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1 Problem Formulation

1.1 Introduction

Section one of this document provides the objective statement which presents an explanation of the goals and characteristics of the product. In this section a Black Box Model, shown in Figure 1-1, is provided which describes the way in which the implementation of this product will affect the state of the world before and after its implementation.

The client for this project is Mary Mattingly, the director of the Wetlands project. Mattingly is an artist out of New York City whose focus is on environmentally sustainable living. In previous years Mary has worked with Engineering 215 students to produce alternate living space projects.

The objective of WetLand is to create a self-sustainable living area within a barge that will be stationed in Philadelphia, PA on the Delaware River. The goal of WetLand is to offer a workspace for artists; a stage for forums on our shared future; as well as to showcase art, life on the water, architecture, and appropriate technology.

1.2 Objective Statement

Our objective is to design and implement a system to effectively measure the quality and quantity of potable water being stored on the Wetland barge, as well as display this information in an easy to understand manner. This system is to be waterproof, shock proof, and user friendly.

1.3 Black Box Model

The black box model shown in Figure 1-1 is a representation of the state of the world before and after the implementation of the design. Before the occupants of the WetLand habitat were unable to easily measure the volume and quality of water stored onboard. After implementation, the occupants of the WetLand habitat are able to measure the volume and quality of the water stored onboard.

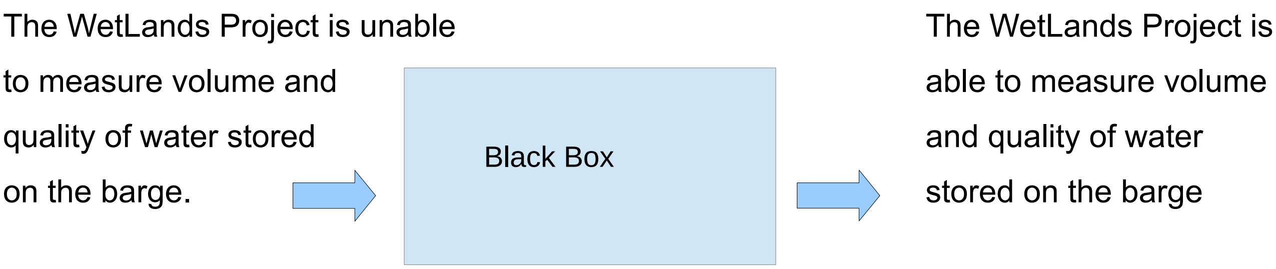

Figure 1-1: The Black Box Model demonstrates the state of the world before and after the implementation of the design.

1.1 Client Criteria

Table 1-1 shows the client criteria for the design, as well as constraints to criteria.

CRITERIA	CONSTRAINT
Cost	Less than $400
Functionality	Must be reliable
Safety	Must not pose threat to occupants
Asthetics	Must look simple and concise
Maintainability	Minimal maintenance
Reproducibility	Must be reproducible
Ease of Use	Must be usable by average person
Power Consumption	Uses as little electricity as possible

Table1 1: Criteria and constraints of the design.

1.2 Usage

The usage of the water meter is to test the quality, and quantity of water collected on the

Wetland habitat.

1.3 Production Volume

One water meter is provided to the inhabitants of the Wetland habitat. Instructions are provided for replication of the water meter as needed.

2 Literature Review

2.1 Wetland Barge

WetLand is an island-based ecosystem and mobile habitat floating on the Delaware River. The expected outcomes for the Wetlands project are two-fold: to educate the Philadelphia community about sustainable use of resources, and to firmly establish Live Arts/Fringe as a commissioner and partner in the world of socially engaged visual arts. (Wetland 2013).

2.1.1 Occupants

There is a total of 3 people living on the Wetlands barge.

2.2 Usage Rates

The EPA estimates that the average American uses approximately 400 gallons of water per day (EPA).

2.3 General water Filtration

2.3.1 Carbon Filter

A typical water filter uses what is called activated carbon. This means that what is usually common charcoal has been ground or shredded into flakes or a powder, in order to increase the total surface area exposed to water. Filter design is very simple. The amount of water allowed to enter the filter is controlled to limit the rate at which water passes over the activated carbon, in order to maximize its exposure. In both tap and pitcher filter designs; this is done simply by using narrow slits or holes that only admit a small maximum of water. In a pitcher-based filter, gravity draws the water through the filter. In a tap-based filter, water pressure pushes it through. As the water passes through the filter, the carbon does its work, leaving clean water to trickle through the bottom.

2.3.2 Point of Use Filters

A point of use (POU) filter is installed in the water supply pipe just before the faucet where people get water.
One example is an under-sink unit; water passes through the carbon filter and travels to a separate water tap, next to the main faucet. Water from the separate tap will be GAC-treated, and water from the main faucet (hot or cold) will be untreated.

2.3.3 Water Catchment and Filtration

2.3.4 Desalination

One method of water catchment on the Wetlands barge is desalination. This method removes salts from saltwater rendering them safe to drink. Several methods of desalination are listed below; distillation, reverse osmosis, and ion exchange.

2.3.4.1 Distillation

The distillation method of desalination uses a phase shift to remove salt from water. The water is heated to a vapor, the vapor is then condensed and captured. In this process salts are removed in the collected distilled water.

2.3.4.2 Reverse Osmosis

Reverse Osmosis (RO) is a filtration process similar to the membrane method with a more precise filter leaving pure water. This process requires pressure to pump the water through the RO membranes.

2.3.4.3 Ion Exchange

The Ion exchange method of desalination is very complex but involves water passing over resin beads. When the water passes over the beads an ionic exchange occurs removing the salts from the water.

2.3.4.4 Membrane Filtration

Membrane Filtration is the process through which water is filtered through microfilters which remove salt along with other contaminants. This process generally does not require outside energy to pump the water though the microfilters.

2.3.5 Rainwater Catchment

One of the major methods of water catchment on the Wetlands barge is rainwater catchment. A system by which rainwater is captured on a surface such as a roof and piped into a storage container (Downey 2001).

2.3.6 Rainwater Treatment Methods

There are multiple ways to treat rain water. They range from chemicals to UV treatment to simply boiling the water (http://www.rainharvest.co.za). Some methods are more labour intensive than others and some are more costly than others. The methods listed below include: Filtration and UV Treatment, Chlorine and Iodine treatment, solar pasteurization, and boiling the water.

2.3.6.1 Filtration and UV Treatment

This is one of the more expensive, but highly effective. The system utilizes a combination of physical filters to remove particulates and then the ultraviolet (UV) light is used to kill bacteria. In order to be effective the light must stay on year around (http://www.rainharvest.co.za).

2.3.6.2 Chlorine & Iodine

This process is less expensive and commonly used in cities to disinfect their water. There is some concern because people use common household bleach and iodine. The process is usually to boil the water prior to adding a few drops of the chemical and let sit for roughly 30 minutes with the water above 70 degrees Fahrenheit or if the water is near freezing an hour to sit (http://www.rainharvest.co.za).

2.3.6.3 Solar Pasteurization

This process is more labor intensive, but more natural. The process requires a bag to be filled and positioned on two feet of aluminum foil in a sunny place. The bag needs to reach above 160 degrees Fahrenheit for several hours to remove pathogens (http://www.rainharvest.co.za).

2.3.6.4 Boiling the Water

This method is simple, boil water for fifteen minutes. This will kill the pathogens, but the process will leave floating particulates, so it is helpful to filter the water before boiling (http://www.rainharvest.co.za)

2.4 Water Quality

There are many ways to contaminate water such as with bacterial diseases, parasitic diseases, viral diseases, and chemical diseases (http://www.cdc.gov/healthywater/disease). Because of the multiple types of contaminants it is imperative to know the source of these contaminants and how to detect them.

2.4.1 Rainwater contamination

Rainwater can become contaminated in storage tanks by bacterial contamination, by animals entering the take or catchment, by fecal matter on the rainwater catchment and washing into the tank, or chemically. A study completed by Carleton College shows that when samples were collected along the East and West Coast, those samples tended to have higher concentrations of chloride with the concentration getting as high as 4.21 mg/L in Kurtistown, HI (http://www.people.carleton.edu). As defined by merriam-webster chlorine is “a compound of chlorine with another element or group; *especially*: a salt or ester of hydrochloric acid” (http://www.merriam-webster.com/dictionary/chloride), and this will contribute to the rainwater having an odor or color in some cases the water may taste foul if the concentration reaches at or around 250 mg/L which is normally seen in wells (http://www.dhss.delaware.gov). The pH of a solution is a measure of the molar concentration of hydrogen ions in the solution and from this a measure of the acidity or basicity of the solution. A scale from zero to twelve is used to classify the acidity or basicity with zero being the most acidic (battery acid is rated here) (http://hyperphysics.phy-astr.gsu.edu). There is always the threat of sulphur and nitrogen compounds traveling long-ranges resulting in increased acidity of precipitation, called acid rain, adding to the acidity of the water (atmospheric pollution 5).

2.4.2 Contamination in salt water

The main types of salt water pollution are organic materials; excessive nutrition; suspended solids; toxic chemicals such as metals, chlorine, ammonia, pesticides; and thermal pollution. Organic materials “are characteristic of untreated or inadequately treated domestic and industrial waste” (water pollution and fish physiology 1). Biochemical oxygen demand (BOD) is a way measure of the quantity of oxygen consumed by microorganisms and bacteria in the degradation of organic matter giving indirectly the amount of biodegradable material in water (http://www.earthforce.org), and when BOD becomes too large because of a larger source of organic material the dissolved oxygen decreases into a state called hypoxia (water pollution and fish physiology 1). Excessive nutrients in water from agricultural runoff or non-biodegradable detergents that are added to the water leads to an excess growth of phytoplankton, and as a result when testing the dissolved oxygen (DO) concentration the consequence is very low DO levels just before sunrise (water pollution and fish physiology 1). In Figure 1.1 a picture is shown that illustrates the severe effects on excessive nutrients in the

Gulf of Mexico (http://www.noaanews.noaa.gov). Notice that where the Mississippi River enters the Gulf of Mexico the dissolved oxygen concentration is the smallest, shown the by the red and orange.

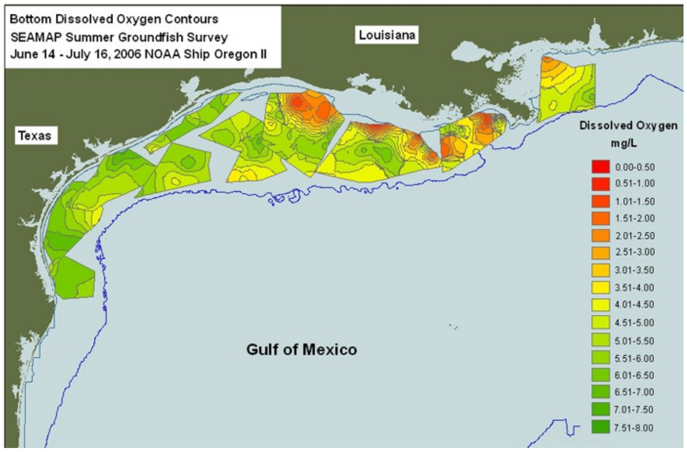

Figure2 1: Dissolved oxygen levels in the Gulf of Mexico (http://www.noaanews.noaa.gov)

This area is referred to as the dead zone because seasonal oxygen levels drop too below the point at which most life in bottom and near-bottom of the Gulf which is caused by agricultural runoff and silt from the Mississippi river (http://www.noaanews.noaa.gov). Turbidity is a measuring the water clarity by quantifying how much the material is suspended in the water that results in a decrease of the passage of light through the water sample. The turbidity of a water sample can be affected by soil erosion, waste discharge, urban runoff, bottom feeders, and algal growth (http://water.epa.gov). Finally many chemicals and metals can contribute to a low water quality, and these can come as a result of industrial work places. Toxics such as mercury, PCB's, chlorinated pesticides, dioxins, and chlorinated benzenes are a continuously a problem because they contaminate the food chain and the fish (http://www.delawareriverkeeper.org/delaware-river/estuary.asp).

2.4.3 Water Quality Standards

The Delaware Division of Public Health regulates the drinking water through the Office of Drinking Water, and they set up regulations and suggestions for the levels of certain minerals, chemicals, and pH. For chloride they suggest 250 mg/L. By law all municipalities are required to add small amounts (2.0 mg/L) for dental benefits. Water has a hardness rating which is affected by the levels of calcium and magnesium. Rating which ranges from soft to moderately hard to extremely hard. The Offices suggest that the pH of the water be between 6.5 and 8.5, pH is on a scale of 0-12 with 0 being the most acidic and 12 being the most basic. Salt concentrations range from less than 20 mg/L for people with salt restricted diets up to but no greater than 200 mg/L (http://www.dhss.delaware.gov/dph/hsp/files/watertest.pdf).

2.5 Water Storage Tanks

Water storage tanks can vary greatly in construction and functionality. The major features of water tanks are discussed below.

2.5.1 Water Towers

Many water storage tanks are constructed in a manor similar to a water tower, using Pressure from the water and its elevation from the ground to create the necessary water pressure from the tank (Brain).

2.5.2 Water Pressure

Water pressure can be achieved through two methods-- gravity, and water pumps. Water towers are built high off the ground to increase the water pressure provided by gravity, each foot of height provides 0.43 psi (Brain), or 1.5 psi (10.3 kPa) per meter off the ground . Most household pumps provide 15-40 psi (103-276 kPa).

The Average household water pressure is generally about 40 psi. Municipal water supplies generally provide water pressure between 50 and 100 psi, most major appliances require at least 20-30 psi (Brain).

2.5.2.1.1 Acceptable Building Materials

Water tanks are constructed out of legally approved materials considered safe for contact with drinking water. Materials that are used in the construction of a water tank are considered acceptable based on three major criteria (FDA Food Code 2009): safety, durability, and surface cleanablility.

2.5.2.1.2 Safety

Materials considered safe can vary, however three common building materials for water storage tanks are fiberglass, cast iron, and polyethylene. (Evison 2004).

2.5.2.1.3 Durability

Materials must be corrosion-resistant and nonabsorbent. Corrosion-resistant is tested by exposing a sample of the material to a salt spray in a salt spray chamber for 192 hours, as outlined in ASTM B 117-95 Standard Practice for Operating a Salt Spray (Fog) Apparatus. After the test period there should be no visible signs of corrosion on the sample material (NSF 1998).

2.5.2.1.4 Surface Cleanability

Materials must have a smooth and easily cleanable surface. This is determined by the amount of soil which remains on the surface after cleaning (NSF 1998).

2.5.3 Storage Tank Volume

There are several ways to measure volume in a water tank which are listed as follows:

2.5.3.1 Floats

Floats work on the simple principle of placing a buoyant object with a specific gravity intermediate between those of the process fluid and the headspace vapor into the tank, then attaching a mechanical device to read out its position. The float sinks to the bottom of the headspace vapor and floats on top of the process fluid. While the float itself is a basic solution to the problem of locating a liquid's surface, reading a float's position (i.e., making an actual level measurement) is still problematic. Early float systems used mechanical components such as cables, tapes, pulleys, and gears to communicate level. Magnet-equipped floats are popular today.

Early float level transmitters provided a simulated analog or discrete level measurement using a network of resistors and multiple reed switches, meaning that the transmitter's output changes in discrete steps. Unlike continuous level-measuring devices, they cannot discriminate level values between steps. (Hambrice 2004).

2.5.3.2 Hydrostatic Devices

Displacers, bubblers, and differential-pressure transmitters are all hydrostatic measurement devices. Any change in temperature will therefore cause a shift in the liquid's specific gravity, as will changes in pressure that affect the specific gravity of the vapor over the liquid. Both result in reduced measurement accuracy.

Displacers work on Archimedes' principle. A column of solid material (the displacer) is suspended in the vessel. The displacer's density is always greater than that of the process fluid (it will sink in the process fluid), and it must extend from the lowest level required to at least the highest level to be measured. As the process fluid level rises, the column displaces a volume of fluid equal to the column's cross-sectional area multiplied by the process fluid level on the displacer. A buoyant force equal to this displaced volume multiplied by the process fluid density pushes upward on the displacer, reducing the force needed to support it against the pull of gravity. The transducer, which is linked to the transmitter, monitors and relates this change in force to level.

A bubbler-type technology is used in vessels that operate under atmospheric pressure. A dip tube having its open end near the vessel bottom carries a purge gas (typically air, although an inert gas such as dry nitrogen may be used when there is danger of contamination of or an oxidative reaction with the process fluid) into the tank. As gas flows down to the dip tube's outlet, the pressure in the tube rises until it overcomes the hydrostatic pressure produced by the liquid level at the outlet. That pressure equals the process fluid's density multiplied by its depth from the end of the dip tube to the surface and is monitored by a pressure transducer connected to the tube.

A differential pressure (DP) level sensor is shown in. The essential measurement is the difference between total pressure at the bottom of the tank (hydrostatic head pressure of the fluid plus static pressure in the vessel) and the static or head pressure in the vessel. As with the bubbler, the hydrostatic pressure difference equals the process fluid density multiplied by the height of fluid in the vessel. The unit in Figure 4 uses atmospheric pressure as a reference. A vent at the top keeps the headspace pressure equal to atmospheric pressure.

In contrast to bubblers, DP sensors can be used in unvented (pressurized) vessels. All that is required is to connect the reference port (the low-pressure side) to a port in the vessel above the maximum fill level. Liquid purges or bubblers may still be required, depending on the process's physical conditions and/or the transmitter's location relative to the process connections (Hambrice 2004). See Figure 2-2.

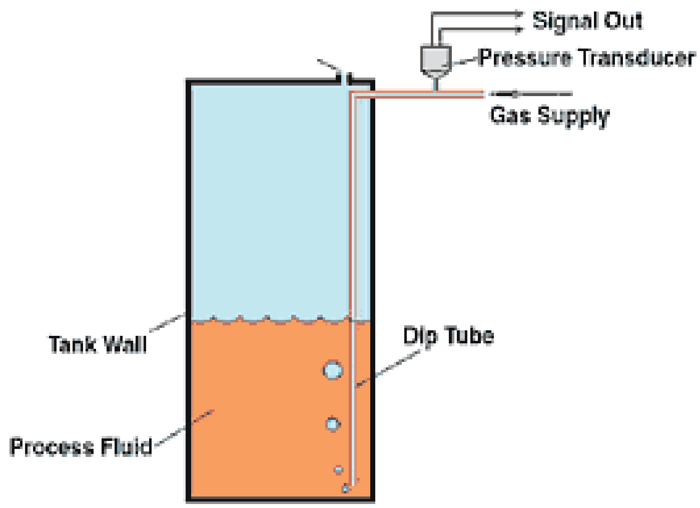

Figure2-2: A hydrostatic volume sensor (Hambrice 2004).

2.5.3.3 Load Cells

A load cell or strain gauge device is essentially a mechanical support member or bracket equipped with one or more sensors that detect small distortions in the support member. As the force on the load cell changes, the bracket flexes slightly, causing output signal changes. Calibrated load cells have been made with force capacities ranging from fractional ounces to tons.

To measure level, the load cell must be incorporated into the vessel's support structure. As process fluid fills the vessel, the force on the load cell increases. Knowing the vessel's geometry (specifically, its cross-sectional area) and the fluid's specific gravity, it is a simple matter to convert the load cell's known output into the fluid level.

While load cells are advantageous in many applications because of their noncontact nature, they are expensive and the vessel support structure and connecting piping must be designed around the load cell's requirements of a floating substructure. The total weight of the vessel, piping, and connecting structure supported by the vessel will be weighed by the load cell system in addition to the desired net or product weight. This total weight often creates a very poor turndown to the net weight, meaning that the net weight is a very small percentage of the total weight. Finally, the supporting structure's growth, caused by uneven heating (e.g., morning to evening sunshine) may be reflected as level, as can side load, wind load, rigid piping, and binding from overturn-prevention hardware (for bottom-mounted load cells). In short, load cell weighing system requirements must be a paramount consideration throughout initial vessel support and piping design, or performance is quickly degraded (Hambrice 2004).See Figure 2-3.

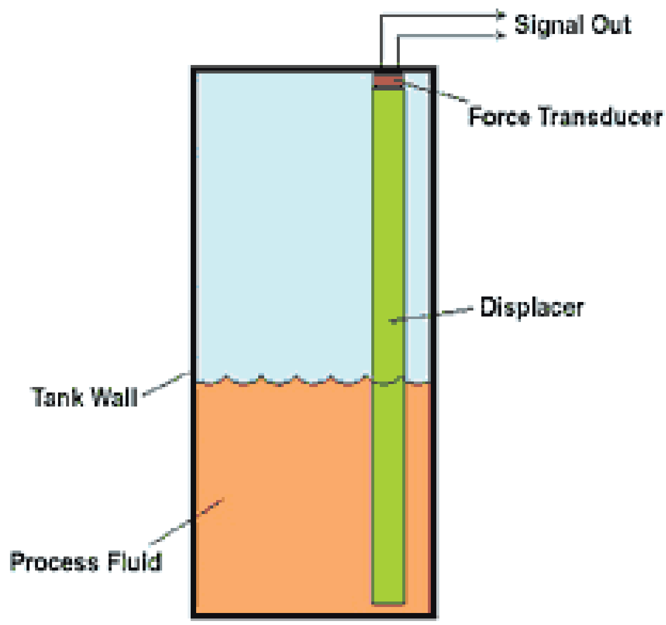

Figure2-3: A force transducer volume sensor (Hambrice 2004).

2.5.3.4 Magnetic Level Gauges

These gauges are the preferred replacement for sight glasses. They are similar to float devices, but they communicate the liquid surface location magnetically. The float, carrying a set of strong permanent magnets, rides in an auxiliary column (float chamber) attached to the vessel by means of two process connections. This column confines the float laterally so that it is always close to the chamber's side wall. As the float rides up and down with the fluid level, a magnetized shuttle or bar graph indication moves with it, showing the position of the float and thereby providing the level indication. The system can work only if the auxiliary column and chamber walls are made of nonmagnetic material.

Many manufacturers provide float designs optimized for the specific gravity of the fluid being measured, whether butane, propane, oil, acid, water, or interfaces between two fluids, as well as a large selection of float materials. This means the gauges can handle high temperatures, high pressures, and corrosive fluids. Oversized float chambers and high-buoyancy floats are available for applications where buildup is anticipated.

Chambers, flanges, and process connections can be made from engineered plastics such as Kynar or exotic alloys such as Hastelloy C-276. Special chamber configurations can handle extreme conditions such as steam jacketing for liquid asphalt, oversized chambers for flashing applications, and cryogenic temperature designs for liquid nitrogen and refrigerants. Numerous metals and alloys such as titanium, Incoloy, and Monel are available for varying combinations of high-temperature, high-pressure, low-specific-gravity, and corrosive-fluid applications. Today's magnetic level gauges can also be outfitted with magnetostrictive and guided-wave radar transmitters to allow the gauge's local indication to be converted into 4-20 mA outputs that can be sent to a controller or control system (Hambrice 2004).

2.5.3.5 Capacitance Transmitters

These devices operate on the fact that process fluids generally have dielectric constants, , significantly different from that of air, which is very close to 1.0.

Oils have dielectric constants from 1.8 to 5. Pure glycol is 37; aqueous solutions are between 50 and 80. This technology requires a change in capacitance that varies with the liquid level, created by either an insulated rod attached to the transmitter and the process fluid, or an uninsulated rod attached to the transmitter and either the vessel wall or a reference probe. As the fluid level rises and fills more of the space between the plates, the overall capacitance rises proportionately. An electronic circuit called a capacitance bridge measures the overall capacitance and provides a continuous level measurement.

Emerging Technologies

Perhaps the most significant difference between earlier continuous liquid-level measuring technologies and those now gaining favor is the use of time-of-flight (TOF) measurements to transduce the liquid level into a conventional output. These new devices typically operate by measuring the distance between the liquid level and a reference point at a sensor or transmitter near the top of the vessel. The systems typically generate a pulse wave at the reference point, which travels through either the vapor space or a conductor, reflects off the liquid surface, and returns to a pickup at the reference point. An electronic timing circuit measures the total travel time. Dividing the travel time by twice the wave's speed gives the distance to the surface of the fluid. The technologies differ mainly in the kind of pulse used to make the measurement. Ultrasound, microwaves (radar), and light all have proven useful (Hambrice 2004). See Figure 2-4.

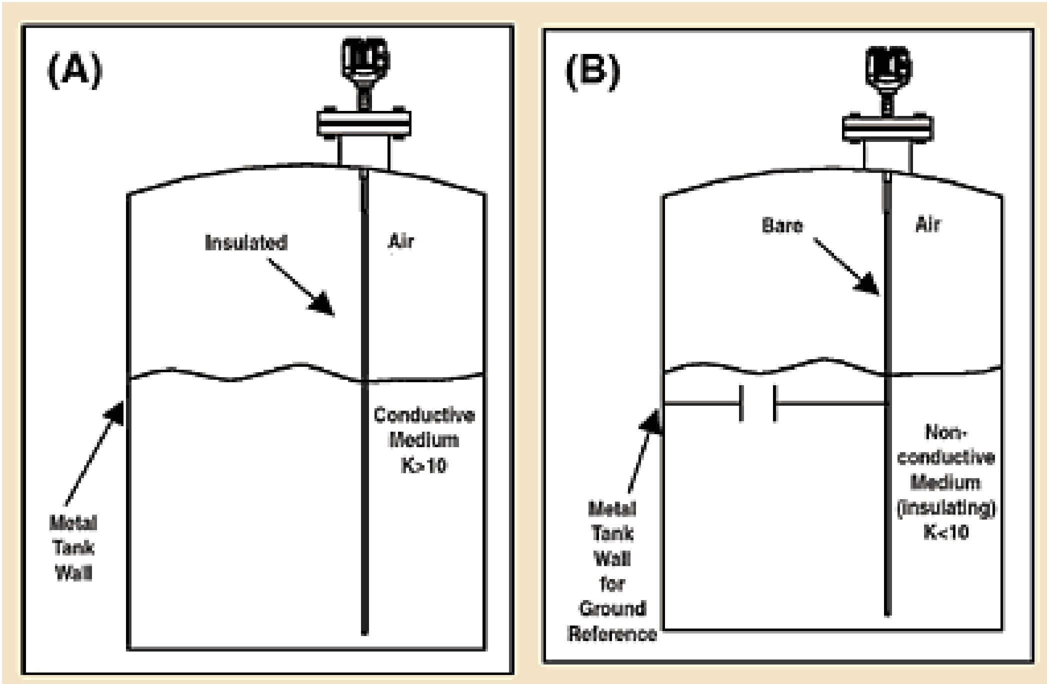

Figure2-4: A conductive volume sensor (Hambrice 2004).

2.5.3.6 Magnetostrictive Level Transmitters

The advantages of using a magnet containing a float to determine liquid level have already been established, and magnetostriction is a proven technology for very precisely reading the float's location. Instead of mechanical links, magnetostrictive transmitters use the speed of a torsional wave along a wire to find the float and report its position.
In a magnetostrictive system, the float carries a series of permanent magnets.A sensor wire is connected to a piezoceramic sensor at the transmitter and a tension fixture is attached to the opposite end of the sensor tube. The tube either runs through a hole in the center of the float or is adjacent to the float outside of a nonmagnetic float chamber.

To locate the float, the transmitter sends a short current pulse down the sensor wire, setting up a magnetic field along its entire length. Simultaneously, a timing circuit is triggered ON. The field interacts immediately with the field generated by the magnets in the float. The overall effect is that during the brief time the current flows, a torsional force is produced in the wire, much like an ultrasonic vibration or wave. This force travels back to the piezoceramic sensor at a characteristic speed. When the sensor detects the torsional wave, it produces an electrical signal that notifies the timing circuit that the wave has arrived and stops the timing circuit. The timing circuit measures the time interval (TOF) between the start of the current pulse and the wave's arrival. From this information, the float's location is very precisely determined and presented as a level signal by the transmitter. Key advantages of this technology are that the signal speed is known and constant with process variables such as temperature and pressure, and the signal is not affected by foam, beam divergence, or false echoes. Another benefit is that the only moving part is the float that rides up and down with the fluid's surface (Hambrice 2004). See Figure 2-5.

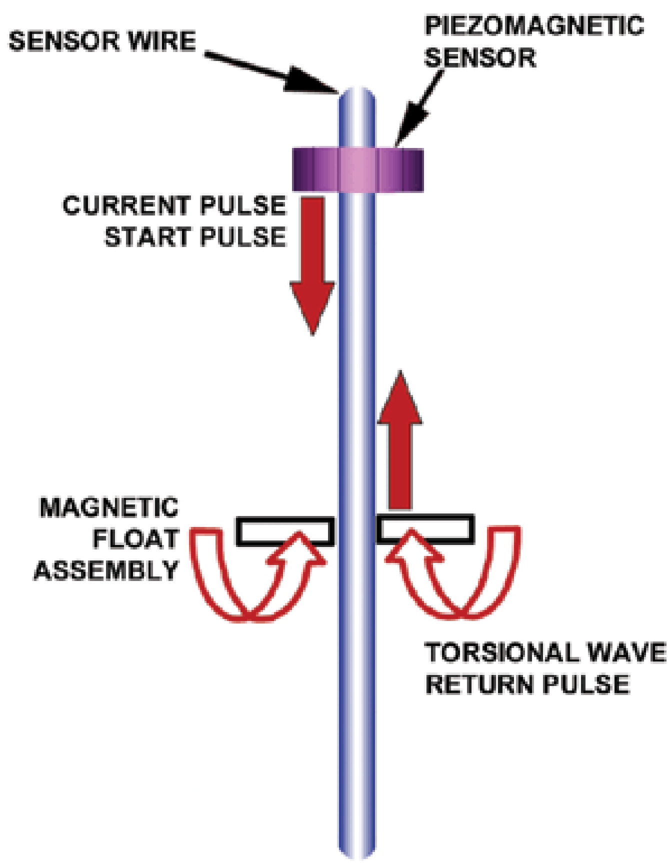

Figure2-5: A magnetic level volume sensor (Hambrice 2004).

2.5.3.7 Ultrasonic Level Transmitters

Ultrasonic level sensors measure the distance between the transducer and the surface using the time required for an ultrasound pulse to travel from a transducer to the fluid surface and back (TOF). These sensors use frequencies in the tens of kilohertz range; transit times are ~6 ms/m. The speed of sound (340 m/s in air at 15°C (1115 fps at 60°F) depends on the mixture of gases in the headspace and their temperature. While the sensor temperature is compensated for (assuming that the sensor is at the same temperature as the air in the headspace), this technology is limited to atmospheric pressure measurements in air or nitrogen (Hambrice 2004). See Figure 2-6.

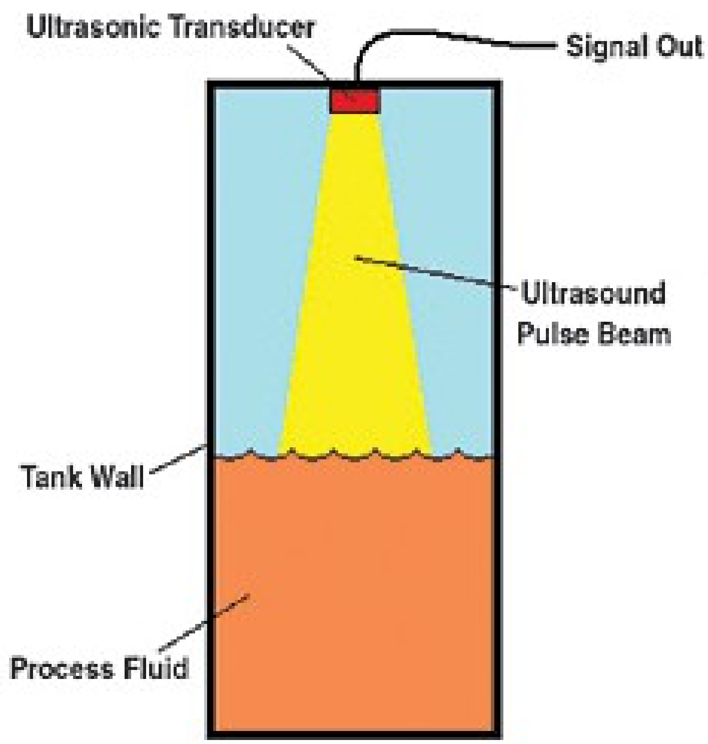

Figure2-6: An ultrasonic volume sensor (Hambrice 2004).

2.5.3.8 Laser Level Transmitters

Designed for bulk solids, slurries, and opaque liquids such as dirty sumps, milk, and liquid styrene, lasers operate on a principle very similar to that of ultrasonic level sensors. Instead of using the speed of sound to find the level, however, they use the speed of light.
A laser transmitter at the top of a vessel fires a short pulse of light down to the process liquid surface, which reflects it back to the detector. A timing circuit measures the elapsed time (TOF) and calculates the distance. The key is that lasers have virtually no beam spread (0.2° beam divergence) and no false echoes, and can be directed through spaces as small as 2 in.[2] Lasers are precise, even in vapor and foam. They are ideal for use in vessels with numerous obstructions and can measure distances up to 1500 ft. For high-temperature or high-pressure applications, such as in reactor vessels, lasers must be used in conjunction with specialized sight windows to isolate the transmitter from the process. These glass windows must pass the laser beam with minimal diffusion and attenuation and must contain the process conditions. (Hambrice 2004). See Figure 2-7.

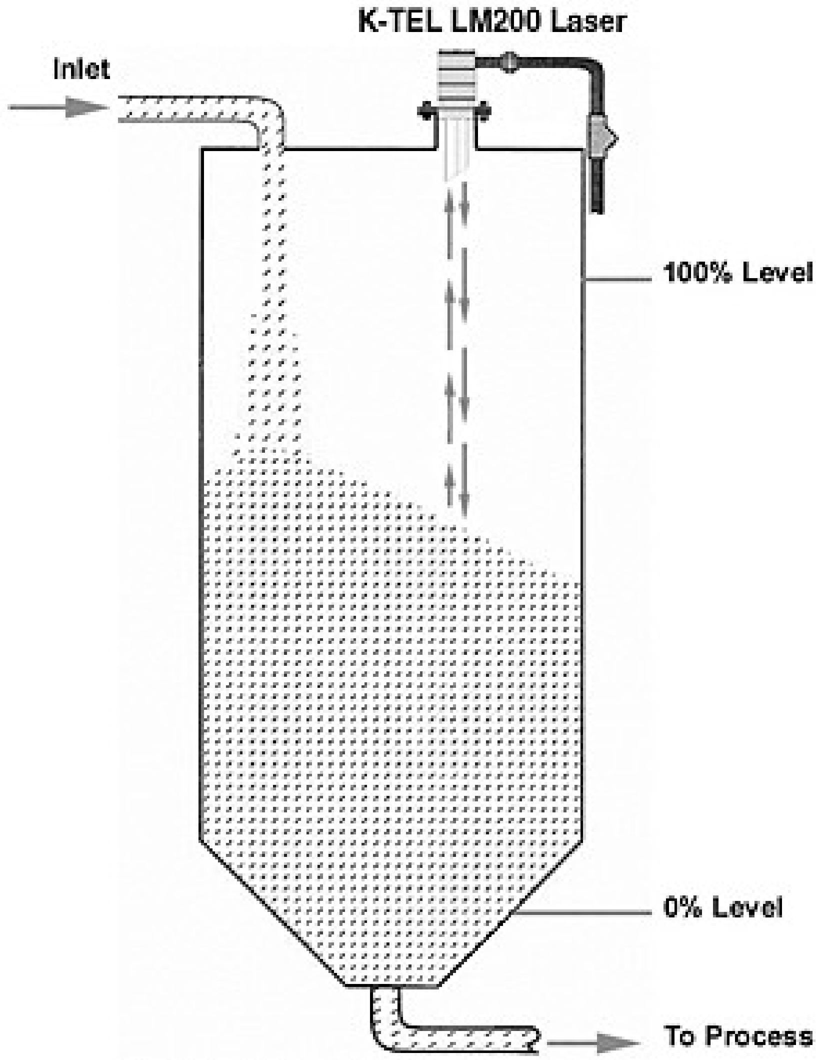

Figure2-7: A laser volume sensor (Hambrice 2004).

2.5.3.9 Radar Level Transmitters

Through-air radar systems beam microwaves downward from either a horn or a rod antenna at the top of a vessel. The signal reflects off the fluid surface back to the antenna, and a timing circuit calculates the distance to the fluid level by measuring the round-trip time (TOF) (Hambrice 2004). See Figure 2-8.

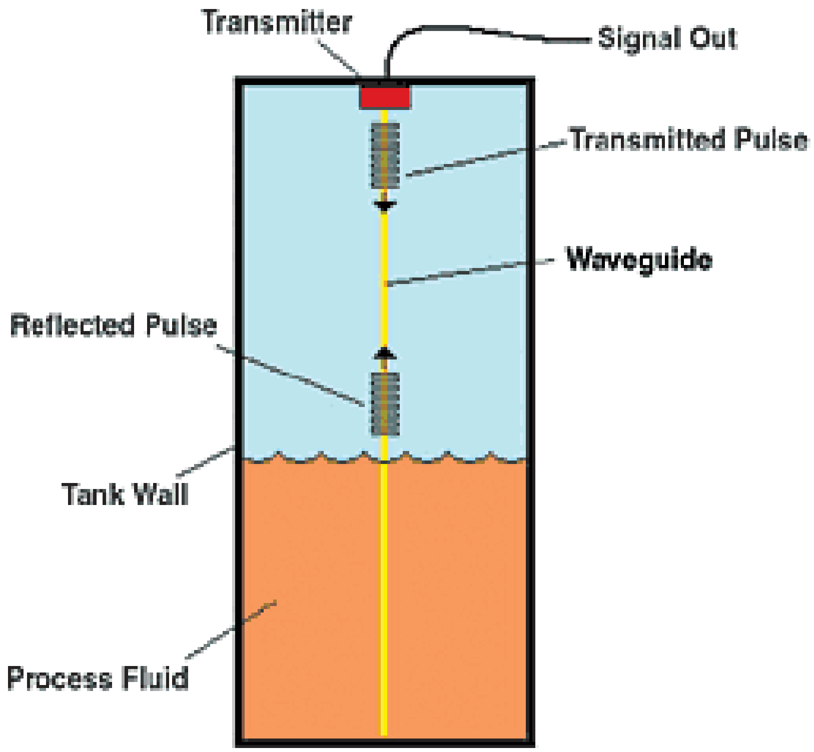

Figure2-8: A radar volume sensor(Hambrice 2004).

2.5.4 Water Meter Volume

One of the major functions of the water meter is to consistently and accurately measure the volume of water on the WetLand barge. The function of this measurement device can be achieved through many different means. The methods considered for the water are listed as followed: an analogue float with a view window, a gas-tank style measurement bob, an Arduino microchip with sonar sensor, and conductive sensors.

2.5.4.1 Float with View Window

Measuring volume with a float and view window is done by using a transparent cylinder of the same height as the storage tank to be used as the view window. The view window is marked with several level markers which correlate to the volume within the storage tank. In the view window is a floating marker which shows the volume at the given level. As the volume in the tank decreases the float lowers accordingly in the view window.

2.5.4.2 Arduino Gas-Tank Bob

The gas-tank bob method uses a floating arm (bob) which can reach to the level of the full tank as well as the empty tank. The floating arm is hooked up to a conductive circuit which is completely closed when the tank is full and completely open when the tank is empty. The level of resistance in the circuit is measured and correlated with the level of the bob and the volume. This resistance data is transferred to an arduino microchip where the volume is calculated.

2.5.4.3 Arduino Sonar Sensor

The arduino sonar sensor method uses an arduino programmable microchip and a sonar sensor to measure volume. The sonar sensor correlates the time to travel the distance to the water and back to the sensor to the volume of water present in the tank. This works because the time to travel to the top of water increases as the depth decreases, so as the time interval increases this is correlated to the volume decreasing. The sonar data is transferred to the arduino microchip which then interprets it and calculates the volume.

2.5.4.4 Arduino Conductive Sensors

Using conductive sensors to calculate volume works by attaching several sensors at several different heights down the side of the tank and using the resistance from the sensors to calculate the water level. This water level data is then fed through a microchip where the volume would be calculated.

2.5.5 Water Storage Tank Sanitation

2.5.5.1 Microbial Growth

Water stored in storage tanks is susceptible to microbial and pathogenic growth.

Temperature, pH, turbidity, chlorine content, and bacterial content can all vary depending on the amount of time water spends in a tank and the time of year during which the water is being stored.

An increase in heterotrophic plate count (HPC), measuring bacterial content, is accompanied by a loss of chlorine residual and an increase in pH after four days. Turbidity and total organic carbon (TOC) decreased after four days of storage, and then increased after seven days of storage.

In addition to the number of days water is stored in a tank, the time of year also effects chlorine content, turbidity, HPC, and temperature. Temperature generally decreases in the winter and increases in the summer. HPCs are lower in the winter than the summer, however this difference is less than the differences in HPCs between four and seven days storage. Turbidity shows a decrease during the winter, and an increase during the summer. Chlorine content shows and increase during the winter and a decrease during the summer.

Microbial growth is affected by how long the water remains in the tank without cycled out. Water stored in a tank for four days showed lower levels of chlorine and higher levels of bacteria than water stored in a tank for seven days.

A breakdown of the measurements of temperature, chlorine, pH, turbidity, HPC, and TOC levels can be seen in Table 2-2 and Table 2-3 ; alongside the different types of water storage tanks in use (Evison et al 2001).

Parameter	No Storage	Four Days' Storage—*average (range)*				Seven Days' Storage—*average (range)*			
	Average *(range)*	Cast-iron 1	Cast-iron 2	Polyethylene	Fiberglass	Cast-iron 1	Cast-iron 2	Polyethylene	Fiberglass
Temperature—*°C*	21.7 (14–27)	20.3 (8–29.8)	20.4 (8–29.8)	20.7 (9–30.0)	21.2 (9–31.5)	21 (8–29.8)	20.4 (9–32.0)	20.7 (9–30.0)	21.4 (10–31.5)
pH	7.7 (7–8.03)	7.9 (7.6–8.2)	7.9 (7.6–8.2)	7.9 (7.6–8.1)	7.9 (7.8–8.1)	8.1 (7.7–8.6)	8.0 (7.7–8.2)	8.0 (7.6–8.2)	8.0 (7.7–8.3)
Turbidity—*ntu*	0.8 (0.2–2.3)	0.7 (0.4–1.1)	0.5 (0.0–2.0)	0.7 (0.4–2.3)	0.7 (0.3–1.6)	0.7 (0.3–1.0)	0.5 (0.0–2.0)	0.7 (0.3–1.4)	0.7 (0.3–1.7)
Cl_2*—*mg/L*	0.6 (0.6–1.0)	0.1 (0.0–0.5)	0.1 (0.0–0.5)	0.1 (0.0–0.5)	0.1 (0.0–0.5)	0.0 (0.0–0.5)	0.1 (0.0–0.5)	0.05 (0.0–0.3)	0.1 (0.0–0.3)
Log HPC†—*cfu/mL*	1.4 (0.9–1.2)	3.0 (0.5–5.7)	3.1 (1.0–5.7)	3.3 (1.1–5.7)	3.2 (1.4–6.7)	3.7 (1.0–6.08)	3.1 (1.0–5.7)	4.3 (1.3–6.8)	4.0 (1.9–6.8)
TOC‡—*mg/L*	1.95 (1.2–2.1)	1.9 (1.0–2.9)	1.6 (1.0–2.1)	2.1 (2.2–2.7)	1.7 (1.1–2.2)	2.7 (2.3–3.2)	1.6 (1.0–2.1)	3.2 (2.4–3.9)	3.3 (2.3–4.3)

*Cl_2—free residual chlorine
†HPC—heterotrophic plate count
‡TOC—total organic carbon

Table2-2: A table comparing differences in water quality between storage tank constructions at four and seven days' storage (Evison et al 2001).

Bacterial Genera/Species	All Tanks	Cast-iron 1	Cast-iron 2	Fiberglass	Polyethylene
Actinomycetes	17.3	31.6	8.3	24.2	14.7
Aeromonas	9.6		0.3	13.8	19.0
Alcaligene-like (CDC vd-1, CDC vd-2)	0.3			0.9	
Arthrobacter	3.8			6.2	6.7
Bacillus	11.2	23.7	16.5	6.2	6.7
Flavobacterium	1.2		3.8		
Flavobacterium aquatile	0.1	0.1			
Klebsiella rhinoscleromatis	3.6			11.9	
Micrococcus luteus	0.1		0.2		
Micrococcus roseus	0.1	0.1			
Micrococcus spp.	0.1		0.2		
Moraxella	5.9	12.2	15.5		
Moraxella nonliquefaciens	2.7				10.2
Moraxella phenylpyruvica	3.7		7.7		5.1
Pseudomonas diminuta	0.3			0.9	
Pseudomonas vesicularis	3.1	0.2			11.8
Pseudomonas/Alcaligenes	5.6		3.7	13.7	
Pseudomonas spp.	0.1	0.1		0.0	0.1
Staphylococcus spp.	0.1				0.1
Identified isolates	49.1	67.8	56.3	77.9	74.4
Unidentified isolates*	50.8	32.2	43.7	22.1	25.5
Number of isolates		13.0	14.0	19.0	22.0

*Unidentified isolates consisted of 20% gram-negative nonfermentative bacteria for each tank; 1% and 2% gram-negative fermentative rods for cast-iron tanks 1 and 2; and 10%, 8%, and 5% of isolates that failed to grow on subsequent subculturing in cast-iron 2, fiberglass, and polyethylene tanks.

Table2-3: A table comparing different ammounts of bacterial growth between different storage tank constructions(Evison et al 2001).

2.5.5.2 Water Stagnation

A major consideration of storing water in a tank over time is stagnation. Water which remains stagnant in a tank over a long period is more susceptible to bacterial growth. This is why it is important that water is continuously circulated through the tank during normal operation. Continuously circulating water through the storage tank ensures that stagnant zones do not develop. To ensure this tanks must have a relatively high exchange rate directly proportional to the size of the tank (Nordblom, Bergdahl 2004).

2.5.6 Climate

It is important to know the climate and surrounding area near the WetLand project because each environment has its own uniqueness. The area that the WetLand project is located in is on the Delaware River in Philadelphia, PA.

2.5.6.1 Delaware River Basin

The area where the barge is going to stationed is on the Delaware River in Philadelphia, PA. This area is known as the Piedmont region with the southern boarder being a fault line that extends from Philadelphia all the way to Trenton, NJ, in figure 1.2 below a map showing the area known as the Piedmont region.

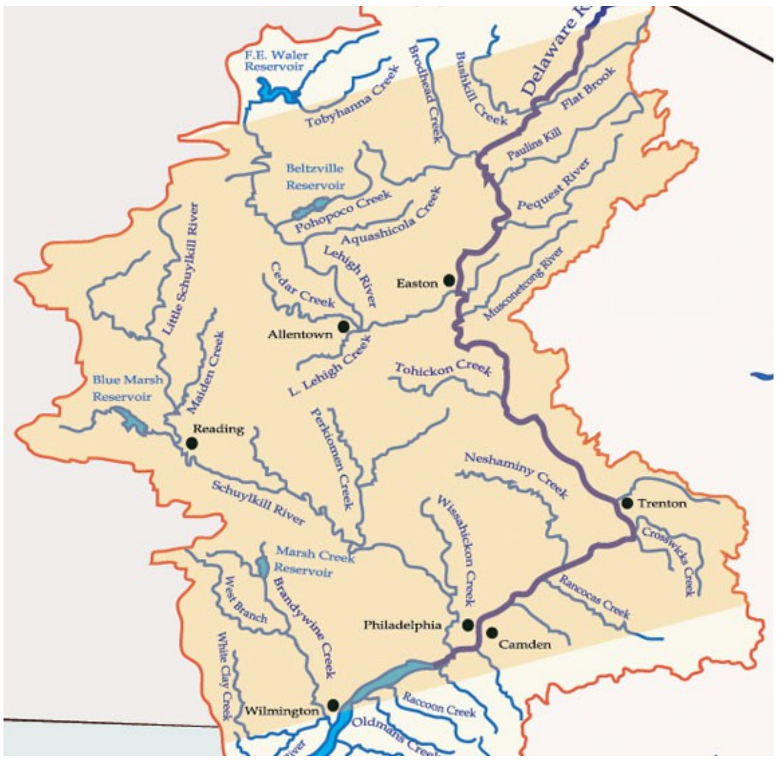

Figure2-9: A map of the Piedmont region (http://www.delawareriverkeeper.org/delaware-river/piedmont.asp)

The Delaware River has two main tributaries called the Schuylkill and the Lehigh Rivers. The wooded area near the river has various aged trees due to logging when the forest was cleared by the settlers, farmers, and lumber operations. The surrounding area has medium sized mammals, including woodchucks, as well as deer and small birds (http://www.delawareriverkeeper.org/delaware-river/piedmont.asp). The fish that inhabit the river are trout, salmon, and walleye (all are stocked in streams and ponds throughout the watershed). In the absence of dams the Delaware River is known to have eels inhabit the waters as well (http://www.delawareriverkeeper.org/delaware-river/piedmont.asp).

2.5.6.2 Delaware Weather

Since the main portion of the WetLand is during the summer of 2014 for three months only months during summer and fall will be used (WetLand Project Proposal 2). For 2013 it was a wet year with Philadelphia, PA setting records in June (10.06 inches) and July (13.24 inches) while August, September (1^{st}-9st) were much more modest, being 5.91 and 1.13 respectively, notice that the report was filled only with data up to the 9^{th} of September). Due to the record setting months in 2013 and the impartial report the 2012 data will also be taken into account. June, July, August, September, October, and November were 2.94 inches, 1.48 inches, 5.37 inches, 5.48 inches, 4.08 inches, and 1.05 inches respectively (http://www.state.nj.us/drbc/library/documents/precip.pdf). As for days with sunshine June and July both had nineteen total days with sun shine while 8 of those were mostly sunny, August also had nineteen total days with sunshine but nine were mostly sunny, September had only eighteen total days with sun but ten days were mostly sunny, October was back to nineteen days with sun and 11 were mostly sunny, and finally November had only sixteen days with sun and eight were mostly sunny (http://www.currentresults.com/Weather/Delaware).

2.6 Microchips

Microchips are electronics made up of semiconductors for functions in integrated circuits. There are many types of microchips that have various types of uses. (Arduino, 2013)

2.6.1 Arduino

An Arduino is an open source microchip platform that is flexible and can be used in many different applications. They can operate on Linux, Windows, and OS X. They are programmed with C, Java, or C++. (Arduino, 2013)

2.6.2 Anatomy of an Arduino microchip

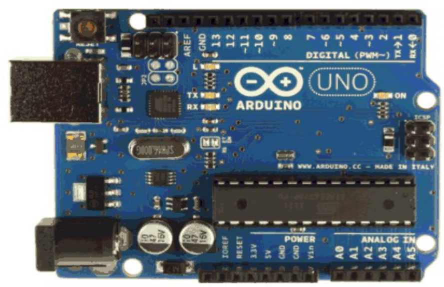

Figure2-10: Arduino Uno (http://arduino.cc/en/Main/arduinoBoardUno)

2.7 Operating Systems

It is software that manages computer hardware.

2.7.1 Linux

Linux is an open source OS. There are many variations of Linux. This allows Linux to be in the fastest super computers to a wristwatch. (Wiki a, 2011)

2.7.2 Windows Microsoft

Windows is one of the most common OS's. (Wiki a, 2011)

2.7.3 OS X

OS X is an open core graphical operating system. (Wiki a, 2011)

2.8 Programming

Programming is the process of formulas forming a computing problem creating executable programs.

2.8.1 Compilers

A compiler is a program for changing source code into another computer language.

2.8.2 C++

C++ is a general purpose programing language. (Stroustrup, 1997)

2.8.3 Java

Java is a programing language that has few implementation dependencies. (Wiki b, 2013)

2.8.4 C

C is General purpose language and is one of the most widely used. (Wiki c, 2013)

2.8.5 Arduino Conductive Sensors

Using conductive sensors to calculate volume works by attaching several sensors at several different heights down the side of the tank and using the resistance from the sensors to calculate the water level. This water level data is then fed through a microchip where the volume would be calculated

2.8.6 Water Quality Sensors

For the WetLand barge an important aspect of the water meter is to have the ability to accurately and efficiently evaluate a wide variety of water quality standards by using multiple sensors.

2.8.7 BOD sensor

Biochemical oxygen demand (BOD) is used to measure the amount of organic pollution in bodies of water. Using "the conventional BOD test requires a 5 day incubation period" (http://www.rpi.edu/dept/chem-eng/Biotech-Environ/BIOSEN2/bod.html) with the sensor using yeast called Trichopsporon cutaneum for waste water treatment. In the sensor "The micro-organisms were immobilized on a porous acetyl cellulose membrane and sandwiched between an oxygen permeable Teflon membrane and a porous membrane. Then, the membrane was directly fixed on the surface of the platinum cathode of an oxygen probe. A continuous flow system using a new microbial sensor was developed for automatic estimation of 5 day BOD tests."

2.8.8 Turbidity

2.8.8.1 OBS-3+ and OBS300

Submersible probe that uses near-infrared light to bounce it off suspended particles. As the obstructions grow higher the light will scatter and the reading will increase (http://www.campbellsci.com/). The desired temperature range for testing is zero to forty degrees Celsius, and the accuracy of the sensor is 2%. The main difference between the two models is that the OBS300 has downward-facing optics and the OBS3+ has side-facing optics.

2.8.8.2 OBS-3A

Combines the OBS probe with pressure, temperature, and conductivity sensors in a battery-powered recording instrument. The operating temperature is zero to thirty-five degrees Celsius, the turbidity ranges from 0.4 to 4,000 nephelometric turbidity units (NTU) (http://www.who.int/water_sanitation_health/hygiene/emergencies/fs2_33.pdf), and the pressure ranges from zero to 200 meters. The accuracy is turbidity<2%, pressure is plus or minus 0.5%, and temperature is also plus or minus 0.5% (http://www.campbellsci.com/obs-3a-specifications).

2.8.9 Salinity

2.8.9.1 Waterproof multiparameter PC tester

Tests for conductivity, pH, and temperature. The sensor is water proof with a replaceable electrode. The sensor has an auto-shutoff feature and a low-batter indicator. The price is $110 for the sensor (http://www.katssafety.com/Products/Waterproof-Multiparameter-PC-Testr-35.aspx).

2.8.9.2 Extech

Similar to the above comes with a one meter cable and tests pH, conductivity, and salinity. The model comes in at $77.51, but fits with an Oyster probe (http://salestores.com/extech804010.html?gclid=CJiniI6GmLoCFSdo7AodbXYAUw#.UlzKn53n8dk).

2.8.10 PH Meter

PH can be measured using a special measuring probe, which is connected to an electronic voltmeter. The probe contains two electrodes that measure hydrogen ion activity. The glass electrode has a glass bulb at the tip that acts as a pH-responsive electrode. A second electrode, known as the reference electrode, contains either a mercury-mercurous chloride, potassium chloride, or a silver-silver chloride. The reference electrode has a neutral pH balance against which the pH level of the substance is measured. A pH meter measures essentially the electro-chemical potential between a known liquid inside the glass electrode (membrane) and an unknown liquid outside. PH changes with temperature so pH meters often contain a thermometer for PH correction according to temperature. When on expedition, measuring sea water, the pH meter can be left moist with sea water. However for prolonged periods, it is recommended to moist it with a solution of potassium chloride at pH=4 or in the pH=4.01 acidic calibration buffer. PH meters do not like to be left in distilled water.

2.8.11 Litmus Paper pH

Litmus paper is paper that has been treated with a specific indicator - a mixture of 10-15 natural dyes obtained from lichens that turns red in response to acidic conditions ($pH < 7$) and blue under alkaline conditions ($pH > 7$). When the pH is neutral ($pH = 7$) then the dye is purple.

2.8.12 Thermometer

The electronic fever thermometers that you can buy in a grocery store use a thermistor to measure temperature. A thermistor is a semiconductor device that acts as a temperature-sensitive electric resistor. At very low temperatures, a thermistor is essentially an insulator; it has no mobile electric charges and thus can't carry electricity. But as its temperature increases, thermal energy rearranges the charges in the thermistor and it has more and more mobile electric charges. Its ability to conduct electricity increases with temperature fairly dramatically it gradually becomes an electric conductor. The thermistor used in a fever thermometer is designed to undergo this rapid change in electric resistance at temperatures near 98Â° F. A simple computer inside the thermometer measures the thermistor's electric resistance and determines the thermistor's temperature. It then uses a liquid crystal-based display to show you what that temperature is."

2.8.13 Data display and Storage

Since there are many different standards for water quality it is important for the user(s) to have the data displayed in one location as well as displayed clearly. Also the volume and water quality can change over time. In order to achieve this, a data storage device is required, and by adding this in the WetLand barge has the ability to track trends of the water on board.

2.8.13.1 LCD

A display is an output device for showing information visually. There are many types of displays. A common display for computers monitors is a LCD. A liquid crystal display (LCD) is a visual display that uses the light modulation of liquid crystals. LCD’s are energy efficient compared to other display types which allow it to be used in electronics that run on batteries. There are many different types of LCD’s that can be wired to an Arduino or other microchip platforms. (Energy Star, 2013)

2.8.13.2 Data Storage

Data storage shields are a technology that holds digital data. It is often called storage or memory. Nonvolatile memory holds information when it is off and volatile memory requires constant power. (Memory, 2013) A data logger would be needed to record information. A data logger records data with a built in sensor or an external sensor (Datalogger, 2013). By implementing this, the user(s) have the ability to see if a trend in the water is occurring and see their volume over time.

2.8.13.3 Wired/wireless

An arduino can be wired or wireless. Wired refers to being connected with wires and carrying electricity through wires. Wireless refers to the transfer of information between points without the use of wires. Many arduino products are wired but can be made wireless. (Wireless SD shield, 2013)

2.8.14 Human computer interface

Human computer interface is how a person interacts with a computer.

2.8.14.1 Graphical user interface

The graphical user interface (GUI) allows users to interact with an electronic graphically. (Meyers, 2004)

2.8.14.2 Touchscreen

A touchscreen allows users to control by touching the screen. (Lewis, Douglas, Monaco, Crowley, 2010)

2.9 CAD

Computer Assisted Drafting (CAD) is the use of a computer program to assist in a design.

2.9.1.1 AutoCAD

AutoCAD is program for design. It makes it easier and user- friendly to make designs on a computer. (Anonymous, 2007)

2.10 Wiring

Wires are made up of different materials, copper and/or aluminum. 2 or more wires are called a cable. There are different sizes of wiring. The sizes influence the amount of amps and volts. (Karre, 2005)

2.11 AC/DC

AC and DC are different ways electric charges move. In AC current is periodically reversed, and in DC current only flows in one direction. (Magnet, 2013)

2.12 3D Printing

A 3D printer is a fabrication device, similar to an inkjet printer, which prints either models or full size components from a variety of materials. 3D printers work by converting a CAD model into an STL file. The file is then digitally sliced into several layers. The 3D printer then prints the model layer by layer creating a solid object (Lowe 36).

2.13 Solar Energy Catchment:

Upon doing extensive research addressing the atmospheric conditions near the Delaware Delta, as well as a recommendation from the client, Mary Mattingly, solar energy has been recommended as the most effective and economical self-sustaining energy source for the Wetlands project. There are many differences and distinctions between specific types of solar panels which effect cost, efficiency, and availability.

Silicone is currently one of the most frequently used materials for solar energy conduction.

2.13.1 Mono Crystalline Solar Panel:

2.13.1.1 Introduction

Solar cells made of monocrystalline silicon (mono-Si), also called single-crystalline silicon (single-crystal-Si), are quite easily recognizable by an external even coloring and uniform look, indicating high-purity silicon. Monocrystalline solar cells are made of silicon ingots, which are cylindrical in shape. To optimize performance and lower costs of a single monocrystalline solar cell, four sides are cut out of the cylindrical ingots to make silicon wafers, which gives monocrystalline solar panels their characteristic look.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.1.2 Pros of Monocrystalline silicone:

2.13.1.2.1 Efficiency

Monocrystalline solar panels have the highest efficiency rates. This is because they are made out of the highest-grade silicon typically around 15-20% efficient. Monocrystalline silicon solar panels are space-efficient. This is because the solar panels yield the highest power outputs to area ratio, they also require the least amount of space compared to any other types. Monocrystalline

2.13.1.2.2 Longevity

Mono crystaline solar panels live the longest of any type of solar panel.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative:
<http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.1.3 Cons of Monocrystalline silicon

2.13.1.3.1 Price

Monocrystalline solar panels are the most expensive type of solar panel. This is because they use higher quality materials than other types of solar panels.

2.13.1.3.2 Weather

A drawback of monocrystaline solar panels is their vulnerability to the elements. If a monocrystaline solar panel is partially covered with shade, dirt or snow, the entire circuit can break down. Monocrystalline solar panels tend to be more efficient in warm weather. Performance suffers as temperature goes up, but less so than polycrystalline solar panels.

2.13.1.3.3 Materials

More silicone is wasted during production of mono crystalline panels. The Czochralski process is used to produce monocrystalline silicon. It results in large cylindrical ingots. Four sides are cut out of the ingots to make silicon wafers. A significant amount of the original silicon ends up as waste.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.2 Polycrystalline Solar Panels

2.13.3 Introduction

The first solar panels based on polycrystalline silicon, which also is known as polysilicon (p-Si) and multi-crystalline silicon (mc-Si), were introduced to the market in 1981. Unlike monocrystalline-based solar panels, polycrystalline solar panels do not require the Czochralski process. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers.(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.3.1 Pros of Polycrystalline

The process used to make polycrystalline silicon is simpler and cost less. The amount of waste silicon is less compared to monocrystalline. Polycrystalline solar panels tend to have slightly lower heat tolerance than monocrystalline solar panels. This technically means that they perform slightly worse than monocrystalline solar panels in high temperatures.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.3.2 Cons of Polycrystalline

The efficiency of polycrystalline-based solar panels is typically 13-16%. Because of lower silicon purity, polycrystalline solar panels are not quite as efficient as monocrystalline solar panels. Lower space-efficiency. You generally need to cover a larger surface to output the same electrical power as you would with a solar panel made of monocrystalline silicon.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.4 Amorphous Silicon

2.13.4.1 Introduction

Because the output of electrical power is low, solar cells based on amorphous silicon have traditionally only been used for small-scale applications such as in pocket calculators. With a manufacturing technique called “stacking”, several layers of amorphous silicon solar cells can be combined, which results in higher efficiency rates (typically around 6-8%).

(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.13.4.2 Pros of Amorphous Silicon

Requires much less silicon. Can be made flexible and lightweight. Potentially inexpensive.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html 02 Oct. 2013.)

2.13.4.3 Cons of Amorphous Silicon

Amorphous thin-film solar cells have lower efficiency rates. The technology has to mature to compete against mono- and polycrystalline solar.
(15 Aug. 2012. "Crystalline Silicon Photovoltaics Research." SunShot Initiative: <http://www1.eere.energy.gov/solar/sunshot/pv_crystalline_silicon.html> 02 Oct. 2013.)

2.14 Energy Storage

One of the ongoing challenges posed to renewable energy technologies is finding an effective way to store the energy. Generally energy can be stored by converting the energy that is being inputted into other forms of energy that can be outputted at a later time. Some of the various forms that the electrical energy is converted to are potential, kinetic or chemical energy.

2.14.1 Batteries

Although there exists many various techniques of storing energy captured from photovoltaics, it seems to me that for such a small scale, and cost dependent project, battery storage will be the most economical option while still performing the task at hand. There are many types of batteries for energy storage, but we will be examining various home-made battery systems, as well as a conventional Lithium Ion Battery.

2.14.1.1 Salt Water Battery

A salt water battery is made of two zinc-air cells in series which produce about a volt and a half. Another way to make the cell produce a higher voltage is to change the chemistry. The zinc-air cell produces more if some hydrogen peroxide is added to the salt water. Chlorine bleach can also be added but hydrogen peroxide is safer and has no odor.
(Field, Simon. "Electrochemistry -- Make Homemade Batteries." Chapter 3: Electrochemistry -- Make Homemade Batteries in Your Kitchen. <http://sci-toys.com/scitoys/scitoys/echem/batteries/batteries.html> 02 Oct. 2013.)

2.14.1.2 Coke Zinc Battery

This process is similar to the salt water battery using different materials. Copper-zinc-coke batteries produce about 3 volts, and can replace the 3 volt lithium battery in this small clock/calendar/calculator. A copper-zinc-coke battery can for days, and can probably last months.
(Field, Simon. "Electrochemistry -- Make Homemade Batteries." Chapter 3: Electrochemistry -- Make Homemade Batteries in Your Kitchen. <http://sci-toys.com/scitoys/scitoys/echem/batteries/batteries.html> 02 Oct. 2013.)

2.14.1.3 Lithium Ion Battery

Lithium ion (Li-ion) batteries achieve energy storage efficiencies of close to 100% and have the highest energy density when compared to the two types of batteries discussed in previous sections. Drawbacks of this technology include high investment costs and complicated charge management systems.
(Nirmal-Kumar C. Nair, Niraj Garimella,(2010) Battery energy storage systems: Assessment for small-scale renewable energy integration, Energy and Buildings, Volume 42, Issue 11, Pages 2124-2130.)

3 Alternative Solutions

3.1 Alternative Solution Sets

3.1.1 Introduction

Several combinations of alternative solution components are shown below. While the number of possible combinations is much greater than what is shown here, these solutions are representative of the scope and scale of formulated solutions. Each of these solution sets is installed in the water storage tank onboard the Wetlands barge, and includes a point-source carbon filter for drinking water.

3.1.2 Analog Meter

The Analog Meter measures volume with the float with view window method described in section 2.3.2.2.. This solution set measures pH using litmus paper described in section 2.11.11.. Measurements with this solution set are viewed through the tick marks on the view window in the volume cylinder, and through the results of the litmus paper.

Pros: The Analog Meter has a low cost, is simple and repair, and does not require power.

Cons: The Analog Meter requires the tank to be visible and can only be viewed from near the tank.

3.1.3 Digital Meter with Analog Backup 1

Digital Meter with Analog Backup 1 measures pH with the meter as described in section 1.2.4, temperature described in section 1.2.6, and salinity as described in section 1.2.3.1. PH is also measured using litmus paper as described in section 1.2.5 as a backup in the case of power failure. Readings from Digital Meter with Analog Backup 1 are accessed through a wired LCD display, the analog volume view window, and the litmus paper.

Pros: The Digital Meter with Analog Backup 1 has easy access and consistent measurements of many types. The Digital Meter with Analog Backup 1 has redundant analog systems which allow it to run without power for an extended period of time.

Cons: The Digital Meter with Analog Backup 1 requires the tank to be visible to read the analog volume measurements.

3.1.4 Digital Meter with Analog Backup 2

The Digital Meter with Analog Backup 2 measures volume using the arduino sensor method described in section 1.1.3, and the float with view window method described in section 1.1.1. The Digital Meter with Analog Backup 2 measures pH as described in section 1.2.5, temperature as mentioned in section 1.2.6, salinity as described in section 1.2.3.1, and turbidity as mentioned in section 1.2.2.1. PH is also measured using litmus paper as described in section 1.2.5 as a backup in case of power failure. Measurements from the Digital Meter with Analog Backup 2 are viewed through a wired LCD screen, from the volume view window, turbidity sensor readings, and the litmus paper.

Pros: The Digital Meter with Analog Backup 2 has easy access and consistent measurements of many types. The Digital Meter with Analog Backup 2 has redundant analog systems which allow it to run without power for an extended period of time.

Cons: The Digital Meter with Analog Backup 2 requires the tank to be visible to read the analog volume measurements. The Digital Meter with Analog Backup 2 also measures turbidity which requires samples to be measured outside the tank, requiring a higher level of technical understanding.

3.1.5 Digital Meter 1

The Digital Meter 1 tests for pH using a digital pH sensor. As described in section 1.2.4 most pH sensors have a temperature sensor as the temperature can control the level of pH. To test for volume this design utilizes the arduino sonar volume sensor as described in section 1.1.3. All of these systems will have an output on a wired LCD display which is described in section 1.2.9.1.

Pros: The Digital meter 1 has the bare necessities that are needed, making the cost low.

Cons: The Digital meter 1 cannot measure anything else besides pH and volume of the water in the storage tanks. There is no back up for the sensors.

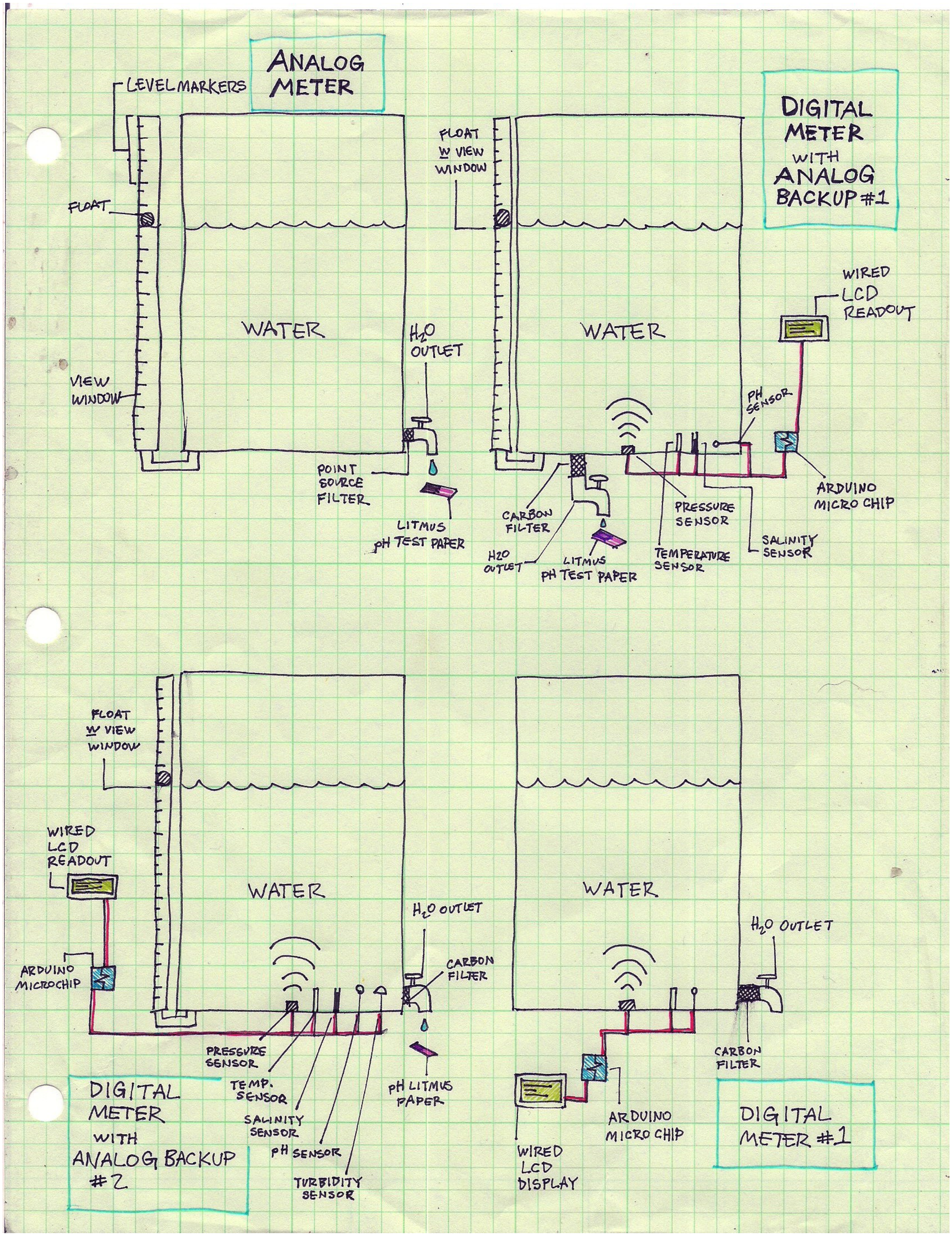

Figure3-1: A diagram showing the different components of alternate solution sets.

3.1.6 Digital Meter 2

The digital meter 2 tests for pH, temperature, and volume all displaying on a LCD wireless display. This system relies on a pH sensor with a built in thermometer. The volume is measured by an arduino volume sensor. All of the data is displayed on the LCD screen.
Pros: The Digital meter 2 can measure temperature and is still at a low cost. Wireless systems allow measurements to be taken at a distance.
Cons: If wireless system fails there is no backup that runs without power. This method can only measure temperature, pH, and volume.

3.1.7 Digital Meter 3

The volume reading for the Digital Meter 3 is provided through a Gas-tank style bob. The Digital Meter 3 tests for pH through an Arduino compatible pH sensor that has a thermometer included for adjusting pH with temperature and a temperature read out. These water qualities are displayed on a wired LCD display.
Pros: The Digital Meter 3 includes the necessities but nothing extraneous which allows it potential of staying reasonably within budget.
Cons: The gas-tank bob method of measuring volume reads full until the water level drops below a certain level that allows the float to start to drop. The Digital Mater 3 only reads volume and pH.

3.1.8 Digital Meter 4

The Digital Meter 4 tests for pH by using an arduino compatible pH sensor while using litmus paper as an analog backup testing method. The Digital Meter 4 measures volume with the arduino sonar sensor method. Digital Meter 4 also has marks on the storage barrel as a backup option of measuring volume and includes a float with a viewing window. Digital Meter 4 method also tests for BOD, salinity, temperature, and turbidity using the appropriate meter technologies. All of the sensors readings will be transmitted to a wired LCD display.

Pros: The Digital Meter 4 measures a wide array of water qualities. Has back-up for some of the more critical water quality measurements. Wireless display option is convenient.
Cons: Expensive. Advanced arduino programming required for meter read-out coordination, difficult troubleshooting, and potentially high maintenance.

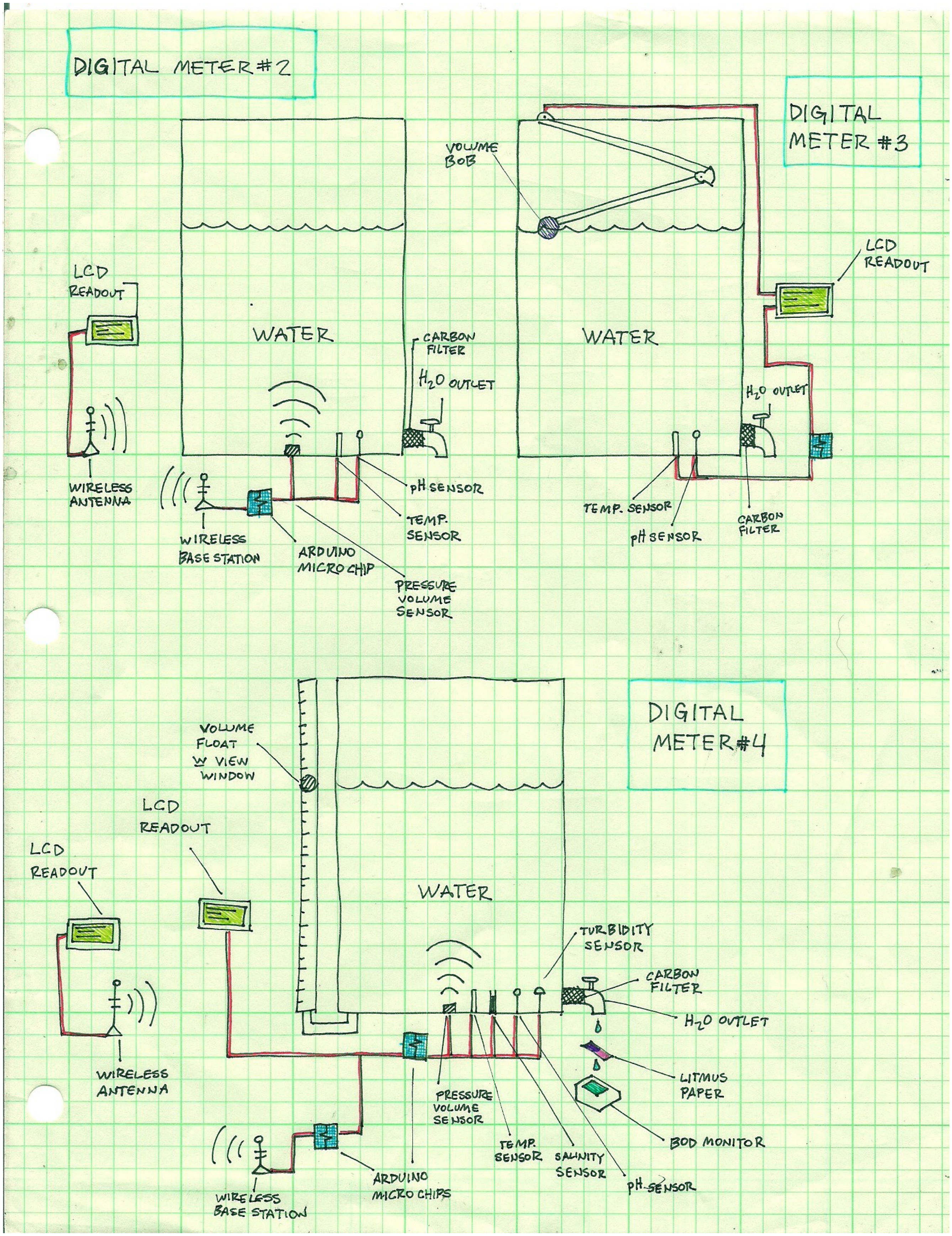

Figure3-2: A diagram showing the different components of alternate solution sets.

3.2 Brainstorming

The brainstorming session to determine alternate designs started with brainstorming what devices were necessary for the water meter. Then the brainstorm was further defined into each section as shown below. From this brainstorm each alternative design was chosen by mixing and matching with varying amounts and types of sensors. Refer to Appendix C for brainstorming notes.

4.2 Alternative Solutions

A variety of alternative solutions were analyzed to decide the best solution for the client. The alternative solutions that are listed below are fully described in Section 3.

Analog Meter

Digital/Analog 1

Digital/Analog 2

Digital 1

Digital 2

Digital 3

Digital 4

4.3 Decision Process

The final decision was come to by using a Delphi Matrix as shown Table 4.1. The matrix uses a weighted scale for the criteria and ranks them from 1-10, with ten being the best. The ratings for the criteria were decided upon by using a combination of client criteria, problem analysis, and the literature review. The values given to each alternative solution for each criterion were then multiplied and each column is added in order to obtain a total value. The alternative solution with the highest score is best fit to satisfy the chosen criteria.

Table4-1: A Delphi Matrix comparing weighted criteria of each solution set.

Criteria	Weight (1-10 high)	Alternate Solutions (1-10 high)						
		Analog Meter	Digital/Analog 1	Digital/Analog 2	Digital 1	Digital 2	Digital 3	Digital 4
Cost	10	10 / 100	6 / 60	5 / 50	4 / 40	3 / 30	2 / 20	1 / 10
Functional	10	4 / 40	5 / 50	6 / 60	7 / 70	8 / 80	9 / 90	10 / 100
Power Consumption	9	10 / 90	9 / 81	8 / 72	7 / 63	6 / 54	5 / 45	4 / 36
Safety	9	10 / 90	9 / 81	9 / 81	8 / 72	8 / 72	8 / 72	7 / 63
Durability	8	8 / 64	9 / 72	9 / 72	5 / 40	5 / 40	5 / 40	5 / 40
Aesthetics	8	5 / 40	8 / 64	8 / 64	8 / 64	9 / 72	8 / 64	10 / 80
Accuracy	7	7 / 49	10 / 70	10 / 70	8 / 56	8 / 56	6 / 42	8 / 56
Reproducibility	6	10 / 60	9 / 54	9 / 54	8 / 48	8 / 48	7 / 42	6 / 36
Ease of Use	6	7 / 42	10 / 60	10 / 60	8 / 48	8 / 48	8 / 48	6 / 36
Total		**575**	**592**	**583**	**501**	**500**	**463**	**457**

Table4-1: Delphi Matrix to determine the design.

4.4 Decision

The final decision chosen by Team X is Digital/Analog 1 defined in Section 3. This solution best fits the client criteria and is the highest scorer in the Delphi Matrix. The digital/Analog 1 implements a pH sensor, saline sensor, volume sensor, and temperature gage. These sensors will read to a wired LCD display. The Digital/Analog 1 implements analog measurement systems for salinity and pH.

5 Specifications

5.1 Introduction

Specifications of the solution cover the details of the final solution. These specifications include a solution description, cost analysis, instructions for implementation, and performance results.

5.2 Description

The final design of the water meter includes the following compontents: flowrate and volume sensors installed in the storage tank, water quality sensors installed in the water quality sampling compartment, an LCD readout, and a data storage bank. Figure 5-1 shows the components of the final water meter design.

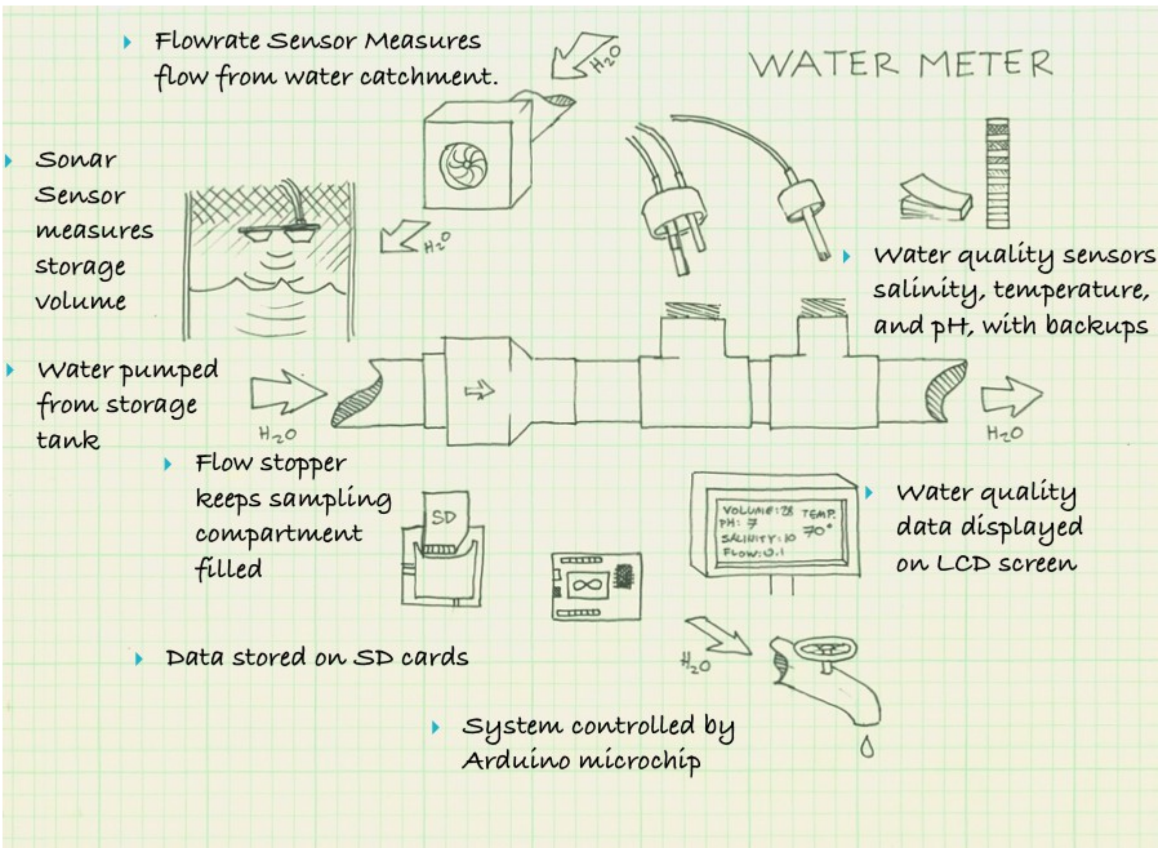

Figure5 1: Components of the final water meter design.

5.2.1 Storage Tank Sensors

Installed in the storage tank are flowrate sensors and an ultrasonic volume sensor. The flowrate sensors are installed at the inlet and the outlet of the water storage tank. The flowrate sensor at the inlet measures the rate at which water is collected from the water catchment systems, the flowrate sensor at the outlet of the storage tank starts the water quality testing process automatically as water flows out of the tank and to the faucet.

5.2.2 Sampling Compartment

The water meter utilizes a 2” PVC pipe housing for the water quality sampling compartment. The sampling compartment consists of: A flow regulator, which insures the sensor compartment is filled with water, this keeps the sensors from drying out and becoming damaged; A 2” PVC pipe section, which attaches other components; 2” T-pipes which are used in combination with plumbing caps to form sensor caps where the water is tested.

5.2.3 Water Quality Sensors

The sensor caps in the T-pipes of the plumbing system contain the water quality testing sensors. The water quality sensors installed in caps in the piping of the sampling compartment. These sensors include a pH sensor, a salinity sensor, and a temperature sensor.

5.2.4 Arduino

All the sensors in the water meter run off an Arduino Uno – programable microchip. The Arduino is wired to the sensors. Software is downloaded onto the Arduino to convert readings from the sensors into data which is displayed to the user on an LCD Screen.

2.14.2 Data Storage

An SD card data storage shield is included to log data collected from the sensors.

2.14.3 Analog Backups

Analog backups are provided to monitor water quality in the event of a power failure, or in a low power environment.

5.2.5 LCD Interface

The readings from the water meter are displayed on an LCD screen near the outlet faucet.

5.3 Cost Analysis

2.14.4 Design Cost

The time spent designing the water meter is broken up into 5 categories: problem formulation, problem analysis and research, alternative solutions, final decision, and building and testing. The total design time is 206 hours.

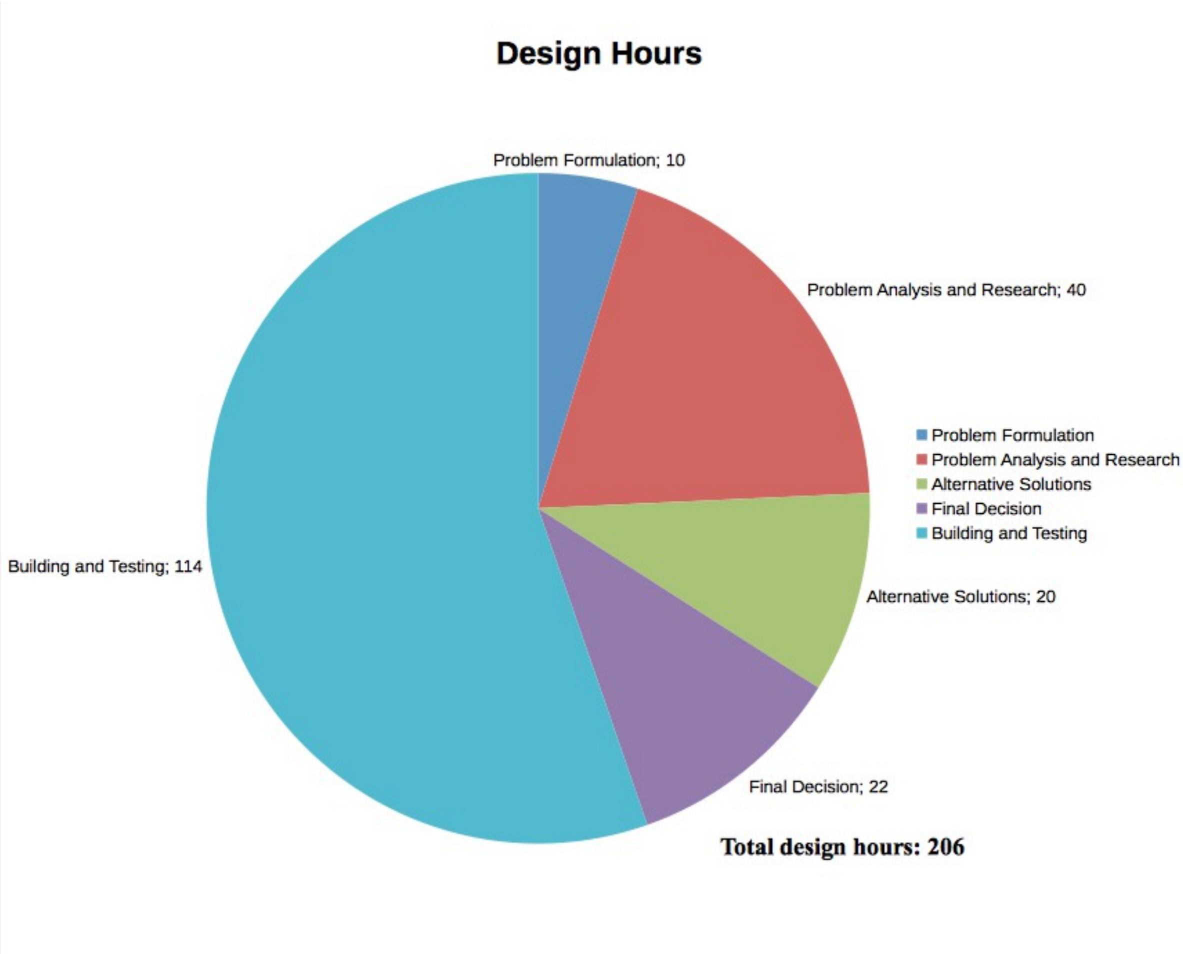

Figure5-2: The time measured in hours spent to design the water meter. A total time of approximately 206 hours.

5.3.1 Implementation Cost

An itemized breakdown of the price of materials used in the construction of the water meter is shown in Table 5.1 below. This list accurately reflects the price of materials needed to construct and implement a water meter.

Table5-1: The price of materials needed to construct a water meter.

Materials	Cost [$]
Arduino Uno Microchip	25.00
LCD Screen	11.00
Sensor Shield	10.00
Temperature Sensor	6.50
pH Sensor	112.00
Flow Rate Sensor	12.00
Data Storage Shield	8.50
Sonar Sensor	5.50
Wiring	12.00
Plumbing	47.00
Total	249.50

5.3.2 Maintenance Costs

2.14.4.1 Weekly Maintenance

The system requires weekly calibration of sensors. During calibration sensor caps are also checked for corrosion. Maintenance can be performed by one person. The duration of maintenance is approximately 30 minutes.

2.14.4.2 Yearly Maintenance

The water storage tank must be cleaned once per year. The duration of yearly maintenance is approximately 1 hour.

5.4 Instructions

Full detailed instructions for implementation of the water meter system can be found in Appendix B.

5.5 Results

The water meter records the inflow of water into the storage tank. The water meter begins taking measurements of volume, pH, temperature, and salinity automatically when the faucet is turned on. These readings are then displayed on and LCD screen at the outlet faucet.

Sensor caps make the water meter easy to maintain. The water meter is also reliable in a power outage because of analog backups. The LCD interface creates a user friendly experience.

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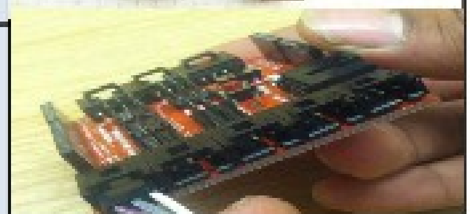
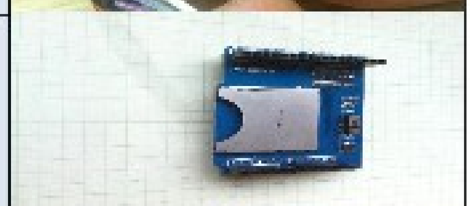
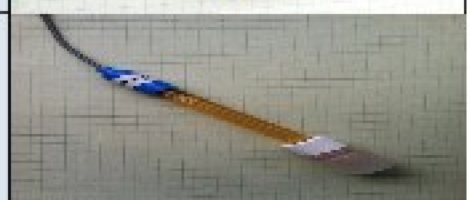
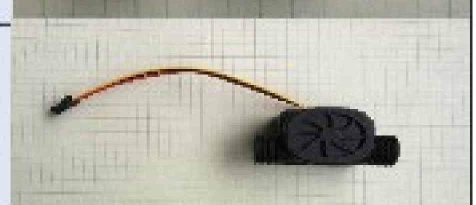
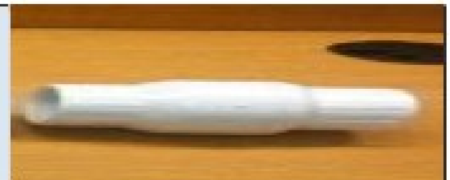
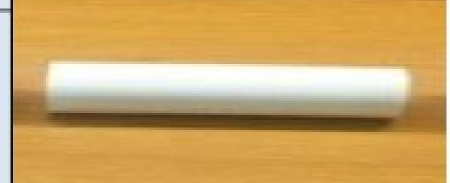
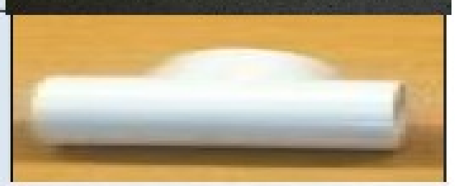
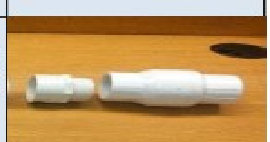
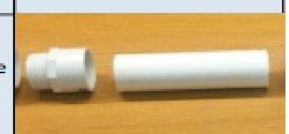
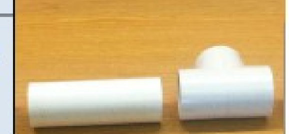
Appendix B: Instructions

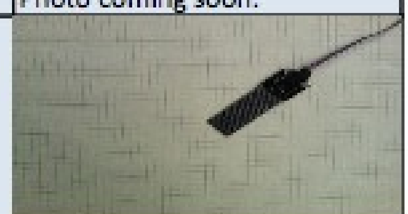
Materials needed	Photo
Arduino Uno	
Sensor Shield	
Data Storage Shield	
pH Sensor	
Salinity Sensor	
Temperature Sensor	
Sonar Sensor	
Flow Gauge X2	
LCD Screen	

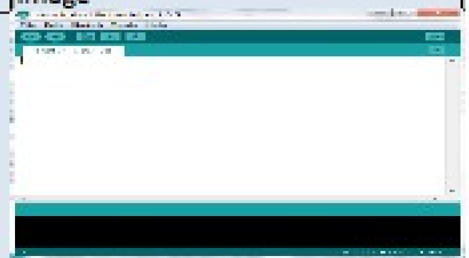
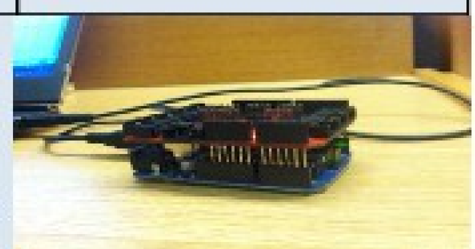
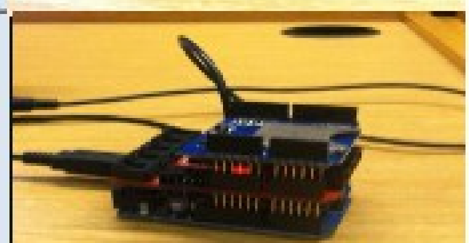
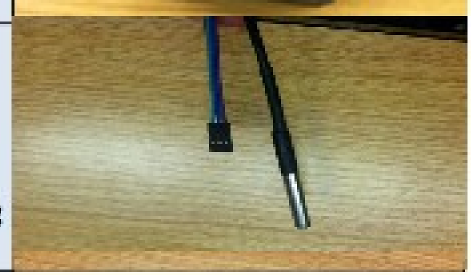
2" Flow Regulator	
2" Male Adapter	
1 Ft 2" PVC	
2" T pipe with 1" top	
2" T pipe with 2" top	
1" pipe threading	
2" pipe threading	
1" PVC cap	
2" PVC cap	

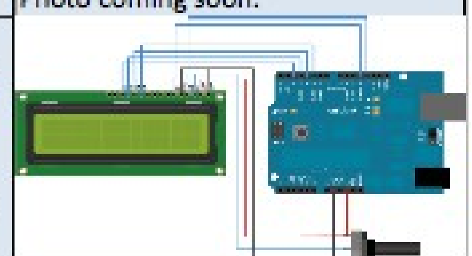
4oz PVC primer	
4oz PVC pipe cement	

Building the sampling compartment

Step	Instructions	Image
1	Cut with saw 1ft. of 2 In PVC pipe into 3 sections	Photo coming soon
2	Drill _In hole in 1 In PVC cap	Photo coming soon
3	Drill _In hole in 2 In PVC cap	Photo coming soon
4	Apply PVC primer to 2 In PVC male adapter's threading	
5	Apply PVC primer to 2 In PVC flow regulator's flow out threading	
6	Apply PVC cement to 2 In PVC male adapter's threading	
7	Connect 2 In PVC male adapter to 2 In PVC flow regulator's flow out threading	
8	Apply PVC Primer to the outside of the ends of 2 In 3 section PVC pipe	
9	Apply PVC Primer to the inside of the ends of the t-pipes and male adapter	
10	Apply PVC cement to the outside of the ends of 2 In 3 section PVC pipe.	
11	Connect 1 section of 2 In PVC pipe to male adapter.	
12	Connect 2 In PVC T-pipe 1 In top into the previous step's 2 In PVC pipe section	
13	Connect 1 section of 2 In PVC pipe to 2 In PVC T-pipe 1In top	
14	Connect 2 In PVC T-pipe 2 In top into the previous step's 2 In PVC pipe section	Photo coming soon
15	Connect 1 section of 2 In PVC pipe to 2 In PVC T-pipe 2In top	
16	Apply primer to inside of tops of PVC t-pipe	

Electronics Installation			
Component	**Steps**	**Instructions**	**Image**
Sonar Sensor	1	Drill two holes in piece of plywood	Photo coming soon.
	2	Fasten sensor to plywood	Photo coming soon.
pH Sensor	1	Sensor is water proof	
	2	Sensor is integrated into the sampling compartment	
	3	The sensor has the cable coming out and going away from the sensor	Photo coming soon.
Electrical Conductivity Sensor	1	The sensor must first be water proofed above the actual sensing strip	
	3	Sensor is integrated into the sampling compartment	Photo coming soon.
	4	The sensor has the cable coming out and going away from the sensor	Photo coming soon.

	Building the Circuit	
Step	Instructions	Image
1	Download Arduino programming software onto computer via http://arduino.cc/.	
2	Plug Arduino into computer via USB cable.	
3	Upload various sensor codes into separate tabs on the Arduino. Code for each sensor can be found here; http://www.appropedia.org/Team_X_Water_Meter_Arduino_Code	
4	Plug Sensor Shield into the Arduino aligning all pins.	
5	Plug Data storage shield into the sensor shield aligning all pins.	
6	Solder Temperature sensor wires to 3 prong male header .	

7	Solder Sonar sensor to 4 prong female header using 4 -5 ft strips of 22 gauge wire.	
8	Extend the Flow rate gauge wire length by cutting its wiring and soldering a 5ft piece of 22 gauge wire into the middle section.	Photo coming soon.
9	Plug Temperature sensor, Sonar sensor, Electrical Conductivity sensor, and Flow Rate Gauge into sensor shield and adjust analog input values in arduino code according to which analog port used.	
	Solder pH sensor probe to its shield using 4-5 ft 22 gauge wire.	
10	Solder 22 gauge wire to pH sensor shield then plug this wiring into Arduino following the wiring diagram shown here; https://www.atlas-scientific.com/_files/instructions/Wiringdiagram.pdf	Photo coming soon.
11	Solder Arduino to LCD screen using 10ft 22 gauge wire. Wiring diagram for 16 pin LCD (shown right) can be found here; http://arduino.cc/en/Tutorial/LiquidCrystal	
12	Plug SD card into data storage shield.	Photo coming soon.

Appendix C: Brainstorming Notes