DEPARTMENT OF ENVIRONMENTAL PROTECTION
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University of Central Florida
College of Engineering & Computer Science

Stormwater Management Academy
"Managed Stormwater is Good Water"

STORMWATER INTELLIGENT CONTROLLER SYSTEM

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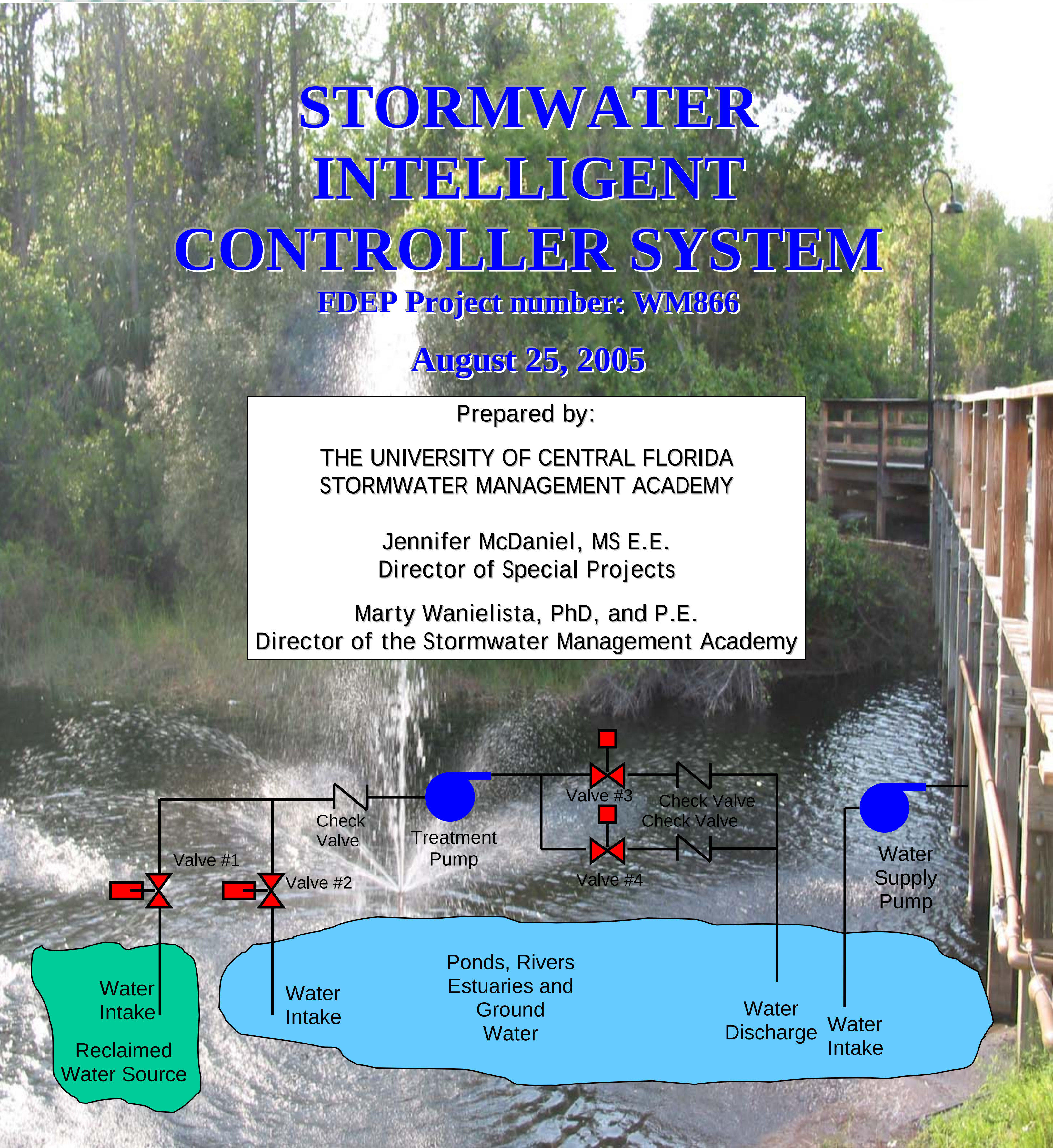

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EXECUTIVE SUMMARY

Water restrictions, pollution control, volume balances, and the emergence of stormwater utilities have lead to the development of an automated intelligent system ("I-Water") for water use and control. With the use of this system, water stored in stormwater ponds or in the surficial aquifer is not discharged to surface waters because it is used to meet water demands, such as, lawn irrigation, environmental protection, agriculture, drinking and industrial uses.

The drop in groundwater levels and the increasing use of reclaimed water illustrates a need for alternative water supplies. Ground water depletion is occurring which is adding to the destruction of wetland areas and reduced spring flows. The supply of available reclaimed water continues to rise but so does the demand for irrigation water. The automation, water quality monitoring, and database that an Intelligent Water ("I-Water") controller provides can make stormwater reuse systems more feasible thus helping to reduce stormwater pollutant loadings, maintain watershed volume balances, and provide an alternative irrigation water supply. Using advanced technology is an efficient and effective way to manage this valuable freshwater resource. Telecommunications has made it possible to monitor water flow, valves, collect data, read instrumentation such as water quality sensors and control things remotely and in 'real time'.

Presented in this report is an automated controller integrating multiple sensors, used to collect data that can be monitored daily (if desired) via home or office computers and that can remotely control the flow of water using home or office computers. The automated controller can be operated at the installation site or via telecommunications from a remote site. The "I-Water" will make stormwater volume control using reuse systems more feasible by decreasing O&M costs. Remote on-line monitoring to provide more reliable data at a greater frequency of collection is possible with the "I-Water" or similar systems. The I-Water" will provide access to pollutant monitoring to assure that the stormwater is safe to use for non-potable purposes. The "I-Water" is available for deployment.

KEYWORDS

Stormwater, intelligent water (I-Water), supervisory control and data acquisition (SCADA), telemetry, water quality monitoring, water reuse, volume balances, irrigation, reclaim water, remote access, remote monitoring, sensors, program logic controller (PLC), micro-controller (MCU), data logger, BMP, Temperature, pH, Dissolved Oxygen, Turbidity, Total Dissolved Solids, Conductivity, Salinity, Rain Sensor, Wind Sensor

INTRODUCTION

The objective of this research project is to design a “Stormwater Intelligent Controller System” using SCADA (Supervisory Control And Data Acquisition) technology to provide a reliable, automated, intelligent (expert) system for the efficient and effective reuse of water from multiple sources. With the use of the system, water stored in ponds and in the ground is not discharged to surface waters because it is used to meet the water demands, such as, lawn irrigation, environmental protection, and agriculture, drinking and industrial uses. Presented is an automated controller, integrating multiple sensors, used to collect data and remotely control the flow of water while decreasing O&M costs. The Intelligent Control System for Water Distribution is known as "I-Water" and allows an operator to view data, control sampling frequency, set parameters, and monitor data “real time” on home or office computers. This system can use multiple sensors to monitor and control the water treatment and distribution of irrigation quality water based on demand. To illustrate the operation, data collected by a system is presented.

Envisioned as a current trend for stormwater management is an increased use of stormwater ponds and surficial aquifers to provide irrigation water. To be cost effective and environmentally safe, technology is needed to reduce the subsequent labor associated with operation and maintenance (O & M), documentation and monitoring of water quality in the source waters. Thus to decrease the O & M cost, an autonomous controller will be used to collect data and remotely control the flow and monitoring of irrigation water from different sources.

HISTORICAL PERSPECTIVE

In the 1950’s the State’s population began to grow rapidly. The Florida Water Resources Act of 1972 (Chapter 373, Florida Statutes) established a form of administrative water law that brought the State’s surface and ground waters under regulatory control of the five regional water management districts (WMDs). Statewide authority for water quality management was vested in the Department of Environmental Regulation which has since merged with the Department of Natural Resources by an act of the 1993 Florida Legislature to become the Department of Environmental Protection (DEP). The State’s WMDs, under the supervisory authority of DEP, have developed State Water Use Plans and water use permitting systems to assure the State’s ground water aquifers are not depleted. The Air and Water Pollution Control Act as amended (Chapter 403, Florida Statutes), provides the statutory basis for regulation of most aspects of water quality in Florida. These provide the DEP powers and duties to accomplish the statutory goal of protecting and improving water quality throughout the State. Thus, monitoring the quality and quantity of stormwater used as a nonpotable supply is an important activity of the DEP.

The importance of stormwater quality on natural receiving water bodies has also come under the scrutiny of both federal and state legislation. The passage of the Clean Water Act (CWA) amendments in 1987 has prompted monitoring and controlling of stormwater quality through provisions requiring stormwater discharge permits for certain stormwater discharges. Previously, the State of Florida implemented a Statewide stormwater treatment regulation that is a model for the CWA. This technology based regulatory program is implemented cooperatively by the DEP and the WMDs. More recently, Section 303(d) of the Federal Clean Water Act and the adoption of the Florida Watershed Restoration Act (Section 403.067, F.S.) have led to the listing of impaired waters, the development of total maximum daily loads to restore the beneficial uses of these impaired waters, and the implementation of Basin Management Action Plans to achieve the needed loaded reductions. A major focus of this program is reducing pollutant loads from existing drainage systems and minimizing stormwater loadings from future growth.

Additional policies and regulations from the State have been used to support nonpoint source, stormwater, and watershed management as listed in Table 1.

Table 1: NPS Programs*

1979 State Stormwater Rule 1984 Wetlands Protection Act 1985 State Comprehensive Plan LGCP&LDR Act 1986 Stormwater utility 1987 SWIM Act 1989 Preservation 2000 Dairy Rule for Okeechobee, Stormwater bill 1991 SJRWMD Rule 40C-44 (Ag/Cost Share)	1992 SFWMD Rule 40E-63 (EAA) 1994 Nitrate Bill/Fee Stormwater PLRGs in SWIM Plans 1996 MSRB PL566/EQIP 1997 SRF opened to urban stormwater 1998 Ag BMP Cost Share ($200,000), 1999 Forever Florida Act Florida Watershed Restoration Act 2000 Lake Okeechobee Protection Program Revised State Revolving Fund 2005 FWRA amendments

* (Livingston, 2004)

Studies such as the "Wekiva Area Water Budget" (Wanielista, 2005) indicate a need to have a water budget or volume control. To achieve a water budget, stormwater must be monitored for water quality and quantity. In a springshed like the Wekiva, there is a decline in aquifer recharge and the decline related to a lack of water reaching the aquifer thus a need for a water budget or volume control. Stormwater that is otherwise discharged directly to surface rivers can be stored and reused to help "balance the budget". The Wekiva area of central Florida consists of a combination of more than 20 springs which are tributary to the Wekiva River. The Wekiva River drains into the Saint Johns River, a major River system in Florida. The Saint Johns River is the fifth largest river in Florida that flows northward. By reusing the stormwater on the watershed, spring flow can be maintained and low flow criteria in the rivers can be achieved. Also, a decrease in spring flow could alter the economic base and the environmental values of the region.

A water budget for an area will show how much spring flow is related to surface water and development conditions. The ground water pressure level and flow is affected by precipitation, well extraction, and directly connected impervious areas of development. By definition, a springshed is the surface area which contributes water to a spring. The springshed area must have a water budget or direct discharge volume control. The Wekiva study area springshed is estimated at 450 square miles or about twice the size of the watershed. Approximately 60 to 65 percent of the estimated Springshed area of 450 square miles is estimated to have a recharge rate equal to or exceeding 8 in/year. In other parts of the State, such as Tallahassee and Ocala, spring flow has been shown to be directly connected to surface ponds and recharge areas. After development, this recharge rate can be maintained by reusing stormwater. The Wekiva springshed contributes at least 7 inches of Springflow during the average year. For Rock Springs, approximately 70 percent of the discharge comes from a springshed within an 8 mile radius of the Spring. In addition, 95 percent of the discharge comes from a springshed within a 14 mile radius of the Spring. The Volume of water percolating into the aquifer from rainfall affects the pressure head and storage volume which in turn affects Springflow. Stormwater can be used to maintain a water budget and surface water direct discharge for a region.

Urbanization of areas of the State with no replacement of infiltration or control of direct discharge can cause either a decrease in spring flows, or an increase in river flows, or both. A post equal pre yearly volume water budget is an approach for maintaining predevelopment recharge rates and discharge volumes. Stormwater management using regional irrigation ponds for watersheds or springsheds and operation by local utilities is an option to maintain the balance.

Stormwater management within these areas can be better defined with the use of the yearly water budget and thus infiltration and discharge can be better protected in terms of quantity and quality. The design of land developments or roadways can follow the water budget method. The construction of regional ponds for irrigation will result in maintenance of the water budget for an area. The water budget maintenance will protect spring flow, ground water resources, and lower pollutant mass discharges to surface water bodies.

Clearly an alternative water supply is needed for residential, agricultural, industrial, and municipal purposes. Studies show that more than 50% of potable water is used by Florida homeowners for irrigation. About 88% of the total ground water withdrawn in Florida in 1990 was obtained from ground water aquifers. The same drinking water that comes from the ground water of Florida is used also for irrigation purposes. Thus, stormwater can be used to replace potable water and save valuable ground water as it replaces potable water used for irrigation. Since 1950, all categories of freshwater source withdrawals in Florida have increased. As Florida experiences an increase in population (Table 2) the water demand will also increase. For example, Orlando is ranked number 2 in population growth. There was a population gain in each year and it is projected in 2011 to be 19,553,303 (Woods & Poole Economics, 2001 MSA Profile).

Stormwater can be an alternative water supply that will help extend other water sources, such as our dependency on ground water. Remotely monitoring and controlling the volume of water from each source will help balance the water budget in Florida.

Table 2: Florida Growth Challenge

Population Increase

1950	2,771,305
1960	4,951,560
1970	6,791,418
1980	9,746,961
1990	12,937,926
2000	15,982,378
2020	20,000,000

East-Central Florida Population Change
(Source: St. Johns River Water Mgt. District)

County	1995	2020	% Change
Brevard	444,992	653,800	47
Lake	176,931	297,100	68
Orange	758,962	1,231,900	62
Seminole	324,130	514,800	59
Volusia	402,970	574,400	43
Total	2,107,985	3,272,000	55

The population numbers for recent years in the State and in metropolitan areas are shown in Appendix B, and show a population growth rate in excess of 20% in the last 15 years. The increase in population impacts the stormwater problem because humans cause changes in land use which affect development in floodplains, alterations of natural stormwater systems, compaction of soil, and an increase in impervious areas. In addition development increases the stormwater discharge in drainage systems and adds additional pollutants to the surface discharges from the watersheds. All of these conditions result in an increased speed of runoff, volume, and pollutants to surrounding water bodies. The stormwater impacts from urbanization changes the watershed hydrology, ground water infiltration, stream hydrology and morphology, riparian zone habitat, water quality, aquatic habitat, and aquatic ecosystems. This impact on our water supply requires us to reduce the demands on our groundwater resources. Stormwater has proven to be a feasible alternative source of water for irrigation and some industrial uses (St. John River Water District, 2000).

STORMWATER MANAGEMENT PONDS

Stormwater ponds are currently one of the most prevalent methods used in stormwater management and are constructed as either a wet or dry pond. Wet ponds, as the name implies, have water in them year around, and provide both water quantity and quality control. Detention ponds are commonly designed as wet ponds and temporarily hold stormwater up to five days with a gradual release into a natural receiving water body through a control structure, such as a weir. Detention ponds can enhance water quality by removing pollutants through the interaction of sedimentation, filtration, absorption, and biological processes (Beck, 2001). Alternatively, a dry retention basin stores the stormwater in the landscape until the water infiltrates into the ground or evaporates.

The intelligent controller “I-Water” can be added to the wet pond to reuse the water for irrigation and thus reduce the discharge to surface waters. It can also be used to maintain aesthetics in the pond by moving water from one location to another based on depth sensors, piping and pumps. A fountain can easily be added to circulate the water or for aesthetic purposes. In addition, the controller is used to monitor the quality and time distribution of detained water in the pond. Maintenance is minimal to nonexistent on the controller itself, but when used with water quality monitoring instruments/sensors, maintenance of the sensors is required. Calibration and cleaning of the water quality instruments/sensors require routine maintenance dependent on each individual instrument/sensor.

The soil beneath a pond works as a natural filtration of stormwater pollutants. Thus, the withdrawal of water using horizontal wells beneath a pond is possible and particulate matter and other pollutants can be reduced. As with all stormwater ponds, there is potential for ground water and surface water contamination to occur. Due to the concern of contamination, the “I-Water” controller with sensors can measure some of the pollutants and thus reduce contamination through the use of a treatment system. Further research in the future on treatment methods will provide other options for the management of stormwater.

APPLICATION OF "I-WATER" TO AUGMENT WATER SUPPLY

Water withdrawn for public supply in Florida totaled 1, 925 million gallons per day in 1990. Ground water was the source of more than 88% of the water withdrawn for public supply, serving about 10.0 million people. Agriculture accounted for the largest use of freshwater in Florida in 1990 (followed by public supply, self-supplied commercial-industrial, domestic and thermoelectric power generation) (Marella, 1992). The Floridian Aquifer system supplied 1,249 gallons per day (62%) of the ground water withdrawn for agricultural irrigation in 1990. However, the aquifer water levels have been decreasing since the1950’s causing surface vegetation losses, spring flow decrease, poorer quality of source water, and more expensive raw water collection. To maintain ground water levels, the dependency on ground water supplies for potable uses is being reduced. Floridians use more than 50% of the public water supply outdoors, mostly for landscape irrigation. Automatic in-ground irrigation systems have become a common method for watering lawns. Many of these irrigation systems are inefficient. Sometimes as much as half of the water delivered through the systems do not benefit the intended plants. Since a significant use of potable water from ground water sources is for lawn irrigation, other water sources for lawn watering are being used. One such source is stormwater and another is treated wastewater, or reclaimed water.

Studies in Florida show that the supply of available reclaimed water continues to rise but the demand for irrigation water also increases (refer to Appendix A - Reclaim water usage, Water Reuse Work Group, Water Conservation Initiative, 2003). The percent of waste water reused based on per capita use of reclaimed water is greater than 97% for six counties and over 100% for two counties. To meet the growing demand for reclaimed water, an alternative water supply to reclaimed wastewater is needed. Stormwater has proven to be a feasible alternative source of water for irrigation and some industrial uses (SJRWMD, 2000). Proposed is the use of stormwater as an additional water supply and the stormwater intelligent controller system "I-Water" to be the system used to monitor, control and move water from multiple water supplies.

To be proactive by helping protect our future water supply, the "I-Water" system was also built to provide data collected with sensors and to evaluate the quality of stormwater collected using sensors and an automated process. The stormwater intelligent controller system, "I-Water" will provide the automated process necessary to perform statistical and historical data analysis. It also demonstrates advanced technology used to remotely access, operate, and maintain the system and its database in 'real time'.

This research showcases the latest knowledge, technology and innovations for the selection of source waters used for irrigation purposes. Some of the benefits and features for the selection process are:

BENEFITS

- Improve stormwater treatment
- Reduce Pollution
- Provide an Alternate Water Supply
- Irrigation
- Save Money
- Rehydrate Wetlands
- Water Treatment

FEATURES

- Database Creation
- Perform Statistical Analysis
- Intelligent Expert System
- Remote Access & Telemetry
- Expandable & Programmable
- Alarm for parameters out of specification

To be proactive in the protection of our future water supply, devices must be developed to evaluate the quality of the stormwater proposed for reuse. This research examines those devices that collect data using an automated process. Stormwater from lakes has been used for many years by lakefront property owners who pump lake water through piping systems for lawn irrigation and agricultural uses. However, irrigating stormwater with high levels of certain algae may lead to possible respiratory problems or other adverse health effects. High turbidity levels can also clog the sprinklers, and high chlorides cause damage to plants. A control system would help assure this water is safe to use and that the stored water is used efficiently. State and city regulations generally restrict the time and day irrigation can occur. Thus, there is an additional justification and a current need for an automated system to adhere to these regulatory parameters.

DESIGN OF CONTROLLER

Three different design approaches were considered to build an automated intelligent expert system. The first approach was to use commercial off the shelf (COTS) technology like a data logger or a Programmable Logic Controller (PLC) versus a custom micro-controller (MCU) design using a microchip controller. The authors researched three design approaches examining cost, design time, reliability, flexibility, and system integration. Standard industrial wiring practices were followed. Since the controller would be mounted outside, NEMA - 4X enclosure was chosen to house the controls, NEMA-3R transformer, and NEMA-4 motor controllers.

A data logger is a device that is designed to collect data from field instruments and store these data in memory for future access at a later time and/or date. The data logger also provides some control capabilities like a PLC; however a data logger does not have the depth of control functions like a PLC. The data logger would not be an acceptable alternative to the PLC based on the type of logic that is required for the "I-Water" controller. The data logger could not provide the local graphic touch panel that was included in the PLC design. The data logger also has a limited amount of I/O (Input/Output) capabilities so some I/O as defined in the PLC design would have to be eliminated for the data logger design. Due to the limited amount of I/O capabilities, the data logger design was not used for this project (refer to Appendix C -System Specifications).

When looking at COTS systems one must also consider lawn irrigation systems that can be designed and built with off the shelf parts. Several controllers and advanced computers with custom software have been developed and are available. Most of these systems require advanced training and certification to program, design, operate, and integrate. These units are very expensive refer to Table 3 for a cost estimate.

Table 3: Irrigation control system with COTS Technology

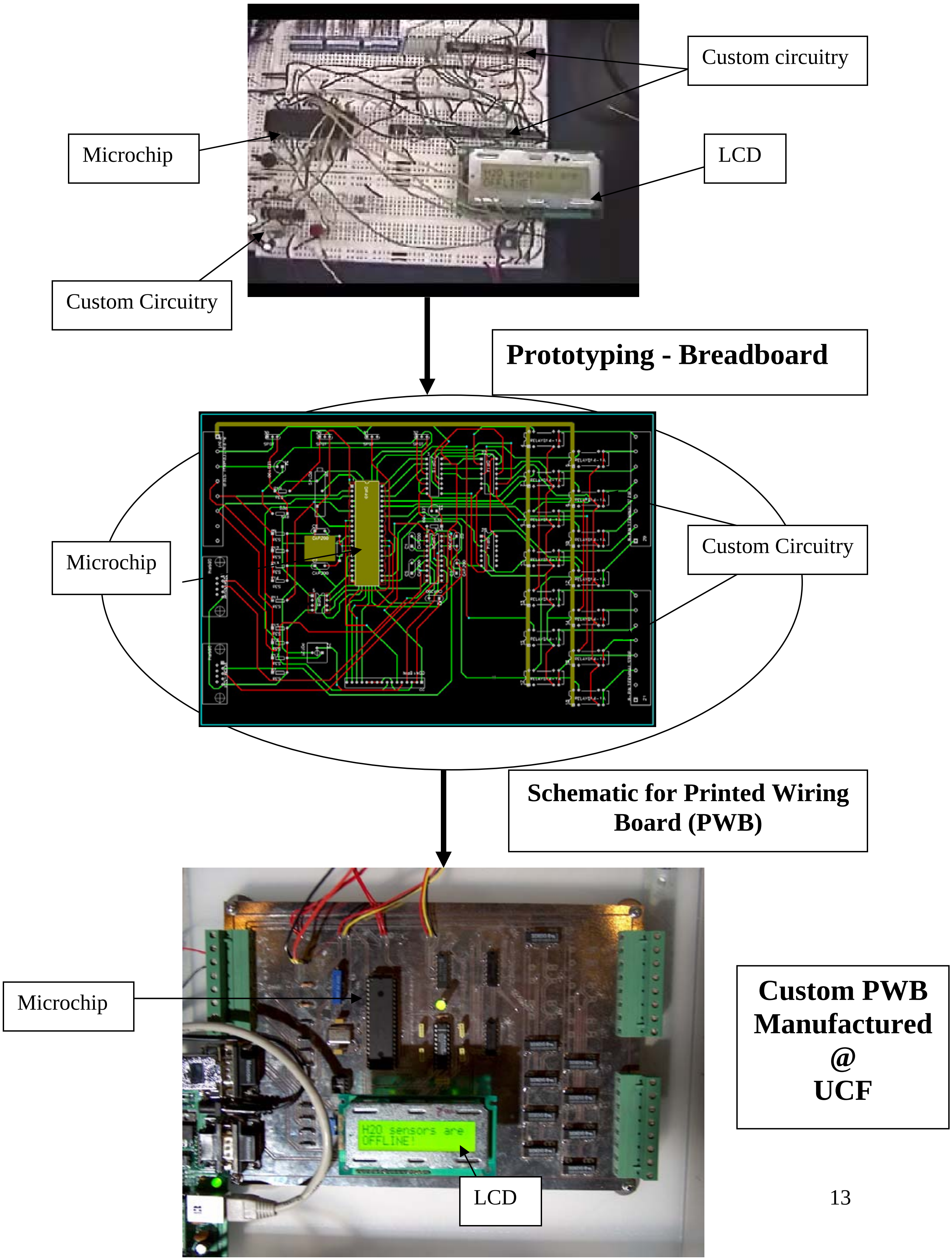
Controller Interface Hardware	**I/O needed**	**Approx Price**	**I-Water Sensor Equiv. Price**
Central Computer (direct phone line)	6 channels	$6K	
	28 Channels	$10K	$10K
Serial server network		$300	$300
Satellites	8 station	$2K	$2K
Decoder for each sensor	1 per decoder	$700*	$6300
Pulse Transformer	1 per	$900*	$8100
		Total	$53700
Weather Station		$14K	

* 'I-Water' system uses approximately 9 different sensors

The heart of the "I-Water" is the controller. Of the several different PLCs available on the market today, there appears to be a few the industry specify in their designs. PLC manufacturers such as Allen-Bradley, Siemens, Modicon, GE, or AutomationDirect appear to be most commonly available. A PLC controller is comprised of several sections and can be of either "modular" or "fix" based on the system requirements. These sections included a CPU (central processing unit), memory, power supply, I/O (input/output) rack, communication, and associated I/O modules (refer to Appendix D & E).

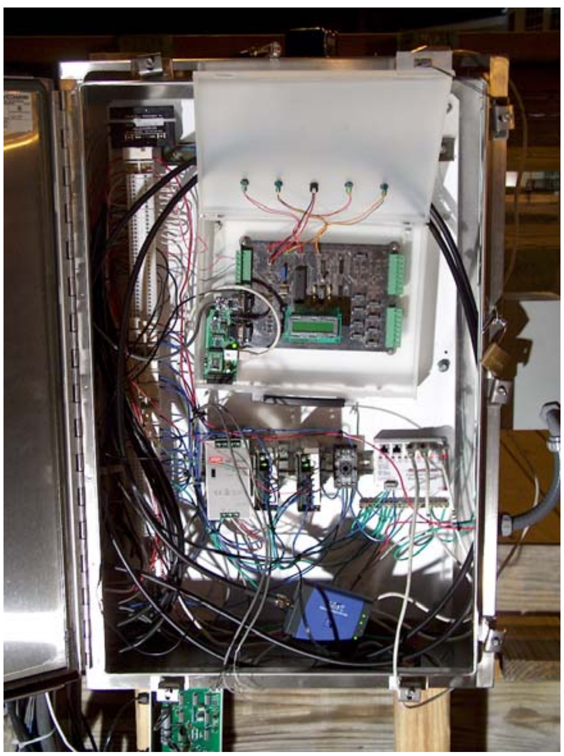
The third option considered was a custom microchip design or micro-controller (MCU). There are a variety of programmable microchips available on the market. Ease of programming, wiring, testing, interfacing, and available I/O were all considered. Designing with a microchip requires custom software and hardware to be developed. The microchip is wired to a breadboard (refer to Figure 1 - Prototyping) along with custom analog and custom digital circuitry to provide the interface necessary to communicate with each channel and the web server co-processor. Once the custom breadboard design is complete and tested then a schematic drawing is created, simulated, and tested in software. That schematic is converted in software to a printed wiring board (PWB). Based on the complexity of the circuitry a single or multilayered board will be manufactured. This custom designed, manufactured, and assembled PWB was built at the University of Central Florida (refer to Figure 1). All of this custom work needed for the microchip interface has already been designed, developed, and tested within the data logger and PLC. The advantage of the custom microchip or MCU design is it is a low cost alternative, flexible, and custom. There are fewer limitations in the MCU design.

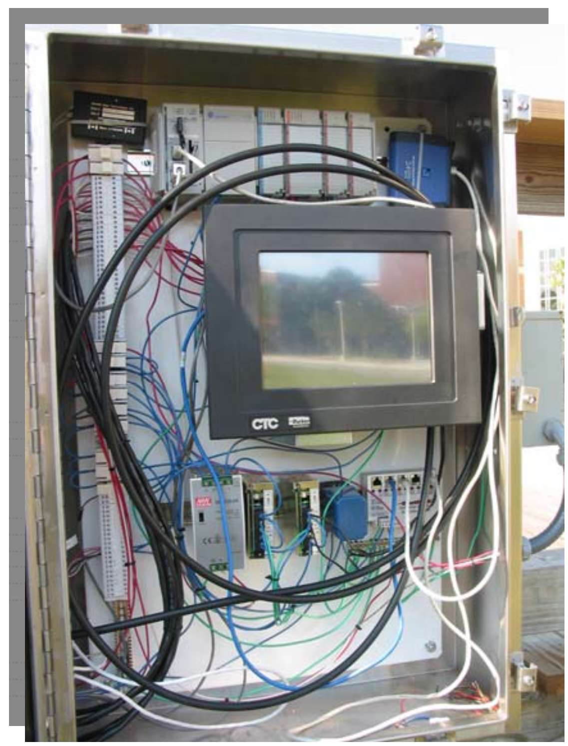
Figure 1: **Prototyping to Schematic Capture (PWB) to UCF Manufactured Board**



There are several issues to consider when designing a control system. The system can be designed from the system overall block diagram shown in Appendix D. The I/O list is divided into the different types of I/O and is referenced in Appendix C. Digital Inputs are inputs that are either in one of two states, on or off. The other type of input is an analog input. An analog input can take on a value from 0 to 100%. The instrumentation chosen will determine what type of communication is needed. In our design the PLC required both RS-232 and Ethernet connections and the sensors required SDI-12 protocol. The enclosure housed the PLC/MCU, graphic touch panel display, converters (24V to 12Vdc and 5Vdc and RS-232 to SDI-12), wireless bridge, battery controller/charger, network hub/switch, terminals, and wiring. To test the MCU the PLC and graphic touch panel display were removed and replaced by a custom designed (refer to Figure 2 - MCU and PLC Interface), manufactured, and assembled printed wiring board (PWB) built at the University of Central Florida.

Figure 2: **MCU & PLC Interface**





Micro-controller (MCU) Interface

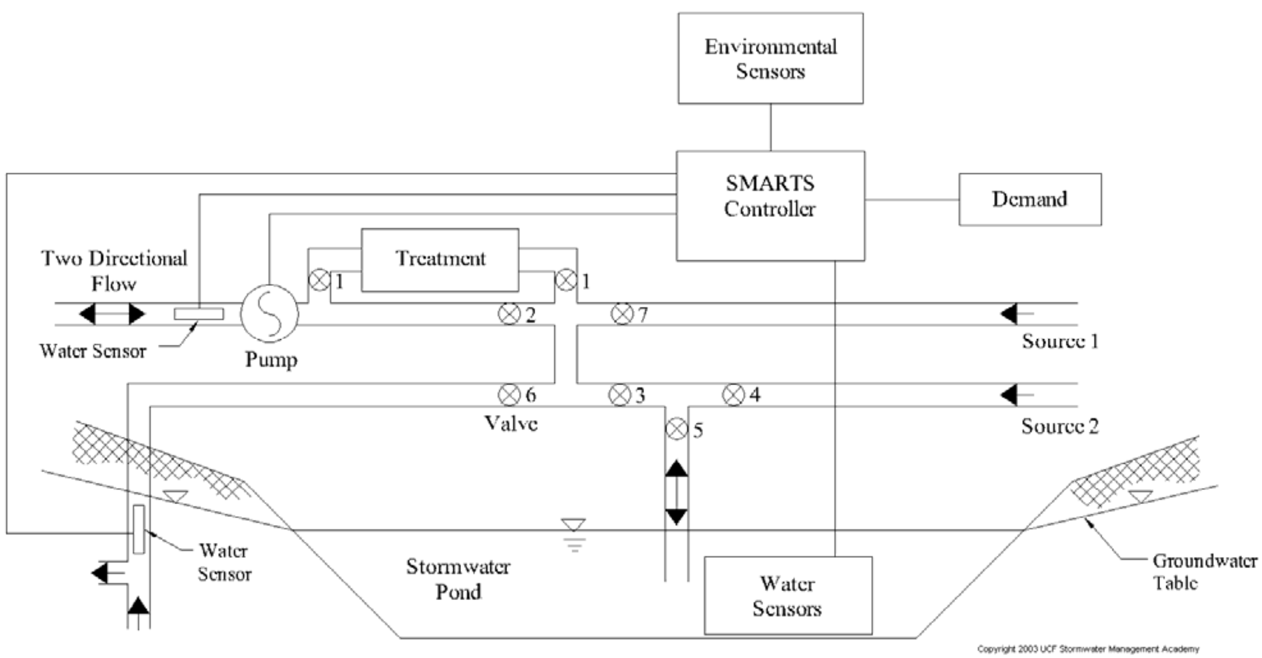
Program Logic Controller (PLC) Interface

After understanding the system requirements the software is programmed from a truth table (refer to Table 4 – Truth table for system operation) that has been defined for valve operation and availability of water sources. The PLC and MCU logic are programmed to select a water source based on demand for irrigation, environmental sensors (rain, wind, moisture etc), water supply choice (reclaim, well, stormwater, potable) and the quality of that water source. All of these sensors are defined in the I/O count and are configured at the system requirement stage. Refer to Appendix C for System Specifications. There is room for expansion and other sensors can be added. The final design included 75% spare I/O to be used for such expansion.

Table 4: Truth Table for System Operation.

Options	Valve Position						
	1	2	3	4	5	6	7
Pond NO Treatment to Output 1	C	O	O	C	O	C	C
Pond + Treatment to Output 1	O	C	O	C	O	C	C
Environmental Sensors ON	C	C	C	C	C	C	C
Source 1 Input NO Treatment to Output 1	C	O	C	C	C	C	O
Source 2 Input NO Treatment to Output 1	C	O	O	O	C	C	C
Source 3 Input NO Treatment to Output 1	C	O	C	C	C	O	C
Source 3 Input + Treatment to Output 1	O	C	C	C	C	O	C
Output 1 NO Treatment into Pond	C	O	O	C	O	C	C
Output 1 + Treatment into Pond	O	C	O	C	O	C	C
Output 1 to Output 2 & Source 3 NO Treatment	C	O	C	C	C	O	C
Output 1 to Output 2 & Source 3 + Treatment	O	C	C	C	C	O	C

Figure 3: **System Conceptual Design**



The PLC and MCU logic is divided into several subroutines such as the Main, ASCII, Environmental data, Pump Valve Control and System Demand. Water source selections are defined for pump valve control, environmental conditions, and water treatment. There is an option to operate the system in automatic mode or manual mode. This allows the operator to initially set the irrigation parameters based on your County water restrictions (real time clock, day of week, date, day to operate, duration etc.) or when using multiple water supplies which water supply you want to pull water from and its condition. All of these parameters are critical and stored in a database.

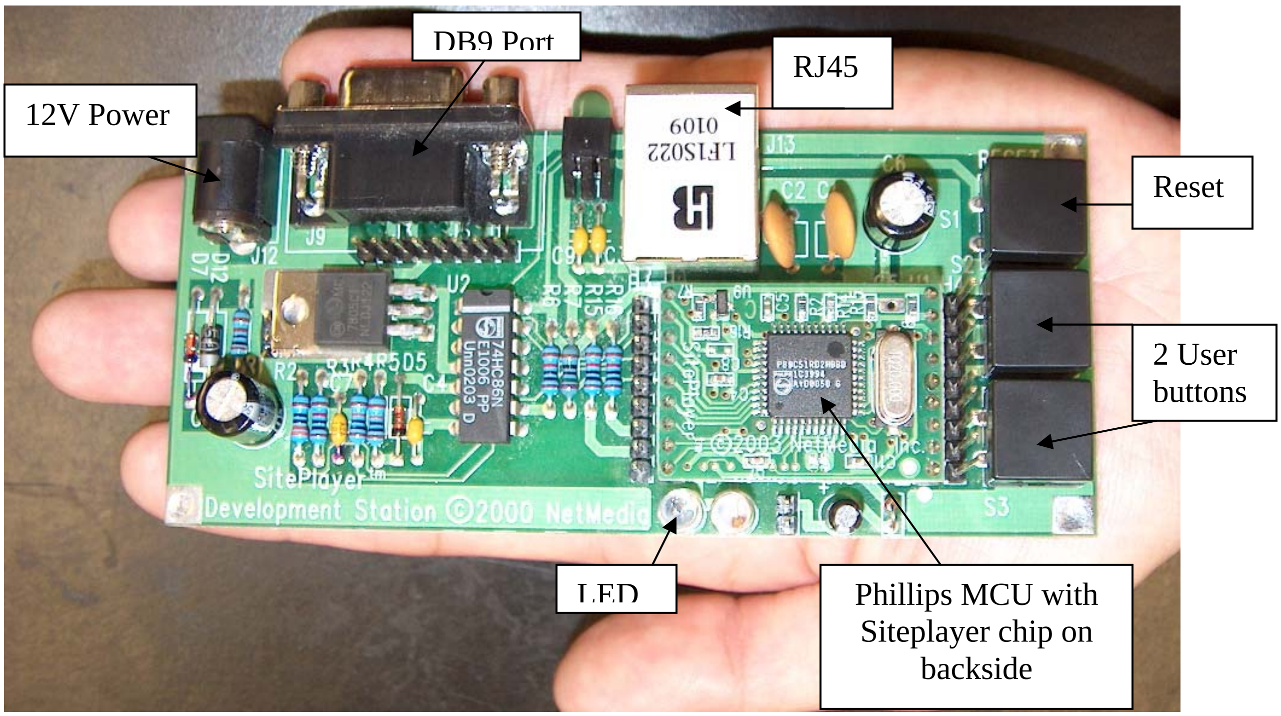
The PLC chosen for this project was the Allen-Bradley CompactLogix controller. The PLC design is comprised of COTs technology. The unit consists of an Allen-Bradley CompactLogix controller with a 1769-L35E processor for Ethernet and RS-232, 1769-IF4 current/voltage analog input (4pt), 1769-IQ16 24VDC direct input (16pt), 1769-OW16 relay output (16pt), and 1769-PB2 24VDC power supply as shown in Appendix E.

This PLC required custom vendor software RSLogix 5000 (ladder logic) and RSLinx Lite for PC to PLC communications. Additional software was written to include a main routine which performs jumps to subroutines. A custom ASCII interface was built to interface with the water quality instruments subroutine for SDI-12 communications. A separate subroutine was developed for environmental data (wind speed, direction and rain amount monitoring and calculations). There was a pump valve control subroutine developed for automatic and manual control of pumps and valves. A system demand subroutine was developed to track the day of week and hour of day determination.

The PLC has a graphic CTC touch panel to allow the operator to view and adjust systems operating parameters, and it will be referred to as HMI (Human Machine Interface). The touch panel provides graphic screens, refer to Appendix F – HMI Interface (PLC Touch Panel), to allow the operator to view and adjust parameters. These screens consist of and are not limited to a system overview, system demand, system set points, set day and time, auto/manual operate. The "I-Water" can be programmed for different data sources and to view the wind speed and direction, rain amount, water depth or pressure, water quality parameters such as pH, Conductivity, Turbidity, DO (Dissolved Oxygen) and others. The touch panel makes it easy to navigate through any of the graphic screens yet it is a costly item to purchase. The touch panel is not required to interface with the PLC, a laptop computer with the appropriate software is sufficient. The panel was chosen and integrated at the installation sight to assist the operator in programming, monitoring, and viewing the control status. If using telemetry, the operator can remotely modify settings at a computer terminal.

The MCU operates in a similar fashion as the PLC without the expensive touch panel (refer to Appendix G – MCU Controller). A keypad and liquid crystal display (LCD) was added to view the status of the controls (as seen in Figure 1). To make changes to the controls a laptop is required. Custom software was developed along with screens for an operator to access a system overview, system demand, system set points, set day and time, auto/manual operate, view environmental sensors, and set water quality parameters as shown in Appendix H. All software is developed on a computer then transferred to the microchip via an Ethernet card and test board (refer to Figure 4 - Ethernet Controller). The MCU uses Ethernet and RS-232 communication protocol. The Ethernet controller has the Siteplayers SPK1 embedded web server which allows the programmer to create web pages to show and control data (refer to Appendix I – MCU Web page). If using telemetry, the operator can remotely modify settings at a computer terminal.

Figure 4: – **Ethernet Controller & Web Page**
Ethernet embedded web server programming board.



The MCU uses a 5Vdc power supply versus a 12V power supply that the PLC uses. It uses 16 different relay digital outputs to control the irrigation system. There are 8 analog inputs (4-20mA) to monitor environmental instruments. Due to the number of I/O needed and the ease of programming the PIC16F877A (PIC) microchip was chosen. The PIC microchip is a 40 pin DIP (dual in-line package) that contains a 10 MHZ crystal, and 10 channel analog to digital converter.

SENSORS

Sensors used in the "I-Water" system consist of meteorological and water quality sensors. The controller is programmed to operate between set points across a range of acceptable readings as seen in Table 4 - Typical Set Point Values for Water Quality Sensors. The placement of these sensors is based on industry standards and recommendations.

Recent technological advancements have increased interest in deploying water quality sensors for environmental monitoring applications. Executing a water quality monitoring and management program for a body of water is a critical element in assuring a sustainable ecosystem. A typical water quality management program uses water quality sensors to measure only a limited number of physical and chemical parameters, such as dissolved oxygen, pH, temperature, conductivity and turbidity. These sensors often foul due to the nature of water body conditions. Consequently, the sensors do not provide measurements that are continuously calibrated or as accurate as laboratory analysis. One of the benefits of using inline sensors is that fast analysis eliminates the risk of sample degradation or contamination that is experienced when samples are collected, stored and transported to a laboratory (South, 2005). Many physical properties can change if the sampled water is exposed to ambient air, sunlight or is stored for a period of time before testing.

METEOROLOGICAL SENSORS

The rain sensor is designed to override the cycle of an automatic irrigation system when adequate rainfall has been received. Florida is the only state with an overall sensor statute per Florida Statute 373.662 "Any person who purchases and installs an automatic lawn sprinkler system after May 1, 1991 shall install, and must maintain and operate a rain sensor device or switch that will override the irrigation cycle of the sprinkler system when adequate rainfall has occurred" (Dukes, ABE325).

The wind sensor is configurable by the operator meaning the operator can define set points for the wind direction and wind speed conditions for the controller to operate within. There are multiple advantages to this based on the water quality, irrigation spray heads to insure you are not watering the road or sidewalk and not watering on a windy day. The standard practice is to not irrigate if the wind speed is greater than 7 mph so a default is set in the program for this condition. To ensure quality the National Electrical Manufacturers Association (NEMA) enclosure standards for mounting electronic equipment outside of a building was followed.

WATER QUALITY

Water quality sensors can be used to determine a base line and monitor the water conditions from different sources, such as stormwater ponds, wells, reclaimed and potable water. One of the functions of "I-Water" is to ensure that water quality stays within the set points for each parameter listed in Table 5. Each parameter set point monitored is configurable by the operator and can be changed on the human machine interface (HMI) or computer if telecommunications are used. The "I-Water" controller is designed to open valves and/or allow irrigation to occur based on the water quality minimum and maximum ranges in addition to the rain and wind readings. Additional sensors maybe added based on the system specifications, there is an additional 75% of inputs and outputs available on the controller for expandability. Bacteria and algae measures are important but there are no sensors available at this time.

Table 5: Typical Set Point Values for Water Quality Sensors

Stormwater	Normal Set Point	Range of Set Points	Units
pH *	7	6.0 – 9.0	
Pressure (barometric) Depth	5	1 - 14	Ft
Electrical Conductivity *, **	1000	500 – 2000	mS/cm
Turbidity +	5	2 – 20	NTU
TDS *	500	250 – 1000	mg/L
DO (Dissolved Oxygen)	7	0 – 12	mg/L
Ion Sensors			
Chloride	386	5 - 13,300	mg/L
Nitrate	1.0	0.01 - 8.4	mg/L

(* Wanielista, 1993 pages 126, 127, ** Hanlon, 2002, and + Pitt, 2004 page 48)

ENVIRONMENTAL QUALITY AND HEALTH INDICATORS

Reclaimed water or stormwater can be used as a source for irrigation. Like many states, Florida has a water reuse program. The DEP reuse program is charged with encouraging and promoting reuse in Florida, and also with protecting public health and environmental quality (DEP website 2005). Rules are established to ensure that reuse projects are designed and operated such that public health and environmental quality will be protected. There is a Code of Good Practices for Water Reuse in Florida that was established by the FDEP Water Reuse Committee, Florida Water Environment Association (FDEP, 2000). This code states that distribution of reclaimed water for non-potable purposes offers potential for public contact and that such contact has significance related to the public health. In addition, reclaim water is not to be used to irrigate vegetable gardens where they will not be peeled, skinned, or cooked before eaten.

Reuse of reclaimed water is regulated pursuant to Chapter 62-610, F.A.C. "Reuse of reclaimed water and land application" (http://www.dep.state.fl.us/legal/rules/wastewater/62-610.pdf). This rule requires reclaimed water to contain not more than 10 mg/L of total suspended solids (TSS) at all times. There are several reasons for the TSS limitation; sedimentation primarily harms watercourses by smothering the benthos region as well as the affinity of other pollutants to sediments. In addition, the Biological Oxygen Demand (BOD) in a waterbody may be reduced by sedimentation (Kiely 1997). TSS can be estimated with a turbidity sensor. Turbidity and TSS are also parameters of stormwater pollution. Thus, monitoring of turbidity in stormwater appears a reasonable option. Some principal constituents of concern in urban runoff are total suspended solids (TSS), nutrients such as phosphorus and nitrogen, heavy metals such as copper, lead, and zinc, and E. Coli (Roesner, 2001).

A fraction of the metals, E. Coli, and nutrients are bound to the particulates. Turbidity sensors are now currently used to measure particulates and as a surrogate for TSS. As additional sensors become available for TSS and other constituents, they can be added to the controller.

Turbidity can also be used to indicate the general contribution from pointless personal pollution, another name for nonpoint source pollution. Pointless personal pollution is generated by a variety of activities spread over a broad area and most people contribute to personal pollution. When it rains, pollutants such as soil particles, pesticides, fertilizers, oil, grass clippings, and pet waste are released into our waterways from plowed fields, streets, rooftops, and neighborhood yards. Awareness of source control for personal pointless pollution is increasing however the runoff waters can end up in detention ponds and in our water supplies.

Chemical nutrients in fertilizers, detergents and sewage cause excessive plant growth and algae blooms. Overgrowth of aquatic plants and algae can clog navigation waterways, impair recreational activities, blocks sunlight from penetrating through the water which reduces dissolved oxygen levels resulting in fish kills. High nutrient levels in groundwater can also be a principal cause for closing potable wells and for methemoglobinemia (blue baby syndrome). Bacteria, waterborne viruses, and pathogens from septic systems, livestock, and pets cause illnesses such as cryptosporidiosis that can result in the closure of swimming areas and shellfish beds. Animal waste collected in stormwater contains disease-causing organisms that can affect human health. These pathogens can cause colds, flu, respiratory illness, gastrointestinal illness and skin, eye and ear infections. Toxins, including heavy metals, pesticides, and organic chemicals from farms, lawns, city streets, driveways, and landfills can pose serious human health risks when they contaminate fish, and drinking water wells. Activities such as over fertilizing the lawn and applying fertilizer minutes before a rainstorm can contribute to water pollution. There are preventive actions that can be taken. Public education and public use of water quality monitoring devices like "I-Water" will raise awareness. It will put the proper tools in the hands of a homeowner to make decisions on when to irrigate or treat the water supply. Additional health related concerns due to algae levels will be presented in future publications and related to irrigation.

Several parameters have been chosen to monitor with the "I-Water" controller. A concern is the concentration at which stormwater discharge could potentially impair, or contribute to impairing water quality or affect human health from ingestion of water or fish (Federal Register, 1995). As an example for pH the range of 6.0 to 9.0 standard units is reasonably achievable and an acceptable range within which aquatic life impacts will not occur. This is further discussed in the pH instrumentation section.

With Florida surrounded by oceans, salt water intrusion becomes a concern. The effects of excess salt water on irrigation will affect growth, vigor and appearance of landscape plants in two ways. The first is damage caused by foliar contact with salts, and the second is the damage induced by exposure of roots to salty soil (Miyamoto, 1997). Concentrations above 1,000 ppm severely affect many shrubs and trees when directly sprinkled on their foliage. Damage due to plant species varies due to frequency, and timing of irrigation, sprinkler type and weather conditions. Salts in the soil water become more concentrated as evaporation and transpiration occur leaving all the salts behind.

Salinity is a measurement of the total salt concentration in units of mg/L. Salt concentration (C) from laboratory analyses is frequently labeled as total dissolved solids (TDS). The "I-Water" system uses a probe to measure TDS in stormwater ponds. Another method to quantify salinity is to measure the electrical conductivity of irrigation water (EC_i) or water extracted from a saturated soil sample (EC_e). The relationship between salt concentration (C) and electrical conductivity (EC) is approximately C = 640 EC. The approximate relationship for irrigation water (EC_i) and soil salinity is $EC_e = 1.5\ EC_i$ if about 15% of the applied water is draining from the crop root zone (Hoffman).

WATER QUALITY DATABASE COLLECTION RESULTS

The "I-Water" system has been programmed to collect data from the instruments based on an operator selectable time interval. Data collected includes the information from the water quality instruments, the meteorological instruments, and date and time of the data collection. The PLC collects up to 160 data sets and stores them in a data array. The data array can be read by either a laptop computer connected directly to the PLC or via the telemetry by the remote computer. The operator can reset the data collection array and also store the data in to an Excel spread sheet for additional analysis. Currently all data collected are shown in Appendix J – Data collected remotely by the controller has been taken on a time interval set to record and transfer data remotely to a PC in the SWMA office every two hour. The micro-controller sends data directly to a website via the Siteplayer. Both the micro-controller and PLC have the capability of uploading data to a website for remote access.

In an effort to compare the data collected by the "I-Water" system in this report with results from other surveys, a search yielded several databases.

- The National Stormwater Quality Database (NSQD, version 1.1) (Pitt, 2004)
- International Stormwater BMP Database (www.bmpdatabase.org)
- Camp, Dresser, and McGee (CDM) national stormwater database
- Nationwide Urban Runoff Program (NURP)
- U.S. Geological survey (USGS)
- NPDES data
- EPA – Stormwater Benchmark Values (EPA, 1995)
- Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, and WEF, www.standardmethods.org
- Federal Register / Vol. 60, No. 189 / Friday, September 29, 1995
- Alternative Approaches to Stormwater Quality Control, 2004, Los Angles Regional Water Quality Control Board.

The date collected by the "I-Water" will be compared to some of the data reported in these reports. The “I-Water” system must then be composed of sensors that can be deployed in the field and return data on constituents that are commonly measured in stormwater. The "I-Water" must also provide data to treat the water if needed, and distribute the water through a series of automatic valves.

INSTRUMENTATION

Due to the need to monitor at least five water quality parameters at one time the authors and research sponsor chose to use integrated digital water quality instruments. Research showed a trend in industry for using multi-parameter water quality sensors. There were three different vendors selected and evaluated as referenced in the data by instrument 1, instrument 2, and instrument 3 (see Appendix J). The vendors that were evaluated were In-Situ, YSI, and Hydrolab. Note the vendors are NOT listed in any particular order and do NOT correspond with the instrument numbers listed. The vendors were chosen based on their sensor specifications. Refer to Appendix L for typical vendor sensor specifications. The purpose of this project was to demonstrate the capability and data collection for controlling water redistribution. This test site is available for vendor alpha and beta testing along with data collection.

The "I-Water" system currently is using multi-parameter sensors to measure and monitor water quality parameters. Single detectors can be used in lieu of multi-parameter sensors to reduce cost. However, the sensor count is based on the amount of I/O present in the controller. These multi-parameter sensors can measure up to fifteen or more parameters simultaneously. This is accomplished through an industry standard called SDI-12 that these instruments operate under. SDI-12 is an industry-originated interface bus designed to allow an operator to connect a variety of instruments, namely; meteorological, water quality, and others to a single data recorder (SDI-12 Controller) with a single cable bus. A cable bus allows for the addressing of multiple sensors on one bus. In addition these instruments can be used for remote or attended monitoring of fresh, salt or polluted water for both ground and surface water. This communication allows the "I-Water" to control, monitor and build a database for each parameter measured. The data collected by the “I-Water” system is illustrated in Appendix J. Appendix J shows data for all parameters measured by the instruments over a three month period. The "I-Water" system demonstrates the capability for using all three of these instruments at the same time for monitoring stormwater runoff in a pond environment.

Several challenges were encountered integrating and maintaining these complex digital instruments.

1. Knowledge of sensor operation and costs are necessary.
2. SDI-12 interface protocol had to be learned.
3. The MCU required additional interface card for SDI-12 communications RS-232 to SDI-12 converter.
4. Calibration of the sensors requires training.
5. Since all of the sensors are measuring simultaneously when one sensor reads out of calibration then all three instruments had to be

removed, cleaned, and re-calibrated. In order to keep all the data consistent. Resulting in -

a. Additional calibration chemicals
b. Delay in data collection
c. Re-calibrate sensor when it was not needed (some sensors needed calibrating every 2 weeks versus other sensors that only needed calibrating once a month)

6. The instruments are digital and were initially designed with little to no lightning protection. With Florida having a high number of days with lightning, two of the three sensors experienced lightning type damage and had to have motherboards replaced. This is important to note as a delay in data collection can result.
7. Two of the three instruments experienced internal water damage causing the instruments to stop working.

It is recommended that future field deployments use single sensors. This will provide cost savings in sensors and calibration chemicals. In addition it will allow for longer data collection. A cleaning and calibration schedule would be developed based on sensor performance. Analog sensors would be preferred due to the ability to withstand lightning damage. A typical calibration schedule is shown in Table 6. This schedule was taken from vendor manuals for a multi-parameter digital instrument used in this study.

Table 6: Typical Calibration Schedule*

Parameter	Manufacturer Recommended Calibration Frequency
PH	1-2 months
Conductivity	2-3 months
Turbidity	Limited suggestions
TDS	Calibration based on conductivity
DO	2-4 weeks
Chloride	3-point calibrate once per week; single-point calib. Daily after 4-6 hrs use
Nitrate	3-point calibrate once per week; single-point calib. Daily after 4-6 hrs use
Ammonium	3-point calibrate once per week; single-point calib. Daily after 4-6 hrs use

*Source: Vendor manuals

TEMPERATURE

Most aquatic species are cold-blooded causing water temperature to be critical for survival. Sunlight exposure can cause temperature increases in a pond. Biologic activity and the toxicity of ammonia increases with a rise in water temperature while the dissolved oxygen that the water can hold decreases. Conversely, heat from the pond may be absorbed away at night or during cooler seasons the water temperature will be lower. Stratification of a pond can occur.

In Appendix J data are presented for all parameters measured by the instruments covering a three month period.

pH

The term pH is used to describe the acidic or basic (alkaline) nature of a solution. The pH parameter is defined as the negative base 10 logarithm of the effective hydrogen ion concentration in gram equivalents per liter (EPA, 2003). The effect of a logarithmic scale is that each whole pH value below 7, or neutral, is ten times more acidic than the next higher value, while each whole pH value above 7 is ten times more basic. Photosynthesis increases pH, while respiration decreases pH. Improper pH in a pond and irrigation water may lead to plant and animal damage. In addition, pH is a factor in solubility of nutrients and heavy metals. A pond's pH value varies due to changes in temperature and plant/algae quantity. The pH value is critical when deciding to irrigate. A high pH will "burn" the grass. The buffering capacity of a pond protects against major pH changes. A pH in the range of 6.0 to 9.0 standard units is reasonable (Table 5) and an acceptable range within which plant impacts will be minimized.

In Appendix J data are presented for all pH readings on three different vendor probes over a three month time frame.

- Instrument 1 (pH1) was soaked in buffer pH 7 for 3 days after noticing in the earlier data the values were out of range. The sensor needed to be recalibrated. Once it was recalibrated then the data returned to an acceptable range.
- Instrument 2 (pH2) was in range to begin with and after one of the calibration and cleaning cycles it was calibrated incorrectly. Once the instrument was recalibrated and cleaned properly it returned to an acceptable range.
- Instrument 3 (pH3) was a defective pH probe to begin with and had to be replaced. Once a new probe was received, installed, cleaned and calibrated the data became stable within the acceptable range.

The pH probe is sensitive to proper calibration and cleaning. Additional pH data were taken using an Accumet pH probe (refer to Table 7) as a source for validating the probe readings. This was a combination pH Electrode with silver/silver chloride references. It is made out of glass with the reference liquid and reference probe inside. The reference measure was made after the pH probe was calibrated and in operation for at least one day.

Table 7: **pH data taken by the "I-Water" system compared to a reference**.

Date	Reference	Probe 1	Probe 2	Probe 3
10/22/2004	6.9	N.O.	6.5	6.9
11/4/2004	7.0	N.O.	7.0	N.O.
11/7/2004	7.1	N.O.	7.0	N.O.
11/21/2004	7.1	6.7	6.9	N.O.
12/3/2004	7.2	7.1	N.O.	7.1
12/9/2004	7.2	6.6	N.O.	6.8
12/19/2004	7.2	6.7	6.9	6.9
12/30/2004	7.2	6.5	6.7	6.8

Where N.O. represents Non Operational

The pH value collected by the "I-Water" system can also be compared to the National Stormwater Quality Database (NSQD, version 1.1) as noted in (Pitt, 2004) see Table 8. Numerous constituents were analyzed, including typical conventional pollutants (TDS, pH, SPC, TSS and others) and are recorded in the NSQD. In many cases, the sampled watersheds have multiple land uses and those designations were included in the database. The database listed the percentages of drainage as residential, commercial, industrial, freeway, institutional, and open space. NSQD represents stormwater only measurements where the "I-Water" database represents data retained in a stormwater pond. The conditions that represented the UCF stormwater prototype test site compared with freeway data. The prototype site collects stormwater runoff from multiple road ways.

Table 8: pH data taken by the "I-Water" system compared to NSQD.

	"I-Water"	NSQD (Freeway)
Median pH	7.0	7.1

(Adapted from Pitt, 2004 and "I-Water" database)

DISSOLVED OXYGEN

A sufficient level of dissolved oxygen is necessary to support life in a pond. Dissolved oxygen (DO) levels increase through the transfer of oxygen from air to water or the photosynthesis process of plants. The ideal condition is complete saturation of dissolved oxygen in water. Saturation is reached when no further oxygen may be dissolved. The DO concentration for 100% air saturated water at sea level is 8.6 mg O_2/L at 25°C (77°F) and increases to 14.6 mg O_2/L at 0°C (Water on the Web, 2004). However, increases in temperature, barometric pressure, and impurities decrease the saturation level. In addition, the dissolved oxygen level is decreased by oxygen consumers such as animals, aerobic bacteria, and plants not exposed to sunlight. These factors cause the dissolved oxygen balance to vary throughout the day and seasonally.

Comparison of a reference measure was related to the field deployed probe. The probe was calibrated at least one day prior to the reference measure. The reference measure for DO was by membrane probe (SM 4500-0G, pages 4-102 to 4-104) see Table 9. Probe 3 was out of range signifying a defective DO probe. In addition, Probe 3 was configured to collect DO Saturation % only. A conversion factor was used to convert % DO to mg/L by multiplying the percentage by 1.33 ml/L of dissolved oxygen is the equivalent of parts per thousand, which is the same as the percentage. However, the volume and mass of gasses are not the same, so ml/L is not the exact same as mg/L. Conversion factor used was 1 PPT (%) = 1.33 mg/L. This conversion yielded out of range data meaning the probe was non operational (N.O.).

Table 9: **Comparison of Selected DO (mg/L) data**.

Date	Reference Measure	Probe 1	Probe 2	Probe 3
11/28/2004	7.0	7.5	6.5	N.O.
12/9/2004	6.9	6.9	6.8	N.O.
12/30/2004	7.0	6.5	5.3	N.O.

Where N.O. represents Non Operational.

TURBIDITY

Total suspended solids (TSS) affect the clarity of pond water. The measurement of the level that particles block light is known as turbidity. Another parameter monitored is Turbidity. Turbidity is a measure of the clarity of the water or of the opaqueness produced in water by suspended particle matter. The greater the amount of total suspended solids (TSS), the murkier it appears and the higher the turbidity. Major sources of turbidity are phytoplankton, clays, silts, re-suspended bottom sediments, organic matter. Even bottom-feeding fish can stir up the bottom sediments and increase the cloudiness of the water. This high concentration of particle matter can change the penetration of light in the water. If there is not enough light penetration, macrophyte growth may decrease, which would, in turn, impact the organisms dependent upon them for food and cover. This would result in reduced photosynthesis, which in turn, results in lower daytime oxygen release into the water. Turbidity is a standard measurement in stream sampling programs where suspended sediment is an important parameter. Great care is taken when calibrating the instrumentation used to monitor this parameter, and when calibrated, laboratory measures substantially agreed with field measures.

Technological advancements in sensor design yielded a probe change in all of the vendor instruments. A wiper arm was added to clean the surface prior to taking a measurement. Only one vendor had an operational wiper arm installed. The other two vendors have upgraded their sensors since these data were collected.

TOTAL DISSOLVED SOLIDS

The total dissolved solids (TDS) parameter describes the concentration of ions in a solution that can pass through a filter. It is analogous to salinity and can be calculated from the conductivity of a water sample. Natural pond water contains many dissolved ions that are beneficial to plants and animals, such as carbonate and salts. However, too much TDS may contribute to poor aesthetics in water quality and can become potentially harmful. In addition, toxic ions, such as heavy metals and pesticide residue, may also be present and cause health concerns.

A search online for stormwater best management practices (BMP) yielded an International Stormwater BMP Database. The database contained several BMP examples and data associated with each. The BMP that compared best with our test site was a wet retention pond surface pond with permanent pool. The pond listed in Table 10 as Silver Star Rd. is located in Orlando, Florida just like our test site. The only parameter collected by both ponds was TDS. As expected the TDS values for three different database sources all fall within an acceptable statistical range.

Table 10: **Total Dissolved Solids (TDS) data taken by the "I-Water" system compared to NSQD.**

	Probe 2 mg/L	**Probe 3** mg/L	*** Silver Star Rd Detention Pond** mg/L	**NSQD (Freeway)** mg/L
Median - TDS	168	125	150	77.5

(Adapted from Pitt, 2004 and "I-Water" database and *BMP database)

CONDUCTIVITY

Conductivity is a measurement of the ability of water to produce an electrical current and it is directly related to amount of dissolved salts (ions) or solids in the water, and is reported in micro-ohms, which has been renamed micro siemens. Temperature affects conductivity with conductivity increasing as temperature increases. Most modern probes automatically correct for temperature and standardize all readings to 25 Celsius degrees or the equivalent of 78 degrees Fahrenheit and then refer to the data as specific conductivity.

A comparison of a reference measure to the field deployed probes is shown in Table 11. The reference measure for conductivity was a direct measure using SM2510B, pages 2-45 to 2-46.

Table 11: **Comparison of Selected Conductivity (μS/cm) data.**

Date	Reference Measure	Probe 1	Probe 2	Probe 3
11/28/2004	181	173	165	185
12/9/2004	175	174	168	186

In addition the "I-Water" data were compared to the NSQD as shown in Table 12. The NSQD value representing a freeway is lower due to the measurements in the NSQD are of stormwater alone. Due to the detention conditions of a detention pond such as the "I-Water" test site one would expect the conductivity to be higher.

Table 12: **Conductivity (SPC) data taken by the "I-Water" system compared to NSQD**.

	"I-Water" mS/cm	**NSQD (Freeway)** mS/cm
Median SPC	175	99

(Adapted from Pitt, 2004 and "I-Water" database)

INDEPENDENT STUDY

Water quality digital sensors were used to collect continuous data at Bonita Springs, Florida. Data from this study compared to data collected with the 'I-Water' system is illustrated in Appendix J. These data show a comparison using the recommended calibration interval of this report. In reviewing the continuous data collected it was noted that real time monitoring would reduce calibration errors and indicate exactly when a sensor needed calibration. (Bonita Bay, 2005)

RAIN SENSOR

Rain sensor used is a tipping bucket design. Data are collected over a 24hr period of time and then reset for the next day. Currently rain amount is monitored every two hours. This value can be modified in the software interface. The rain sensor is programmed to interface with the controller to turn on the irrigation system if there is less than ¾ of an inch of rainfall in a window time of two days. If more than ¾ of an inch of rainfall has occurred in the last two days then the irrigation system turns off. Table 13 illustrates rain data comparison during the hurricane season for August and September of 2004. This was an atypical event and those months were not illustrated in Appendix J. There is a comparison of rain data taken by the UCF controller compared to the City of Orlando data collected at the International Airport shown in Appendix K. This illustrates that during the months of November to January the data seen in Appendix J covers over twelve storm events.

Table 13: **Rain Data Comparison to 2004 Hurricane Data**

Month	Historic Monthly Average	2004 Monthly Average	Previous Monthly Maximum
August	6.88	16.29	16.11 (1972)
September	6.53	15.00	12.83 (1994)

http://www.cityoforlando.net/public_works/stormwater/rain/rainfall.htm

WIND SENSOR

A wind speed and wind direction sensor was integrated into the controller. If the wind speed was greater than 7mph and the wind direction was towards a sidewalk or road versus the grass then "I-Water" system would not allow irrigation to occur. This data was recorded in the database. The system worked great until the hurricanes with over 90mph wind gusts damaged the wind speed system.

CALIBRATION

Calibration was required for each of the multi-parameter water quality monitoring sensors. A procedure and process can be viewed in Appendix M. The calibration required an extensive learning curve. Additional cables and chemicals were needed. The data indicated operator error in calibrating and deploying the sensors at times. Not all of the sensors needed to be calibrated at the same time but since they were all integrated all sensors were calibrated once resulting in additional chemical usage and potential for damage. The continuous collected data indicated a “drift” in the measurements. In reference to the Department of Environmental Protection standard operation procedures it is recommended that the sensors be recalibrated every 4 days. This can be confirmed by viewing the database and reviewing the data. It is recommended that future designs be built with single sensors appropriate to the use. This will provide cost savings in sensors and calibration chemicals. In addition it will allow for longer data collection intervals.

TELEMETRY

Telemetry is the technology and process of automatic measurement and transmission of data by wire, radio, or other means from remote sources to receiving stations, for the purpose of recording and analysis. The "I-Water" system deals with the collection of data from and control of remote sensors and transfers the data to a central location being a PC in the SWMA. SCADA (Supervisory Control And Data Acquisitions) systems generally contain some form of telemetry in their design to accomplish their intended task. SCADA systems generally consist of a master station and one or more remote stations.

Several different technologies were evaluated and researched to determine the transmission media including copper wire, fiber optics, and radio waves or microwaves often referred to as wireless or RF transmissions. During the evaluation the network design was important to determine system requirements and location. Expandability was a key factor in choosing the technology as well. When evaluating point-to-point communication the cost was extremely high for multiple remote terminal units (RTU). Local Area Networks (LAN) technology was reviewed as it does allow for a shared communication medium where many RTU's can communicate to a host station. Coordination must be used to prevent more than one computer device from sending data at the same time and also insure that each device has access to the hub. Many LAN technologies have been invented for computer devices networking.

The design of the communication link for the "I-Water" system includes a combination of wire and wireless technology coupled with a LAN system provided by UCF. In Appendix N – Telemetry Map, shown is a map of the UCF campus where the "I-Water" system was installed. It also shows the location of the different types of transmission medium available to gain access to the campus network. Using the wireless access point to gain access to the Engineering building network was chose due the simplicity of installation and cost.

The telemetry system wire used for "I-Water" was an Ethernet “CAT-5” 10Base-T, wireless, and RF – 2.4 GHz Spread Spectrum system. The MCU interface required a SitePlayer, HUB, WET ll, R-SMA to N-male 25 ft low loss coax cable, and 9 dB gain passive directional WiFi antenna (refer to Appendix O - Telemetry system block diagram). Challenges were encountered when interfacing the MCU to the computer in the SWMA. There was a 2.5 dB gain omni-directional antenna that yielded a weak signal so this was replaced with a 9 dB gain directional antenna. The directional antenna was aimed directly at access points located in the SWMA.

POWER SYSTEM

In addition to the network requirements discussed above, the “I-Water” system also required power to operate the pumps and valves associated with the irrigation system along with power for the controller and instruments of the system. The “I-Water” system consisted of 240VAC two phase power for the irrigation pump and treatment pump, 24VAC for the valves and motor controllers, 24VDC for the controller and instrumentation, and 12VDC for the SDI-12 communication link. The MCU also required 5VDC for its operations and wireless communication link equipment. In addition to these power requirements the “I-Water” system was also outfitted with a 24VDC power battery backup system. The battery backup system automatically charges the batteries when 24VDC power is present and will switch to battery when the 24VDC power is not present (refer to Appendix P - Power distribution block diagram). This is a bump-less power transfer. The battery backup system will allow the "I-Water" system to continually collect data during a power outage. An additional design was demonstrated with solar power backup for continual collection of system data. It is possible to run all of the electronics off of solar power.

PLC vs MICROCONTROLLER

Since the PLC and the micro-controller are the brains of the "I-Water" unit, it is important to understand the differences. The PLC is a Commercial Off The Shelf (COTS) device that is purchased along with special software to program the unit. Whereas the micro-controller in this case is a microprocessor that is mounted on a custom printed circuit board with conditioning circuitry surrounding it. This custom unit has been manufactured and tested at UCF.

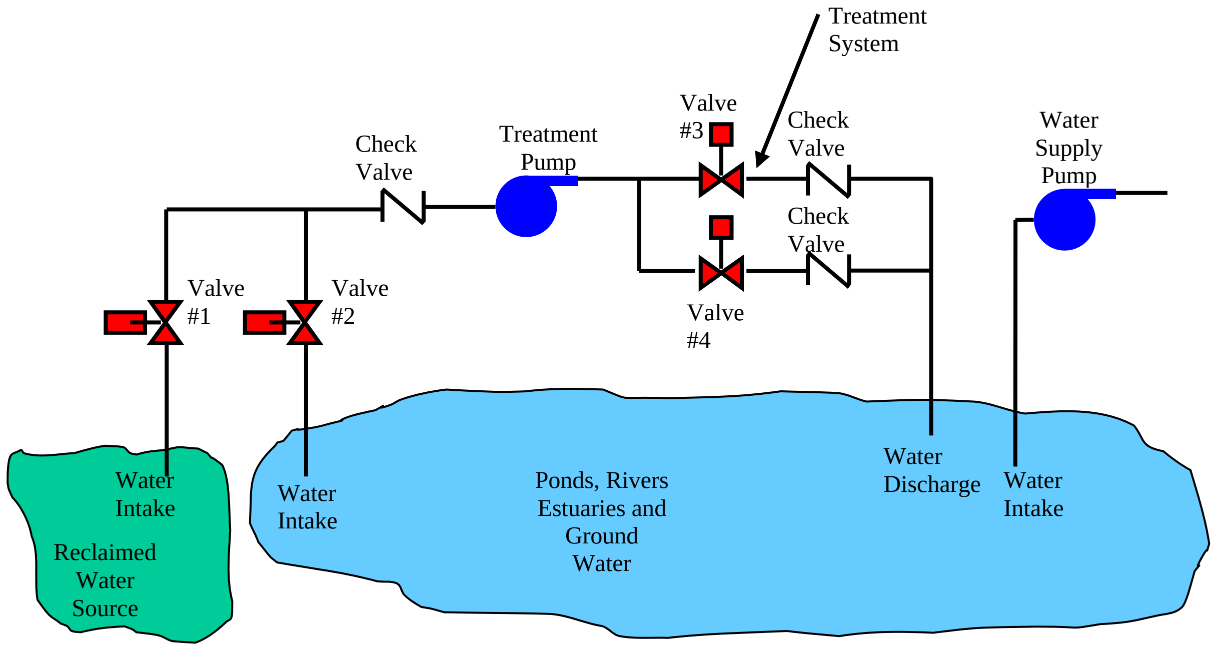
The comparisons of the PLC and the MCU provided the following results. From an initial equipment cost standpoint, the MCU is far less costly than the PLC. The MCU is 1/16 the cost of the PLC. There are additional costs associated with the micro-controller that are not required for the PLC. Cost such as design, board layout and manufacturing, board checkout and testing. Both systems required programming software and time for application development. The PLC required custom software from the vendor (RS Logix 5000 - ladder logic and RSLinx Lite – PC to PLC Communications). This software is costly. Both systems did provide the level of control required for "I-Water". Therefore either system could be used however, additional consideration should be reviewed based on system specifications and cost constraints. If the system specifications are dynamic and the customer envisions several changes, the user would consider how easy either system is to program. The PLC can be programmed rapidly using special software where as the micro-controller has its program saved directly into the memory of the processor. To modify the hard code in the micro-controller memory requires a flash programmer and software.

PROTOTYPE SYSTEM

The prototype "I-Water" system consists of two pumps. One pump is used as a treatment pump, the other pump is used as the irrigation pump (refer to Figure 5 and Appendix Q – Pump and Valve System). There are five electrical operated control valves in this system. Two valves allow the water to be distributed to the treatment system if required; two other valves allow the water to be distributed directly to the irrigation system. The final valve is an irrigation zone valve. The system has also been design to accommodate seven additional irrigation zones. The irrigation systems has 16 irrigation spray heads, 5 electrical operated valves, two 1HP irrigation pumps, 400ft of PVC irrigation pipe, and the ability to pump 40 to 60gpm at 15-25psi. It is designed to irrigate trees and rehydrate the wetlands in the center of UCF campus.

Figure 5: – Pump and Valve System

Intelligent Water Supply System



Illustrated and proven as an application for "I-Water" is to provide stormwater in the form of irrigation to landscape and re-hydrate wetlands. Refer to Appendix R to view one of the many applications for "I-Water". In addition to irrigation and water control and distribution the design includes the capability to perform experiments on various water treatment options. There is an additional pump and piping to route water through a treatment section.

The current prototype consists of the following:

- Program Logic Controller (PLC)
- Touch Panel Display
- Industrial Hardened
- Program Software
- Machine Logic Program Software
- Water Treatment Provisions
- Precipitation & Wind Speed Sensors
- Water Quality Sensors
- Database Creation / Computer

- Microchip Controller
- Webserver co-processor
- Over 30 I/O
- Relay Switches up to 150VAC using TTL Signals
- Expandable & Programmable
- Remote Access via Telemetry (Antenna)
- SDI-12 Interface
- Control or Set Point Parameters
- Intelligent Expert System

"I-WATER" SYSTEM

The initial "I-Water" system was built at the University of Central Florida (UCF) as a proof of concept prototype to show the capabilities and set a baseline for stormwater reuse. Refer to Appendix R to view the "I-Water" system at UCF. This system can be controlled remotely through telemetry. The prototype “I-Water” system demonstrates the ability to monitor the quality of water and make decisions for the redistribution of water from within the pond. The "I-Water" controller is designed with a 24Vdc power supply, Ethernet communication protocol for remote monitoring and data collection, RS-232 communication protocol for RS-232 to SDI-12 conversion for water instruments, 14 digital outputs to control irrigation system such as motor controllers and valves, 2 analog inputs to monitor environmental instruments such as wind speed and direction and a local human machine interface to adjust operating parameters and monitor system operations.

This is the test site where the PLC, Micro-controller, environmental sensors, water sensors and treatment options are evaluated. The fountain is present for esthetics. This system is using stormwater in an existing pond and redistributing the water for re-hydration of the wetlands and irrigation. The key here is to perform reliability testing and demonstrate the "I-Water" controls and expandability.

This test site is available for further water quality instrument testing. In addition a pump control and close loop pipe system is operational to develop experiments and evaluate various water treatment processes. The database can easily be modified to accommodate additional experiments.

SUMMARY & CONCLUSIONS

The drop in ground water levels and the increasing use of reclaimed water illustrates a need for alternative water supplies for irrigation. Ground water depletion is occurring which is destroying wetland areas and reducing spring flows. Stormwater provides an alternative water supply for irrigation. The automation, water quality monitor, and database that an Intelligent Water (“I-Water”) controller provides can make stormwater reuse systems more feasible thus helping to reduce stormwater pollutant loadings. Using advanced technology is an efficient and effective way to manage this resource.

Manual operations are not always efficient or provide necessary and sufficient data. The design and development of a Stormwater Intelligent Controller System such as "I-Water" using advanced technology is critical to automate the process. The objective of "I-Water" is to provide a reliable, automated, intelligent system that meets the demands for water supply such as lawn irrigation, agricultural, drinking and industrial usage. This "I-Water" automated system will provide the quantity of data necessary to perform statistical analysis and make decisions on monitoring and controlling water resources. This continuous water quality monitoring sensor can be used to identify trends, plot measurements, and real-time report on parameters collected. Decisions are based on "operational set points" that are configurable by the operator. The "I-Water" system can be used with several water sources such as reclaim water, ground water (wells, potable), stormwater, river water and estuary water to name a few. Existing water resources are limited and worth protecting. Using advanced technology is an efficient and effective way to manage this precious necessity.

Sensors often foul due to the nature of water body conditions. Consequently, the sensors do not provide measurements that are continuously calibrated or as accurate as laboratory analysis. However, one of the benefits of using online sensors is that rapid analysis eliminates the risk of sample degradation or contamination that is experienced when samples are collected, stored and transported to a laboratory. Many physical properties can change if the sampled water is exposed to ambient air, sunlight or is stored for a period of time before testing. Continuous monitoring does require an investment in calibration time and chemicals to maintain a reliable measurement.

The continuous collected data in this report indicated a “drift” in the measurements. Daily inspection of the database is recommended to determine recalibration. It is recommended that future deployment and designs use single sensors. This will provide cost savings in sensors and calibration chemicals. In addition it will allow for longer data collection periods. A cleaning and calibration schedule would be developed based on sensor performance. It is also noted that analog sensors can withstand lightning damage. However, all vendor sensors selected met the range of measurement required for the stormwater pond test site as stated in Appendix I.

All of the custom work needed for a microchip interface has already been designed, developed, and tested within the data logger and PLC. The advantage of the custom microchip or MCU design is it is a low cost alternative, flexible, and custom. There are fewer limitations in the MCU design. Several telemetry options were evaluated and WiFi technology was chosen. Challenges were encountered when interfacing the “I-Water” system to the computer in the Stormwater Management Academy. Moving to a higher gain directional antenna solved the transmission problem. Security of networks and scheduled maintenance should be considered when using the “I-Water” system on-line.

ACKNOWLEDGEMENTS

The “I-Water” was developed under a cooperative grant and contract with the State Department of Environmental Protection, Bureau of Watershed Management, and the Stormwater Management Academy at the University of Central Florida http://stormwater.ucf.edu/ . The authors appreciate the comments and advice of Eric Livingston, DEP Project Manager. Also, the help of students who prototyped the initial models is appreciated. The authors would like to recognize the Electrical Engineering Department at UCF and Dr. Samuel Richie along with students from the Senior Design class, namely Thanh T. Dinh, Patrick Peach, Charles Scott Turner, Vickie Cordon, and Richard Baddar. In addition the authors would like to recognize S. Marie Romah, a graduate student in the Environmental Engineering graduate program, for her contributions in water quality calibration, testing, development of the calibration procedures, and editing.

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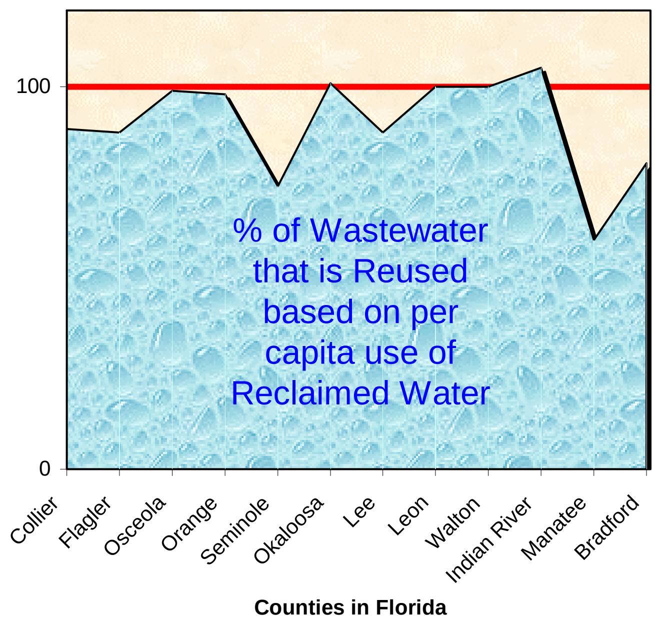
Appendix A: Reclaimed water usage.

We are running out of Reclaimed water.



Source: 2001 Reuse Inventory (7)
Water Reuse for Florida 4/15/03

Appendix B: State of Florida Population Numbers.
From : http://www.stateofflorida.com/Portal/DesktopDefault.aspx?tabid=95

Population Rank - 4th in U.S. behind California, Texas & New York

Florida's Population (2003) - 17,019,068
Florida's Population (2002) - 16,713,149
Florida's Population (2001) - 16,396,515 and Population Growth Rate (1990-2000) - 23.5%

Most Populous Metro Areas (2000):
(Rounded to the Nearest Thousand)

1. Tampa/St. Petersburg - 2,396,000
2. Miami - 2,253,000
3. Orlando - 1,645,000
4. Ft. Lauderdale - 1,623,000
5. Jacksonville - 1,100,000

<u>Appendix C</u>: System Specifications
Controller – PLC based, using Allen-Bradley SLC-5, Siemens S7-200, Modicon Momentum, or Automation Direct PLC
MCU - PIC16F877A

<u>I/O List</u>

Inputs – Digital (120VAC or 24VDC)	**Inputs – Analog (4-20mA)**
Valve #1 Open Position (Limit Switch on Valve) Valve #1 Close Position Valve #2 Open Position Valve #2 Close Position Valve #3 Open Position Valve #3 Close Position Valve #4 Open Position Valve #4 Close Position Valve #5 Open Position Valve #5 Close Position Valve #6 Open Position Valve #6 Close Position Valve #7 Open Position Valve #7 Close Position Pump Hand Mode (Selector Switch on dead front panel) Pump Automatic Mode (Selector Switch on dead front panel) Phase Monitor Fault Power Loss 24VDC Power (Battery) On 24VDC Power (Battery) Low Panel Intrusion Alarm	Pond pH Pond Level Pond Conductivity Pond Turbidity Pond Dissolved Oxygen Pond Chlorine Pond Nitrogen Pond Level Well pH Well Conductivity Well Dissolved Oxygen Well Chlorine Well Nitrogen Distribution pH Distribution Conductivity Distribution Dissolved Oxygen Distribution Chlorine Distribution Nitrogen Wind Speed Rain Gauge

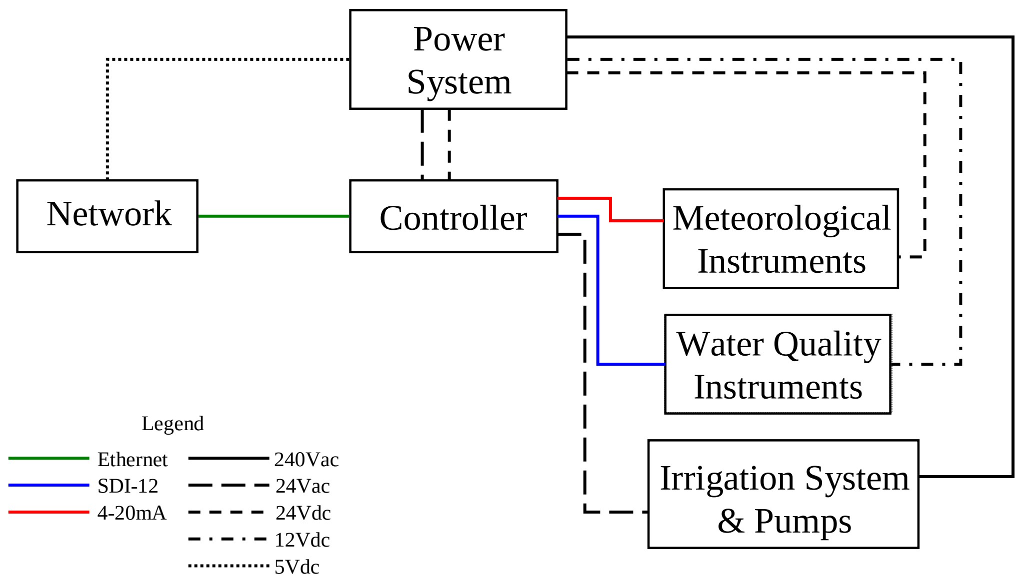
Outputs (120VAC or 24VDC)	Logic based on valve truth table
Valve #1 Open (Spring Close) Valve #2 Open (Spring Close Valve #3 Open (Spring Close) Valve #4 Open (Spring Close) Valve #5 Open (Spring Close) Valve #6 Open (Spring Close) Valve #7 Open (Spring Close)	Select water source (based on day, date, time and rain fall) Rain fall to be a 2-day sliding window of < ¾” rain 1 – Pond (based on quality and depth) 2 – Well (based on quality) 3 – Reclaimed (based on wind speed) 4 – Potable

Appendix C: System Specifications Cont.

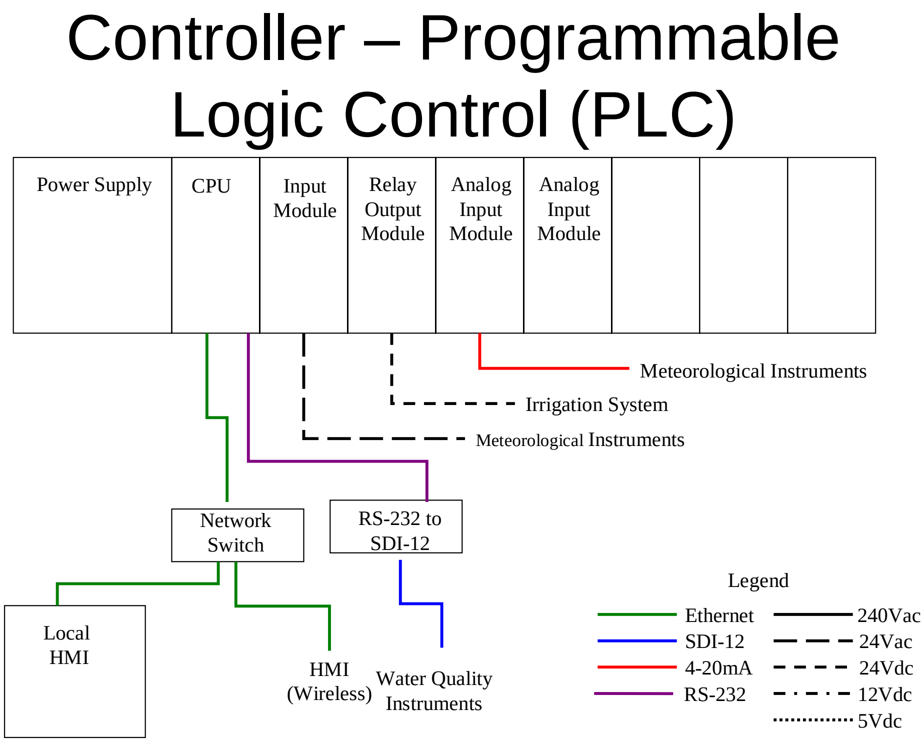
System alarms to be displayed on graphic touch panel
Pump Fail to Start Valve #1 Fail to Open Valve #1 Fail to Close Valve #2 Fail to Open Valve #2 Fail to Close Valve #3 Fail to Open Valve #3 Fail to Close Valve #4 Fail to Open Valve #4 Fail to Close Valve #5 Fail to Open Valve #5 Fail to Close Valve #6 Fail to Open Valve #6 Fail to Close Valve #7 Fail to Open Valve #7 Fail to Close Pond pH Out of Scale Pond Level Out of Scale Pond Conductivity Out of Scale Pond Turbidity Out of Scale Pond Dissolved Oxygen Out of Scale Pond Level Out of Scale Well pH Out of Scale Well Conductivity Out of Scale Well Dissolved Oxygen Out of Scale Distribution pH Out of Scale Distribution Conductivity Out of Scale Distribution Dissolved Oxygen Out of Scale Wind Speed Out of Scale Rain Gauge Out of Scale Loss of Power 24VDC Power (Battery) On 24VDC Power (Battery) Low Phase Monitor Fault Intrusion Alarm Clock Demand Set Point Adjustment (Day and Time) Clock Day, Date and Time Adjustment

<u>Appendix D</u>: – Block diagram of the Controller
Process and instrumentation diagram.

System Overall Block Diagram

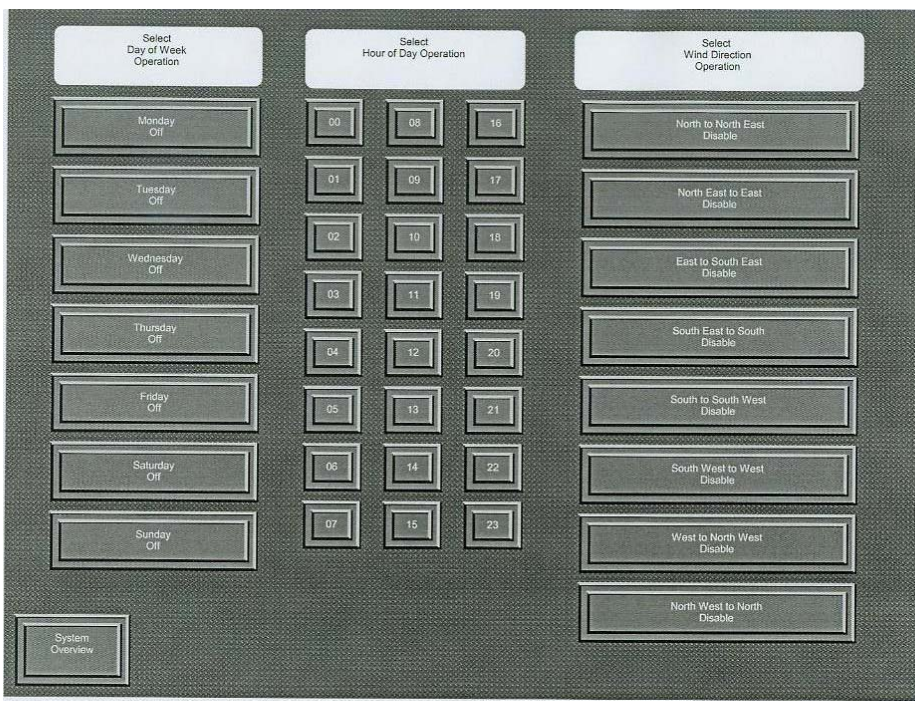


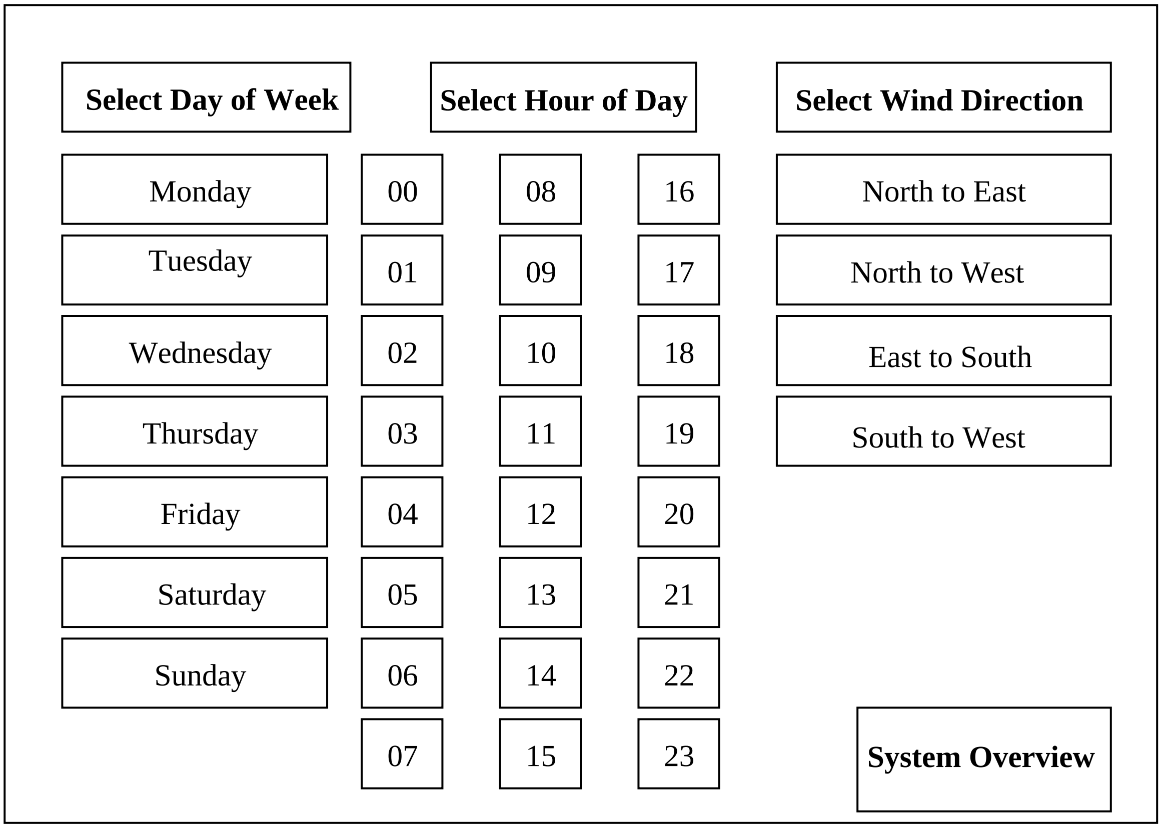
Appendix E: – PLC Controller



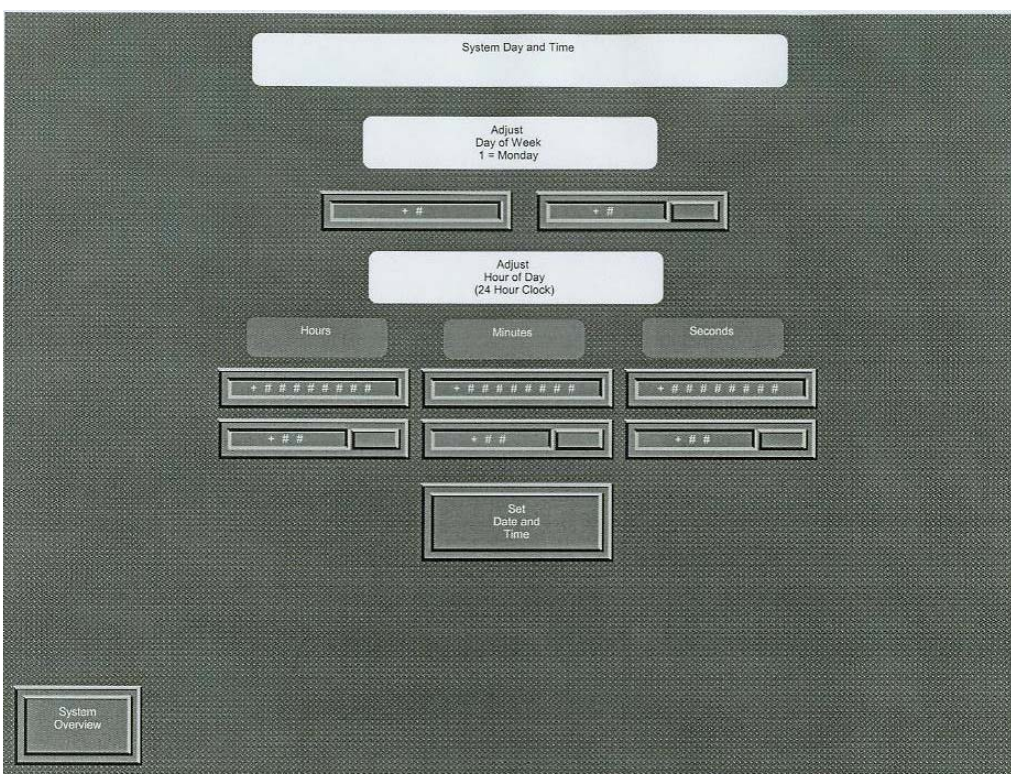
Appendix F: – HMI Interface (PLC Touch Panel)

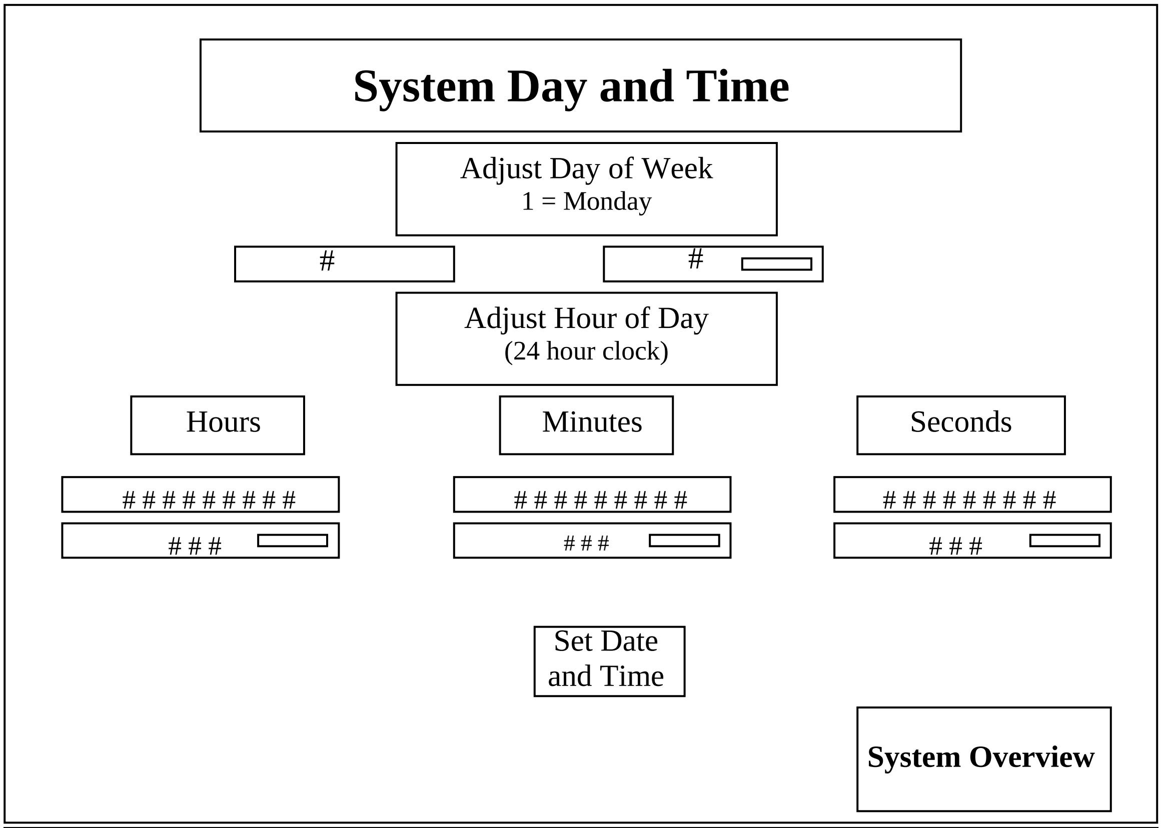
PLC screen shots from the local HMI (13" diagonal screen).





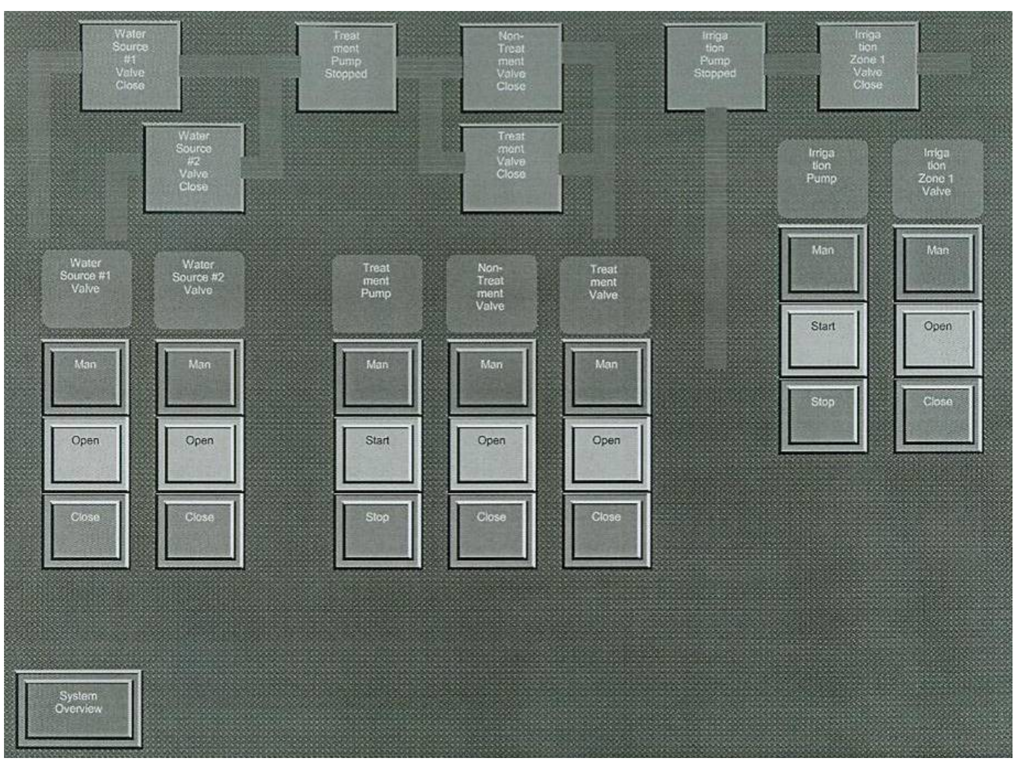
Appendix F: – HMI Interface (PLC Touch Panel) Cont.
PLC screen shots from the local HMI (13" diagonal screen).

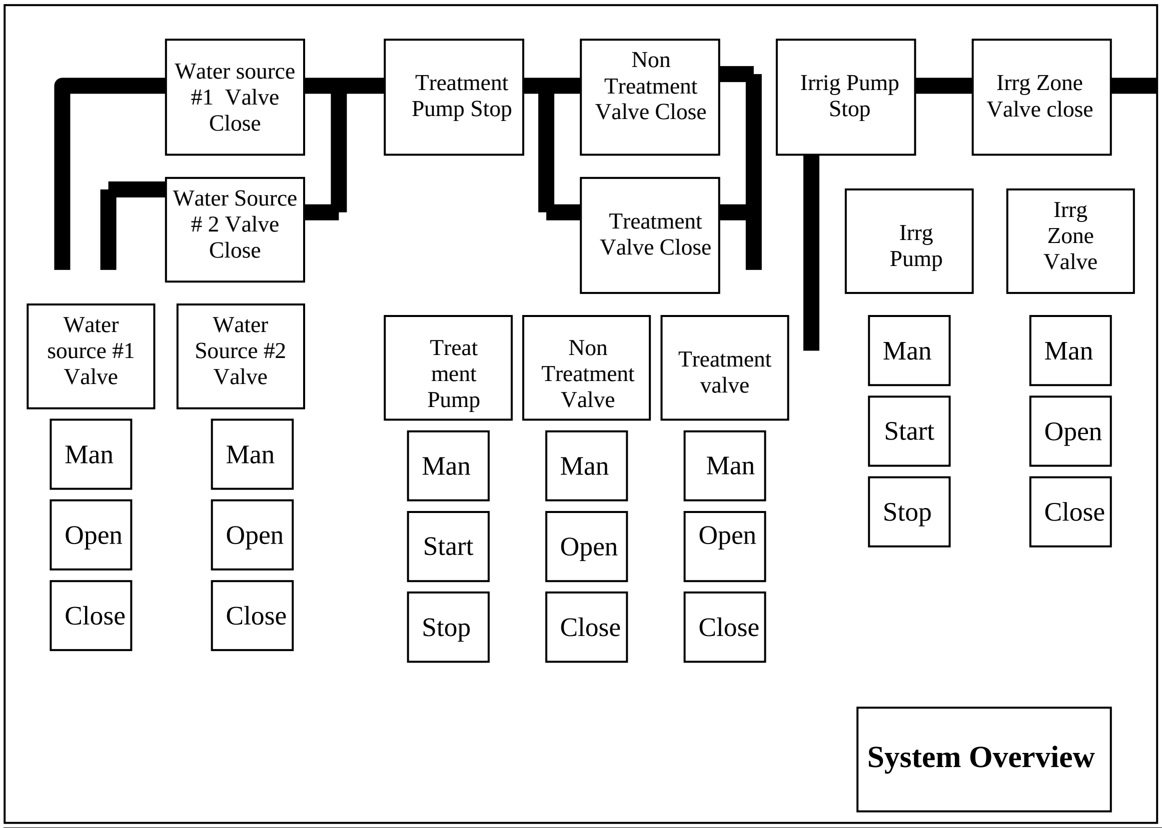




Appendix F: – HMI Interface (PLC Touch Panel) Cont.

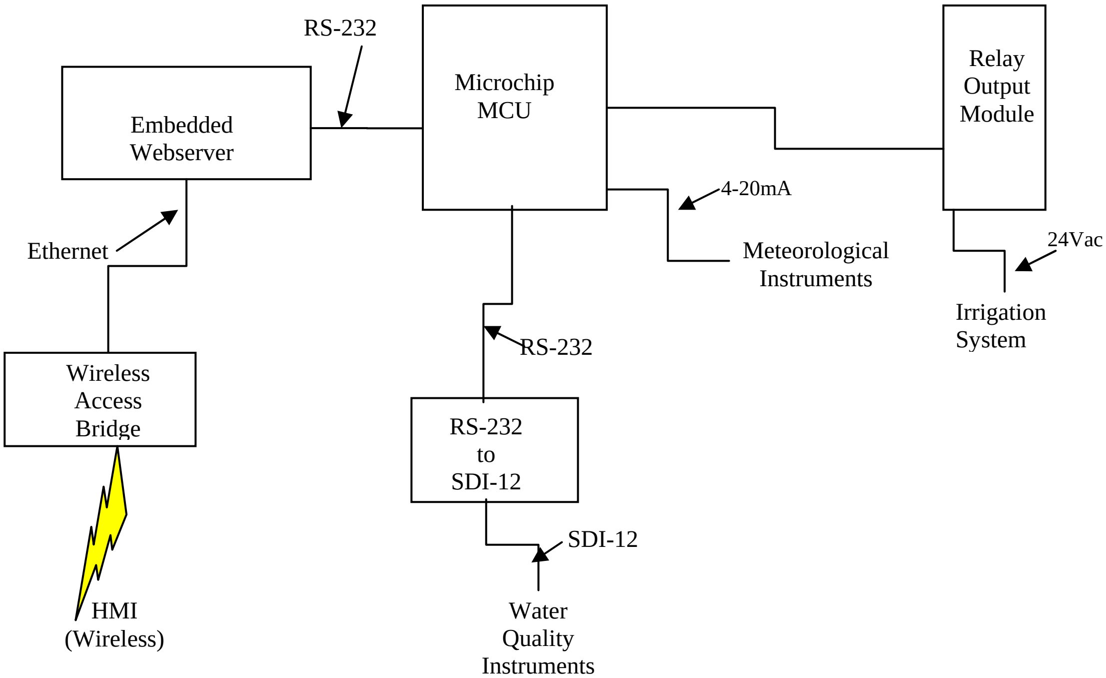
PLC screen shots from the local HMI (13" diagonal screen).




Water source #1 Valve Close
Treatment Pump Stop
Non Treatment Valve Close
Irrig Pump Stop
Irrg Zone Valve close
Water Source # 2 Valve Close
Treatment Valve Close
Irrg Pump
Irrg Zone Valve
Water source #1 Valve
Water Source #2 Valve
Treat ment Pump
Non Treatment Valve
Treatment valve
Man
Open
Close
Man
Open
Close
Man
Start
Stop
Man
Open
Close
Man
Open
Close
Man
Start
Stop
Man
Open
Close
System Overview

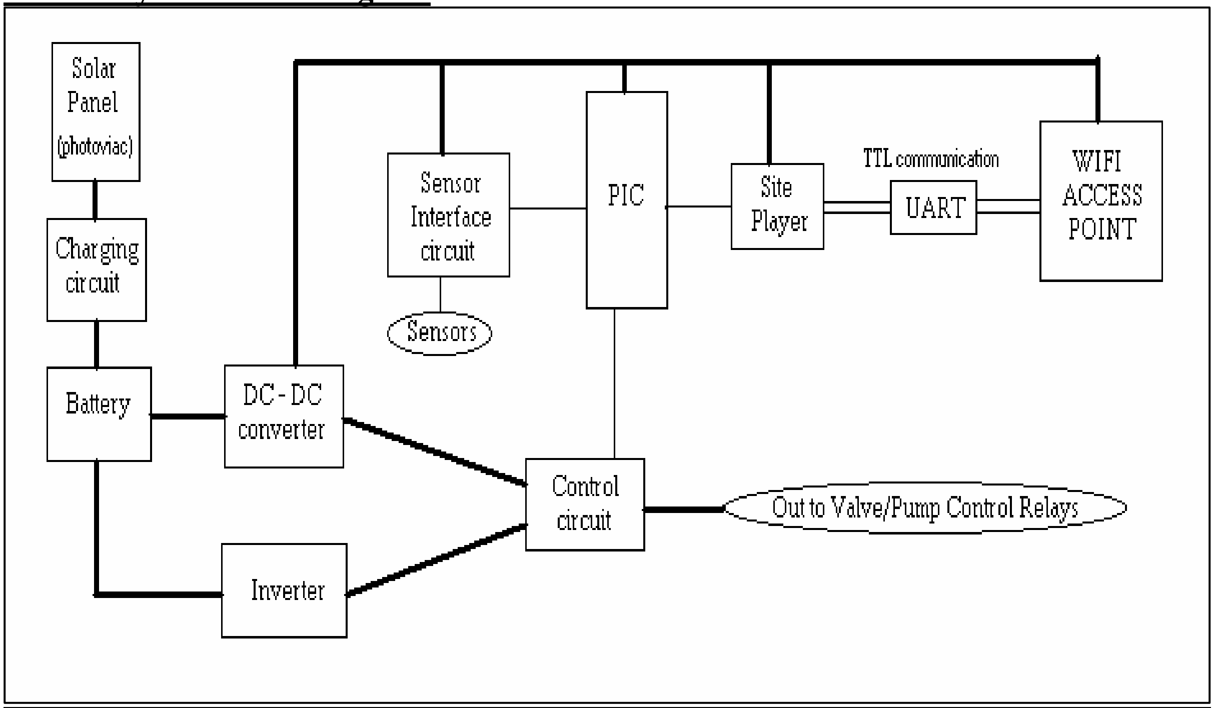
Appendix G: MCU Controller Block Diagram.

Controller – Microcontroller (MCU)

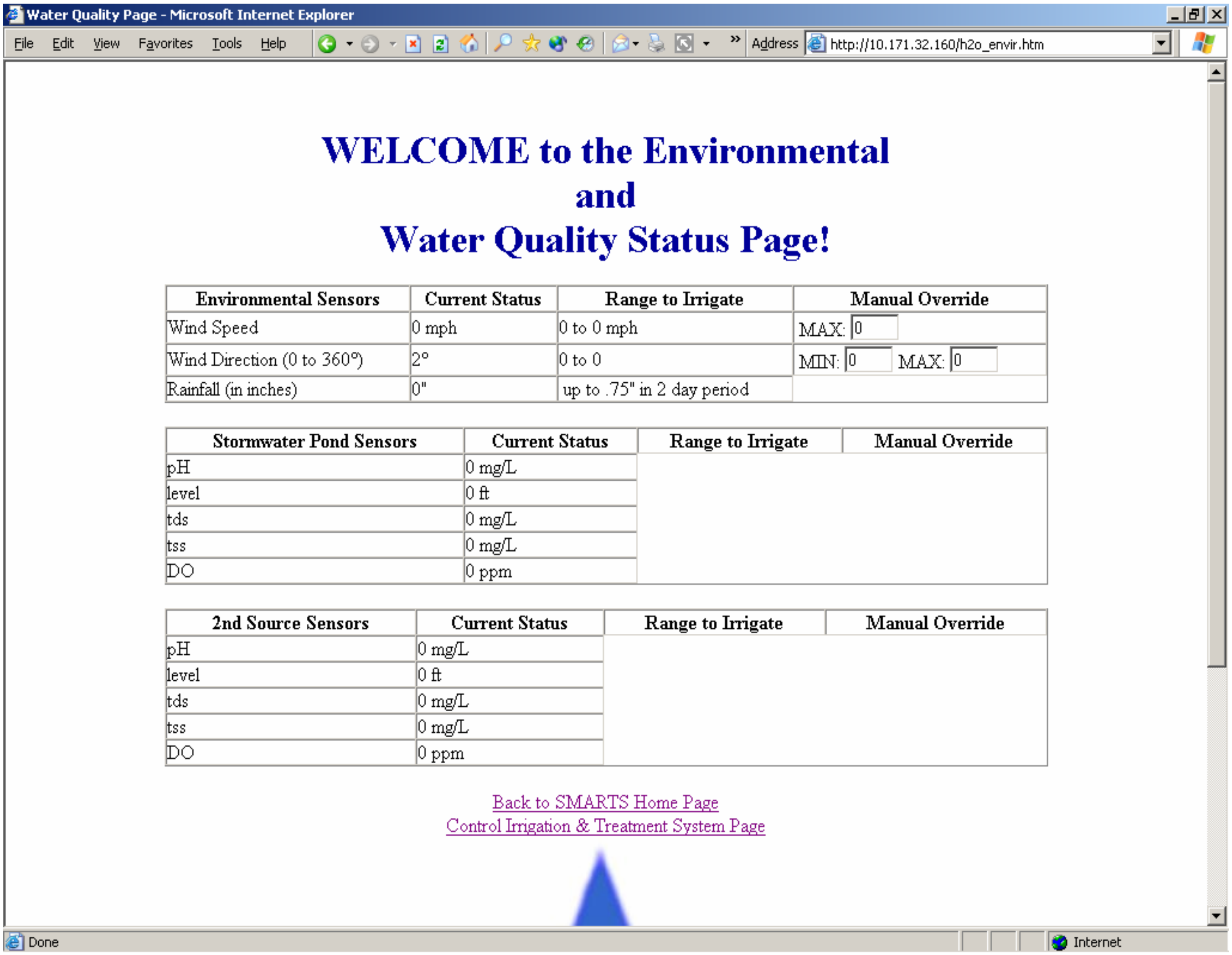


Appendix H: Overall System Block Diagram

Over all system Block Diagram



<u>Appendix I</u>: MCU webpage.
Created using the Ethernet embedded webserver.



Water Quality Page - Microsoft Internet Explorer

http://10.171.32.160/h2o_envir.htm

WELCOME to the Environmental and Water Quality Status Page!

Environmental Sensors	Current Status	Range to Irrigate	Manual Override
Wind Speed	0 mph	0 to 0 mph	MAX: 0
Wind Direction (0 to 360°)	2°	0 to 0	MIN: 0 MAX: 0
Rainfall (in inches)	0"	up to .75" in 2 day period	

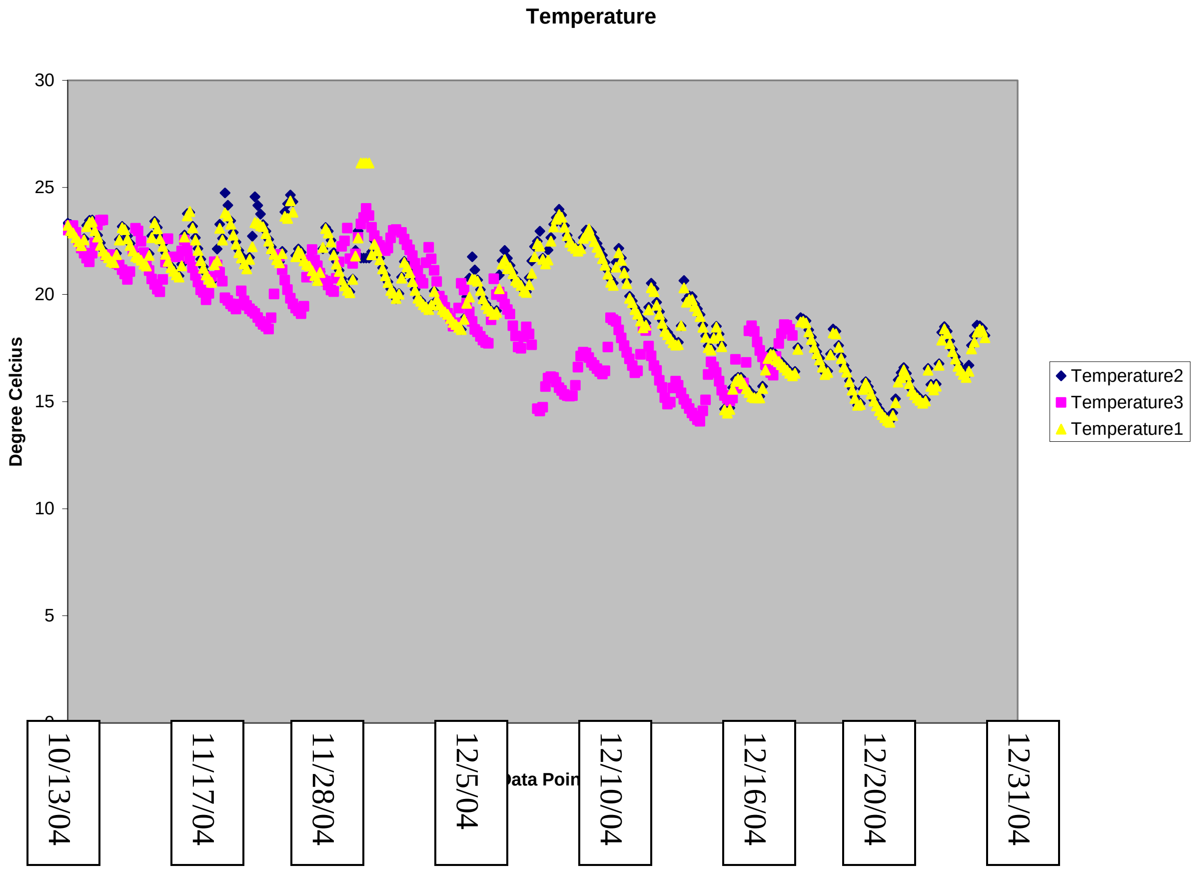
Stormwater Pond Sensors	Current Status	Range to Irrigate	Manual Override
pH	0 mg/L		
level	0 ft		
tds	0 mg/L		
tss	0 mg/L		
DO	0 ppm		

2nd Source Sensors	Current Status	Range to Irrigate	Manual Override
pH	0 mg/L		
level	0 ft		
tds	0 mg/L		
tss	0 mg/L		
DO	0 ppm		

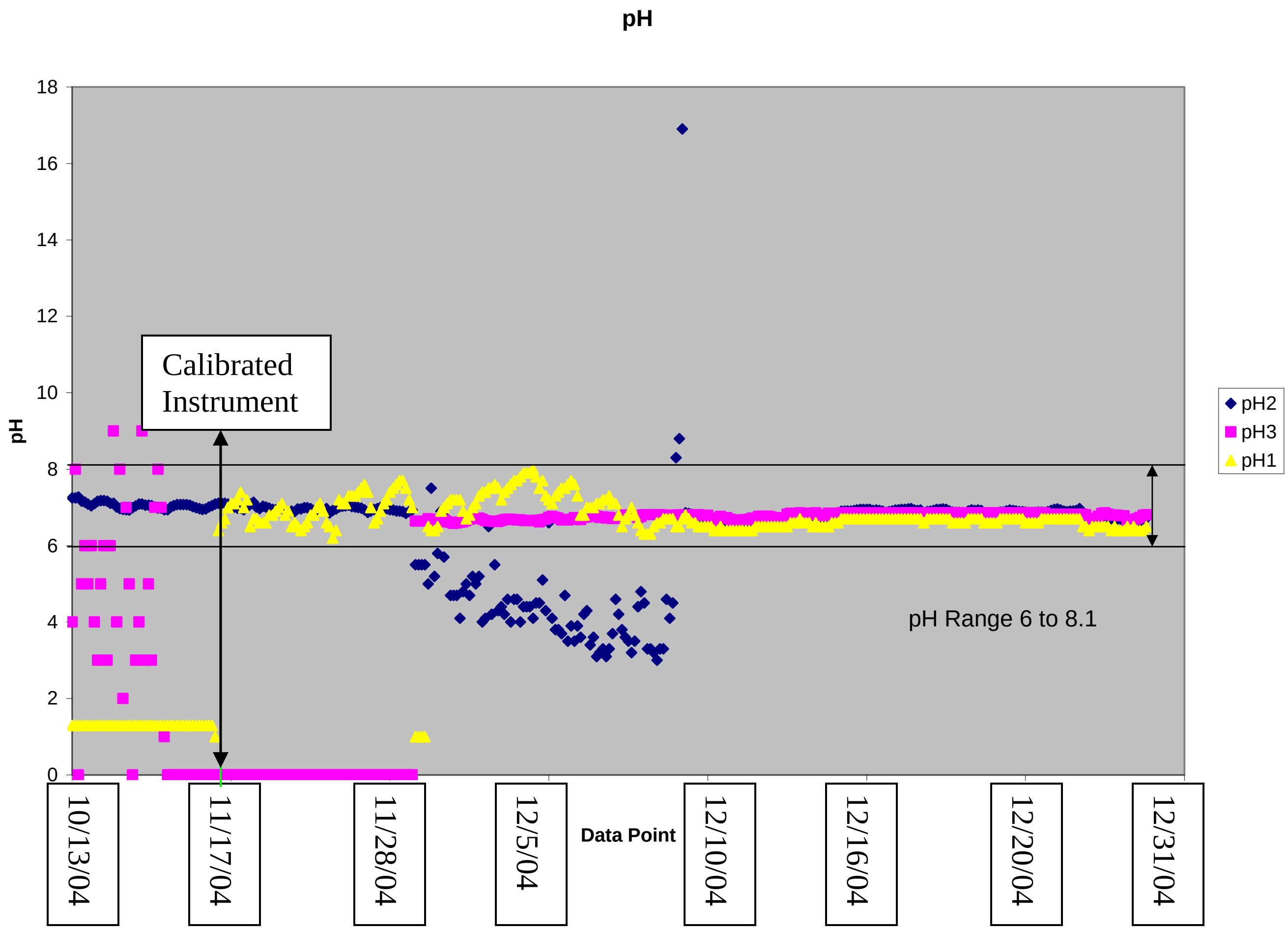
Back to SMARTS Home Page
Control Irrigation & Treatment System Page

Done Internet

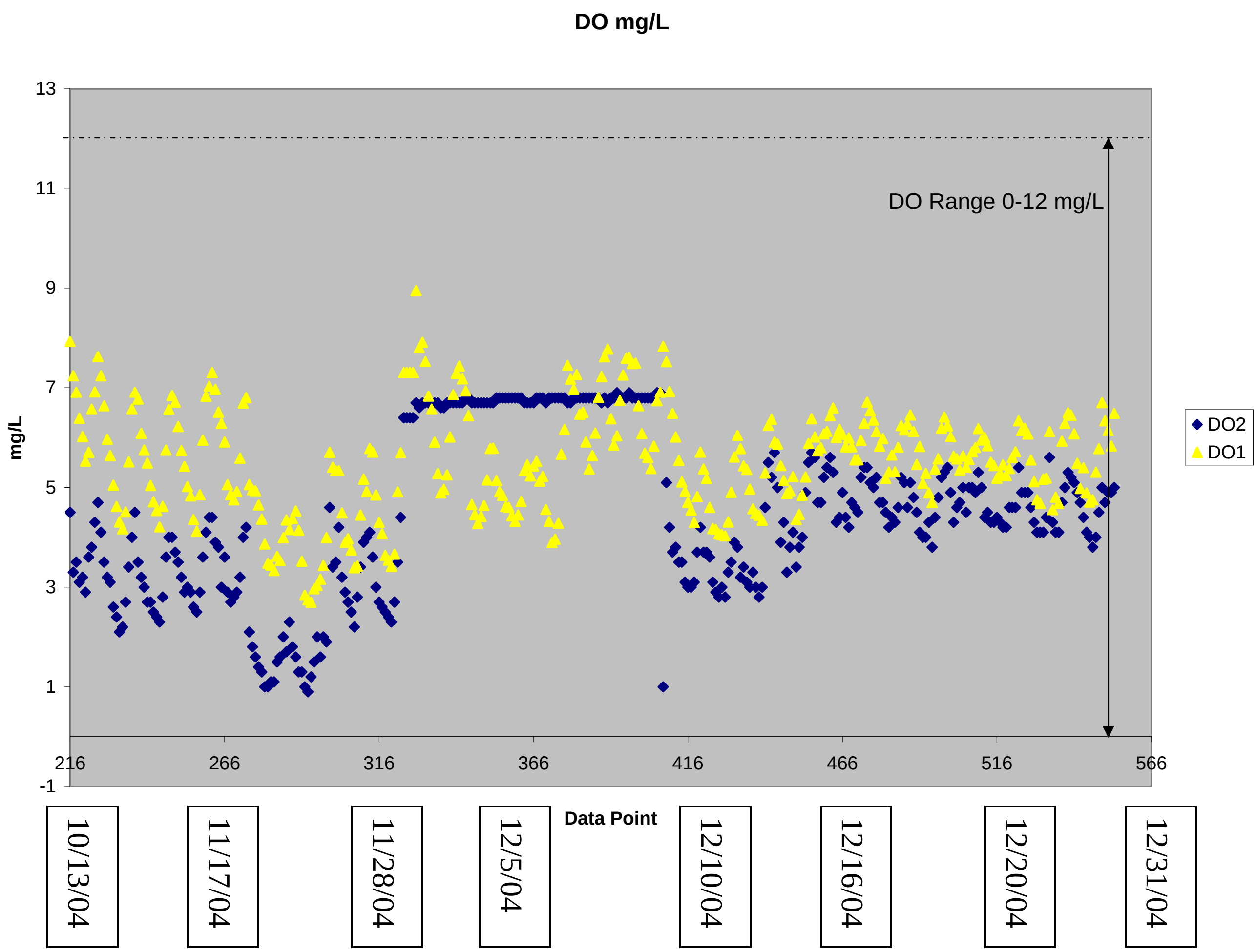
Appendix J – Data collected remotely by the controller for Temperature.



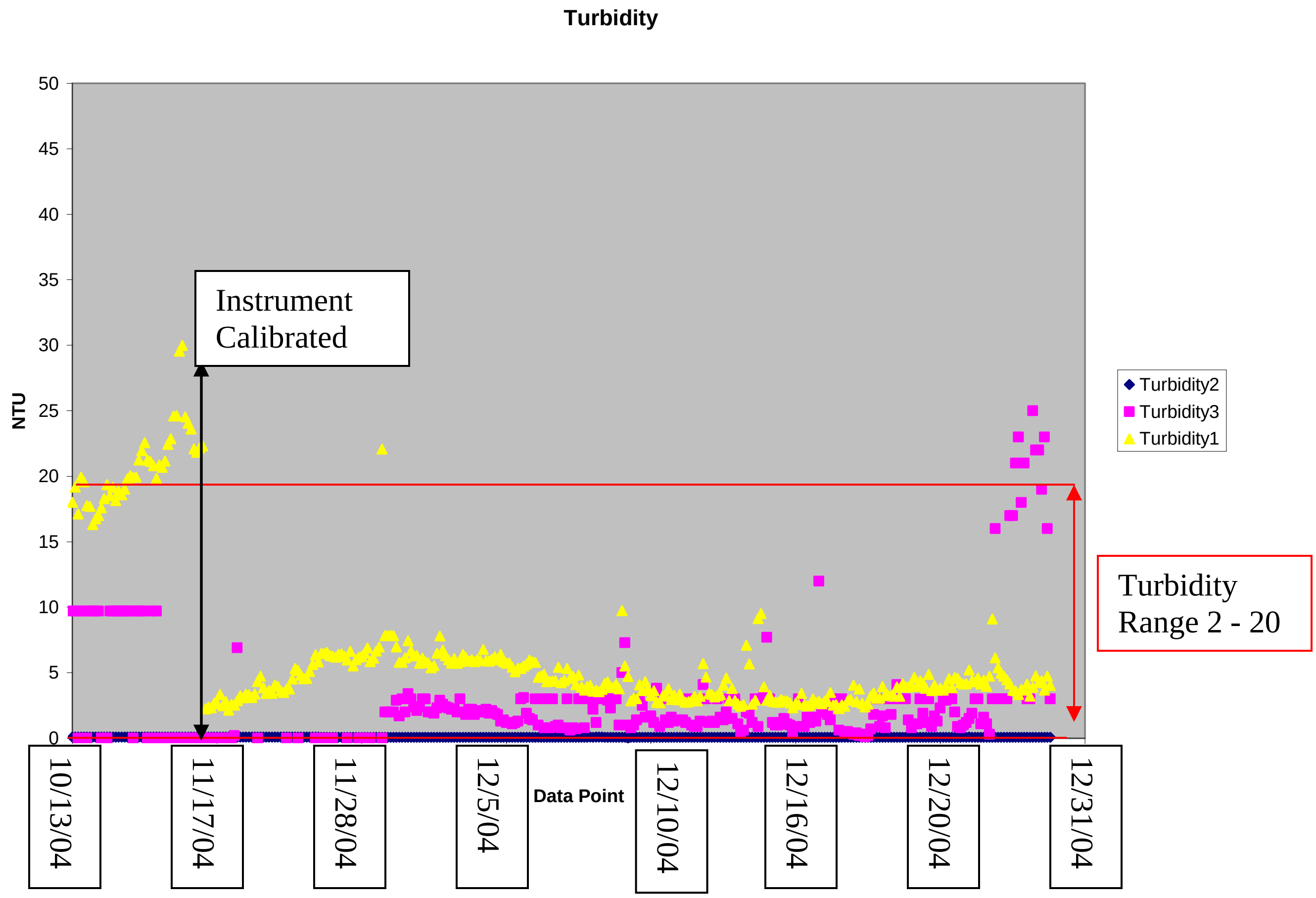
<u>Appendix J</u> – Data collected remotely by the controller for pH.



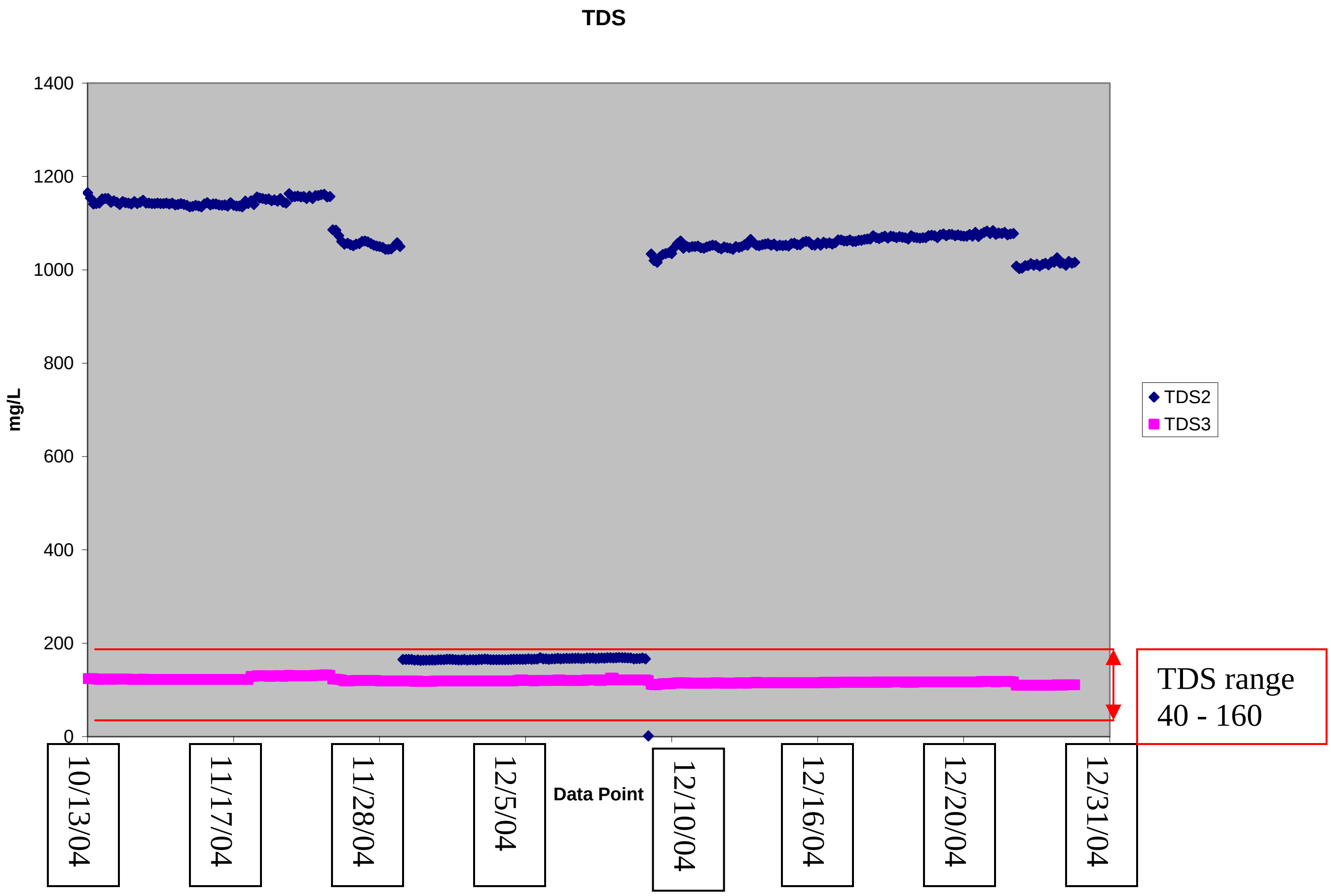
Appendix J – Data collected remotely by the controller for Dissolved Oxygen.



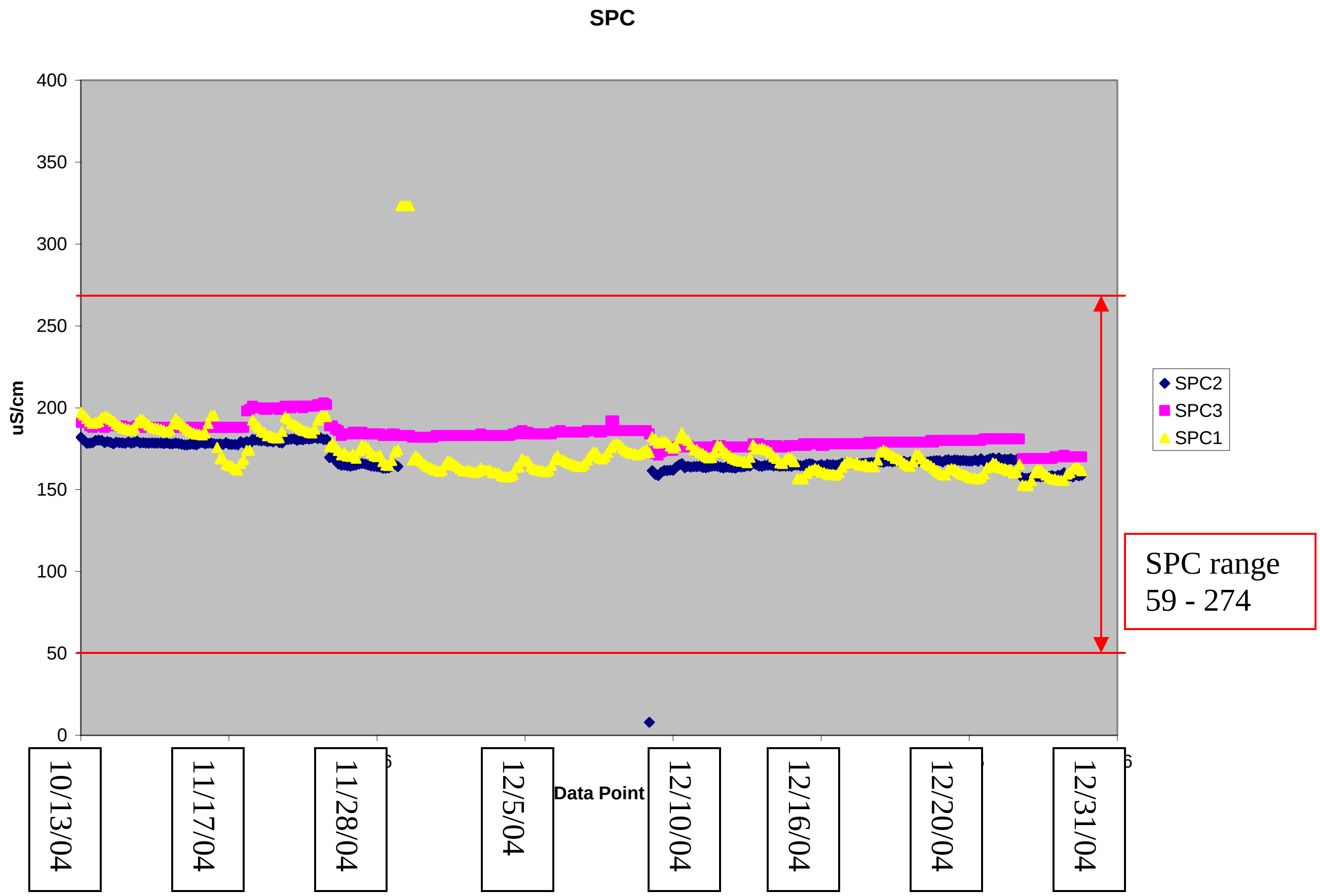
Appendix J – Data collected remotely by the controller for Turbidity.



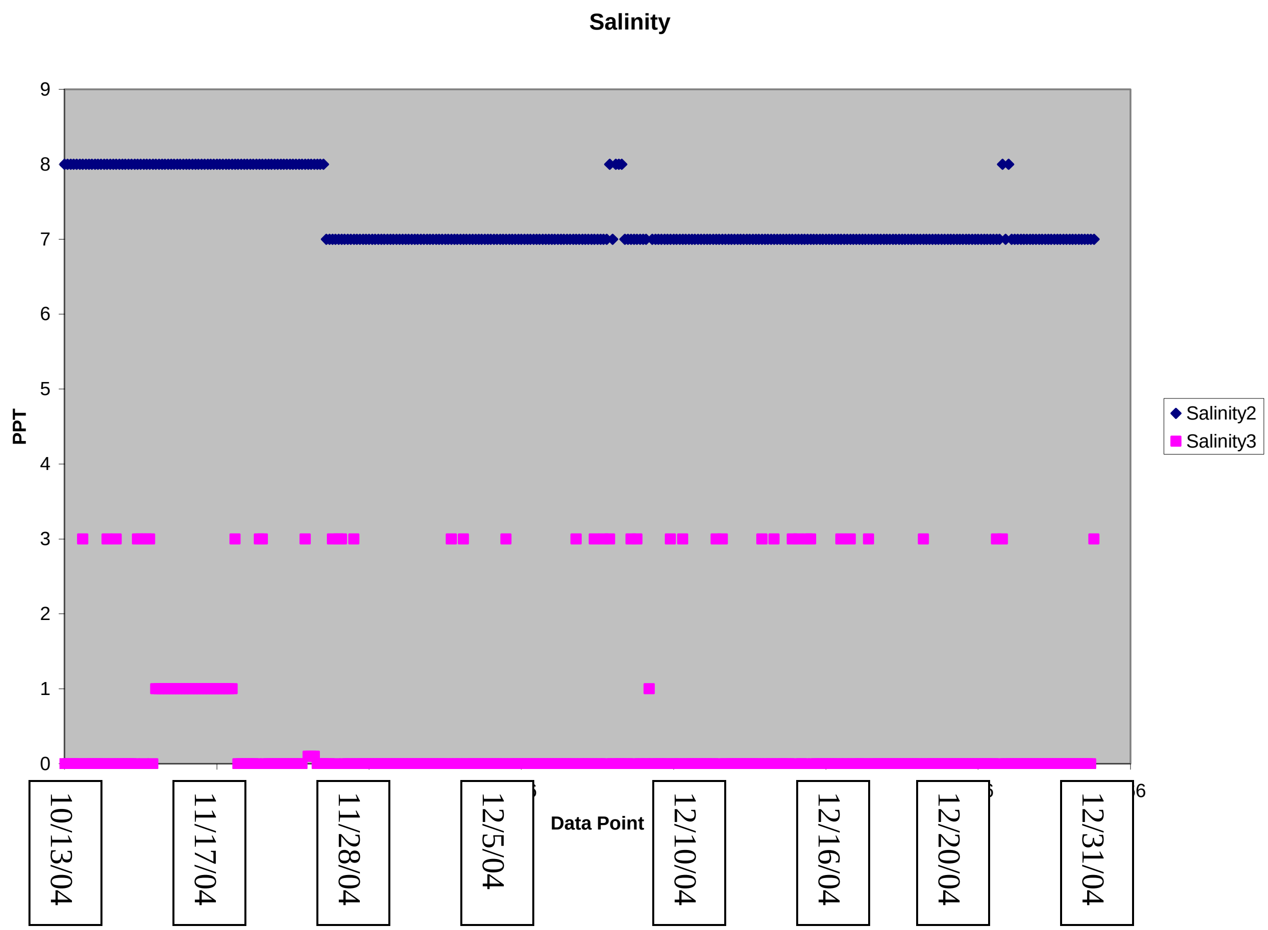
Appendix J – Data collected remotely by the controller for Total Dissolved Solids.



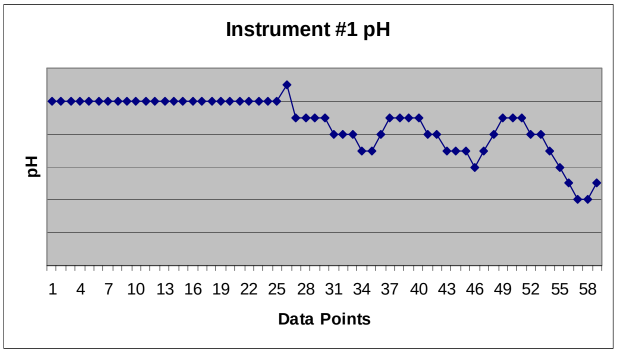
Appendix J – Data collected remotely by the controller for Specific Conductivity.

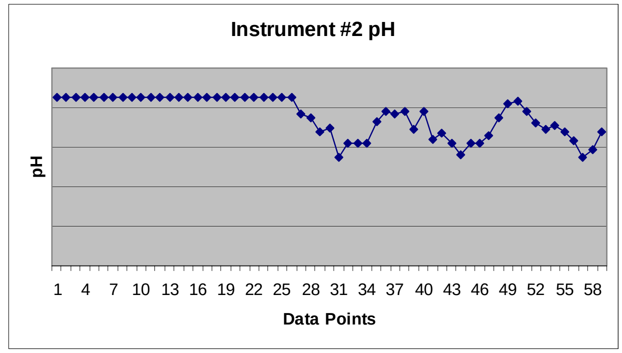


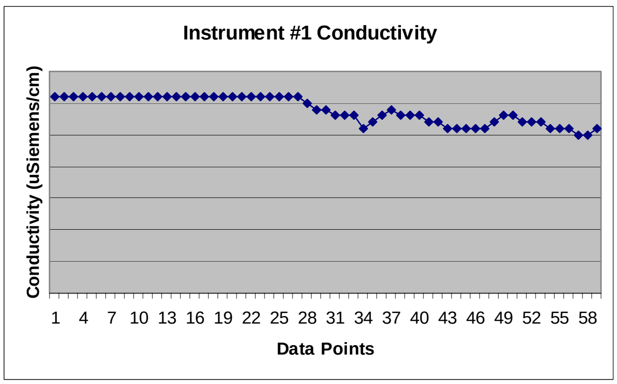
Appendix J – Data collected remotely by the controller for Salinity.

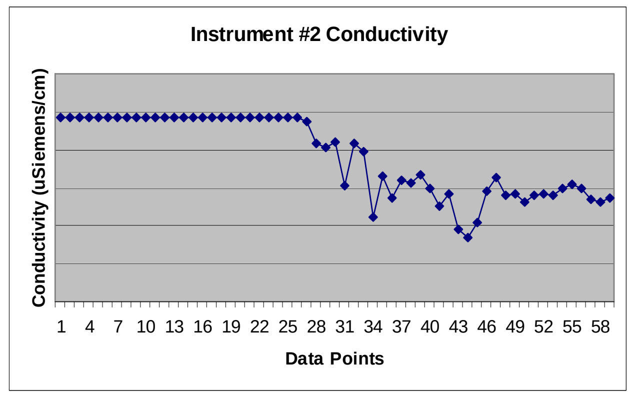


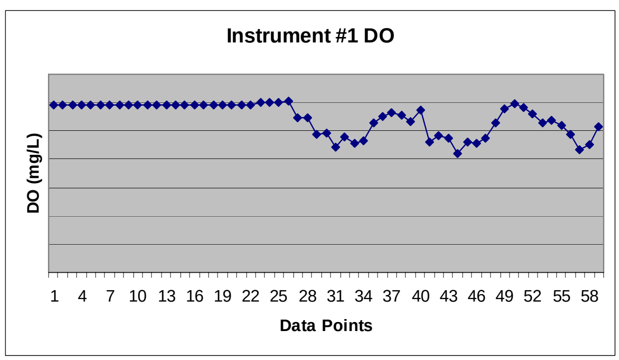
Appendix J: Water quality measurements – sample data over one business week with only 2 probes deployed.



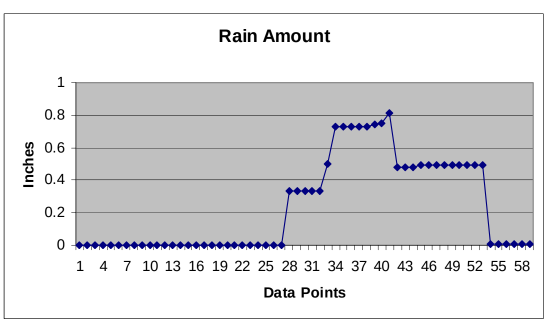


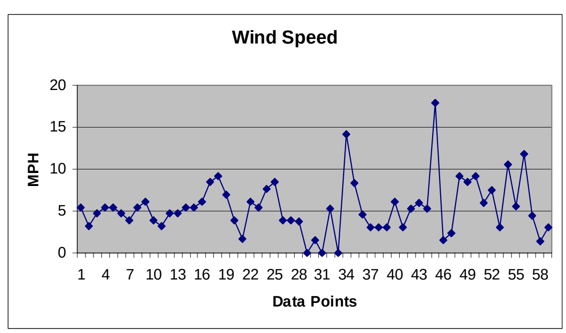




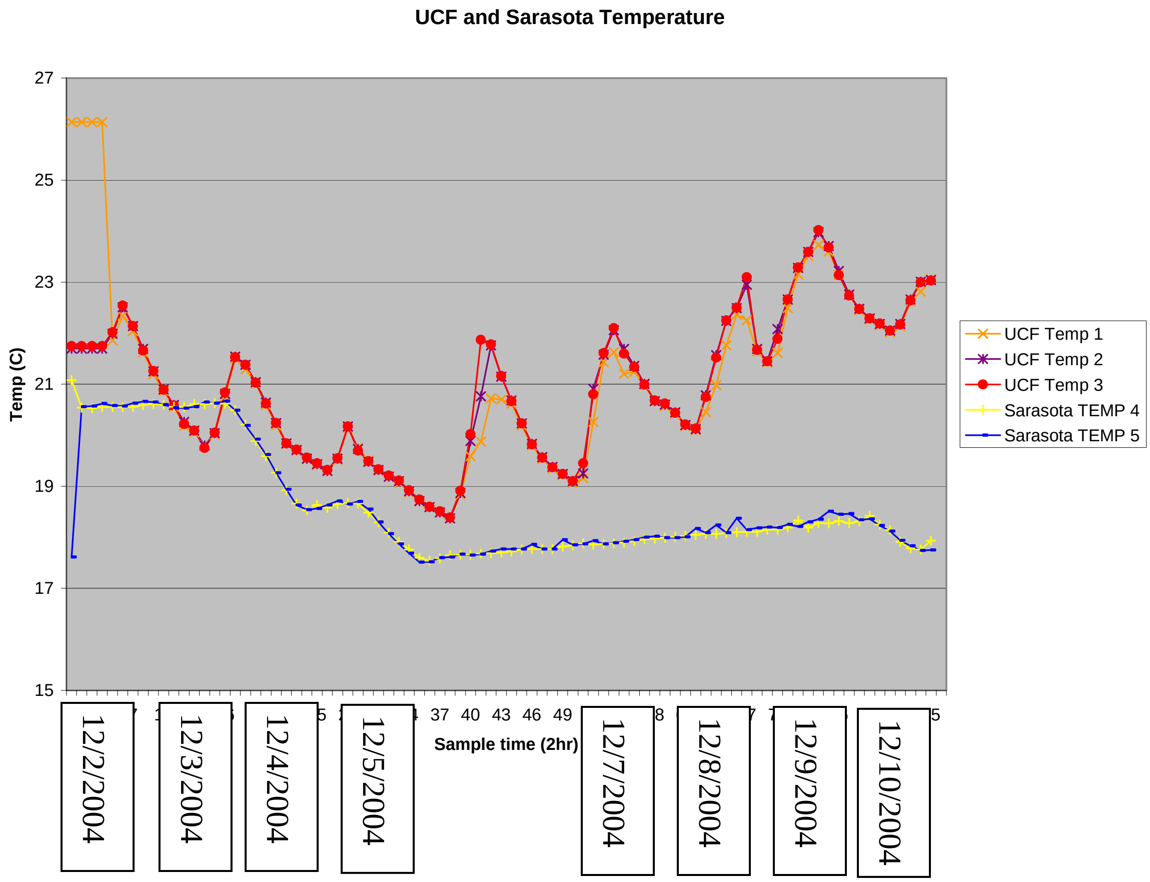


Meteorological Sensors

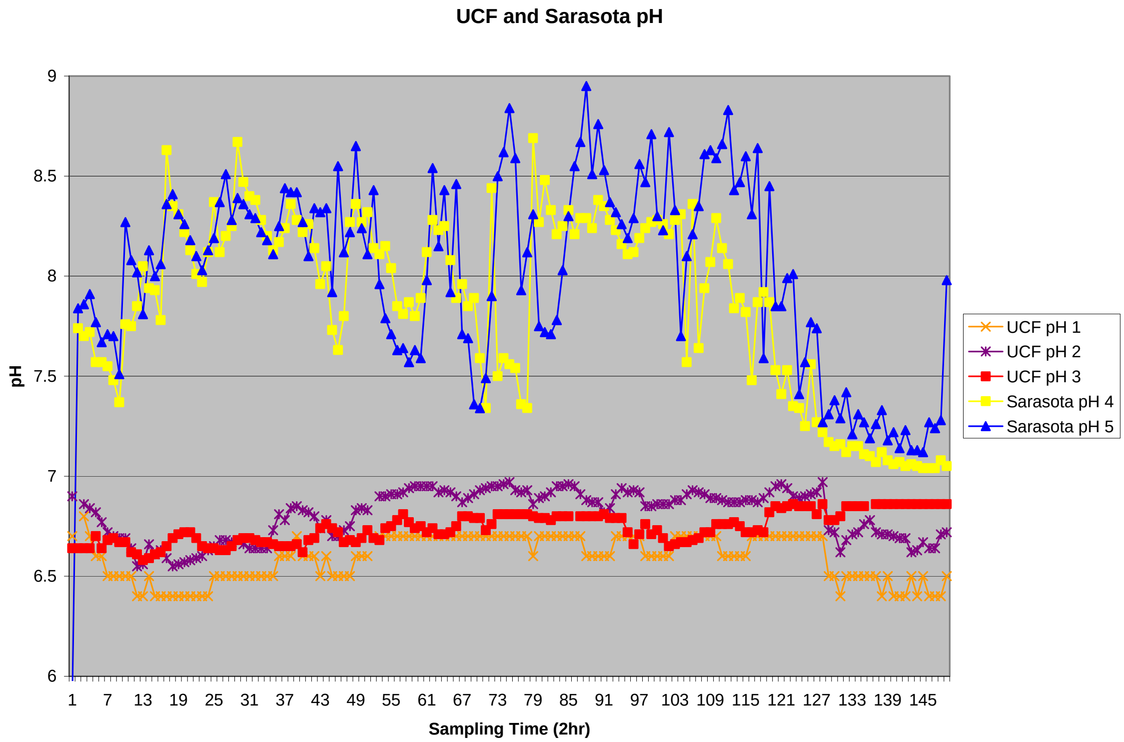


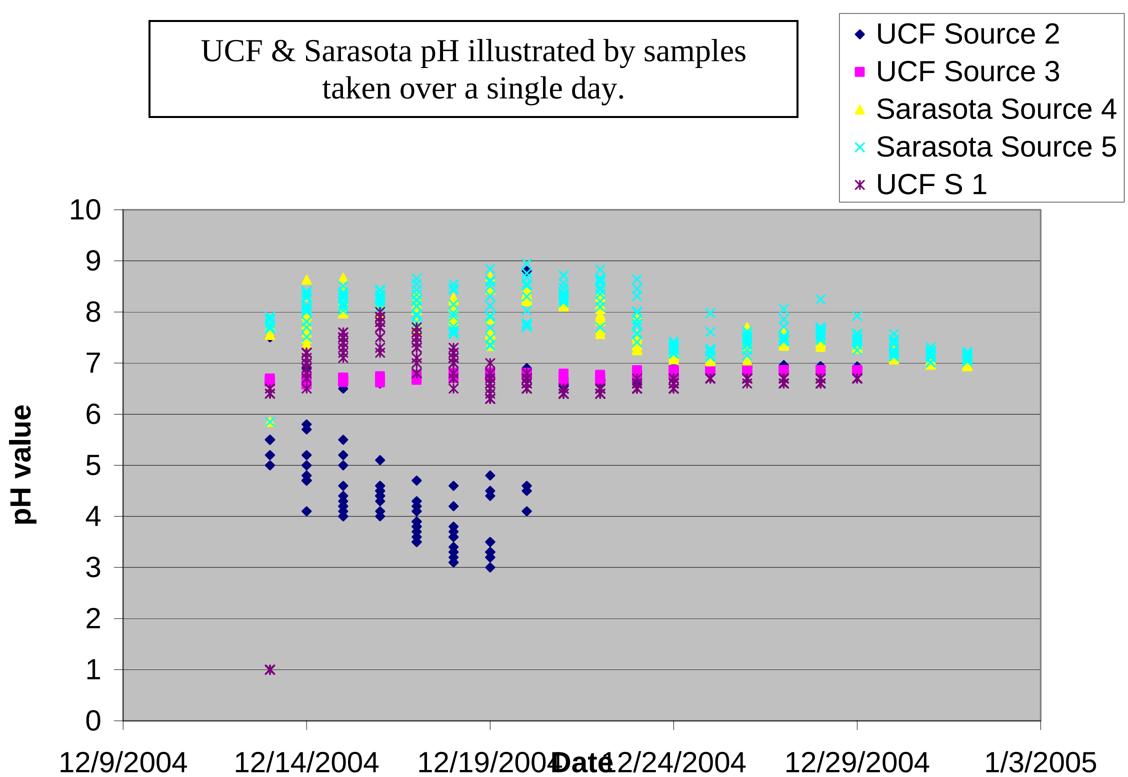


Appendix J: Water quality measurements – Comparison of UCF data collected to an independent study performed on Lake 62 in Sarasota.

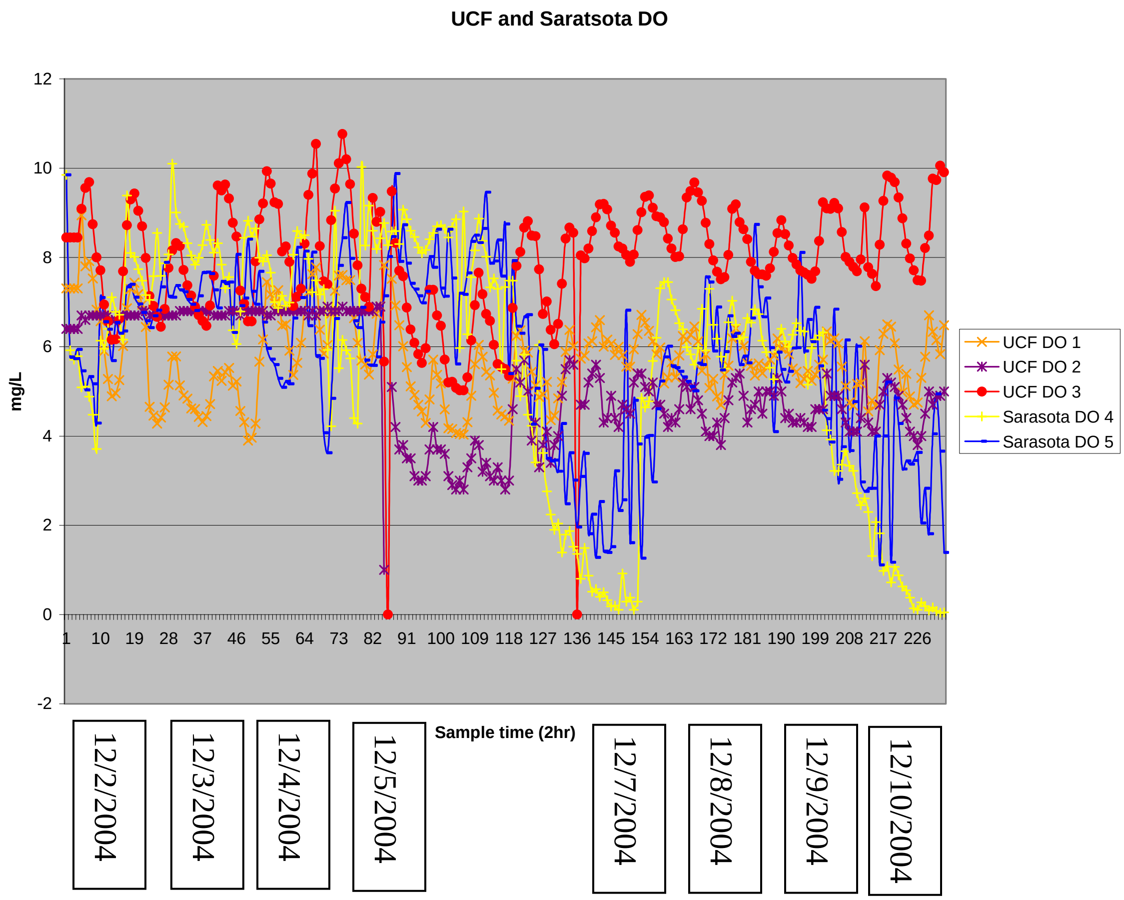


<u>Appendix J</u>: Water quality measurements – Comparison of UCF data collected to an independent study performed on Lake 62 in Sarasota.

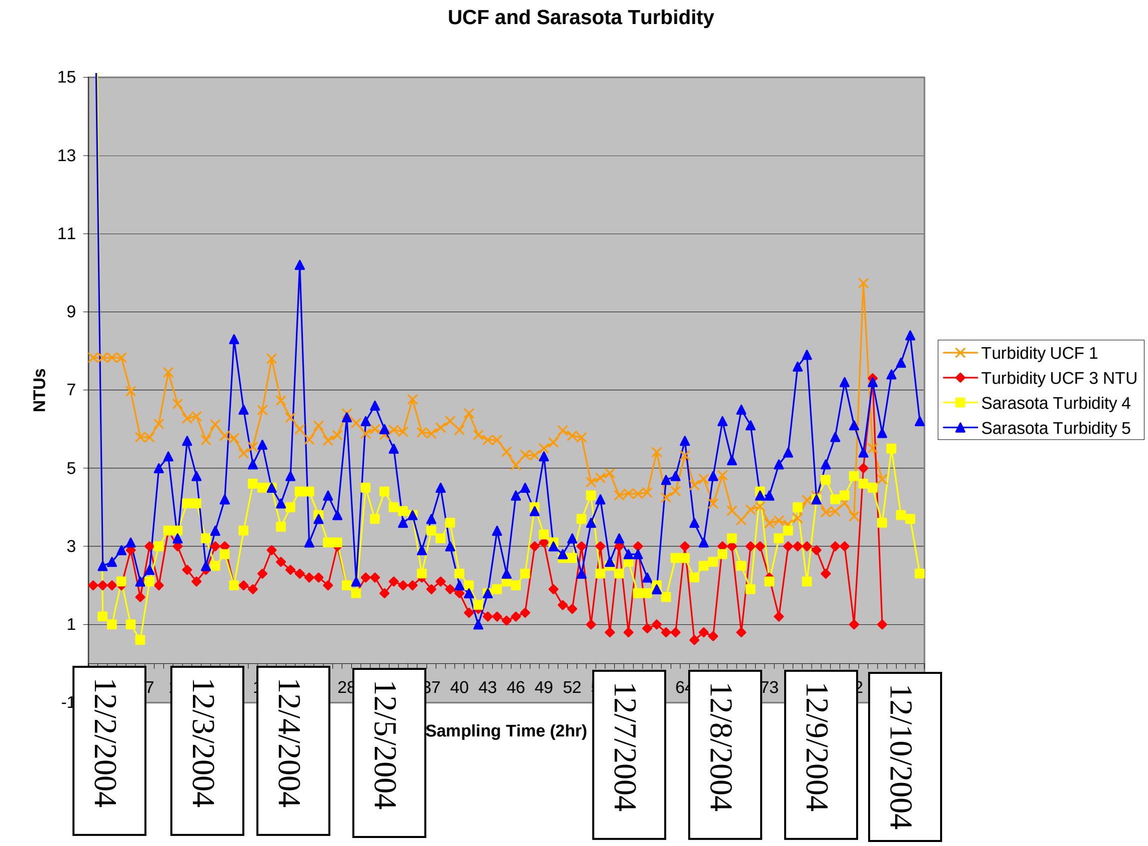


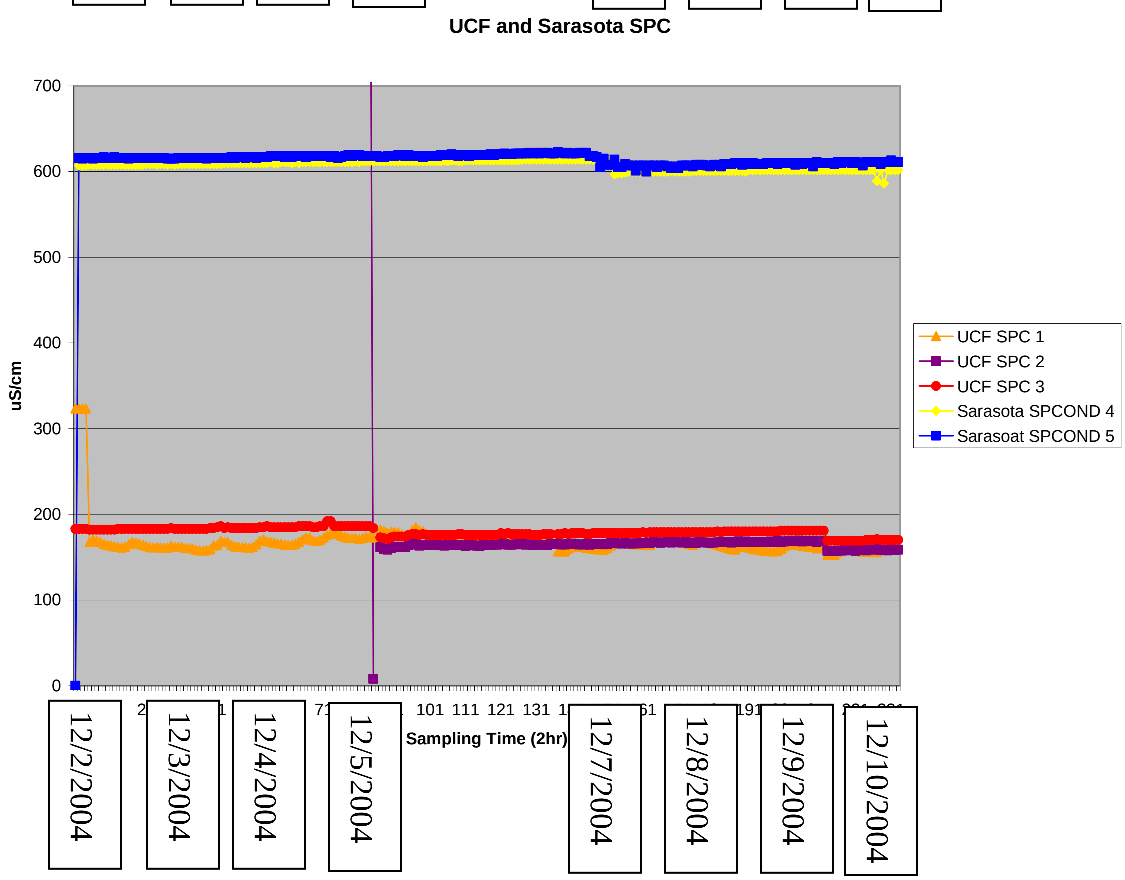


<u>Appendix J</u>: Water quality measurements – Comparison of UCF data collected to an independent study performed on Lake 62 in Sarasota.

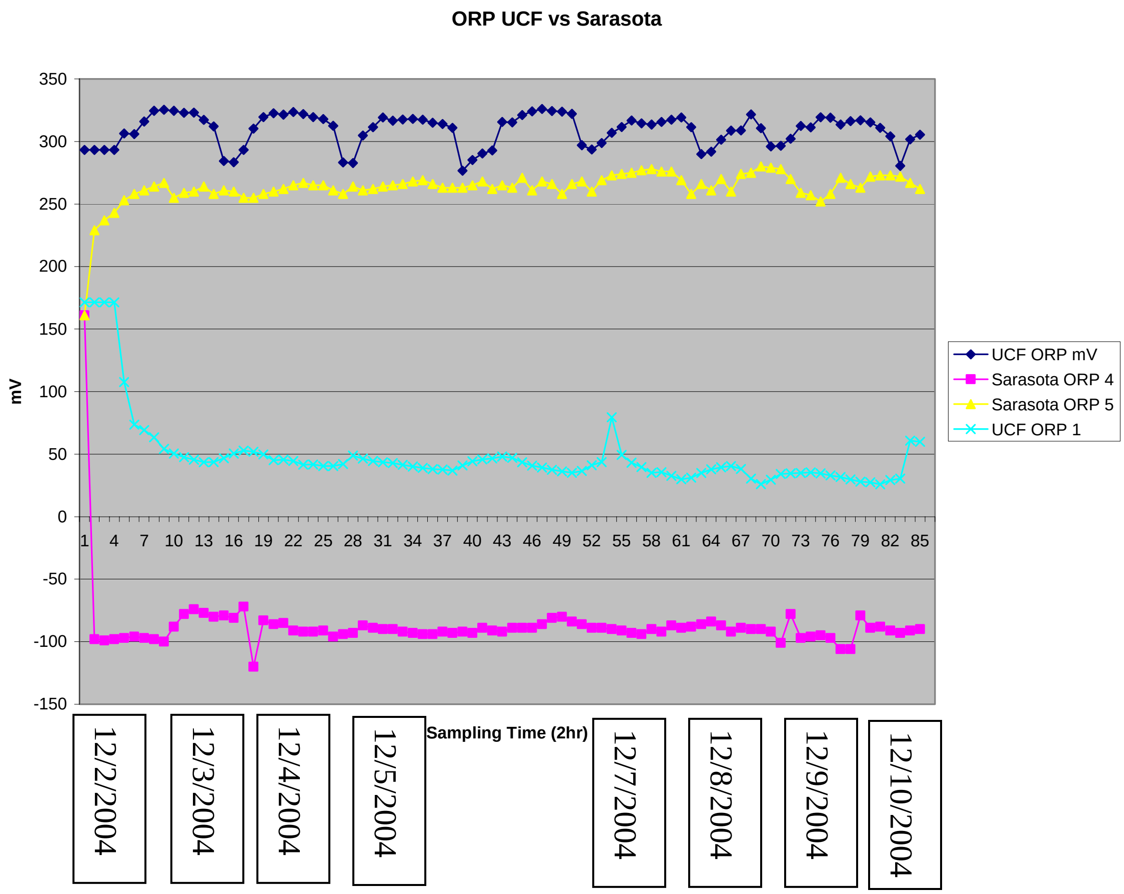


Appendix J: Water quality measurements – Comparison of UCF data collected to an independent study performed on Lake 62 in Sarasota.

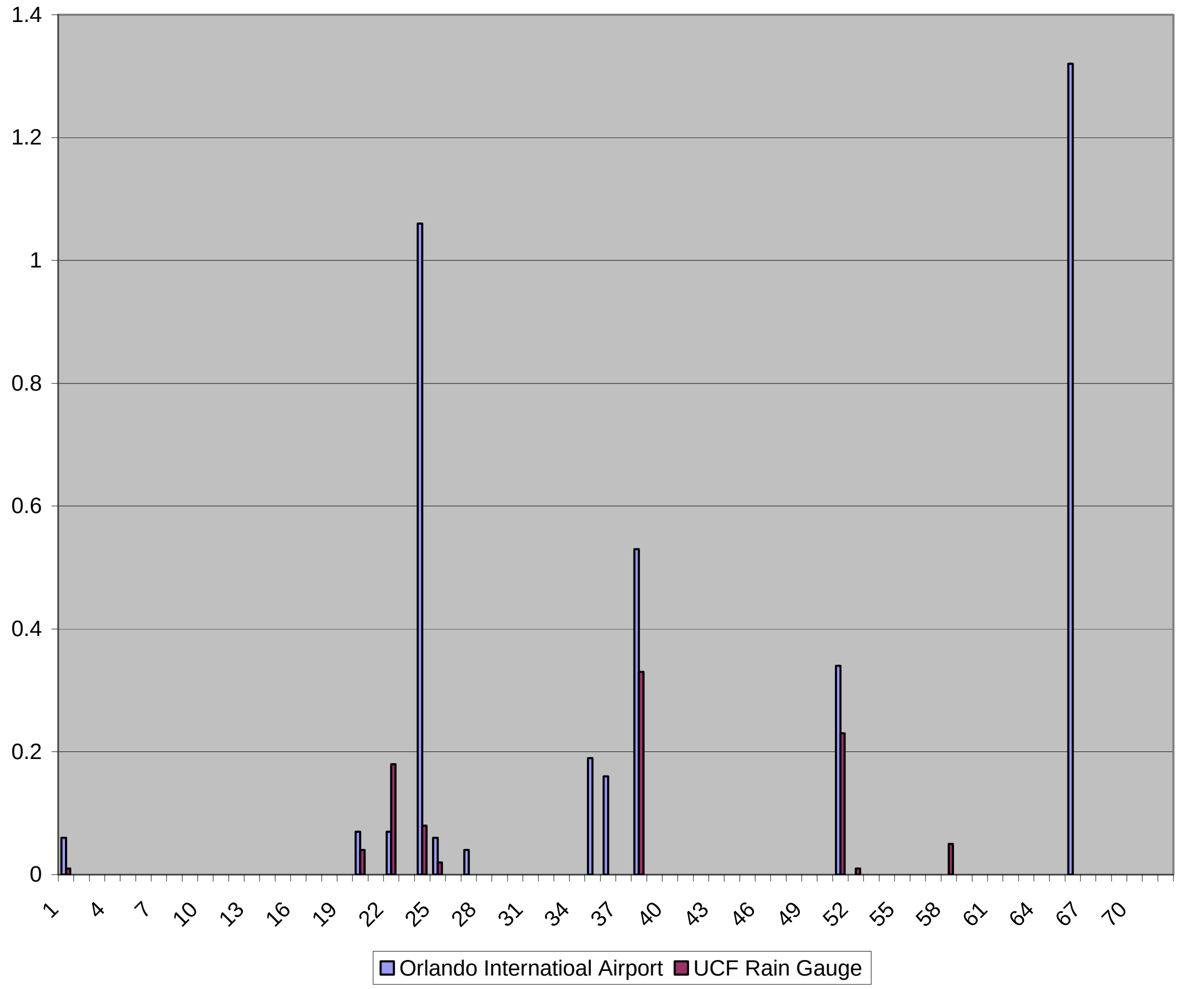




Appendix J: Water quality measurements – Comparison of UCF data collected to an independent study performed on Lake 62 in Sarasota.



<u>Appendix K</u> – Rain Data collected by the controller at UCF and compared to the City of Orlando data from the airport.



Appendix L – Typical Performance Specifications for Sensors.

Temperature	
Sensor Type	Thermistor
Range	-5 to 45 ˚C
Accuracy	+/- 0.15 ˚C
Depth	200 meters

pH	
Sensor type	Glass electode
Range	0-14
Accuracy	+/- 0.2
Depth	200 meters

Dissolved Oxygen, mg/L	
Sensor Type	Depends on vendor
Range	0 to 50 mg/L
Accuracy	Varies per vendor
Depth	200 meters

Turbidity	
Sensor type	Optical
Range	0 to 1000 NTU
Accuracy	Varies per vendor – several vendors offer a wiper which improves the measurements.
Depth	60 meters

Conductivity	
Sensor type	electrode cell
Range	0 to 100 mS/cm
Accuracy	varies per vendor
Depth	200 meters

Salinity	
Sensor type	Typically a calculation from conductivity and temperature
Range	0 to 70 ppt
Accuracy	Varies per vendor

Appendix L – Typical Performance Specifications for Sensors cont.

TDS	
Sensor Type	Generally a conversion calculation
Range	0 to 100 g/L
Accuracy	+/- 5 g/L

- All vendor sensors met the range of measurement required for the stormwater pond test site as stated in Appendix I.

Sensors for Nutrients

Nitrate-Nitrogen	
Sensor Type	Ion-selective electrode
Range	0 to 200 mg/L-N
Accuracy	2 mg/L
Depth	15 meters

Ammonium – Nitrogen & Ammonia-Nitrogen	
Sensor Type	Ion-selective electrode vs calculated from ammonium, pH & Temp
Range	0 to 200 mg/L-N
Accuracy	2 mg/L
Depth	15 meters

Chloride	
Sensor Type	Solid state ion-selective electrode
Range	0 to 1000 mg/L
Accuracy	5 mg/L
Resolution	1 mg/L (range dependent)
Depth	15 meters

Chlorophyll	
Sensor Type	Optical, fluorescence, with mech. cleaning (varies per vendor)
Range	0 – 400 μg/L Chl
Depth	66 meters

Phosphorus (PO4)	
System Type	Analytical system (other nutrient parameters available with flush method at varying ranges and methods)
Method	Colorimetric Std. Method 4500 – NO3 D
Range	0.05 – 3 mg/L
Total Phosphorus	
Method	Colorimetric Std. Method 4500 -B
Range	0.1 – 3 mg/L

Appendix M: Calibration Procedures

Before Calibration Procedure begins:
A laptop with wireless card and proper calibration programs installed is necessary to perform the calibration process. In addition, blank copies of the calibration worksheet are printed.

Water Quality Instrument 1 (WQI1):

1) The WQI1 cord is connected to the computer through the USB port while the other end is screwed into the top of the WQI1 unit
2) Open WQI1 software from computer desktop
3) Click COM1-9600 and select *Find*
4) Select Parameters from the left-hand side toolbar

Note: When connecting the unit to the connection cord, turn the WQI1 upside down and carefully engage threading. The unit can be damaged if over-tightened

Conductivity:

1) Place a small amount of conductivity standard reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Repeat the process with new calibration standard
4) Fill calibration cup halfway full of new calibration standard, and tilt to completely cover conductivity sensor while laying flat
5) Select Port 4: Conductivity
6) Select *Calibrate*, followed by *Next*, and then *Run*
7) Allow the program to run and wait a few minutes until stabilization occurs
8) Save calibration report in folder, confirm the K-cell range: 5.1-5.7
9) Remove calibration cup, reserve conductivity standard for future pre-rinsing
10) Rinse cup and sensors with tap water

pH:

1) Place a small amount of pH 7 buffer reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Repeat the process with new pH 7 buffer
4) Fill calibration cup halfway full of new pH 7 buffer, and tilt to completely cover pH sensor while laying flat
5) Select pH
6) Select *Calibrate*, followed by *Next*, and then *Run*
7) Allow the program to run and wait a few minutes until stabilization occurs
8) Remove calibration cup, reserve pH 7 buffer for future pre-rinsing
9) Rinse cup and sensors with tap water
10) Place a small amount of pH 4 buffer reserved from last calibration in calibration cup, tighten cup around sensors, and swirl

Appendix M: Calibration Procedures continued.

11) Empty calibration cup and repeat the process
12) Repeat the process with new pH 4 buffer
13) Fill calibration cup halfway full of new pH 4 buffer, and tilt to completely cover pH sensor while laying flat
14) Select *Calibrate*, followed by *Next*, and then *Run*
15) Allow the program to run and wait a few minutes until stabilization occurs
16) Save calibration report in folder, confirm the range: 4.4 – 5.8
17) Remove calibration cup, reserve pH 4 buffer for future pre-rinsing
18) Rinse cup and sensors with tap water

Turbidity:

1) Place a small amount filtered DI water in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Remove calibration cup and replace with slotted guard with small black cap on, but spinner portion removed.
4) Place In-Situ unit into a beaker of filtered DI water in black bag to avoid exposure to light
5) On computer, select: 1 point calibration
6) Key 0 for 0 NTU
7) Hit enter to run program
8) Allow the program to run and wait a few minutes until stabilization occurs
9) Save calibration report in folder

DO Calibration:

Note: The DO membrane must relax at least three hours prior to calibration

1) If the DO membrane was not changed, skip to step 3
2) Select the DO parameter from the left-hand side toolbar and allow the program to run for a few minutes
3) Remove slotted guard and replace with calibration cup
4) Turn the WQI1 unit upside down
5) Confirm calibration cup is filled with filtered DI water to DO sensor membrane
6) Blot DO membrane dry with lint-free tissue
7) Loosen black end cap of calibration cup until small hole in threads in exposed and let the unit sit undisturbed for 10 minutes
8) Key 760 mm Hg for atmospheric pressure
9) Hit enter to run program
10) Allow the program to run and wait a few minutes until stabilization occurs
11) Save calibration report in folder, confirm a slope of 15-34 nA/mg/L

Appendix M: Calibration Procedures continued.

After the calibration session ends:

1) Record values on calibration worksheet and confirm range is sufficient, according to Table 1 below:

Table 1: WQI1 Diagnostic Values

Parameter	Range
Conductivity Cell Constant	5.1 - 5.7
pH 7 offset	390 - 450 MV
DO slope	15 - 34 nA/mg/L
DO offset	2 nA

Water Quality Instrument 2 (WQI2):

1) The WQI2 cord is connected to the computer through the USB port while the other end is plugged into the top of the WQI2 and the external power cable is connected to an electricity source
2) Open WQI2 software from computer desktop
3) Select *Operate WQI2*
4) Select *Calibration* tab

Note: When connecting the unit to the connection cord, line dot with large prong in connector unit

Conductivity:

1) Place a small amount of conductivity standard reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Repeat the process with new calibration standard
4) Fill calibration cup halfway full of new calibration standard, and tilt to completely cover conductivity sensor while laying flat
5) Select *Conductivity* tab
6) Record real-time calibration value and key in calibration standard
7) Select *Calibrate*
8) Allow the program to run and wait a few minutes until stabilization occurs
9) Remove calibration cup, reserve conductivity standard for future pre-rinsing
10) Rinse cup and sensors with tap water

Appendix M: Calibration Procedures continued.

pH:

1) Place a small amount of pH 7 buffer reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Repeat the process with new pH 7 buffer
4) Fill calibration cup halfway full of new pH 7 buffer, and tilt to completely cover pH sensor while laying flat
5) Select *pH* tab
6) Record real-time calibration value and key in 7 for pH 7 buffer
7) Select *Calibrate*
8) Allow the program to run and wait a few minutes until stabilization occurs
9) Remove calibration cup, reserve pH 7 buffer for future pre-rinsing
10) Rinse cup and sensors with tap water
11) Place a small amount of pH 4 buffer reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
12) Empty calibration cup and repeat the process
13) Repeat the process with new pH 4 buffer
14) Fill calibration cup halfway full of new pH 4 buffer, and tilt to completely cover pH sensor while laying flat
15) Record real-time calibration value and key in 7 for pH 7 buffer
16) Select *Calibrate*
17) Allow the program to run and wait a few minutes until stabilization occurs
18) Remove calibration cup, reserve pH 4 buffer for future pre-rinsing
19) Rinse cup and sensors with tap water

Turbidity:

1) Place a small amount filtered DI water in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Fill calibration cup halfway full with filtered DI water, pouring down sides to avoid aerating the sample
4) Place calibration cup in black bag to avoid exposure to light
5) Place sonde on top of calibration cup, but do not tighten cap
6) Select *Turbidity* tab
7) Record real-time calibration value and key in 0 for 0 NTU
8) Select *Calibrate*
9) Allow the program to run and wait a few minutes until stabilization occurs

Appendix M: Calibration Procedures continued.

DO Calibration:

Note: The DO membrane must relax at least six hours prior to calibration

1) If the DO membrane was not changed, skip to step 3
2) Allow the DO parameter to sample for a few minutes
3) Select DO% tab
4) Tighten calibration cup and turn sonde upside down
5) Confirm calibration cup is filled with filtered DI water to DO sensor 0-ring
6) Blot DO membrane dry with lint-free tissue
7) Loosen black end cap of calibration cup and let unit sit undisturbed 10 minutes
8) On computer, select: DO and enter 760 mm Hg for atmospheric pressure
9) Record real-time calibration value and key in calibration standard
10) Select *Calibrate*
11) Allow the program to run and wait a few minutes until stabilization occurs

After the calibration session ends:

1) Record values on calibration worksheet and confirm range is sufficient, according to Table 2 below:

Table 2: WQI2 Diagnostic Values

Parameter	Range
pH 7	295 ± 20MV
pH 4	470 ± 20MV

Water Quality Instrument 3 (WQI3):

1) The WQI3 cord is connected to the computer through the USB port while the other end is plugged into the top of the WQI3 unit
2) WQI3 software is opened from computer desktop and the WQI3 icon is selected
3) Type Menu and select: 2 - Calibrate

Conductivity:

1) Place a small amount of conductivity standard reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat process
3) Repeat process with new calibration standard
4) Fill calibration cup halfway full of new calibration standard, and tilt to completely cover conductivity sensor while laying flat
5) On computer, select: 1 - Conductivity

6) On computer, select: 1 - Specific conductance
7) Key standard strength
8) Allow the program to run and wait a few minutes until stabilization occurs

Appendix M: Calibration Procedures continued.

9) Copy the stabilized conductivity value onto the calibration worksheet as actual value in μS units
10) Press enter to calibrate WQI3 and record after calibration value
11) Remove calibration cup, reserve conductivity standard for future pre-rinsing
12) Rinse cup and sensors with tap water
13) Press 0 on keyboard to return to Calibration menu

pH:

1) Place a small amount of pH 7 buffer reserved from last calibration into calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Repeat the process with new pH 7 buffer
4) Fill calibration cup halfway full of new pH 7 buffer, and tilt to completely cover pH sensor while laying flat
5) On computer, select: 3 - pH
6) On computer, select: 2 - 2 point calibration
7) Key 7 for pH 7 buffer
8) Hit enter to run program
9) Allow the program to run and wait a few minutes until stabilization occurs
10) Copy the pH reading onto calibration worksheet as actual calibration value
11) Press enter to calibrate WQI3 and record after calibration value
12) Remove calibration cup, reserve pH 7 buffer for future pre-rinsing
13) Rinse cup and sensors with tap water
14) Place a small amount of pH 4 buffer reserved from last calibration in calibration cup, tighten cup around sensors, and swirl
15) Empty calibration cup and repeat the process
16) Repeat the process with new pH 4 buffer
17) Fill calibration cup halfway full of new pH 4 buffer, and tilt to completely cover pH sensor while laying flat
18) Key 4 for pH 4 buffer
19) Hit enter to run program
20) Allow the program to run and wait a few minutes until stabilization occurs
21) Record the pH reading onto calibration worksheet as actual calibration value
22) Press enter to calibrate WQI3 and record after calibration value
23) Remove calibration cup, reserve pH 4 buffer for future pre-rinsing
24) Rinse cup and sensors with tap water
25) Press 0 on keyboard to return to Calibration menu

Appendix M: Calibration Procedures continued.

Turbidity:

1) Place a small amount of filtered DI water into calibration cup, tighten cup around sensors, and swirl
2) Empty calibration cup and repeat the process
3) Fill calibration cup halfway full with filtered DI water, pouring down sides to avoid aerating the sample
4) Place calibration cup in black bag to avoid exposure to light
5) Place WQI3 on top of calibration cup, but do not tighten cap
6) On computer, select: 5 - turbidity
7) On computer, select: 1 - 1 point calibration
8) Key 0 for 0 NTU, or appropriate value
9) Hit enter to run program
10) Allow the program to run and wait a few minutes until stabilization occurs
11) Copy the turbidity reading onto calibration worksheet as actual calibration value
12) Press enter to calibrate WQI3 and record after calibration value
13) Press 0 on keyboard to return to Calibration menu

DO Calibration:

Note: The DO membrane must relax at least six hours prior to calibration

1) If the DO membrane was not replaced, skip to step 7
2) Press 0 on keyboard to return to main menu
3) On computer, select: 1 - run
4) On computer, select: 1 – discrete sample
5) Press enter to begin sampling and allow DO burn-in to occur for 15 minutes
6) Press enter to stop sampling and 0 to return to main menu
7) Tighten calibration cup and turn WQI3 upside down
8) Confirm calibration cup is filled with filtered DI water to DO sensor o-ring
9) On computer, select: 2 - calibrate
10) Blot DO membrane dry with lint-free tissue
11) Loosen black end cap of calibration cup and let sit undisturbed for 10 minutes
12) On computer, select: DO and enter 760 mm Hg for atmospheric pressure
13) Hit enter to run program
14) Allow the program to run and wait a few minutes until stabilization occurs
15) Confirm that DO% displays a positive number and decreases until it stabilizes
16) Copy the DO reading onto calibration worksheet as actual calibration value
17) Press enter to calibrate WQI3 and record after calibration value

Appendix M: Calibration Procedures continued.

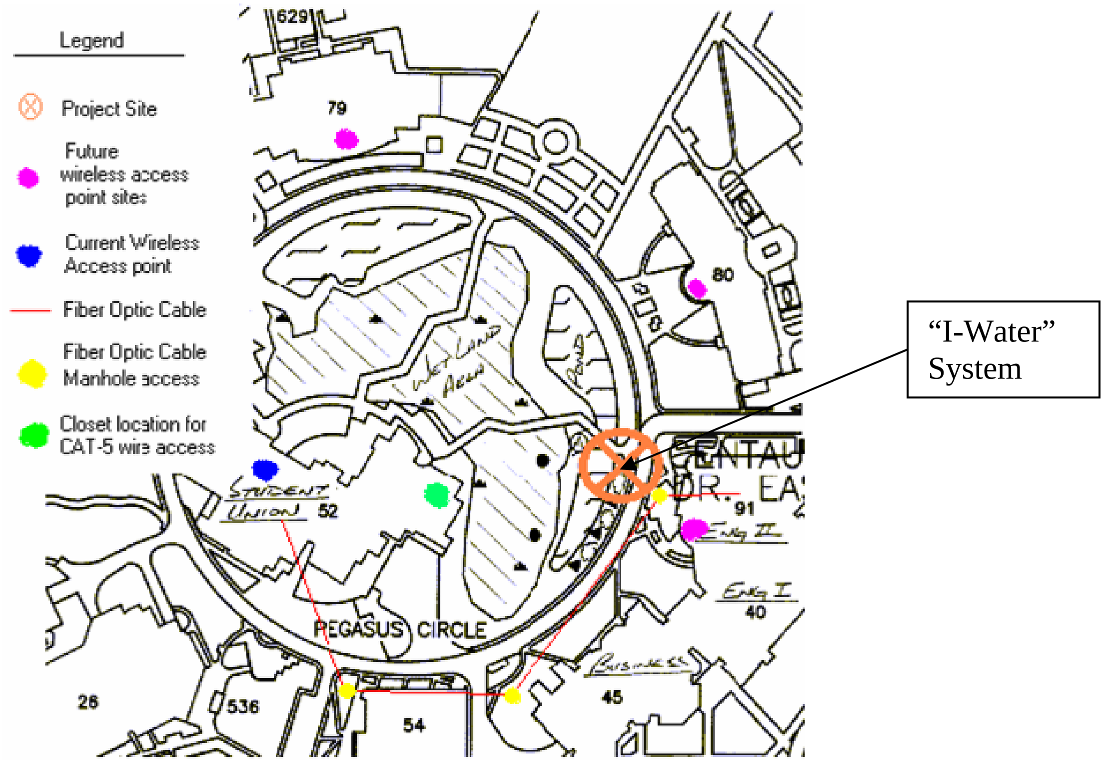
After the calibration session ends:

1) Return to main menu by pressing 0
2) On computer, select: 8 – Advanced
3) On computer, select cal constants
4) Record values on calibration worksheet and confirm range is sufficient, according to Table 3 below:

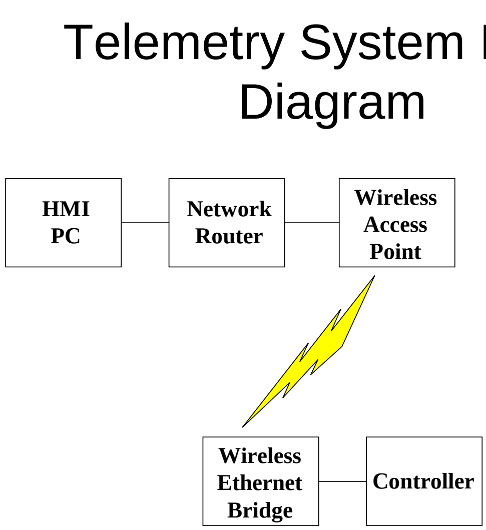
Table 3: WQI3 Diagnostic Values

Parameter	**Range**
Conductivity Cell Constant	5.0 ± 0.45
ph mV Buffer 4	180 ± 50 MV
pH mV Buffer 7	0 ± 50 MV
DO charge	50 ± 25
DO gain	-0.7 - + 1.5

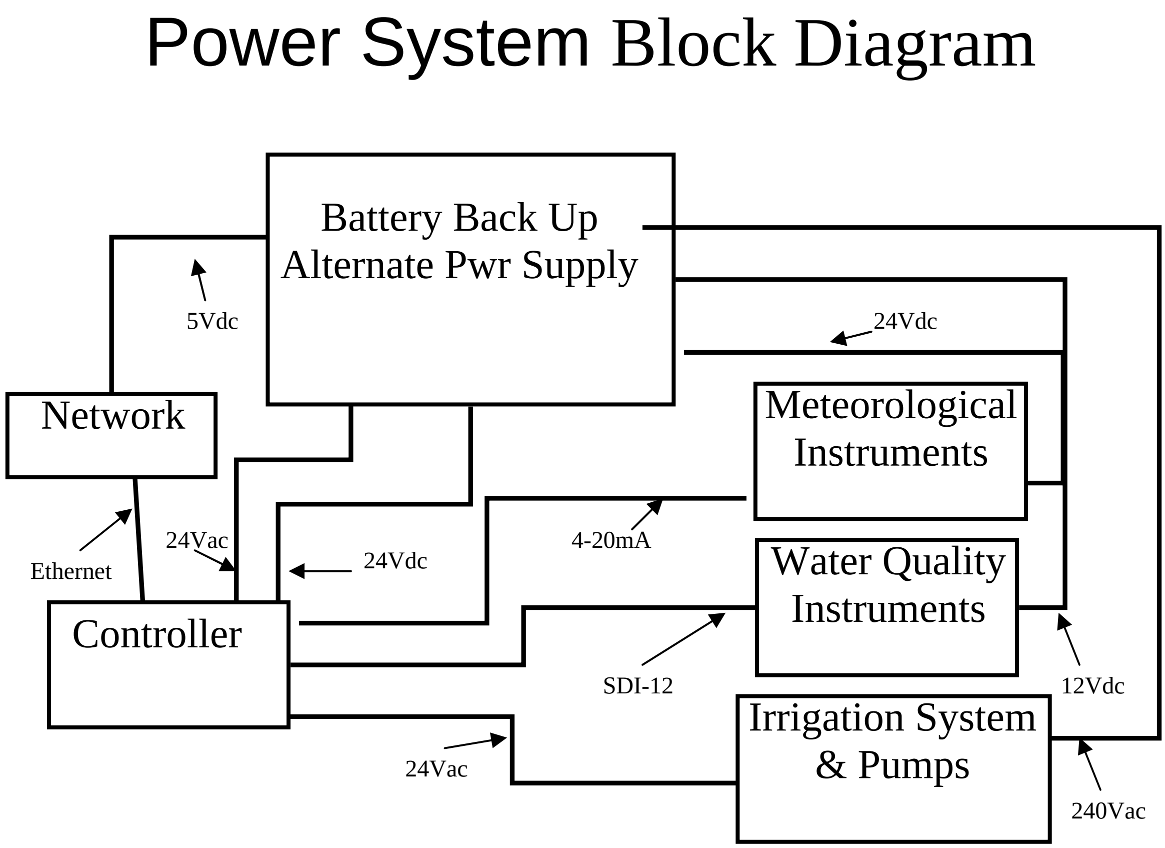
Appendix N: Telemetry map of UCF campus.



Appendix O: Telemetry system block diagram for MCU.

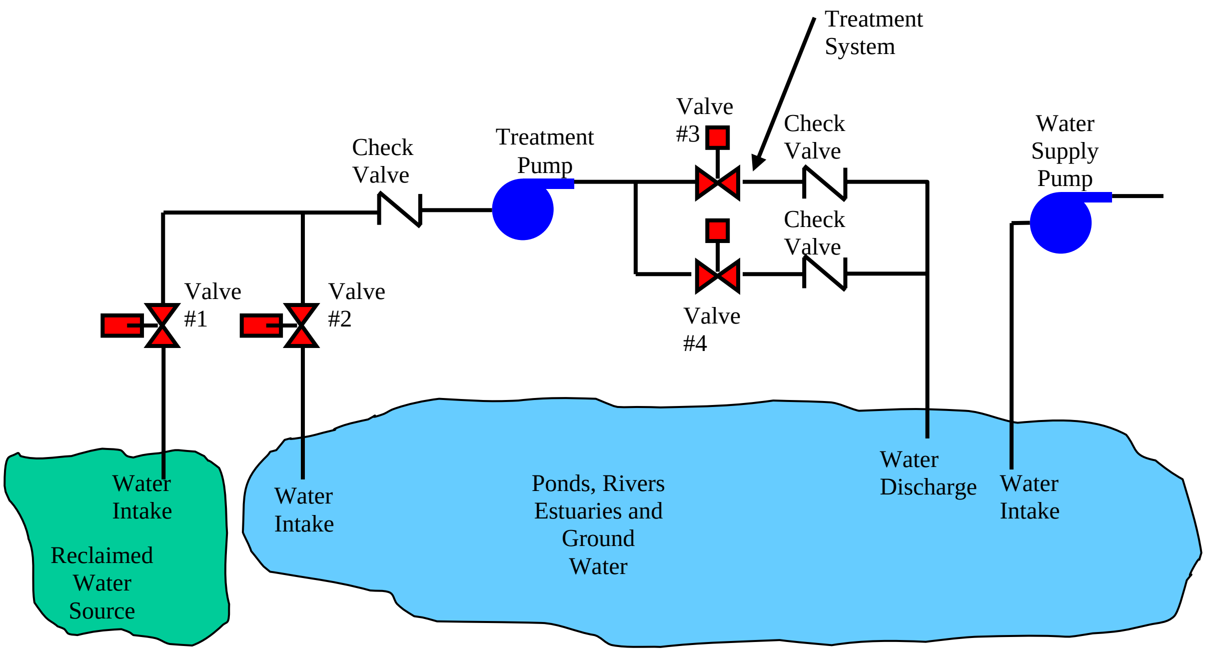


Appendix P: Power distribution block diagram.

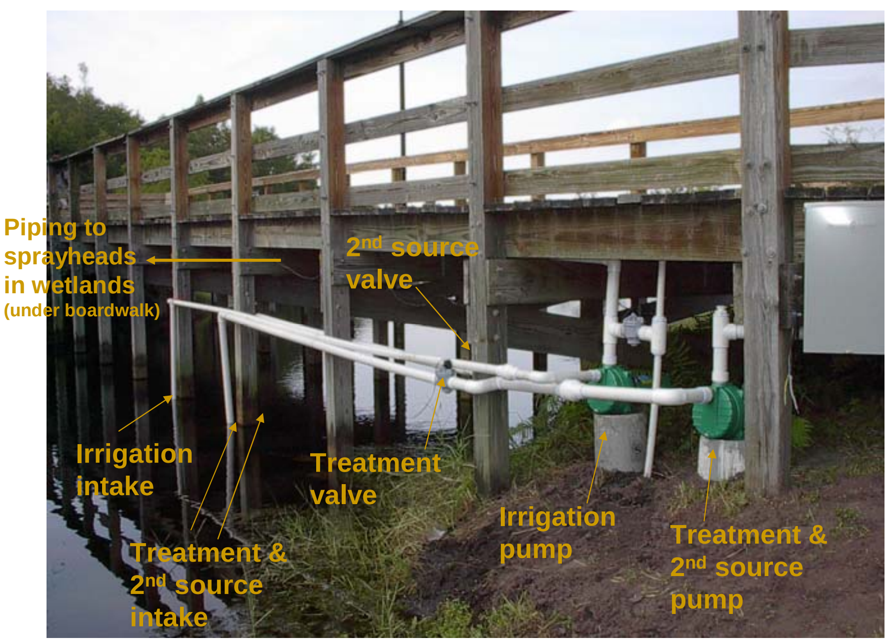


Appendix Q: Pump and Valve System (Conceptual and Actual Design).

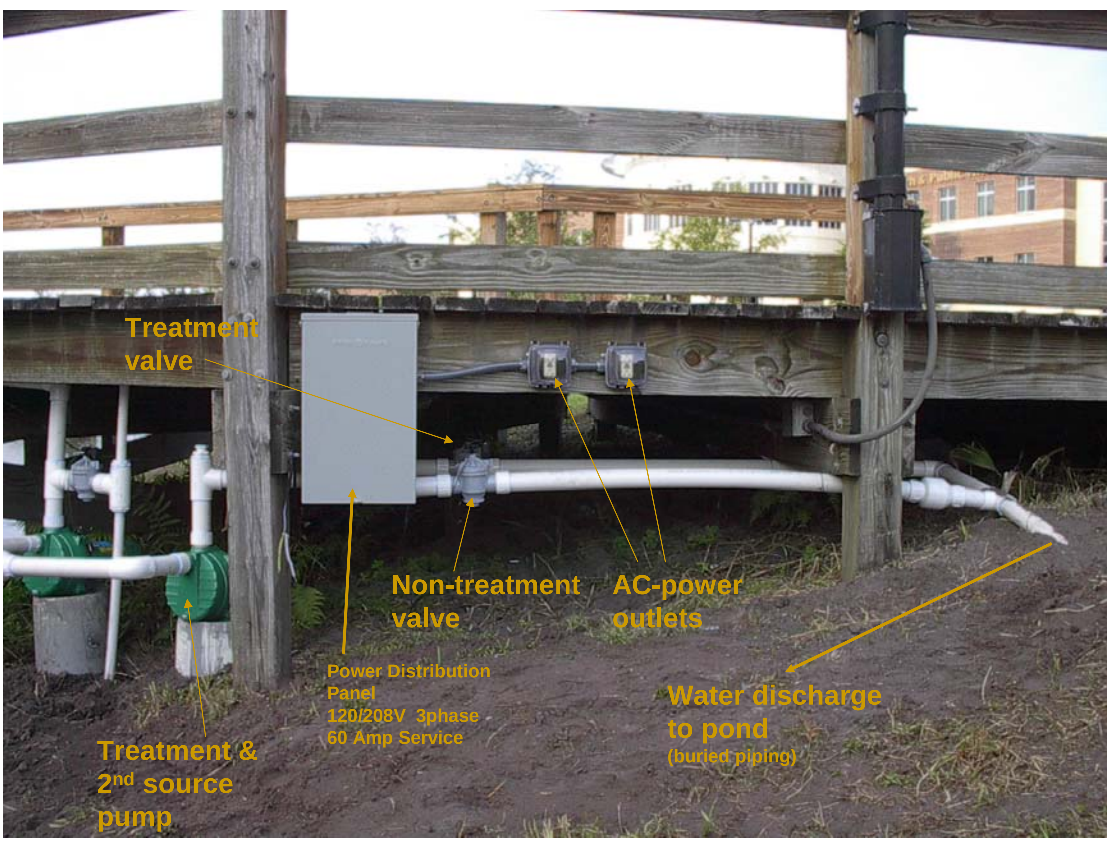
Intelligent Water Supply System



View of 2 pumps and intake



Appendix R: Prototype System "I-Water" at the University of Central Florida



<u>Appendix R</u>: Prototype System "I-Water" at the University of Central Florida