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Optimization of Wastewater Lift Stations for Reduction of Energy Usage and Greenhouse Gas Emissions

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OPTIMIZATION OF WASTEWATER LIFT STATIONS FOR REDUCTION OF ENERGY USAGE AND GREENHOUSE GAS EMISSIONS

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ABSTRACT AND BENEFITS

Abstract:

One of the major contributions of Greenhouse Gas (GHG) emissions from water resource recovery facilities results from the energy used by the pumping regime of the lift stations. This project demonstrated an energy-efficient control method of lift station system operation that utilizes hydraulic modeling results generated from site-specific conditions to optimize the pumping units and reduce simultaneous running cycles. The new control system, which features new generation Supervisory Control and Data Acquisition (SCADA) configurations, allows data communication directly from each lift station to the wastewater central control room. This configuration eliminates slow, conventional two-way communication via aging radio, telephone, and hardwired copper networks that require data to pass through data concentrators located miles away from the central control room. This new method of operation reduced operating pressures in the common force main, reduced the energy demands of the pumping units, and stabilized the influent flow into the wastewater treatment facility. Pilot tests conducted in this study demonstrated that the energy savings obtained through such operational optimization is approximately 15%.

A set of guidelines developed in this study detail how lift stations can be optimized using advanced hydraulic modeling and new generation SCADA systems. The findings of this study should allow wastewater facilities to:

- Reduce greenhouse gas emissions from the wastewater facility.
- Reduce force main operating pressures, total dynamic head and power consumption.
- Reduce facility operating cost by designing system capacity based on optimized system operations.
- Schedule motor and pump operating cycles to increase service life and reduce service calls.

Benefits:

- Introduces capabilities of new generation hydraulic models and SCADA systems.
- Demonstrates how hydraulic modeling can be utilized to identify energy efficient operating conditions.
- Illustrates how hydraulic modeling can be integrated to develop optimal control strategies for lift stations.
- Provides guidance on how to improve energy efficiency and reduce GHG emissions of wastewater lift station.

Keywords: Greenhouse Gas (GHG) emissions, wastewater treatment, lift station.

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BEP	Best efficiency point
BOD	Biological oxygen demand
CSO	Combined sewer overflow
DCS	Distributed control system
eGRID	Emissions and generation resource integrated database
EF	Emission factors
GDP	Gallons per day
GHG	Greenhouse gas
GIS	Geographic information system
GPM	Gallons per minute
GWP	Global warming potential
HI	Hydraulic Institute
HMI	Human machine interface
I&I	Inflow and Infiltration
IP	Internet protocol
IPCC	Intergovernmental panel on climate change
JCP	Julington Creek Plantation
KW	Kilowatt
kWh	Kilowatt hour
LCC	Life cycle cost
NYSERDA	New York State Energy Research and Development Authority
O&M	Operation and maintenance
PAC	Process automation controller
PLC	Programmable logic controller
PV	Present value
RAM	Random access memory
RTC	Real time control
RTU	Remote telemetry units
SCADA	Supervisory control and data acquisition
SOCC	Satellite operations control center
TCP	Transmission control protocol
U.S. EPA	United States Environmental Protection Agency
VFD	Variable frequency drive
VSD	Variable speed drive
WRRF	Water resource recovery facility

EXECUTIVE SUMMARY

ES.1 Background

One of the major sources of greenhouse gas (GHG) emissions from wastewater facilities is the energy used for lift station operations, especially in flat topographic regions where hundreds of pump stations are needed. Many of the collection system lift stations still operate with local or basic controls that have no hydraulic relationship with other collection system lift stations, and are operated with instrumentation and control systems that were developed many years ago. A new control system featuring new generation Supervisory Control and Data Acquisition (SCADA) configurations allows data communication directly from each lift station to the wastewater central control room. This configuration eliminates slow, conventional two-way communication via aging radio, telephone, and hardwired copper networks that require data to pass through data concentrators located miles away from the central control room. This report provides a conceptualized revised operational control method for a lift station system that utilizes hydraulic modeling results generated from specific site conditions that optimized the pumping units and reduced simultaneous running cycles. This method of operation should reduce operating pressures in the common force main, reduce the energy demands of the pumping units, and stabilize the influent flow into the water resource recovery facility (WRRF).

The guidebook developed as part of this study details how lift stations can be optimized using advanced hydraulic modeling and new generation SCADA systems. This guidebook is developed to assist wastewater facilities in addressing one or more of the following objectives:

- Reduce greenhouse gas emissions from the water resource recovery facility.
- Reduce force main operating pressures, total dynamic head, and power consumption.
- Reduce facility operating cost by designing system capacity based on optimized system operations.
- Schedule motor and pump operating cycles to increase service life and consequently to reduce service calls.

ES.2 Project Approach

A modified operational control method for the lift station system was conceptualized by utilizing the hydraulic modeling results generated from specific site conditions that were obtained by optimizing the pumping units and reducing simultaneous running cycles. This method of operation was expected to reduce operating pressures in a common force main, reduce the energy demands of the pumping units, and stabilize the influent flow entering the water resource recovery facility (WRRF). These changes should translate to lower energy costs for the aeration requirements of the biological processes.

Pilot testing was conducted at JEA in order to validate the above operating hypothesis. The first demonstration test was conducted in an area that does not have infiltration and inflow (I&I) problems. A second pilot study was performed in an area, which had documented I&I problems. The pilot sites are described in Table ES-1.

Table ES-1. Description of the Pilot Sites.

Description	Site 1	Site 2
Name	JCP	San Jose
Type	New, very tight system	Old, many issues with pipe burst
Number of lift stations	21	22
Force main length (ft)	85,192	56,130
Gravity pipe length (ft)	230,867	183,868
Pipe type	PVC	PVC, HDPE, and VCP
I&I Problem	No	Yes

Innovyze InfoWorks CS software was utilized for the hydraulic modeling. JEA rehabilitated and installed new control panels in both the JCP and San Jose lift station pilot study areas. Based on previous experience and comparative evaluation of another vendor project, a Siemens S7-mEC controller (Optimization Master) along with a SINAUT communication network was selected. The RTUs on the force mains were controlled based on flow to the WRRF and level of the lift station wet well. The results obtained from the pilot testing were then critically reviewed to develop a set of guidelines on wastewater lift station optimization.

ES.3 Results and Discussion

Hydraulic model simulation for the JCP pilot network was conducted for four operational scenarios in order to find the most energy efficient strategy. The simulation conditions and associated results are summarized in Table ES-2. Both JCP and San Jose pilot sites were optimized according to the strategy mentioned in Run #4 below.

Table ES-2. Hydraulic Model Simulated Scenarios and Corresponding Observations.

Model Run	Description	Observation
Run #1	Run only one lift station at a time with current on/off levels.	Resulted in the highest energy consumption due to pumps running on the right side of their curve.
Run #2	Run all pumps on VFDs.	Resulted in the lowest energy consumption, but was the most costly option due to capital investment in VFDs and therefore it was not selected for the pilot studies.
Run #3	Run all pumps near their BEP.	Resulted in an ability to maintain the BEP only when additional pumps were called to run and therefore was not selected for the pilot studies.
Run #4	Level out influent flows to the wastewater plant and store wastewater in the collection system. In order to simulate this concept, gravity systems were developed in the model and the respective volumes were determined. Then the lowest manhole elevation was determined in order to assess the highest acceptable wastewater elevation. An iterative pump control scheme was used to determine the optimal inflow to the wastewater plant as well as to minimize pump run out and dead head conditions.	Resulted in the lowest energy consumption while still being a cost-effective option and therefore was selected for the pilot studies.

The JCP and San Jose pilot-site lift stations were operated continuously under the optimized conditions for five and three months, respectively. The energy consumed at every lift station of both pilot sites was monitored and recorded on a real-time basis during the pilot operation. Prior to pilot testing, the baseline energy consumption (i.e., energy consumption prior to optimized operation) of each lift station was recorded as well. The daily average energy consumption during the optimized operation was compared with the daily average baseline energy consumption of a particular pilot site to determine energy improvement at that site. The total average energy consumption at the JCP pilot site during the pre-optimized and optimized period for all of the lift stations was about 669 and 556 kWh, respectively. These data suggest that the average energy efficiency improvement was approximately 17%. A comparison between the baseline energy consumption and optimized operation for the San Jose pilot plant suggested an energy savings of approximately 14%.

ES.4 Key Study Conclusions

The study findings suggest that the development of optimal collection system control strategies utilizing hydraulic modeling results may provide energy savings of approximately 15%

with corresponding GHG emission reductions. Solely on the basis of energy savings, this strategy might not always provide an advantageous payback period, but consideration of other operational benefits might prove that this approach is still economically advantageous. The additional operational benefits observed in this study are listed below:

- This technology greatly improved the methodology that JEA needed to employ to manage their installed assets. For example, this system provided detailed information on each pump's run times, current, voltage, power and other diagnostic alarm set points.
- Due to the improved understating of the system, future oversizing of pumps should be avoided.
- The smaller pumps can now operate based on a sequencing program, thereby, saving energy and increasing useful pump life.
- Since the pumps now operate more efficiently, the costs associated with their renewal and replacement should be reduced.
- Labor costs should be reduced since system troubleshooting and reprogramming can now be performed remotely.

Implementation of an optimal collection system control strategy may create some unforeseen challenges. For instance, the storage of wastewater in the collection system that occurred in this pilot study, resulted in a build-up of grease and solids in the system (pipes and lift station), which increased the cleaning frequency of the system. However, this problem may be alleviated by lowering the pump run levels or by running the pumps to a low level (system flush) daily. It should also be noted that the optimization program implemented in this study is not applicable to all systems. For instance, if the system is a combined sewer system, this method of operation is not recommended. In addition, the utility must have a good understanding of their infiltration/inflow (I/I) into the sewer system in order to implement appropriate operational modifications. The guidance provided in this report is developed to assist WRRFs in minimizing energy consumption in their lift stations by detailing the benefits of integrating optimal control strategies.

CHAPTER 1.0

INTRODUCTION

1.1 Background

Climate change has focused local and global attention on reducing the energy needed to clean and transport water through the environment. Energy consumption results in greenhouse gas emissions. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) demonstrated a clear relationship between increasing GHG concentrations and higher global temperatures (IPCC, 2007). One key component of sustainable water and wastewater operations is the mitigation of indirect GHG emissions resulting from power usage obtained from offsite energy providers. Mitigating inefficient pumping due to aging infrastructure and control systems associated with wastewater collection systems is a key way to reduce wasted energy. Hydraulic modeling can be utilized in conjunction with upgraded SCADA systems to enable optimized pump performance through intelligent setpoint adjustment that minimizes energy usage. Upgrading existing systems to operate sustainably is a relatively new, but rapidly growing concept.

Water and wastewater infrastructure are aging, with some system components exceeding 100 years in age. Wastewater lift stations designed to accommodate a 50-year planning period for major components such as wet wells, pumps, and piping networks become inefficient when operated over these long periods. Aging infrastructure, within collection and distribution systems, influences energy primarily through pumping demands. For example, poor condition of buried infrastructure (i.e., pipes) with resultant inflow and infiltration (I&I) conditions within the sewer system may increase pumping. It is not unusual for I&I to represent as much as 30% of the flow being treated at a wastewater treatment plant (NYSERDA, 2008). A reduction in electric energy use of 5-10% is possible through improvement of buried infrastructure (NYSERDA, 2008). However, the cost of repairing widespread I&I is often difficult to justify based solely on electrical savings. Therefore, alternative methods of achieving energy savings need to be evaluated and implemented.

A critical component for estimating reductions in GHG emissions via energy usage reductions in water and wastewater facilities is the utilization of appropriate energy supply conversion factors. The emission values published by the Emissions and Generation Resource Integrated Database (eGRID) can be employed to convert grid energy to emissions. Utilizing the 2007 eGRID database, the total carbon equivalent emissions per megawatt hour of energy usage would be about 1,336 lbs. CO2e (Rothschild et al., 2009). It is important to realize that small reductions in energy use achieved through minimal system operational modifications can translate into a significant reduction in both annual GHG emissions and facility operating costs, especially for large facilities (Biehl and Inman, 2010).

One of the major contributions of GHG emissions from WRRFs occurs from the pumping regime of lift stations (NYSERDA, 2008). In the majority of cases these sewage collection systems were designed and built many years ago without adequate consideration of energy conservation issues.

Computer programming and man-machine interfaces have advanced significantly in the last decade; lift stations, however, are still being operated with instrumentation and control systems that were manufactured and developed many years ago. Lack of widespread implementation of the latest advancements in technology occurs because lift stations are typically designed to last 50 years and planned to operate for 20 years. Manually operated or outdated control systems often cause significant energy wastage. Some of the common energy inefficiencies associated with the operation and control of older wastewater lift stations arise from:

- Problems associated with utilization of oversized pumps that develop because the system is designed for peak loads, while normal operating loads are much smaller. Unknowns related to pump performance, pipeline fouling and scaling, and planned future production rates that never materialize also result in design conservatism leading to pump oversizing.
- Lack of adequate two-way communication bandwidth availability in aging networks that utilize radio signal, telephone wire, and copper cables that require data to pass through multiplexers, de-multiplexers (mux/de-mux), and data concentrators located at electrical substations.
- Lack of data throughput from conventional low-speed data transfer systems and inadequate Random Access Memory (RAM) space or computer processing capacity in existing Programmable Logic Controllers (PLCs) restrict implementation of optimization strategies that require a technician to physically travel to all of the lift stations (typically hundreds) distributed across a wide geographic area individually to make a simple configuration change.

In consideration of such issues, a strong financial need has arisen to conceptualize operational revisions of older collection systems. This can be implemented through new control system configurations that enable data communication directly from the PLC at each lift station to the wastewater central control room. Such revisions would remove the bottlenecks present in the older systems that rely upon a mux/de-mux network and data concentrators at satellite operations control centers (SOCCs).

This project details a case study from a facility committed to upgrading their collection system through the use of integrated state-of-the-art technology in order to create generalized guidance for similar applications at other facilities. The integrated state-of-the-art technology consists of computer generated hydraulic models that are generated from specific site conditions that directly integrate into the programmed application control software. The integration of the technology in conjunction with the advanced communication capability of modern SCADA systems, contributed to optimizing the operations of multiple lift stations discharging into a common force main. By tying real-time flow and climate data into the hydraulic model and SCADA system application software, the SCADA system can generate commands to sequence the pumping units to maximize capacity and reduce simultaneous running cycles. This strategy is expected to reduce operating pressures in the common force main, reduce the energy demands of the pumping units and have the added benefit of a much smoother flow profile into the WRRF.

1.2 Project Objectives

This study demonstrated how integration of hydraulic model simulation with new generation SCADA programming in order to schedule and control lift station pumping from a central location results in more energy efficient operations. The findings of this study, derived from case study pilot projects, were used to develop this guidebook for pump station designers in order to optimize pumping scenarios to fulfill one or more of the following objectives:

- Reduce force main operating pressures and total dynamic head, thereby reducing electrical power consumption.
- Schedule motor and pump on/off operating cycles to increase drive component service life and reduced service calls.
- Reduce facility operating cost by designing system capacity based on optimized system operations (i.e., reduced pumping capacity, force main capacity, peaking flow treatment works capacity).
- Reduce greenhouse gas emissions from the WRRF.

1.3 Organization of the Report

This guidebook is organized into the following chapters:

- Chapter 1.0 – Introduction
- Chapter 2.0 – Background on SCADA Systems and Hydraulic Modeling Tools
- Chapter 3.0 – Case Study Results
- Chapter 4.0 – Guidance on Wastewater Lift Station Optimization

Chapters 1.0 and 2.0 discuss the background of this project. Chapter 3.0 discusses the results of the case study. Chapter 4.0 provides guidance on how to implement the findings of this study at other facilities. The strategies provided in Chapter 4.0 are intended to be used for initial feasibility studies, pilot studies, and full-scale implementation. The strategies provided in this chapter identify energy-efficient lift station operation principles that were observed through the case studies conducted. It is also important to note that the magnitude of energy savings may vary on a case by case basis. Thus, users are encouraged to conduct their own/independent feasibility studies, pilot studies, and life cycle cost benefit analysis prior to implementing any of the recommends/guidance included in Chapter 4.0.

CHAPTER 2.0

BACKGROUND ON SCADA SYSTEMS AND HYDRAULIC MODELING TOOLS

This chapter will provide background information on the new generation SCADA systems and hydraulic modeling tools. The information presented in this chapter was obtained through literature review (e.g., journal papers, white papers, vendor products, etc.).
A proper understanding of these tools is essential to implementing energy-efficient SCADA systems in wastewater lift stations.

2.1 Supervisory Control and Data Acquisition (SCADA) Systems

SCADA systems consist of a central processing capability that sends and receives data via a communication network from a number of microprocessor-based process control devices at remote locations. The remote process control devices control local equipment and gather data from local monitoring and measuring instruments. A SCADA system consists of five essential components:

- ♦ A central processing unit with data transmission and gathering capability, historical data storage and retrieval, and graphical Human Machine Interface (HMI).
- ♦ A robust communication network.
- ♦ One or more remote process automation controllers (PAC).
- ♦ Control, monitoring, and measuring devices.
- ♦ Specialized software at both the central and remote facilities.

2.1.1 Early SCADA System Functionality

Early conventional SCADA systems consisted of a proprietary "master" station running supervisory software applications that communicated with Remote Telemetry Units (RTUs) that had a limited number of discrete and analog inputs and outputs often over a tenuous, low-bandwidth radio or telephone-based communication system (Miller, 2008).

The master station processed the data and presented it in a graphical form for a plant operator to analyze and issue a limited set of control commands, as necessary. The master station would then transmit any such commands via the communication network to the appropriate RTU. The local equipment was hard-wired to provide and receive data from the remote telemetry unit.

As electronic devices with more affordable memory rapidly developed, the first generation of basic alarm/monitoring RTUs became more sophisticated and could be programmed to carry out basic control logic. The new RTUs also provided a limited capability for remote set point changes from the master station. At the same time, programmable logic controllers (PLC) that could be programmed to undertake basic control logic and eliminate the need for local control panels full of electromechanical relays could be programmed to undertake the basic control logic. The new RTUs also provided a limited capability for remote set point changes from the master station.

Early SCADA systems tended to be supplied and implemented by a single manufacturer which resulted in all knowledge of the system residing outside of the facility. Any changes to the control logic would require the manufacturer's representative to be called out, often at great expense to the facility. Not only were the early SCADA systems proprietary, but there were often a number of different manufacturer's systems spread throughout a facility due to historical changes in ownership. The cost of maintaining a number of disparate systems with limited availability of replacement parts, resulted in facilities implementing regional SCADA systems. At the time, these were a major improvement over the early systems, but again they were often proprietary systems that required control logic changes to be under taken locally rather than from the master control station.

2.1.2 New Generation SCADA System Functionality

The new generation SCADA systems provide similar functionality to the proprietary Distributed Control System (DCS) and run on commercial-grade personal computers or servers. They provide more open and interoperable standards-based HMI and supervisory applications. In newer generation SCADA implementation, the central process controller may have embedded "knowledge" that allows it to automatically process the incoming data and issue control commands without the intervention of a human operator. These replace the proprietary master station and they are often a hybrid control systems that use open architecture platforms with industrial PLC or PAC and current high-speed networking technology.

A typical PAC offers multiple programming languages, open communications, and scalability for different applications. There are many systems integrators able to integrate PLC/PAC technology into SCADA systems, often with specific industry or application knowledge.

New generation SCADA is defined by systems where HMI software interacts directly with PACs that all share the same key functionality:

Common PAC Functionality

- Central Processing Unit (CPU).
- Random Access Memory (RAM).
- Battery backed power supply.
- Physical discrete and analog input and output (I/O) modules.
- Communication interface modules, e.g., DeviceNet, Modbus, Profibus, Foundation Fieldbus.
- Multiple control logic software programming languages and the ability to modify the program remotely via the communication network.
- High-speed Ethernet TCP/IP communication interface.

Common Human Machine Interface (HMI) Functionality

- Database capable of being linked to a number of remote PACs.
- Graphical operator interface.
- Alarm and event management.
- Trend and report generation.

- Historical data archive.
- High level control logic, e.g., Visual Basic for Applications (VBA).
- Interface to higher level business software applications.
- Web-based interface.

All of the most widely used HMI applications can communicate with the most widely used PACs. The only limitation is the reduced amount of functionality in the scaled down versions of PACs. The choice of PAC in a modern SCADA system is more likely to be based on the functionality it provides rather than its capability to handle the required I/O, as was the case in conventional systems.

A number of manufacturer's now offer SCADA products that provide complete vertical integration from "Smart" field devices ("Smart" field devices are devices that contain an embedded microprocessor, firmware, and a communication port that enables them to be connected directly to a local network.) all the way up to the Enterprise Information Level, e.g., Rockwell Automation's "Integrated Architecture", Siemens "Sinaut" Telecontrol system, and Schneider Electric's "PlantStruxure" (Figure 2-1). This has led to the expectation that such products have been designed and tested to provide ease of integration. However it should be noted that a similar level of vertical integration can be achieved by utilizing similar products from a number of different manufacturer's, providing an experienced integrator with extensive knowledge of the industry is engaged.

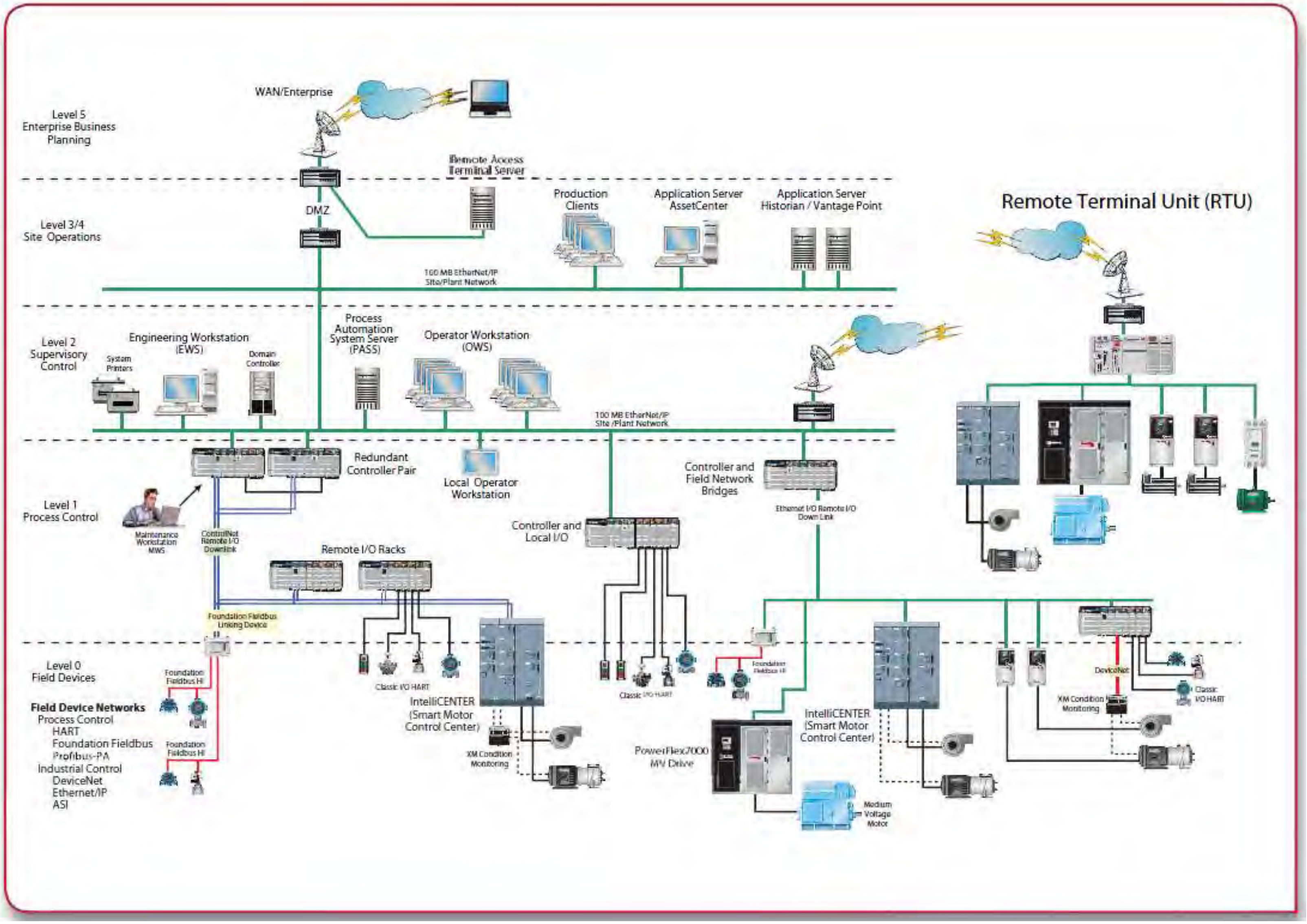
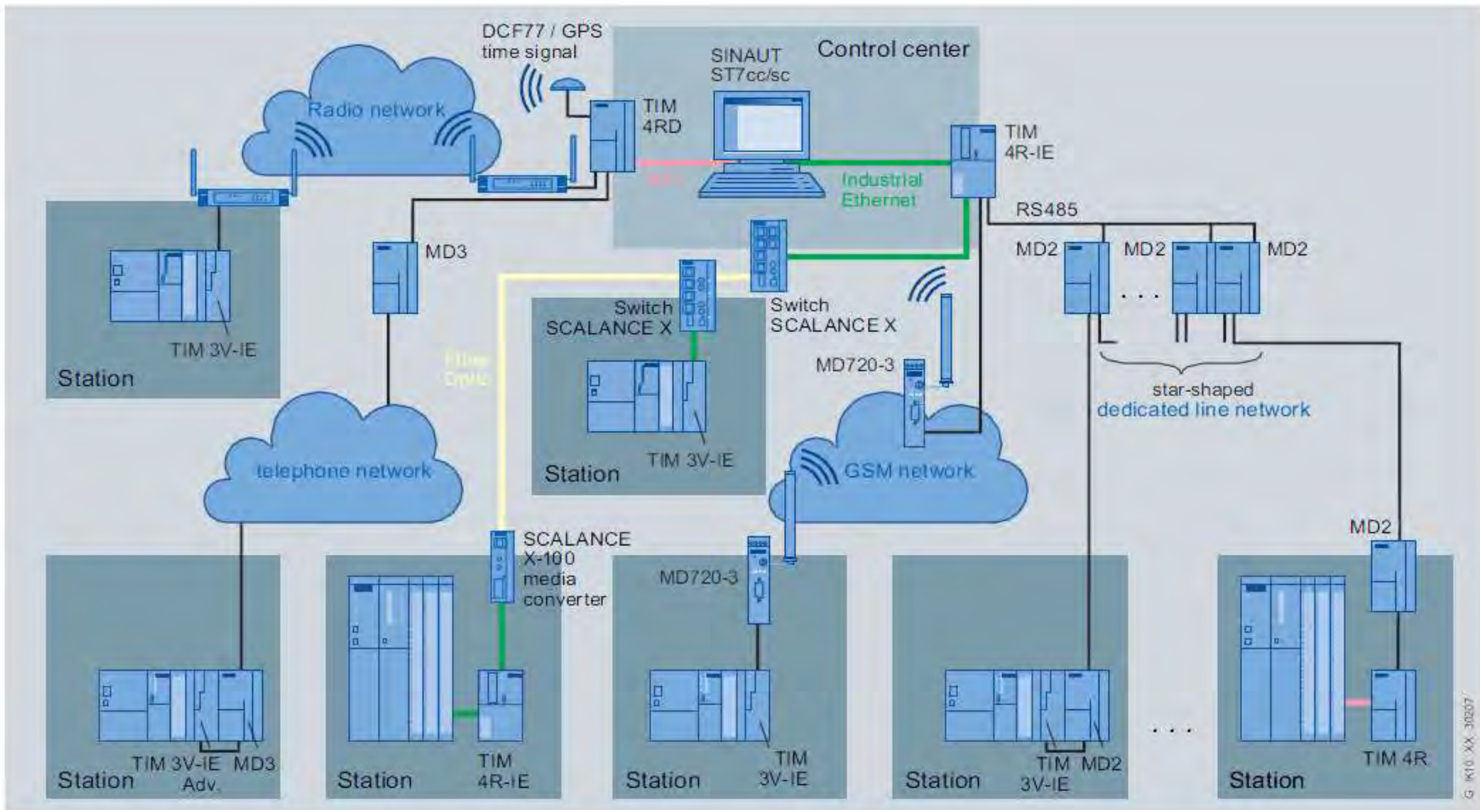
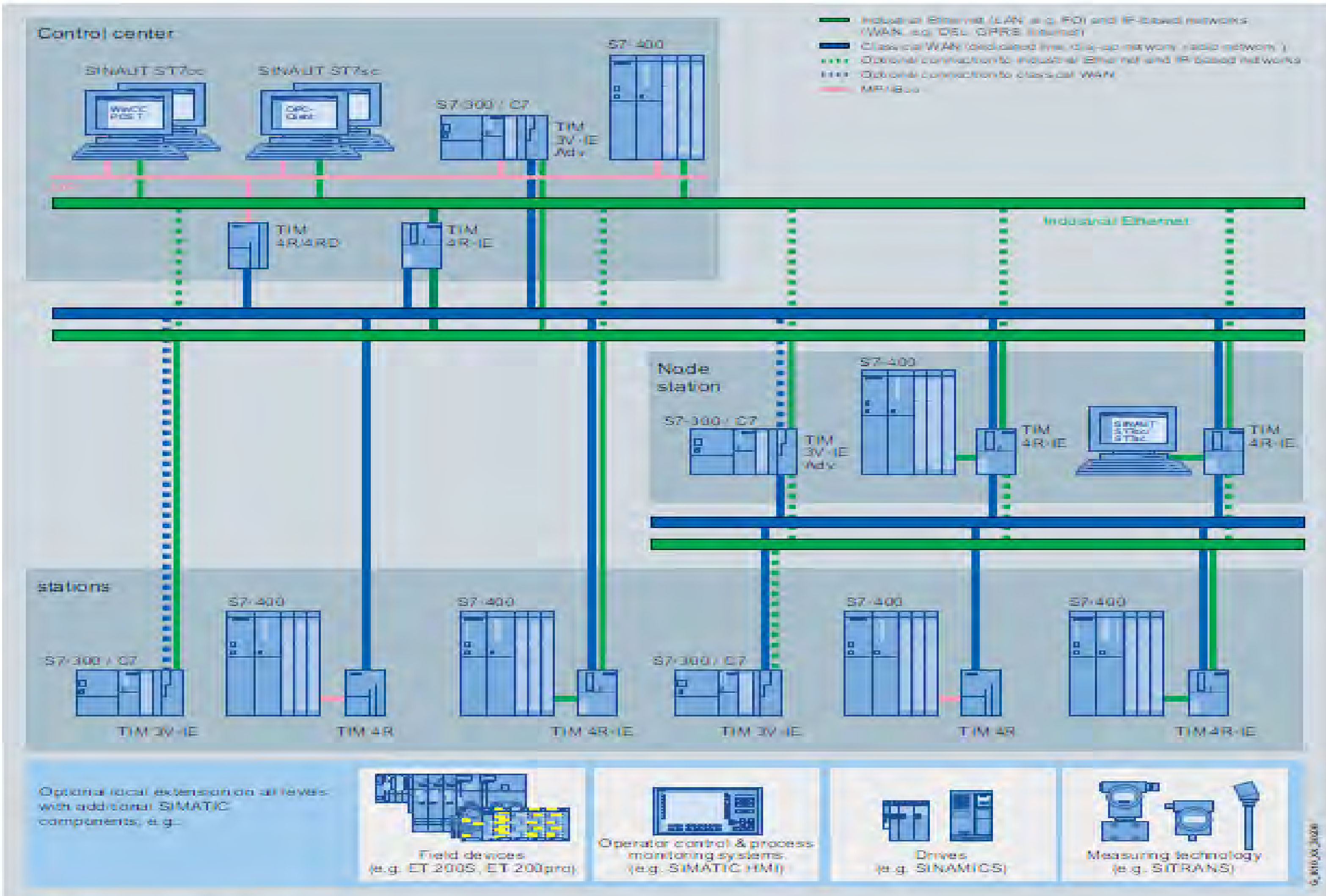


Figure 2-1. Rockwell Automation Integrated Architecture.
Courtesy of Rockwell Automation, Inc.



SINAUT ST7 - communication over different transmission networks

Figure 2-2. Layout of Siemens SINAUT System (a).
Used with permission from Siemens Corporation.



Network solutions with SINAUT ST7

Figure 2-3. Layout of Siemens SINAUT System (b).
Used with permission from Siemens Corporation.

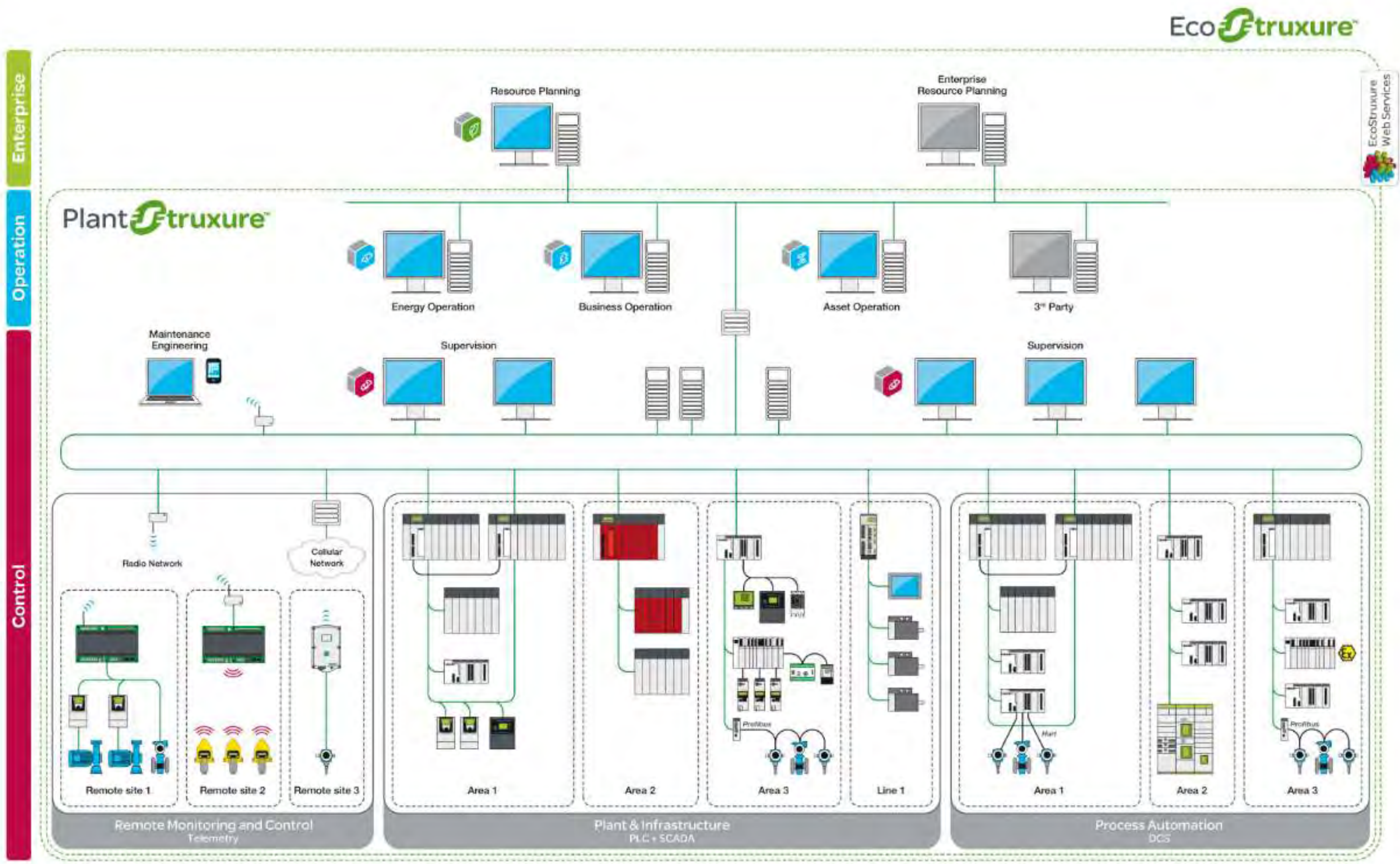


Figure 2-4. Schneider Electric Plant Structure.
Used with permission from Schneider Electric.

2.1.2.1 Real-Time Control

Each of the systems shown above enables "Real-Time Control" (RTC) to be implemented. RTC improves the operation of flow regulation devices by way of automation. According to Colas et al. (2004), RTC maximizes the use of conveyance, storage and treatment capacities available in wastewater systems in order to achieve the following:

- Reduce overflows.
- Maximize the use of conveyance system capacity.
- Allow dynamic flow diversion.
- Save energy costs.
- Reduce the risk of flooding.
- Better balance flows at the WRRF.
- Improve the management of wastewater systems subject to shut-downs, maintenance, etc.

2.1.2.2 Real-Time Control Levels

There are three different levels of RTC, which are classified according to their progressive increases in complexity, performance, and benefits (Schütze et al., 2002), as follows:

- Local Reactive Control. A system is operated on a local reactive control level if the actuators are controlled autonomously (by a PAC) in response to process measurements that are taken directly at the actuator facility. The SCADA system will allow an operator to send set points remotely to the local PAC. Local reactive control is the simplest form of automatic control, where a flow regulating device, such as a pumping station, a sluice gate or an inflatable dam is activated according to flow, pressure or water level measurements, either upstream or downstream of the site (Campisano et al., 2002).
- Extended Reactive Control. Extended real-time control is similar to local reactive control except that process measurements are also received at the local PAC from a remote facility or a number of remote facilities. The extended real-time control system can be a SCADA system that exchanges data with numerous local facilities or the local facilities can be programmed to communicate directly with other facilities that are directly affected.
- Predictive Global Optimal Control. When system objectives require greater operational efficiency from interdependent flow control facilities, and/or if the actuators have to be jointly operated, global control becomes necessary (Pleau et al., 2001; Schütze et al., 2002). A decision support system processes a large quantity of data in order to determine the "best" control strategy. The implementation of this strategy can be automatic or the regulating devices can be engaged manually by an operator. The decision support system will contain optimization algorithms that minimize an objective function (CSO volume, energy cost, actuator movements, etc.) while respecting a set of constraints (e.g., maximum water levels in sewers, maximum flow capacity, maximum retention volume, WRRF/pump station flow capacity).

It should be recognized that as the level of control increases from local control to global automatic control, all the lower levels should still be present in the system so system failures are designed to fall back progressively to a lesser degree of performance and thus of efficiency.

2.1.3 Next Generation SCADA in Wastewater Collection Systems

One of the major advantages of modern SCADA systems, when applied to wastewater collection systems, is that they enable direct two-way communication between individual lift stations as well as between each lift station and a central control facility. The ability to readily communicate throughout the collection system allows the system to be considered as a whole when developing optimal control strategies. Two key opportunities are provided by modern SCADA systems:

- The control set points at each lift station can easily be adjusted from the central control facility.
- A particular collection system can be controlled as a whole system rather than a collection of individual lift stations.

In order to determine the most effective method of controlling the whole collection system, the system should first be dynamically modeled using a hydraulic model. Modern lift station SCADA systems allow a determined quantity of flow to be transported from each lift station for a known energy. Not only does a modern SCADA system allow complete control and monitoring of each lift station, it also allows the operation of the collection system to be controlled as a whole entity. Modern communication networks not only enable each lift station to communicate with a central control but also allow communication between lift stations. Communication between lift stations allows the collection system to be managed and controlled as a whole to minimize the total energy consumption. In the past, because each station was autonomous, it was extremely difficult to establish control regimes at each lift station that would avoid having some detrimental impact on some other lift station(s). It still may be difficult to avoid some lift stations impacting others, but with system wide control it should be possible to minimize the energy cost of such conflicts.

With the control and knowledge of the collection system afforded by a SCADA, it is possible to implement the minimal energy strategies predicted from a system calibrated hydraulic model. Various "optimization" goals can be evaluated using the hydraulic model. For the collection system the goal is to minimize the energy consumption of the system without the following consequences:

- Breaching any regulatory compliance.
- Impacting customers.
- Increasing the cost of maintaining the system.
- Unduly impacting the receiving WRRF.
- Reducing the expected life of the equipment or the system.

Typical examples of unfavorable outcomes that must be avoided are:

- Producing any uncontrolled discharge outside of the system.
- Producing undesirable odor due to excessive retention.
- Producing a buildup of fat that requires additional manual action to eliminate.
- Producing irregular flow to the receiving treatment facility.
- Producing "shock" loading at the treatment facility due to periodic manual cleaning of buildup in the system.
- Operating equipment more frequently than recommended by the manufacturer.

2.2 Hydraulic Modeling and Optimization

Hydraulic modeling of the sewer collection system is one of the most critical steps in an energy optimization process. Integration of collection system modeling with GIS provides the following benefits:

- Allocation of household and industry loads to pipes and manholes using geocoding and spatial relationships.
- Prevention of overflows that cause flooding and release of untreated wastewater into the environment.
- Incorporation of runoff data, available as GIS layers into collection system modeling.

2.2.1 Model Evaluation and Selection Criteria

In order to determine whether an existing software package is suitable to meet the requirements of an application, a set of criteria must be established for model evaluation. Parameters taken into consideration for the case study model evaluation included the following five criteria:

Hydraulic Models There are two ways of traditionally classifying hydraulic models: either 1) steady-state or dynamic, or 2) uniform or non-uniform. In the steady-state assumption of the first classification, a peak flow is either defined or calculated from an average daily flow and then at each step the flow is incrementally added as the analysis proceeds downstream. Dynamic models incorporate time-dependent flow activities that represent realistic system events, such as diurnal flows, dry season events, pump station operation, and storage elements. In the second classification, uniform models compute a single uniform flow depth for each pipe segment, while non-uniform models use complex hydraulic formulations that can simulate backwater and surcharged flow conditions which can identify areas of interest in a system.

Flow Generation The model needed to be able to accommodate time-varying flow inputs from land use, population, per capita flows and/or billing information, groundwater infiltration and industrial or commercial flow inputs, and computation of rainfall-dependent infiltration and inflow (I&I). Inflow could enter from a number of sources, such as street drains and unsealed manhole covers. It was a model requirement to have hydrologic equations and various runoff factors built into the model to account for sources of I&I. The capability and flexibility of adding smaller sub-basins or catchment areas such that diurnal flow patterns were accounted for over a designated area was also required.

Model Calibration Model calibration should ensure accurate representation of real conditions of the service area. Uncertainty regarding data within a system still always exists to some extent and arises from several factors. These factors include unknown overflow locations, changes to sewer capacities resulting from sediment accumulation, collapses, and blockages, operation of system structures, such as lift stations and pumps; and I&I. Calibration is achieved by comparing peak flows, total volume, and the shape of the recorded flows with the simulated results. Using the data over three storm events, impermeable and permeable surfaces (or similar parameters, depending on the model) are adjusted until correlation between simulated and recorded flows is high enough.

Modeling System Details In order to modify the energy consumption of the wastewater treatment system via the lift station operation, it was necessary to accurately model the dimensions and operation of each sewer system appurtenance, such as incoming and outgoing pipes, weirs, throttle plates, penstocks and gates, vortex regulators, inverted siphons, and pump/lift stations. The model had to consider these complex details for accurate analysis of energy consumption.

Model Data Management and Interfacing Ease of data interfacing is a key requirement in order that the model information can be linked with the SCADA interface. Visual programs with user-friendly graphical interfaces were preferentially selected. A portion of the existing system data is stored in GIS format, so GIS integration capability is a criterion for evaluation along with ability of the model to handle large datasets.

2.2.2 Comparison of Software Packages

Five main software packages, HYDRA®, SewerGEMS, Mike Urban, InfoSWMM, and InfoWorks™ CS were evaluated. A comparison of model properties is presented in Table 2-1.

Table 2-1. Comparison of Selected Modeling Software.
Adapted from WE&T August 2005.

Element	HYDRA®	SewerGEMS	Mike Urban	InfoSWMM	InfoWorks CS
Hydraulic calculations	Manning's equation	Both implicit and explicit solution to unsteady state St. Venant eq.	Implicit solution to unsteady state St. Venant eq.	Explicit solution to unsteady-state St. Venant eq. with variable time step	Implicit solution to unsteady state St. Venant eq.
Flow input	Constant and time varying	Constant and time varying	Constant and time varying	Constant and time varying	Constant and time varying
Momentum and continuity conservation	No	Yes	Yes	Yes	Yes
Instability	No	Model prone to some minor degree of instability under certain conditions	Model prone to some minor degree of instability under certain conditions	Model prone to some minor degree of instability under certain conditions	Stable
Real system correlation	Simplified approach, simple dendritic systems	Capable of modeling complex, looped, and dendritic systems	Capable of modeling complex, looped, and dendritic systems	Capable of modeling complex, looped, and dendritic systems	Capable of modeling complex, looped, and dendritic systems
Model pumping stations	No	Yes	Yes	Yes	Yes
Advantages	Simple, good planning tool for designing new systems and screening alternatives; runs in less time than numerically based models	Sophisticated allowing simulation; sophisticated hydraulics and hydrology; Able to analyze surcharge; fairly stable	Sophisticated allowing simulation; sophisticated hydraulics and hydrology; Able to analyze surcharge and complex hydraulic structures; fairly stable	Sophisticated allowing simulation; sophisticated hydraulics and hydrology; Able to analyze surcharge and complex hydraulic structures; fairly stable	Sophisticated allowing simulation; sophisticated hydraulics and hydrology; Able to analyze surcharge and complex hydraulic structures; robustly stable
Disadvantages	Unable to model complex structures	New, not extensively used; instability	Instability	Instability	Expensive

CHAPTER 3.0

CASE STUDY RESULTS

This chapter provides the approach and results of a case study performed at two separate lift station pilot sites within JEA. Discussion of the general piloting approach, the pilot sites, and the results observed at each pilot location is provided. The information presented in this chapter was then critically reviewed to develop guidance on wastewater lift station optimization that is presented in Chapter 4.0.

3.1 General Approach

The approach used for the pilot testing is presented in Figure 3-1. Detailed descriptions of each step are presented in the following subsections. Both of the sites at JEA have a large number of manifold pumping stations that transition to gravity and then back to pressure. In order to model this properly, the software needed to be able to perform this transition without encountering problems. In addition to this transition requirement, additional critical criteria include asset management abilities and GIS interface of the modeling software. The other underlying reason for selecting Innovyze's InfoWorks CS was that the JEA basins were modeled with the InfoWorks CS software.

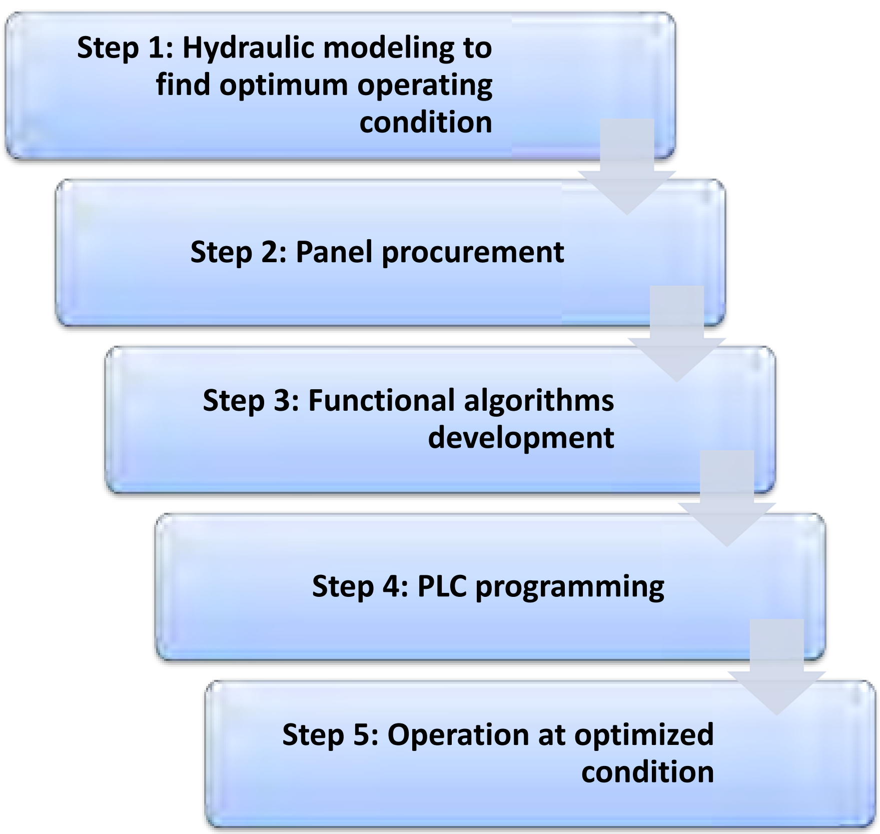


Figure 3-1. Conceptual Steps of the Pilot Tests Conducted.

3.1.1 Selection of Pilot Sites

Pilot testing with new generation SCADA systems was conducted at two separate pilot locations with the JEA water-wastewater facility: Julington Creek Plantation (JCP) and San Jose. The JCP system is a newer collection system that does not experience I&I problems. The San Jose system has experienced I&I problems in the past and is an old collection system. The basic characteristics of these two sites are listed in Table 3-1. The pump stations are duplex pump stations run based on wet well elevations, with motor capacities that vary from 1 to 60 hp. The detailed design characteristics of the JCP pilot location pump stations are provided in Table 3-2. The motor capacities of the San Jose pump stations varied from 3 to 20 hp. The detailed design characteristics of the San Jose pilot location pump stations are provided in Table 3-3.

The inflows into the model are estimated using a sub-catchment construct. Sub-catchments are polygons drawn around neighborhoods or businesses in which flow is applied. The amount of flow is based on the number of units/houses within a neighborhood multiplied by an estimated flow per unit which was assumed to be 280 gallons per day (GPD). The flow from each sub-catchment is then directed to a manhole in order to input flow into the gravity system. The inflows are peaked using a diurnal curve to match the daily flow patterns in the wastewater system. The network was derived using their as-builts and GIS systems. These networks consist of gravity pipes, manholes, force mains, force main nodes, and pumps. Pipe attributes included elevation, diameter, and roughness factor. The collection network of the JCP pilot location is shown in Figure 3-2.

Table 3-1. Description of Pilot Sites.

Description	Site 1	Site 2
Name	JCP	San Jose
Type	New, very tight system	Old, many issues with pipe burst
Number of lift stations	21	22
Force main length (ft)	85,192	56,130
Gravity pipe length (ft)	230,867	183,868
Pipe type	PVC	PVC, HDPE and VCP
I&I Problem	No	Yes

Table 3-2. Design Characteristics of the JCP Pump Stations.

Pump Stations	Total Pump Station Flow (GPD) (This includes Repumped Flows)	Average Daily Flow (GPD)	Lowest Manhole Rim Elevation (ft)	Storage Volume 1 (gal)	Highest Allowable Level (ft)	Allowable Storage Volume 2 (gal)	Nominal Allowable Level (ft)	Nominal Storage Volume 3 (gal)	Average Pump Rate (gpm)
Afton Ln - 125	85,400	85,400	18.14	47,673	16.14	39,329	14.14	29,355	300
Bishop Estates Rd - 1920	RP	65,800	11.00	44,980	9.00	33,880	7.00	24,193	300
Bishop Estates Rd - 3366	RP	70,000	9.35	52,415	7.35	42,593	5.35	31,908	400
Bishop Estates Rd - 3640	129,640	59,640	18.57	32,446	16.57	25,374	14.57	18,779	550
Blackberry Ln - 921	79,800	79,800	13.11	54,972	11.11	40,000	9.11	25,864	400
Buckbean Branch Ln E - 1140	37,800	37,800	8.92	37,200	6.92	31,196	4.92	23,854	200
Cattail Cr - 142	50,960	50,960	10.00	32,354	8.00	20,000	6.00	13,301	350
Dewberry Dr - 702	94,560	94,560	15.73	101,181	13.73	86,091	11.73	66,504	500
Dewberry Dr - 801	26,600	17,080	15.96	19,000	13.96	16,515	11.96	12,346	200
Dewberry Dr - 814	RP	9,520	14.35	16,185	12.35	14,701	10.35	13,217	150
Durbin Creek Bv - 500	210,840	103,320	16.15	72,192	14.15	61,613	12.15	46,453	500
Durbin Creek Bv - 800	43,400	43,400	17.00	41,717	15.00	36,041	13.00	26,328	350
Elmwood Dr - 220	RP	41,720	11.52	19,000	9.52	16,141	7.52	12,096	150
Flora Branch Bv - 1325	RP	77,920	14.29	34,378	12.29	31,713	10.29	21,454	200
Flora Branch Bv - 2301	RP	98,360	17.02	57,922	15.02	47,378	13.02	34,930	300
Flora Branch Bv - 677	133,000	107,520	11.26	86,437	9.26	68,682	7.26	50,783	1,300
Lotus Ln S - 900	256,280	81,480	14.50	61,115	12.50	46,248	10.50	32,098	400
Pawnee Pl - 1124	RP	76,440	14.34	32,992	12.34	22,248	10.34	12,663	350
Peppervine Av - 852	RP	25,480	11.05	27,494	9.05	24,560	7.05	20,162	350
Southern Creek Dr - 921	179,200	179,200	19.11	51,201	17.11	40,728	15.11	25,000	1,200
SR 13 N - 450	24,336	24,336	14.04	62,262	12.04	56,191	10.04	48,709	350

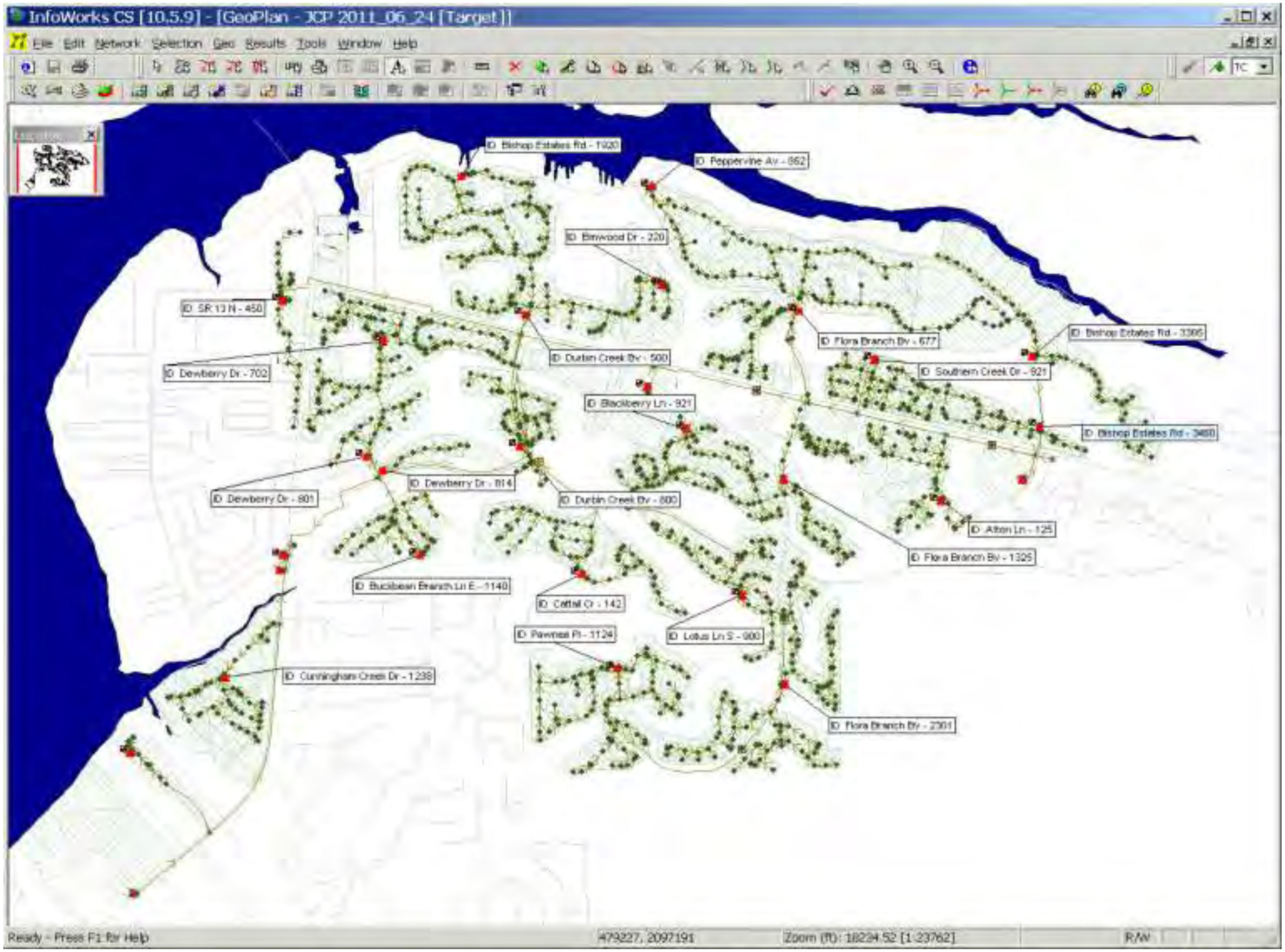


Figure 3-2. Collection Network of JCP Site.

Table 3-3. Design Characteristics of the San Jose Pump Stations.

Facility ID	Design Capacity for Each Pump (gpm)	Design TDH for Each Pump (ft)	Motor Horsepower (hp)
Baymeadows Rd - 3847	225	35	5
Dupont Av - 2859	100	70	9
Dupont Av - 3701	N/A	N/A	5
Cesperdes Av - 8156	200	27	3
Conga St - 3878	600	74	20
Hernando Rd - 7309	500	47	15
Holly Grove Av - 3655	200	25	3
Jose Cr W - 8241	200	45	5.4
La Vaca Rd - 2004	100	20	3
La Vista Cr - 4181	660	69	20
Old Kings Rd S - 8153	200	42	5
Plaza Gate Ln - 8201	300	25	5
Praver Dr E - 7742			5
San Clerc Rd - 4241	600	74	20
San Fernando Rd - 2731	461		9.4
San Fernando Pl - 7019	450	50	10
San Jose Bv - 8520	150	21	3
Segovia Av - 2337	190	67	9.4
Smullian Tl S - 2301	100	35	5
University Bv W - 3534	300	34	5
University Bv W - 3737	150	15	3
Via De La Reina - 3431	150	17	3

3.1.2 Pumping System Evaluation

A systematic study was conducted to evaluate the pumping systems of the pilot sites and their baseline energy consumption according to the following procedure:

- ♦ P**ump station characterization:** Wet well size, pump on/off cycles, pump head discharge curve, number of pumps at each station, and type of pumps (booster vs. local pumps).
- ♦ **Collection system characterization:** Pipes and fitting materials, pipe dimensions (diameter, length, and connectivity), slope, and air pocket accumulation.
- ♦ **Hydraulic modeling scenario selection and calibrations:** Modeling was conducted on scenarios similar to actual conditions. Hydraulic model calibration was conducted for flow distribution and diurnal flow patterns.
- ♦ **Energy measurement:** Energy consumption measurements of the existing system were obtained through review of electricity bills and use of onsite measurement devices.

3.1.3 Control Scheme Algorithms and Functionality

A new control scheme was generated for the pilot studies. The main parts of the control system are the Servers, Optimizer PLC, Communication Converters (Gateways), Remote Control Unit (RTU) and the Human Machine Interface (HMI). A brief description of each part of the system is described below.

- Servers – The servers are used to control and collect all data from the RTUs. All data is stored in one central database serving as the data gateway interface between the optimizer PLC and RTUs.
- Optimizer PLC – This PLC is used to control/optimize stations throughout the collection system.
- Gateways – This is basically a gateway that is used to interface between the servers and the RTUs.
- RTU – Communicates and controls logic flow from the field.
- HMI – The operators can monitor and control the system on the HMI screens.

Once the basin was selected, the HMI showed an overview of each pump station in the basin. The main optimization button was utilized to activate and/or deactivate all the stations in the basin. Individual stations could also be deactivated if needed. Each station provided data on well level, force main pressure, run status, fault, and communication and optimization status. A sample screen of the force main pressure of one of the pilot sites is presented in Figure 3-3. The lift station optimization was made up of four blocks that were the Optimizer Mode Select, the Pump Modeling, the Total Flow/Power Calculation, and the Manhole Monitoring.

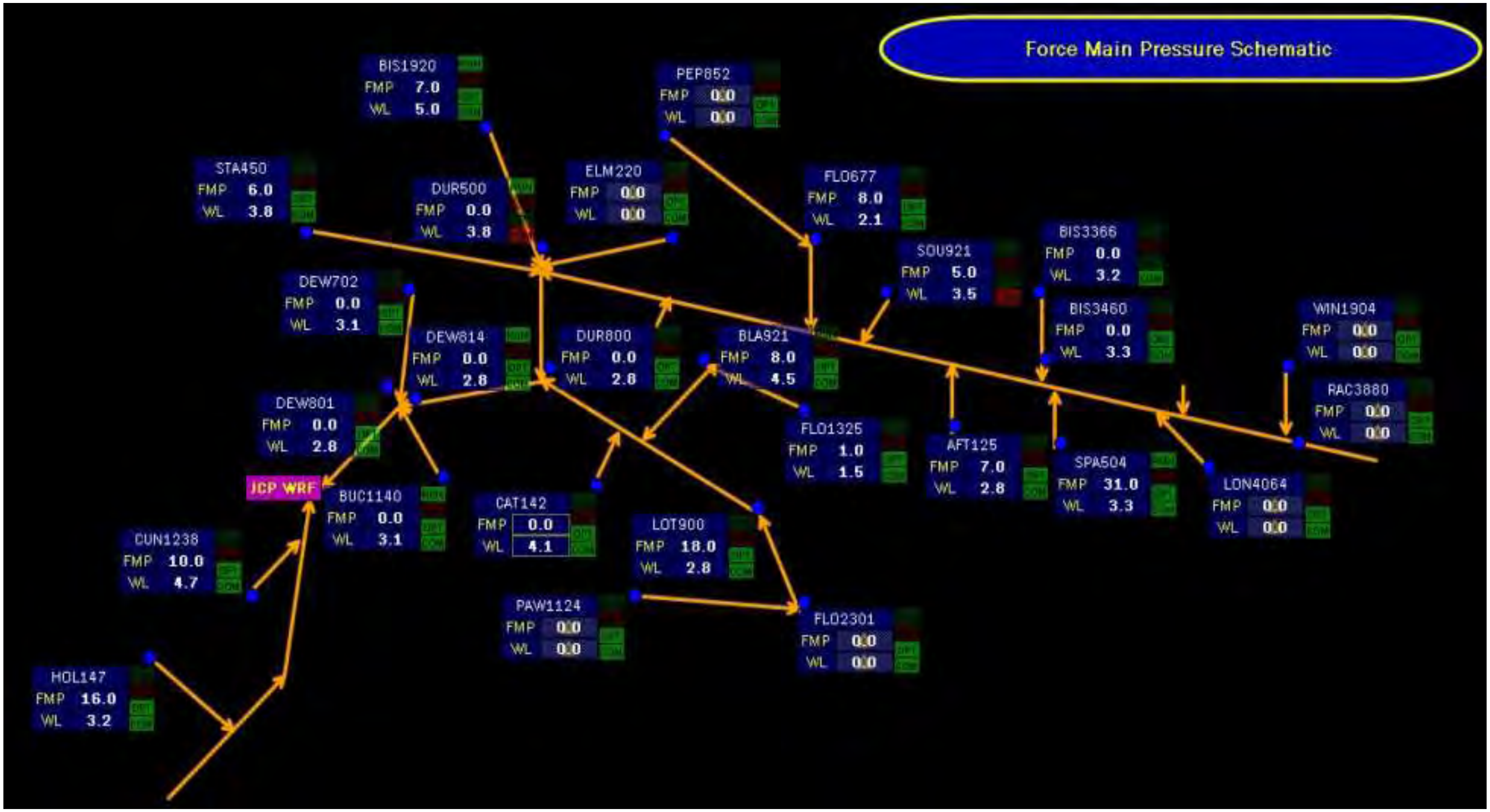


Figure 3-3. JCP Force Main Pressure Schematic Sample Screen.

3.1.4 Design and Installation Evaluation of the Pilot-Scale SCADA System

The JEA project team rehabilitated and installed new control panels in the JCP lift station. Based on the project team's experience and comparative evaluation of the other vendor projects, Siemens mEC controller (Optimization Master) along with Sinaut communication network were selected and employed at this site. A photograph of the installed lift station control panel is presented in Figure 3-4.

Figure 3-4. Photograph of Lift Station Control Panel Interior.

3.2 Results and Discussion

A summary of the results of the pilot-site lift station study follows.

3.2.1 Hydraulic Model Simulation Results

Hydraulic model simulation for the JCP pilot network was conducted for four operational scenarios in order to find the most energy-efficient strategy. The model calibration was based on SCADA (field) data in order to calibrate both the pressures and pump run times in the hydraulic model. The hydraulic model used in this study was run for an extended period simulation. The base model calibration was then used to estimate energy consumption, based on the manufacturer's pump data sheet, in Excel in order to sum up the energy consumption over a 24-hour period. This data was then compared to the NMR data from the power meter. The simulation conditions and associated results are summarized in Table 3-4.

Table 3-4. Hydraulic Model Simulated Scenarios and Corresponding Observations.

Model Run	Description	Observation
Run #1	Run only one lift station at a time with current on/off levels.	Resulted in the highest energy consumption due to pumps running on the right side of their curve.
Run #2	Run all pumps on VFDs.	Resulted in the lowest energy consumption, but most costly option due to capital investment of VFDs and so it was not implemented for the pilot studies.
Run #3	Run all pumps near their BEP.	Resulted in inability to maintain the BEP when additional pumps were called to run. So this strategy was not implemented for the pilot studies.
Run #4	Level out influent flows to the WRRF and store wastewater in the collection system. In order to simulate this concept, the gravity systems were developed in the model and the respective volumes were determined. Then the lowest manhole elevation was determined in order to determine the acceptable highest wastewater elevation. The pump control scheme was iterative to determine the optimal inflow to the WRRF as well as to minimize pump run out and dead head conditions.	Resulted in the lowest energy consumption while still being a cost-effective option and so it was implemented for the pilot studies.

Both JCP and San Jose pilot sites were optimized according to the strategy mentioned in Run #4 above. A comparison of inflows to the WRRF from pre-optimized operation (left) and optimized operation (right) for one of the pilot sites is shown in Figure 3-5.

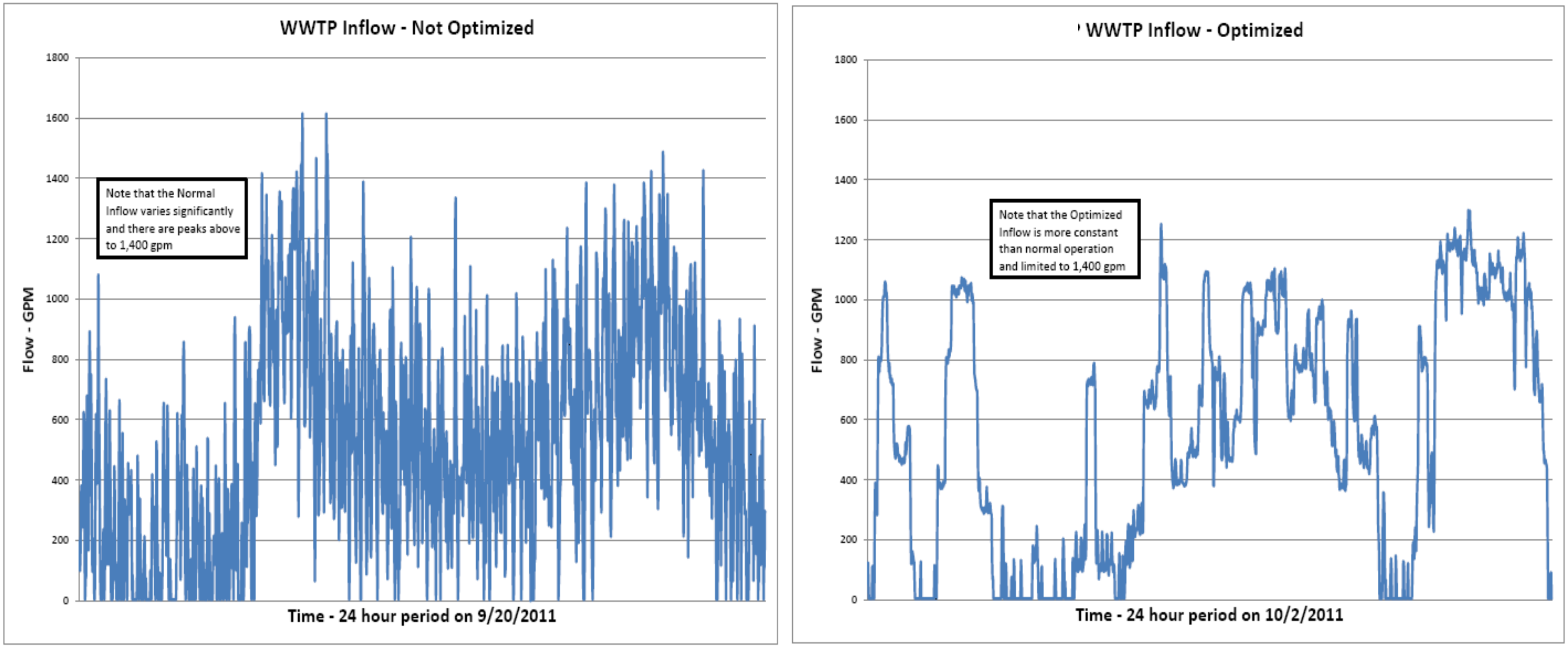


Figure 3-5. Example of Flow Optimization Results.

3.2.2 Energy Usage Comparison

The JCP and San Jose pilot-site lift stations were operated continuously accordingly to the optimized conditions for five and three months, respectively. The energy consumed at each lift station of both pilot sites was monitored and recorded on a real-time basis during the pilot operation. Prior to the pilot testing, the baseline energy consumption (i.e., energy consumption prior to optimized operation) of each lift station was recorded as well. The daily average of energy consumption observed during the optimized operation was compared with the daily average of baseline energy consumption of a particular lift station to determine energy improvement at that lift station. It should be noted that the objective of the study was to improve the energy efficiency of the entire operation of a given pilot site. That operational strategy may not improve the energy efficiency of each pump station of that pilot site. In order to understand the overall efficiency gain in a pilot site, total daily energy consumption of all the lift stations of that site observed during baseline and optimized operations was calculated and compared.

A comparison between the baseline and optimized energy consumption for the JCP pilot site lift stations is presented in Table 3-5. The total average energy consumption during the pre-optimized and optimized period of all the lift stations of that pilot site was about 669 and 556 kWh, respectively. These data suggest that the average energy efficiency improvement was approximately 17%. A comparison between the baseline energy consumption and optimized operation for the San Jose pilot plant is presented in Table 3-6. The baseline data collected in January, 2012 and the optimized operation data collected in May, 2012 suggest that about 14% energy savings was observed.

Table 3-5. Comparison between the Baseline and Optimized Energy Consumption for the JCP Pilot Site.

Pump Station Address	Baseline Energy Consumption (kWh)	Optimized Energy Consumption (kWh)	% Difference	% tot Kwh
1124 PAWNEE PL	30.86	29.87	3.23	4.61
1140 BUCKBEAN BRANCH LN E	19.08	28.18	-47.71	2.85
125 AFTON LN	36.85	25.61	30.52	5.51
1325 FLORA BRANCH BV	11.93	8.24	30.98	1.78
142 CATTAIL CIR	36.52	26.06	28.65	5.46
1920 BISHOP ESTATES RD	21.52	15.76	26.76	3.22
220 ELMWOOD DR	19.75	14.91	24.51	2.95
2301 FLORA BRANCH BV	19.57	13.61	30.43	2.92
3366 BISHOP ESTATES RD	17.00	13.36	21.37	2.54
3460 BISHOP ESTATES RD	38.76	33.13	14.53	5.79
450 STATE RD 13 N	18.46	19.71	-6.80	2.76
500 DURBIN CREEK BV	42.36	31.35	26.01	6.33
677 FLORA BRANCH BV	77.52	61.92	20.13	11.58
720 DEWBERRY DR	39.49	29.91	24.26	5.90
800 DURBIN CREEK BV	12.48	15.28	-22.47	1.86
801 DEWBERRY DR	6.17	5.24	15.18	0.92
814 DEWBERRY DR	2.68	3.32	-23.79	0.40
852 PEPPERVINE AVE	22.51	11.06	50.88	3.36
900 LOTUS LN S	83.37	71.33	14.44	12.46
921 BLACKBERRY LN	42.39	36.18	14.63	6.33
921 SOUTHERN CREEK DR	69.94	61.62	11.89	10.45
Total	669.19375	555.62	16.97	669.19

Table 3-6. Comparison between Baseline and Optimized Energy Consumption Results for the San Jose Pilot Site.

Pump Station Address	Baseline Energy Consumption (kW)	Optimized Energy Consumption (kW)	% Difference	% tot Kwh
2004 LA VACA RD APT LS01	2.69	1.94	28.08	0.35
2301 SMULLIAN TRL S APT LS01	52.45	33.27	36.58	5.94
2337 SEGOVIA AVE APT LS01	0.00	17.44	–	3.11
2731 SAN FERNANDO RD APT LS01	25.56	23.59	7.69	4.21
2859 DUPONT AVE APT LS01	42.14	37.11	11.95	6.63
3431 VIA DE LA REINA APT LS01	4.59	4.18	8.80	0.75
3534 UNIVERSITY BV W APT LS01	11.64	11.68	-0.37	2.09
3655 HOLLY GROVE AVE APT LS01	2.59	2.36	8.68	0.42
3701 DUPONT AV APT LS01	17.61	20.77	-17.95	3.71
3737 UNIVERSITY BLVD W APT LS01	3.02	1.74	42.23	0.31
3847 BAYMEADOWS RD APT LS01	3.97	6.31	-59.06	1.13
3878 CONGA ST APT LS01	54.42	41.53	23.68	7.42
4181 LAVISTA CR APT LS01	161.09	133.43	17.17	23.83
4241 SAN CLERC RD APT LS01	81.09	81.46	-0.46	14.55
7017 SAN FERNANDO PL APT LS01	54.00	34.02	36.99	6.08
7309 HERNANDO RD APT LS01	78.91	65.92	16.46	11.77
7742 PRAVER DR E APT LS01	4.18	3.88	7.13	0.69
8153 OLD KINGS RD S APT LS01	6.97	6.68	4.12	1.19
8156 CESPERDES AVE APT LS01	6.33	5.85	7.47	1.05
8201 PLAZA GATE LN APT LS01	16.84	11.15	33.80	1.99
8241 JOSE CIR W APT LS01	12.72	10.81	15.04	1.93
8520 SAN JOSE BLVD APT LS01	4.89	4.79	2.05	0.85
Total	647.68	559.92	13.55	559.92

3.2.3 Economic Evaluation of Energy Savings from Pilot Studies

Annual energy savings and associated GHG emissions reduction observed from both pilot sites are presented in Table 3-7. The implemented energy efficient operational modification resulted in a substantial cost savings and GHG emissions reduction annually for the pilot study areas that consisted of only fifty-three lift stations. If this energy efficient operation is implemented in JEA's entire wastewater system that consists of over 1,200 lift stations, the annual cost savings and GHG emissions reduction will be many folds higher than the values presented in Table 3-7. The benefits of less power consumption, less service calls, reduction in capital facility costs, and system peaking capacity to facilities operating such systems will contribute to local and regional air quality and help electric utilities manage their peak and off-peak energy generation. Wastewater facility collection systems are large energy users and the environmental, economic, health, and social benefits of less energy consumption by large facilities like JEA are widespread. The broad environmental benefits relate to the ability for utilities to better manage their energy use, systems operations, and redirect capital costs avoided to other environmental programs.

Table 3-7. Annual Energy Savings and GHG Emissions Reduction Observed.

Topic	Units	JCP Site	San Jose Site
Annual electricity savings	MWh	41.45	32.03
Annual energy cost savings @ 0.10/kWh	$	4,100	3,200
Annual GHG remissions reduction[£]	Ton CO_2 eq	24.41	18.87

[£]Emission factors were collected from eGRID data base

Solely on the basis of energy savings, this strategy might not always provide an advantageous payback period but consideration of other operational benefits might prove that this approach is still economically advantageous. The additional operational benefits observed in this study are listed below:

- This technology greatly improved the methodology that JEA needed to employ to manage their installed assets. For example, this system provided detailed information on each pump's run times, current, voltage, power, and other diagnostic alarm set points.
- Due to the improved understating of the system, future oversizing of pumps should be avoided.
- The smaller pumps can now operate based on a sequencing program, thereby, saving energy and increasing useful pump life.
- Since the pumps now operate more efficiently, the costs associated with their renewal and replacement should be reduced.
- Labor costs should be reduced since system troubleshooting and reprogramming can now be performed remotely.

Implementation of an optimal collection system control strategy may create some unforeseen challenges. For instance, the storage of wastewater in the collection system that occurred in this pilot study, resulted in a build-up of grease and solids in the system (pipes and lift station), which increased the cleaning frequency of the system. However, this problem may be alleviated by lowering the pump run levels or by running the pumps to a low level (system flush) daily. It should also be noted that the optimization program implemented in this study is not applicable to all systems. For instance, if the system is a combined sewer system, this method of operation is not recommended due to overflow concerns during rain events. In addition, the facility must have a good understanding of their infiltration/inflow (I/I) into the sewer system in order to implement appropriate operational modifications.

CHAPTER 4.0

GUIDANCE ON WASTEWATER LIFT STATION OPTIMIZATION

4.1 Benefits of Implementing Optimization of Wastewater Lift Stations

The key benefits of optimizing wastewater lift stations are reduced operating costs which are achieved by:

- Reducing energy costs.
- Reducing operating and maintenance costs.
- Extending equipment life.
- Deferring capital expenditure.

Brief description of these cost elements are presented below.

4.1.1 Reducing Energy Costs

Energy consumption is one of the major cost components for any pumping system. The initial purchase price of a pumping system component is generally a fraction of the properly estimated life cycle cost (LCC) of that component. For example, according to Barry (2007), when all costs to operate and maintain a pump are considered over the lifetime of a typical pump, about 3% of the total cost is for purchase, and 74% is for energy usage. Therefore, it is important to understand the ways to accomplish energy efficiency of wastewater lift stations. Obsolete or manually operated control systems often cause significant energy wastage.

Using commercially available technology, utilities are analyzing these costs and modifying standard procedures to avoid significant costs. The calculations used to analyze costs of a pump or lift station are seemingly simple formulas. The real challenge or complexity, however, is extracting, validating and converting data from disparate sources such as a SCADA system, energy meters, billing statements, computerized maintenance management systems, spreadsheets, and other databases.

4.1.2 Reducing Operating and Maintenance Costs

Operating and maintenance costs constitute the largest expenditure for WRRFs and consequently any optimization of wastewater lift stations must result in lower operating and maintenance costs. Optimization will reduce operating and maintenance costs by ensuring that wastewater lift stations are operated most effectively and efficiently. Effective operation will reduce wear and tear of equipment and minimize the time required for cleaning and flushing the wet well and discharge system.

4.1.3 Extending Equipment Life

When plant equipment is operated effectively, detrimental impacts are minimized and the life of the equipment is extended.

4.1.4 Deferring Capital Expenditure

By implementing more effective use of the capacity of the collection system through wastewater lift station optimization, the need for capital expenditure to expand the capacity of the system may be deferred. Similarly, extending equipment life has the potential to defer the need for capital expenditure as the equipment continues to give useful service.

4.2 Optimization Considerations for Wastewater Lift Stations

Optimizing the operation of wastewater lift stations within a collection system requires:

- ♦ Detailed knowledge of the collection system to be encapsulated in some form of hydraulic model.
- ♦ Selection of an appropriate hydraulic model.
- ♦ Initiation and maintenance of hydraulic model calibration.
- ♦ Monitoring and controlling the collection system via a modern SCADA system.
- ♦ Availability of a robust communication network that links all salient nodes in the collection system with a central control facility.

Optimization of a system should be focused upon minimizing some cost function within the constraints of appropriate boundary conditions. For instance, the case study presented in the previous chapter focused on minimizing energy consumed and the corresponding reduction in greenhouse gas emissions within the bounds of effective collection system operation. In order to accomplish effective collection system operation, the assumed boundary conditions must ensure that:

- ♦ Each pump does not operate outside of its system operating envelope.
- ♦ The minimum velocity is not allowed to fall below the recommended 2ft./sec (Note: Some authors are recommending a minimum velocity of 3ft./sec to avoid settling of solids.) unless some appropriate flushing procedure is introduced to prevent the settlement of solids and any possible increase in gas production.
- ♦ Customers are not disturbed or inconvenienced.
- ♦ The collection system does not surcharge.
- ♦ The receiving WRRF receives a minimum continuous flow or a fairly constant flow as possible.
- ♦ The load on the receiving WRRF is not increased to a point where the operational costs of the plant are increased.

4.3 Identifying Existing Asset Limitations

A significant number of lift stations are either operated in accordance with original design assumptions or according to some local perception of what is required, neither of which may be producing the best performance. As most lift stations are initially very conservatively designed and over time are subject to wear and tear, the creation of a calibrated hydraulic collection system model enables each lift station control system to be fine-tuned to the actual physical conditions. In order to take full advantage of system optimization, the actual performance of each lift station must be determined to assess the best optimization strategies with the largest energy savings.

One of the most common inefficiencies is lack of focus in determining the actual performance of a lift station, due to either a lack of competent resources or a perception that the lift station capacity is so small that it does not warrant the time and effort of this type of analysis. However, the small size may not be insignificant if there are a large number of them. What is required is a proven procedure for evaluating each station that can be then replicated at every location for a minimal cost. One other constraint utilities have had until recently has been the sole preoccupation with initial capital cost with very little attention to whole life or life cycle cost. When the whole life cost, i.e., the total cost of operating the asset over its useful life, is taken into consideration, investing time and effort into determining the actual performance usually proves to be extremely worthwhile.

One of the recognized opportunities for improving lift station efficiency is by minimizing rising main (or force main) pressure. Consider the example of a wet well lift station with two fixed speed submersible pumps designed to meet peak flow discharging into a force main that flows into a gravity sewer. Each time a pump operates it empties the wet well at the peak flow rate. Consequently the head loss in the force main is at its maximum and so is the energy consumed. Now under normal operating conditions the flow into the wet well is typically far less than the peak flow, so the energy required to pump at this lower flow at a similar flow rate to that which the flow is entering the pump station will be substantially lower than the peak flow rate. Consequently, if a smaller capacity pump was available, the typical flow rate could be pumped with a substantial saving in energy. It may well prove that the required capacity of the smaller pump is insufficient to maintain the recognized minimum self-cleansing velocity in the pipeline, in which case the lift station control system could be programmed to operate the peak flow pump a number of times a day to ensure the system is kept scoured.

To take advantage of these potential energy savings, some designers are now designing lift stations with two peak flow pumps and a much smaller “jockey” pump. The main duty pumps are run only a few times a day during peak hours while the jockey runs most of the day to pump the off-peak inflow to the lift station (Chapin, 2006). The reduced daily run time of the peak-duty pumps will also help to increase their lifetime and reduce their maintenance costs. Since the peak-duty pumps represent much greater capital and maintenance costs compared to the jockey pump, this design benefits from not only reduced operating cost, but also a significantly reduced life cycle cost for the lift station. Such lift station designs are made easier to assess using modern software analysis tools such as Engineered Software’s PIPE-FLO Professional (Lightle, 2008).

4.4 Identifying Operational Constraints on Minimizing Energy Consumption

When operating a lift station, the goal is to:

- Match the flow in, to the flow out, to minimize settlement. Too much settlement can lead to:
  - Ragging of pumps.
  - Increased BOD due to decomposition in the sewer.
  - Increased off gas and odor.
  - Buildup of coating on the inside of the pipeline.
- Maintain a self-cleansing velocity of 2ft/sec – “Some communities have adopted sewer criteria that established a minimum velocity of 2.5 to 3.0ft/sec rather than the 2ft/sec at half or full pipe flow conditions.” (WEF MOP 7) “Other communities have oversized their interceptors to provide inline storage during wet weather and incorporate O&M activities to induce cleansing velocities.”

- Reduce overall operating costs. If by reducing energy costs of pumping gives rise to additional costs due to additional efforts of pump maintenance crews and additional loading on treatment plants, then all these factors must be taken into account. Optimizing to reduce greenhouse gas is only one aspect.

4.5 Developing Optimal Control Strategies

Utilizing hydraulic models to develop optimal collection system control strategies enables:

- The control system at each lift station to be finely tuned to the capabilities of the equipment installed and the characteristics of the sewer system feeding the lift station.
- Operation of the lift stations to be scheduled to minimize pumping against unnecessarily high pressures.

Additionally:

- Any optimization of the collection system control system must not have a detrimental impact on some other aspect of the collection system operation or receiving WRRF operation. There must be no increased requirement for sewer maintenance and the load on the WRRF must be maintained as constant as possible.
- To take advantage of modern SCADA systems, a comprehensive understanding of the whole collection system must be known so that appropriate control strategies can be developed.
  - The control strategies should be developed as a set of generic rules that can be applied to each station thereby simplifying the local software programming effort and allowing for a standard interface at the central control facility.
  - Different rule sets may be required for fixed and variable speed pumping stations.

The rule sets will all focus on scheduling operation of the lift stations to maintain a constant flow (i.e., load – stations with higher BOD, for example, may be weighted above higher volume with lower BOD) for minimum energy consumption. In a simple system where more than one station is pumping into a force main, the control may simply attempt to restrict more than one station from pumping at a time. Now, in order to accomplish this it may be necessary to consider the rate of input into a lift station. It may not be possible to achieve this restriction, if, in fact, the flow into a particular pump station is so high that pumping must be maintained at all times. In this scenario, the goal may be to restrict the remaining stations such that only one additional station is pumping at any one time.

A variety of operational scenarios must be evaluated using the model in an attempt to identify the various different operating conditions. For example, it may be found that one particular station must always be given priority due to some sensitive operational implications. From this evaluation it may be possible to develop some priority rules. For example, station A has priority over station B – this may result in the need to develop alternative rules e.g., if station B is already operating when A wants to start, should B be forced to stop or are some other considerations made first, such as, how long has B been operating, how is the level in B wet well varying when compared to a normal pump down condition? The number of possible different scenarios to consider could be very large. So an assessment of the likely impact must be made to determine which scenarios have a significant impact and which can be ignored.

It may be necessary to determine the typical operating time for each station that operates only periodically to assist in the decision process. However it is essential that the acceptable operating conditions at each station are not violated. It may be possible to restrict or eliminate a significant number of operating scenarios that result in potential violations. Typical traditional stand-alone lift station constraints:

- Maximum wet well level.
- Minimum wet well level.
- Maximum time between pump starts.
- Maximum number of starts per hour for each pump.

Additional collection system wide constraints:

- "Higher" priority station already running.
- "Flow" required by treatment plant.

The control strategies will vary depending upon whether the collection system is combined or not or has significant I&I. It may be possible to break the collection system down into sub systems if parts of the network all feed into one common point. It may be found that the hydraulic model predicts different optimal control strategies for different seasons as the inflow may vary significantly seasonally.

4.6 Guidance on Hydraulic Modeling Approach

Collection system hydraulic models are typically developed with assumed lift station loads that are based upon the number and type of properties served by the sewer systems feeding the lift station, the manufacturer's original pump performance data and assumptions regarding the restriction imposed by the rising main. However this data set may result in a predicted performance that is somewhat different to that experienced in actual practice. By analyzing historical SCADA data on lift station operation it should be possible to determine the actual loads experienced and thus improve the hydraulic model such that it provides a predicted performance that more accurately matches the actual performance.

The following guidance should be considered in the application of hydraulic modeling for optimizing lift station operation.

- To calibrate the hydraulic model it is most likely that data loggers will be required to capture the current performance of the existing equipment.
- Three key parameters to be measured are lift station discharge flow, discharge pressure, wet well level. A means of determining the actual pump(s) running must also be established, so that any difference in pump performance can also be identified.
- Sophisticated multi-lift station control strategies can be extracted from the hydraulic model, as appropriate, such that the operation of each lift station can be scheduled to have minimum impact on the other stations.

Depending upon the number of lift stations in a collection system and their size, e.g., if there is currently only basic stop/start level control, it may be acceptable to establish diurnal flow based upon standard heuristic assumptions for the number of households/commercial premises served by a particular lift station. The SCADA system can be used to evaluate the appropriateness of such an approach by determining the number of hours per day that each pump operates, assuming that it is known from the pump curve what volume is pumped by each pump.

In multi-pump installations, consideration should be given to stopping and starting additional units based on the total energy consumed, rather than some level or flow condition, always assuming that all other criteria for efficient pump operation is satisfied (i.e., no pump is operated outside of its best efficiency points).

4.7 Implementing Optimal Control Strategies

At the central monitoring facility, the SCADA system interface can be set up so that all the key set points at a remote lift station can be modified by someone with the appropriate access privilege. Thus, as a greater knowledge is gained of collection system operation, or because of seasonal variations, different control points can be down loaded to the lift station without the need for an operator or specialist to physically visit the facility to change these control points locally. The interface at the central control facility allows control strategy set point changes to be transmitted to a remote facility as more information is gained from SCADA about system operation.

Ideally the SCADA system should consist of standard equipment at all lift stations so that common software can be utilized and maintained. It may be possible to integrate equipment from different manufacturers but it will undoubtedly result in an increased support requirement and possibly greater complexity. The PLC at the lift station must have the capability to receive control set point changes from the Central Monitoring Facility.

The PLC at the lift station must be programmed so that in the event of a loss of communication with the central control facility, the controller will maintain the control of the pump station based on the last set points from the Central Monitoring Facility. When the controller fails, the lift station should revert to classic level control. The central controller will monitor communication with all the remote lift stations associated with it and in the event of a detected loss of communication with any lift station, it will take appropriate action.

Depending upon the size of the lift station that has lost contact and its known impact on system operation, the central controller may be programmed to ignore the loss and continue in optimization mode or disable the whole system. If the whole system is taken out of optimization mode each lift station will revert to classic level control (or whatever method was being used prior to optimization).

When switching from individual lift station control to system-wide "optimal" control, consideration must be given to ensuring that a "bump-less" transfer takes place. For example, that the transfer causes no major disturbance to any part of the system. Consideration should be given to switching control modes once the pumps at a particular lift station stop, or in the case of a lift station where pumping never stops, and to switching modes when the minimum number of pumps are operating.

4.8 Understanding Other System Design and Process Optimization

A discussion of additional system design and processes follows.

4.8.1 Lift Station Design for Energy Efficiency

Common lift station design practice over the past 50 years has been to provide two pumps sized for the peak design flow rate, one of which is a standby pump. For pump stations with long force mains, the friction loss when operating at the design peak flow rate is excessive, resulting in high energy costs (Chapin, 2006).

It is also common practice to add approximately 10% to the estimated friction losses of a pipe work system design and then to specify the pumps based on the elevated figure, resulting in oversized pumps. This practice has developed to allow for any fall off in pump efficiency through wear, and to allow for any pipe work fouling which may occur as the system ages. However oversized pumps not only cost more to purchase but because they are not operating at their BEP they also cost more to operate.

According to the Department of Energy's Office of Industrial Technology, a number of optimization and efficiency methods can be used to achieve energy savings and help justify reliability projects as listed in Table 4-1.

Table 4-1. Potential Energy Savings.

Action	Energy Savings
Reduce speed for fixed load	5-40%
Install parallel system for highly variable loads	10-30%
Equalize flow over peak periods by utilizing system capacity	10-20%
Impeller trims	1-8%
Replace motor with more efficient model	1-3%
Replace pump with more efficient model	1-2%

EPA (2000) describes the key elements of wastewater lift stations as: a wastewater receiving well (wet-well), often equipped with a screen or grinding to remove coarse materials; pumps and piping with associated valves; motors; a power supply system; an equipment control and alarm system; and an odor control system and ventilation system. Energy efficiency optimization of lift stations requires that each of these key elements be analyzed to identify potential energy reduction and improvements to overall operating effectiveness. The recommended design practices for energy efficient lift stations design are presented in Appendix A.

4.8.2 Pumping Strategies for Energy Efficiency

Once all the points of input into a collection system are monitored and controlled via a modern SCADA system, it is possible to consider integrated control of the collection system as a whole rather than multiple standalone supply points. Considering the whole collection system allows individual supply points to be operated optimally, in that they can be scheduled to avoid competing with one another, thereby minimizing energy consumption.

Modern SCADA systems enable collection system lift station performance to be both monitored and controlled. Typical monitoring parameters are wet well level and pump discharge pressure. Ideally the researchers would also like to monitor discharge flow and station electricity power supply. Wet well level has been traditionally monitored and utilized to control pump operation. However, it can also be used to determine the volume accumulated.

Pump discharge pressure may be thought to be most useful when pumping into a pressurized system. However it also provides useful information regarding pump performance when pumping into a gravity fall system. In a gravity fall system the rising main head should remain constant. Consequently, increase in pressure would indicate some constriction in the rising main. Monitoring station discharge flow not only allows the volume the station contributes to be determined, but also allows pump performance to be measured constantly and deviations in performance to be identified.

4.8.3 Selection of Energy Efficient Devices and Control Systems

As the most expensive cost (excluding labor) in operating a lift station is energy, monitoring the electrical power supply should be a standard requirement, i.e., voltage, frequency, current, real power, apparent power, and reactive power. Managers cannot be expected to manage energy costs effectively if they are not provided with the appropriate timely data.

For example, motors should be operated as close to name plate voltage as practical, because any deviation from the name plate rating affects the motor's efficiency. In general, it is recommended that the motor line drop not exceed 5% of the line voltage (WEF MOP 32). Without a local power monitor it would be extremely difficult to know if such power fluctuations have occurred.

In the past, financial reasons have been cited for not providing all the aforementioned monitoring at smaller-sized lift stations; however this reasoning is purely based on minimizing initial capital cost and does not consider minimizing "whole life cost". The whole life cost of operating a lift station (e.g., the cost of operating it over the expected equipment life), far exceeds the initial capital cost. Consequently, the increased initial capital cost may allow a significant reduction in whole life cost if it provides data that can be used to operate the assets more efficiently and effectively.

4.8.4 Selection of Non-Process Heating, Ventilation, Air Conditioning (HVAC), and Lighting

Any non-process heating, ventilation, air conditioning (HVAC) and lighting must be designed to meet the required conditions for minimum energy consumption by selecting the most efficient and effective devices currently available.

On average, lighting accounts for 35-45% of an indoor and outdoor building's energy use (CEC 2000b). Thus, systems' retrofitting with new high-efficiency lighting technologies has the potential to significantly reduce energy use and improve efficiency. Today, many options are available and include improved and advanced fluorescent bulb technologies, long-life, and small-sized *light-emitting diodes (LEDs)* (U.S. EPA, 2013). As part of the energy savings effort, the installation of occupancy sensors and controls that will automatically turn off lights in unattended rooms is also recommended.

HVAC systems' efficiency can be improved with the purchase of energy-efficient systems, such as new heaters or air conditioners, which may provide 30-40% cooling energy abatement. Retrofitting options, such as the increase of insulating envelopes, sealing of leaks and regular cleaning of air filters can also be considered as improvement scenarios. Recently, the use of temperature control systems and automated energy management systems can optimize energy use based on weather conditions and building use patterns. They can potentially yield about 10-20% of energy savings (CEC, 2005b).

4.8.5 Continuously Monitoring Effect of Energy Minimization

When updates are made to the SCADA system software, a provision must also be made to continuously monitor the performance of the system to ensure that sufficient data is available to determine the effectiveness of the changes. As more data and experience is gathered the optimization strategy must be reviewed to ensure that the control strategy being followed is optimal. If it is found not to be optimal, then further enhancement must be planned and implemented.

4.9 Evaluting Environmental and Economic Benefits

In order to understand the benefits of energy efficiency projects, the project team is required to investigate the environmental and economic benefits. The environmental and economic matrices to be employed are described below.

4.9.1 Environmental Evaluation

GHG emissions associated with and from a lift station arise from electricity usage. They also arise from the possible use of alternative fuels such diesel fuel, natural gas, and gasoline (EPA, 2004). In order to understand GHG emission metrics, the GHG accounting process needs to be understood. The widely accepted unit for reporting GHG emissions is carbon dioxide equivalents (typically shown in metric tons, as mt $CO_{2\ equiv}$, or alternatively in pounds as lb. $CO_{2\ equiv}$), calculated by multiplying the quantity of emitted mass of each of the six GHGs by its associated global warming potential (GWP), as presented in Table 4-2. The GWP concept is intended to allow comparison of the total cumulative warming effects of different GHGs over a specified time period (GHG Protocol, 2011a, 2011b). The GWP scale compares a given GHG to the warming effects of the same mass of carbon dioxide, whose GWP is therefore equal to 1.

Table 4-2. Global Warming Potentials.
Adapted from IPCC, 2011.

Global Warming Potentials (SAR 100 yr)		
CO_2	1	lbs CO_{2e}/lb CO_2
CH_4	21	lbs CO_{2e}/lb CH_4
N_2O	310	lbs CO_{2e}/lb N_2O
HFCs	90 – 11,700	lbs CO_{2e}/lb HFC
PFCs	6,500 – 9,200	lbs CO_{2e}/lb PFC
SF_6	23,900	lbs CO_{2e}/lb SF_6

Emissions from stationary combustion are dependent upon the composition of the fuel (CO_2), as well as the combustion technology (CO_2, CH_4, and N_2O). Suitable emissions factors selection is an important aspect of developing an accurate GHG inventory. Table 4-3 summarizes the most general emission factors (EFs) established by the U.S. Environmental Protection Agency (U.S. EPA), included in Sub-part C of the EPA Mandatory GHG Reporting Rule (Federal Register, 2009). It should be noted that a water utility is typically not covered by this rule.

Table 4-3. Emission Factors for Stationary Combustion.
Adapted from Federal Register, 2009.

Gas Type	High Heat Value	GHG Specific EFs			Totalized EF
		lb CO_2/mmBtu	lb CH_4/mmBtu	lb N_2O/mmBtu	lb CO_{2e}/mmBtu
Natural gas	1,028 BTU/ scf	116.89	1.0×10^{-3}	1.0×10^{-4}	116.94
Propane	0.091 mmBtu/ gal	135.50	1.0×10^{-3}	1.0×10^{-4}	135.55

A number of standards, such as U.S. EPA Climate Leaders and the Climate Registry, provide more detailed guidance (U.S. EPA, 2005). Table 4-4 provides EFs for mobile combustion.

Table 4-4. Emission Factors for Mobile Combustion.

Gas Type	High Heat Value	GHG Specific EFs			Totalized EF
	mmBtu/ gal	lb CO_2/mmBtu	lb CH_4/mmBtu	lb N_2O/mmBtu	lb CO_2e/mmBtu
Gasoline	0.125	154.81	Controls technology dependent		> 154.81
Diesel	0.138	163.05	Controls technology dependent		> 163.05

For grid electricity purchase, U.S. standards refer to eGRID, an accepted source of emission factors. eGRID2010 is the most recent dataset, based on year 2007 emissions. EFs are reported on a “sub-region” level, which can cover several states or part of states. The U.S. EPA provides a tool that can be used to select the appropriate sub-region based on the zip code (U.S. EPA, 2007).

- Actual reduction in electrical power consumption.
- Actual reduction in GHG emissions.
- Benefits or challenges to integration with the overall energy management plan (e.g., peak and off-peak energy cycle).

4.9.2 Economic Evaluation

The wastewater utilities should conduct a lifecycle cost (LCC) analysis to understand the project annualized cost and revenue impacts. In addition to initial capital costs, LCC also considers annual costs of operations, maintenance, and other annually recurring costs. Thus a project system with a higher initial capital cost estimate may be more attractive due to savings in the operational costs. The elements of LCC expressed by the Europump and HI (2001) are presented in Equation
4-1. A brief description of all cost components are presented in Table 4-5.

$$LCC = f(C_{ic}, C_{in}, C_e, C_o, C_m, C_s, C_{env}, C_d, \text{economics factors}) \qquad \text{Equation 4-1}$$

where,

LCC = life cycle cost;
C_{ic} = initial cost of the pumping components;
C_{in} = installation and commissioning cost;
C_e = energy cost;
C_o = operating cost;
C_m = maintenance and repair cost;
C_s = down time and loss of production cost;
C_{env} = environmental cost; and
C_d = decommissioning and disposal cost.

Table 4-5. Brief Description of Different Cost Elements.
Adapted from Europump and HI, 2001.

Cost Type	Description
C_{ic}, Initial cost	- Equipment acquisition costs - Engineering, bid, purchase and other ancillary costs - Testing and inspection - Spare parts
C_{in}, Installation and commissioning cost	- Civil engineering works, settings and grouting of equipment, employee training - Connection to process piping, electrical wiring, and instrumentation and other auxiliary systems
C_e, Energy cost	- For variable output, a time-based energy usage pattern
C_o, Operating cost	- Primarily labor costs related to the operation of a pumping system - Lubricants. - Rental of ancillary equipment/services
C_m, Maintenance and repair cost	- Frequency and extent of routine maintenance and cost of consumable materials - Costs of maintaining dedicated buildings and grounds
C_s, Downtime and loss of production	- Installation of a spare pump due to unexpected failure of the existing pump despite the design or target life of pumping systems
C_{env}, Environmental Cost	- Includes disposal of environmentally hazardous materials
C_d, Disposal and Decommissioning Cost	- Includes restoration of the local environment and disposal of auxiliary services

All the costs mentioned above are incurred over a life time period (e.g., 15-20 years), so the present values (PV) of all the annual costs must be calculated. The present value can be expressed as the sum of the present cost of 'x' number of cost elements (C_n):

$$PV = \sum_{1}^{x} \frac{C_n}{((1+i)/(1+p))^n} \qquad \text{Equation 4-2}$$

Energy costs with respect to the present LCC value can be calculated through dividing present value of energy cost by the present LCC (i.e., summation of all cost elements). In order to assess energy cost during the planning and design stages of improvements to the SCADA systems, a better understanding of the aforementioned LCC elements and how they impact LCC analysis is important. It is important to note that in order to decide whether to make new investment, the facility should also account for the costs of the existing condition ("no action" or "status quo") alternative. According to the U.S. EPA Sustainability Planning Framework (U.S. EPA, 2012), the following cost items need to be included: 1) cost of inefficient operation, excess maintenance for older "under-performing" capital; 2) cost of expensive reactive emergency repairs to aging infrastructure (vs. predictive and preventive maintenance for newer infrastructure); and 3) fines and other penalties (e.g., for not meeting regulatory requirements).

4.10 Step-by-Step Procedure for Lift Station Optimization

This section summarizes a step-by-step procedure, with examples, that should be followed in optimizing wastewater lift stations.

Step 1: Identify primary optimization goal

- Minimize energy consumption.
- Reduce GHG emissions.
- Reduce overall operating cost.

Step 2: Determine constraints

- Maintain constant flow rate into treatment works within acceptable variation limits.
- Maintain minimum cleansing flow velocity.
- Identify maximum age of sewage – fat build up (commercial discharge), septicity, grit settlement (combined systems), odor, asset degradation (corrosion).
- Identify maximum and minimum pump control levels in wet wells.
- Identify maximum number of pump starts/hour.
- Identify electricity tariff.
- Maintain pressure in force mains.
- Identify any seasonal specific constraints – (combined systems – rainy seasons).

Step 3: Identify potential beneficial improvements (While considering whole life costs)

- Septicity control technology improvement.
- Pump efficiency improvement – impeller replacement.
- Motor efficiency improvement.
- Motor control method improvement – variable speed drive (inherent energy loss in drive).

Step 4: Determine extent of collection/transfer system

- Identify number of lift stations.
- Identify number and size of pumps at each lift station.
- Compare motor and pump performance curves for compatibility (other than submersible pumps).
- Identify age of lift station equipment.
- Identify method of pump control.
- Identify method of level control-reliability.
- Identify known problems at each lift station.

Step 5: Obtain data from SCADA system

- Determine existing flow rates, level changes, number of pump starts/day, and frequency of pump starts.
- Determine pressure monitoring in force mains.
- Determine system diurnal flow rates.
- Determine any significant seasonal variation.

Step 6: Identify energy consumption at each lift station

- Monitor energy consumption at each lift station.
    - Energy consumption for each pump can be determined from the manufacturers' supplied motor and pump curves or combined curve in the case of submersible pumps and the head on the pump discharge.
- Monitor electric heating.
    - Ensure operating efficiently – consider replacement with lower total cost alternative.
- Identify the total cost of operating the collection/transfer system.

Step 7: Determine inter-relationship of lift stations

- Verify size of civil infrastructure.
- Verify hydraulic model is representative of system.
- Validate hydraulic model.

Step 8: Heuristic approach to optimization

- Use a hydraulic model (e.g., InfoWorks CS) to determine a heuristic optimization solution.
- Consider the predicted diurnal flow to the treatment plant output from the validated model as a starting point.
    - Vary the operating control parameters at each lift station within the identified constraints until the model output predicts a reasonably steady flow to the treatment plant at the lowest operating cost.
- Use the operational requirements derived from the final model to write a number of rules for each lift station.

Step 9: Control action implementation

- Implement required operating conditions for each lift station in SCADA system.
- Make control decisions in the local lift station PLC, whenever possible.
- Give full consideration to ensure that all control actions take into account all possible failure modes.
- Identify any missing capability at each lift station and develop a plan to rectify.
- Ensure that all control modifications can accommodate the full range of operating conditions if a seasonal influence has been identified.

Step 10: Environmental and financial benefits analysis

- Estimate energy savings.
- Estimate annual cost savings.
- Estimate greenhouse gas emissions reduction estimates.
- Conduct life cycle cost analysis.

Step 11: Operational improvements and system maintenance

- Monitor the performance of the network and compare against the hydraulic model prediction once all lift stations have been modified to provide the required control action.
- Update the hydraulic model to accommodate any refinements identified in the physical realization.
- Further modify the local control system to reflect the refined output from the model.
- Implement continued periodic evaluation of system operation and further refine as necessary.

APPENDIX A

SYSTEM DESIGN AND OPTIMIZATION

The two most common types of lift stations are the dry-pit, or dry-well, and submersible pump lift stations. In dry-well lift stations, pumps and valves are housed in a pump room (dry pit or dry-well), that is easily accessible. The wet-well is a separate chamber attached or located adjacent to the dry-well (pump room) structure.

Submersible pump lift stations do not typically have a separate pump room; the lift station header piping, associated valves, and flow meters are located in a separate dry vault at grade for easy access.

Submersible lift stations include sealed pumps that operate submerged in the wet-well. The pumps are removed to the surface periodically for inspection and cleaning and reinstalled using guide rails and a hoist.

A key advantage of dry-well lift stations is that they allow easy access for routine visual pump inspection and maintenance. Submersible lift stations do not usually include large above ground structures and they typically require less space and are easier and less expensive to construct for wastewater flow capacities of 10,000 gallons per minute or less.

Although dry-well lift stations have been used in wastewater conveyance systems for many years, the current industry-wide trend is to install submersible pump lift stations for small and medium size loads (typically less than 6,500 gallons per minute) mainly because of lower costs, a smaller footprint, and simplified operation and maintenance.

Cost effective and efficient lift stations are designed to:

- Match pump capacity, type, and configuration with wastewater quantity and quality.
- Provide reliable and uninterruptible operation.
- Allow for easy operation and maintenance of the installed equipment; accommodate future capacity expansion.
- Avoid septic conditions and excessive release of odors in the collection system and at the lift station.
- Minimize environmental and landscape impacts on the surrounding residential and commercial developments.
- Avoid flooding of the lift station and the surrounding areas.

Wet Well Design Considerations

- Wet-well design depends on the type of lift station configuration (submersible or dry-well) and the type of pump controls (constant or variable speed).
- Wet wells are typically designed large enough to prevent rapid pump cycling but small enough to prevent a long detention time and associated odor release.

- Wet-well maximum detention time in constant speed pumps is typically 20-30 minutes. Use of variable frequency drives for pump speed control allows wet-well detention time reduction to 5-15 minutes.
- The effective volume of the wet-well may include sewer pipelines, especially when variable speed drives are used.
- Wet wells should always hold some level of sewage to minimize odor release.
- Bar screens or grinders are often installed in or upstream of the wet-well to minimize pump clogging problems.

Lift Pumps Design Considerations

The traditionally accepted design guidelines for selecting lift pumps have been:

- The number of wastewater pumps and associated capacity should be selected to provide head capacity characteristics that correspond as nearly as possible to wastewater quantity fluctuations.
- The number of pumps to be installed in a lift station depends on the station capacity, the range of flow and the regulations.
- In small stations, with maximum inflows of less than 700 gallons per minute, two pumps are customarily installed, with each unit able to meet the maximum influent rate.
- For larger lift stations, the size and number of pumps should be selected so that the range of influent flow rates can be met without starting and stopping pumps too frequently and without excessive wet-well storage. Depending on the system, the pumps are designed to run at a reduced rate. The pumps may also alternate to equalize wear and tear. Additional pumps may provide intermediate capacities better matched to typical daily flows. An alternative option is to provide flow flexibility with variable speed pumps.
- For pump stations with high head-losses, the single pump flow approach is usually the most suitable. Parallel pumping is not as effective for such stations because two pumps operating together yield only slightly higher flows than one pump.
- If the peak flow is to be achieved with multiple pumps in parallel, the lift station must be equipped with at least three pumps: two duty pumps that together provide peak flow and one standby pump for emergency backup. Parallel peak pumping is typically used in large lift stations with relatively flat system head curves. Such curves allow multiple pumps to deliver substantially more flow than a single pump. The use of multiple pumps in parallel provides more flexibility.

Several types of centrifugal pumps are used in wastewater lift stations:

- In the straight-flow centrifugal pumps, wastewater does not change direction as it passes through the pumps and into the discharge pipe. These pumps are well suited for low-flow/high head conditions.
- In angle-flow pumps, wastewater enters the impeller axially and passes through the volute casing at 90° to its original direction. This type of pump is appropriate for pumping against low or moderate heads.
- Mixed flow pumps are most viable for pumping large quantities of wastewater at low head. In these pumps, the outside diameter of the impeller is less than an ordinary centrifugal pump, increasing flow volume.

Variable Speed Pumping Considerations

- Variable speed pumping is often used to optimize pump performance and minimize power use. Variable-speed pumping can reduce the size and cost of the wet well and allows the pumps to operate at maximum efficiency under a variety of flow conditions.
- Because variable-speed pumping allows lift station discharge to match inflow, only nominal wet-well storage volume is required and the well water level is maintained at a near constant elevation.
- Variable-speed pumping may allow a given flow range to be achieved with fewer pumps than a constant-speed alternative.
- Variable-speed stations also minimize the number of pump starts and stops, reducing mechanical wear.
- Although there is significant energy saving potential for stations with large friction losses, it may not justify the additional capital costs unless the cost of power is relatively high.
- Variable speed equipment also requires more room within the lift station and may produce more noise and heat than constant speed pumps.

Ventilation and Heating Considerations

- Ventilation and heating are required if the lift station includes an area routinely entered by personnel.
- Ventilation is particularly important to prevent the collection of toxic and/or explosive gases.
- According to the Nation Fire Protection Association (NFPA) Section 820, all continuous ventilation systems should be fitted with flow detection devices connected to alarm systems to indicate ventilation system failure.
- Dry-well ventilation codes typically require six continuous air changes per hour or 30 intermittent air changes per hour.
- Wet-wells typically require 12 continuous air changes per hour or 60 intermittent air changes per hour.
- Motor control center (MCC) rooms should have a ventilation system adequate to provide six air changes per hour and should be air conditioned to between 55-90°F.
- If the control room is combined with an MCC room, the temperature should not exceed 85°F.
- All other spaces should be designed for 12 air changes per hour.
- The minimum temperature should be 55°F whenever chemicals are stored or used.

Odor Control Considerations

- Odor control is frequently required for lift stations.
- A relatively simple and widely used odor control alternative is minimizing wet-well turbulence. More effective options include collection of odors generated at the lift station and treating them in scrubbers or bio-filters or the addition of odor control chemicals to the sewer upstream of the lift station.
- Chemicals typically used for odor control include chlorine, hydrogen peroxide, metal salts (ferric chloride and ferrous sulfate) oxygen, air, and potassium permanganate. Chemicals should be closely monitored to avoid affecting downstream treatment processes, such as extended aeration.

Lift Station Performance Considerations

The overall performance of a lift station depends on the performance of the pumps. All pumps have four common performance characteristics: capacity, head, power, and overall efficiency. Capacity (flow rate) is the quantity of liquid pumped per unit of time, typically measured as gallons per minute (gpm) or million gallons per day (mgd). Head is the energy supplied to the wastewater per unit weight, typically expressed as feet of water. Power is the energy consumed by a pump per unit time, typically measured as kilowatt-hours. Overall efficiency is the ratio of useful hydraulic work performed to actual work input. Efficiency reflects the pump relative power losses and is usually measured as a percentage of applied power.

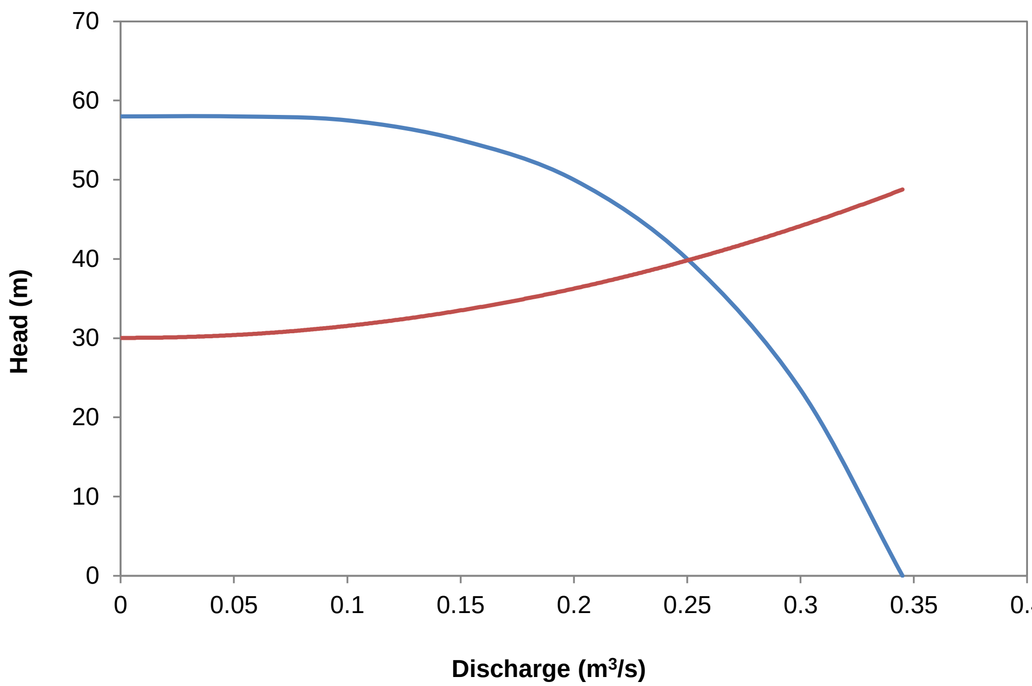


Figure A-1. Typical Pump Performance Curve.

Pump performance curves, as shown in Figure A-1, are used to define and compare the operating characteristics of a pump and to identify the best combination of performance characteristics under which a lift station pumping system will operate under typical conditions (flows and heads). Pump systems operate at 75-85% efficiency most of the time, while overall pump efficiency depends on the type of installed pumps, their control system, and the fluctuation of influent wastewater flow.

Performance optimization strategies focus on different ways to match pump operational characteristics with system flow and head requirements. They may include the following options: adjusting system flow paths installing variable speed drives; using parallel pumps installing pumps of different sizes trimming a pump impeller; or putting a two-speed motor on one or more pumps in a lift station. Optimizing system performance may yield significant electrical energy savings.

Even systems that adhere to the original design can undergo changes over time. For example, the addition of new lift stations to an existing force main will increase system head and may force some pumps to operate well to the left of BEP. Because of these potential system changes it is important that the actual operating point of the pump on its H/Q curve is determined and corrective action taken if that point is too far off BEP.

A key to improving system performance and reliability is to fully understand system requirements (peak demand, average demand, and the variability of demand) with respect to time of day and time of year. Problems with oversized pumps often develop because the system is designed for peak loads, while normal operating loads are much smaller. Excess flow energy is then forced into the system. In addition to increasing operating costs, this excess flow energy creates unnecessary wear on components such as valves, piping, and piping supports.

The operating cost and reliability of many systems can be improved by recognizing the variability of system demand and by matching flow and pressure requirements more closely to system needs.

Lift Station Pump Motors

Installing electric motors that have the highest electrical energy efficiency can improve equipment reliability, reduce downtime and repair costs, and result in lower releases of carbon dioxide to the atmosphere. Energy-efficient motors pay for themselves in a few years or sometimes even a few months, after which they will continue to accrue savings worth many times their purchase cost for as long as they remain in service (Copper Development Association, 2008).

Electric motors are designed to operate at full rated output, at rated voltage, 24 hours per day, 365 days per year; however very few are running at their full rated output in practical operation. The traditional practice of adding a 10% or perhaps 15% margin to motor sizing can often lead to the selection of a higher power rating and, in some cases an increase in the physical size, and therefore cost of the machine. The loading on the motor affects its efficiency and so in most cases the motor will be operating below its rated output. The difference in efficiency at full load and at the actual operating load may be as small as 1-3%, but if the motor has a high utilization this difference can result in a significant waste of energy.

Life time operating costs and not just first cost are what need to be evaluated when buying a new motor. It can even be worthwhile to replace fully serviceable standard efficiency (pre-EPAct) motors, including ones that were recently overhauled.

Energy losses in electric motors fall into four categories:

- Power losses
- Magnetic core losses
- Friction and windage losses
- Stray load losses

Power losses and stray load losses appear only when the motor is operating under load. They are therefore more important – in terms of energy efficiency – than magnetic core losses and friction and windage losses, which are present, even under no-load conditions (when the motor is running, of course). Power losses, also called I^2R losses, are the most important of the four categories and can account for more than one-half of a motor's total losses. Power losses appear as heat generated by resistance to current flowing in the stator windings and rotor conductor bars and end rings.

Stator losses make up about 66% of power losses, and it is here that motor manufacturers have achieved significant gains in efficiency. Since increasing the mass of stator windings lowers their electrical resistance (and therefore reduces I^2R losses), highly efficient motors typically contain about 20% more copper than standard efficiency models of equivalent size and rating.

Rotor losses, another form of power losses, are also called slip losses because they are largely, but not entirely, dependent on the degree of slip the motor displays. Slip is the difference in rpm between the rotational speed of the magnetic field and the actual rpm of the rotor and shaft at a given load.

$$S = (Ns - N) / Ns \qquad \text{Equation A-1}$$

Where:
S = Slip
N = Output speed under load and
Ns = Synchronous (no-load) speed, rpm

Rotor losses are reduced by decreasing the degree of slip. This is accomplished by increasing the mass of the rotor conductors (conductor bars and end-plates) and/or increasing their conductivity (see below), and to a lesser extent by increasing the total flux across the air gap between rotor and stator.

Conductivity is an important characteristic of the rotor. Conductor bars in large motors are normally made from high-conductivity copper. Conductor bars in small-to-intermediate size motors, up to about 200hp, depending on manufacturer, are in the form of a die-cast aluminum "squirrel cage" that gives these motors their common name. Increasing the mass of the die-cast bars requires changes in the slots in the rotor laminations, through which the bars are cast, and that changes the rotor's magnetic structure. Lowering rotor I^2R losses in what are typically aluminum alloy squirrel cage motors is therefore not a simple task.

Copper has higher electrical conductivity than aluminum, and it would be an ideal conductor bar material except for the fact that it is difficult to die cast. A process to produce die-cast copper rotors has recently been developed and, when fully commercialized, it will enable the production of motors with even higher efficiencies than the best models currently available.

Magnetic core losses arise from hysteresis effects, eddy currents and magnetic saturation, all of which take effect in the steel laminations. Magnetic losses can account for up to 20% of total losses. With proper design, use of better materials and stringent quality control, these losses can be reduced considerably. The most effective means to reduce hysteresis and saturation losses is to utilize steels containing up to 4% silicon for the laminations in place of lower-cost plain carbon steels. The better magnetic properties offered by silicon steels can reduce core losses by 10-25%. Reducing the laminations' thickness also helps: substituting 26-ga or 29-ga steel for the 24-ga steel found in standard-efficiency motors lowers core losses by between 15 and 25%. Lengthening the lamination stack, which reduces the flux density within the stack, also reduces core losses. Eddy current losses can be reduced by ensuring adequate insulation between laminations, thus minimizing the flow of current (and I^2R losses) through the stack.

Premium efficiency motors are generally made to higher manufacturing standards and tighter quality controls than the old standard-efficiency motors they are meant to replace. The new motors run cooler because they generate less I^2R heat, producing less stress on windings, consequently the motors should last longer, with reduced downtime and lower repair costs over the life of the motor.

The Board of Directors of the Hydraulic Institute (HI), the largest association of pump manufacturers in North America has endorsed the Premium Efficiency Electric Motor program, known and marketed as "NEMA Premium.™". This designation is given to electric motors that meet an industry-defined standard for premium efficiency. NEMA Premium™ was established by the National Electrical Manufacturers Association (NEMA), whose members make over 80% of the electric motors sold in the U.S.

Electric motors can draw large currents when accelerating up to speed following start up. As a result in order to prevent overheating, motors are limited in the number of times per hour they may be started. The limit varies according to motor type but in general it decreases with increasing motor size and for small- and medium-sized motors the typical range is between four and eight starts per hour. Soft starters are electronic devices that limit the current supplied to the motor at start-up and achieve a smoother acceleration profile.

Benefits of soft starters:

- Increased number of restarts per hour: Limiting the starting current supplied to the motor reduces the internal heating and enables more starts per hour.
- Reduced electrical demands on the supply: Limiting the starting current drawn by the motor reduces the overload capacity required of the supply; this is of increasing importance with very large motors.
- Increased equipment life: Controlling the rate at which motors and equipment accelerate and decelerate at start up and stop can result in reduced stresses, and equipment life can be prolonged as a result.
- Energy optimization: Some soft starters offer an 'energy optimizing' function. Through a dynamic process of monitoring the load on the motor, the supply voltage to the motor is reduced resulting in an energy saving in the region of 1-4% during the period of light loading.

Lift Station Control Methods

Following is a description of control method options.

Stop/Start Control Stop/Start control is extremely simple, when the water in the wet well rises to some maximum level a pump starts and pumps the well down to some predetermined lower level. The pump then shuts down and waits for the water to rise again. Usually a wet well is sized for some minimum pump run time in order to keep the number of pump starts within the guidelines of the manufacturer. Some wet wells may be oversized and employ multiple smaller pumps in an attempt to remove the entire inflow at the same rate as its entry thereby allowing a pump (or pumps) to run continuously at the BEP.

Historically, one of the challenges of lift station design, especially high flow ones, has been keeping the number of pump starts to an acceptable level (Evans, 2007). In some cases this can be attained by installing multiple pumps and alternating them with each successive pump down cycle. Another method is to stage multiple smaller pumps and attempt balance outflow with inflow. Although both of these methods work well in many installations, there are times when the necessary wet well volume becomes unrealistic or the number of staged pumps required cannot be accommodated. An alternative approach would be to vary the pumping rate by changing pump speed. This would allow outflow to be closely matched to inflow and thus reduce, significantly, the number of pump starts.

From an energy efficiency standpoint, basic level control provides opportunity for improvement as the pumps always operate at their full capacity. Since most pumps may be oversized, an increase in energy consumption is required to overcome the higher frictional losses when pumping at a higher flow rate.

Level Control Level control is a development of the basic stop/start control, when the water in the wet well rises to some predetermined level a pump starts and its speed is regulated in such a way as to attempt to maintain a specific level in the wet well. If the flow into the wet well reduces and the level starts to fall, the pump speed is reduced until the minimum speed to maintain the self-cleansing velocity in the rising main is reached, or some predetermined lower level is reached, at which time the pump shuts down and waits for the water to rise again.

The goal of level control is to attempt to match the outflow with the inflow, but this may not always be possible when wishing to maintain the minimum self-cleansing velocity in the rising main. Consequently, the control regime is modified in some instances to allow lower velocities for most of the day, but to then to "flush" the wet well and the rising main once a day by allowing the wet well to rise and forcing the pump(s) to run at a higher speed.

On systems with a high static head, where the pump must overcome the resistance to lifting the wastewater before any flow starts, the benefits of using VSDs will be reduced. This is because higher speeds need to be maintained in order to overcome the additional resistance due to the high static head.

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