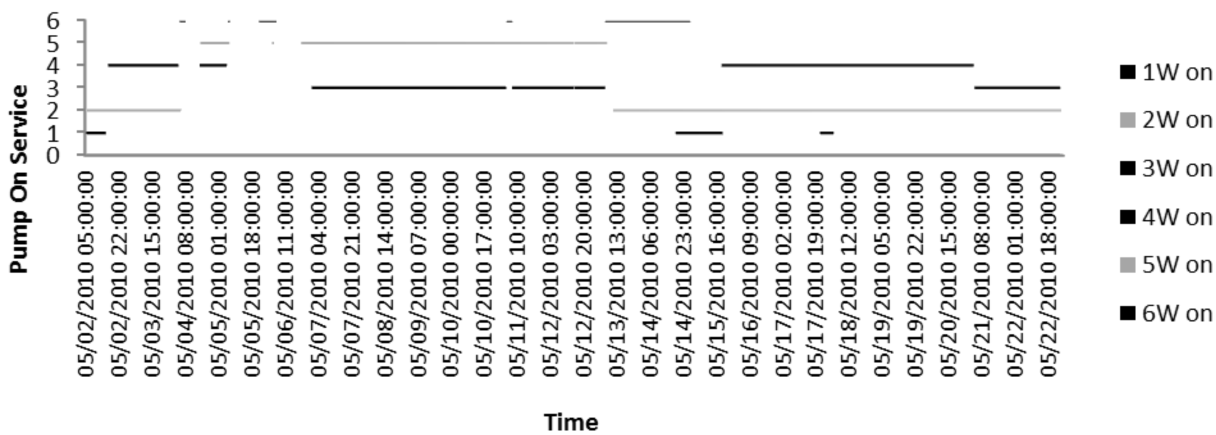

Q(MGD)
200
150
100
50
0
9000
9100
9200
9300
9400
9500
Time
Q predicted
Q real time
Detected Error

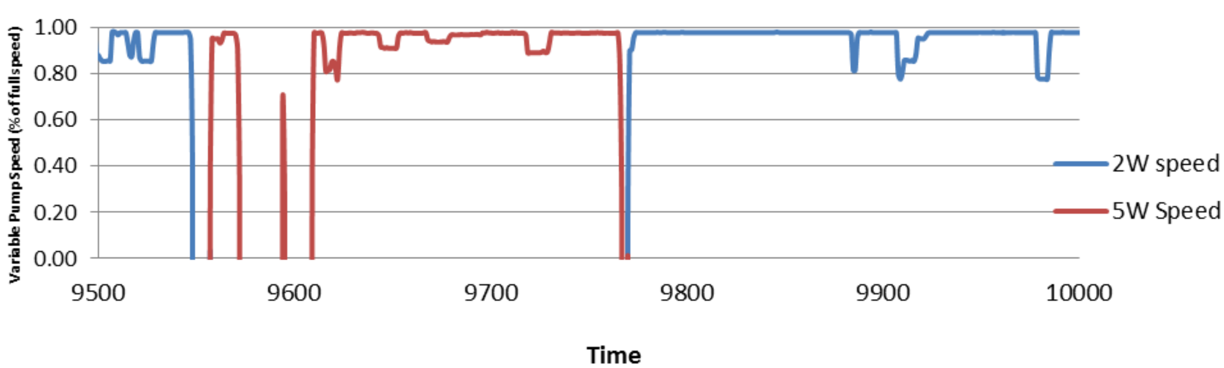

Pump On Service
6
5
4
3
2
1
0
04/11/2010 09:00:00
04/12/2010 02:00:00
04/12/2010 19:00:00
04/13/2010 12:00:00
04/14/2010 05:00:00
04/14/2010 22:00:00
04/15/2010 15:00:00
04/16/2010 08:00:00
04/17/2010 01:00:00
04/17/2010 18:00:00
04/18/2010 11:00:00
04/19/2010 04:00:00
04/19/2010 21:00:00
04/20/2010 14:00:00
04/21/2010 07:00:00
04/22/2010 00:00:00
04/22/2010 17:00:00
04/23/2010 10:00:00
04/24/2010 03:00:00
04/24/2010 20:00:00
04/25/2010 13:00:00
04/26/2010 06:00:00
04/26/2010 23:00:00
04/27/2010 16:00:00
04/28/2010 09:00:00
04/29/2010 02:00:00
04/29/2010 19:00:00
04/30/2010 12:00:00
05/01/2010 05:00:00
05/01/2010 22:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

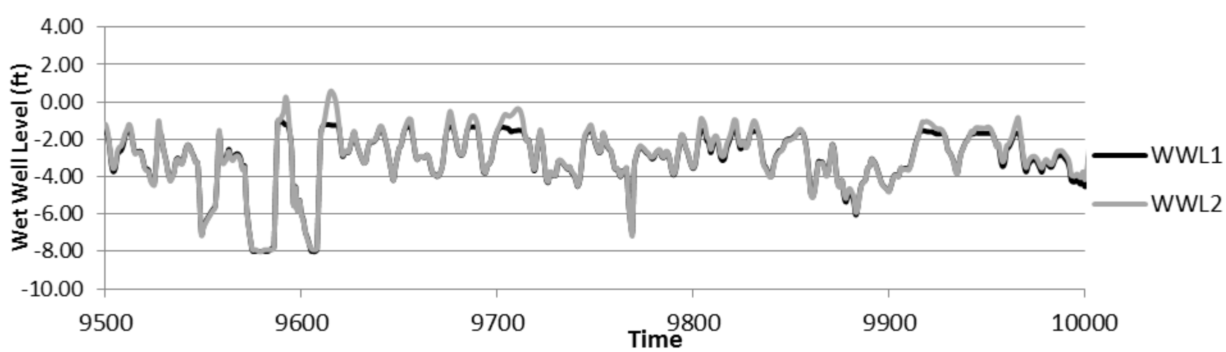

Variable PumpSpeed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
9000
9100
9200
9300
9400
9500
Time
2W speed
5W Speed

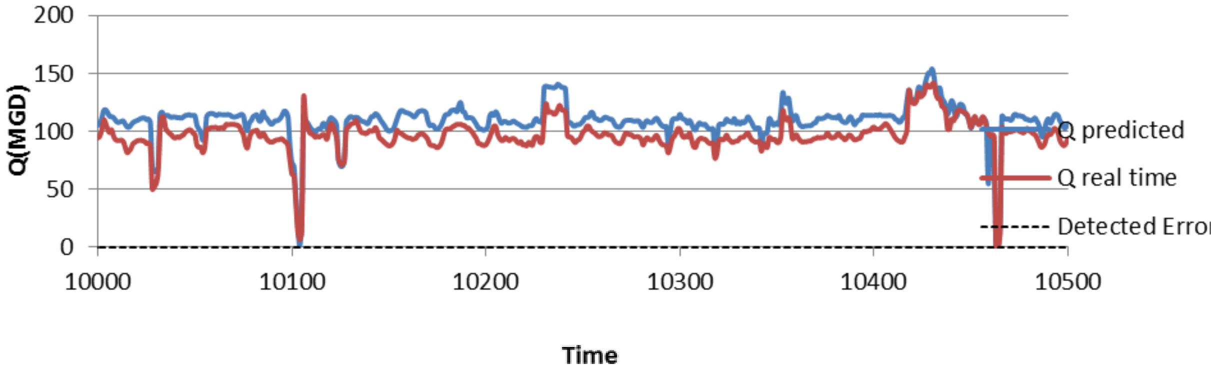

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
9000
9100
9200
9300
9400
9500
Time
WWL1
WWL2

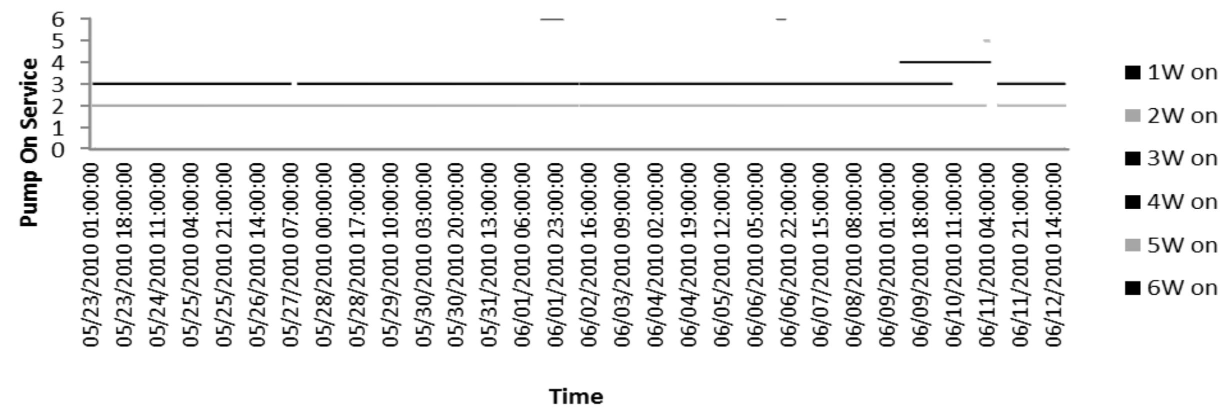

Q(MGD)
200
150
100
50
0
9500
9600
9700
9800
9900
10000
Time
Q predicted
Q real time
Detected Error

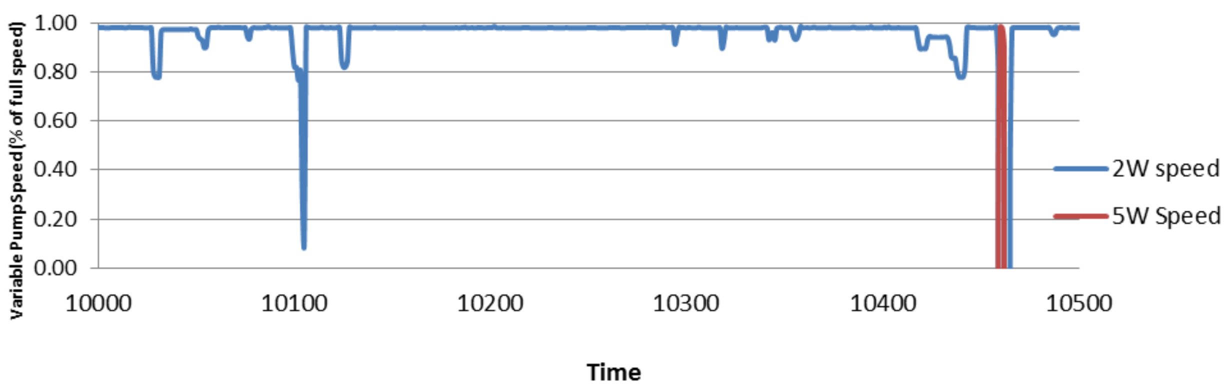

Pump On Service
6
5
4
3
2
1
0
05/02/2010 05:00:00
05/02/2010 22:00:00
05/03/2010 15:00:00
05/04/2010 08:00:00
05/05/2010 01:00:00
05/05/2010 18:00:00
05/06/2010 11:00:00
05/07/2010 04:00:00
05/07/2010 21:00:00
05/08/2010 14:00:00
05/09/2010 07:00:00
05/10/2010 00:00:00
05/10/2010 17:00:00
05/11/2010 10:00:00
05/12/2010 03:00:00
05/12/2010 20:00:00
05/13/2010 13:00:00
05/14/2010 06:00:00
05/14/2010 23:00:00
05/15/2010 16:00:00
05/16/2010 09:00:00
05/17/2010 02:00:00
05/17/2010 19:00:00
05/18/2010 12:00:00
05/19/2010 05:00:00
05/19/2010 22:00:00
05/20/2010 15:00:00
05/21/2010 08:00:00
05/22/2010 01:00:00
05/22/2010 18:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

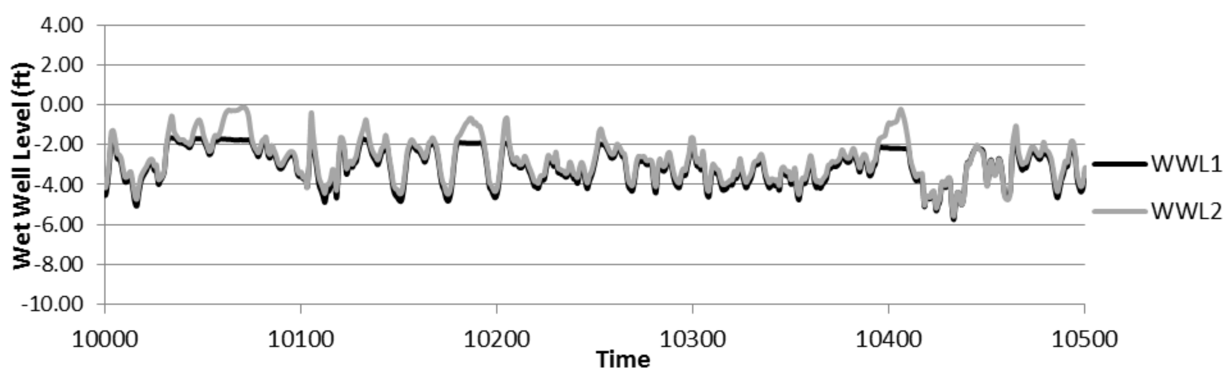

Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
9500
9600
9700
9800
9900
10000
Time
2W speed
5W Speed

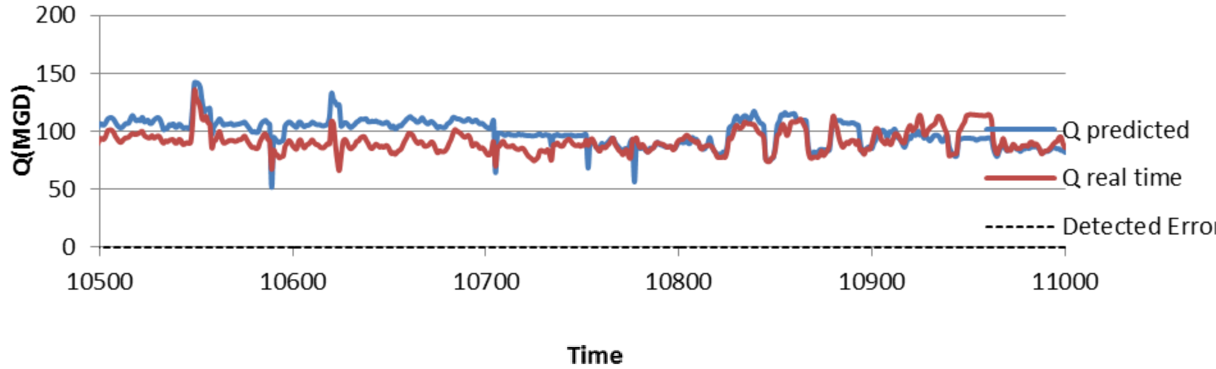

Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
9500
9600
9700
9800
9900
10000
Time
WWL1
WWL2


200
150
100
50
0
Q(MGD)
10000
10100
10200
10300
10400
10500
Time
Q predicted
Q real time
Detected Error

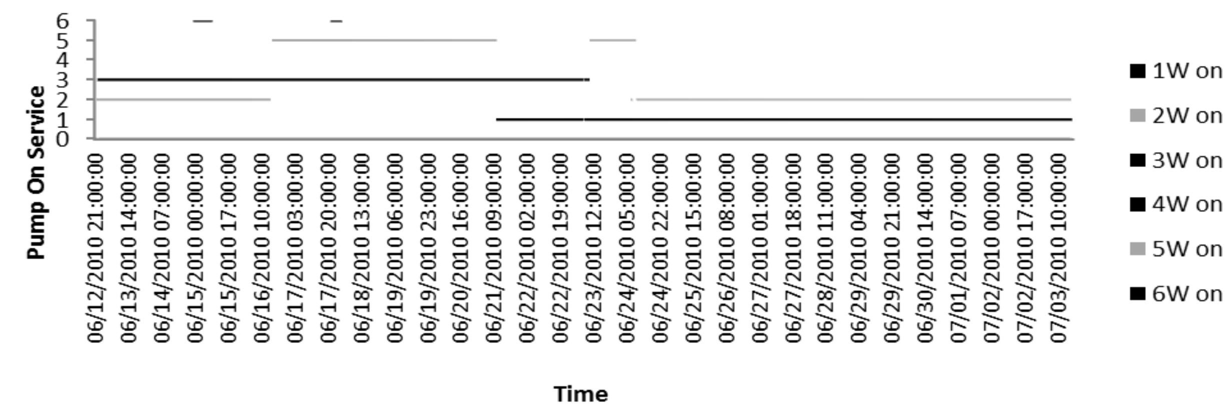

6
5
4
3
2
1
0
Pump On Service
05/23/2010 01:00:00
05/23/2010 18:00:00
05/24/2010 11:00:00
05/25/2010 04:00:00
05/25/2010 21:00:00
05/26/2010 14:00:00
05/27/2010 07:00:00
05/28/2010 00:00:00
05/28/2010 17:00:00
05/29/2010 10:00:00
05/30/2010 03:00:00
05/30/2010 20:00:00
05/31/2010 13:00:00
06/01/2010 06:00:00
06/01/2010 23:00:00
06/02/2010 16:00:00
06/03/2010 09:00:00
06/04/2010 02:00:00
06/04/2010 19:00:00
06/05/2010 12:00:00
06/06/2010 05:00:00
06/06/2010 22:00:00
06/07/2010 15:00:00
06/08/2010 08:00:00
06/09/2010 01:00:00
06/09/2010 18:00:00
06/10/2010 11:00:00
06/11/2010 04:00:00
06/11/2010 21:00:00
06/12/2010 14:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
10000
10100
10200
10300
10400
10500
Time
2W speed
5W Speed

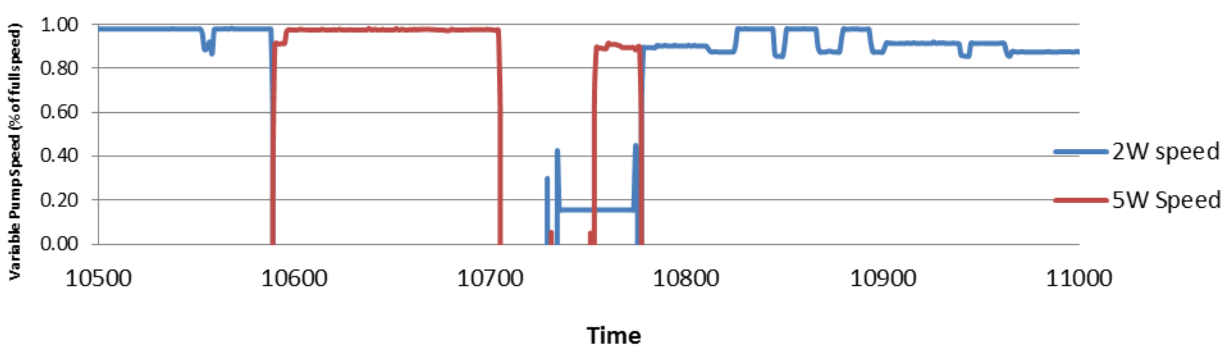

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
10000
10100
10200
10300
10400
10500
Time
WWL1
WWL2



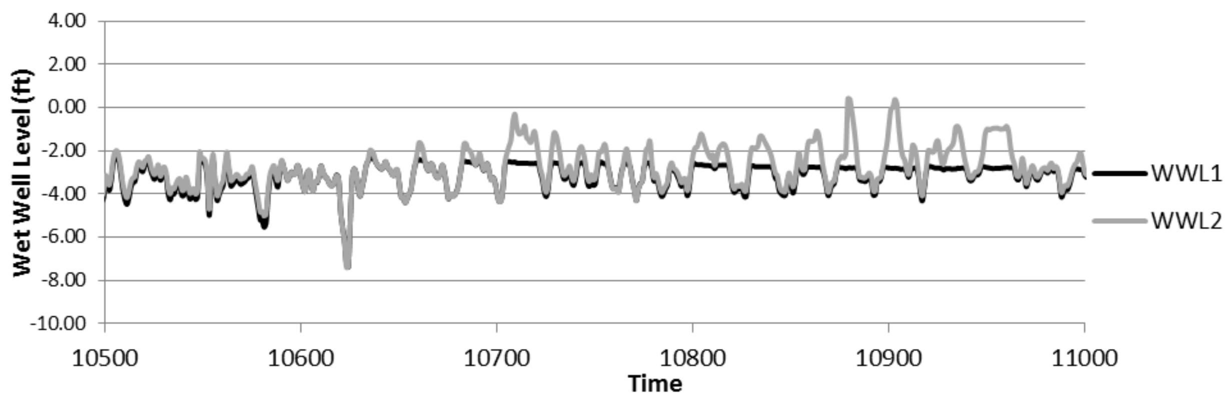
Q(MGD)
200
150
100
50
0
10500
10600
10700
10800
10900
11000
Time
Q predicted
Q real time
Detected Error



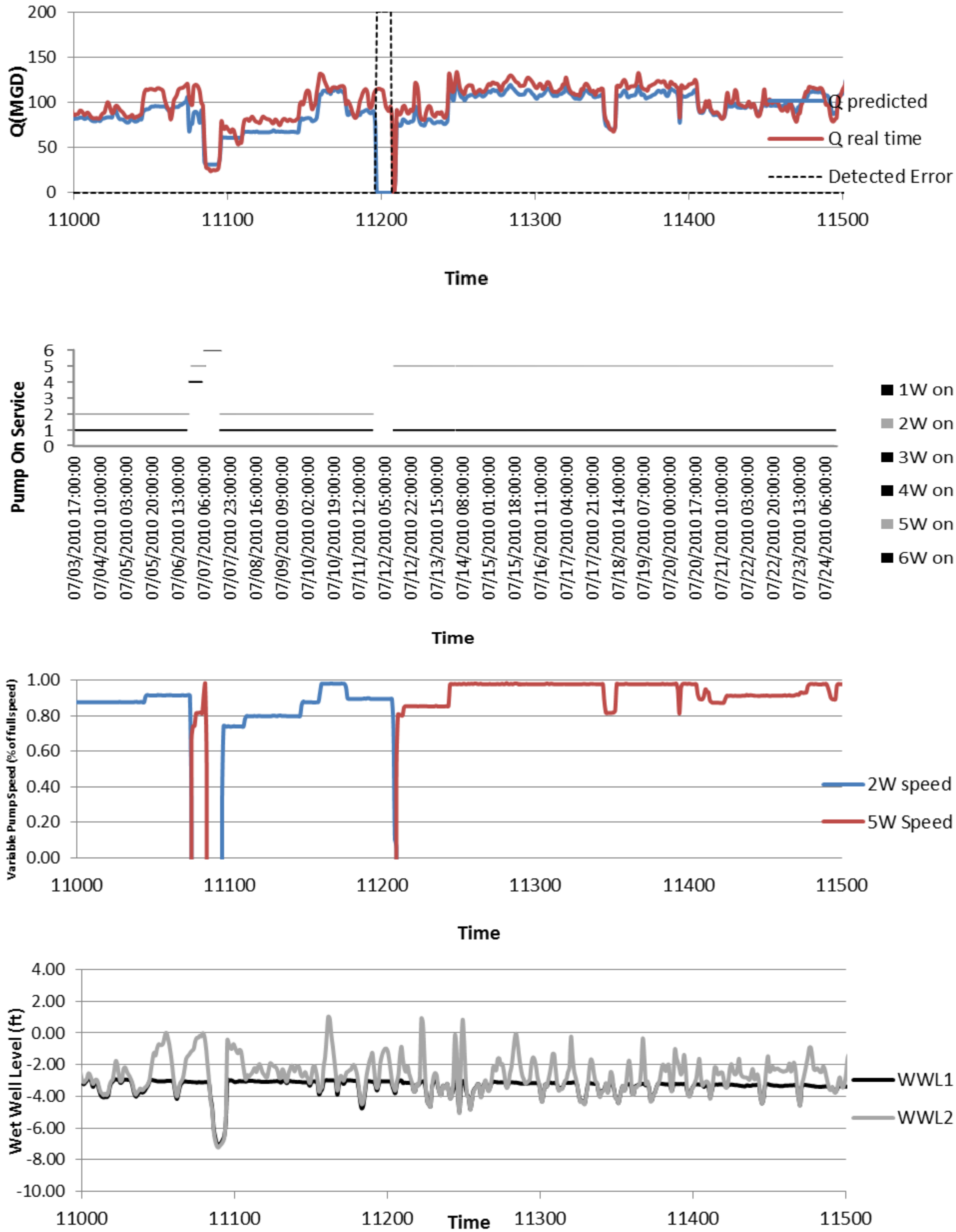
Pump On Service
6
5
4
3
2
1
0
06/12/2010 21:00:00
06/13/2010 14:00:00
06/14/2010 07:00:00
06/15/2010 00:00:00
06/15/2010 17:00:00
06/16/2010 10:00:00
06/17/2010 03:00:00
06/17/2010 20:00:00
06/18/2010 13:00:00
06/19/2010 06:00:00
06/19/2010 23:00:00
06/20/2010 16:00:00
06/21/2010 09:00:00
06/22/2010 02:00:00
06/22/2010 19:00:00
06/23/2010 12:00:00
06/24/2010 05:00:00
06/24/2010 22:00:00
06/25/2010 15:00:00
06/26/2010 08:00:00
06/27/2010 01:00:00
06/27/2010 18:00:00
06/28/2010 11:00:00
06/29/2010 04:00:00
06/29/2010 21:00:00
06/30/2010 14:00:00
07/01/2010 07:00:00
07/02/2010 00:00:00
07/02/2010 17:00:00
07/03/2010 10:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on



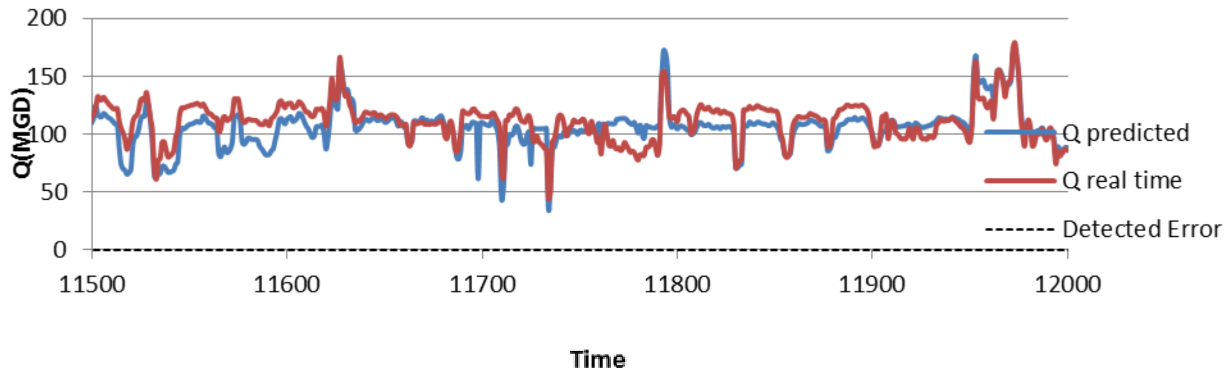
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
10500
10600
10700
10800
10900
11000
Time
2W speed
5W Speed

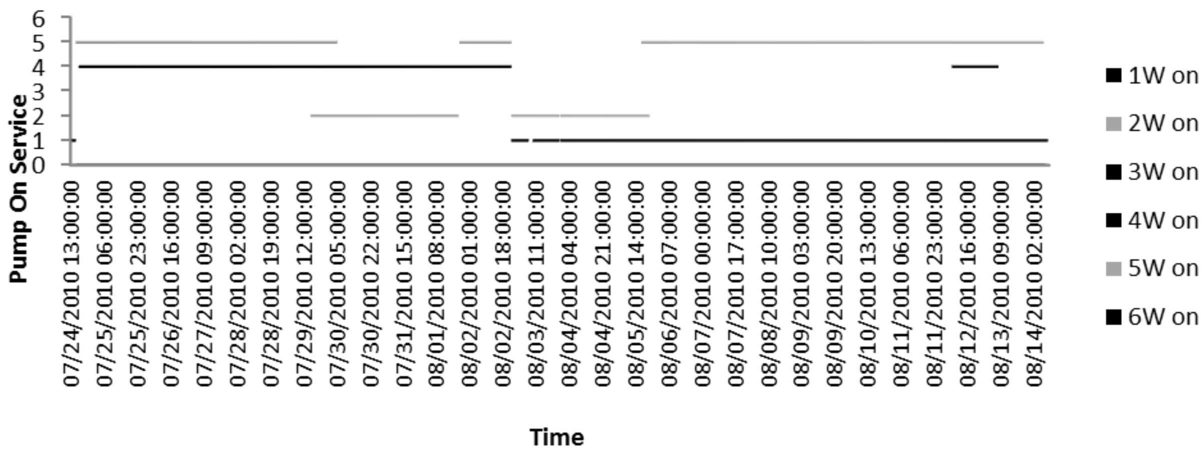


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
10500
10600
10700
10800
10900
11000
Time
WWL1
WWL2



Q(MGD)
200
150
100
50
0
11000
11100
11200
11300
11400
11500
Time
Q predicted
Q real time
Detected Error
Pump On Service
6
5
4
3
2
1
0
07/03/2010 17:00:00
07/04/2010 10:00:00
07/05/2010 03:00:00
07/05/2010 20:00:00
07/06/2010 13:00:00
07/07/2010 06:00:00
07/07/2010 23:00:00
07/08/2010 16:00:00
07/09/2010 09:00:00
07/10/2010 02:00:00
07/10/2010 19:00:00
07/11/2010 12:00:00
07/12/2010 05:00:00
07/12/2010 22:00:00
07/13/2010 15:00:00
07/14/2010 08:00:00
07/15/2010 01:00:00
07/15/2010 18:00:00
07/16/2010 11:00:00
07/17/2010 04:00:00
07/17/2010 21:00:00
07/18/2010 14:00:00
07/19/2010 07:00:00
07/20/2010 00:00:00
07/20/2010 17:00:00
07/21/2010 10:00:00
07/22/2010 03:00:00
07/22/2010 20:00:00
07/23/2010 13:00:00
07/24/2010 06:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on
Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
11000
11100
11200
11300
11400
11500
Time
2W speed
5W Speed
Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
11000
11100
11200
11300
11400
11500
Time
WWL1
WWL2


200
150
100
50
0
Q(MGD)
11500
11600
11700
11800
11900
12000
Time
Q predicted
Q real time
Detected Error


6
5
4
3
2
1
0
Pump On Service
07/24/2010 13:00:00
07/25/2010 06:00:00
07/25/2010 23:00:00
07/26/2010 16:00:00
07/27/2010 09:00:00
07/28/2010 02:00:00
07/28/2010 19:00:00
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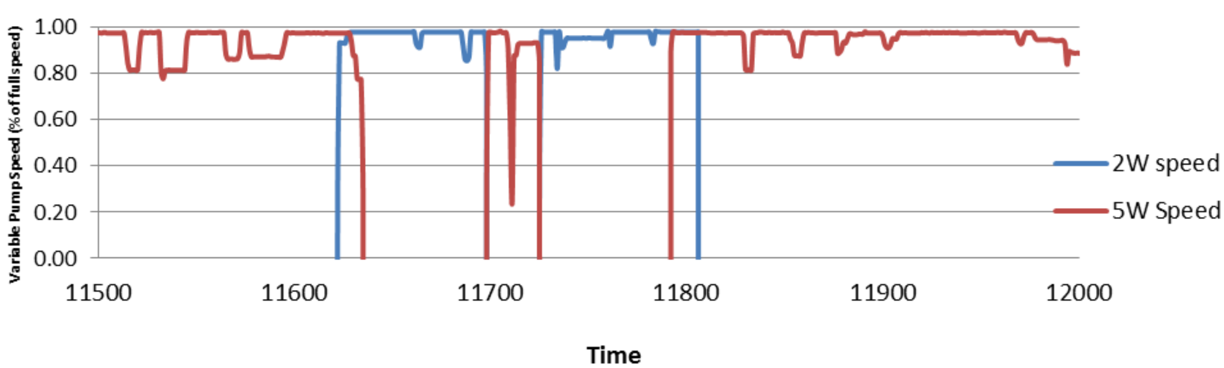
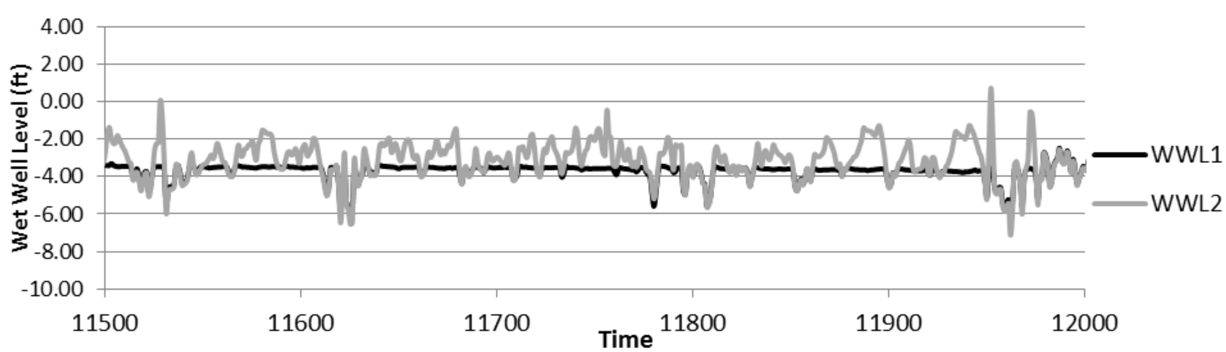
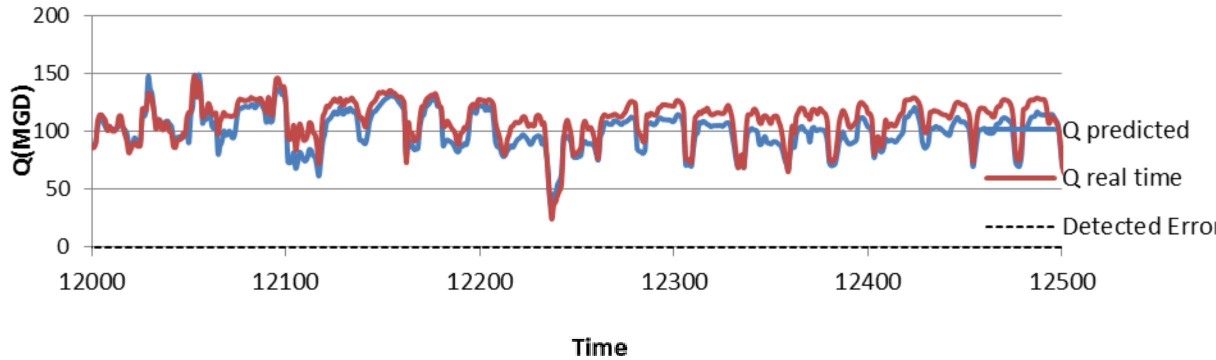
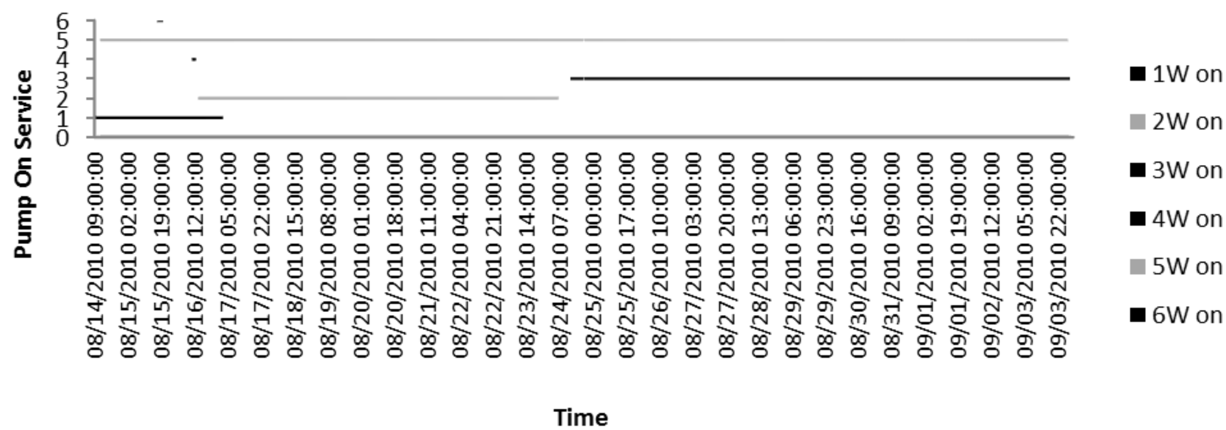
07/30/2010 05:00:00
07/30/2010 22:00:00
07/31/2010 15:00:00
08/01/2010 08:00:00
08/02/2010 01:00:00
08/02/2010 18:00:00
08/03/2010 11:00:00
08/04/2010 04:00:00
08/04/2010 21:00:00
08/05/2010 14:00:00
08/06/2010 07:00:00
08/07/2010 00:00:00
08/07/2010 17:00:00
08/08/2010 10:00:00
08/09/2010 03:00:00
08/09/2010 20:00:00
08/10/2010 13:00:00
08/11/2010 06:00:00
08/11/2010 23:00:00
08/12/2010 16:00:00
08/13/2010 09:00:00
08/14/2010 02:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
11500
11600
11700
11800
11900
12000
Time
2W speed
5W Speed


4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
11500
11600
11700
11800
11900
12000
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
12000
12100
12200
12300
12400
12500
Time
Q predicted
Q real time
Detected Error


Pump On Service
6
5
4
3
2
1
0
08/14/2010 09:00:00
08/15/2010 02:00:00
08/15/2010 19:00:00
08/16/2010 12:00:00
08/17/2010 05:00:00
08/17/2010 22:00:00
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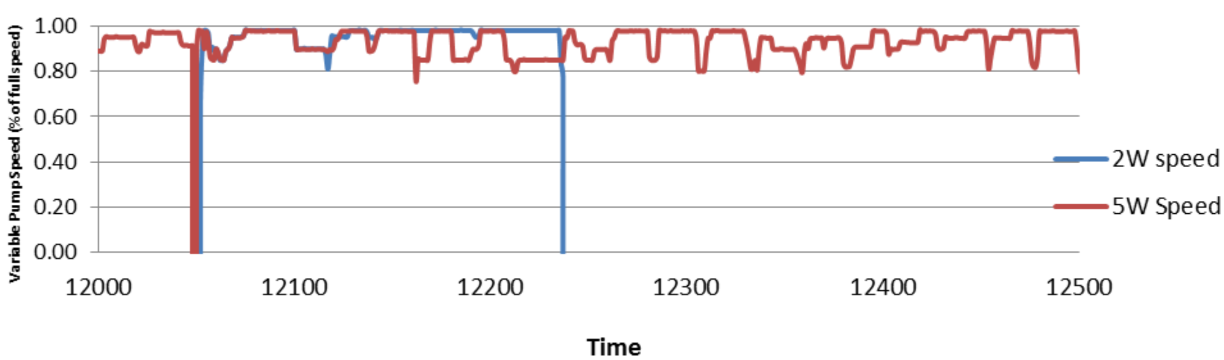
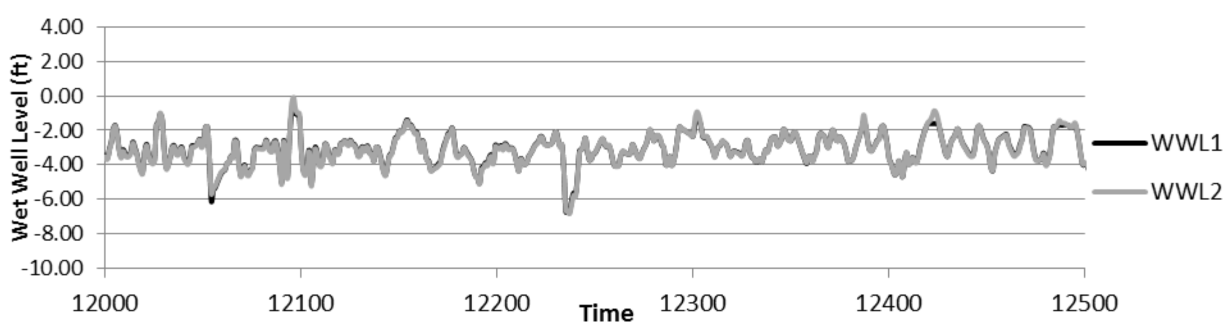
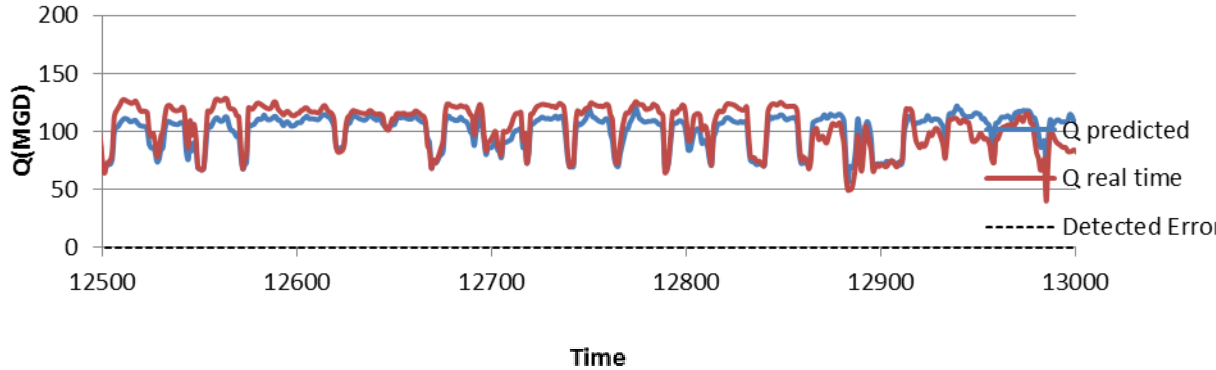
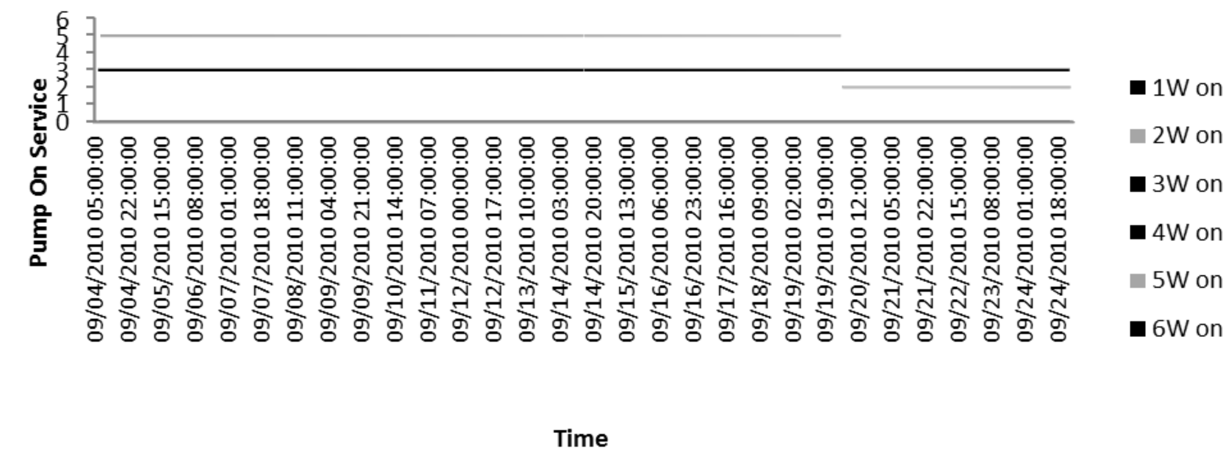
08/19/2010 08:00:00
08/20/2010 01:00:00
08/20/2010 18:00:00
08/21/2010 11:00:00
08/22/2010 04:00:00
08/22/2010 21:00:00
08/23/2010 14:00:00
08/24/2010 07:00:00
08/25/2010 00:00:00
08/25/2010 17:00:00
08/26/2010 10:00:00
08/27/2010 03:00:00
08/27/2010 20:00:00
08/28/2010 13:00:00
08/29/2010 06:00:00
08/29/2010 23:00:00
08/30/2010 16:00:00
08/31/2010 09:00:00
09/01/2010 02:00:00
09/01/2010 19:00:00
09/02/2010 12:00:00
09/03/2010 05:00:00
09/03/2010 22:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
12000
12100
12200
12300
12400
12500
Time
2W speed
5W Speed


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
12000
12100
12200
12300
12400
12500
Time
WWL1
WWL2


200
150
100
50
0
Q(MGD)
12500
12600
12700
12800
12900
13000
Time
Q predicted
Q real time
Detected Error


Pump On Service
6
5
4
3
2
1
0
09/04/2010 05:00:00
09/04/2010 22:00:00
09/05/2010 15:00:00
09/06/2010 08:00:00
09/07/2010 01:00:00
09/07/2010 18:00:00
09/08/2010 11:00:00
09/09/2010 04:00:00
09/09/2010 21:00:00
09/10/2010 14:00:00
09/11/2010 07:00:00
09/12/2010 00:00:00
09/12/2010 17:00:00
09/13/2010 10:00:00
09/14/2010 03:00:00
09/14/2010 20:00:00
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09/17/2010 16:00:00
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09/19/2010 02:00:00
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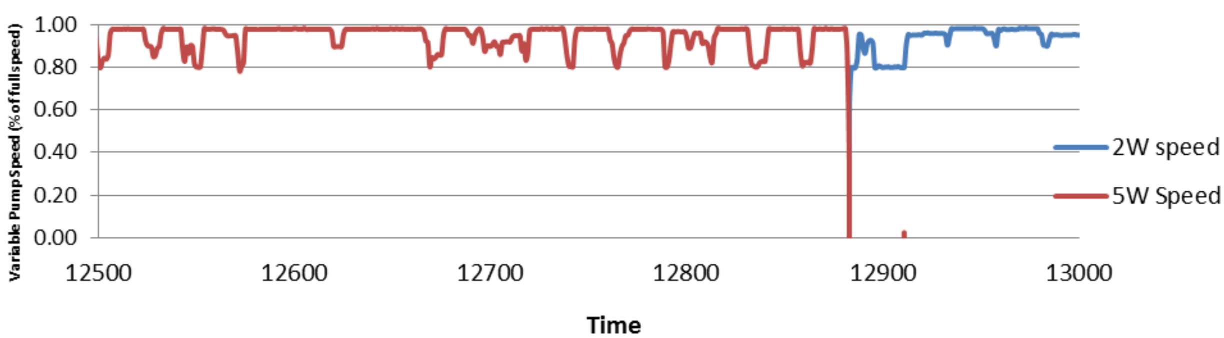
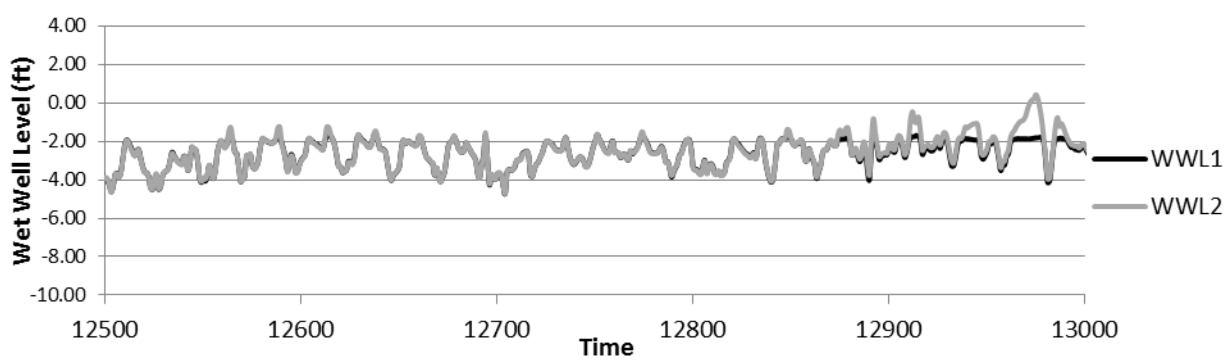
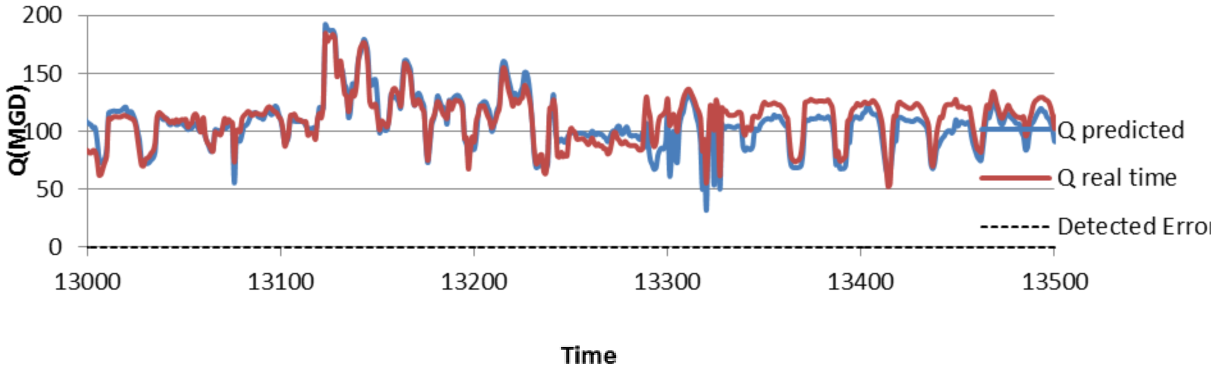
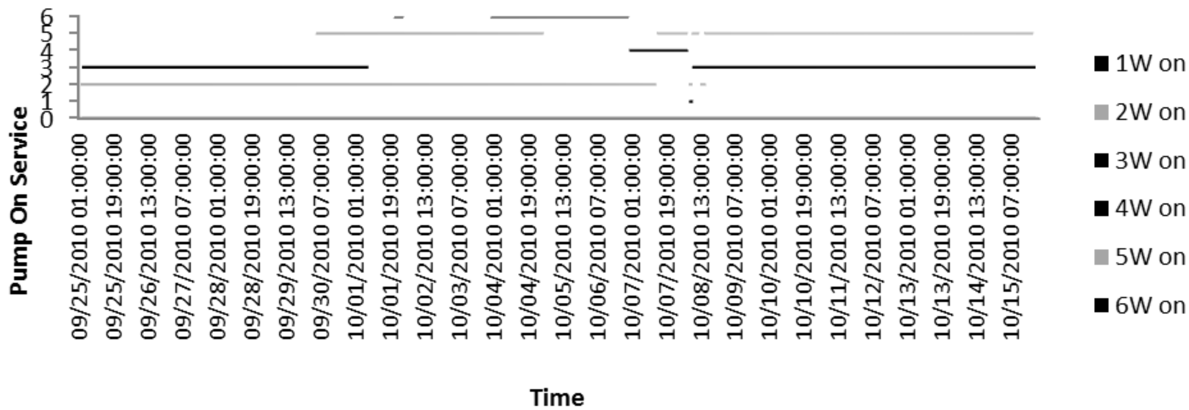
09/21/2010 22:00:00
09/22/2010 15:00:00
09/23/2010 08:00:00
09/24/2010 01:00:00
09/24/2010 18:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
12500
12600
12700
12800
12900
13000
Time
2W speed
5W Speed


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
12500
12600
12700
12800
12900
13000
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
13000
13100
13200
13300
13400
13500
Q predicted
Q real time
Detected Error
Time


Pump On Service
6
5
4
3
2
1
0
09/25/2010 01:00:00
09/25/2010 19:00:00
09/26/2010 13:00:00
09/27/2010 07:00:00
09/28/2010 01:00:00
09/28/2010 19:00:00
09/29/2010 13:00:00
09/30/2010 07:00:00
10/01/2010 01:00:00
10/01/2010 19:00:00
10/02/2010 13:00:00
10/03/2010 07:00:00
10/04/2010 01:00:00
10/04/2010 19:00:00
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10/07/2010 01:00:00
10/07/2010 19:00:00
10/08/2010 13:00:00
10/09/2010 07:00:00
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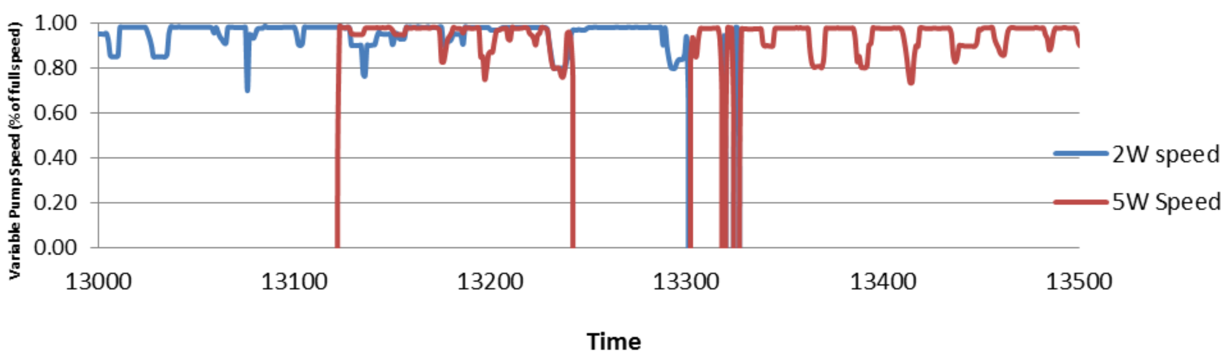
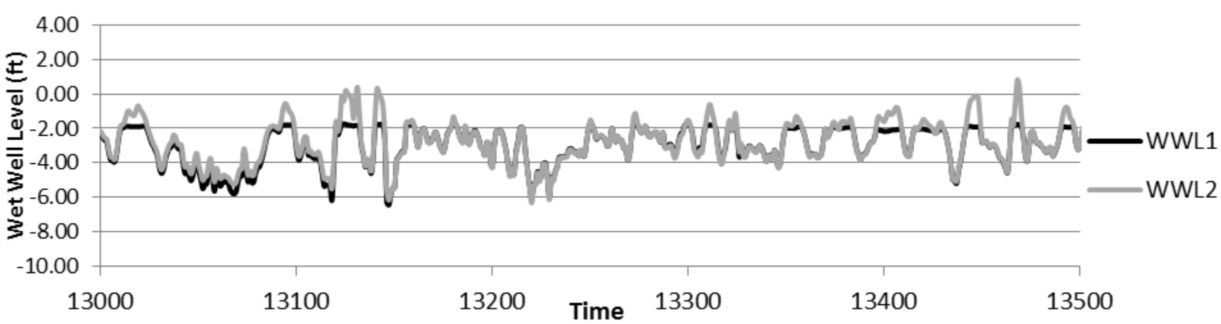
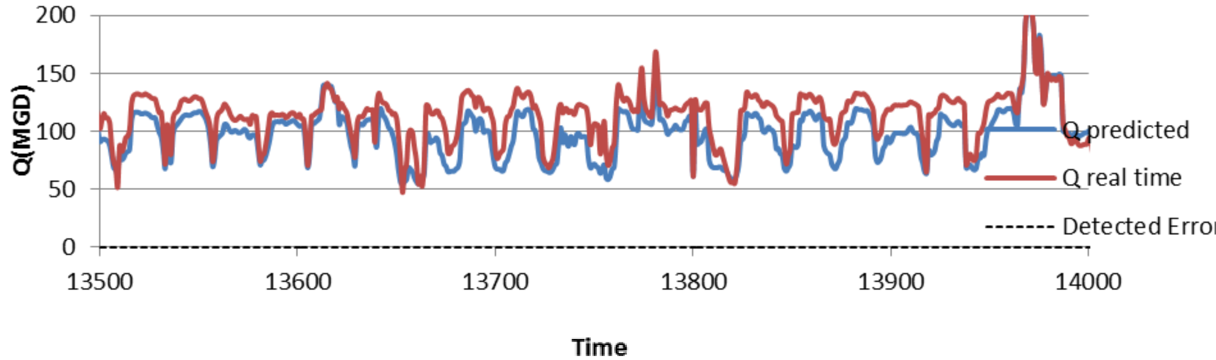
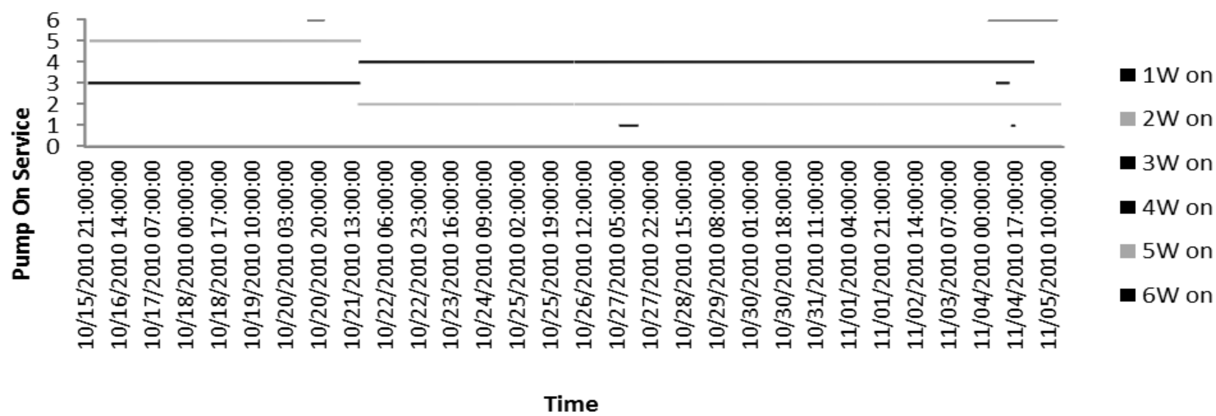
10/10/2010 19:00:00
10/11/2010 13:00:00
10/12/2010 07:00:00
10/13/2010 01:00:00
10/13/2010 19:00:00
10/14/2010 13:00:00
10/15/2010 07:00:00
1W on
2W on
3W on
4W on
5W on
6W on
Time


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
13000
13100
13200
13300
13400
13500
2W speed
5W Speed
Time


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
13000
13100
13200
13300
13400
13500
WWL1
WWL2
Time



200
150
100
50
0
Q(MGD)
13500
13600
13700
13800
13900
14000
Time
Q predicted
Q real time
Detected Error



6
5
4
3
2
1
0
Pump On Service
10/15/2010 21:00:00
10/16/2010 14:00:00
10/17/2010 07:00:00
10/18/2010 00:00:00
10/18/2010 17:00:00
10/19/2010 10:00:00
10/20/2010 03:00:00
10/20/2010 20:00:00
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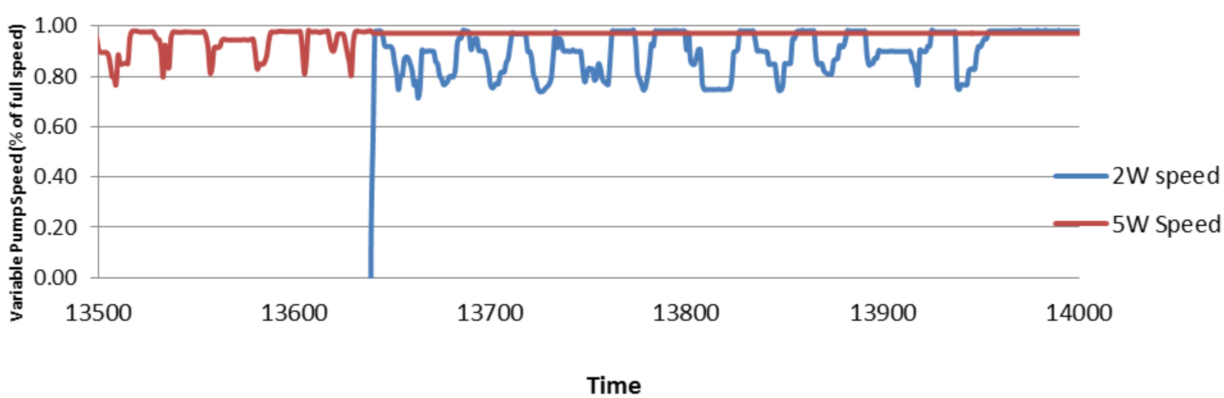
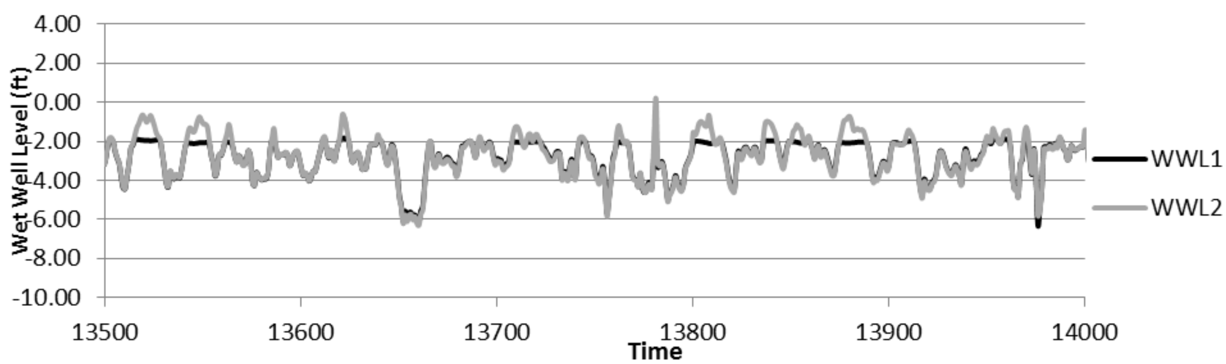
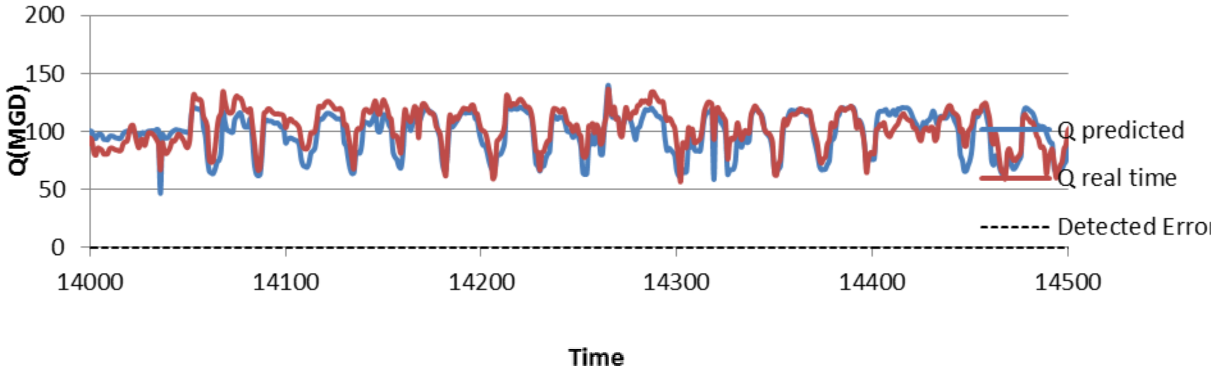
10/22/2010 06:00:00
10/22/2010 23:00:00
10/23/2010 16:00:00
10/24/2010 09:00:00
10/25/2010 02:00:00
10/25/2010 19:00:00
10/26/2010 12:00:00
10/27/2010 05:00:00
10/27/2010 22:00:00
10/28/2010 15:00:00
10/29/2010 08:00:00
10/30/2010 01:00:00
10/30/2010 18:00:00
10/31/2010 11:00:00
11/01/2010 04:00:00
11/01/2010 21:00:00
11/02/2010 14:00:00
11/03/2010 07:00:00
11/04/2010 00:00:00
11/04/2010 17:00:00
11/05/2010 10:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

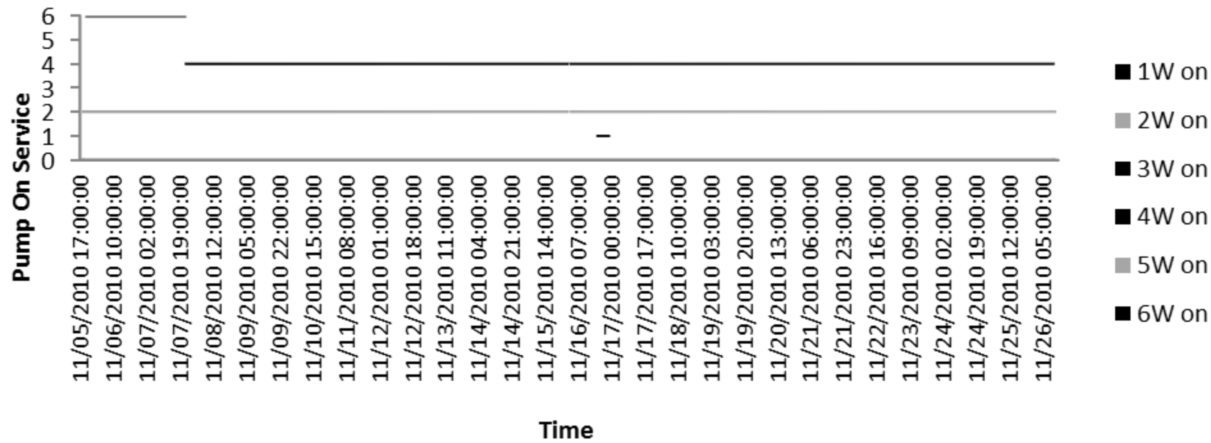


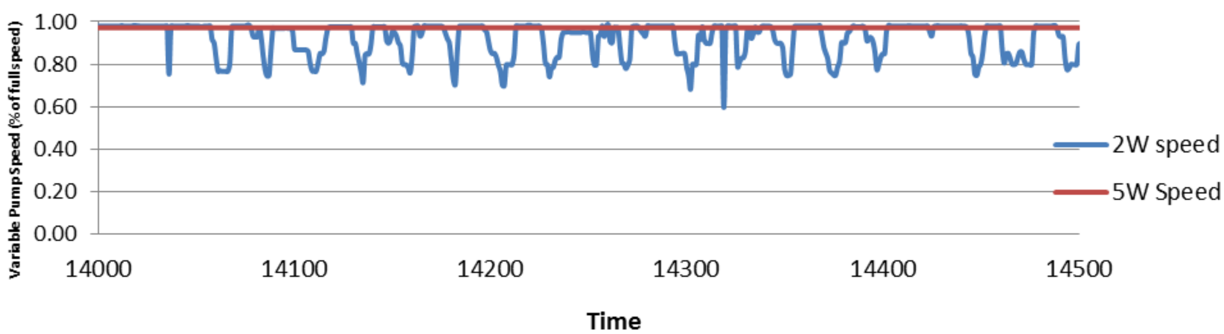
1.00
0.80
0.60
0.40
0.20
0.00
Variable PumpSpeed (% of full speed)
13500
13600
13700
13800
13900
14000
Time
2W speed
5W Speed

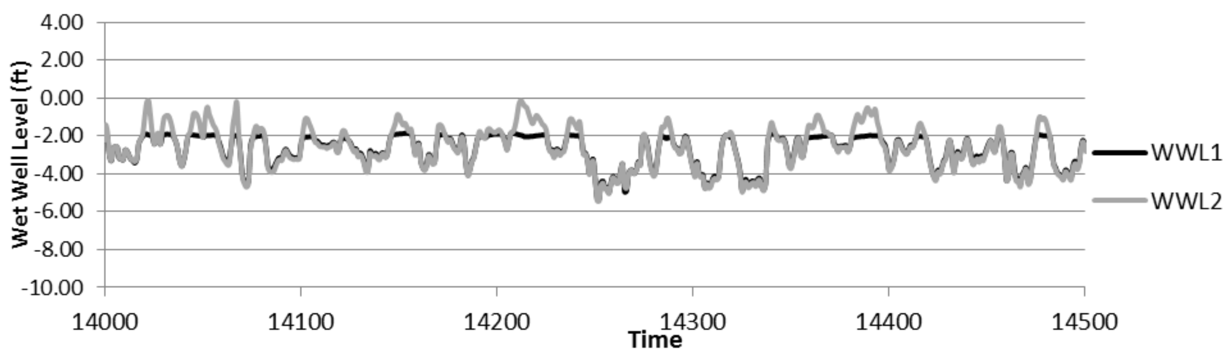


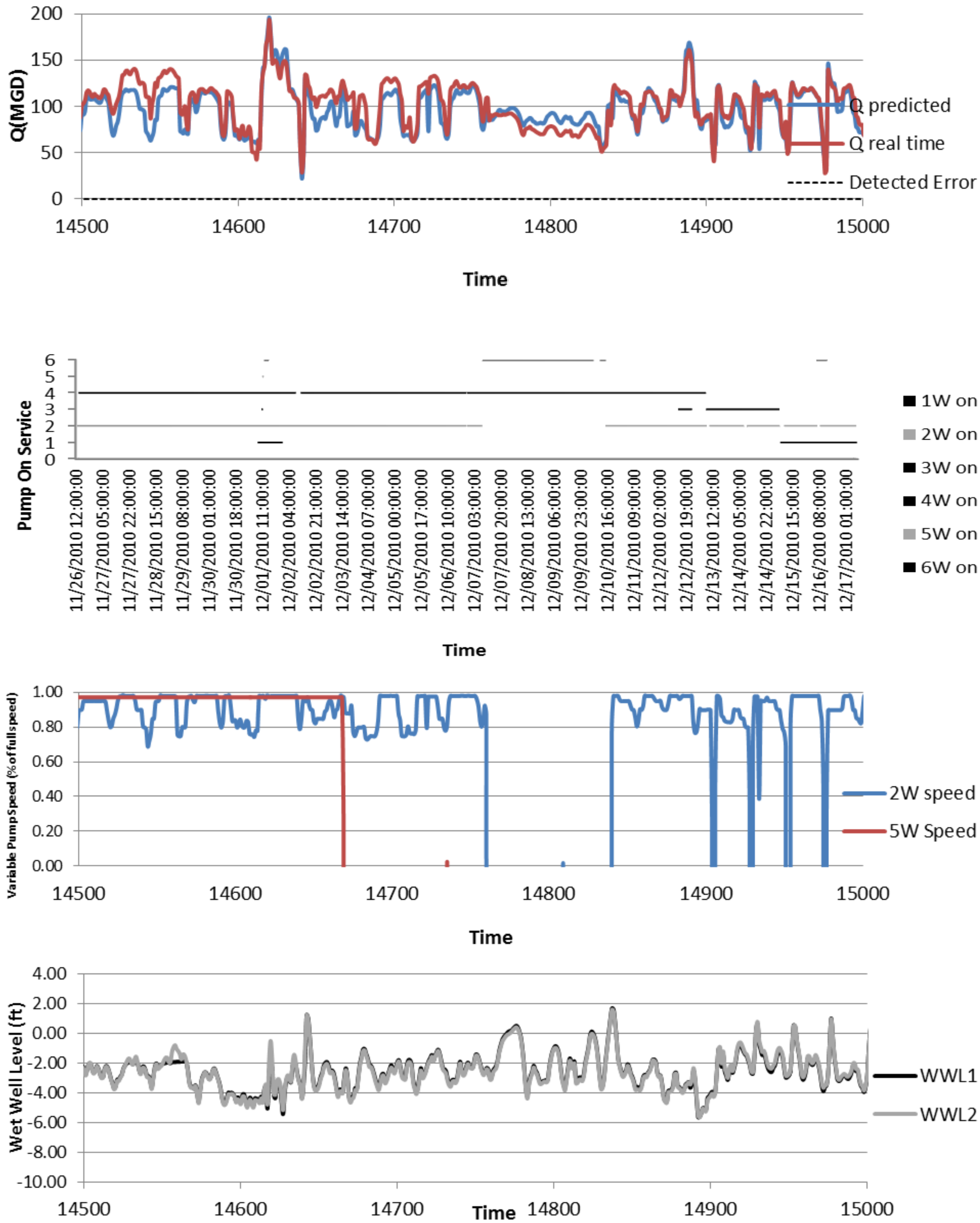
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
13500
13600
13700
13800
13900
14000
Time
WWL1
WWL2

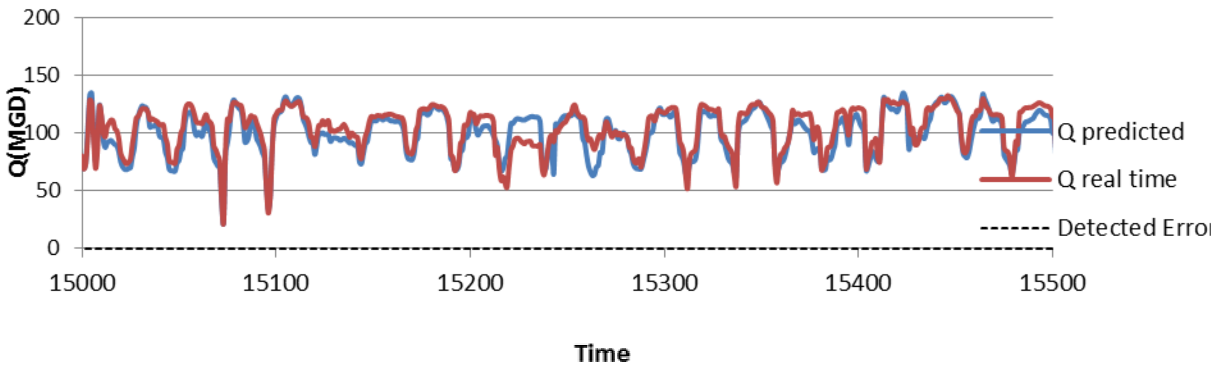

200
150
100
50
0
Q(MGD)
14000
14100
14200
14300
14400
14500
Time
Q predicted
Q real time
Detected Error

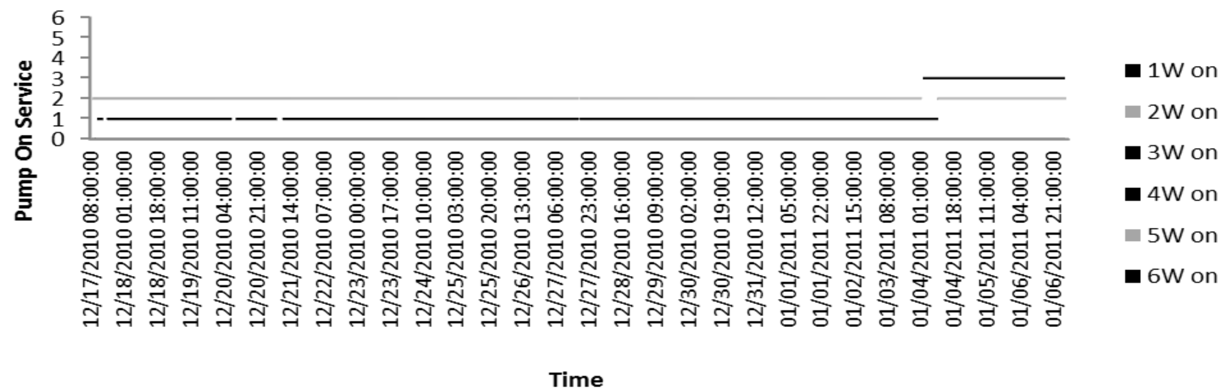

6
5
4
3
2
1
0
Pump On Service
11/05/2010 17:00:00
11/06/2010 10:00:00
11/07/2010 02:00:00
11/07/2010 19:00:00
11/08/2010 12:00:00
11/09/2010 05:00:00
11/09/2010 22:00:00
11/10/2010 15:00:00
11/11/2010 08:00:00
11/12/2010 01:00:00
11/12/2010 18:00:00
11/13/2010 11:00:00
11/14/2010 04:00:00
11/14/2010 21:00:00
11/15/2010 14:00:00
11/16/2010 07:00:00
11/17/2010 00:00:00
11/17/2010 17:00:00
11/18/2010 10:00:00
11/19/2010 03:00:00
11/19/2010 20:00:00
11/20/2010 13:00:00
11/21/2010 06:00:00
11/21/2010 23:00:00
11/22/2010 16:00:00
11/23/2010 09:00:00
11/24/2010 02:00:00
11/24/2010 19:00:00
11/25/2010 12:00:00
11/26/2010 05:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

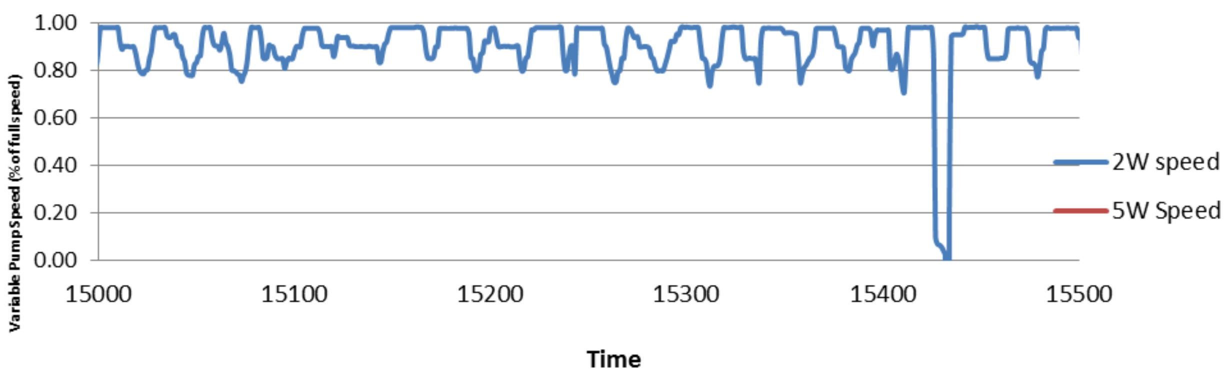

1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
14000
14100
14200
14300
14400
14500
Time
2W speed
5W Speed

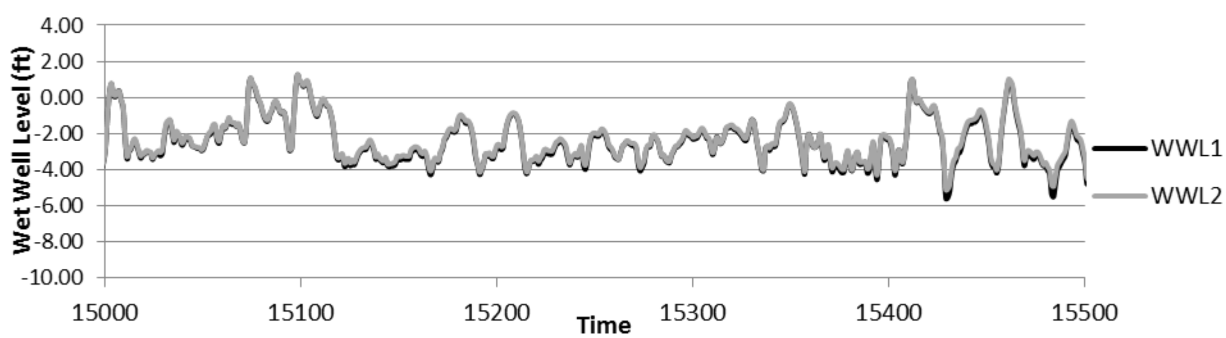

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
14000
14100
14200
14300
14400
14500
Time
WWL1
WWL2

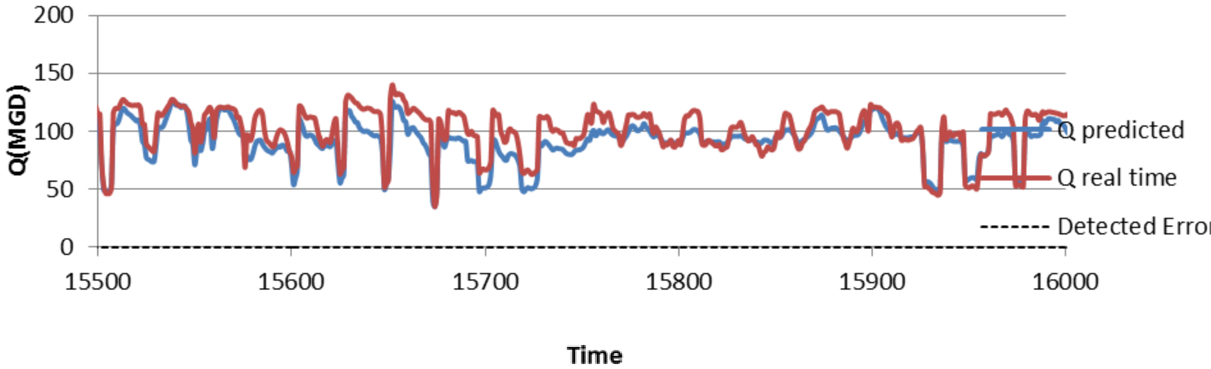

Q(MGD)
200
150
100
50
0
14500
14600
14700
14800
14900
15000
Time
Q predicted
Q real time
Detected Error
Pump On Service
1W on
2W on
3W on
4W on
5W on
6W on
Time
Variable Pump Speed (% of full speed)
2W speed
5W Speed
Time
Wet Well Level (ft)
WWL1
WWL2
Time

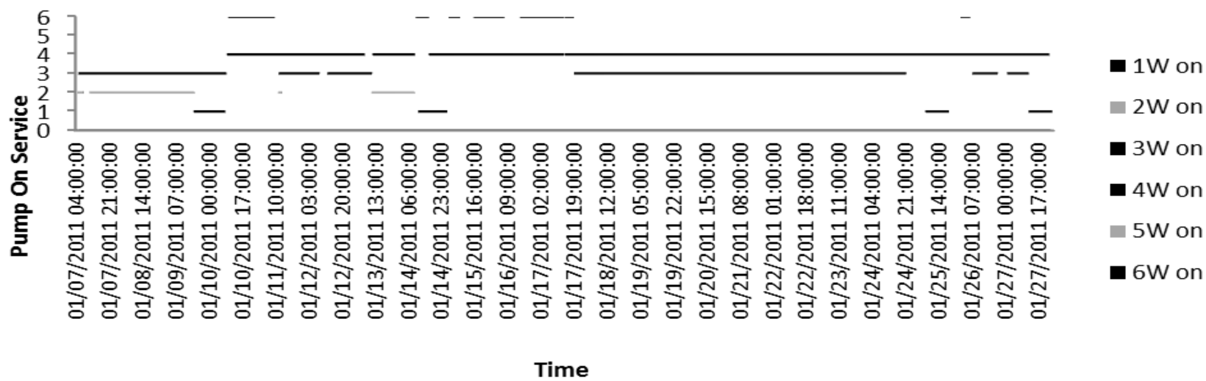

200
150
100
50
0
Q(MGD)
15000
15100
15200
15300
15400
15500
Time
Q predicted
Q real time
Detected Error

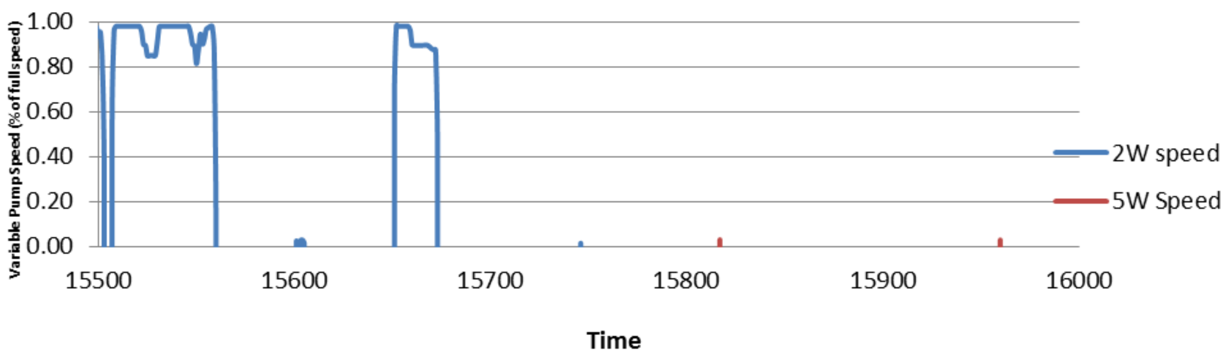

6
5
4
3
2
1
0
Pump On Service
12/17/2010 08:00:00
12/18/2010 01:00:00
12/18/2010 18:00:00
12/19/2010 11:00:00
12/20/2010 04:00:00
12/20/2010 21:00:00
12/21/2010 14:00:00
12/22/2010 07:00:00
12/23/2010 00:00:00
12/23/2010 17:00:00
12/24/2010 10:00:00
12/25/2010 03:00:00
12/25/2010 20:00:00
12/26/2010 13:00:00
12/27/2010 06:00:00
12/27/2010 23:00:00
12/28/2010 16:00:00
12/29/2010 09:00:00
12/30/2010 02:00:00
12/30/2010 19:00:00
12/31/2010 12:00:00
01/01/2011 05:00:00
01/01/2011 22:00:00
01/02/2011 15:00:00
01/03/2011 08:00:00
01/04/2011 01:00:00
01/04/2011 18:00:00
01/05/2011 11:00:00
01/06/2011 04:00:00
01/06/2011 21:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

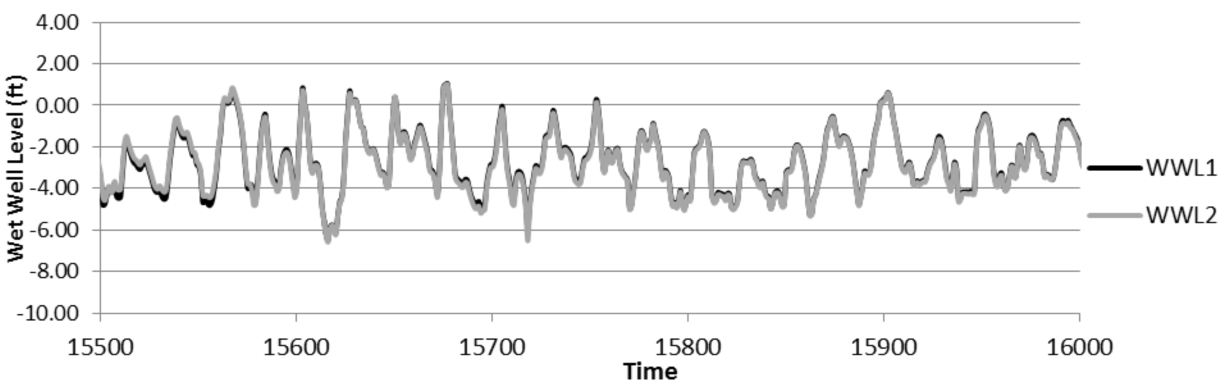

1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
15000
15100
15200
15300
15400
15500
Time
2W speed
5W Speed

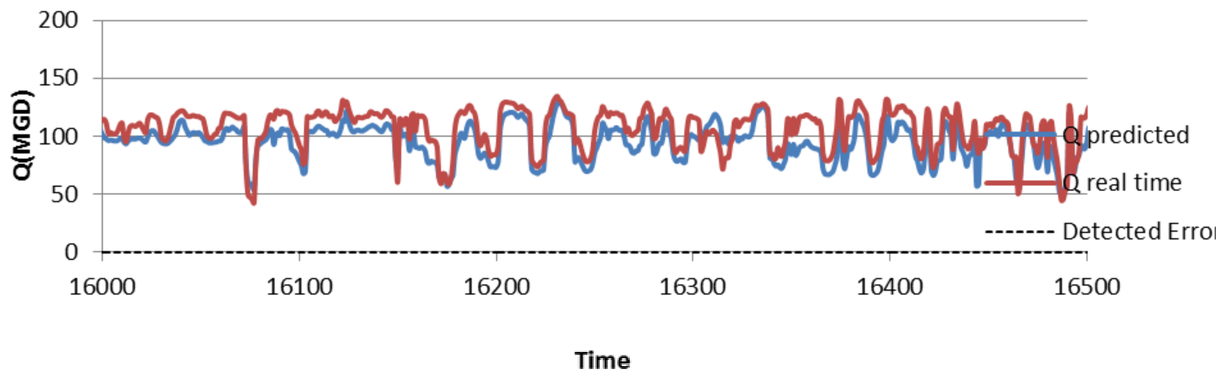

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
15000
15100
15200
15300
15400
15500
Time
WWL1
WWL2

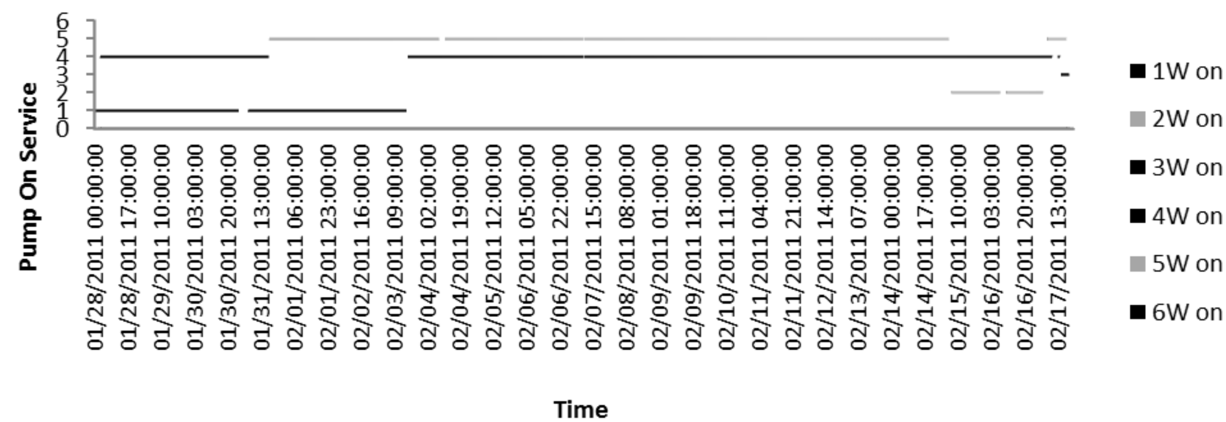

200
150
100
50
0
Q(MGD)
15500
15600
15700
15800
15900
16000
Time
Q predicted
Q real time
Detected Error

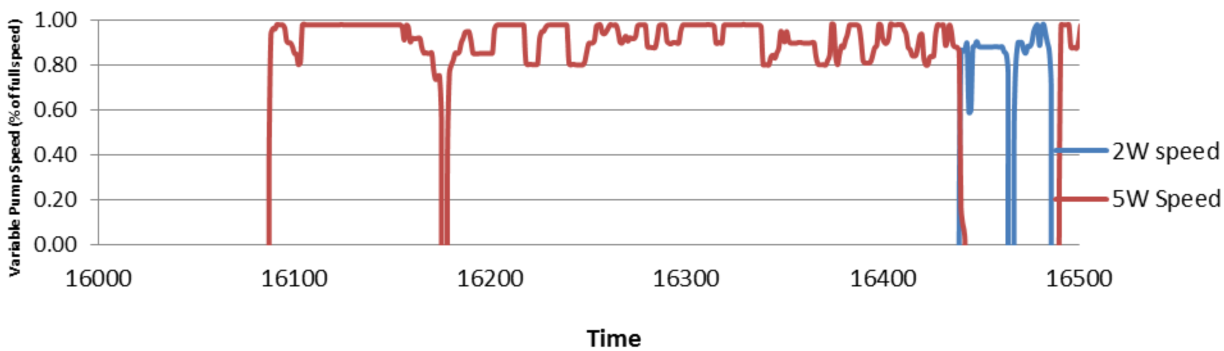

6
5
4
3
2
1
0
Pump On Service
01/07/2011 04:00:00
01/07/2011 21:00:00
01/08/2011 14:00:00
01/09/2011 07:00:00
01/10/2011 00:00:00
01/10/2011 17:00:00
01/11/2011 10:00:00
01/12/2011 03:00:00
01/12/2011 20:00:00
01/13/2011 13:00:00
01/14/2011 06:00:00
01/14/2011 23:00:00
01/15/2011 16:00:00
01/16/2011 09:00:00
01/17/2011 02:00:00
01/17/2011 19:00:00
01/18/2011 12:00:00
01/19/2011 05:00:00
01/19/2011 22:00:00
01/20/2011 15:00:00
01/21/2011 08:00:00
01/22/2011 01:00:00
01/22/2011 18:00:00
01/23/2011 11:00:00
01/24/2011 04:00:00
01/24/2011 21:00:00
01/25/2011 14:00:00
01/26/2011 07:00:00
01/27/2011 00:00:00
01/27/2011 17:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

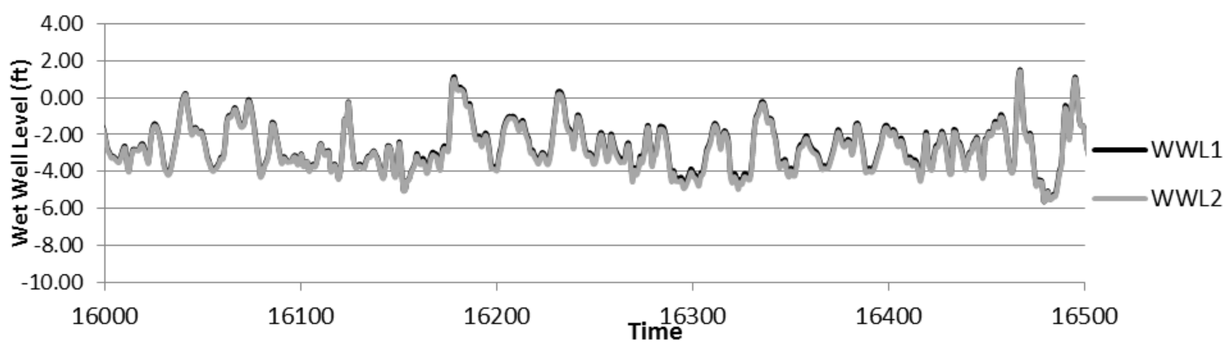

1.00
0.80
0.60
0.40
0.20
0.00
Variable Pump Speed (% of full speed)
15500
15600
15700
15800
15900
16000
Time
2W speed
5W Speed

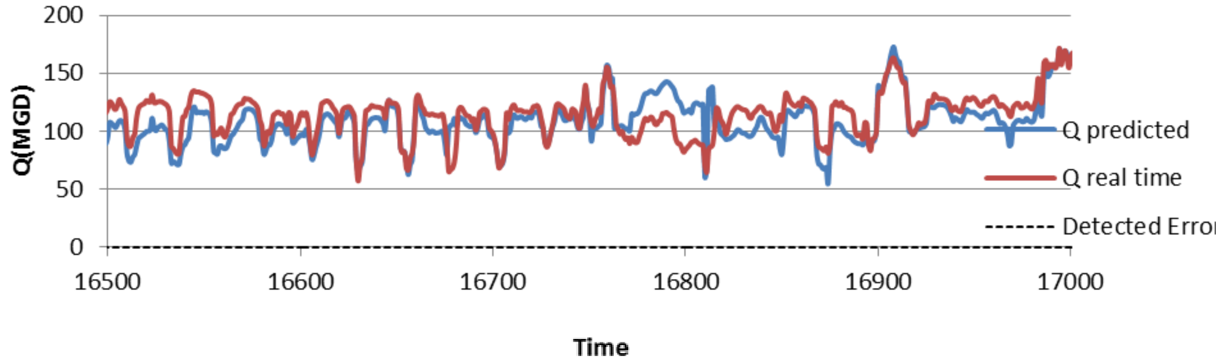

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
15500
15600
15700
15800
15900
16000
Time
WWL1
WWL2

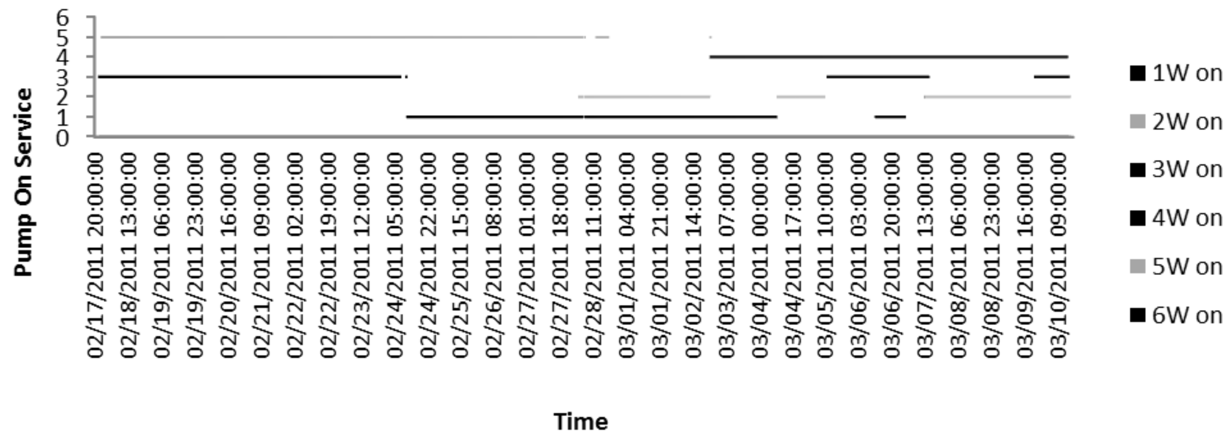

Q(MGD)
200
150
100
50
0
16000
16100
16200
16300
16400
16500
Time
Q predicted
Q real time
Detected Error


Pump On Service
6
5
4
3
2
1
0
01/28/2011 00:00:00
01/28/2011 17:00:00
01/29/2011 10:00:00
01/30/2011 03:00:00
01/30/2011 20:00:00
01/31/2011 13:00:00
02/01/2011 06:00:00
02/01/2011 23:00:00
02/02/2011 16:00:00
02/03/2011 09:00:00
02/04/2011 02:00:00
02/04/2011 19:00:00
02/05/2011 12:00:00
02/06/2011 05:00:00
02/06/2011 22:00:00
02/07/2011 15:00:00
02/08/2011 08:00:00
02/09/2011 01:00:00
02/09/2011 18:00:00
02/10/2011 11:00:00
02/11/2011 04:00:00
02/11/2011 21:00:00
02/12/2011 14:00:00
02/13/2011 07:00:00
02/14/2011 00:00:00
02/14/2011 17:00:00
02/15/2011 10:00:00
02/16/2011 03:00:00
02/16/2011 20:00:00
02/17/2011 13:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable Pump Speed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
16000
16100
16200
16300
16400
16500
Time
2W speed
5W Speed


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
16000
16100
16200
16300
16400
16500
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
16500
16600
16700
16800
16900
17000
Time
Q predicted
Q real time
Detected Error


Pump On Service
6
5
4
3
2
1
0
02/17/2011 20:00:00
02/18/2011 13:00:00
02/19/2011 06:00:00
02/19/2011 23:00:00
02/20/2011 16:00:00
02/21/2011 09:00:00
02/22/2011 02:00:00
02/22/2011 19:00:00
02/23/2011 12:00:00
02/24/2011 05:00:00
02/24/2011 22:00:00
02/25/2011 15:00:00
02/26/2011 08:00:00
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03/01/2011 21:00:00
03/02/2011 14:00:00
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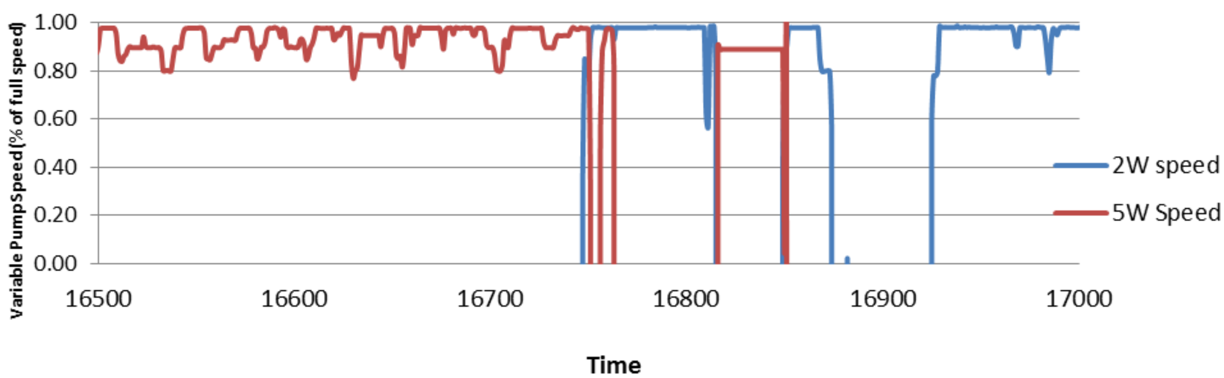
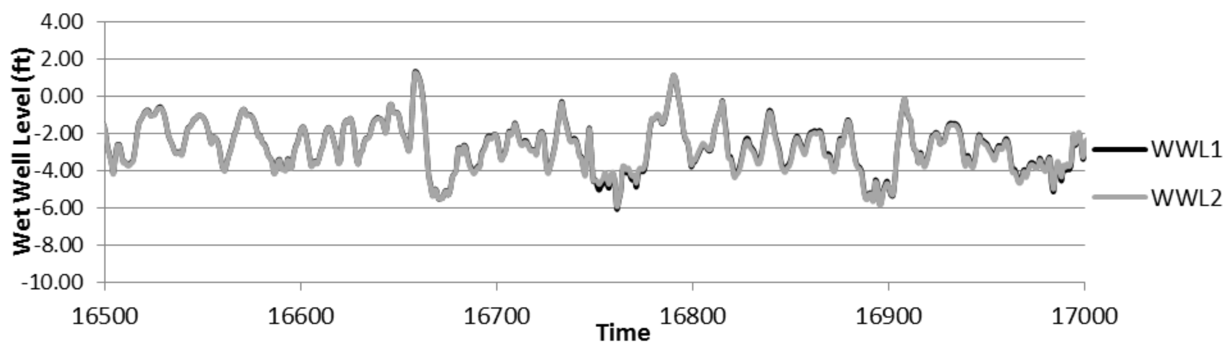
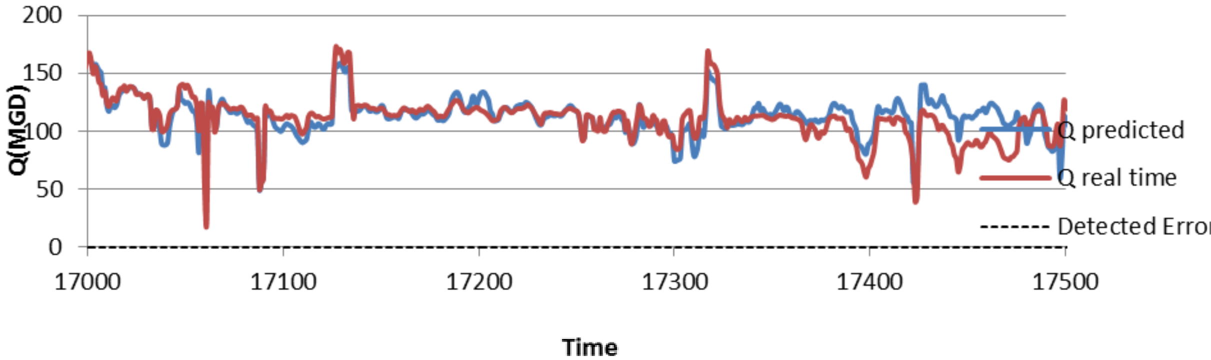
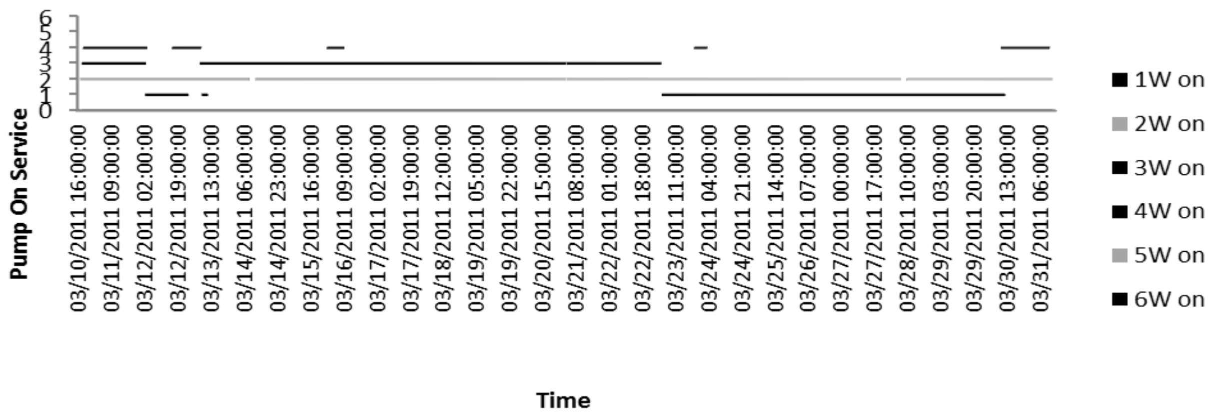
03/04/2011 00:00:00
03/04/2011 17:00:00
03/05/2011 10:00:00
03/06/2011 03:00:00
03/06/2011 20:00:00
03/07/2011 13:00:00
03/08/2011 06:00:00
03/08/2011 23:00:00
03/09/2011 16:00:00
03/10/2011 09:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable PumpSpeed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
16500
16600
16700
16800
16900
17000
Time
2W speed
5W Speed


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
16500
16600
16700
16800
16900
17000
Time
WWL1
WWL2


Q(MGD)
200
150
100
50
0
17000
17100
17200
17300
17400
17500
Time
Q predicted
Q real time
Detected Error


Pump On Service
6
5
4
3
2
1
0
03/10/2011 16:00:00
03/11/2011 09:00:00
03/12/2011 02:00:00
03/12/2011 19:00:00
03/13/2011 13:00:00
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03/14/2011 23:00:00
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03/17/2011 19:00:00
03/18/2011 12:00:00
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03/24/2011 21:00:00
03/25/2011 14:00:00
03/26/2011 07:00:00
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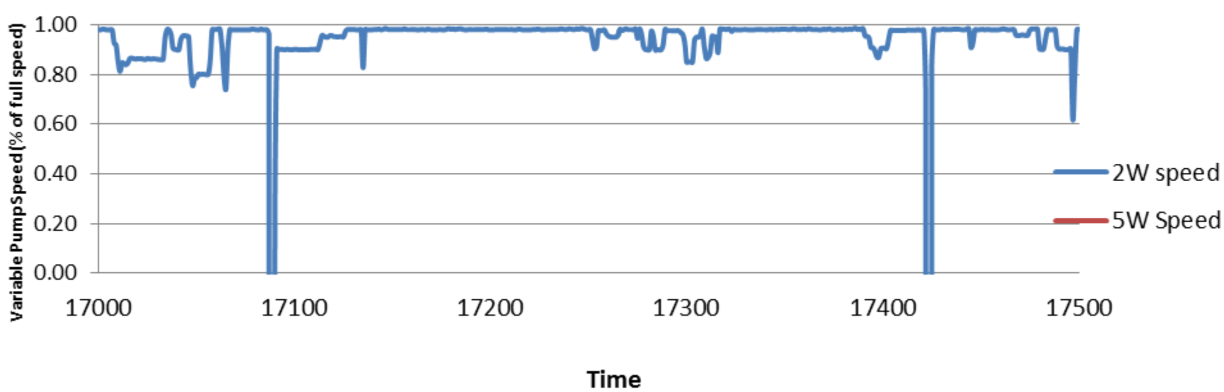
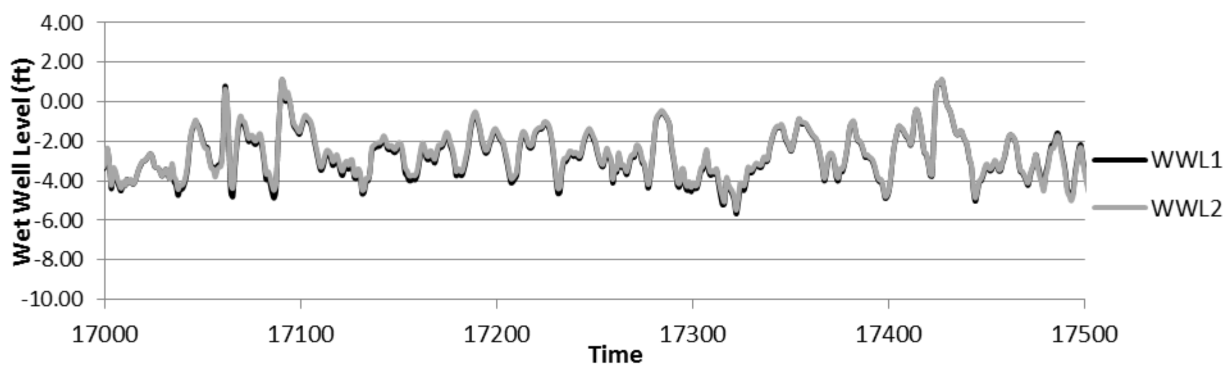
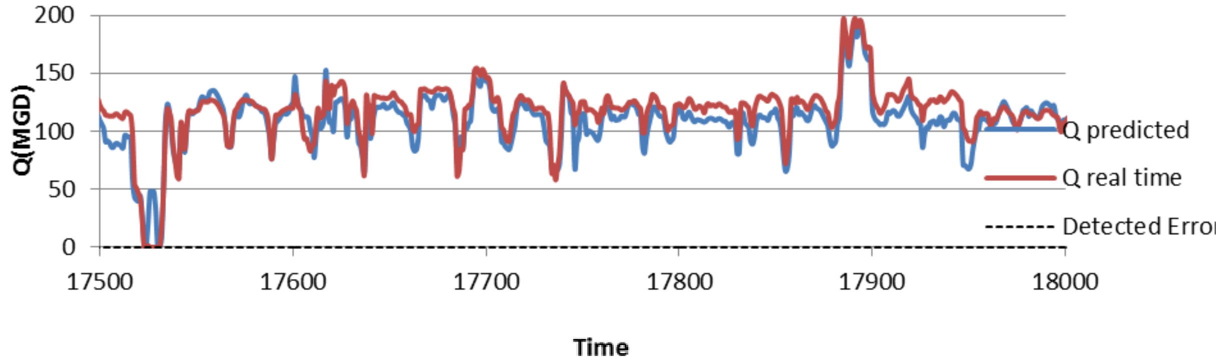
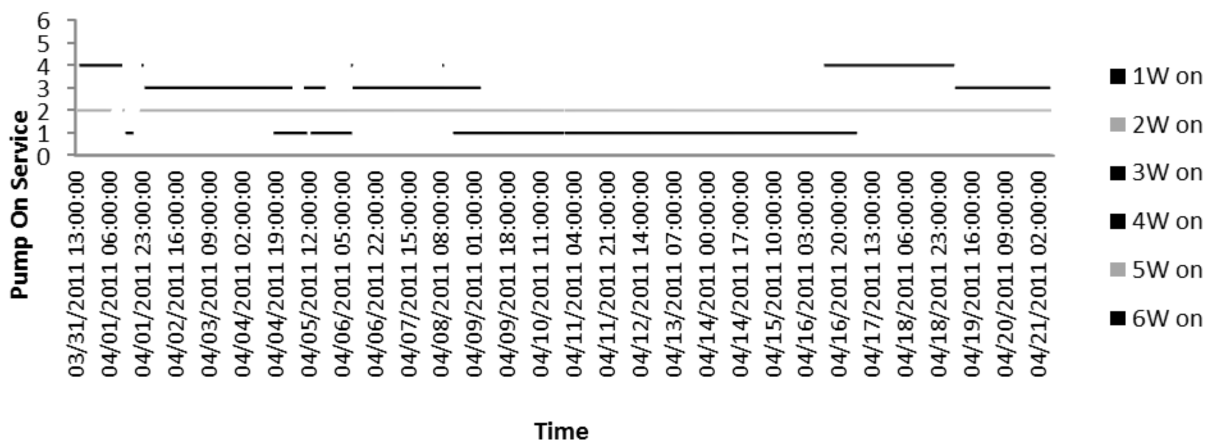
03/27/2011 17:00:00
03/28/2011 10:00:00
03/29/2011 03:00:00
03/29/2011 20:00:00
03/30/2011 13:00:00
03/31/2011 06:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on


Variable PumpSpeed (% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
17000
17100
17200
17300
17400
17500
Time
2W speed
5W Speed


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
17000
17100
17200
17300
17400
17500
Time
WWL1
WWL2



Q(MGD)
200
150
100
50
0
17500
17600
17700
17800
17900
18000
Time
Q predicted
Q real time
Detected Error



Pump On Service
6
5
4
3
2
1
0
03/31/2011 13:00:00
04/01/2011 06:00:00
04/01/2011 23:00:00
04/02/2011 16:00:00
04/03/2011 09:00:00
04/04/2011 02:00:00
04/04/2011 19:00:00
04/05/2011 12:00:00
04/06/2011 05:00:00
04/06/2011 22:00:00
04/07/2011 15:00:00
04/08/2011 08:00:00
04/09/2011 01:00:00
04/09/2011 18:00:00
04/10/2011 11:00:00
04/11/2011 04:00:00
04/11/2011 21:00:00
04/12/2011 14:00:00
04/13/2011 07:00:00
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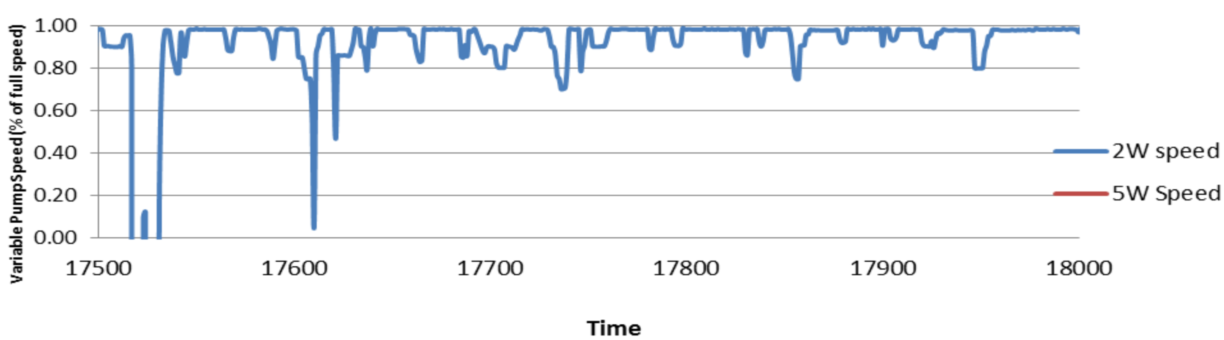
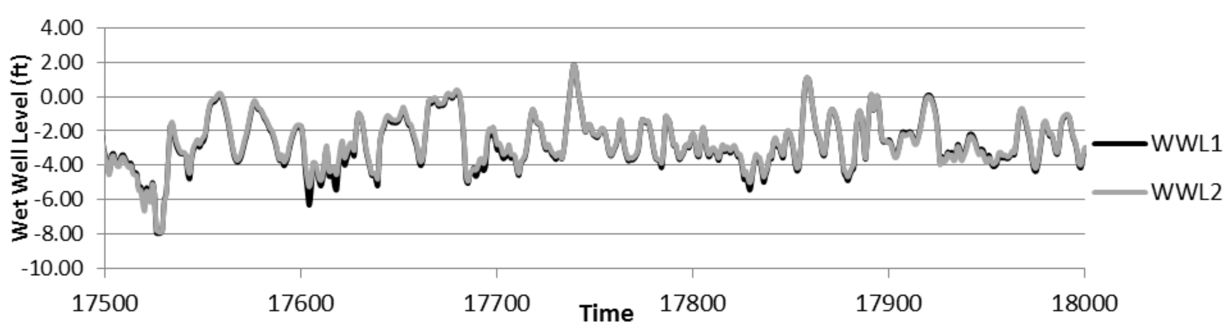
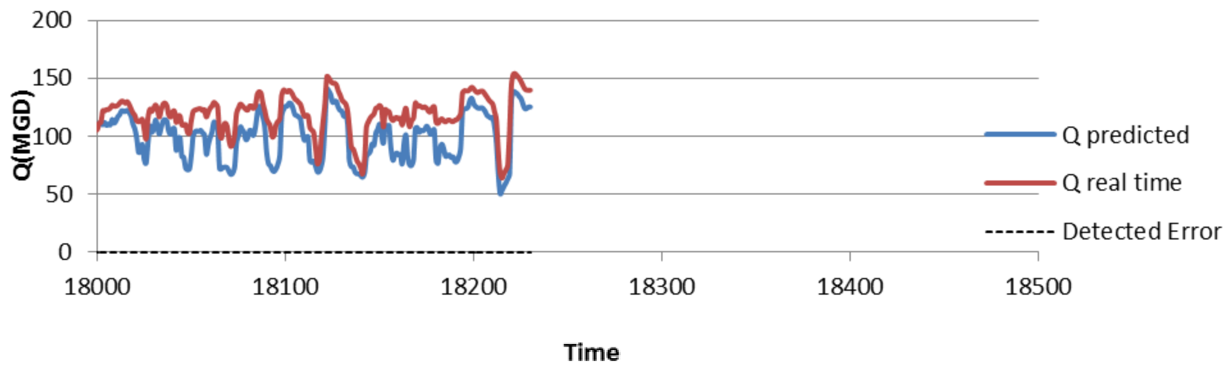
04/14/2011 17:00:00
04/15/2011 10:00:00
04/16/2011 03:00:00
04/16/2011 20:00:00
04/17/2011 13:00:00
04/18/2011 06:00:00
04/18/2011 23:00:00
04/19/2011 16:00:00
04/20/2011 09:00:00
04/21/2011 02:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

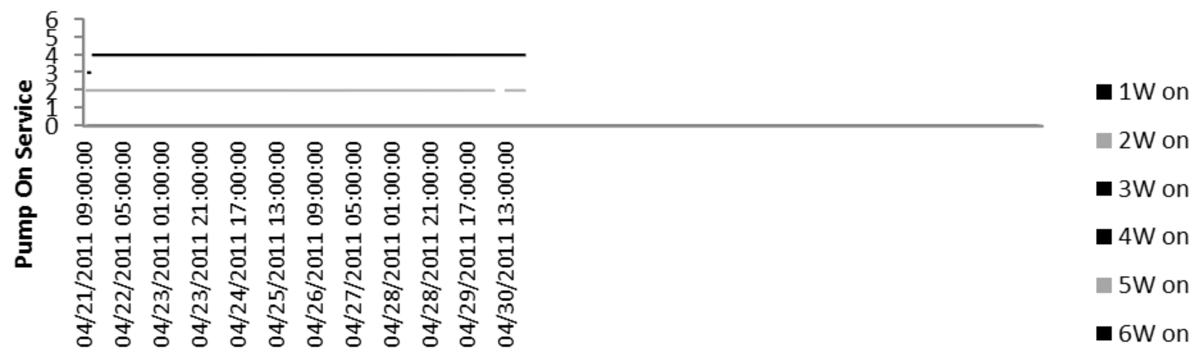


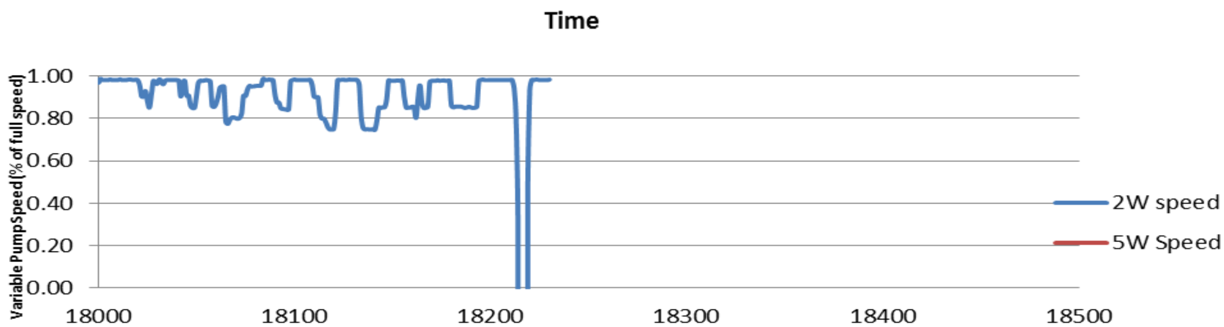
Variable PumpSpeed(% of full speed)
1.00
0.80
0.60
0.40
0.20
0.00
17500
17600
17700
17800
17900
18000
Time
2W speed
5W Speed

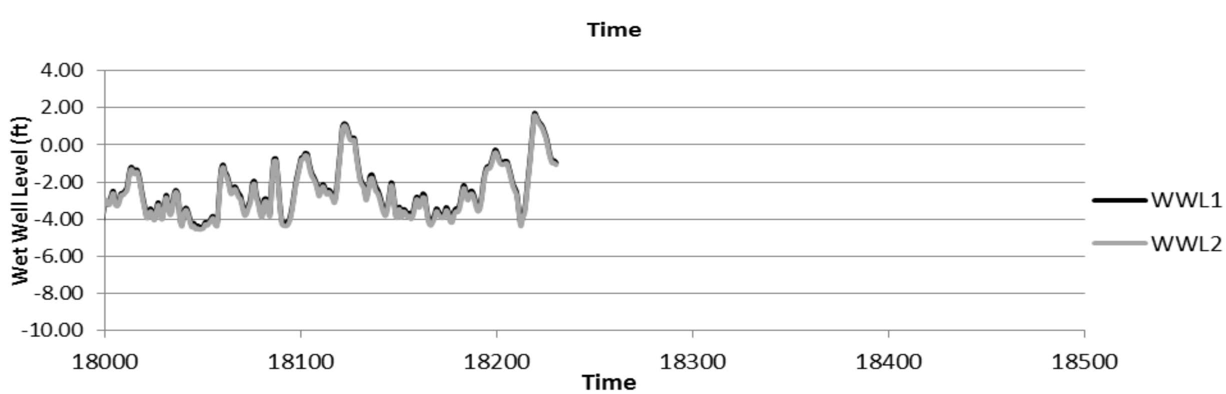


Wet Well Level (ft)
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
17500
17600
17700
17800
17900
18000
Time
WWL1
WWL2

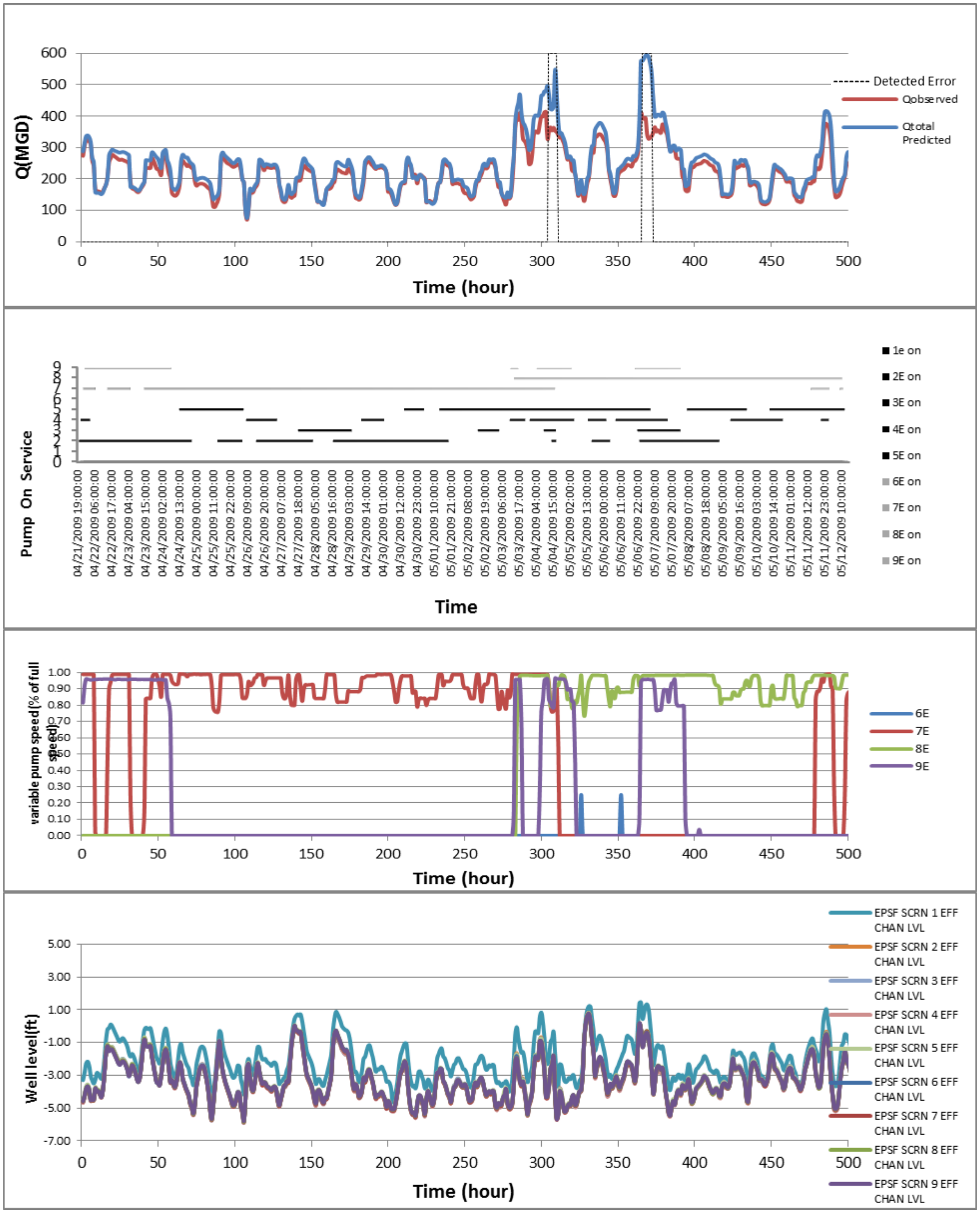

200
150
100
50
0
Q(MGD)
18000
18100
18200
18300
18400
18500
Time
Q predicted
Q real time
Detected Error


6
5
4
3
2
1
0
Pump On Service
04/21/2011 09:00:00
04/22/2011 05:00:00
04/23/2011 01:00:00
04/23/2011 21:00:00
04/24/2011 17:00:00
04/25/2011 13:00:00
04/26/2011 09:00:00
04/27/2011 05:00:00
04/28/2011 01:00:00
04/28/2011 21:00:00
04/29/2011 17:00:00
04/30/2011 13:00:00
Time
1W on
2W on
3W on
4W on
5W on
6W on

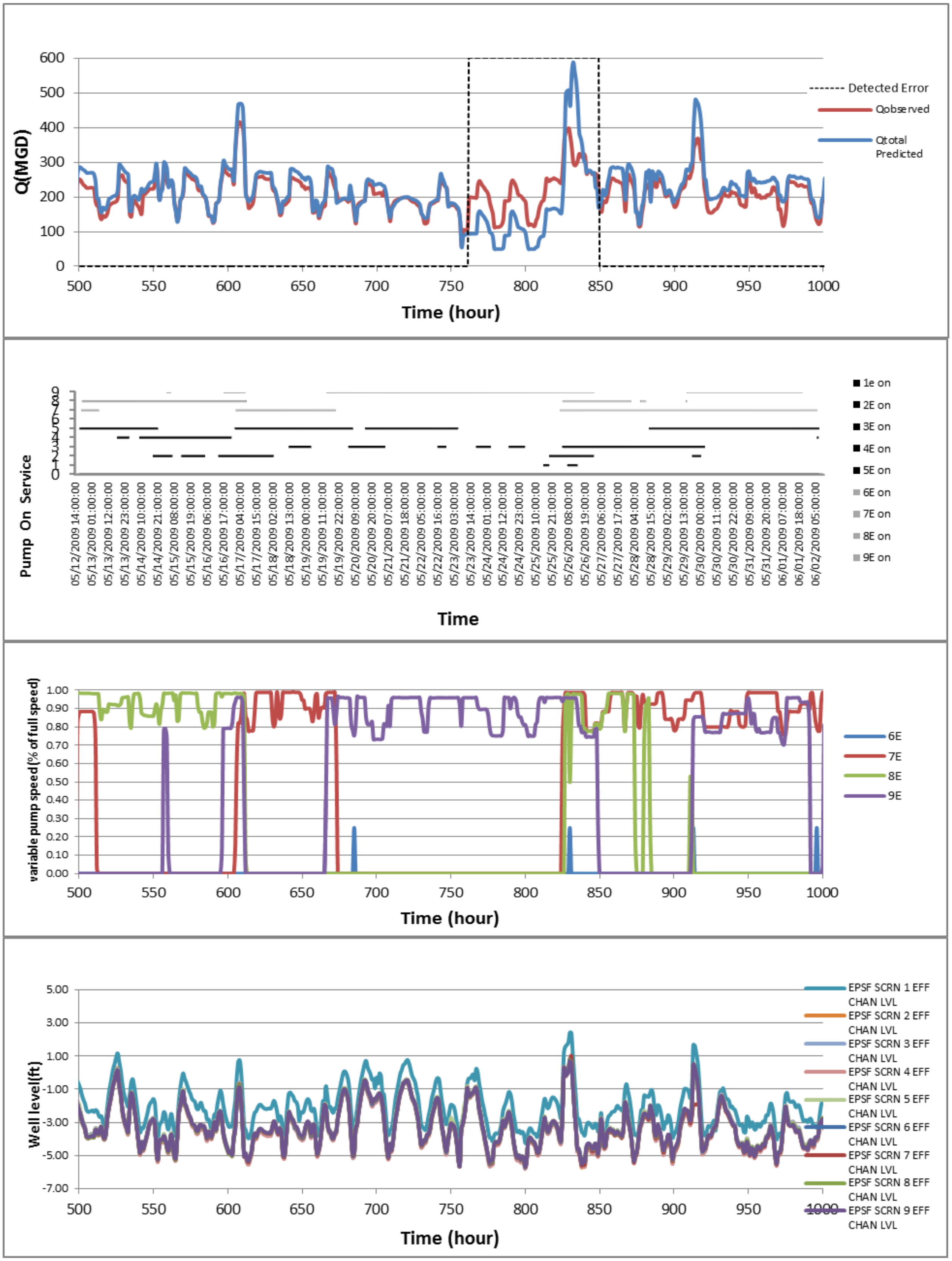

1.00
0.80
0.60
0.40
0.20
0.00
Variable PumpSpeed(% of full speed)
18000
18100
18200
18300
18400
18500
Time
2W speed
5W Speed

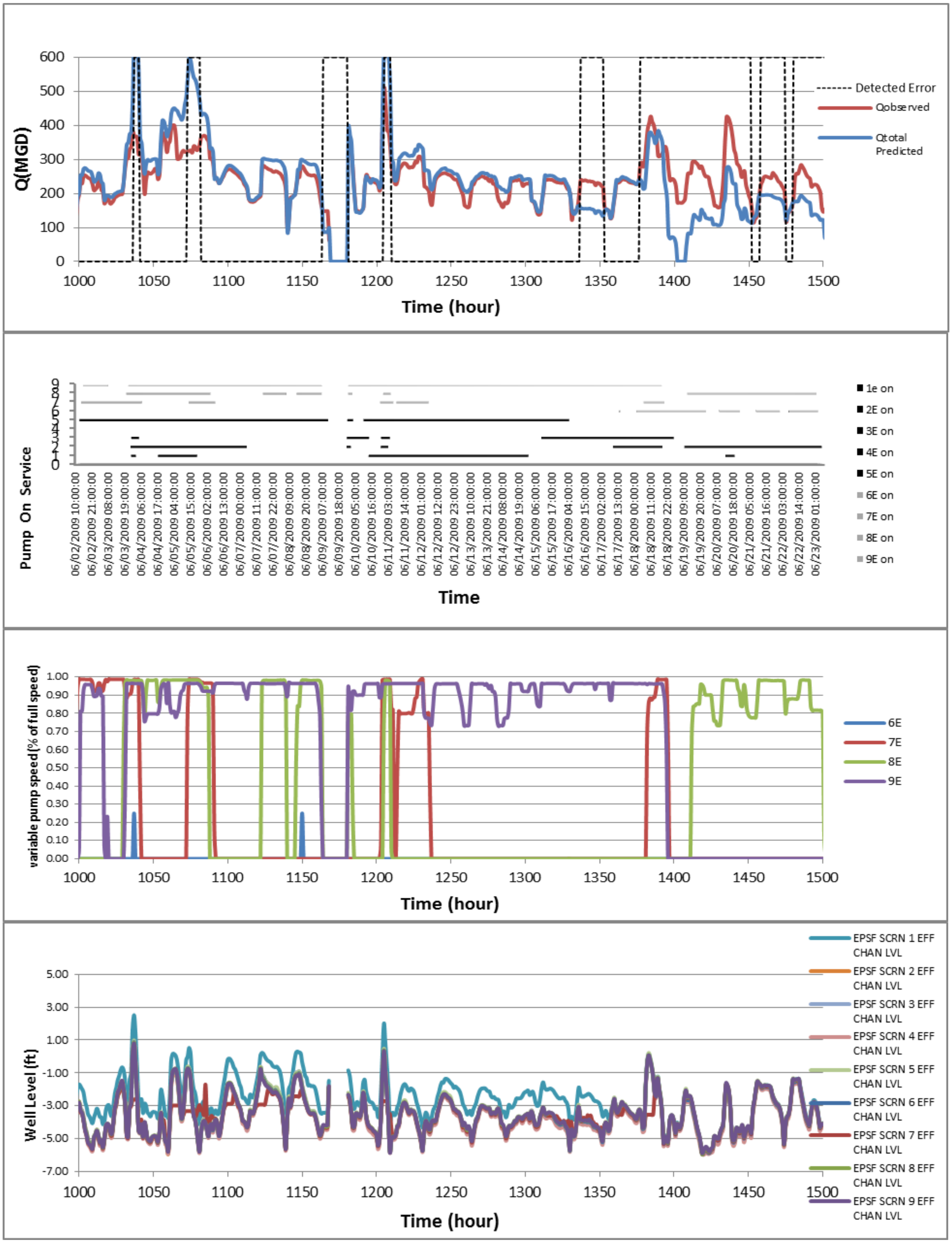

4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Wet Well Level (ft)
18000
18100
18200
18300
18400
18500
Time
WWL1
WWL2

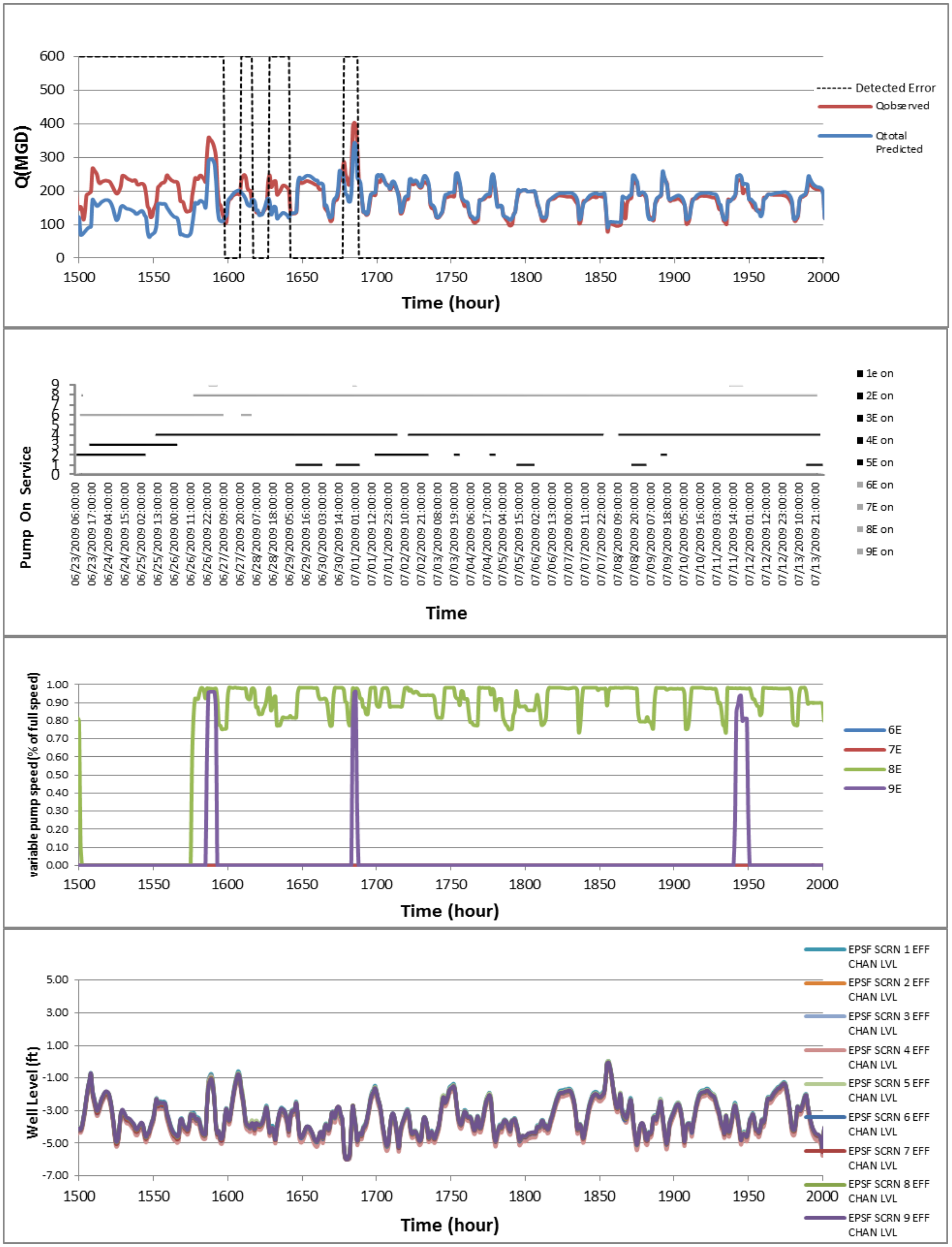
(2) RWWPS2

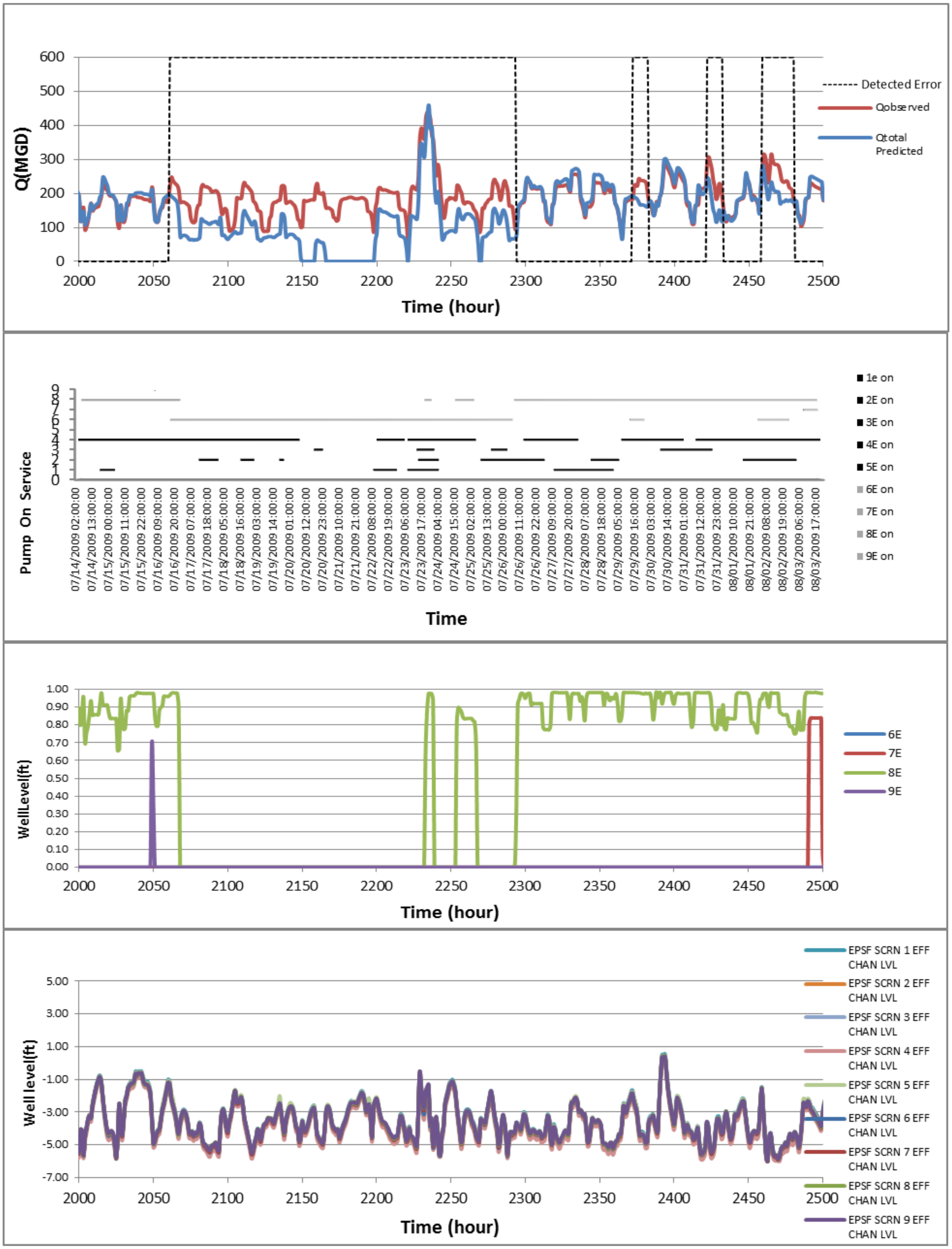


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
6E
7E
8E
9E
Well level(ft)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

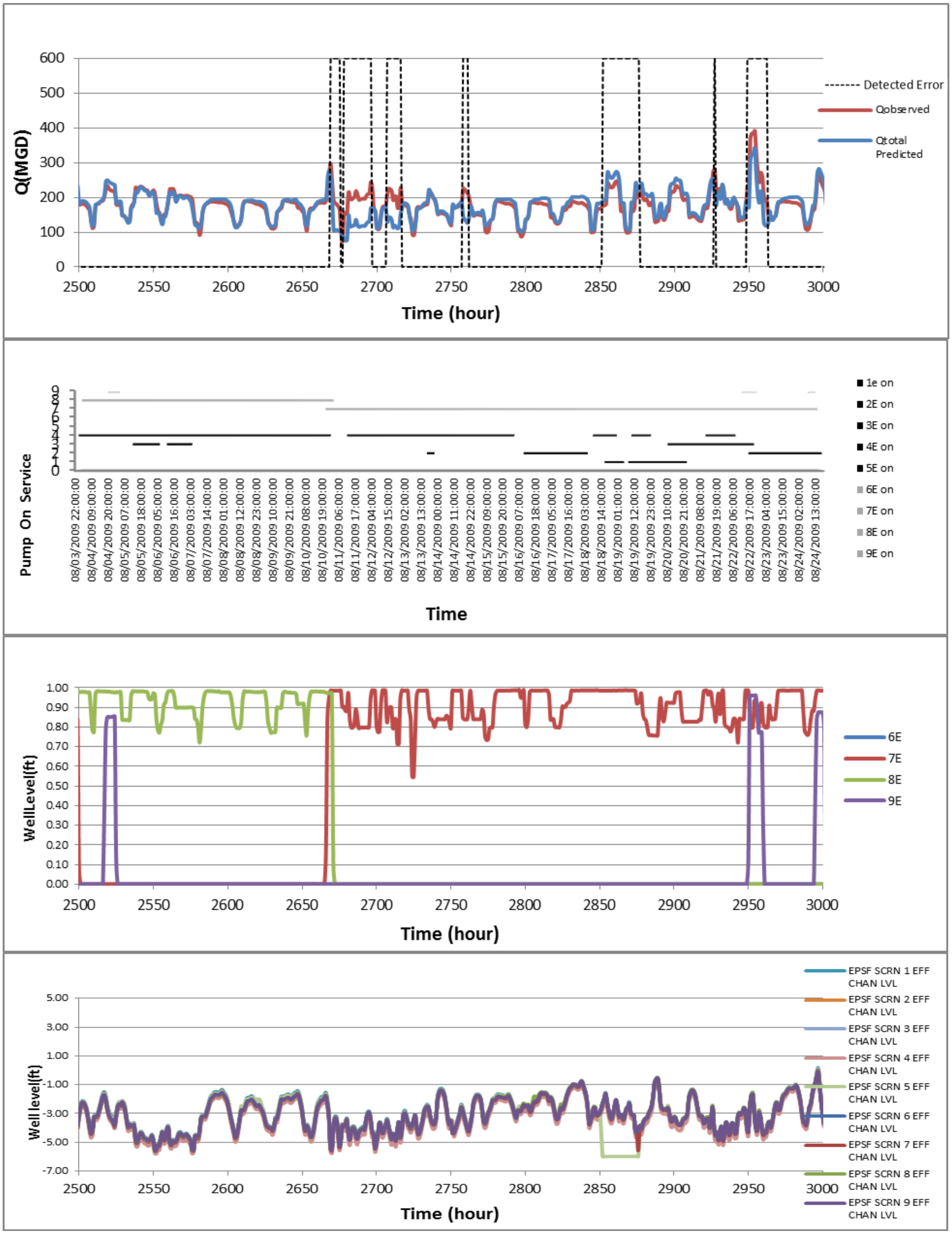

Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Well level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
06/02/2009 10:00:00
06/02/2009 21:00:00
06/03/2009 08:00:00
06/03/2009 19:00:00
06/04/2009 06:00:00
06/04/2009 17:00:00
06/05/2009 04:00:00
06/05/2009 15:00:00
06/06/2009 02:00:00
06/06/2009 13:00:00
06/07/2009 00:00:00
06/07/2009 11:00:00
06/07/2009 22:00:00
06/08/2009 09:00:00
06/08/2009 20:00:00
06/09/2009 07:00:00
06/09/2009 18:00:00
06/10/2009 05:00:00
06/10/2009 16:00:00
06/11/2009 03:00:00
06/11/2009 14:00:00
06/12/2009 01:00:00
06/12/2009 12:00:00
06/12/2009 23:00:00
06/13/2009 10:00:00
06/13/2009 21:00:00
06/14/2009 08:00:00
06/14/2009 19:00:00
06/15/2009 06:00:00
06/15/2009 17:00:00
06/16/2009 04:00:00
06/16/2009 15:00:00
06/17/2009 02:00:00
06/17/2009 13:00:00
06/18/2009 00:00:00
06/18/2009 11:00:00
06/18/2009 22:00:00
06/19/2009 09:00:00
06/19/2009 20:00:00
06/20/2009 07:00:00
06/20/2009 18:00:00
06/21/2009 05:00:00
06/21/2009 16:00:00
06/22/2009 03:00:00
06/22/2009 14:00:00
06/23/2009 01:00:00
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Well Level (ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

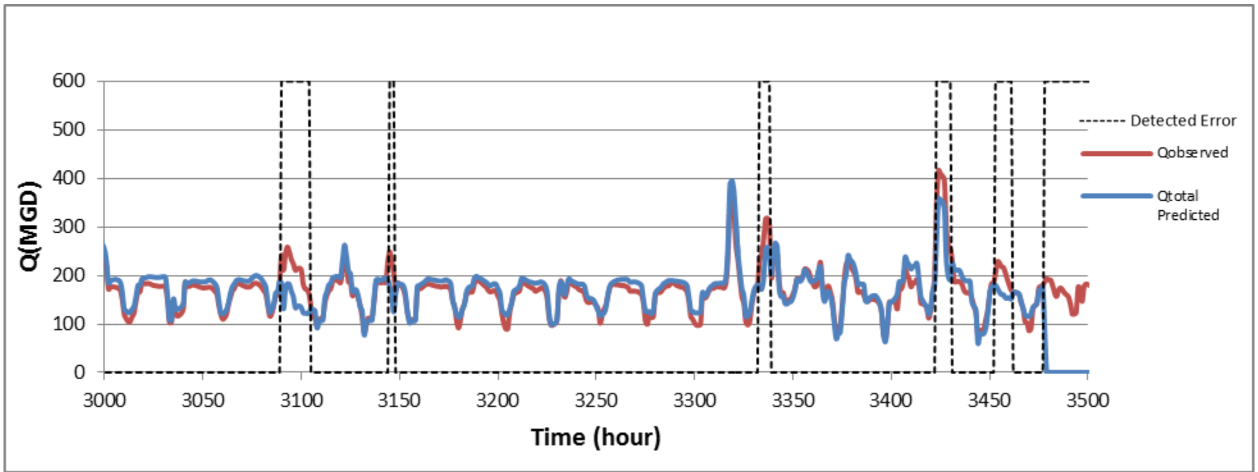

Q(MGD)
600
500
400
300
200
100
0
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
0
1
2
3
4
5
6
7
8
9
06/23/2009 06:00:00
06/23/2009 17:00:00
06/24/2009 04:00:00
06/24/2009 15:00:00
06/25/2009 02:00:00
06/25/2009 13:00:00
06/26/2009 00:00:00
06/26/2009 11:00:00
06/26/2009 22:00:00
06/27/2009 09:00:00
06/27/2009 20:00:00
06/28/2009 07:00:00
06/28/2009 18:00:00
06/29/2009 05:00:00
06/29/2009 16:00:00
06/30/2009 03:00:00
06/30/2009 14:00:00
07/01/2009 01:00:00
07/01/2009 12:00:00
07/01/2009 23:00:00
07/02/2009 10:00:00
07/02/2009 21:00:00
07/03/2009 08:00:00
07/03/2009 19:00:00
07/04/2009 06:00:00
07/04/2009 17:00:00
07/05/2009 04:00:00
07/05/2009 15:00:00
07/06/2009 02:00:00
07/06/2009 13:00:00
07/07/2009 00:00:00
07/07/2009 11:00:00
07/07/2009 22:00:00
07/08/2009 09:00:00
07/08/2009 20:00:00
07/09/2009 07:00:00
07/09/2009 18:00:00
07/10/2009 05:00:00
07/10/2009 16:00:00
07/11/2009 03:00:00
07/11/2009 14:00:00
07/12/2009 01:00:00
07/12/2009 12:00:00
07/12/2009 23:00:00
07/13/2009 10:00:00
07/13/2009 21:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
Time (hour)
6E
7E
8E
9E
Well Level (ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
1500
1550
1600
1650
1700
1750
1800
1850
1900
1950
2000
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



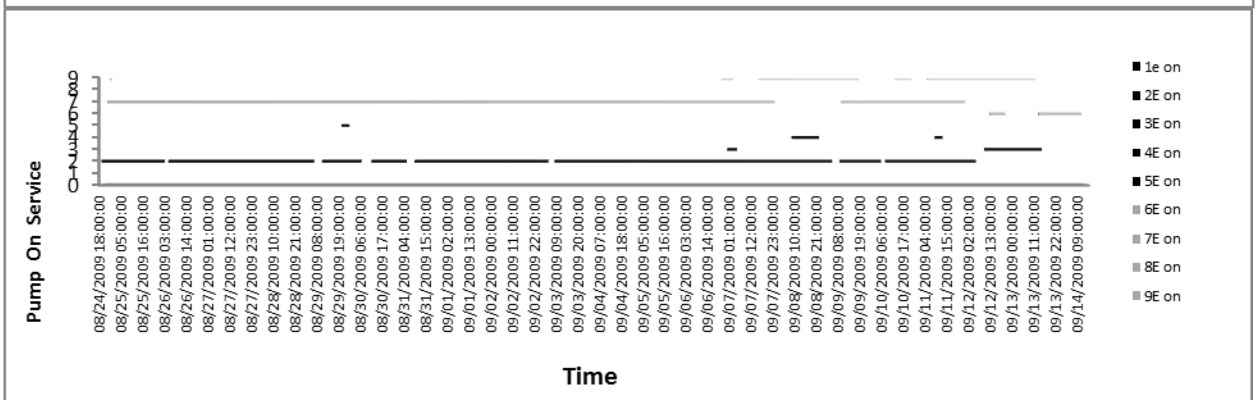
Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
07/14/2009 02:00:00
07/14/2009 13:00:00
07/15/2009 00:00:00
07/15/2009 11:00:00
07/15/2009 22:00:00
07/16/2009 09:00:00
07/16/2009 20:00:00
07/17/2009 07:00:00
07/17/2009 18:00:00
07/18/2009 05:00:00
07/18/2009 16:00:00
07/19/2009 03:00:00
07/19/2009 14:00:00
07/20/2009 01:00:00
07/20/2009 12:00:00
07/20/2009 23:00:00
07/21/2009 10:00:00
07/21/2009 21:00:00
07/22/2009 08:00:00
07/22/2009 19:00:00
07/23/2009 06:00:00
07/23/2009 17:00:00
07/24/2009 04:00:00
07/24/2009 15:00:00
07/25/2009 02:00:00
07/25/2009 13:00:00
07/26/2009 00:00:00
07/26/2009 11:00:00
07/26/2009 22:00:00
07/27/2009 09:00:00
07/27/2009 20:00:00
07/28/2009 07:00:00
07/28/2009 18:00:00
07/29/2009 05:00:00
07/29/2009 16:00:00
07/30/2009 03:00:00
07/30/2009 14:00:00
07/31/2009 01:00:00
07/31/2009 12:00:00
07/31/2009 23:00:00
08/01/2009 10:00:00
08/01/2009 21:00:00
08/02/2009 08:00:00
08/02/2009 19:00:00
08/03/2009 06:00:00
08/03/2009 17:00:00
WellLevel(ft)
Time (hour)
6E
7E
8E
9E
Well level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



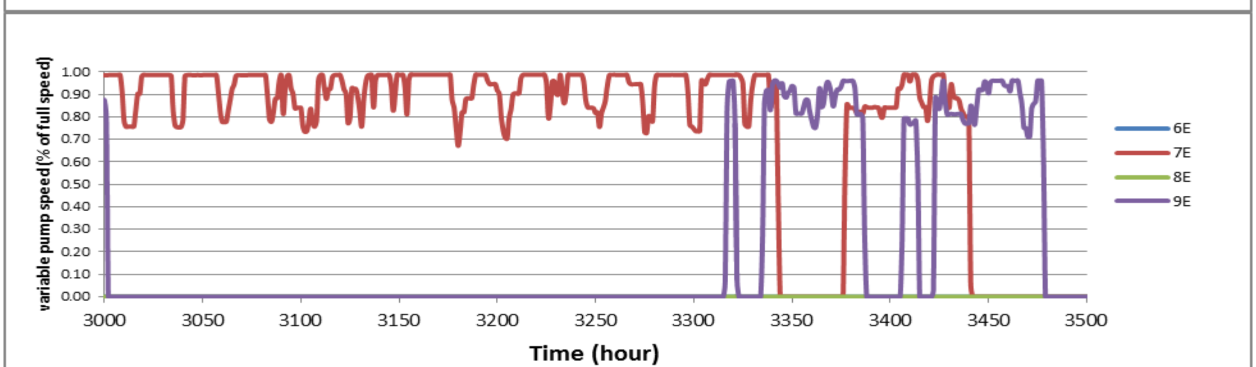
Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
WellLevel(ft)
Time (hour)
6E
7E
8E
9E
Well level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



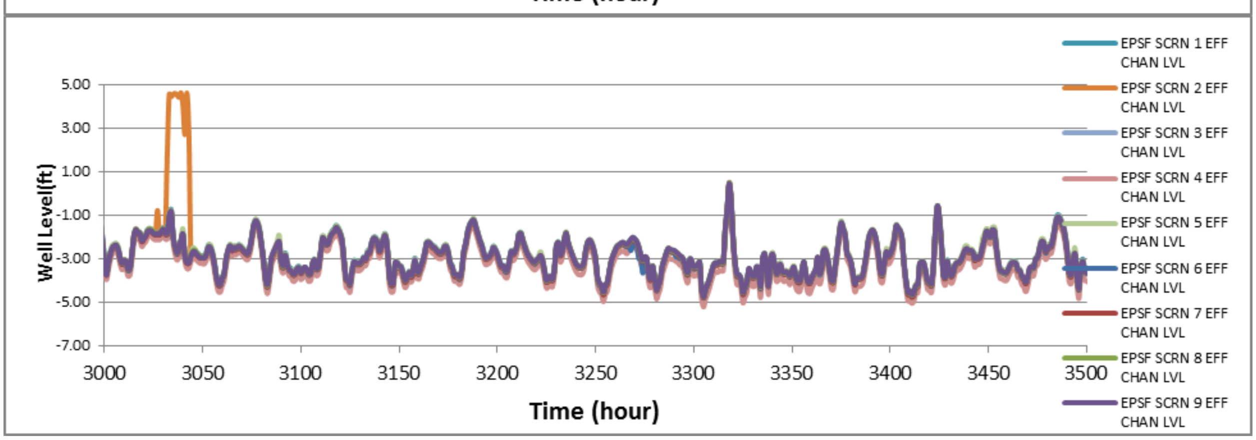
600
500
400
300
200
100
0
Q(MGD)
3000
3050
3100
3150
3200
3250
3300
3350
3400
3450
3500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted



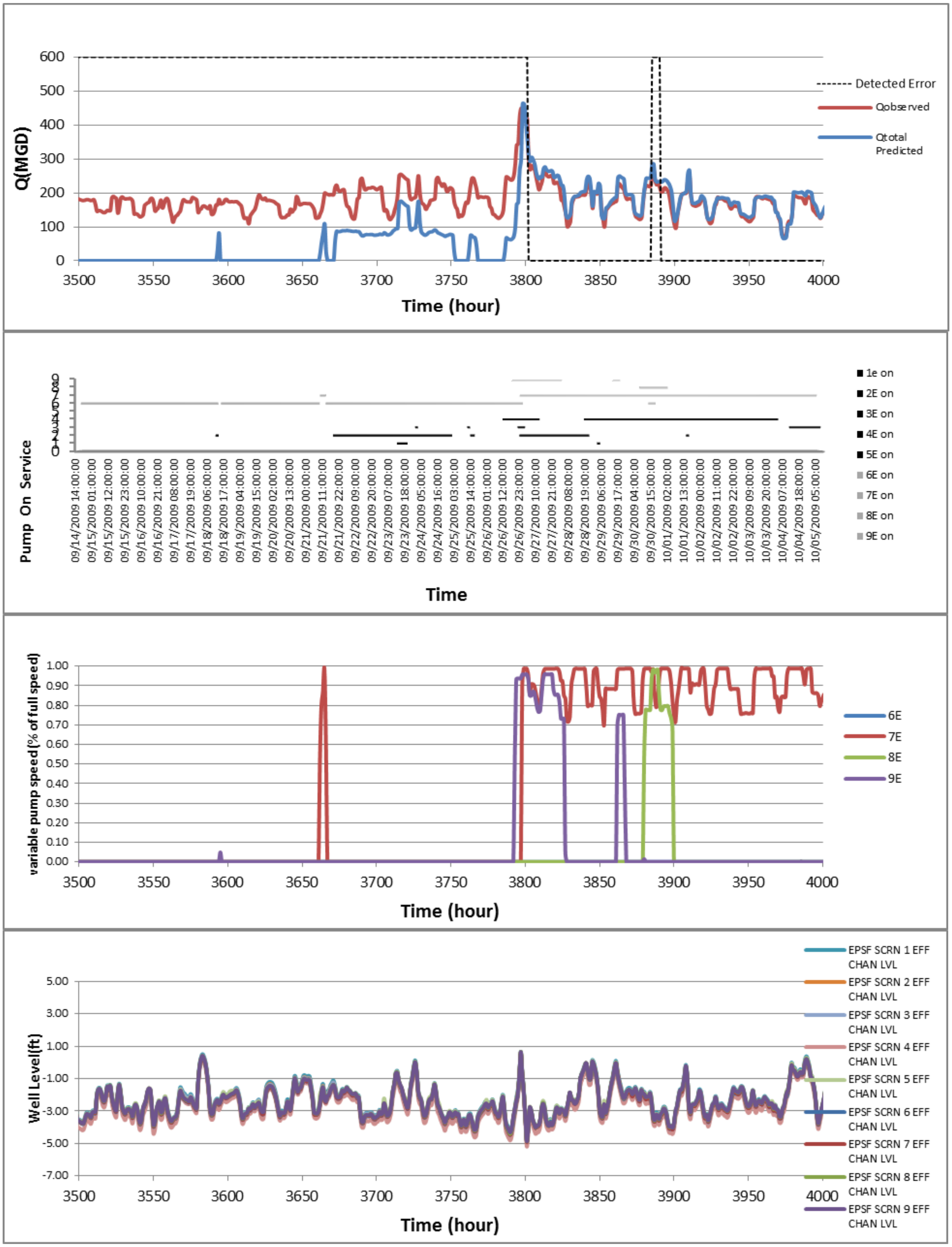
9
8
7
6
5
4
3
2
1
0
Pump On Service
08/24/2009 18:00:00
08/25/2009 05:00:00
08/25/2009 16:00:00
08/26/2009 03:00:00
08/26/2009 14:00:00
08/27/2009 01:00:00
08/27/2009 12:00:00
08/27/2009 23:00:00
08/28/2009 10:00:00
08/28/2009 21:00:00
08/29/2009 08:00:00
08/29/2009 19:00:00
08/30/2009 06:00:00
08/30/2009 17:00:00
08/31/2009 04:00:00
08/31/2009 15:00:00
09/01/2009 02:00:00
09/01/2009 13:00:00
09/02/2009 00:00:00
09/02/2009 11:00:00
09/02/2009 22:00:00
09/03/2009 09:00:00
09/03/2009 20:00:00
09/04/2009 07:00:00
09/04/2009 18:00:00
09/05/2009 05:00:00
09/05/2009 16:00:00
09/06/2009 03:00:00
09/06/2009 14:00:00
09/07/2009 01:00:00
09/07/2009 12:00:00
09/07/2009 23:00:00
09/08/2009 10:00:00
09/08/2009 21:00:00
09/09/2009 08:00:00
09/09/2009 19:00:00
09/10/2009 06:00:00
09/10/2009 17:00:00
09/11/2009 04:00:00
09/11/2009 15:00:00
09/12/2009 02:00:00
09/12/2009 13:00:00
09/13/2009 00:00:00
09/13/2009 11:00:00
09/13/2009 22:00:00
09/14/2009 09:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on



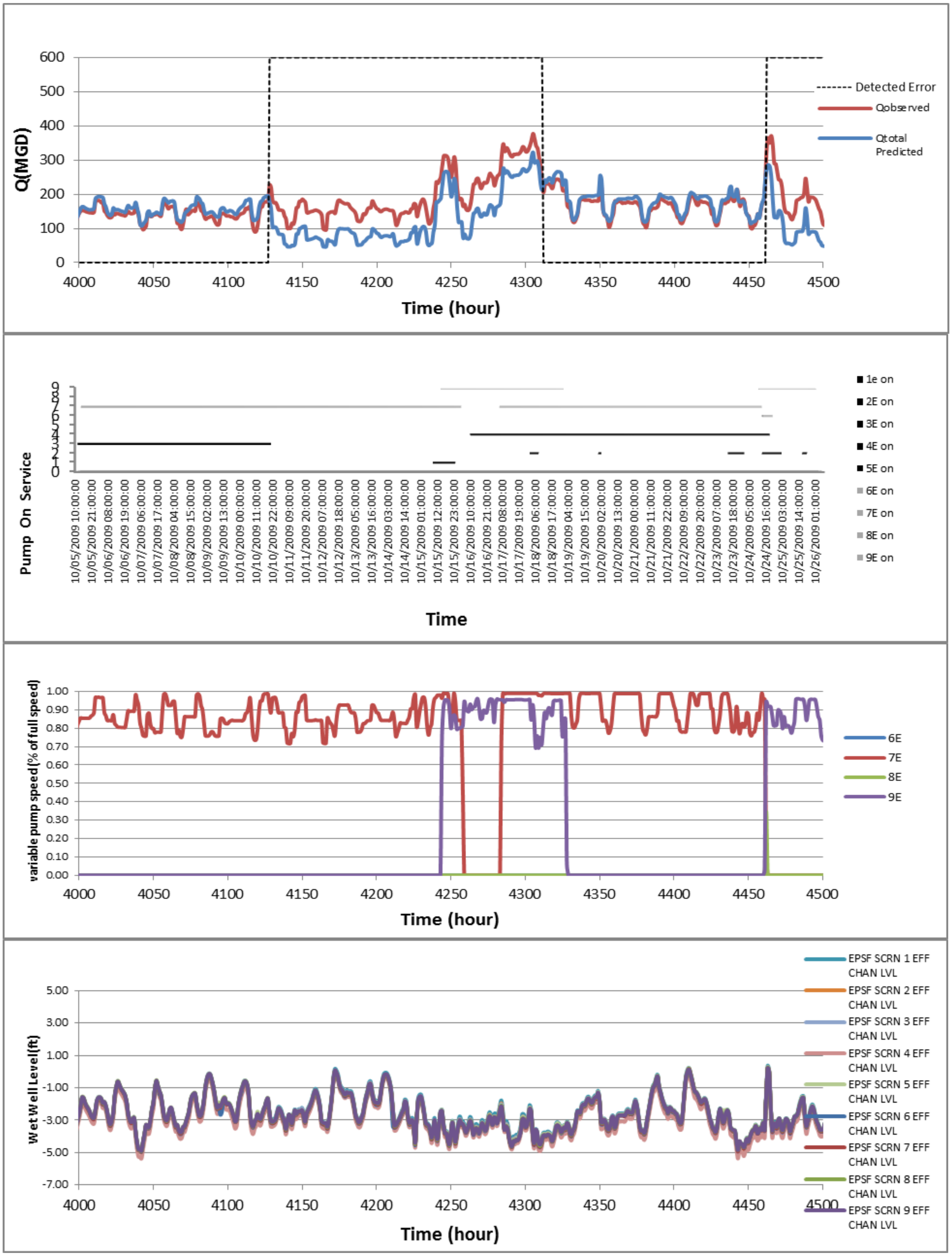
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
variable pump speed (% of full speed)
3000
3050
3100
3150
3200
3250
3300
3350
3400
3450
3500
Time (hour)
6E
7E
8E
9E



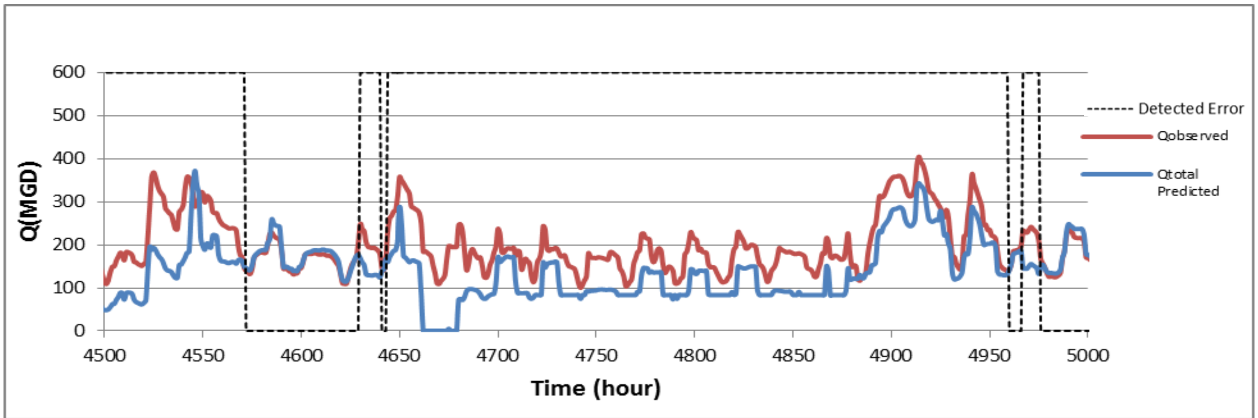
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
Well Level(ft)
3000
3050
3100
3150
3200
3250
3300
3350
3400
3450
3500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

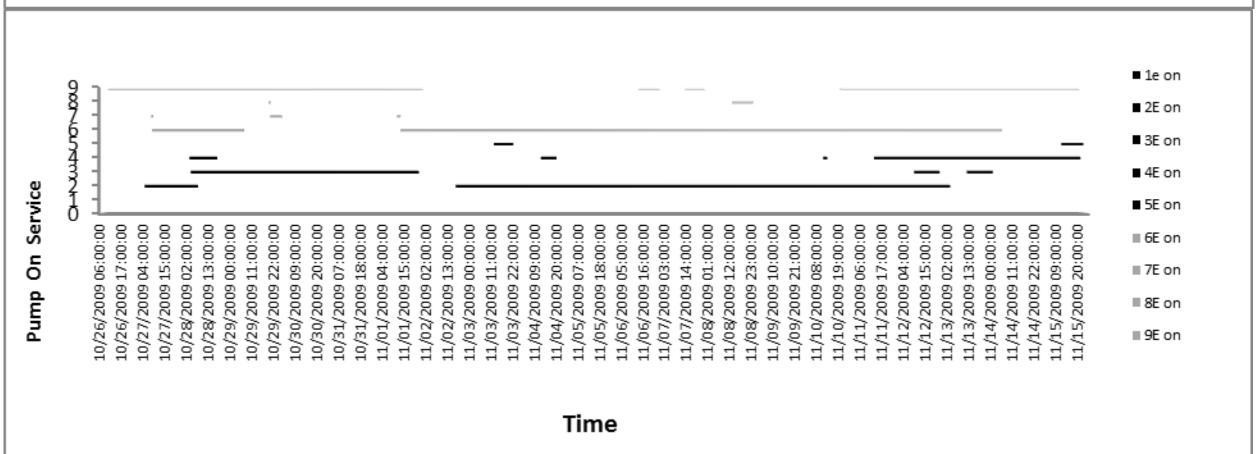


Q(MGD)
600
500
400
300
200
100
0
3500
3550
3600
3650
3700
3750
3800
3850
3900
3950
4000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Time (hour)
6E
7E
8E
9E
Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
600
500
400
300
200
100
0
4000
4050
4100
4150
4200
4250
4300
4350
4400
4450
4500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
0
1
2
3
4
5
6
7
8
9
10/05/2009 10:00:00
10/05/2009 21:00:00
10/06/2009 08:00:00
10/06/2009 19:00:00
10/07/2009 06:00:00
10/07/2009 17:00:00
10/08/2009 04:00:00
10/08/2009 15:00:00
10/09/2009 02:00:00
10/09/2009 13:00:00
10/10/2009 00:00:00
10/10/2009 11:00:00
10/10/2009 22:00:00
10/11/2009 09:00:00
10/11/2009 20:00:00
10/12/2009 07:00:00
10/12/2009 18:00:00
10/13/2009 05:00:00
10/13/2009 16:00:00
10/14/2009 03:00:00
10/14/2009 14:00:00
10/15/2009 01:00:00
10/15/2009 12:00:00
10/15/2009 23:00:00
10/16/2009 10:00:00
10/16/2009 21:00:00
10/17/2009 08:00:00
10/17/2009 19:00:00
10/18/2009 06:00:00
10/18/2009 17:00:00
10/19/2009 04:00:00
10/19/2009 15:00:00
10/20/2009 02:00:00
10/20/2009 13:00:00
10/21/2009 00:00:00
10/21/2009 11:00:00
10/21/2009 22:00:00
10/22/2009 09:00:00
10/22/2009 20:00:00
10/23/2009 07:00:00
10/23/2009 18:00:00
10/24/2009 05:00:00
10/24/2009 16:00:00
10/25/2009 03:00:00
10/25/2009 14:00:00
10/26/2009 01:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
4000
4050
4100
4150
4200
4250
4300
4350
4400
4450
4500
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
4000
4050
4100
4150
4200
4250
4300
4350
4400
4450
4500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
0
100
200
300
400
500
600
4500
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted


Pump On Service
0
1
2
3
4
5
6
7
8
9
10/26/2009 06:00:00
10/26/2009 17:00:00
10/27/2009 04:00:00
10/27/2009 15:00:00
10/28/2009 02:00:00
10/28/2009 13:00:00
10/29/2009 00:00:00
10/29/2009 11:00:00
10/29/2009 22:00:00
10/30/2009 09:00:00
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10/31/2009 07:00:00
10/31/2009 18:00:00
11/01/2009 04:00:00
11/01/2009 15:00:00
11/02/2009 02:00:00
11/02/2009 13:00:00
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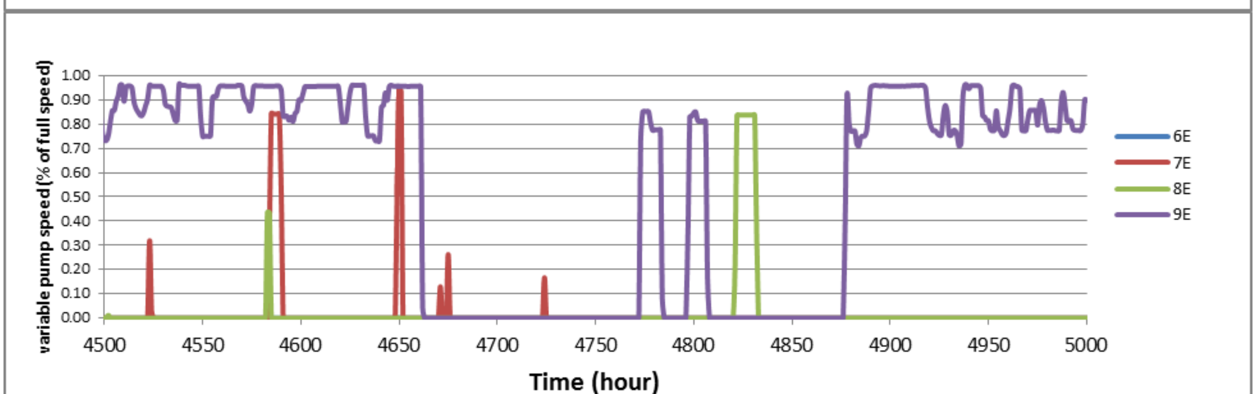
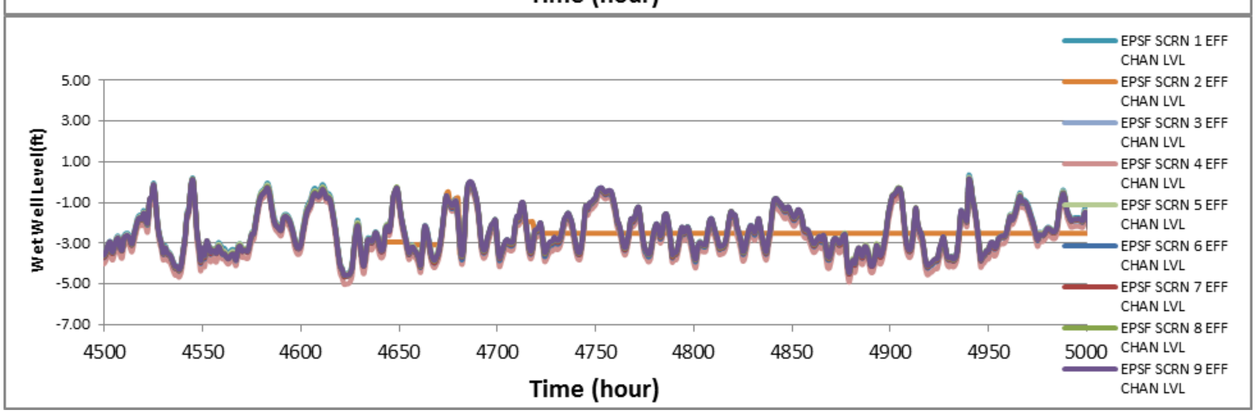
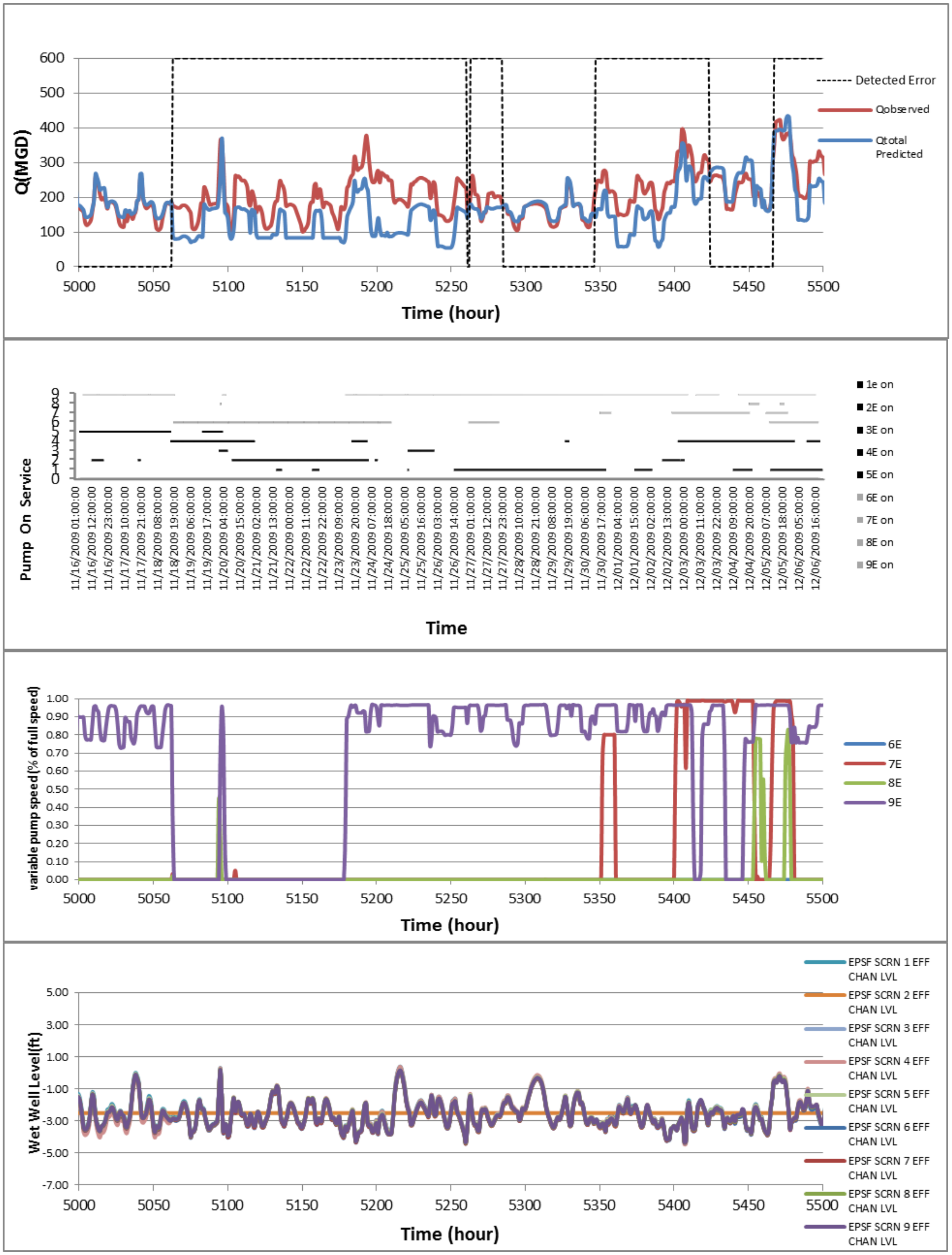
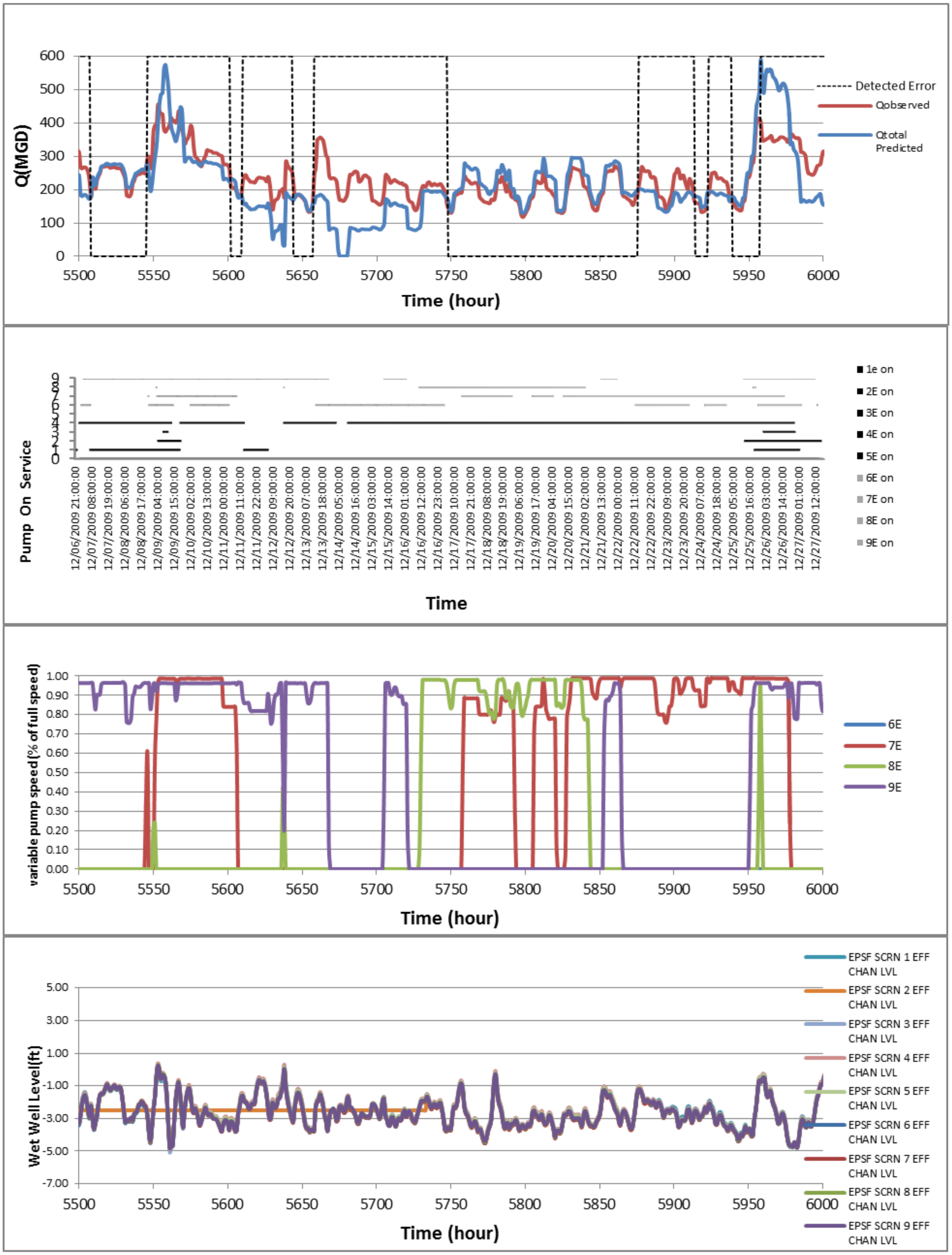
11/03/2009 11:00:00
11/03/2009 22:00:00
11/04/2009 09:00:00
11/04/2009 20:00:00
11/05/2009 07:00:00
11/05/2009 18:00:00
11/06/2009 05:00:00
11/06/2009 16:00:00
11/07/2009 03:00:00
11/07/2009 14:00:00
11/08/2009 01:00:00
11/08/2009 12:00:00
11/08/2009 23:00:00
11/09/2009 10:00:00
11/09/2009 21:00:00
11/10/2009 08:00:00
11/10/2009 19:00:00
11/11/2009 06:00:00
11/11/2009 17:00:00
11/12/2009 04:00:00
11/12/2009 15:00:00
11/13/2009 02:00:00
11/13/2009 13:00:00
11/14/2009 00:00:00
11/14/2009 11:00:00
11/14/2009 22:00:00
11/15/2009 09:00:00
11/15/2009 20:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on


variable pump speed (% of full speed)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
4500
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
Time (hour)
6E
7E
8E
9E

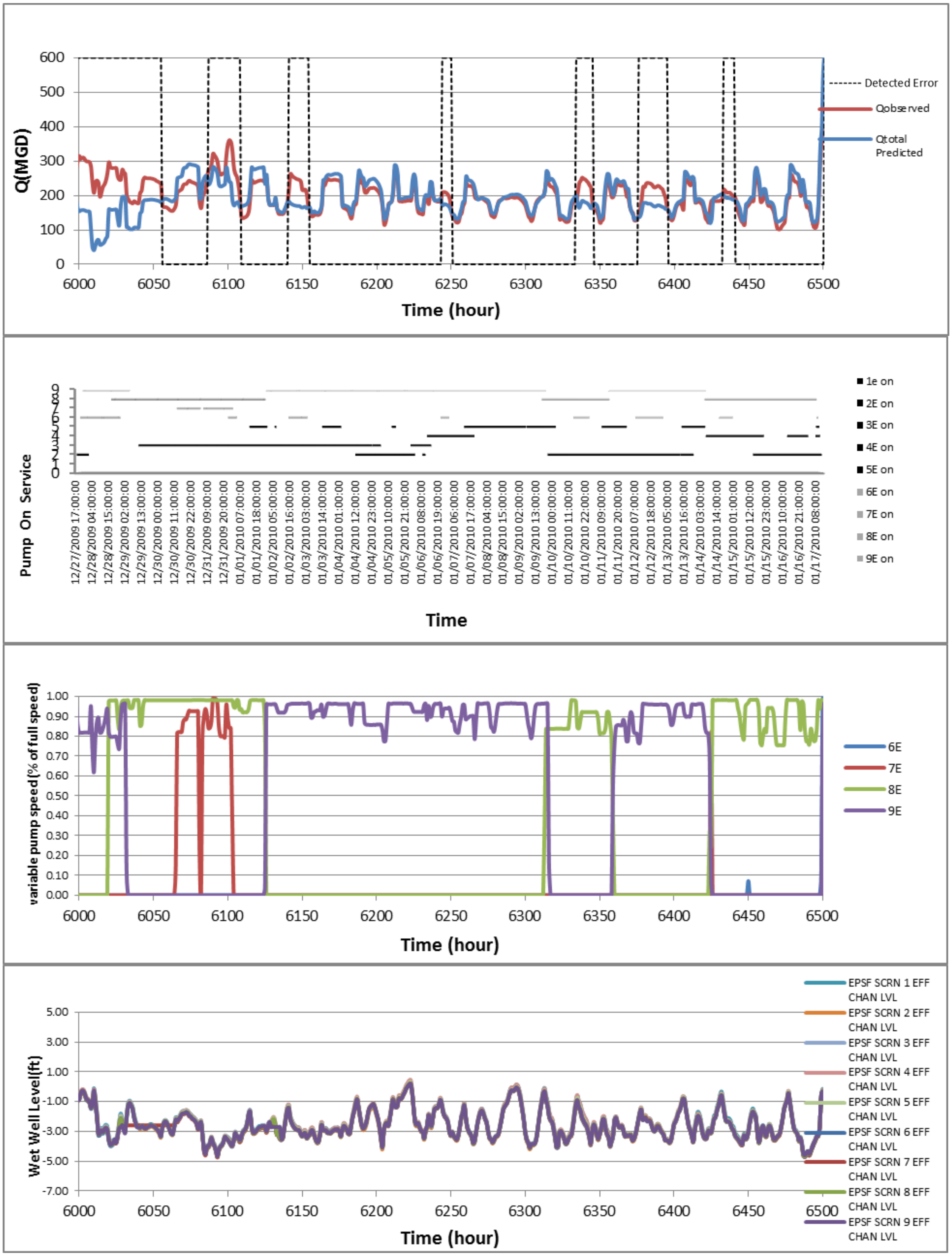

Wet Well Level(ft)
-7.00
-5.00
-3.00
-1.00
1.00
3.00
5.00
4500
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

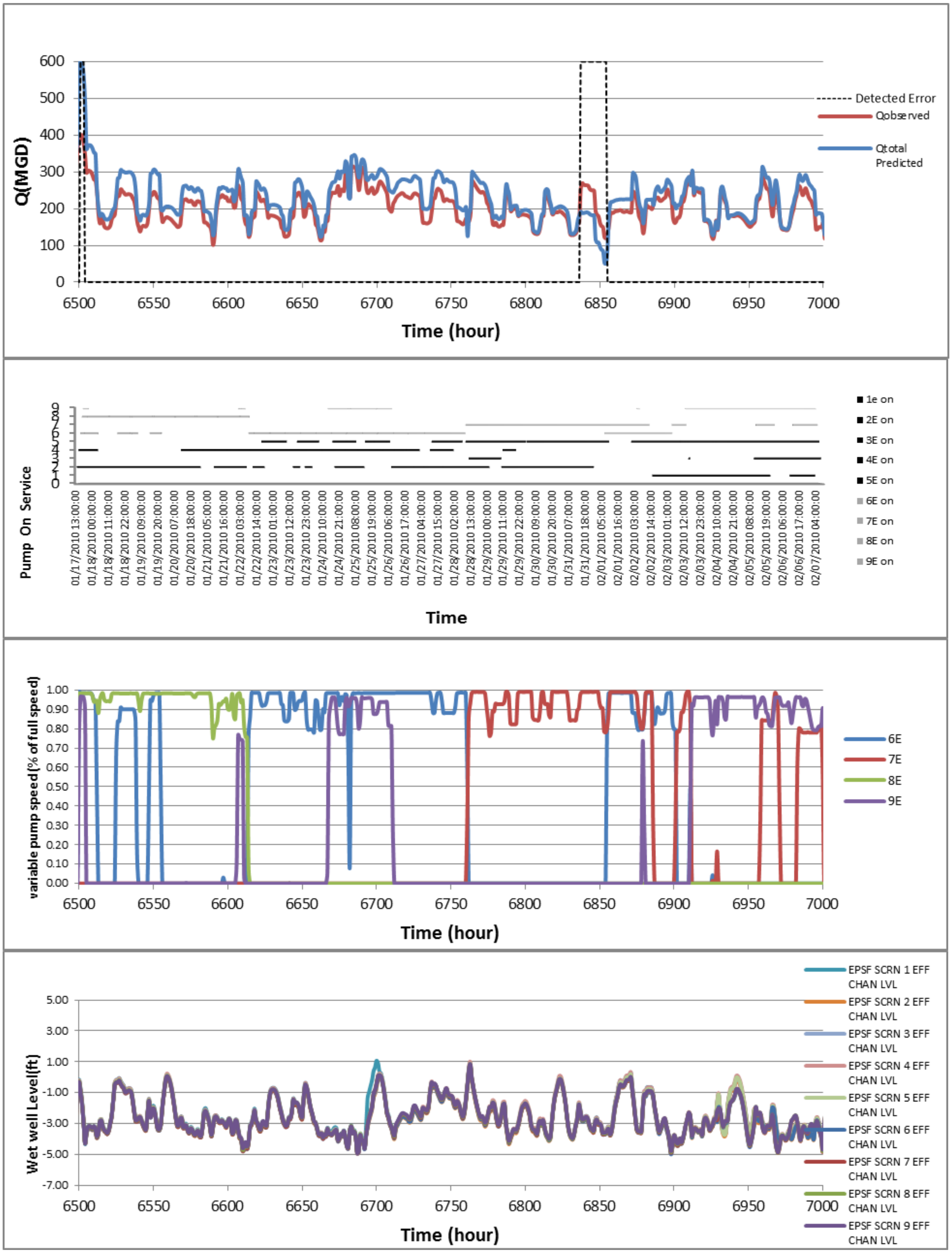


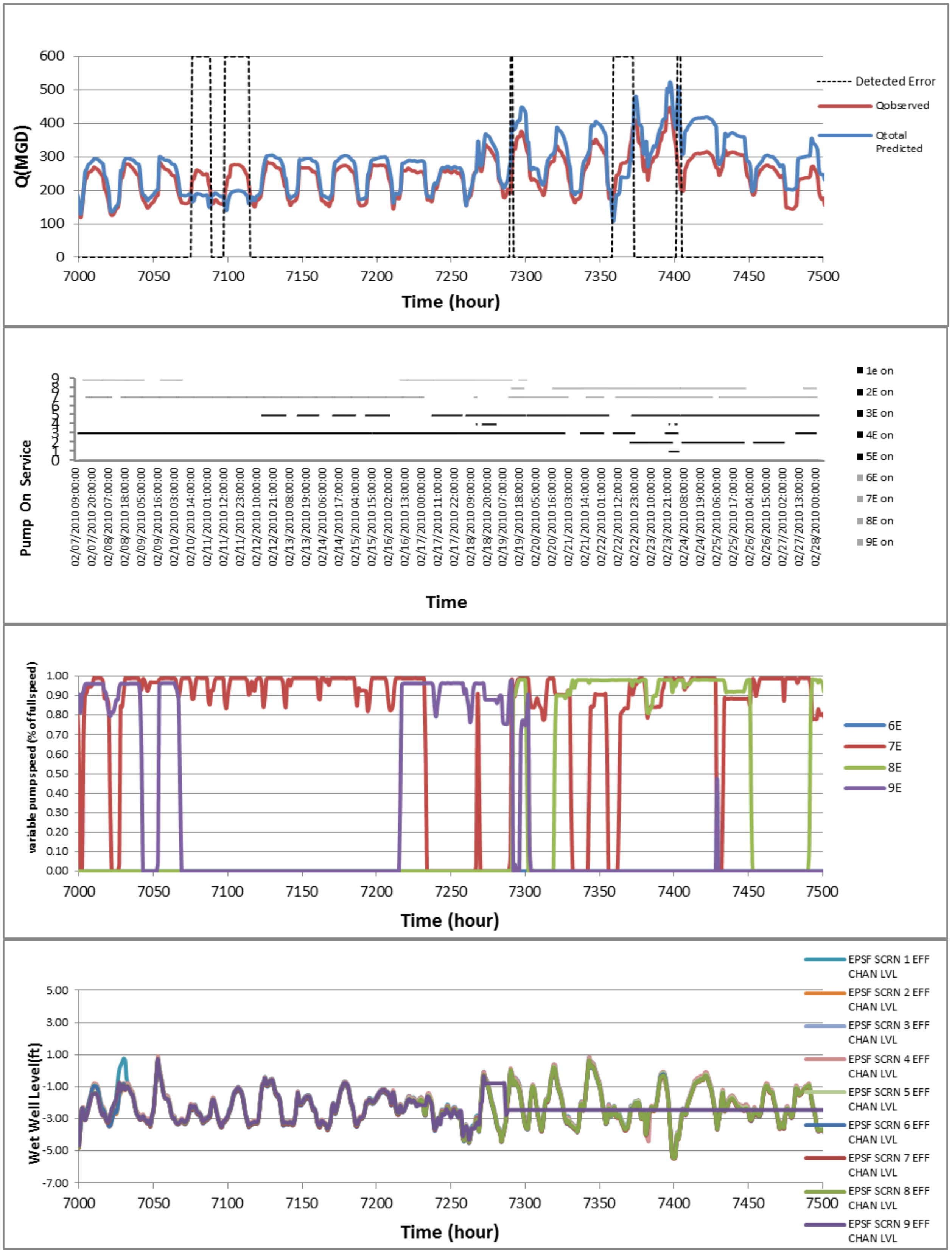
Q(MGD)
600
500
400
300
200
100
0
5000
5050
5100
5150
5200
5250
5300
5350
5400
5450
5500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
0
1
2
3
4
5
6
7
8
9
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
11/16/2009 01:00:00
11/16/2009 12:00:00
11/16/2009 23:00:00
11/17/2009 10:00:00
11/17/2009 21:00:00
11/18/2009 08:00:00
11/18/2009 19:00:00
11/19/2009 06:00:00
11/19/2009 17:00:00
11/20/2009 04:00:00
11/20/2009 15:00:00
11/21/2009 02:00:00
11/21/2009 13:00:00
11/22/2009 00:00:00
11/22/2009 11:00:00
11/22/2009 22:00:00
11/23/2009 09:00:00
11/23/2009 20:00:00
11/24/2009 07:00:00
11/24/2009 18:00:00
11/25/2009 05:00:00
11/25/2009 16:00:00
11/26/2009 03:00:00
11/26/2009 14:00:00
11/27/2009 01:00:00
11/27/2009 12:00:00
11/27/2009 23:00:00
11/28/2009 10:00:00
11/28/2009 21:00:00
11/29/2009 08:00:00
11/29/2009 19:00:00
11/30/2009 06:00:00
11/30/2009 17:00:00
12/01/2009 04:00:00
12/01/2009 15:00:00
12/02/2009 02:00:00
12/02/2009 13:00:00
12/03/2009 00:00:00
12/03/2009 11:00:00
12/03/2009 22:00:00
12/04/2009 09:00:00
12/04/2009 20:00:00
12/05/2009 07:00:00
12/05/2009 18:00:00
12/06/2009 05:00:00
12/06/2009 16:00:00
Time
variable pump speed(% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5000
5050
5100
5150
5200
5250
5300
5350
5400
5450
5500
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
5000
5050
5100
5150
5200
5250
5300
5350
5400
5450
5500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
600
500
400
300
200
100
0
5500
5550
5600
5650
5700
5750
5800
5850
5900
5950
6000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Wet well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


600
500
400
300
200
100
0
Q(MGD)
7000
7050
7100
7150
7200
7250
7300
7350
7400
7450
7500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
9
8
7
6
5
4
3
2
1
0
Pump On Service
02/07/2010 09:00:00
02/07/2010 20:00:00
02/08/2010 07:00:00
02/08/2010 18:00:00
02/09/2010 05:00:00
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02/10/2010 03:00:00
02/10/2010 14:00:00
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02/11/2010 12:00:00
02/11/2010 23:00:00
02/12/2010 10:00:00
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02/13/2010 08:00:00
02/13/2010 19:00:00
02/14/2010 06:00:00
02/14/2010 17:00:00
02/15/2010 04:00:00
02/15/2010 15:00:00
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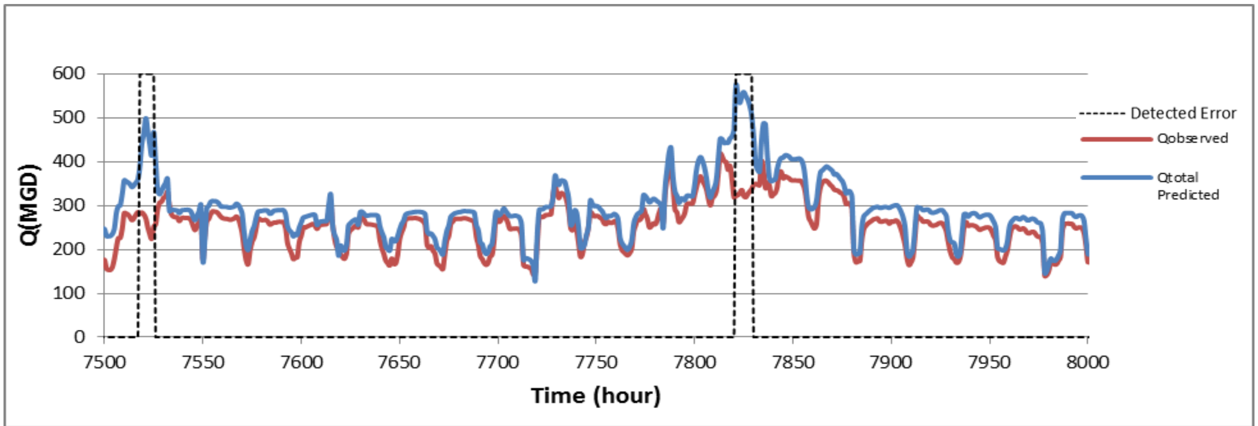
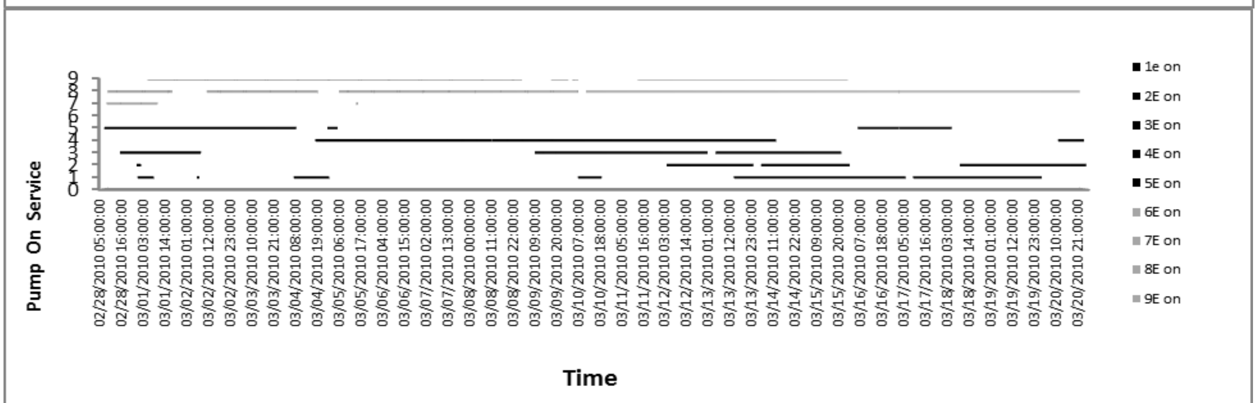
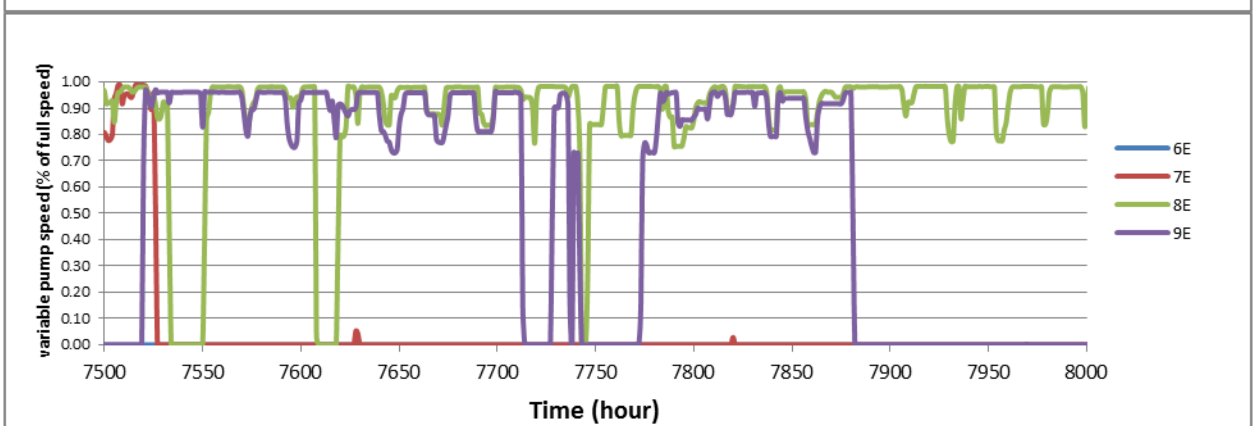
02/26/2010 04:00:00
02/26/2010 15:00:00
02/27/2010 02:00:00
02/27/2010 13:00:00
02/28/2010 00:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
variable pump speed (% of full speed)
7000
7050
7100
7150
7200
7250
7300
7350
7400
7450
7500
Time (hour)
6E
7E
8E
9E
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
Wet Well Level(ft)
7000
7050
7100
7150
7200
7250
7300
7350
7400
7450
7500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



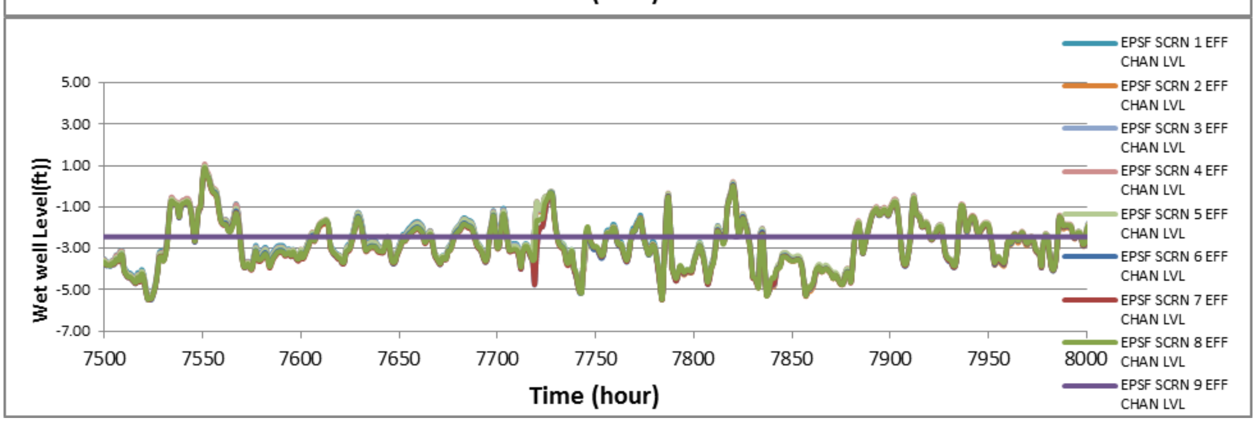
Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted



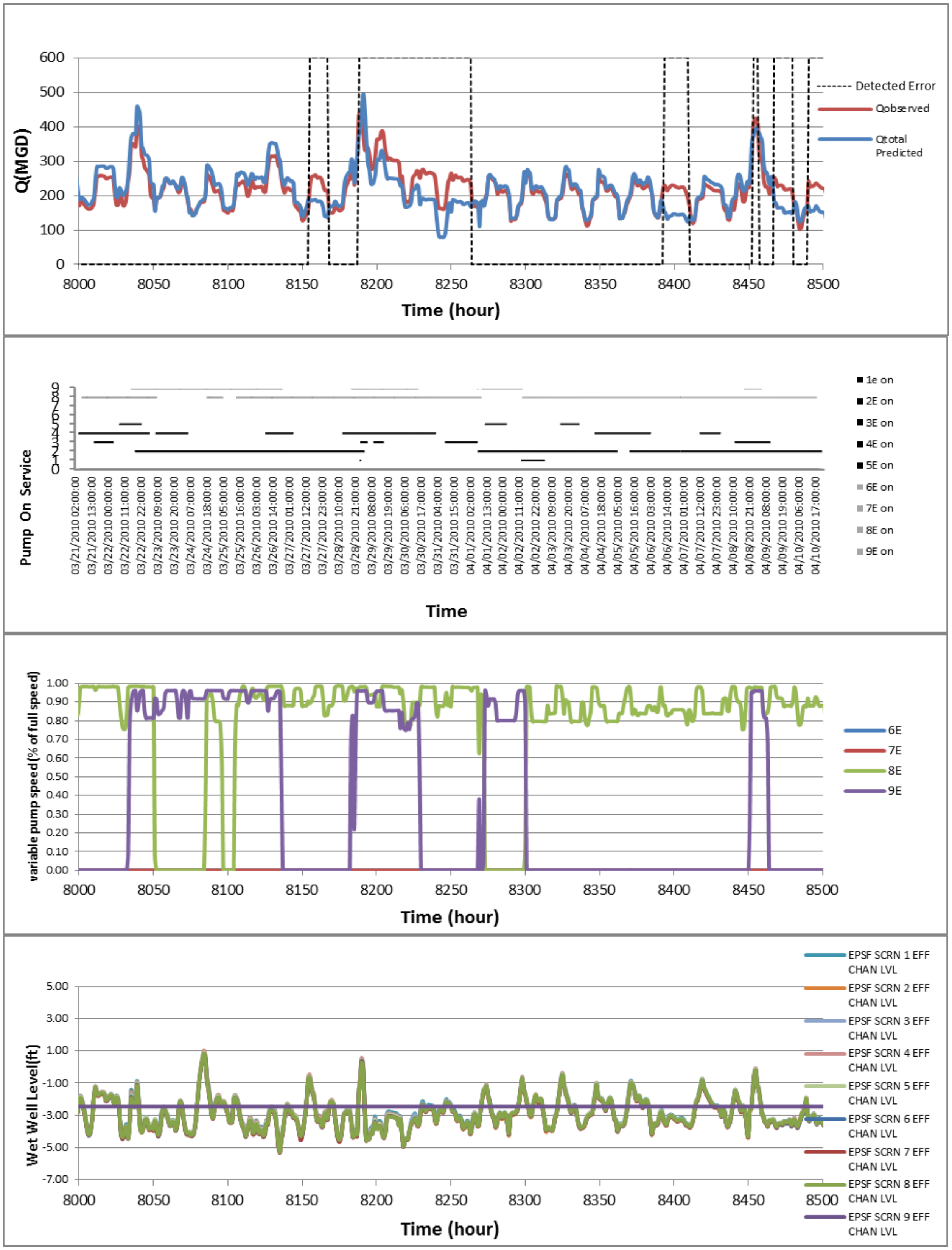
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on



variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E



Wet well Level(ft))
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
600
500
400
300
200
100
0
8000
8050
8100
8150
8200
8250
8300
8350
8400
8450
8500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
9
8
7
6
5
4
3
2
1
0
03/21/2010 02:00:00
03/21/2010 13:00:00
03/22/2010 00:00:00
03/22/2010 11:00:00
03/22/2010 22:00:00
03/23/2010 09:00:00
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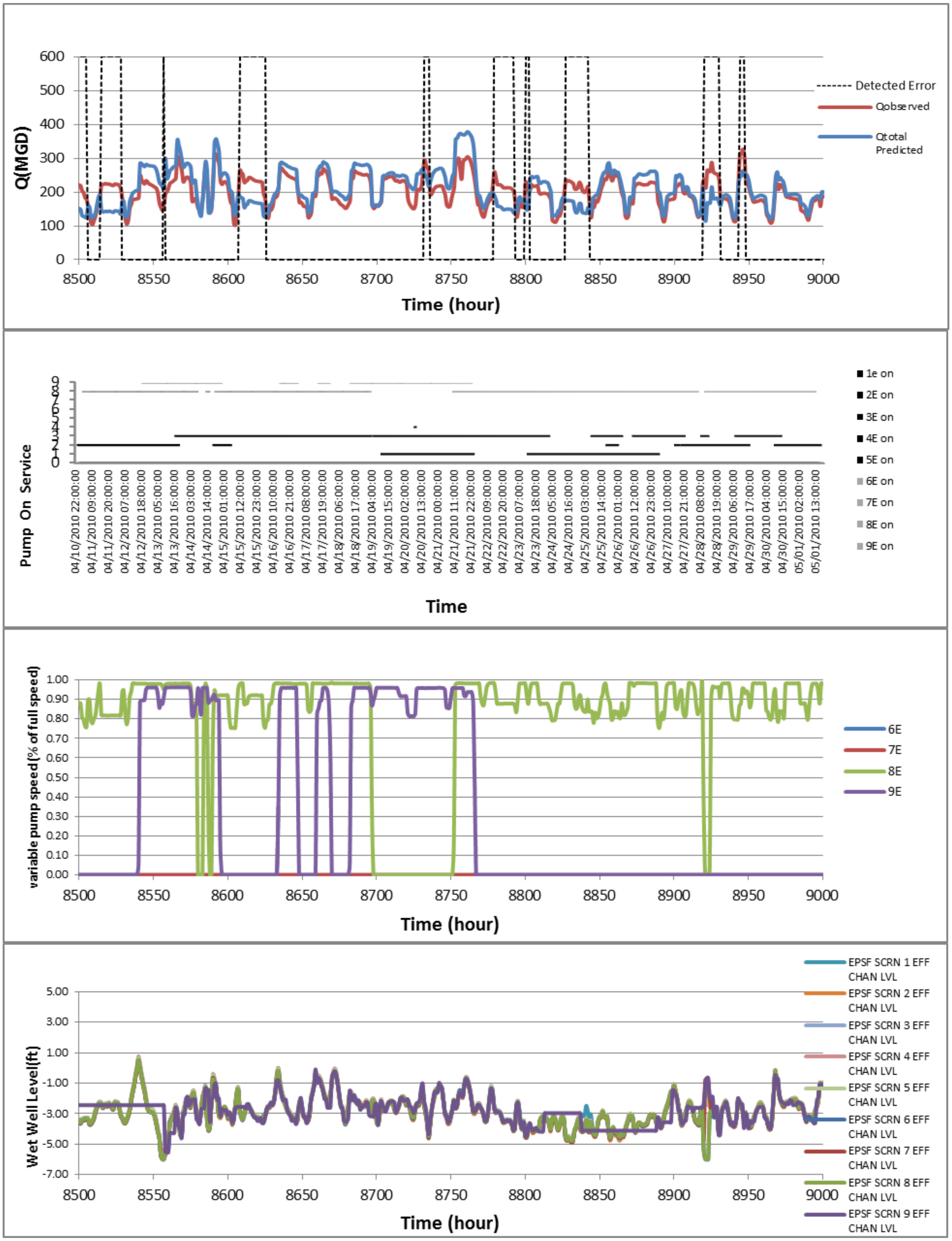
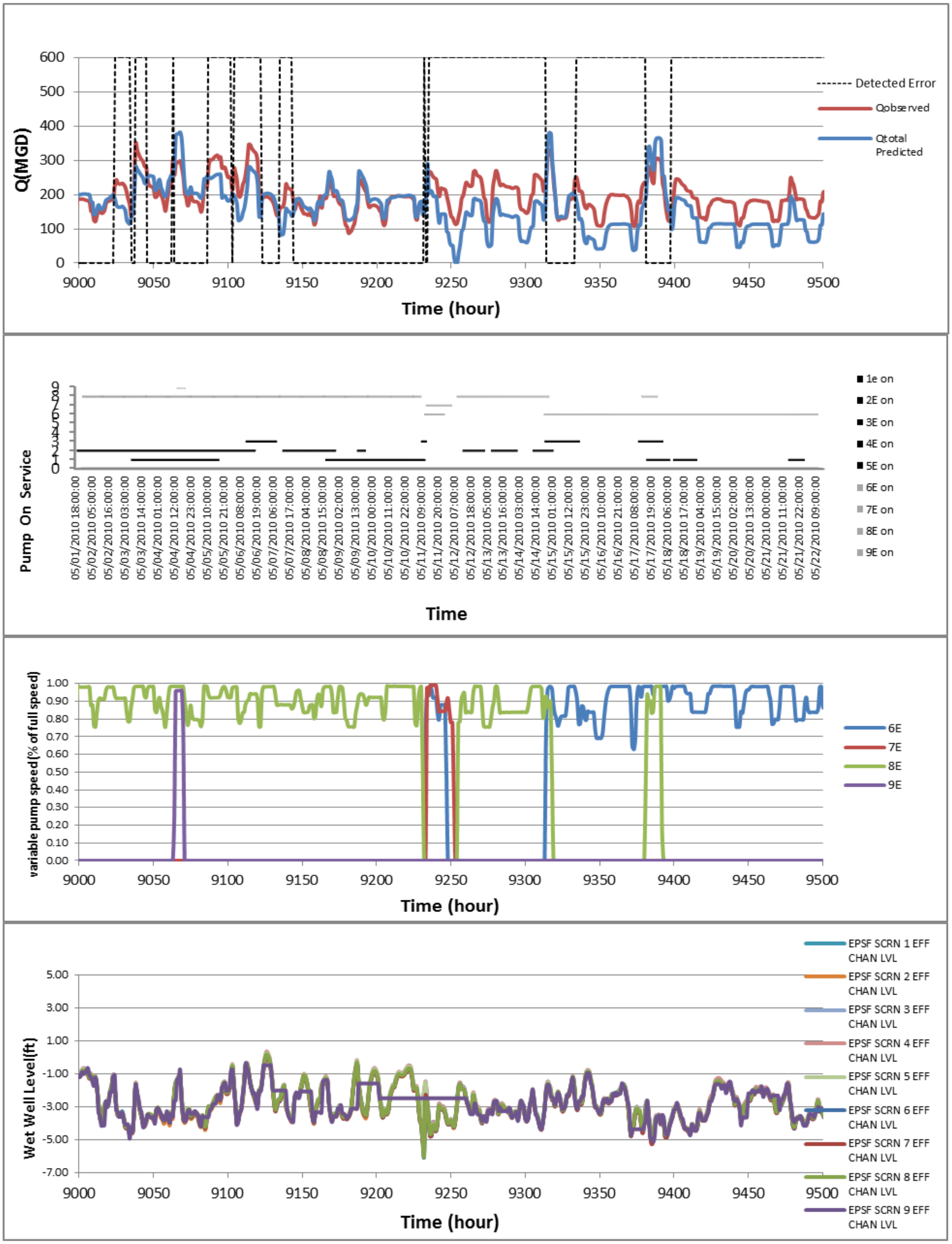
04/06/2010 14:00:00
04/07/2010 01:00:00
04/07/2010 12:00:00
04/07/2010 23:00:00
04/08/2010 10:00:00
04/08/2010 21:00:00
04/09/2010 08:00:00
04/09/2010 19:00:00
04/10/2010 06:00:00
04/10/2010 17:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
8000
8050
8100
8150
8200
8250
8300
8350
8400
8450
8500
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
8000
8050
8100
8150
8200
8250
8300
8350
8400
8450
8500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


600
500
400
300
200
100
0
Q(MGD)
9000
9050
9100
9150
9200
9250
9300
9350
9400
9450
9500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
0
1
2
3
4
5
6
7
8
9
05/01/2010 18:00:00
05/02/2010 05:00:00
05/02/2010 16:00:00
05/03/2010 03:00:00
05/03/2010 14:00:00
05/04/2010 01:00:00
05/04/2010 12:00:00
05/04/2010 23:00:00
05/05/2010 10:00:00
05/05/2010 21:00:00
05/06/2010 08:00:00
05/06/2010 19:00:00
05/07/2010 06:00:00
05/07/2010 17:00:00
05/08/2010 04:00:00
05/08/2010 15:00:00
05/09/2010 02:00:00
05/09/2010 13:00:00
05/10/2010 00:00:00
05/10/2010 11:00:00
05/10/2010 22:00:00
05/11/2010 09:00:00
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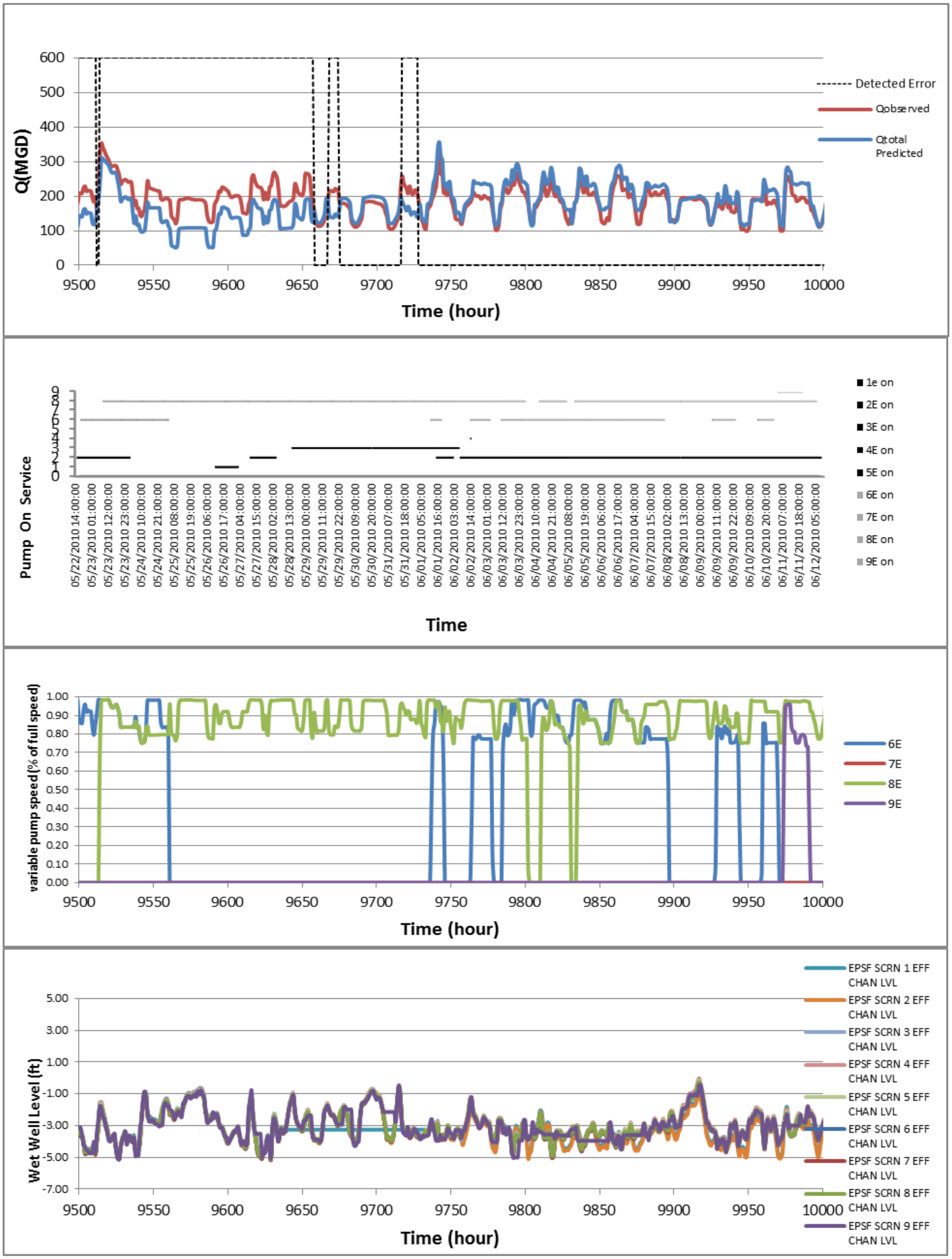
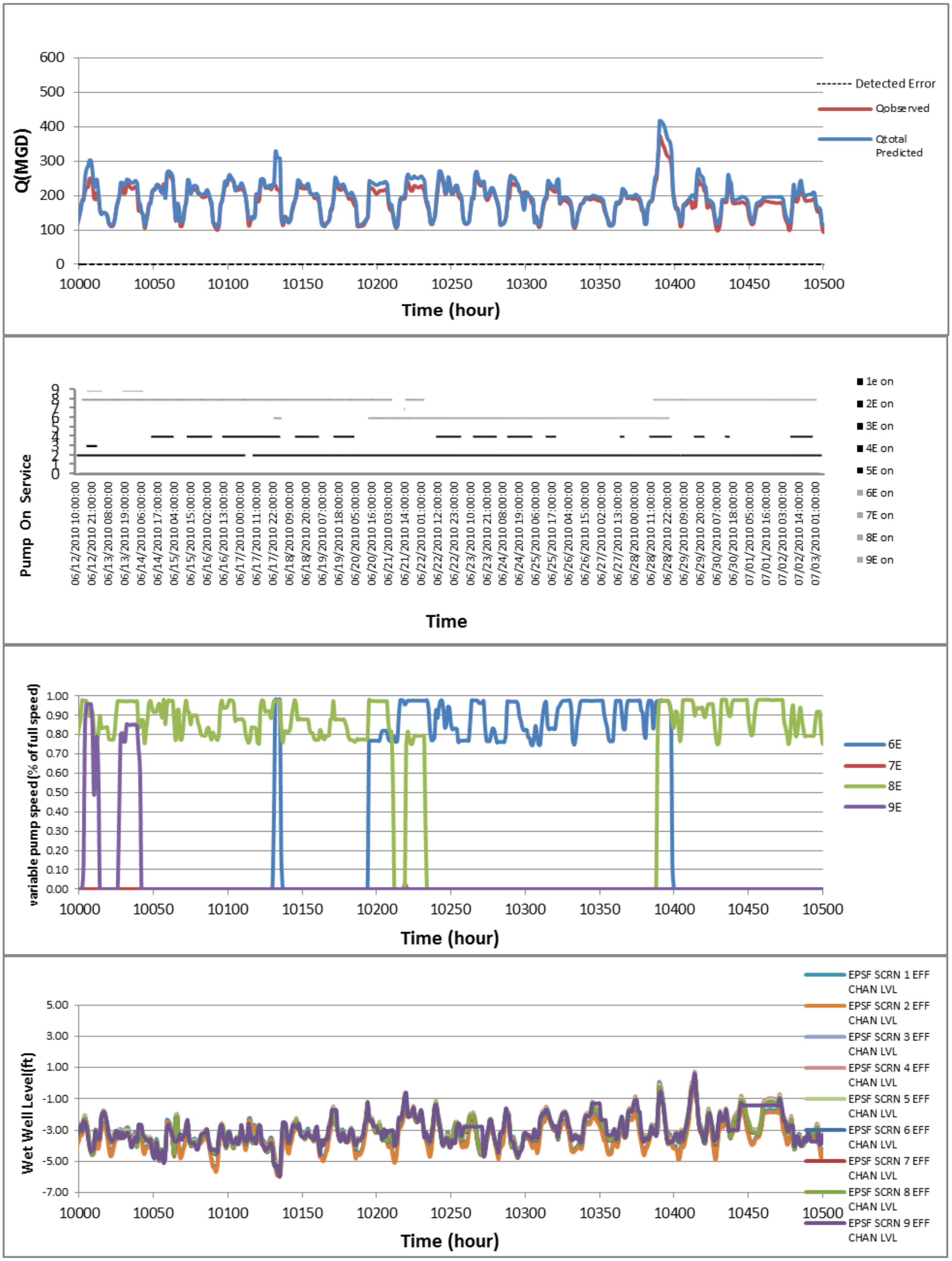
05/12/2010 07:00:00
05/12/2010 18:00:00
05/13/2010 05:00:00
05/13/2010 16:00:00
05/14/2010 03:00:00
05/14/2010 14:00:00
05/15/2010 01:00:00
05/15/2010 12:00:00
05/15/2010 23:00:00
05/16/2010 10:00:00
05/16/2010 21:00:00
05/17/2010 08:00:00
05/17/2010 19:00:00
05/18/2010 06:00:00
05/18/2010 17:00:00
05/19/2010 04:00:00
05/19/2010 15:00:00
05/20/2010 02:00:00
05/20/2010 13:00:00
05/21/2010 00:00:00
05/21/2010 11:00:00
05/21/2010 22:00:00
05/22/2010 09:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
9000
9050
9100
9150
9200
9250
9300
9350
9400
9450
9500
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
9000
9050
9100
9150
9200
9250
9300
9350
9400
9450
9500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level (ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



600
500
400
300
200
100
0
Q(MGD)
10000 10050 10100 10150 10200 10250 10300 10350 10400 10450 10500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
9 8 7 6 5 4 3 2 1 0
Pump On Service
06/12/2010 10:00:00
06/12/2010 21:00:00
06/13/2010 08:00:00
06/13/2010 19:00:00
06/14/2010 06:00:00
06/14/2010 17:00:00
06/15/2010 04:00:00
06/15/2010 15:00:00
06/16/2010 02:00:00
06/16/2010 13:00:00
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06/17/2010 22:00:00
06/18/2010 09:00:00
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06/19/2010 18:00:00
06/20/2010 05:00:00
06/20/2010 16:00:00
06/21/2010 03:00:00
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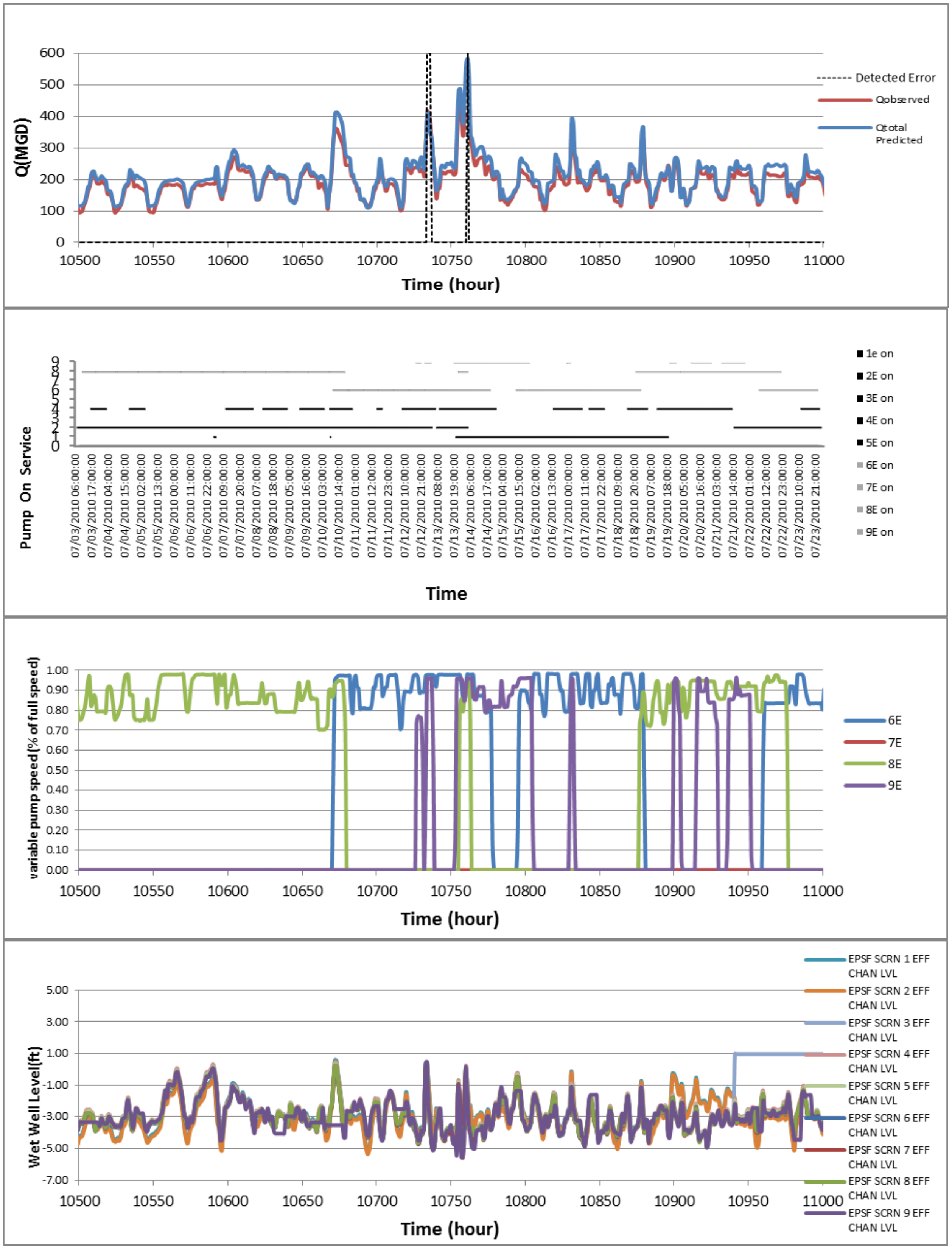
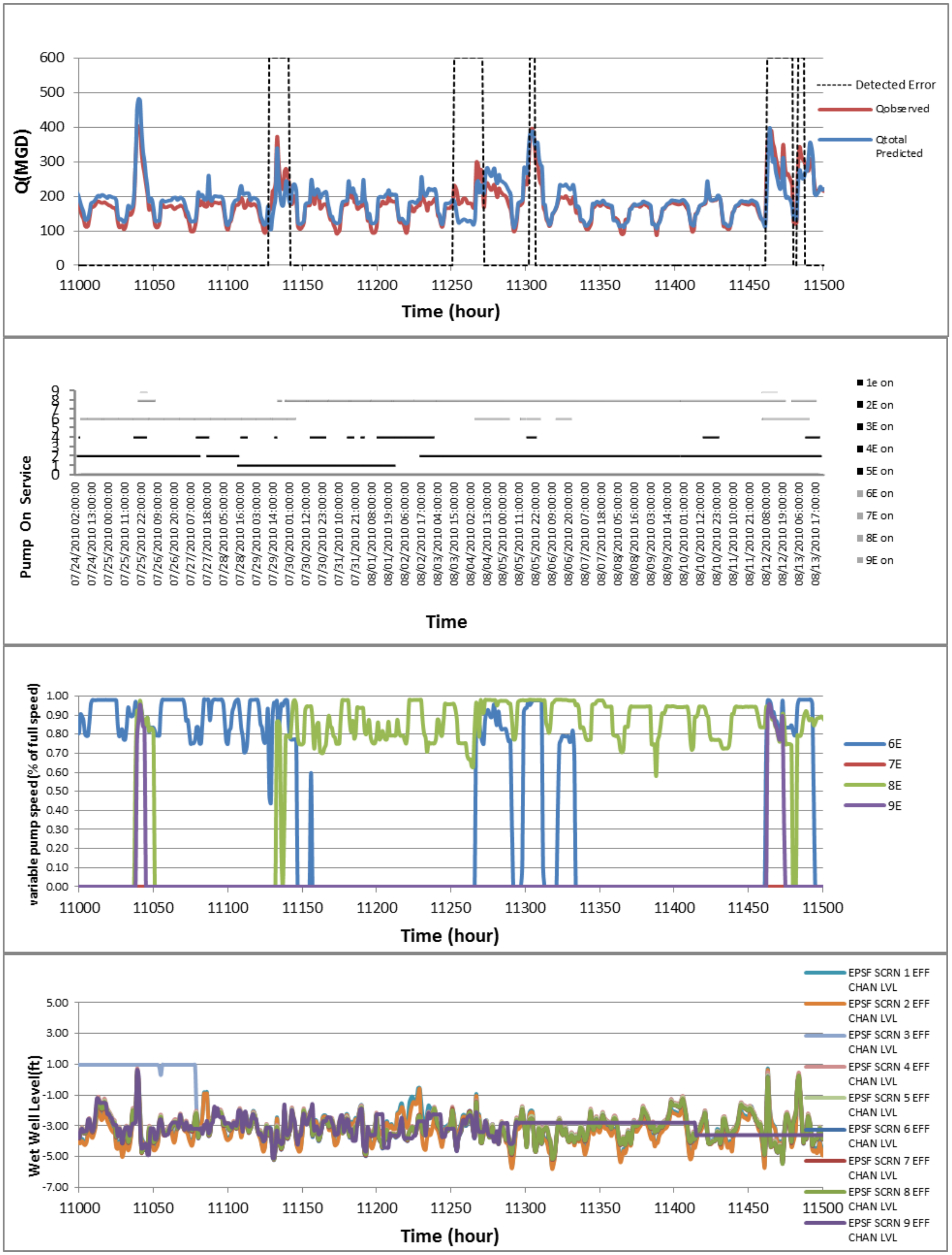
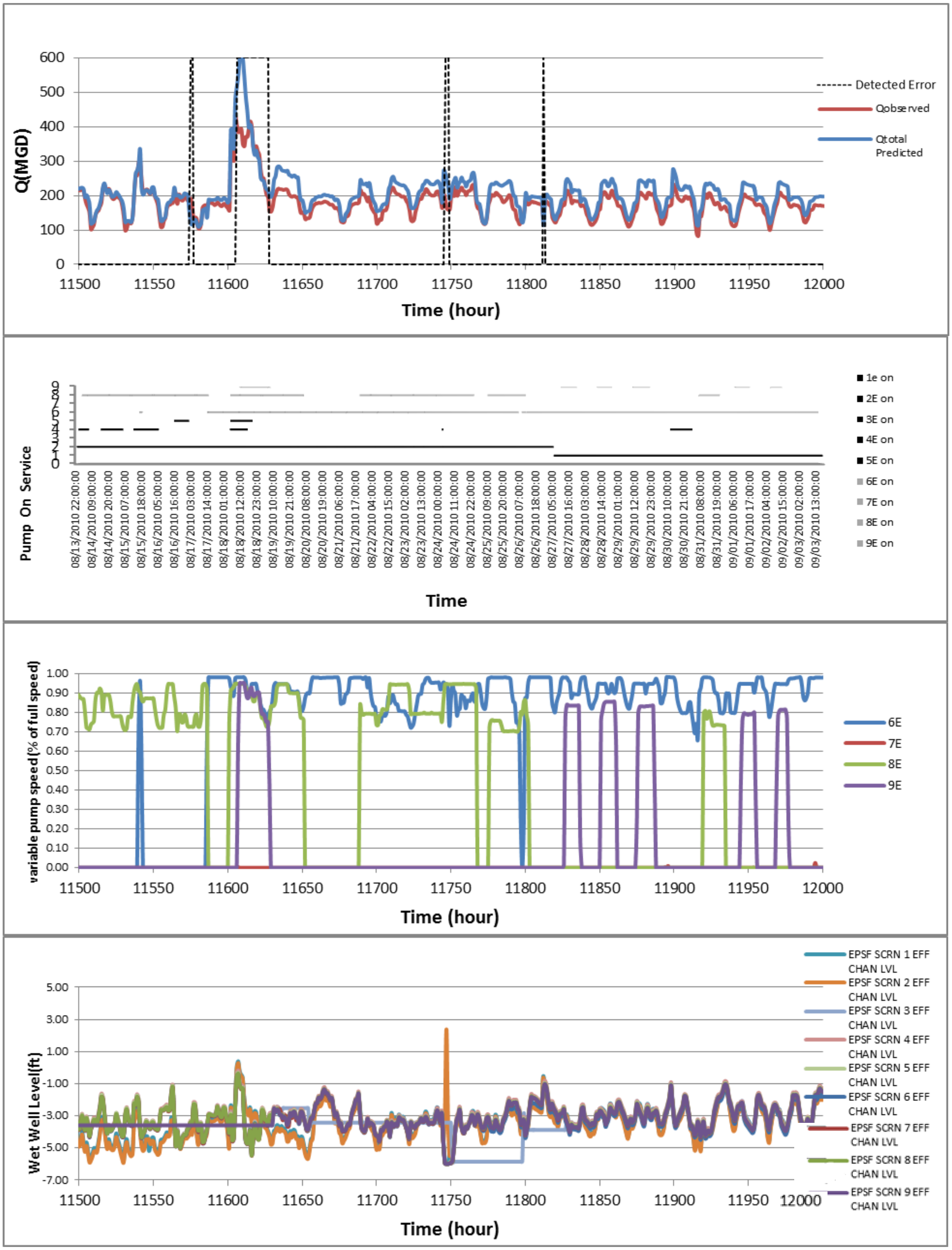
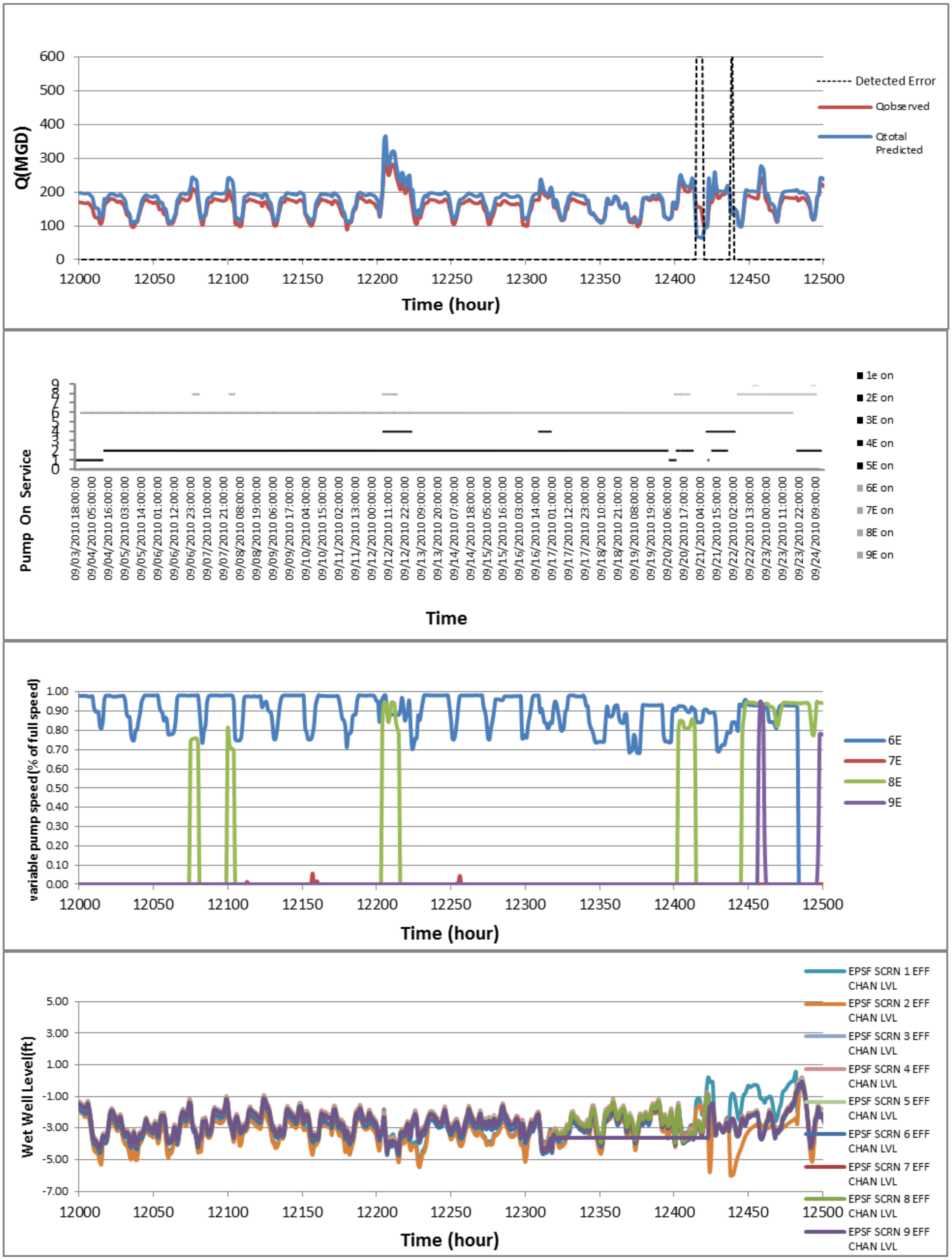
07/01/2010 05:00:00
07/01/2010 16:00:00
07/02/2010 03:00:00
07/02/2010 14:00:00
07/03/2010 01:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
1.00 0.90 0.80 0.70 0.60 0.50 0.40 0.30 0.20 0.10 0.00
variable pump speed(% of full speed)
10000 10050 10100 10150 10200 10250 10300 10350 10400 10450 10500
Time (hour)
6E
7E
8E
9E
5.00 3.00 1.00 -1.00 -3.00 -5.00 -7.00
Wet Well Level(ft)
10000 10050 10100 10150 10200 10250 10300 10350 10400 10450 10500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
6E
7E
8E
9E
Wet Well Level(ft)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



600
500
400
300
200
100
0
Q(MGD)
12000
12050
12100
12150
12200
12250
12300
12350
12400
12450
12500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
9
8
7
6
5
4
3
2
1
0
Pump On Service
09/03/2010 18:00:00
09/04/2010 05:00:00
09/04/2010 16:00:00
09/05/2010 03:00:00
09/05/2010 14:00:00
09/06/2010 01:00:00
09/06/2010 12:00:00
09/06/2010 23:00:00
09/07/2010 10:00:00
09/07/2010 21:00:00
09/08/2010 08:00:00
09/08/2010 19:00:00
09/09/2010 06:00:00
09/09/2010 17:00:00
09/10/2010 04:00:00
09/10/2010 15:00:00
09/11/2010 02:00:00
09/11/2010 13:00:00
09/12/2010 00:00:00
09/12/2010 11:00:00
09/12/2010 22:00:00
09/13/2010 09:00:00
09/13/2010 20:00:00
09/14/2010 07:00:00
09/14/2010 18:00:00
09/15/2010 05:00:00
09/15/2010 16:00:00
09/16/2010 03:00:00
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09/21/2010 15:00:00
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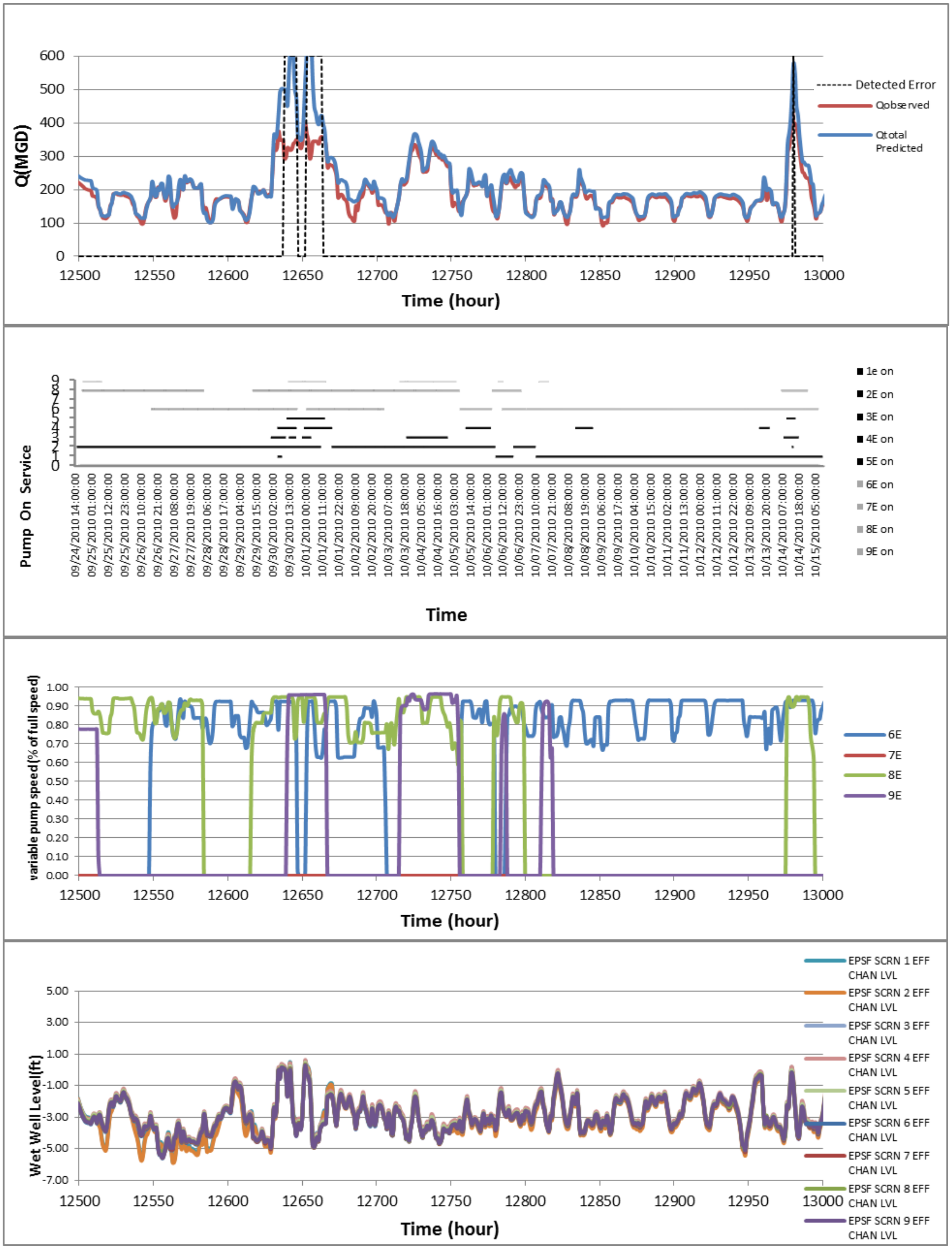
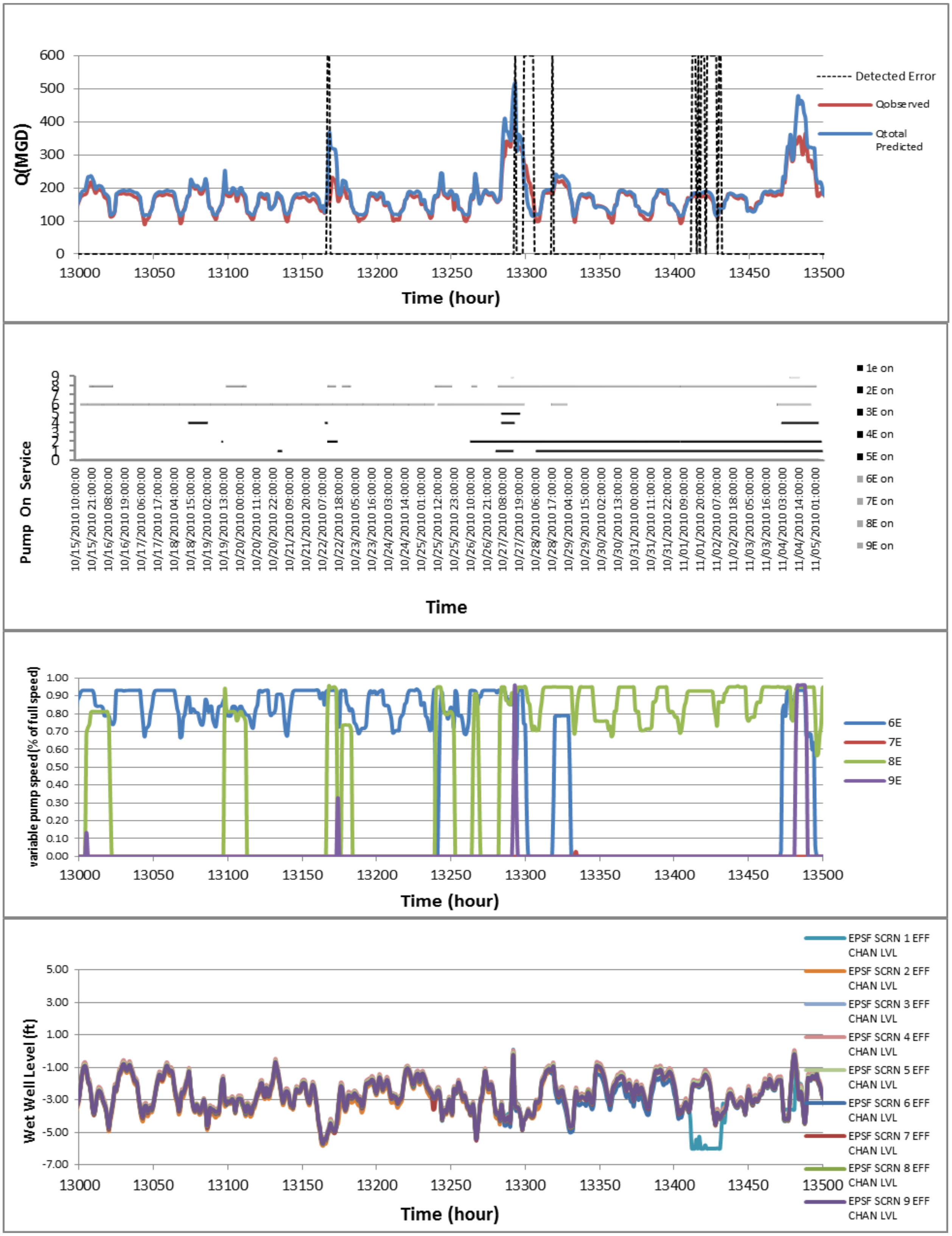
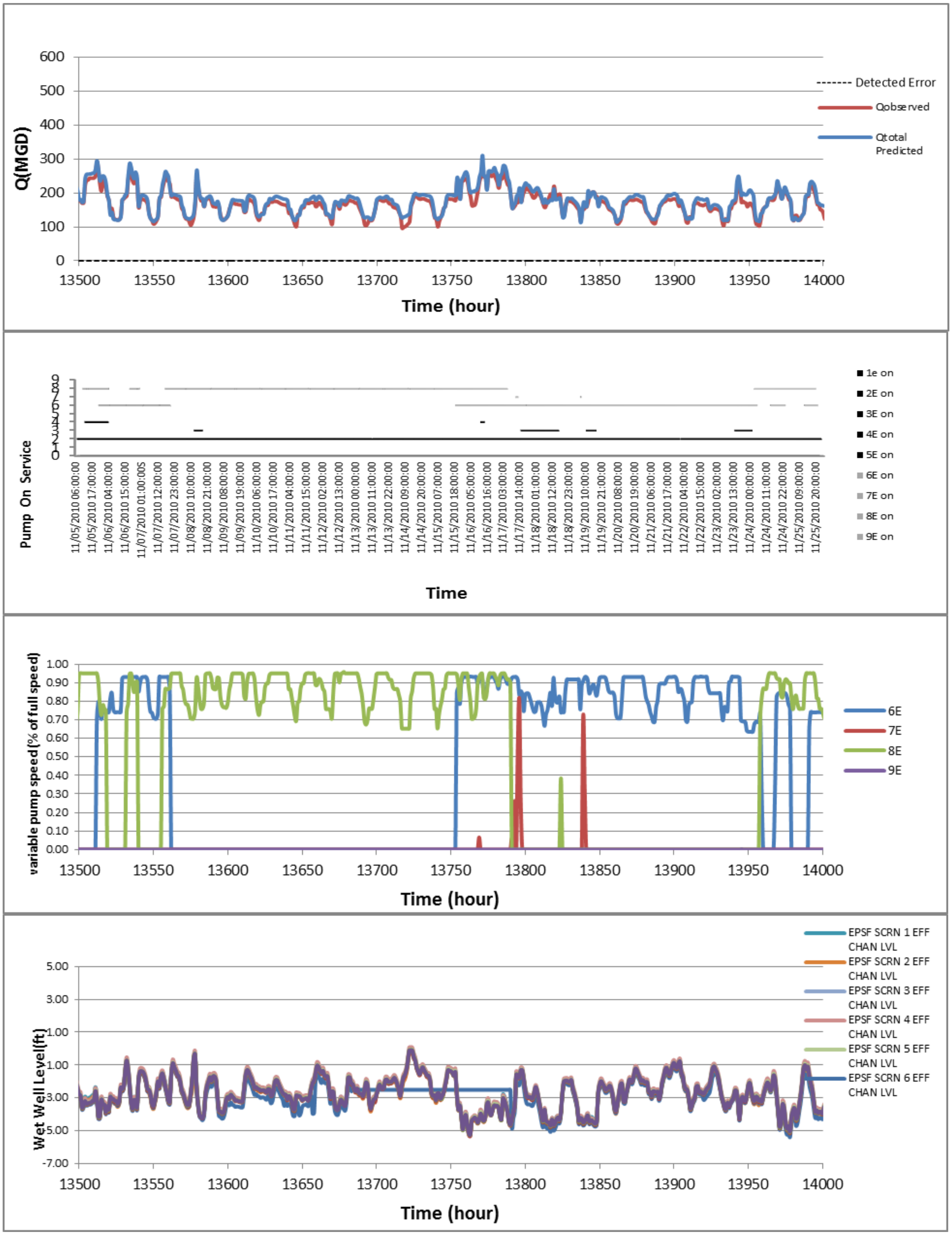
09/22/2010 13:00:00
09/23/2010 00:00:00
09/23/2010 11:00:00
09/23/2010 22:00:00
09/24/2010 09:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
variable pump speed(% of full speed)
12000
12050
12100
12150
12200
12250
12300
12350
12400
12450
12500
Time (hour)
6E
7E
8E
9E
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
Wet Well Level(ft)
12000
12050
12100
12150
12200
12250
12300
12350
12400
12450
12500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



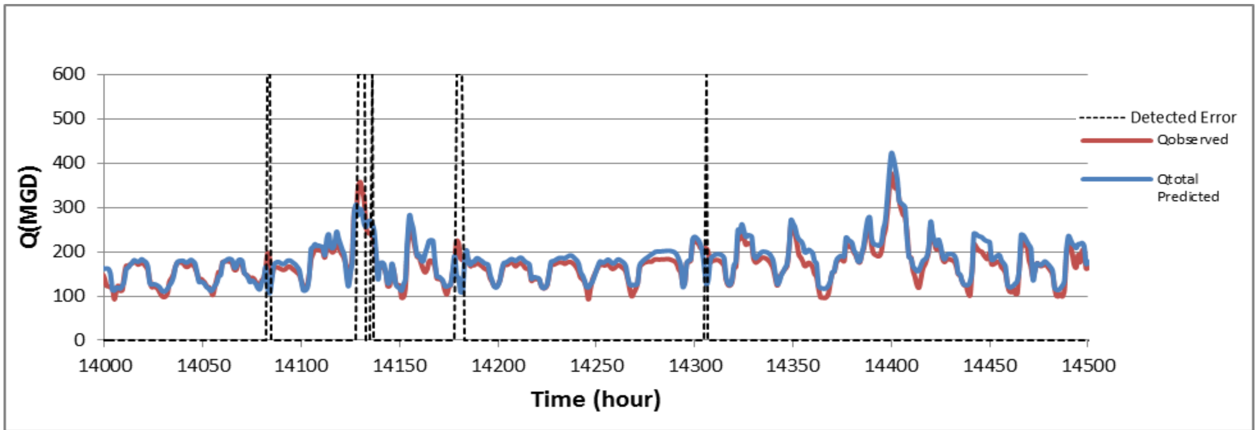
Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

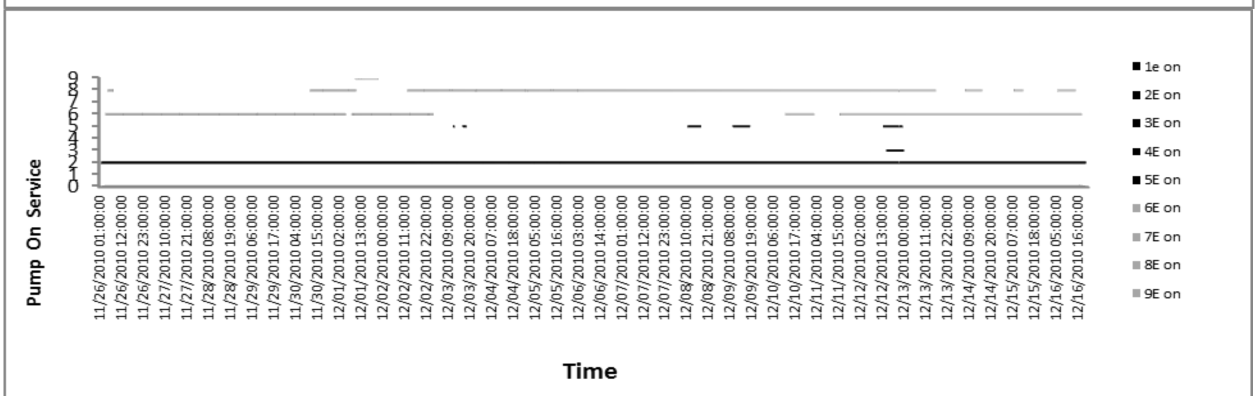


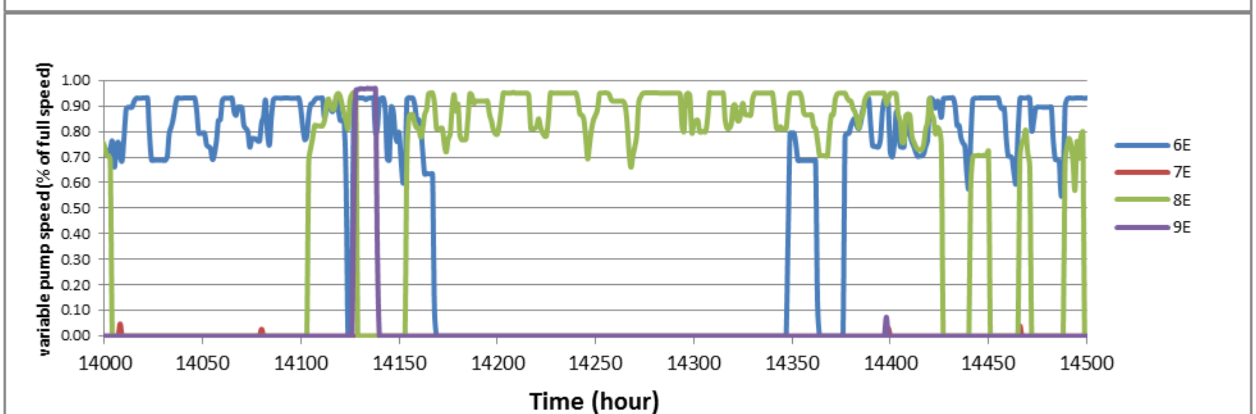
Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level (ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

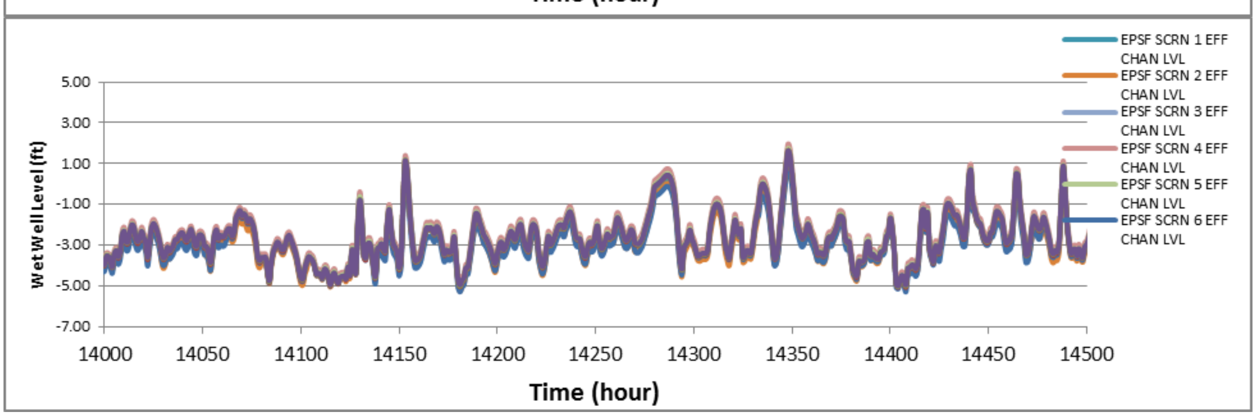


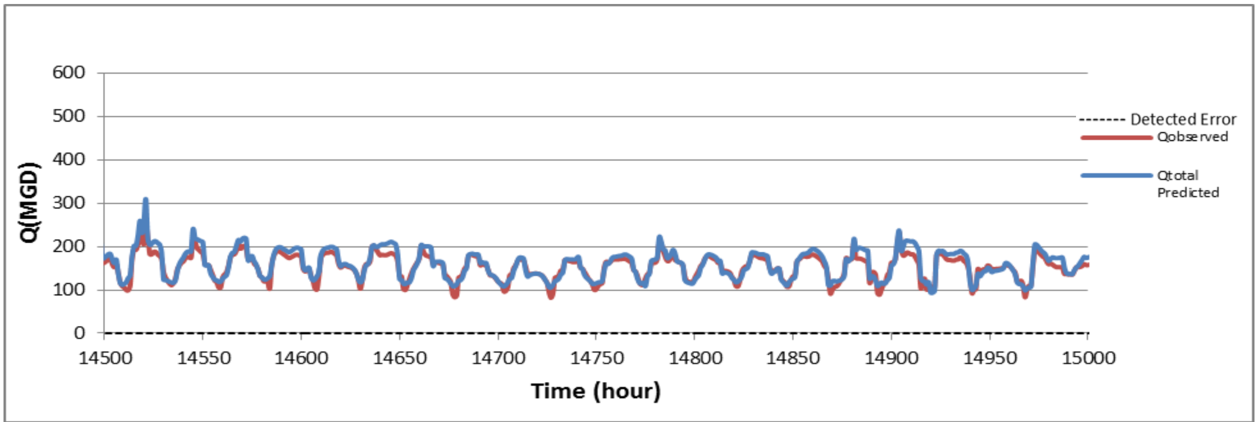
Q(MGD)
Detected Error
Qobserved
Qtotal Predicted
Time (hour)
Pump On Service
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
Time
variable pump speed (% of full speed)
6E
7E
8E
9E
Time (hour)
Wet Well Level(ft)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
Time (hour)

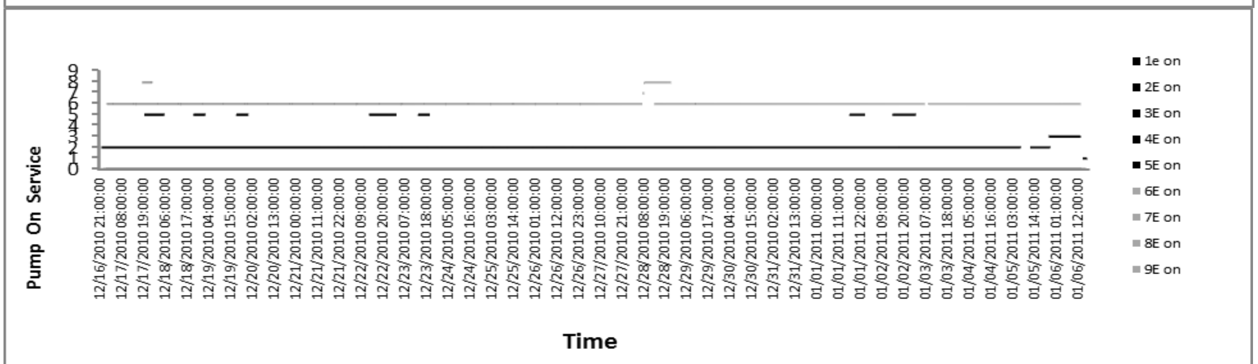

Q(MGD)
600
500
400
300
200
100
0
14000
14050
14100
14150
14200
14250
14300
14350
14400
14450
14500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted


Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on


variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
14000
14050
14100
14150
14200
14250
14300
14350
14400
14450
14500
Time (hour)
6E
7E
8E
9E


Wet Well Level (ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
14000
14050
14100
14150
14200
14250
14300
14350
14400
14450
14500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL


Q(MGD)
600
500
400
300
200
100
0
14500
14550
14600
14650
14700
14750
14800
14850
14900
14950
15000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted


Pump On Service
9
8
7
6
5
4
3
2
1
0
12/16/2010 21:00:00
12/17/2010 08:00:00
12/17/2010 19:00:00
12/18/2010 06:00:00
12/18/2010 17:00:00
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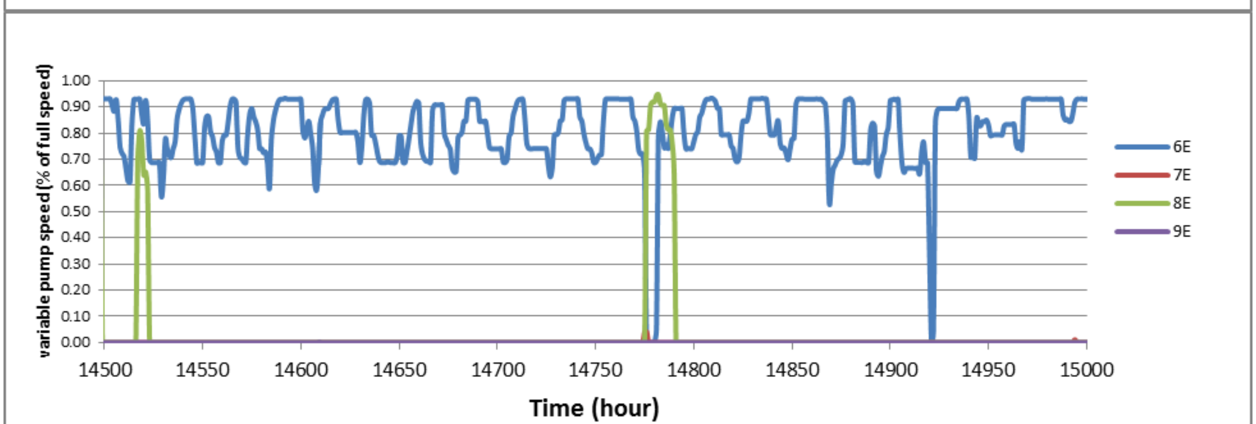
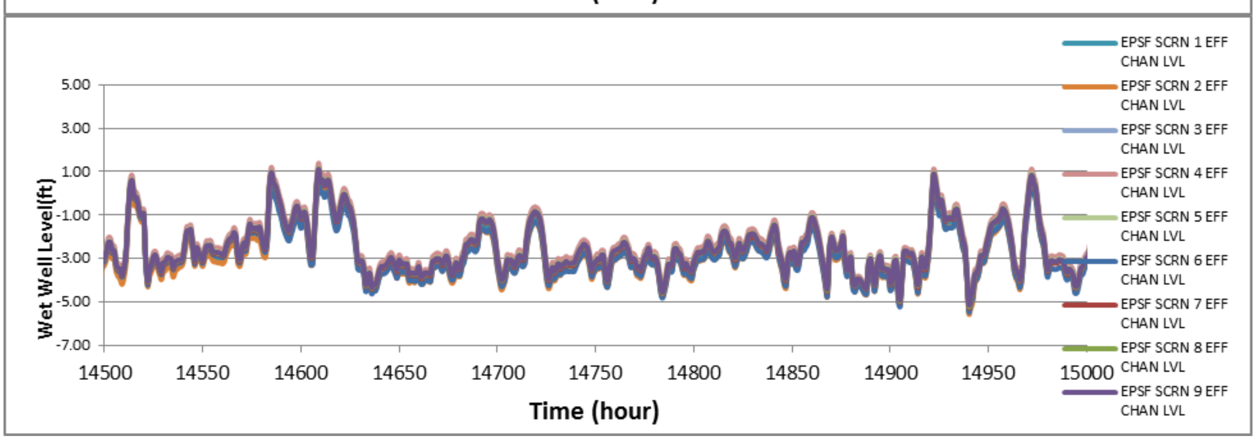
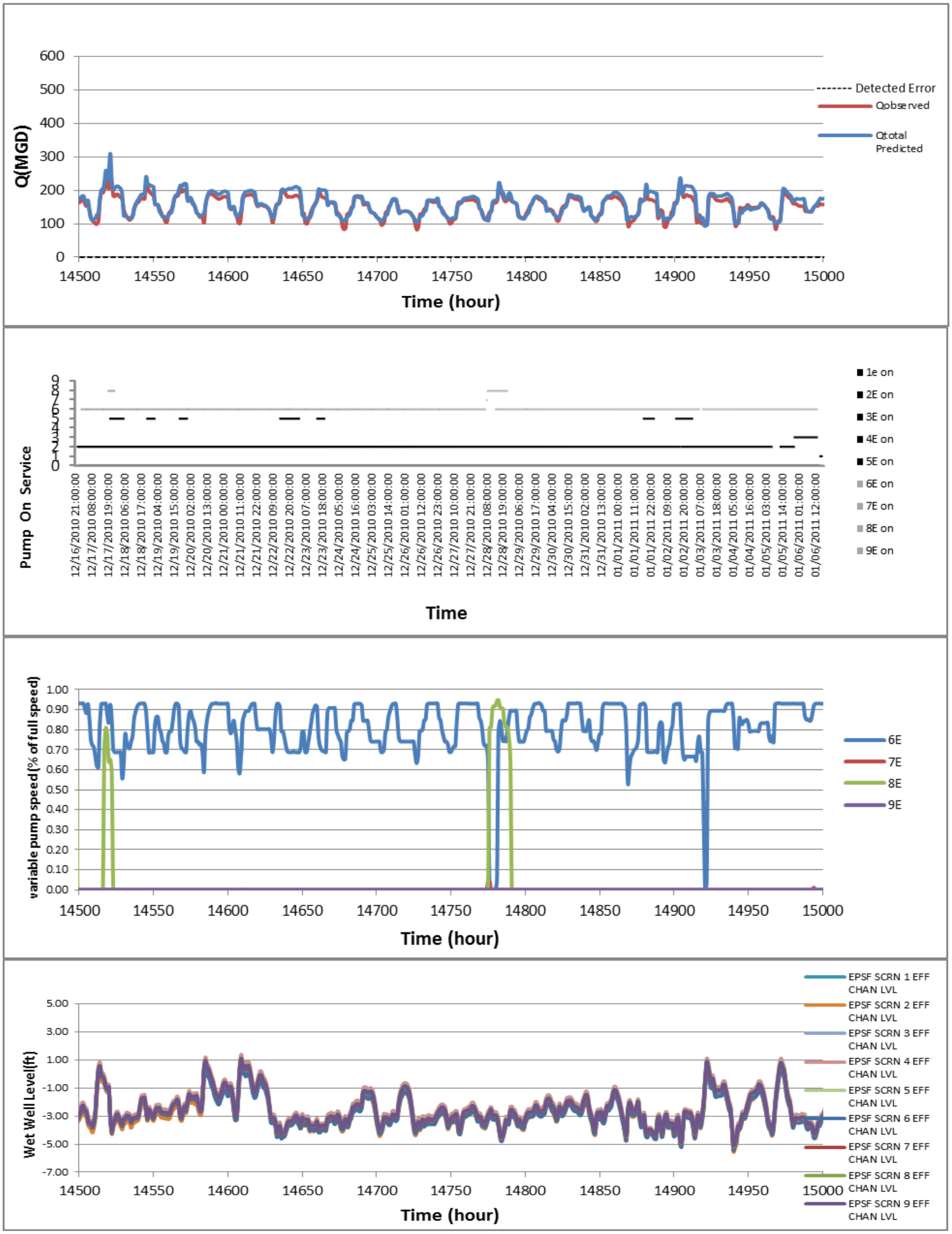
01/04/2011 16:00:00
01/05/2011 03:00:00
01/05/2011 14:00:00
01/06/2011 01:00:00
01/06/2011 12:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on


variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
14500
14550
14600
14650
14700
14750
14800
14850
14900
14950
15000
Time (hour)
6E
7E
8E
9E


Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
14500
14550
14600
14650
14700
14750
14800
14850
14900
14950
15000
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
600
500
400
300
200
100
0
14500 14550 14600 14650 14700 14750 14800 14850 14900 14950 15000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
9 8 7 6 5 4 3 2 1 0
12/16/2010 21:00:00
12/17/2010 08:00:00
12/17/2010 19:00:00
12/18/2010 06:00:00
12/18/2010 17:00:00
12/19/2010 04:00:00
12/19/2010 15:00:00
12/20/2010 02:00:00
12/20/2010 13:00:00
12/21/2010 00:00:00
12/21/2010 11:00:00
12/21/2010 22:00:00
12/22/2010 09:00:00
12/22/2010 20:00:00
12/23/2010 07:00:00
12/23/2010 18:00:00
12/24/2010 05:00:00
12/24/2010 16:00:00
12/25/2010 03:00:00
12/25/2010 14:00:00
12/26/2010 01:00:00
12/26/2010 12:00:00
12/26/2010 23:00:00
12/27/2010 10:00:00
12/27/2010 21:00:00
12/28/2010 08:00:00
12/28/2010 19:00:00
12/29/2010 06:00:00
12/29/2010 17:00:00
12/30/2010 04:00:00
12/30/2010 15:00:00
12/31/2010 02:00:00
12/31/2010 13:00:00
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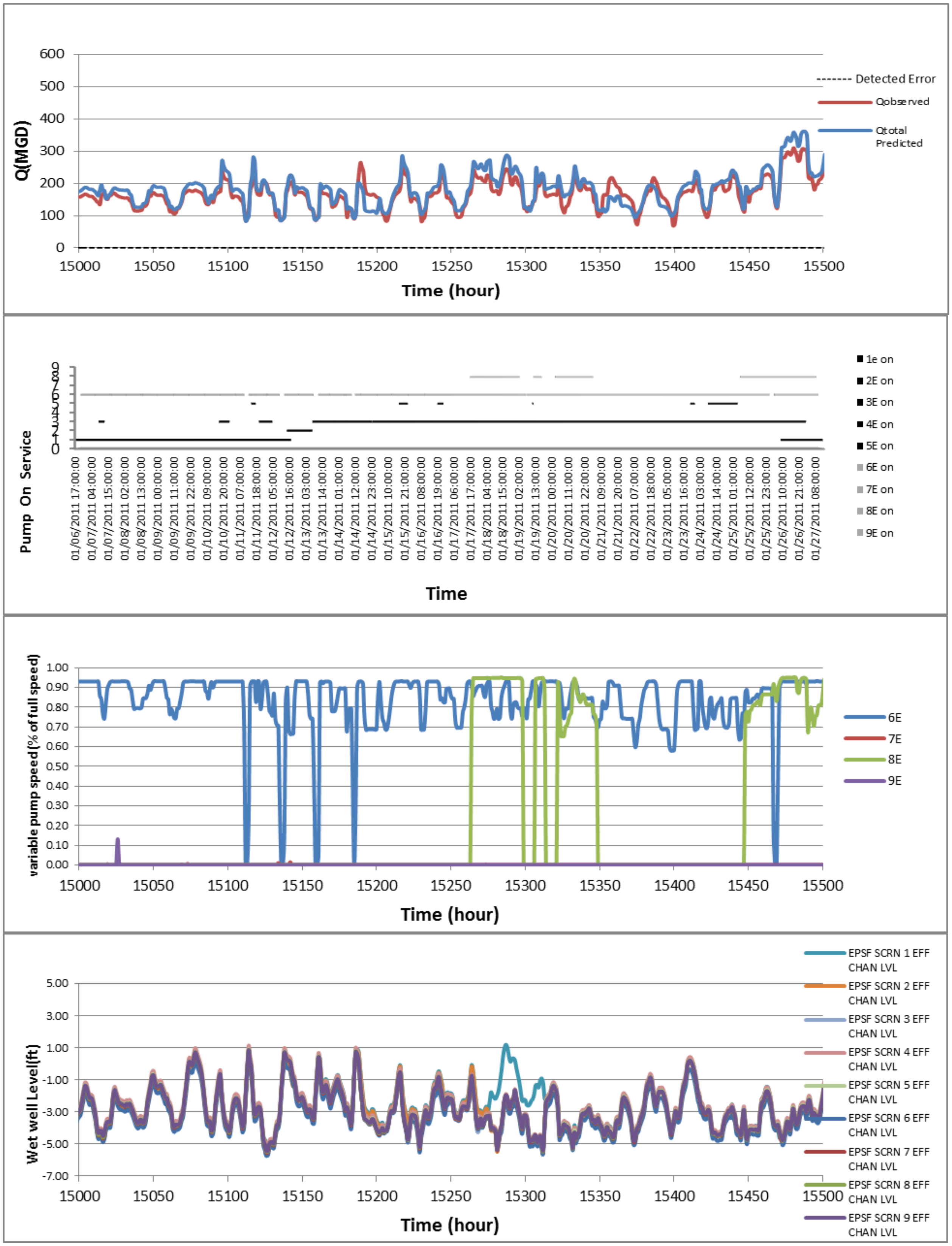
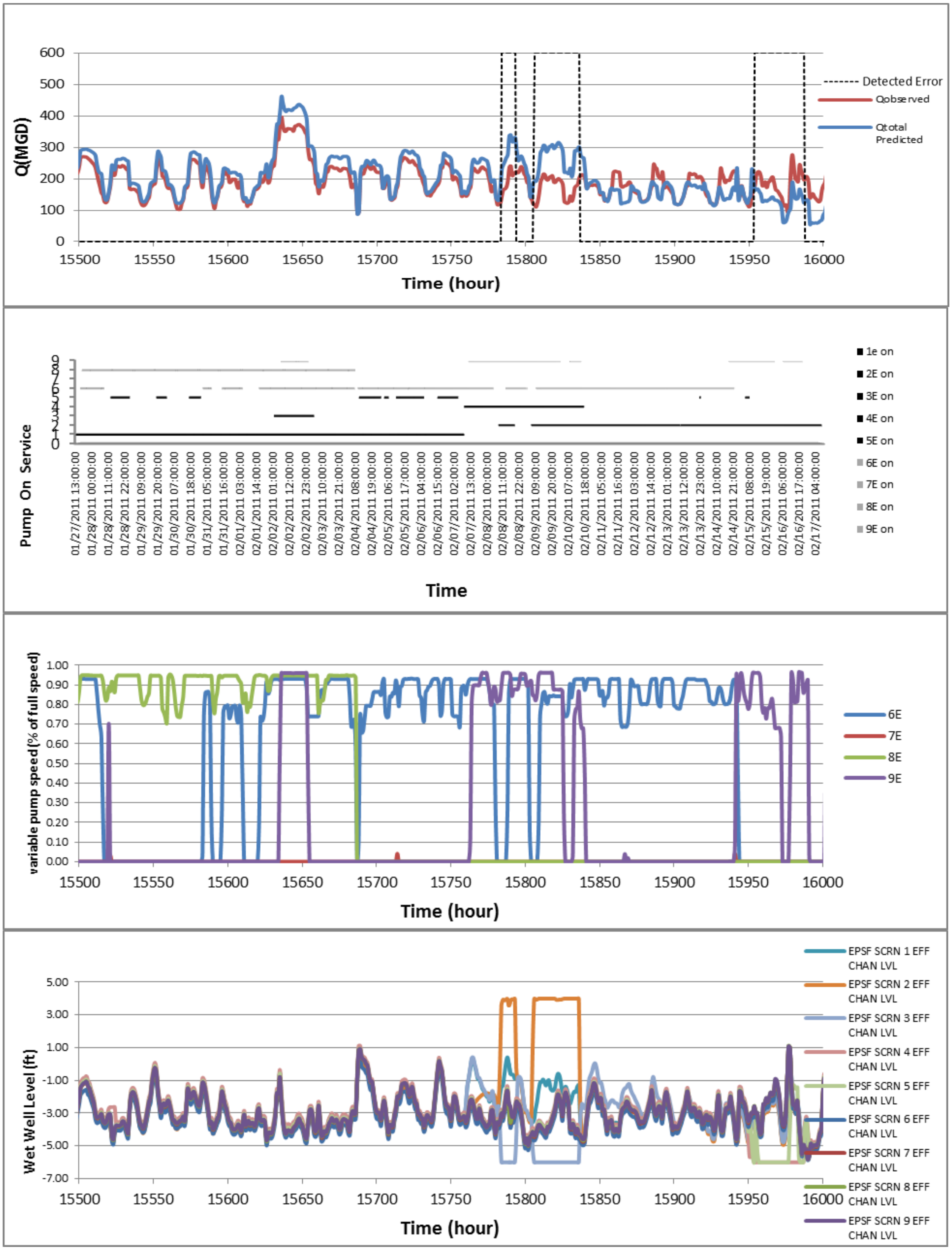
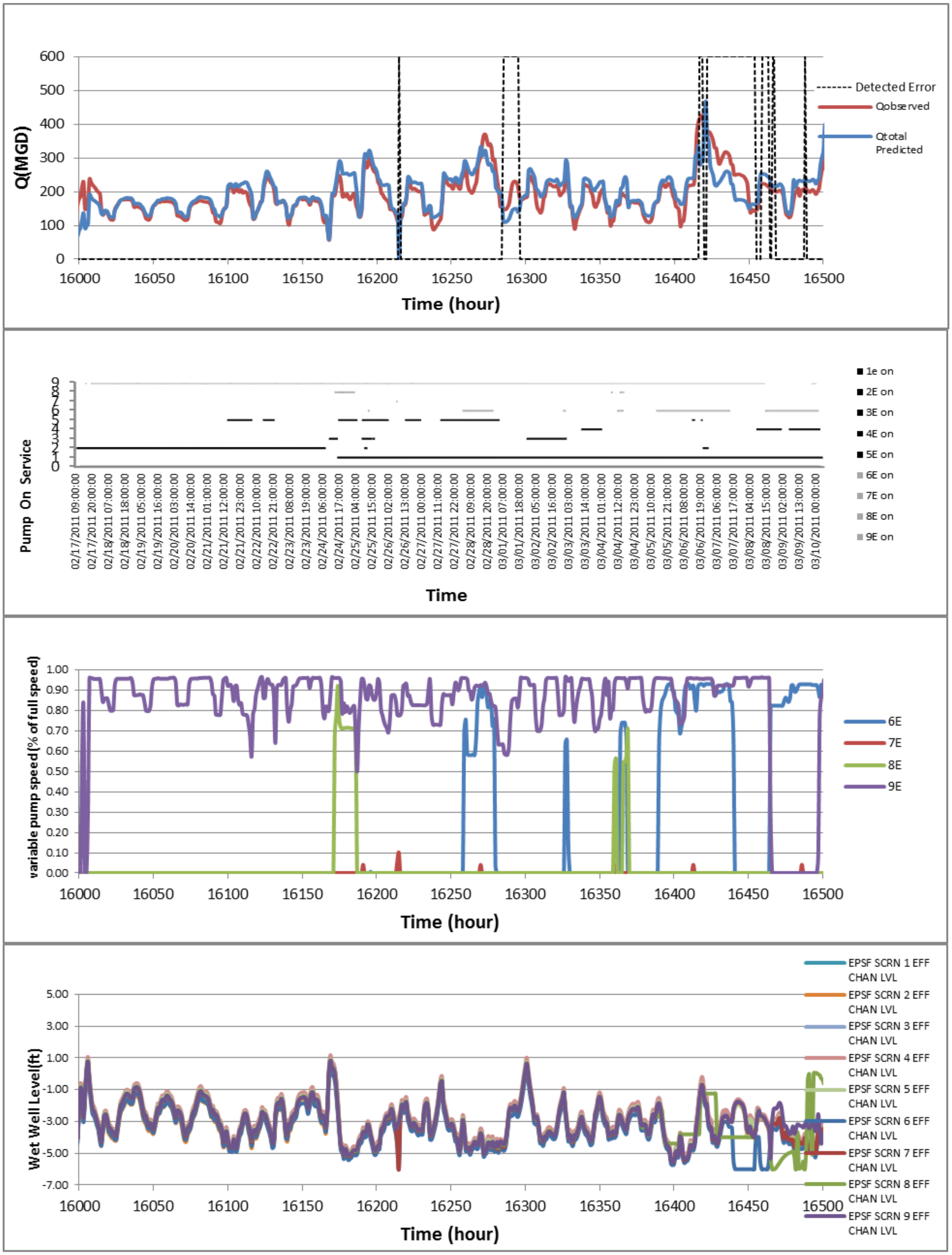
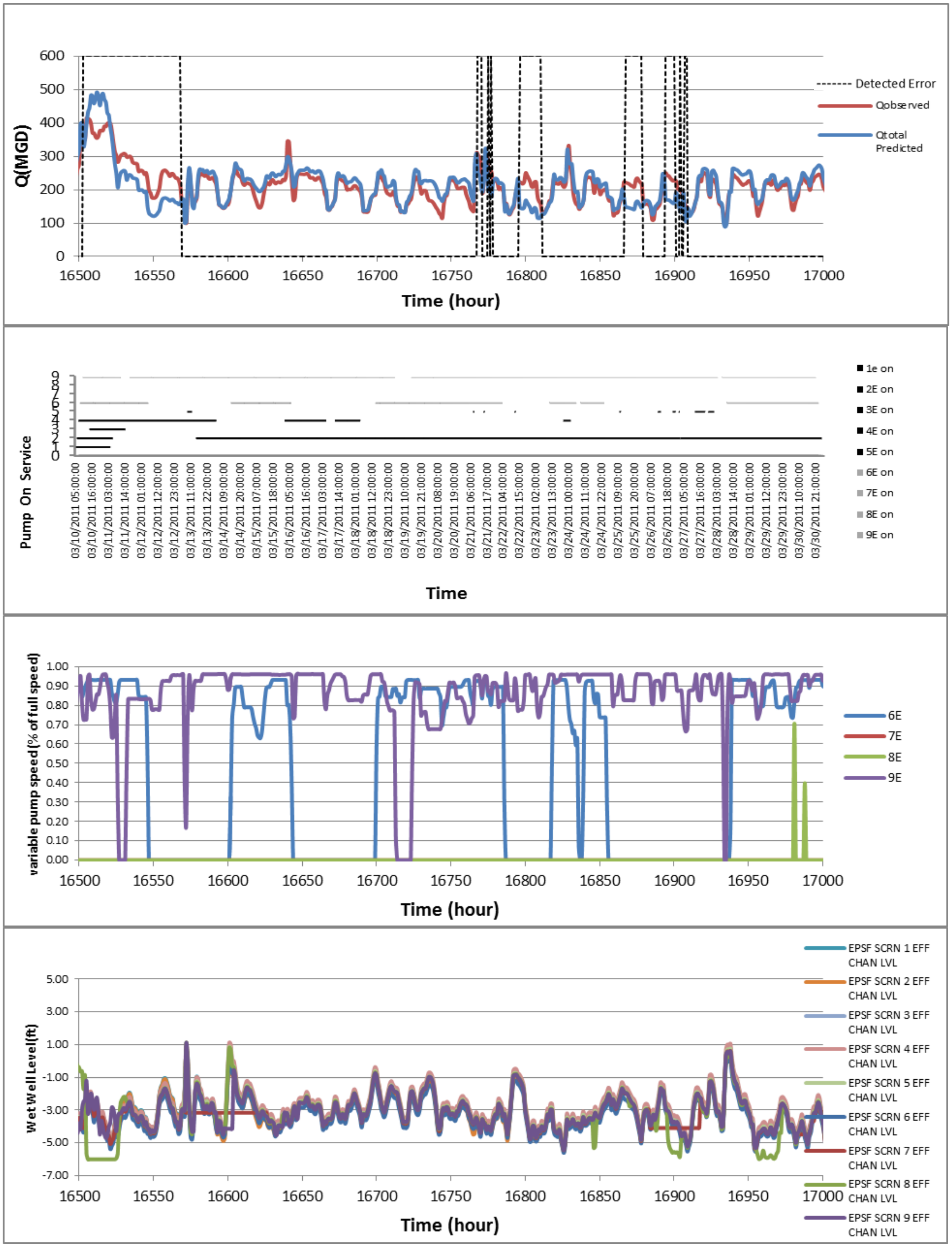
01/02/2011 09:00:00
01/02/2011 20:00:00
01/03/2011 07:00:00
01/03/2011 18:00:00
01/04/2011 05:00:00
01/04/2011 16:00:00
01/05/2011 03:00:00
01/05/2011 14:00:00
01/06/2011 01:00:00
01/06/2011 12:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
14500 14550 14600 14650 14700 14750 14800 14850 14900 14950 15000
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
14500 14550 14600 14650 14700 14750 14800 14850 14900 14950 15000
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Wet well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

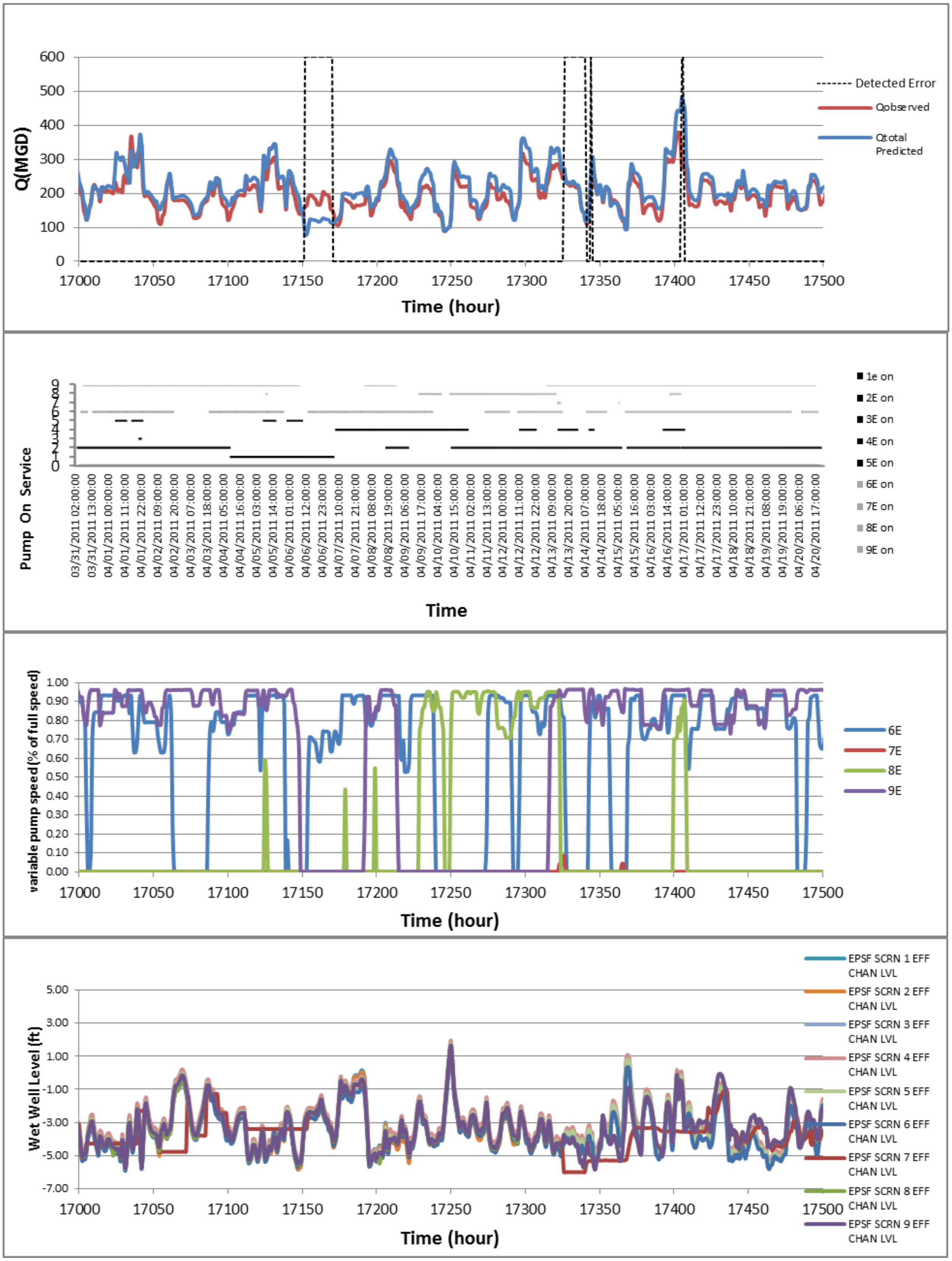


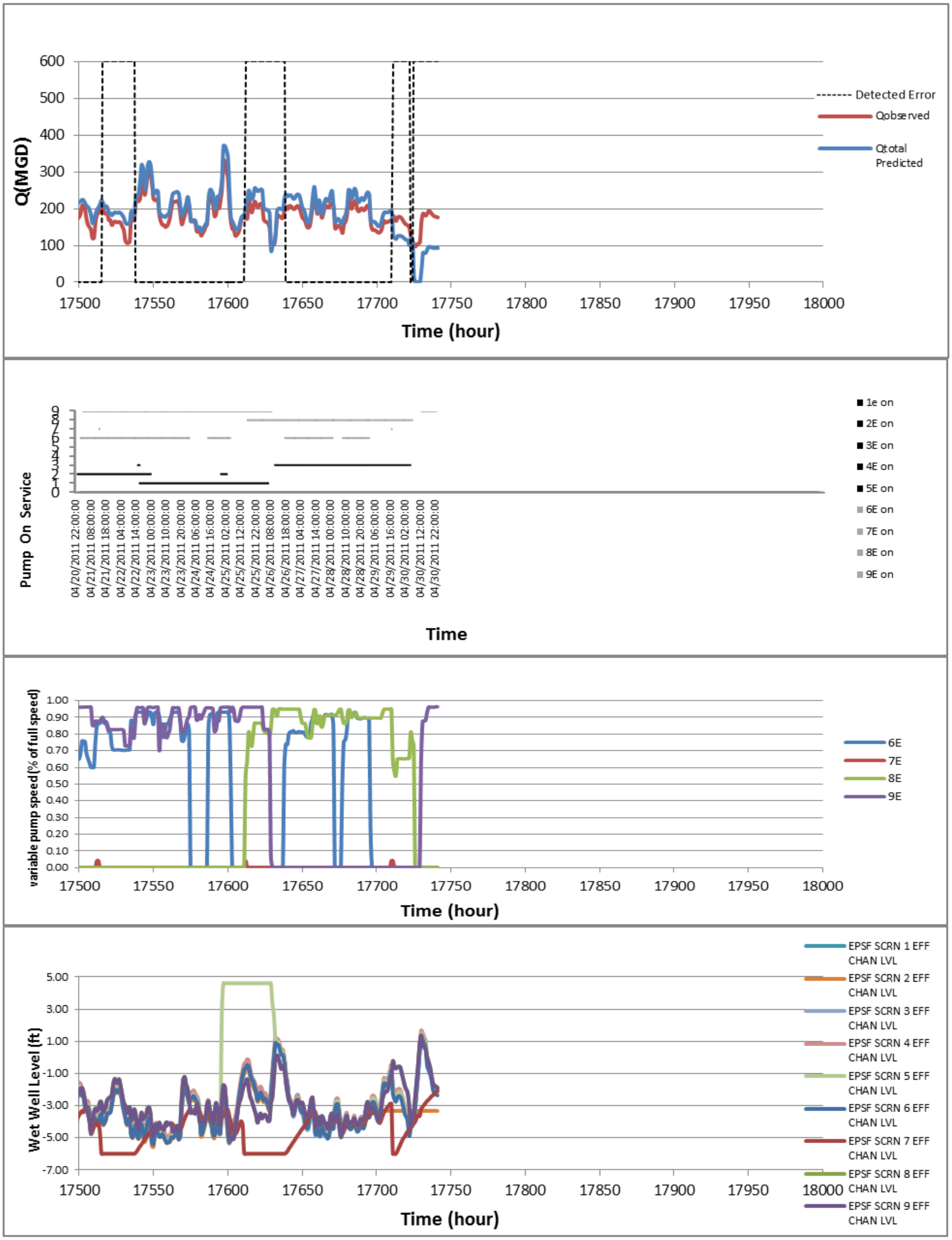
Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level (ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
600
500
400
300
200
100
0
16000
16050
16100
16150
16200
16250
16300
16350
16400
16450
16500
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed(% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
6E
7E
8E
9E
Wet Well Level(ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
Time (hour)
6E
7E
8E
9E
Wet Well Level(ft)
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL


Q(MGD)
600
500
400
300
200
100
0
17000
17050
17100
17150
17200
17250
17300
17350
17400
17450
17500
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
9
8
7
6
5
4
3
2
1
0
03/31/2011 02:00:00
03/31/2011 13:00:00
04/01/2011 00:00:00
04/01/2011 11:00:00
04/01/2011 22:00:00
04/02/2011 09:00:00
04/02/2011 20:00:00
04/03/2011 07:00:00
04/03/2011 18:00:00
04/04/2011 05:00:00
04/04/2011 16:00:00
04/05/2011 03:00:00
04/05/2011 14:00:00
04/06/2011 01:00:00
04/06/2011 12:00:00
04/06/2011 23:00:00
04/07/2011 10:00:00
04/07/2011 21:00:00
04/08/2011 08:00:00
04/08/2011 19:00:00
04/09/2011 06:00:00
04/09/2011 17:00:00
04/10/2011 04:00:00
04/10/2011 15:00:00
04/11/2011 02:00:00
04/11/2011 13:00:00
04/12/2011 00:00:00
04/12/2011 11:00:00
04/12/2011 22:00:00
04/13/2011 09:00:00
04/13/2011 20:00:00
04/14/2011 07:00:00
04/14/2011 18:00:00
04/15/2011 05:00:00
04/15/2011 16:00:00
04/16/2011 03:00:00
04/16/2011 14:00:00
04/17/2011 01:00:00
04/17/2011 12:00:00
04/17/2011 23:00:00
04/18/2011 10:00:00
04/18/2011 21:00:00
04/19/2011 08:00:00
04/19/2011 19:00:00
04/20/2011 06:00:00
04/20/2011 17:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
17000
17050
17100
17150
17200
17250
17300
17350
17400
17450
17500
Time (hour)
6E
7E
8E
9E
Wet Well Level (ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
17000
17050
17100
17150
17200
17250
17300
17350
17400
17450
17500
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL



Q(MGD)
600
500
400
300
200
100
0
17500
17550
17600
17650
17700
17750
17800
17850
17900
17950
18000
Time (hour)
Detected Error
Qobserved
Qtotal Predicted
Pump On Service
0 1 2 3 4 5 6 7 8 9
04/20/2011 22:00:00
04/21/2011 08:00:00
04/21/2011 18:00:00
04/22/2011 04:00:00
04/22/2011 14:00:00
04/23/2011 00:00:00
04/23/2011 10:00:00
04/23/2011 20:00:00
04/24/2011 06:00:00
04/24/2011 16:00:00
04/25/2011 02:00:00
04/25/2011 12:00:00
04/25/2011 22:00:00
04/26/2011 08:00:00
04/26/2011 18:00:00
04/27/2011 04:00:00
04/27/2011 14:00:00
04/28/2011 00:00:00
04/28/2011 10:00:00
04/28/2011 20:00:00
04/29/2011 06:00:00
04/29/2011 16:00:00
04/30/2011 02:00:00
04/30/2011 12:00:00
04/30/2011 22:00:00
Time
1e on
2E on
3E on
4E on
5E on
6E on
7E on
8E on
9E on
variable pump speed (% of full speed)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
17500
17550
17600
17650
17700
17750
17800
17850
17900
17950
18000
Time (hour)
6E
7E
8E
9E
Wet Well Level (ft)
5.00
3.00
1.00
-1.00
-3.00
-5.00
-7.00
17500
17550
17600
17650
17700
17750
17800
17850
17900
17950
18000
Time (hour)
EPSF SCRN 1 EFF CHAN LVL
EPSF SCRN 2 EFF CHAN LVL
EPSF SCRN 3 EFF CHAN LVL
EPSF SCRN 4 EFF CHAN LVL
EPSF SCRN 5 EFF CHAN LVL
EPSF SCRN 6 EFF CHAN LVL
EPSF SCRN 7 EFF CHAN LVL
EPSF SCRN 8 EFF CHAN LVL
EPSF SCRN 9 EFF CHAN LVL

Time period with detected error for flow prediction (4/2009-4/2011)

	Period with Data Error	Problem Description
RWWPS1	04/13/2009 19:00:00	MN show on but no power consumption
	04/15/2009 16:00:00	well level + 3.5
	04/20/2009 10:00:00	well level +3.5
	06/09/2009 6:00:00	all MN point missing
	06/09/2009 11:00:00 - 6/9/2009 21:00:00	well level missing
	01/01/2010 19:00:00 - 01/02/2010 06:00:00	well level lower than -8 ft
	01/07/2010 02:00:00 - 01/07/2010 09:00:00	well level lower than -8 ft
	03/02/2010 04:00:00	well level lower than -8 ft
	05/05/2010 09:00:00 - 05/05/2010 15:00:00	well level lower than -8 ft
	05/06/2010 15:00:00 - 05/06/2010 16:00:00	well level lower than -8 ft
	07/11/2010 22:00:00 - 07/12/2010 07:00:00	1W- no MN feedback but consume power
RWWPS2	05/23/2009 12:00:00 - 5/27/2009 3:00:00	5E no MN feedback
	06/09/2009 06:00:00 - 06/09/2009 22:00:00	missing data
	06/16/2009 11:00:00 - 6/17/2009 2:00:00	5E no MN feedback
	06/18/2009 03:00:00 - 06/18/2009 14:00:00	6E no speed feedback
	06/18/2009 15:00:00 - 06/20/2009 02:00:00	6E.5E no speed feedback
	06/20/2009 03:00:00 - 06/20/2009 10:00:00	5E no MN feedback
	06/20/2009 11:00:00 - 06/21/2009 01:00:00	6E.5E no speed feedback
	06/21/2009 02:00:00 - 6/21/2009 5:00:00	5E no MN feedback
	06/21/2009 12:00:00 - 06/29/2009 03:00:00	6E no speed feedback
	06/30/2009 16:00:00 -7/1/2009 1:00:00	5E no MN feedback
	07/16/2009 15:00:00 -07/20/2009 07:00:00	6E no speed feedback
	07/20/2009 08:00:00 -07/22/2009 07:00:00	6E.5E no speed feedback
	07/22/2009 08:00:00 - 07/26/2009 07:00:00	6E no speed feedback
	07/29/2009 14:00:00 - 07/30/2009 00:00:00	6E no speed feedback
	07/31/2009 16:00:00 - 8/1/2009 2:00:00	5E no MN feedback
	08/02/2009 05:00:00 - 08/03/2009 02:00:00	6E no speed feedback
	08/10/2009 23:00:00 - 8/12/2009 22:00:00	5E no MN feedback
	08/14/2009 16:00:00 - 8/14/2009 19:00:00	5E no MN feedback
	08/22/2009 15:00:00 - 8/23/2009 4:00:00	5E no MN feedback
	08/28/2009 12:00:00 - 08/29/2009 02:00:00	5E no MN feedback
	08/30/2009 19:00:00 - 8/30/2009 21:00:00	5E no MN feedback
	09/07/2009 15:00:00 - 9/7/2009 20:00:00	5E no MN feedback
	09/11/2009 09:00:00 -9/11/2009 16:00:00	5E no MN feedback
	09/12/2009 15:00:00 - 09/12/2009 23:00:00	6E no speed feedback
	09/13/2009 16:00:00 - 09/27/2009 02:00:00	6E.5E no speed feedback
	09/30/2009 15:00:00 - 09/30/2009 20:00:00	6E no speed feedback
	10/10/2009 18:00:00 - 10/18/2009 9:00:00	5E no MN feedback
	10/24/2009 17:00:00 - 10/24/2009 23:00:00	6E.5E no speed feedback
	10/25/2009 00:00:00 - 10/27/2009 5:00:00	5E no MN feedback
	10/27/2009 06:00:00 -10/28/2009 13:00:00	6E.5E no speed feedback
	10/28/2009 14:00:00 - 10/29/2009 05:00:00	6E no speed feedback
	10/31/2009 16:00:00 - 11/1/2009 11:00:00	5E no MN feedback
	11/01/2009 12:00:00 - 11/02/2009 20:00:00	6E.5E no speed feedback
	11/02/2009 21:00:00 - 11/14/2009 08:00:00	6E.5E no speed feedback
	11/14/2009 16:00:00 - 11/15/2009 00:00:00	5E no MN feedback

	11/18/2009 17:00:00 - 11/24/2009 00:00:00	6E no speed feedback
	11/24/2009 01:00:00 - 11/24/2009 20:00:00	6E.5E no speed feedback
	11/24/2009 21:00:00 - 11/26/2009 21:00:00	5E no MN feedback
	11/27/2009 00:00:00 - 11/27/2009 21:00:00	6E no speed feedback
	11/30/2009 12:00:00 - 12/3/2009 16:00:00	5E no MN feedback
	12/05/2009 12:00:00 - 12/07/2009 04:00:00	6E no speed feedback
	12/08/2009 19:00:00 - 12/09/2009 04:00:00	6E no speed feedback
	12/09/2009 05:00:00 - 12/09/2009 12:00:00	6E.5E no speed feedback
	12/09/2009 13:00:00 - 12/9/2009 21:00:00	5E no MN feedback
	12/10/2009 03:00:00 - 12/11/2009 02:00:00	6E no speed feedback
	12/11/2009 11:00:00 - 12/12/2009 20:00:00	5E no MN feedback
	12/13/2009 12:00:00 - 12/15/2009 01:00:00	6E.5E no speed feedback
	12/15/2009 02:00:00 - 12/17/2009 04:00:00	6E no speed feedback
	12/22/2009 13:00:00 - 12/25/2009 03:00:00	6E no speed feedback
	12/26/2009 06:00:00 - 12/27/2009 06:00:00	6E.5E no speed feedback
	12/27/2009 07:00:00 - 12/27/2009 15:00:00	5E no MN feedback
	12/27/2009 16:00:00 - 12/28/2009 20:00:00	6E.5E no speed feedback
	12/28/2009 21:00:00 - 12/30/2009 00:00:00	5E no MN feedback
	12/31/2009 08:00:00 - 12/31/2009 20:00:00	5E no MN feedback
	12/31/2009 21:00:00 -01/01/2010 03:00:00	6E.5E no speed feedback
	01/02/2010 14:00:00 -01/03/2010 03:00:00	6E no speed feedback
	01/06/2010 21:00:00 - 01/07/2010 03:00:00	6E no speed feedback
	01/10/2010 15:00:00 - 01/11/2010 02:00:00	6E no speed feedback
	01/12/2010 09:00:00 - 01/13/2010 04:00:00	6E no speed feedback
	01/14/2010 18:00:00 -01/15/2010 01:00:00	6E no speed feedback
	01/31/2010 14:00:00 - 02/01/2010 07:00:00	5E no MN feedback
	02/10/2010 13:00:00 -2/11/2010 1:00:00	5E no MN feedback
	02/11/2010 11:00:00 - 02/12/2010 03:00:00	5E no MN feedback
	02/22/2010 08:00:00 - 02/22/2010 21:00:00	5E no MN feedback
	03/27/2010 13:00:00 - 03/28/2010 01:00:00	5E no MN feedback
	03/28/2010 22:00:00 - 04/01/2010 01:00:00	5E no MN feedback
	04/06/2010 11:00:00 -04/07/2010 03:00:00	5E no MN feedback
	04/09/2010 13:00:00 -04/10/2010 01:00:00	5E no MN feedback
	04/10/2010 12:00:00 -04/12/2010 02:00:00	5E no MN feedback
	04/15/2010 10:00:00 -04/16/2010 03:00:00	5E no MN feedback
	04/20/2010 14:00:00 -04/20/2010 17:00:00	5E no MN feedback
	04/22/2010 13:00:00 -04/23/2010 12:00:00	5E no MN feedback
	04/24/2010 13:00:00 -04/25/2010 04:00:00	5E no MN feedback
	04/28/2010 10:00:00 -04/29/2010 13:00:00	5E no MN feedback
	05/02/2010 18:00:00 -05/03/2010 15:00:00	5E no MN feedback
	05/05/2010 09:00:00 -05/07/2010 17:00:00	5E no MN feedback
	05/11/2010 13:00:00 -05/14/2010 19:00:00	5E no MN feedback
	05/15/2010 16:00:00 -06/01/2010 01:00:00	5E no MN feedback
	07/13/2010 00:00:00 -7/13/2010 2:00:00	3E no MN feedback
	07/29/2010 10:00:00 -07/29/2010 23:00:00	5E no MN feedback
	08/03/2010 14:00:00 -08/04/2010 09:00:00	5E no MN feedback
	08/05/2010 17:00:00 -8/5/2010 8:00:00 PM	3E no MN feedback
	08/12/2010 08:00:00 -08/13/2010 09:00:00	5E no MN feedback

	08/18/2010 08:00:00 -8/19/2010 5:00:00	3E no MN feedback
	09/21/2010 01:00:00 -09/21/2010 05:00:00	5E no MN feedback
	10/27/2010 21:00:00 -10/28/2010 03:00:00	5E no MN feedback
	12/01/2010 10:00:00 -12/01/2010 13:00:00	5E no MN feedback
	3/1/2011 6:00:00 -3/1/2011 16:00:00	5E no MN feedback
	03/06/2011 18:00:00 -03/08/2011 03:00:00	5E no MN feedback
	03/11/2011 06:00:00 -03/13/2011 01:00:00	5E no MN feedback
	03/22/2011 14:00:00 - 03/23/2011 04:00:00	5E no MN feedback
	03/25/2011 13:00:00 - 03/27/2011 06:00:00	5E no MN feedback
	04/06/2011 10:00:00 - 04/07/2011 04:00:00	5E no MN feedback
	04/29/2011 17:00:00 -04/30/2011 23:00:00	5E no MN feedback

Appendix 7. Example of Inefficient Pumping

Due to pump priming problem or other undesirable condition, raw wastewater pumps sometimes deliver less sewage than the designed capacity. As illustrated in Fig. 45, significant difference of pump discharge is observed by two tests of pump 6W under same operation condition. Pump discharge of test of 12/16/2010 is approximately 57% of test on 1/14/2011 while the power consumption is even slightly higher (Fig. 46), which indicates significant power waste. In the future pump operation, the operator should be aware of obvious low pump discharge reading from PCS system and avoid energy waste by diagnosing the potential problem.

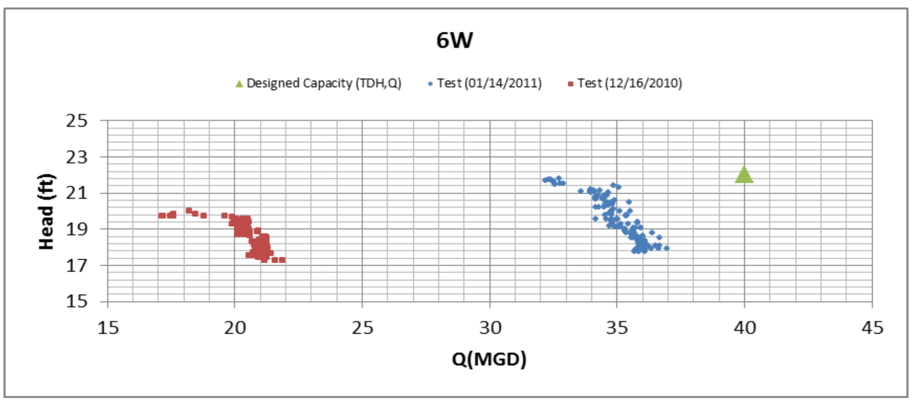


Figure 45 Comparison of pump discharge of pump 6W in two tests

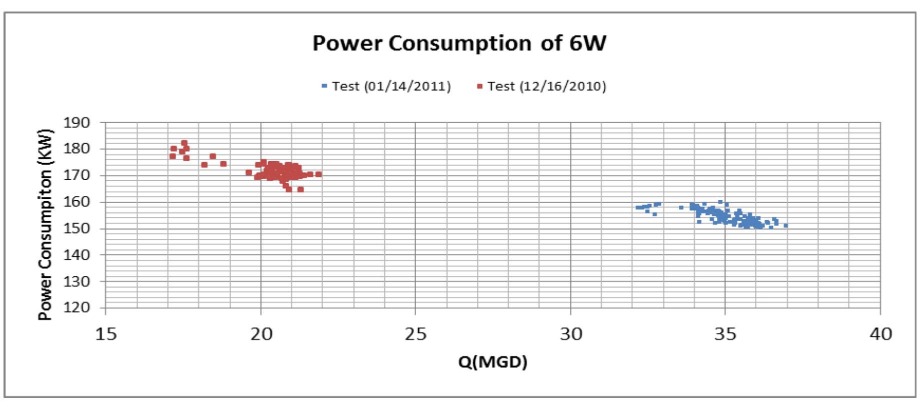


Figure 46 Comparison of power consumption of pump 6W in two tests

References

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