The Ohio State University
Department of Food, Agricultural, and Biological Engineering

April 23, 2021

The Ohio State University
281 W Lane Ave
Columbus, Ohio 43210

Dear Mrs. VanCleave

It is with great pleasure that we deliver our final report *OSU WaterHub: Testing EPA Parameters Within a Living Learning Lab.* This report details research, design description, design evaluation, final design results, cost analysis, further design considerations, and conclusions and recommendations.

After extensive research and thoughtful consideration, the final design the team presents includes sensor placements, the number of sensors at each placement, a pump and piping system to retrieve draw samples, a clear pipe section in the hydroponic reactor room with slide cover, and an interactive dashboard that visitors can interact with to get a better understanding of what a WaterHub is and why it is important monitor and test for different Environmental Protection Agency (EPA) parameters.

We would like to thank you for your time and support over the course of the past year. This has been a challenging time for all of us. We would also like to acknowledge Kristen Conroy, Dr. Jane Fife, Dr. David Wituszynksi, Melodi Clarke, Bob Salvatelli, and Eric Lohan for their guidance and expertise throughout this process. We would be happy to answer any questions regarding this project and can be reached at the contact information below. Again, thank you for the opportunity to work on this project.

Best,

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OSU WaterHub: Testing EPA Parameters Within a Living Learning Lab

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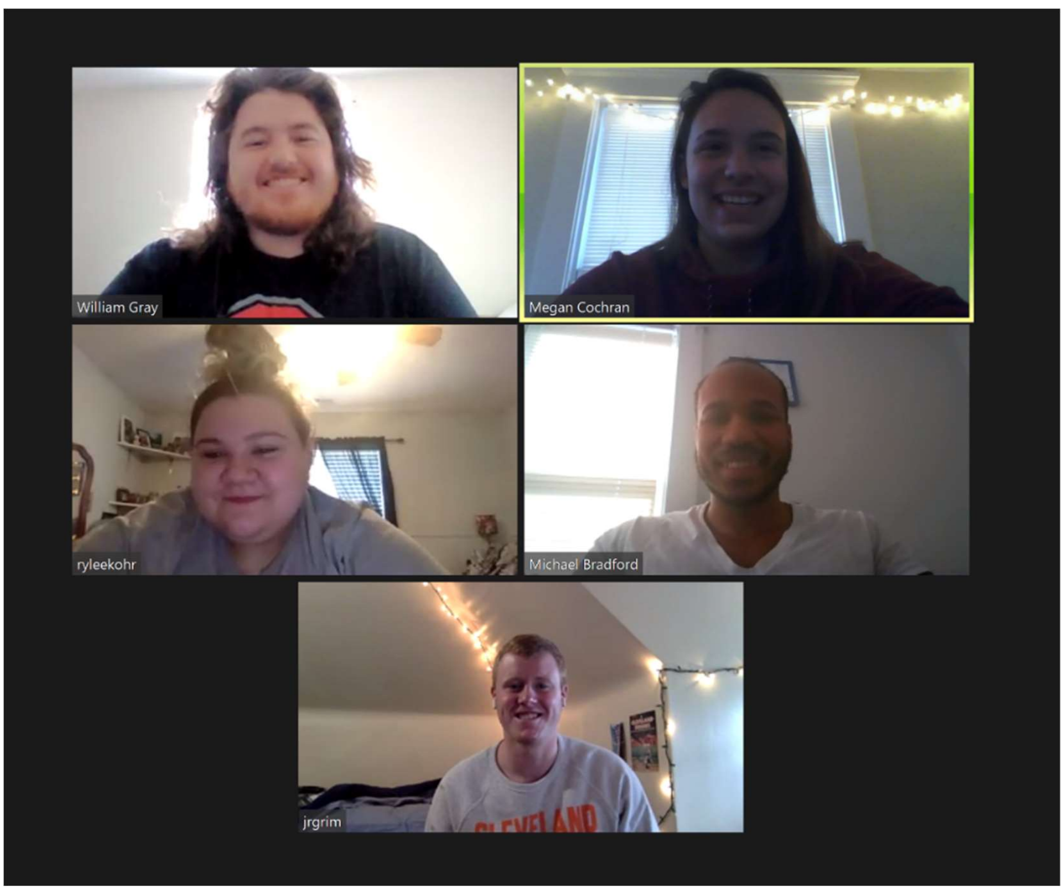

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Executive Summary

Ohio State University (OSU) is planning to construct a district-scale wastewater reclamation and reuse plant. Partnering with sustainable water, OSU will be introducing the WaterHub to campus within the next five years. Ohio State Sustainability needs constant and accurate measurements of the water quality within the WaterHub so that Environmental Protection Agency (EPA) wastewater requirements can be met and maintained while the facility is showcased as a living, learning lab. Wastewater will flow through nine major tanks/steps within the WaterHub in order to be fully treated and reused. This design will divert wastewater from the city of Columbus and help OSU Energy and Sustainability successfully reuse around 1.5 million gallons of wastewater each day.

The proposed solution to test for these EPA parameters consists of using sensors and a pump and piping system in seven different main tanks. An interactive dashboard with live updates will be installed in the hydroponic reactor room. This dashboard will give information on the seven different tanks/steps and the EPA parameters as well. There will be a clear section of pipe that is available for viewing the wastewater from the different steps in the hydroponic reactor room. A slide cover will be put over this clear section to prevent being exposed to sunlight for a prolonged period of time.

There were three different ways of evaluating our design. The sensors were evaluated using company specification sheets. The pump and piping system was evaluated by using Bernoulli's equation to calculate the horsepower needed. Lastly, the dashboard was evaluated by sending out a survey, which consisted of a video on how it works, and evaluating feedback.

According to specification sheets, the sensors will update in less than two seconds which is far more frequent than the EPA recommends, and they are accurate enough to be within 0.1 of the target measurements. The pump and piping system requires 0.00257 horsepower, so a 1/200, or 0.005 horsepower pump will be selected. The survey feedback showed an 86% rate of people gaining knowledge about a WaterHub. The dashboard was also able to update less than two minutes when data in excel was changed every 45 seconds.

Based on the research and evaluations, the team came up with the following conclusions. Only Yellow Springs Instruments (YSI) sensors will be selected. There will be four sensors and 7 tanks to place them in, totaling twenty-eight sensors. The sensors will be placed in through the top and middle of each tank through a latch station directly above each tank. A 1/200 horsepower pump will be selected along with quarter inch pipe and a clear section with covering that is accessible to the public. Use a SCADA system to create a pathway to the excel spreadsheet used to log the sensor data for MATLAB to retrieve. A touch screen monitor and a computer with MATLAB to run the graphical user interface in an area of the WaterHub that is accessible to the public.

1.0 Introduction

Ohio State University's Department of Facilities Operations and Development is currently working on making the campus more sustainable through numerous diverse efforts. One such effort is creating a WaterHub, which is a water reclamation system. To create the WaterHub, Ohio State University (OSU) will be working with Sustainable Water. Sustainable Water is a company that creates WaterHubs and is a leading provider of water reclamation sites in the United States. The WaterHub will be using wastewater from various campus buildings and treating it to turn it into non-potable water for use in the chiller plants and other non-potable water uses on campus. The goals of the WaterHub at OSU are to provide the campus with greater water resiliency with a backup water supply, conserve 20-30% of campus potable water, create long-term water and sewer utility cost savings of 28-60 million dollars over 30 years for the campus, increase sewer capacity for campus development, reduce combined sewer overflows of the campus by up to 30-70% in equivalent discharges, and improve the water quality of the surrounding environment such as the Olentangy River. (VanCleave, 2020) While the main function of the WaterHub is to be used as a water reclamation site, it is also going to serve as an educational tool for Ohio State. Part of the work going into planning the water reclamation site is to create a system for testing the water with the use of sensors that provides an efficient and effective way to collect live data on the wastewater throughout different parts of the treatment process. To ensure the functionality of the WaterHub, EPA regulations must be met so that the water is safe to use. This requires different tests to be conducted throughout the process of the water reclamation. While some of the tests have sensors and can quickly obtain the required data, others require samples to be taken and tested in the lab. To ensure that the test can be done as quickly and accurately as possible, it is necessary to have a sampling system in place. The purpose of the project is to design a system for accurately testing the water and create a way to show the results of the testing in an easy manor. The purpose of this report is to provide background information on water testing technologies and recommend a design of a system to test the water within OSU's WaterHub.

1.1 Problem Definition

For a water treatment plant to legally run with a permit, the water quality parameters must meet EPA standards. The team was specifically tasked with developing a testing system for monitoring the water quality parameters within the different parts of the WaterHub and provide a display of the data to be used for a university showcase and for the lab technician to monitor the water treatment performance.

After the first meeting with the project sponsor, the team constructed a preliminary problem statement as follows:

Who:

- Ohio State University Facilities Operations and Development Department

Needs What:

- Efficient and effective sensors and sampling that provide updated measurements of the wastewater flowing through the WaterHub.
- A convenient process to take draw samples that keeps the samples uncontaminated for lab testing.

- A way to display the results of the wastewater testing that can also be used as an educational tool.

Because Why:

- To stay within EPA standards of treating wastewater.
- Provide an educational experience for students, faculty, and guests.
- To reduce university potable water usage by 5%.

Based on feedback from the project sponsor and technical advisor, the scope of the project was redefined. The team needed to specifically focus on testing water quality for the WaterHub to stand out in research and provide an educational tool. Therefore, the final problem definition is as follows:

Ohio State Sustainability needs constant and accurate measurements of the water quality within the WaterHub so that EPA wastewater requirements can be met and maintained while the facility is showcased as a living, learning lab.

2.0 Background (Literature Review)

2.1 Technical Background

Ohio State University (OSU) is planning to construct a district-scale wastewater reclamation and reuse plant. Partnering with Sustainable Water, OSU will be introducing the WaterHub to campus within the next five years. Sustainable Water has constructed WaterHub facilities at Duke University and Emory University that will be similar in design to the WaterHub facility being implemented at OSU. Pictured below [Figure 1], is a schematic showing the wastewater treatment processes encompassed within the WaterHub at Emory University. The four crucial tanks where the wastewater will need to be regularly tested include the anoxic tank, aerobic tank, hydroponic reactor, and clarifier. These four processes are where the wastewater will undergo the most chemical and biological cleansing. To ensure that the wastewater is being properly cleaned, it is important to regularly measure the chemical and biological parameters of these four specific tanks. The parameters that the EPA requires to be tested are listed in [Table 1].

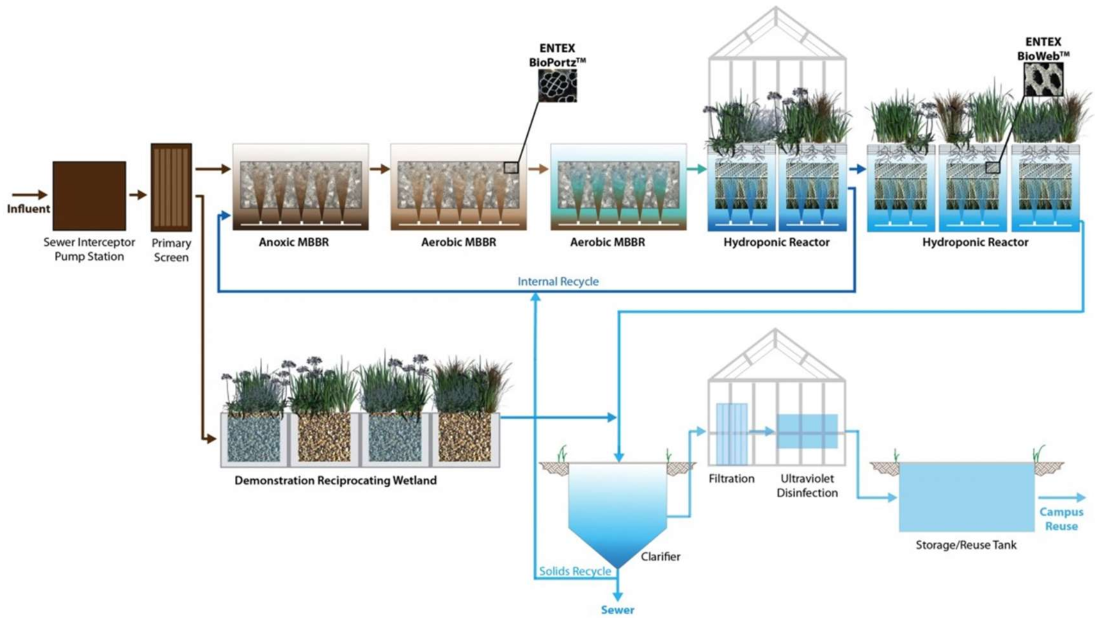


Figure 1: Schematic of treatment processes at Emory WaterHub

Table 1: List of EPA parameters commonly tested in wastewater treatment

Parameter	Unit	EPA Effluent Limit / Target	California Title 22 Effluent Limit / Target
Turbidity	NTU	< 2 NTU	< 2 NTU
Biochemical Oxygen Demand (BOD_5)	mg/l	< 10	< 5
pH	S.U.	6.0 – 9.0	6.5 – 8.5
Total Residual Chlorine	mg/l	> 1.0	> 1.0
Total Phosphorus	mg/L		< 1.0
Nitrogen, Ammonia	mg/L		< 2.0
TSS	mg/L		< 5.0
Fecal Coliform	Col/ml	Non-Detected	Non-Detected

Currently, the university is consuming around 1.18 billion gallons of potable water per year. The use of 238 million gallons can be directly linked to campus utility plant water use [Figure 2]. The objective of the WaterHub is to retrieve wastewater from OSU's sanitary sewers and pump it into the treatment plant. The plant will then treat the water using a four-step treatment process consisting of an anoxic tank, aerobic tank, hydroponic reactor, and clarifier. The result of the treatment process will be non-potable water that can be reused by the chiller plants and other nonportable water users. The implementation of the WaterHub will have positive results including a net savings of $28 to $60 million over a 30-year time period. The WaterHub is projected to conserve 20-30% of campus's potable water use, along with a reduction in sewer overflow by up to 70% (VanCleave, 2020).

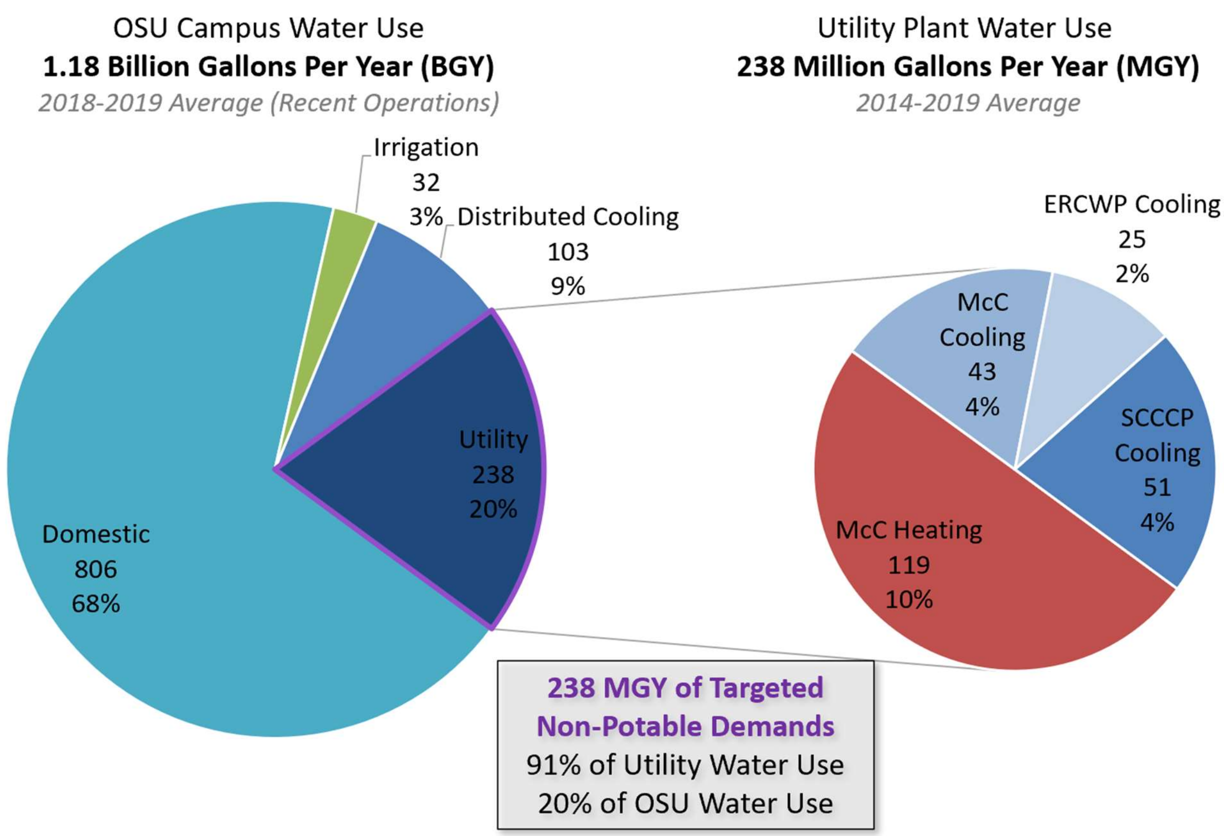


Figure 2: Average water use on campus

Meeting summaries

After a brainstorming meeting, the team met with Brenda VanCleave and David Wituszynski and talked about multiple designs. The two advisors gave their feedback and notified the team that not all EPA requirements would be able to be tested with an automatic sensor. Draw samples will be needed to test for the parameters that cannot be tested for by an automatic sensor. A pumping system will be needed for each tank to take the draw samples. The two advisors also set up a meeting between the team and Melodi Clarke, who is a wastewater engineer and lab manager for the city of Columbus.

The team meeting with Melodi Clarke occurred on October 28, 2020. The team wanted to ask questions on where the City of Columbus places their sensors in their wastewater treatment plants and how they perform draw samples. Melodi told the team during the meeting that the sensors are placed through the tops of the tanks. The tanks at the wastewater treatment facilities have walkways over them, and the sensors are placed in the middle of those walkways. The sensors are suspended in the middle of the tanks to get a uniform measurement. Melodi also told the team that the sensors have casings around them to help protect them, and that the sensors will need regular maintenance. This regular maintenance period is found after decline in accurate sensor data. There are two main companies that Melodi recommended to get sensors through which are Yellow Springs Instruments (YSI) and Hach companies. The draw samples were performed by using regular clean buckets or a scooper with a long rod. To end the meeting, the team asked where throughout the treatment process should they test for the EPA requirements. Melodi gave her recommendations to the team and concluded the meeting.

Two meetings were held with representatives from Sustainable Water. The first meeting occurred on January 27, 2021. Representative Bob Salvatelli met with the team to discuss any questions and concerns that the team had. Some of the key takeaways from this meeting was that the sensors will be accessible through a latch station directly about and in the middle of the tanks, the wastewater volumetric flow rate can be controlled using gravity and hydraulic pressure, there is a SCADA system in place that controls where the data is being sent and stored, and no other WaterHub has attempted to make a live interactive dashboard within a WaterHub. Mr. Salvatelli also provided a team with a schematic of the Phillip Morris WaterHub that will be like the one that is being built at Ohio State. The WaterHub that is being built at Ohio State will not Tank 11 as the treated wastewater is being sent to the McCracken Power Plant.

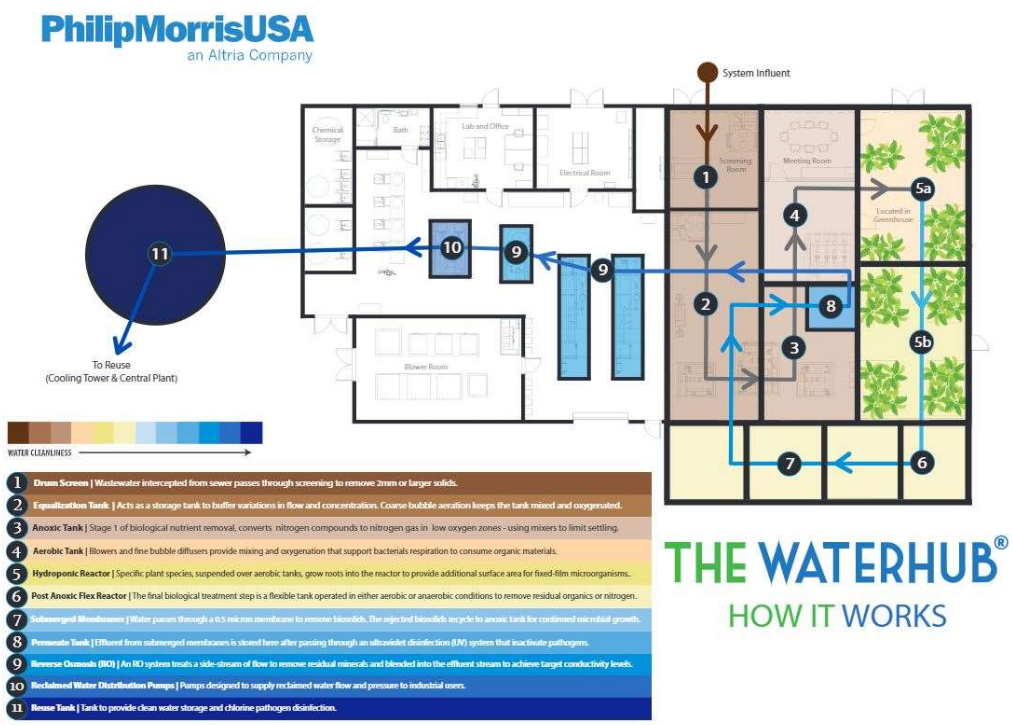


Figure 3: Phillip Morris WaterHub layout

The second meeting occurred on February 11, 2021. Representatives Bob Salvatelli and Eric Lohan met with the team to discuss any further questions about the dashboard, draw sample testing, and EPA testing locations. The two representatives confirmed our testing locations and suggested testing in a few more locations. The team was told that Sustainable Water already has a data base system in place, and the data would have to be extracted from this data base. Lastly, the two recommended to create an AutoCAD drawing of the tanks and piping system based off the Phillip Morris WaterHub.

2.2 Literature Review

The goal of the project is to develop a system to test the wastewater that flows through the treatment facility on campus. The goal of this project is to reduce the consumption of water from the City of Columbus by at least 5% to cut costs and move in a more sustainable direction for the future. Various topics related to the project were researched, including sensors and parameters, EPA requirements, wastewater treatment, hydroponics, bioreactors chiller plants/cooler towers, and living learning labs. Each of the topics are discussed in the following sections.

Sensors and Parameters

Turbidity is a measurement of a water sample's transparency. A turbidity sensor measures the presence of total suspended solids in the water (Escriva 2018). Turbidity can be used as an initial indicator to the overall quality of the water. Most turbidity sensors are low cost and follow the Beer-Lambert Law using a series of LED feedback to measure the number of solids in the water. The Beer-Lambert Law relates the reduction of a light signal through a material as a quantifiable unit (Escriva 2018). A turbidity sensor is set up by installing a device to shine a beam of light through the desired body of water and a detection device on the opposite side to detect how much light has made it through the water sample (Escriva 2018). This measurement is taken in-flow within the water tanks themselves. A turbidity sensor is relatively low maintenance and will only require periodic calibration.

Biological oxygen demand (BOD) is the measurement of oxygen consumed by microorganisms in the water. The BOD is directly proportional to the amount of organic matter in the water that the microorganisms need to decompose. Therefore, BOD is a proxy measurement to determine how much organic matter is in the water sample. An excess of organic matter in a water sample is considered a pollutant. Because BOD levels are dependent on the function of aerobic microorganisms, it is a difficult parameter to measure. Most BOD measuring systems require a sample of water to be taken from the desired body of water. This sample must set for 3 to 5 days until the probe can get an accurate reading (Biochemical Oxygen Demand – BOD 2020). This practice of measuring BOD is standardized and accurate. However, it is important to consider other options when speed of sampling is a want of the client. The use of a microbial fuel cell biosensor could be an alternative solution to meet the time related goal. A microbial fuel cell can be directly placed in the desired body of water and operated for measurement. For example, Gil (2003) used an electrochemically active metal-reducing bacterium *Shewanella putrefaciens*. The bacteria are placed at the anode of the fuel cell so that it oxidizes the organic substrate which in return transfers electrons to the electrode. The coulomb generated from the microbial fuel cell is directly proportional to the (BOD) strength of the wastewater (Cheol Gil 2003). A biosensor could be left in the wastewater tank to continually send the electrical information to a database which would allow regular measurements of the water's current BOD levels.

Residual chlorine is the measurement of the low amount of chlorine remaining in the wastewater after the sanitation process (Residual chlorine; Technical datasheet n.d.). It is important to monitor residual chlorine in wastewater treatment because while chlorine is essential to disinfecting the water, too high of chlorine levels can make the water toxic. Therefore, a residual chlorine sensor needs to be implemented in the wastewater treatment system just before the water is discharged from the facility for drinking. While residual chlorine is an important parameter to monitor in potable wastewater treatment systems, it is not applicable to the WaterHub since the WaterHub's effluent will be non-potable water.

PH is the measured amount of hydrogen and hydroxyl ions which range from zero to 14. A seven on the scale is defined as neutral. PH values less than seven are defined as acidic, while values greater than seven are defined as basic. Glass electrodes in pH sensors are used to detect and measure the difference in potential energy between the two sides of the glass. During their long-term use, periodic calibration is required to maintain the accuracy of the measurements due to the small change in electrodes over time (Wiora & Wiora, 2018).

When ammonia is present in water at high levels it can be toxic to the consumer. YSI's ProDSS ammonium sensor uses membranes to measure nitrogen ammonium. Ammonium measurements can be displayed if we have an ammonium pH and CT sensor installed on YSI's ProDSS ammonium sensor. To measure nitrate, the nitrate nitrogen mg/L selection and nitrate mV must be enabled on the sensor during sampling. To calibrate the YSI ProDSS ammonium sensor, the electrodes must be martially placed in the wastewater. Nitrate is selected on the calibration menu and the user waits until the white line on the instrument is stable. When it is stable, the calibration is complete, and the instrument is ready to use.

Conductivity in wastewater measures the ability of the water to pass an electrical current. If wastewater has a high conductivity, it indicates that it has dissolved metallic ions such as chloride, sulfate, and nitrate. Conductivity can be measured using a probe sensor. The sensor works by applying voltage between two electrodes in the submerged probe. The electrical resistance of the water creates a voltage drop that can be measured by the probe. The magnitude of the voltage drop correlates to the conductivity of the wastewater (Environmental Protection Agency 2012).

In terms of reliability and access, it was determined that the measurements for fecal chloroform, biological oxygen demand, total suspended solids, and total phosphorous would be more accurately tested using a draw sample. For BOD specifically, the technology discussed in the earlier paragraph is too new and not well tested on a large scale to be reliable for this size of wastewater treatment plant. For the remaining parameters, the hold times for the tests make it difficult to use a sensor and gather an extremely accurate reading.

EPA requirements

In terms of reuse, the EPA does not have restrictions on what water can or cannot be reused. Reuse of water is referred to the states for regulation, in which most states have established programs for reuse or added to the existing programs (Basic 2020). These programs are implemented through the Safe Drinking Water Act, standards set in 1974 to ensure the quality of drinking water for those in the United States (Summary 2020). Since the programs are set by the state, the targeted parameters are also subject to change state to state; but in general, the parameters are similar, given that there are national standards set with the Safe Drinking Water Act and the Clean Water Act. These parameters will differ based on the project and what will be done with the product. For example, the water from the WaterHub will be non-potable or used in toilets, chiller towers, and similar places, so the parameters for it will be different than if the water was for drinking.

For the Ohio EPA, there are two permits required for most wastewater treatment centers. These are the permits to install (PTI) and a discharge permit (NPDES). The PTI needs to be obtained before construction of the system. The NPDES is for parameters that need to be tested and monitored in the system. This permit will need to be renewed every year as regulations change and systems evolve. Ohio EPA, and most of the other EPA state branches, follow the Clean Water Act, which was put in place to protect the waters of the United States. This is done by the state and federal agencies working together to monitor the activity and ensure compliance (Mancl).

Wastewater Treatment

Within commercial wastewater treatment there are three main stages of treatment: preliminary, primary, and secondary (National 2012). Preliminary is focused on monitoring the amount of water coming into the system and what is in the water. Primary takes all to the containments out of the water that were found during the preliminary treatment, including the extraction of solids that could not be processed out of the water during the preliminary step. Secondary treatment removes containments that cannot be seen to meet targeted parameters set by the city or state, like the BOD and the rest of the suspended solids. Most places, especially in the United States only focus on the primary and secondary methods of wastewater treatment.

Wastewater treatment can be done using one or more of the four most common treatments, which are physical water treatment, biological water treatment, chemical treatment, and sludge treatment (Four 2018). Physical is used primarily for removing debris and other insoluble particles. This can be done through sedimentation, aeration, or filtration. Biological water treatment is used to break down particles that are present in the water, like soap, human waste, or food (Four 2018). In this process microorganisms digest and break down the containments in the water until there is nothing left or physical treatment is then used. There are three categories of biological water treatment; aerobic, anaerobic, and composting, which are all used in different circumstances depending on what is present in the water. The third type of treatment is chemical treatment which involves chemicals being added to the water to clean and bring it into specification, or to meet the targeted parameters that are set based on the type of project and what the effluent will be used for. The most common chemical used is chlorine to kill the bacteria and other organisms that can be present in water like fungi, algae, or microbes. The chlorine is used to neutralize the water and stop any bacteria from growing. The final treatment is sludge treatment, which is used for solid-liquid separations when there is minimal moisture in the solid phase and little to no particles in the liquid separation. One of the most common uses for sludge treatment is a centrifuge to separate the liquid from the solid matter.

Aerobic and Anaerobic Bacteria

There are four main tanks that the wastewater will travel through in the WaterHub as seen in Figure 1. Two of these tanks are the anoxic and aerobic tanks, where anaerobic and aerobic bacteria are located, respectively to treat the wastewater. Oxygen will be pumped into the tanks to mix the wastewater. Aerobic bacteria use mechanically added oxygen in order to remove and break down contaminants, and anaerobic bacteria get oxygen from the food they break down, such as sludge, and produce methane gas (Cooper, 2019). Bacteria such as these will be key to cleaning the wastewater as it travels throughout the WaterHub. Anaerobic Bacteria have been recorder being able to lower the amount of phosphorous within a medium (Cooper, 2019). Bacteria can consume biodegradable organic materials which are critical in the wastewater cleaning process (Cooper, 2019).

Hydroponics

Hydroponics is the act of growing plants in nutrient solutions with or without an inert medium (such as soil) to provide mechanical support. A few examples of mediums for hydroponics are rockwool, oasis cubes, and perlite. However, not all mediums are solids. Wastewater is an example of a medium where certain plants can grow. Emory University's WaterHub provides an example of hydroponic being able to partially treat wastewater. The plants' roots are suspended in the water where microbes can reduce BOD, while the upper part of the plants are held in racks (Day, 2018). Like the WaterHub at Emory University, the plants will require a platform to grow. This platform will keep the plant's foliage above water while the roots will be suspended in the water. Hydroponic plants are now being used as a treatment process for partially treated wastewater (Cifuentes-Torres et al., 2020). The wastewater travels through multiple tanks and reactors to be treated. An anoxic moving-bed bioreactor (MBBR) is used to remove BOD, and two aerobic MBBRs are used to remove carbonaceous material and odorous gases through filters (Day, 2018). MBBR stands for moving-bed bioreactors. After the wastewater moves through the anoxic and aerobic tanks, it moves onto the hydroponic reactor where the plants begin their process of treatment. Day talked to Brent Zern who said that plants were selected because of roots they grow and the bacteria that they disperse (Day, 2018). The plants release beneficial bacteria and other microorganisms to help clean the wastewater of its contaminants.

Living Learning Labs

Living learning laboratories (LLL) are solution-based research projects that work on a problem in real time while also being used as a form of teaching and learning. Living learning labs are being used for sustainability projects in higher education. (Zen, 2017). Many colleges are using LLLs to help further their sustainability efforts by teaching students and faculty more about sustainability and the importance of getting more involved (Zen. 2017). The important part of making a LLL is to make sure there is a good framework in place that can promote sustainability while also linking the research and innovation, policy and management, and the education communities to make sure that all the involved parties can work together to produce the best solutions for the problems that the LLL is working to address. To create this framework, it is important to facilitate the design, implementation, and evaluation of the practical interventions. An example of LLLs is Yale's Carbon Change program that was started in 2015 to reduce their carbon dioxide generated by the school by placing a price tag on the amount of carbon used by their buildings. (Shelton. 2015).

Draw Sample Retrieval Practices

There are two types of sampling techniques used in the wastewater industry. These two techniques are grab and composite samples. A grab sample is a singular discrete sample or individual samples that are collected over a certain time interval (Simpson et al., 2013). The grab sample should be representative of which the source it is being taken from, and the volume of the sample depends on the test that is being run. A composite sample is a sample that is continuously collected over a certain interval. A composite sample should also be a good representative of the source that it is being taken from. Composite samples can be dependent on either time or flow proportioning (Simpson et al., 2013). Auto samplers are devices that are used to collect composite or grab samples at specific intervals (Simpson et al., 2013). When auto samplers are in Proportional mode, a compatible flow meter is in control of when the sample is being taken. There can be multiple containers within an autosampler that can be collected and replace when full.

Manual sampling is mostly used to collect grab samples. A sample container is dipped into a source and is then transported straight to a lab for inspection (Simpson et al., 2013). Samples are less likely to be contaminated this way. Another manual way is to use a pump to withdraw wastewater from a source (Simpson et al., 2013). If the pumping system is exposed to an outside source, it should be cleaned in order to prevent contamination of the water sample.

MATLAB Graphical User Interface

MATLAB is a programing platform used to analyze data, design systems, and create products. MATLAB has a built-in graphical user interface application that allows the programmer to create interactive user interfaces with a programing guide function. The user interface design options that MATLAB offers include axes for image inputs, buttons, slide bars, data tables, panels, and more. Every design element within the MATLAB GUI guide is customizable for color, font, and size (MATLAB 2021).

3.0 Detailed Design Description

3.1 Sensor Detailed Design

Proposed Designs

After multiple brainstorming sessions, the team created two designs for sensor placement (shown in figures 4 and 5 below). The first design idea was to drill holes into the side of the tanks where a pipe would be inserted as a conduit for the sensors to be placed into to test the water in the tank. The second design idea was to use a conduit that went through the top of the tank and have the sensors hang down into the water at the middle of the tank. After a meeting with Bob Salvatelli and Eric Lohan where they explained how their designs for the WaterHub had latches above the water tanks that could be opened allowing access to the water in the tanks, the team created a third design. The third design was similar to the second with the sensors being placed through the top of the tank, but instead of using a conduit through the top of the tank the sensors would be placed through the latches above the tanks that were already apart of the WaterHub's design.

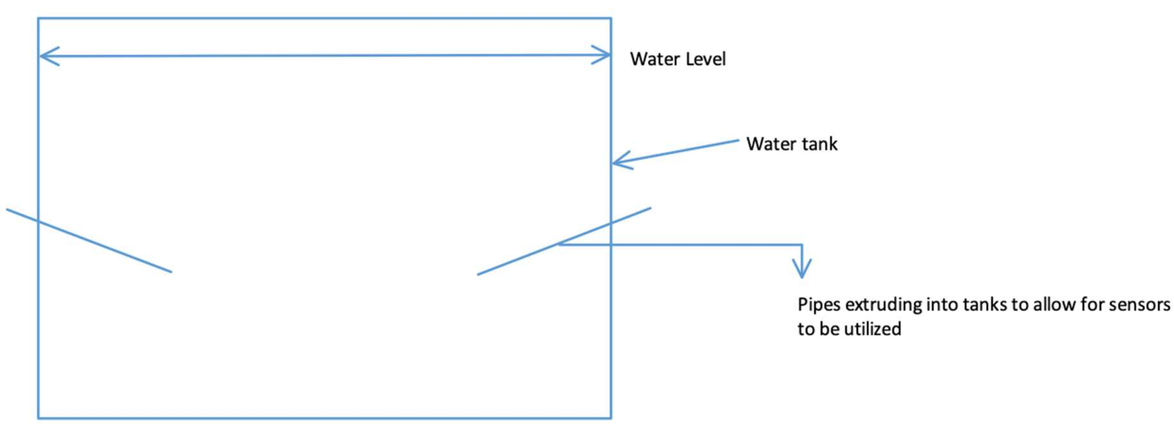


Figure 4: First design for sensor placement

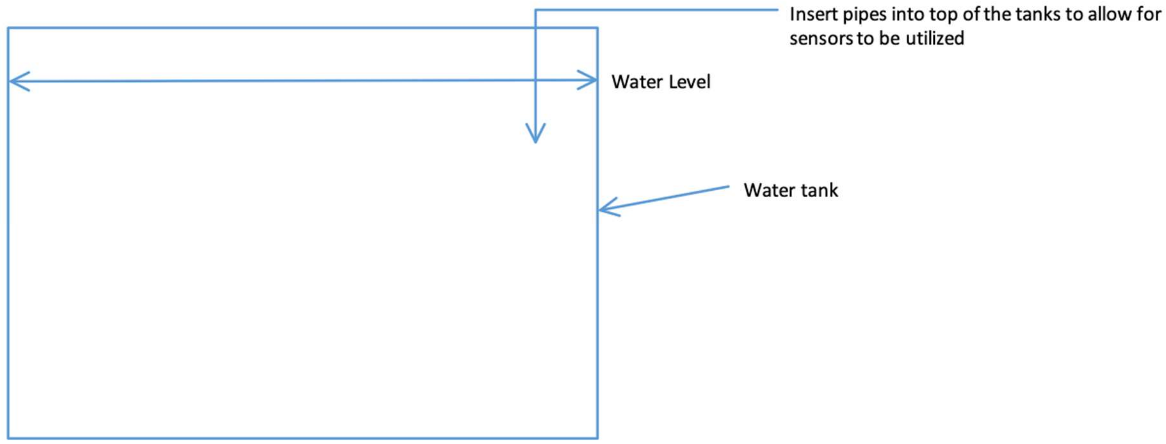


Figure 5: Second design for sensor placement

Another design consideration was which tanks the sensors should be placed in. The team came up with two different ideas. The first was to place the sensors in each tank. The second idea was to only place the sensors in a select few of the tanks.

The last design consideration that the team had to investigate was which company the sensors should be bought from. The team came up with two design concepts, the first was to get all the sensors from one company and the second was to get the sensors from different companies.

Selected Design and Rationale

The team decided to go with the third design for the sensor placement where the sensors would be placed through the latches in the top of the tanks. Since the latch is an already planned part of the tanks using them for the sensor placement saves the added effort and cost of adding a new part in the tanks for sensor placement.

After multiple meetings with Bob Salvatelli and Eric Lohan, and with Melodi Clark where the team learned that it is unnecessary to test every tank to meet the EPA parameters for the WaterHub the team decided to only place sensors in a few of the tanks to lower the cost of buying more sensors.

The team decided to get all the sensors from a single company because the advantages of the connectivity between the sensors bought from one company and the convenience of only working with one company outweighs the advantage of being able to get the best sensor for each type. The team selected YSI as the company to buy all the sensors from because they had the overall best sensors based on our evaluations.

Detailed Description

The sensors from YSI will be placed in the specified tanks through the latches above the tanks so that they can take automatic tests of the water to make sure that the WaterHub is preforming correctly so that the treated water meets the EPA parameters. The sensors will be put on a specific time schedule so that the sensors will automatically take tests to provide a consistent flow of data that can be used for both the practical and education uses of the WaterHub. The sensors will be used to test the drum screen, equalization tank, anoxic tank, aerobic tank, hydroponic reactor, submerged membranes, reverse osmosis, and the inlet and outlet sections of the WaterHub.

Explanation of Design Variables

For the placement of the sensors the design variables the team considered were ease of access, cost, and accuracy of testing.

The important design variables that had to be considered for the sensors were accurate measurements, compatibility with the other sensors, frequency that tests could be run, frequency of needed maintenance, cost, and durability.

Explanation of Success Metrics

The main success metric for the sensors was their ability to take measurements with the accuracy that the EPA parameters required.

Another success metric was that the sensors could take tests within the time needed to meet the EPA parameters for how often the tests needed to be run.

3.2 Draw Sample Detailed Design

Proposed Designs

The team looked to create a simple yet effective way to take the draw samples. In a meeting with Bob Salvatelli and Eric Lohan, the team was told that auto samplers were used in the previous WaterHub's that were built by Sustainable Water.

The first proposed design concept was to use auto samplers. Auto samplers are widely used in the wastewater industry and can take composite samples at specified time intervals. These samplers can hold multiple samples. After a sample is ready it needs to be collected, analyzed, cleaned, and then replaced.

The second proposed design concept is to use a pump and piping system. Using a pump and piping system is practiced for taking grab samples rather than composite samples. Pump and piping systems are a quick and easy way of retrieving samples that need maintenance in order to keep the system clean and contaminate free.

Selected Design and Rationale

The team decided to move forward with the pump and piping system as opposed to the auto sampler design. This design will save the University money as opposed to buying auto samplers, and it is a chance to showcase and separate Ohio State's WaterHub as an interactive living learning lab. This will design will also save the lab technician time collecting the draw samples.

Figure 6: Inside of an autosampler

Figure 7: Submersible pump to be used in the piping system

The cost of one pump and piping system out of the seven that will be needed costs around $550.14 as opposed to the cost of YSI's cheapest auto sampler at $1875.00.

Detailed Description

The pump and piping system would take water from the tanks within the WaterHub and push it to the lab all with the flip of a switch. This application doesn't require a pump with a whole lot of power because the water isn't traveling that far horizontally or vertical. In order to select a pump, the team had to make some assumptions and select a pipe size. A design goal of a 1 gallon per minute volumetric flow rate and ¼ inch stainless-steel nominal 40 piping for the application. The team then performed the necessary calculations to select a pump with the proper horsepower for the application. This pump and piping system will require regular maintenance on a specified interval.

To make the pump design more interactive with guests, the piping system will run through the hydroponic reactor room with a clear section break in the stainless-steel piping. This will allow for guests to the quality of the wastewater as it passes through the WaterHub. The clear section will be roughly 6 inches of clear pvc ¼ inch pipe. However, this clear section break can cause a problem with the piping system. Sunlight will be hitting this section in the hydroponic reactor room which will encourage the growth of organisms and bacteria within the piping system. To combat this problem, the team proposed three different designs for a cover. The three designs were a slide cover, box cover, and velcro cover. The teams created a decision matrix and found that the slide cover was the best fit option. This slide cover was designed in AutoCAD and is 21 inches long with an inside diameter of 0.88 inches. A 6-inch section will be cut out of the cover to allow for viewing of the clear section.

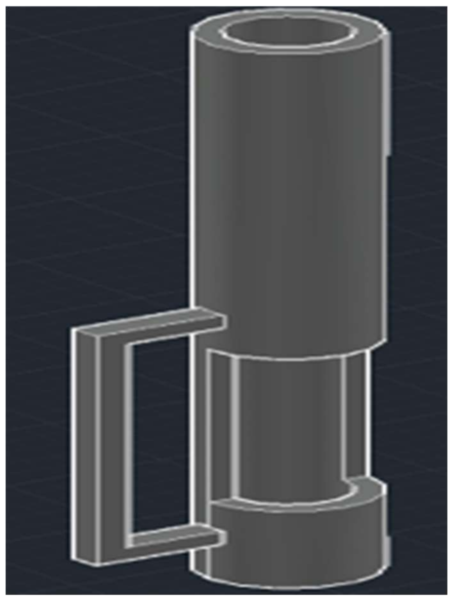


Figure 8: AutoCAD drawing of slide pipe covering

Explanation of Design Variables

Volumetric Flow Rate

The volumetric flow rate was the main design variable in the pump and piping system. This variable was a controlling factor in many of the calculations such as water velocity and mass flow rate. The velocity and mass flow rate values were then used in other calculations.

Pipe Size

The pipe size was another design variable in the pump and piping system. This variable had a big impact on the velocity calculation which played a big factor in the friction losses.

Cost

The cost of the pump and piping system and auto samplers was another design variable. The auto samplers cost much more than the total cost of the pump and piping system.

Explanation of Success Metrics

The main success metric used to evaluate the design of the pumping system is that the horsepower of the pump exceeds the calculated horsepower value. It is important that the pump has a greater horsepower than the calculated value because if it didn't, then the wastewater would never reach the lab.

Another success metric is that slide covering will fully block out the sunlight and that the clear section is covered when not being looked at. It is important that as minimum light as possible enters the piping system. This is to prevent the growth of harmful bacteria and organisms within the piping system.

Another success metric is that the clear section is properly demonstrating how much clearer/cleaner the wastewater is getting as it travels through the WaterHub. The WaterHub is supposed to be an interactive living learning lab, and the clear section can add to this learning aspect when demonstrated properly.

3.3 Dashboard Detailed Design

Proposed Designs

The concept of the dashboard was created to enhance the living learning lab aspect of the WaterHub. The proposed dashboard was designed to display the EPA parameter data recorded from the sensors and the draw samples tests. To begin the design of the dashboard the team defined the design needs in order to meet the goal of the concept.

List of needs from Dashboard initial brainstorm:

- Live accurate data from sensors
- Provide a short description of the WaterHub
- Include OSU branding
- Looks professional and is aesthetic

To accomplish these needs the team investigated different programs that allowed the creation of a user interface. Programs considered included html coding platforms, YSI's SCADA system, and MATLAB. MATLAB was the final decision as it was readily available to students and did not require additional licensing. Additionally, MATLAB had the highest rated graphical user interface guide for the most user friendly in terms of the coding process.

The dashboard went through a series of design iterations using a test and fail technique as the team attempted to include every desired aspect from initial brainstorming into the boundaries of MATLAB's GUI code.

The following figures represent a series of design iterations for the dashboard.

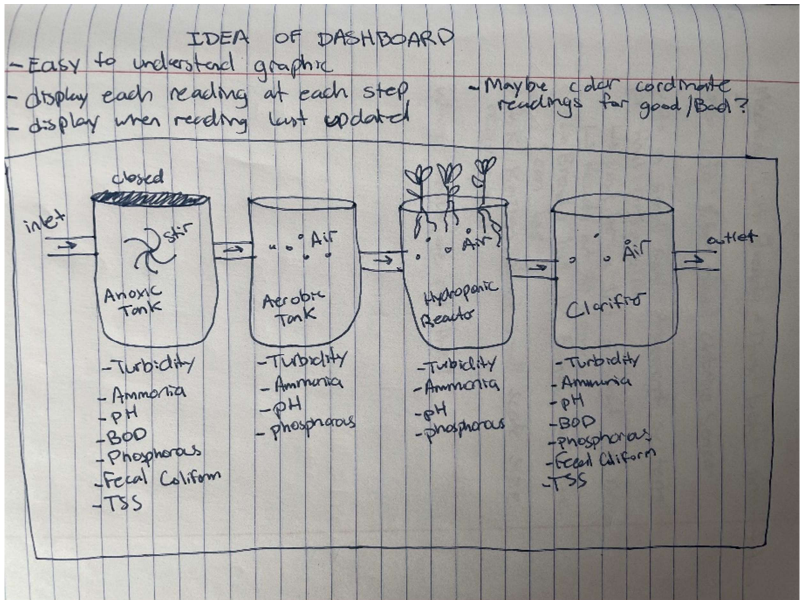


Figure 9: Initial dashboard layout from brainstorming

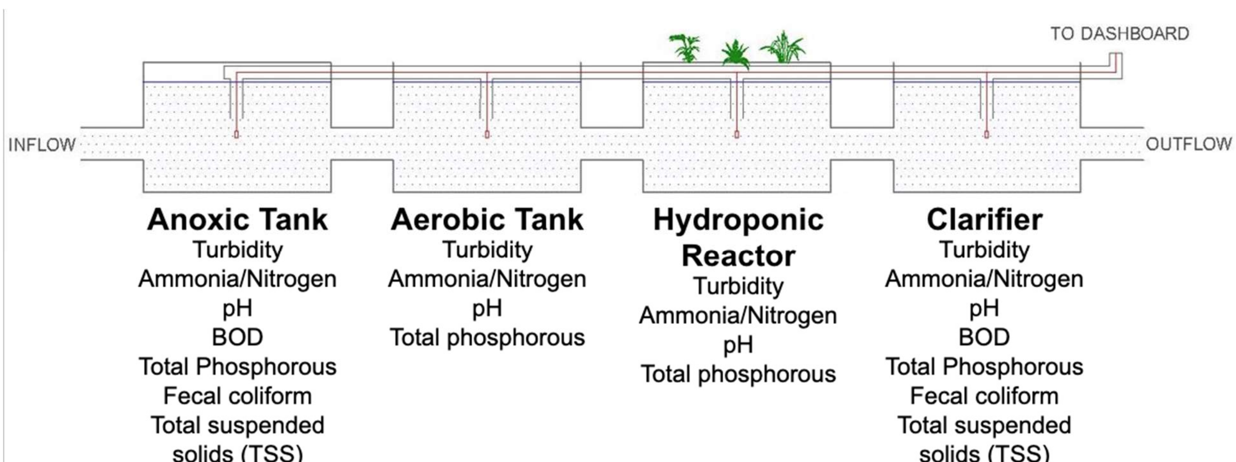


Figure 10: Second dashboard design iteration from brainstorming

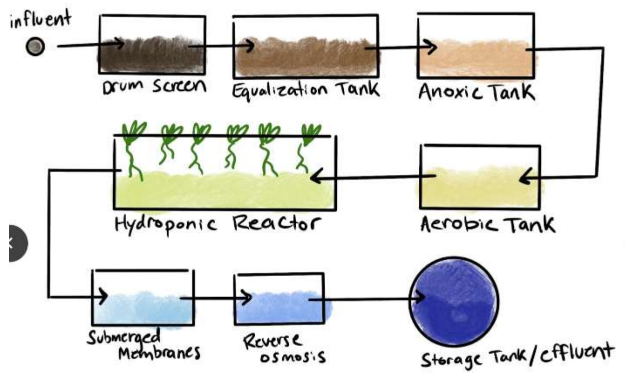


Figure 11: Third design iteration after more testing points were added

Selected Design and Rationale

As seen in figures 9 and 10 the first design iterations contained every tank in a row and the data displayed underneath. This layout was not ideal when the team found that more tanks needed to include testing because the entire row would consume the dashboard and leave no space for a description component. The selected design showcases three sets of data at a time where the middle data set can be changed by pressing buttons. This also allows from a more interactive design. Figure 12 represents the home screen of the selected design that the team decided to proceed with for evaluation.

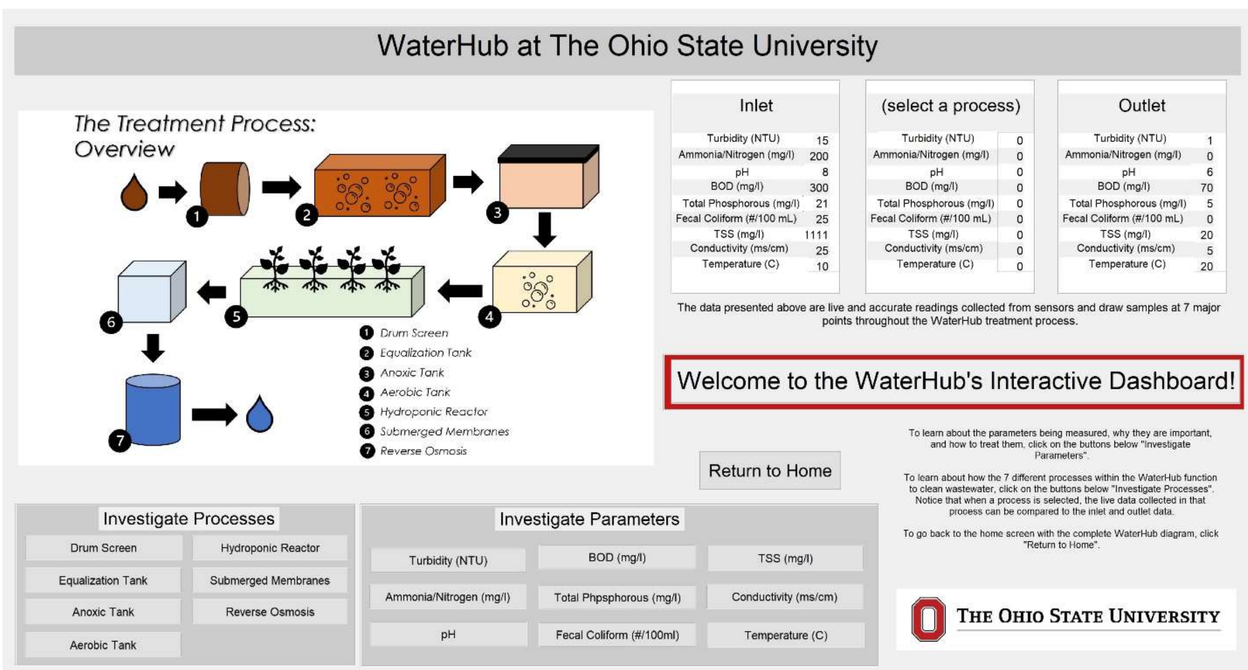


Figure 12: Dashboard home screen

Detailed Description

Before interacting with this design, the user is presented with a brief description of how to navigate through the dashboard as seen in the mid-right. The large axis on the left depicts a numbered layout of the seven main wastewater treatment processes within the WaterHub. The three tables located at the top right of the dashboard populate with the live data from the sensors and draw sample tests. This design allows the user to navigate through a series of buttons as seen in the bottom left of the user interface. Each button changes the large axes screen to give more information on the button selected. The "Investigate Parameters" buttons populate an image that describes what the EPA parameter selected is, why it is important to monitor in wastewater, how to treat it, and a small graphic. An example of the output from an "Investigate Parameters" button is shown in figure 13. The "Investigate Processes" buttons populate an image of the process itself along with a small description of how the selected process works within the WaterHub. Additionally, the "Investigate Processes" buttons populate the table between the "Inlet" and "Outlet" data with the live data recordings within the selected process. An example of the output from an "Investigate Processes" button is shown in figure 14.

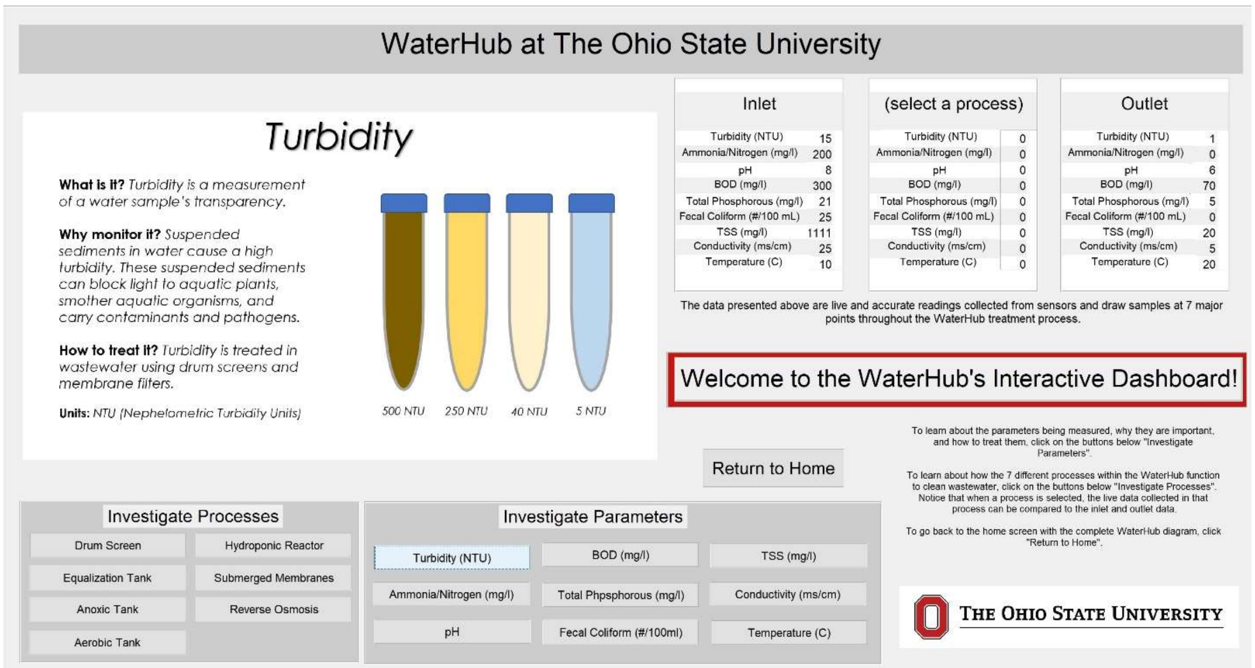


Figure 13: Dashboard after clicking "Turbidity"

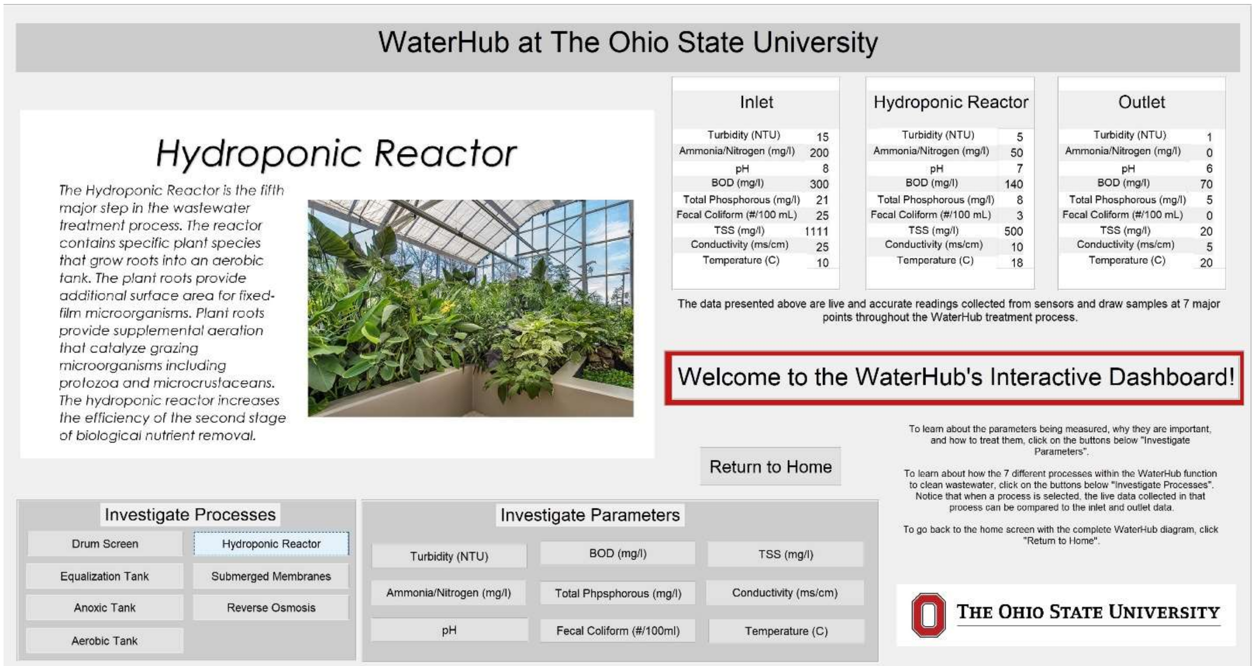


Figure 14: Dashboard after clicking "Hydroponic Reactor"

In order for the dashboard to include the live parameter measurements, the team had to find compatible data pathways so that the data presented in the GUI is live and accurate. Through consults with Melodi Clarke, Lab Manager for the City of Columbus Wastewater Treatment, the team found that YSI sensors can use a SCADA system to input data into an excel spreadsheet. The SCADA system allows the team to direct the sensor data to a specific spreadsheet using a copy and replace method. This means that as new data is collected, it replaces the old data in the same cell within the spreadsheet. The spreadsheet that the team has created also allows for input of data from the draw sample tests. With all of the data compiled into one spreadsheet, the MATLAB program is able to pull all of the information for the GUI.

Explanation of Design Variables

Design elements that were important to consider for the design of the dashboard include the live parameter measurements from different tanks, organization of the data, thorough explanation of the data, and visual representations of the EPA parameters.

Explanation of Success Metrics

The success metrics used to measure the effectiveness of the design were split into educational and technical sections. The dashboard must be able to display the live data recordings accurately and efficiently from the sensors and draw sample tests. Additionally, the dashboard must be able to provide an educational component and be user friendly and interactive for the audience. These metrics will be expanded upon in the design evaluation section.

4.0 Design Evaluation

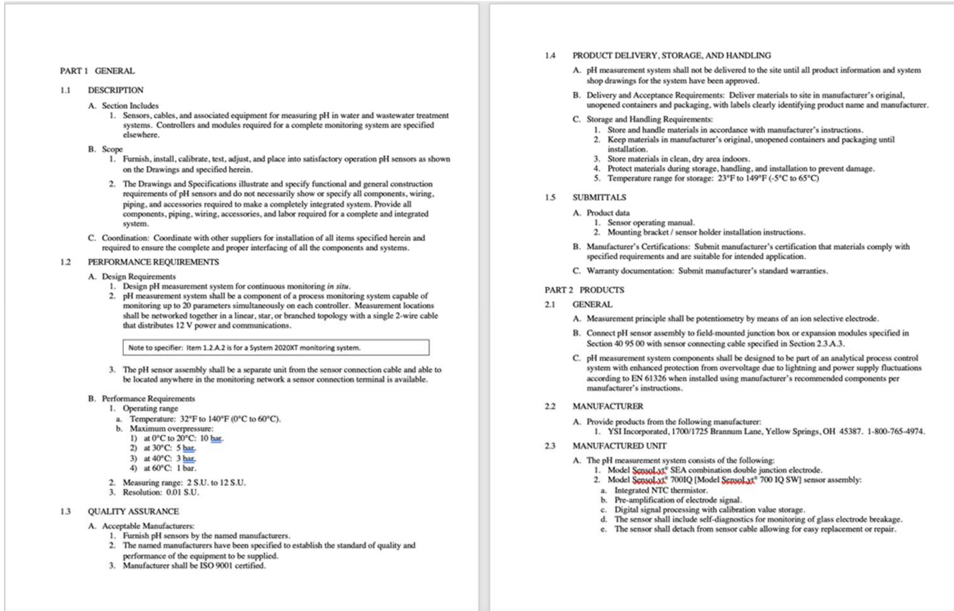
4.1 Sensor Evaluation

A decision matrix was completed to compare companies as compatibility of all the sensors may be simplified if purchased through a single company. YSI and Hach were compared because they were the two companies that were recommended to the team by Melodi Clark, as well as when talking with the sponsor. Given that all the data from the sensors will be sent back to the digital database to be displayed, it was the teams' thought that it might be simpler to use only one company for the sensors. This idea came when looking into software and data acquisition, because it would be easier to use the same software for all the sensors, but not every sensor company uses the same software, hence the reason it is weighted higher than the other criteria. The customer support and ease of reach was rated at a 3 because there will most likely not be a lot of instances where help is needed from the company, however, the customer support and aid from YSI was one of the big reasons that the company is recommended so it seemed to be necessary to consider in the matrix. The combined sensor cost was rated a 2 because the cost of the sensors does not differ that much for most of the sensors, but it can still be a determining factor in the decision. YSI received the highest score from the decision matrix as seen in Table 5. Therefore, the YSI sensors are recommended for the project.

Table 2: Decision matrix for sensor companies

Criteria	Weight	YSI	Hach
Combined sensor performance	5	+1	+1
Customer support and ease of reach	3	+1	0
Combined sensor cost	2	0	-1
Total	-	8	3

The sensors were also evaluated by comparing the recommended frequency that the parameters are tested and how often the sensors are supposed to update based on the data in the specification sheets. For ammonia/nitrogen and turbidity it is recommended that they are tested at least every 15 minutes, and pH and conductivity need to be monitored continuously. The parameters will also need to be measured to the tenths place which the sensors are capable of, allowing for adequate and correct measurements.



PART 1 GENERAL

1.1 DESCRIPTION

A. Section Includes
1. Sensors, cables, and associated equipment for measuring pH in water and wastewater treatment systems. Controllers and modules required for a complete monitoring system are specified elsewhere.

B. Scope
1. Furnish, install, calibrate, test, adjust, and place into satisfactory operation pH sensors as shown on the Drawings and specified herein.
2. The Drawings and Specifications illustrate and specify functional and general construction requirements of pH sensors and do not necessarily show or specify all components, wiring, piping, and accessories required to make a completely integrated system. Provide all components, piping, wiring, accessories, and labor required for a complete and integrated system.

C. Coordination: Coordinate with other suppliers for installation of all items specified herein and required to ensure the complete and proper interfacing of all the components and systems.

1.2 PERFORMANCE REQUIREMENTS

A. Design Requirements
1. Design pH measurement system for continuous monitoring *in situ*.
2. pH measurement system shall be a component of a process monitoring system capable of monitoring up to 20 parameters simultaneously on each controller. Measurement locations shall be networked together in a linear, star, or branched topology with a single 2-wire cable that distributes 12 V power and communications.

Note to specifier: Item 1.2.A.2 is for a System 2020XT monitoring system.

3. The pH sensor assembly shall be a separate unit from the sensor connection cable and able to be located anywhere in the monitoring network a sensor connection terminal is available.

B. Performance Requirements
1. Operating range
a. Temperature: 32°F to 140°F (0°C to 60°C).
b. Maximum overpressure:
1) at 0°C to 20°C: 10 bar.
2) at 30°C: 5 bar.
3) at 40°C: 3 bar.
4) at 60°C: 1 bar.
2. Measuring range: 2 S.U. to 12 S.U.
3. Resolution: 0.01 S.U.

1.3 QUALITY ASSURANCE

A. Acceptable Manufacturers:
1. Furnish pH sensors by the named manufacturers.
2. The named manufacturers have been specified to establish the standard of quality and performance of the equipment to be supplied.
3. Manufacturer shall be ISO 9001 certified.

1.4 PRODUCT DELIVERY, STORAGE, AND HANDLING

A. pH measurement system shall not be delivered to the site until all product information and system shop drawings for the system have been approved.

B. Delivery and Acceptance Requirements: Deliver materials to site in manufacturer's original, unopened containers and packaging, with labels clearly identifying product name and manufacturer.

C. Storage and Handling Requirements:
1. Store and handle materials in accordance with manufacturer's instructions.
2. Keep materials in manufacturer's original, unopened containers and packaging until installation.
3. Store materials in clean, dry area indoors.
4. Protect materials during storage, handling, and installation to prevent damage.
5. Temperature range for storage: 23°F to 149°F (-5°C to 65°C)

1.5 SUBMITTALS

A. Product data
1. Sensor operating manual.
2. Mounting bracket / sensor holder installation instructions.

B. Manufacturer's Certifications: Submit manufacturer's certification that materials comply with specified requirements and are suitable for intended application.

C. Warranty documentation: Submit manufacturer's standard warranties.

PART 2 PRODUCTS

2.1 GENERAL

A. Measurement principle shall be potentiometry by means of an ion selective electrode.

B. Connect pH sensor assembly to field-mounted junction box or expansion modules specified in Section 40 95 00 with sensor connecting cable specified in Section 2.3.A.3.

C. pH measurement system components shall be designed to be part of an analytical process control system with enhanced protection from overvoltage due to lightning and power supply fluctuations according to EN 61326 when installed using manufacturer's recommended components per manufacturer's instructions.

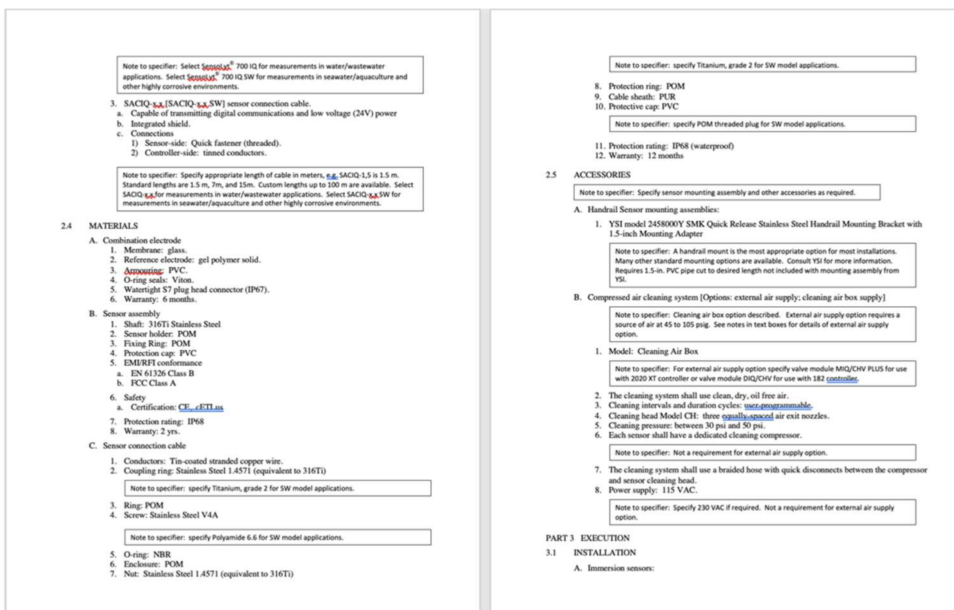
2.2 MANUFACTURER

A. Provide products from the following manufacturer:
1. YSI Incorporated, 1700/1725 Brannum Lane, Yellow Springs, OH 45387. 1-800-765-4974.

2.3 MANUFACTURED UNIT

A. The pH measurement system consists of the following:
1. Model SensoLyt® SEA combination double junction electrode.
2. Model SensoLyt® 700IQ [Model SensoLyt® 700 IQ SW] sensor assembly:
a. Integrated NTC thermistor.
b. Pre-amplification of electrode signal.
c. Digital signal processing with calibration value storage.
d. The sensor shall include self-diagnostics for monitoring of glass electrode breakage.
e. The sensor shall detach from sensor cable allowing for easy replacement or repair.

Figure 15: Example of Specification sheet for pH Sensor



Note to specifier: Select SensoLyt® 700 IQ for measurements in water/wastewater applications. Select SensoLyt® 700 IQ SW for measurements in seawater/aquaculture and other highly corrosive environments.

3. SACIQ-x.x [SACIQ-x.x SW] sensor connection cable.
a. Capable of transmitting digital communications and low voltage (24V) power
b. Integrated shield.
c. Connections
1) Sensor-side: Quick fastener (threaded).
2) Controller-side: tinned conductors.

Note to specifier: Specify appropriate length of cable in meters, e.g. SACIQ-1,5 is 1.5 m. Standard lengths are 1.5 m, 7m, and 15m. Custom lengths up to 100 m are available. Select SACIQ-x.x for measurements in water/wastewater applications. Select SACIQ-x.x SW for measurements in seawater/aquaculture and other highly corrosive environments.

2.4 MATERIALS

A. Combination electrode
1. Membrane: glass.
2. Reference electrode: gel polymer solid.
3. Armouring: PVC.
4. O-ring seals: Viton.
5. Watertight S7 plug head connector (IP67).
6. Warranty: 6 months.

B. Sensor assembly
1. Shaft: 316Ti Stainless Steel
2. Sensor holder: POM
3. Fixing Ring: POM
4. Protection cap: PVC
5. EMI/RFI conformance
a. EN 61326 Class B
b. FCC Class A
6. Safety
a. Certification: CE, cETLus
7. Protection rating: IP68
8. Warranty: 2 yrs.

C. Sensor connection cable
1. Conductors: Tin-coated stranded copper wire.
2. Coupling ring: Stainless Steel 1.4571 (equivalent to 316Ti)

Note to specifier: specify Titanium, grade 2 for SW model applications.

3. Ring: POM
4. Screw: Stainless Steel V4A

Note to specifier: specify Polyamide 6.6 for SW model applications.

5. O-ring: NBR
6. Enclosure: POM
7. Nut: Stainless Steel 1.4571 (equivalent to 316Ti)

Note to specifier: specify Titanium, grade 2 for SW model applications.

8. Protection ring: POM
9. Cable sheath: PUR
10. Protective cap: PVC

Note to specifier: specify POM threaded plug for SW model applications.

11. Protection rating: IP68 (waterproof)
12. Warranty: 12 months

2.5 ACCESSORIES

Note to specifier: Specify sensor mounting assembly and other accessories as required.

A. Handrail Sensor mounting assemblies:
1. YSI model 2458000Y SMK Quick Release Stainless Steel Handrail Mounting Bracket with 1.5-inch Mounting Adapter

Note to specifier: A handrail mount is the most appropriate option for most installations. Many other standard mounting options are available. Consult YSI for more information. Requires 1.5-in. PVC pipe cut to desired length not included with mounting assembly from YSI.

B. Compressed air cleaning system [Options: external air supply; cleaning air box supply]

Note to specifier: Cleaning air box option described. External air supply option requires a source of air at 45 to 105 psig. See notes in text boxes for details of external air supply option.

1. Model: Cleaning Air Box

Note to specifier: For external air supply option specify valve module MIQ/CHV PLUS for use with 2020 XT controller or valve module DIQ/CHV for use with 182 controller.

2. The cleaning system shall use clean, dry, oil free air.
3. Cleaning intervals and duration cycles: user-programmable.
4. Cleaning head Model CH: three equally-spaced air exit nozzles.
5. Cleaning pressure: between 30 psi and 50 psi.
6. Each sensor shall have a dedicated cleaning compressor.

Note to specifier: Not a requirement for external air supply option.

7. The cleaning system shall use a braided hose with quick disconnects between the compressor and sensor cleaning head.
8. Power supply: 115 VAC.

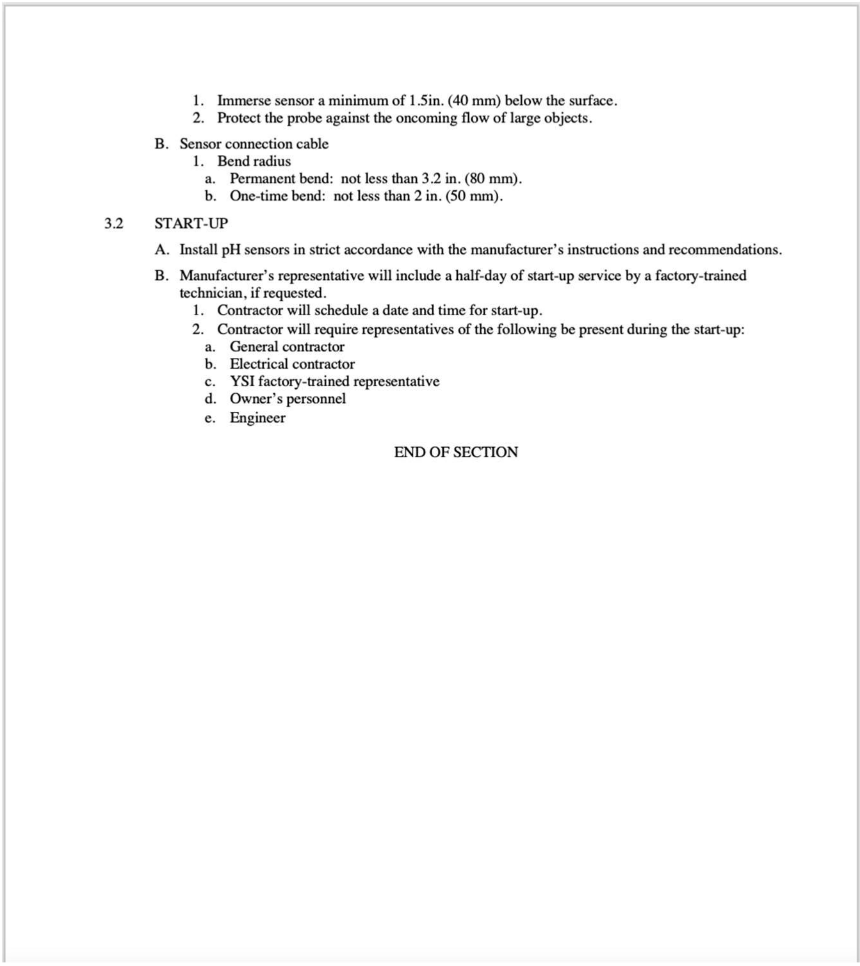
Note to specifier: Specify 230 VAC if required. Not a requirement for external air supply option.

PART 3 EXECUTION

3.1 INSTALLATION

A. Immersion sensors:

Figure 16: Example Specification sheet for pH sensor



1. Immerse sensor a minimum of 1.5in. (40 mm) below the surface.
2. Protect the probe against the oncoming flow of large objects.

B. Sensor connection cable
  1. Bend radius
    a. Permanent bend: not less than 3.2 in. (80 mm).
    b. One-time bend: not less than 2 in. (50 mm).

3.2 START-UP

A. Install pH sensors in strict accordance with the manufacturer's instructions and recommendations.

B. Manufacturer's representative will include a half-day of start-up service by a factory-trained technician, if requested.
  1. Contractor will schedule a date and time for start-up.
  2. Contractor will require representatives of the following be present during the start-up:
    a. General contractor
    b. Electrical contractor
    c. YSI factory-trained representative
    d. Owner's personnel
    e. Engineer

END OF SECTION

Figure 17: Example of Specification sheet for pH sensor

4.2 Draw Sample Evaluation

The pump and piping system was evaluated by calculating the necessary horsepower of a pump that would be able to send water from each tank back to the lab where the samples are to be collected and analyzed. However, before any calculations were to be made, the team had to make some assumptions about the system. A volumetric flow rate goal of 1 gallon per minute, or 0.00223 $\frac{ft^3}{sec}$, and ¼ inch stainless steel piping was selected for the design to be 0.0303 feet. From here, the continuity equation was used along with the area of a circle in order to calculate the velocity of the wastewater.

$$Q = VA \rightarrow V = \frac{Q}{A} = \frac{Q}{\pi \frac{D^2}{4}}$$

$$Q = Volumetric\ flow\ rate\ \left(\frac{ft^3}{sec}\right)$$

$$V = Velocity\ \left(\frac{ft}{sec}\right)$$

$$A = Area\ (ft^2)$$

$$V = \frac{0.00223\frac{ft^3}{sec}}{\pi\frac{(0.0303ft)^2}{4}} = 3.093\frac{ft}{sec}$$

In order to calculate the necessary horsepower required by the system, Bernoulli's equation was used to calculate the pressure head. It was assumed that the pressured and velocity terms were equal, and the equation was simplified.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 + \frac{dw/_{dt}}{\dot{m}g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + \sum F_{maj} + \sum F_{min}$$

$$P = Pressure\left(\frac{lbs}{ft^2}\right)$$

$$\rho = Density\left(\frac{lbs}{ft^3}\right), \left(\frac{slugs}{ft^3}\right)$$

$$g = Gravity\left(\frac{ft}{sec^2}\right)$$

$$V = Velocity\left(\frac{ft}{sec}\right)$$

$$z = Elevation\ (ft)$$

$$\dot{m} = Mass\ flow\ rate\left(\frac{slugs}{sec}\right)$$

$$dw/_{dt} = power(hp)$$

$$\sum F_{maj} = Major\ friction\ losses\ (ft)$$

$$\sum F_{min} = Minor\ friction\ losses\ (ft)$$

$$\frac{dw/_{dt}}{\dot{m}g} = z_2 - z_1 + \sum F_{maj} + \sum F_{min}$$

Using dimensions from previous WaterHub's built by sustainable water, it was determined the wastewater would travel a maximum horizontal distance of 60 feet and a vertical distance of 5 feet. The density of water was found to be 62.4 $\frac{lbs}{ft^3}$, or 1.94 $\frac{slugs}{ft^3}$. The dynamic viscosity of water was found to be 2.09x10^-5 $\frac{lbs}{ft*sec}$. The absolute roughness of the stainless-steel pipe was found to be 0.015×10^{-3} feet. There is an estimated five 90° bends with a k-value of 0.31 within the pump and piping system.

$$N_{RE} = \frac{\rho V D_h}{\mu} = \frac{\rho V\left(\frac{4\pi\left(\frac{D}{2}\right)^2}{2\pi\left(\frac{D}{2}\right)}\right)}{\mu}$$

$$D_h = hydraulic\ diameter\ (ft)$$

$$D = diameter\ (ft)$$

$$\mu = dynamic\ viscosity($$

$$N_{RE} = \frac{62.4\frac{lbs}{ft^3}\left(3.093\frac{ft}{sec}\right)\left(\frac{4\pi\left(\frac{0.0303ft}{2}\right)^2}{2\pi\left(\frac{0.0303ft}{2}\right)}\right)}{2.09\times10^{-5}\frac{lbs}{ft*sec}} = 279808.5$$

The Reynolds number is greater than 2,000 which classifies the flow as turbulent. Since flow is turbulent, the friction factor must be calculated using a moody chart.

$$\frac{\varepsilon}{D}$$

$$\varepsilon = Roughness\ of\ the\ pipe\ (ft)$$

$$\frac{\varepsilon}{D} = \frac{0.015\times10^{-3}ft}{0.0303ft} = 4.95\times10^{-4}$$

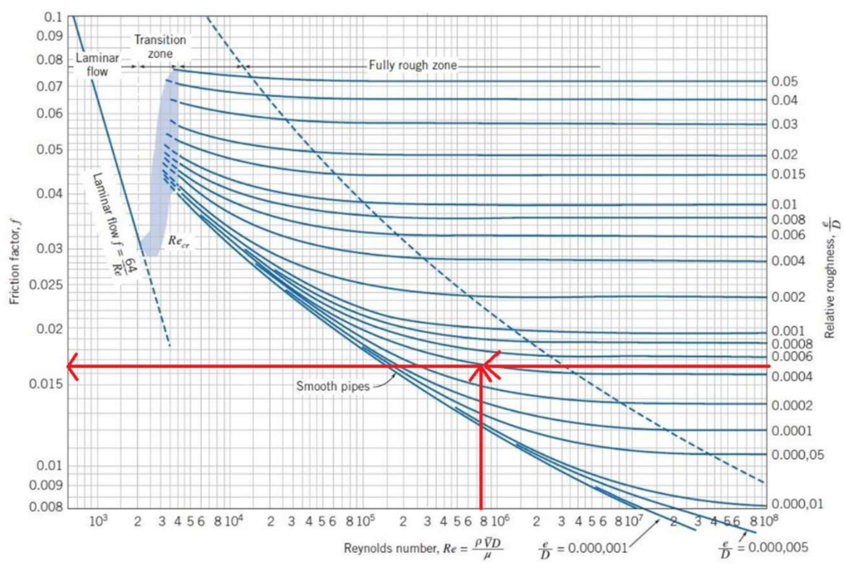


Figure 18: Friction factor was obtained using a moody chart

$$f = friction\ factor = 0.017$$

$$\sum F_{maj} = \frac{fLV^2}{2Dg}$$

$$L = Length\ of\ pipe\ (ft)$$

$$\sum F_{maj} = \frac{0.017(60ft)\left(3.093\frac{ft}{sec}\right)^2}{2(0.0303ft)\left(32.2\frac{ft}{sec^2}\right)} = 5ft$$

$$\sum F_{min} = \frac{kV^2}{2g}$$

$$k = Minor\ losses\ coefficient\ for\ bends$$

$$k = 5(0.31) = 1.55$$

$$\sum F_{min} = \frac{1.55\left(3.093\frac{ft}{sec}\right)^2}{2\left(32.2\frac{ft}{sec^2}\right)} = 0.23ft$$

$$\frac{{}^{dw}/_{dt}}{\dot{m}g} = 5ft - 0ft + 5ft + 0.23ft = 10.23ft$$

The pressure head was calculated to be 10.23 feet of total pressure head. Now the pressure head is known, it can be multiplied by the mass flow rate and converted to horsepower. The mass flow rate of the system was calculated by multiplying the density of the wastewater by gravity.

$$\dot{m} = \rho Q = 1.94\frac{slugs}{ft^3}\left(0.00223\frac{ft^3}{sec}\right) = 0.00433\frac{slugs}{sec}$$

$${}^{dw}/_{dt} = 10.23ft(\dot{m}g) = 10.23ft\left(0.00433\frac{slugs}{sec}\right)\left(32.2\frac{ft}{sec^2}\right) = 1.426\frac{ft*lbs}{sec}$$

$${}^{dw}/_{dt} = 1.426\frac{ft*lbs}{sec}\left(\frac{0.0018hp}{1\frac{ft*lbs}{sec}}\right) = 0.00257hp$$

The final value calculated to be 0.00257 horsepower.

The clear pipe coverings were evaluated using a decision matrix. This decision matrix weighed the three designs proposed. The team ranked each element with a +1, 0, and –1. The elements were weighted based on importance to the project.

Table 3: Decision matric for the clear pipe coverings

Criteria	Weight	Box Covering	Slide Covering	Velcro Covering
Easy access	4	+1	+1	-1
Exposure time to light	5	+1	+1	0
Cost	1	0	0	+1
Aesthetics	2	0	+1	-1
Total	-	9	11	-5

The slide covering had the highest net score with a value of 11. The box covering with a latch that would open had the second highest net score with a value of 9. The Velcro covering had the lowest nest score with a value of –5. The team looked at the final net scores and select the slide cover for the design for the cover.

4.3 Dashboard Evaluation

The educational value of the dashboard was evaluated with a survey presented to users after a brief interaction. This survey was sent out to people of various age groups that will be the likely demographics to visit the WaterHub, which include high school students, faculty, and college students. The survey gathered some initial information on the respondents like their knowledge of wastewater treatment, school year, and major as applicable. Following this section of the survey, a video explanation of the dashboard was provided and followed by five comprehension and open-ended feedback questions to gauge their understanding after the video.

The main focus of the survey was to gauge the if the GUI was simply enough to understand while still remaining educational. This was achieved by the comprehension questions as well as the question asking if the respondent felt they learned more about wastewater treatment or the WaterHub, and the responses are as follows:

- Yes (20 responses)
- Yes, I believe I was able to learn more about the steps within the wastewater treatment
- Yes, I believe that it has the potential to teach people about how the filtration works

- For the most part it did provide an understanding of wastewater treatment at the WaterHub
- Yes. it is complicated. Did not know what many things were
- Yes, the slides helped me understand how the WaterHub would clean the wastewater effectively
- Kind of
- No, I did not understand anything really
- Yes, I went in without really knowing the processes and steps, but by the end I could comprehend the steps, their order, what they were removing, and why
- Yes, I think I was able to learn more about the wastewater treatment
- No response
- I somewhat understood the processes
- Yes, it was very descriptive about how the process works and the order
- Vague. Good overall pictures
- The interactive dashboard provided a clear understanding of the processes and explained the steps right
- Having no prior knowledge about the process, I learned a lot from the video/dashboard
- It gave me a basic understanding of the processes and equipment used
    - Overall, we had 31 positive responses (about 86% positive)
    - 1 no response
    - 1 no
    - 3 unsure/indifferent

The technical efficiency and accuracy of the dashboard was evaluated using MATLAB and excel. This was completed by altering the values in the excel file that are linked to the GUI every 45 seconds and timing how long it takes the GUI to display these changes.

5.0 Results

5.1 Sensor Results

The team chose the YSI sensors because they are capable of measuring to the tenths place for correct measurements, according to EPA requirements. The parameters also need to be tested continuously, or every 15 minutes. YSI sensors measure in less than two seconds when changes are detected.

5.2 Draw Sample Results

After calculations, it was seen that the horsepower requirement to send the wastewater from the furthest tank back to the lab is 0.00257 horsepower. A 1/200, or 0.005 horsepower pump was selected for this application. Since the pump horsepower is greater than the calculated horsepower, this means that the wastewater will successfully reach the lab from the farthest tank. This pump horsepower is almost double the calculated horsepower which leaves some flexibility for error in the application.

5.3 Dashboard Results

From the google survey we found 86% indicated that they learned something about the treatment process and understand something about wastewater from the screen recorded video of the GUI. The results are listed above of the answers that the participants selected.

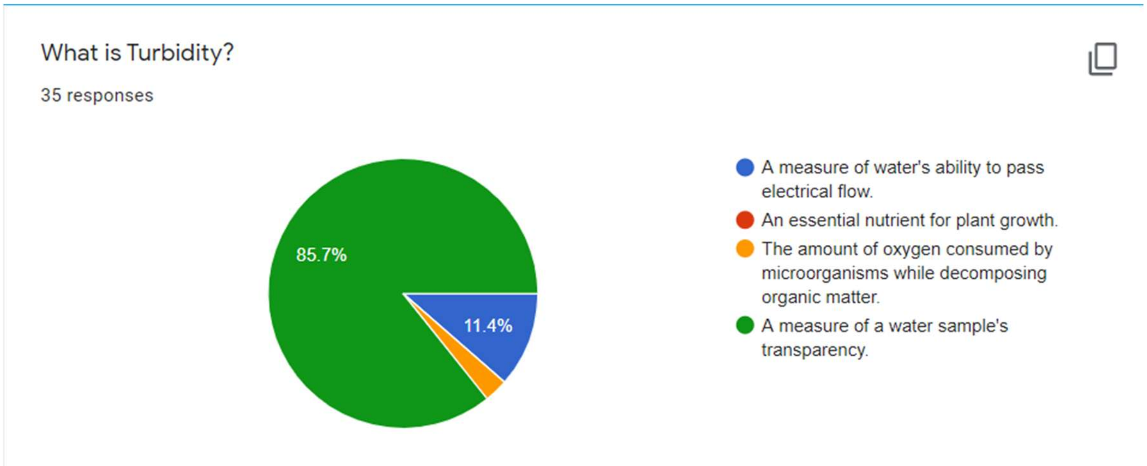


Figure 19:Results from a comprehensive survey question

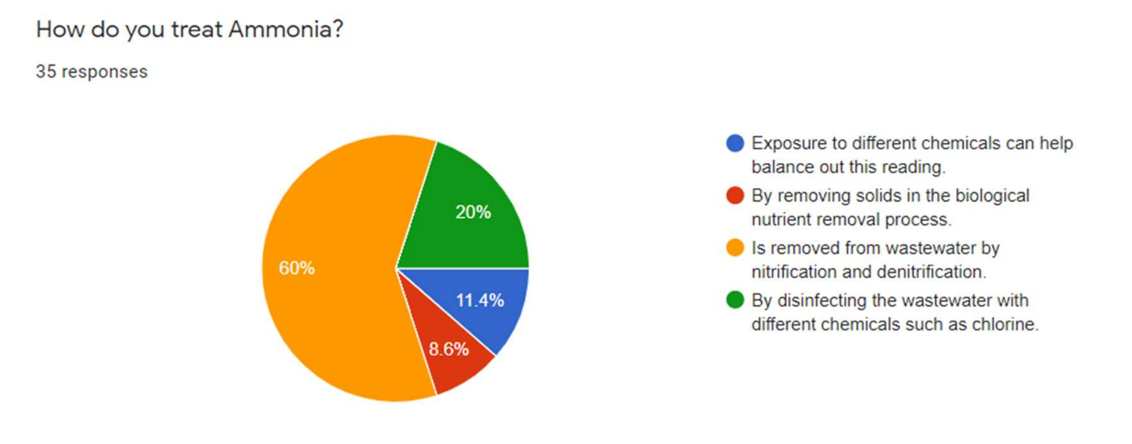


Figure 20:Results from a comprehensive survey question

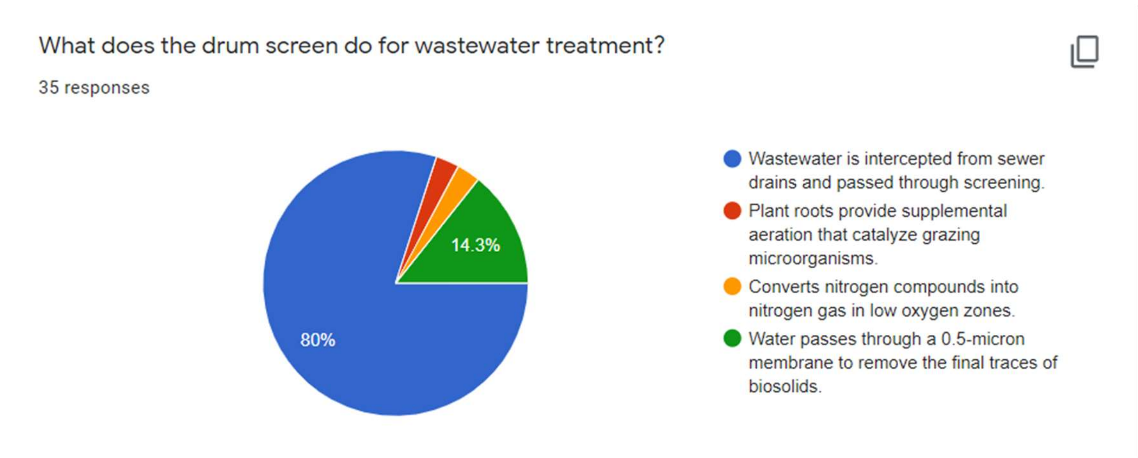


Figure 21: Results from a comprehensive survey question

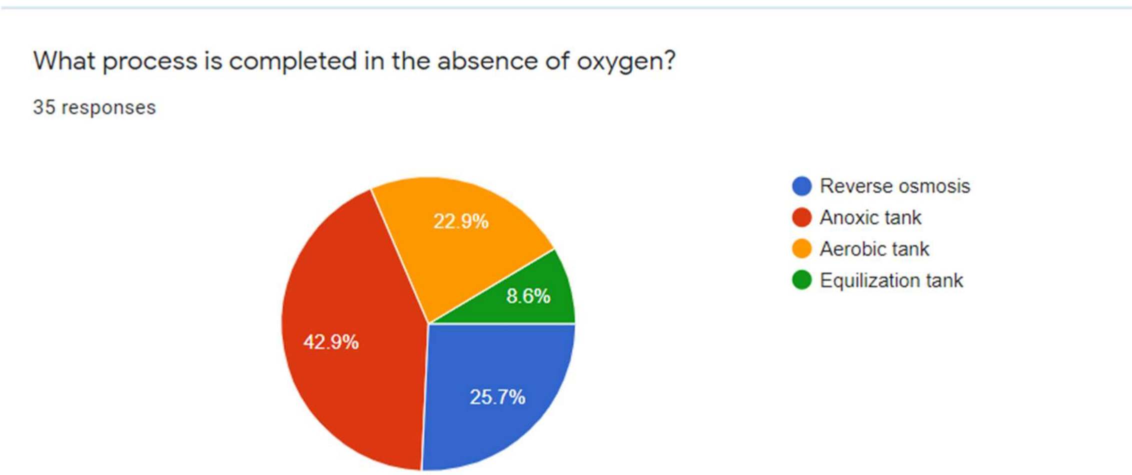


Figure 22: Results from a comprehensive survey question

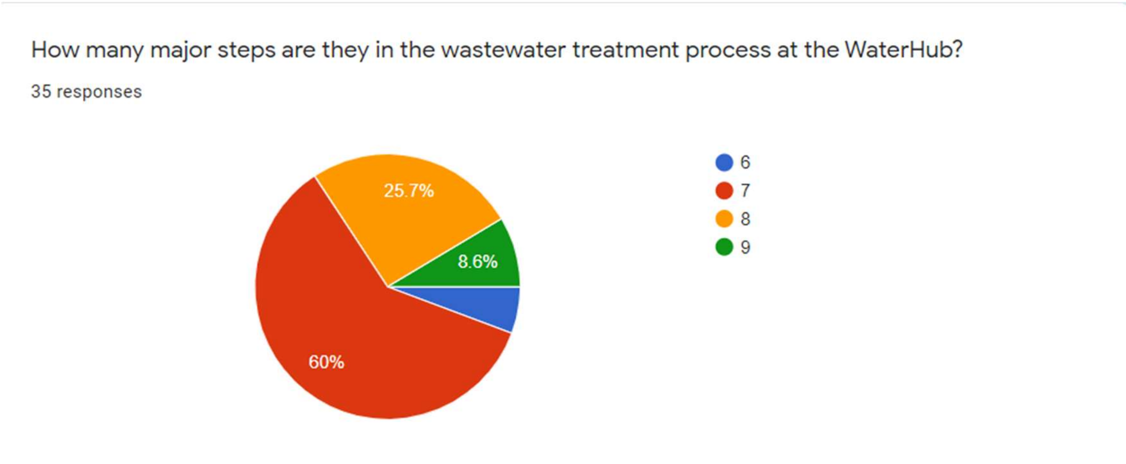


Figure 23: Results from a comprehensive survey question

As can be seen from these responses about 86% of the respondent indicated that they did in fact learn something from the about the process or the WaterHub from the video and based on an article found (Assefa and Frostell, 2006). For our conclusion based on the survey data to be considered relevant or statistically significant, it needs to meet or exceed 65%. Given this the team made some small changes to some of the wording, added some more explanation, and made some small changes to the layout of the GUI.

For technical evaluation, the team altered the excel sheet to mimic the SCADA system and found that when the excel sheet was updated every 45 seconds it took the GUI less than 2 minutes to display these changes. This is more frequent than EPA suggested.

6.0 Cost Analysis

These design recommendations will be implemented as the WaterHub is being constructed therefore, we are assuming the labor costs will be absorbed into the cost of the construction.

Sensors

Table 4: Costs for the individual sensors

Product (Quantity)	Cost per Sensor
YSI-EXO Turbidity Smart Sensor SKU: 599101-01 (9)	$1,100.00
YSI-IQ SensorNet SensoLyt 700 IQ Series (9)	$1,550.00
YSI-ProDSS Ammonium Sensor SKU: 626906 (9)	$575.00
5560 Conductivity/Temperature Probe (9)	$476.00

Since the plan is for the sensors to be used in nine sections of the WaterHub requiring the purchase of nine sensors for each type shown above. The total cost for the turbidity sensors is $9,900.00. The cost for the pH sensors is $13,950.00. The cost of the nitrogen/ammonium sensors is $5,175.00. The cost for the conductivity/temperature sensors is $4,284.00. The total cost of all the sensors combined is $33,309.00.

Draw Samples

Auto Samplers

Table 5: Costs for individual YSI Auto Samplers

Product	**Cost**
WS700 Water Sampler, 1 Pump	$1,875.00
WS700-IBO Ice Bag Water Sampler	$1950.00
WS705 Improved Water Sampler, 1 Pump	$1,945.00
WS700R Refrigerated Water Sampler 115V AC	$2,333.00
WS750 Water Sampler, 2 Pump	$2,098.00

Pump and Piping System

Table 6: Costs for the pump and piping system

Product (Quantity)	**Cost Per Product**
1-A 1/200 HP Submersible Only Recirculating Pump	$82.39
¼" x 10ft 304 Stainless Steel Pipe, Pipe Schedule 40, Threaded on Both Ends (6)	$70.50
316 Stainless Steel Coupling, FNPT, ¼" Pipe Size – Pipe Fitting (5)	$6.80
¼" Threaded 150# 316 90 Degree Elbow (5)	$2.15

The total for a single pump and its piping system comes out to a total of $550.14. This is significantly less than the price of YSI's cheapest auto sampler. Since draw samplers will be collected in seven different tanks, there will need to be seven different pump and piping systems or 7 different auto samplers. The total pump and piping system and cheapest auto sampler costs are $3850.98 and $13,125.00, respectively.

Dashboard

Table 7: Costs for the dashboard system

Product	Cost Per Product
55 inch Multi-Touch Panel, Infrared, Cables included	$218.00
Hp 800 G1 Desktop PC, Intel Core i5, 16GB Ram, 512GB M.2	$379.99
Annual MATLAB License	$149/year (or $0.00 with OSU academic subscription)

The total estimated cost for the dashboard system is $746.99. This will allow for the purchase of a mid-size touch screen monitor with the minimum resolution size to clearly display the dashboard. Additionally, the computer recommended for this design has enough Ram and processing speed to run the MATLAB program during all hours of operation. If the customer desires, upgrades in monitor and computer choice can be made.

7.0 Further Design Considerations

Environmental & Sustainability

To ensure sustainability of the pipe system for accurate draw sample recording, the team would investigate installing a cleaning system onto the pump and piping system. A non-submersible pump could sit near the top of the latch system while having a pipe down into the tank. A valve that could divert a cleaning agent into the piping system followed by passes of clean water could be attached to the pipe system in order to maintain cleanliness within the system.

The team would also investigate diverting flow from the clear section of pipe with a series of valves and bends. This would give the chance for the lab technician to keep the clear section clean and reduce the buildup on the inside diameter of the piping.

Manufacturability

When putting together the pump and piping system, there were a few things to consider such as type of pump, piping material, valves, and clear covering material. Given more time, the team would investigate more material specific aspects of the system. A 3D printed cover could possibly save some money on material cost for the cover.

Ethical, Health & Safety

It is extremely important to keep the pump and piping system closed. The team would recommend properly disposing of the draw samples after analysis and regular maintenance on the pump and piping system in order to keep avoid contaminating draw samples.

Social & Political

It is important to follow all University guidelines and restrictions when creating the dashboard. The use of logo on the dashboard should be approved by the Ohio State University. Sustainable Water restrictions and guidelines should be followed as well. The Ohio EPA has set strict guidelines on wastewater regulations, and it is important to treat these within their standards.

8.0 Conclusions and Recommendations

Conclusions

The needs of this project are as follows:

- Efficient and effective sensors and sampling that provide updated measurements of the wastewater flowing through the WaterHub.
- A convenient process to take draw samples that keeps the samples uncontaminated for lab testing.
- A way to display the results of the wastewater testing that can also be used as an educational tool.

To achieve these needs, the team created a three-part solution including sensors, draw samples, and a dashboard. The sensors were chosen based off a series of decision matrices. The team concluded that getting all the needed sensors from one company was most optimal for the project. Sensors for turbidity, pH, ammonia/nitrogen, and conductivity will be purchased from YSI for use in the WaterHub. Based on information from Bob Salvatelli and Eric Lohan, the sensors will be placed in a latch state above each tank so that the wastewater treatment remains a closed system.

To retrieve draw samples for measuring BOD, total phosphorous, fecal coliform, and TSS, the team recommends creating a piping system. The piping system will bring wastewater samples from several points within the WaterHub to the lab directly. The piping system is more affordable and convenient than using autosamplers. This system can also be used as an educational component by adding a clear section into the piping so that visitors of the WaterHub can view what is happening underground. The clear piping needs to be covered when not in use to avoid algae growth, therefore the team developed a sliding pipe covering.

The dashboard will use a SCADA system to create a data pathway for the sensors and graphical user interface to communicate. The team recommends implementing a touch screen monitor in a public area within the WaterHub that is connected to a computer with MATLAB to run the graphical user interface of the dashboard where it is accessible to people touring the facility.

Recommendations

To further solidify our proposed solution a few more considerations and further testing should occur. Further data collection and experimentation should occur with the data pathways between the sensors and the dashboard. The team did not have access to sensors to perform testing on the dashboard as the WaterHub has not yet been constructed. To ensure that the data pathways research function for the dashboard needs, a sensor should be placed in a wastewater tank and connected to a SCATA system. The SCATA system should add a pathway to the excel spreadsheet and the MATLAB GUI should be running at a refresh interval of 2 minutes. If the dashboard updates correctly every 2 minutes, then the data pathways are functional.

Further testing should occur on the piping system. Since the pipe size chosen is relatively small, there is a concern for pipe buildup and blockage. To test this, a small pipe and pumping system should be built in a wastewater tank. Wastewater should be pumped through the pipes for a set period of time and any buildup or reduction of flow should be recorded. To avoid build up, the team recommends considering a second piping system that can act as a bypass so that clear piping section can be removed and cleaned periodically to ensure it is translucent. Additionally, a loop system can be added to the piping to clean the entire system. Clean water can be flushed through the pipes to remove blockage and the used water will be recycled through the entire wastewater treatment system. If there is not enough resources to implement a clear section in the piping, the team recommends using other methods to add an educational element. Another option to display the wastewater for the public to view is to create clear jars or canisters that the lab technician can fill with wastewater from the pumps and periodically clean as needed.

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Appendix

A1. Qualifications of Personnel

Megan Cochran

28 E 11th Ave, Columbus, Ohio 43201 | 614-359-7005(mobile) | Cochran.437@osu.edu

OBJECTIVE

-

EDUCATION

Ohio State University, Columbus, OH
Expected Graduation: December 2021
B.S. Food, Agricultural, Bio & Ecological Engineering
Biological Engineering Specialization

Olentangy High School, Lewis Center, OH
Graduation: May 2017
Summa Cum Laude-Honors Diploma
GPA: 4.2

WORK EXPERIENCE

Ohio State FOD, Columbus, OH
Water Engineering Intern [March 2019—present]
- Conducts and interprets campus wide building water use audits
- Supports planning of campus hydroponic wastewater treatment plant

Duck Donuts, Westerville, OH
Shift Lead/Key Holder [December 2016—August 2019]
- Managed active store, employees, and inventory
- Promoted a healthy and productive work environment

APPLICABLE SKILLS
- MATLAB
- Solidworks/AutoCAD
- GIS
- Microsoft Office
- Technical Writing
- Problem Solving
- Communication

APPLICABLE COURSEWORK
- Fluid Mechanics
- Thermodynamics
- Instruments and Measurements
- System Dynamics
- Ecological Engineering and Science
- Sustainable Waste Management
- Engineering Economics

PROJECT EXPERIENCE

Water-Hub Live Interactive Water Quality Report [Fall 2020-Present]
- Tasked with the creation and implementation of a live updating dashboard that displays the EPA water treatment parameters and requirements for the hydroponic wastewater treatment system.
- Elected team leader with the responsibility of coordinating the research and development of a interactive, educational dashboard displaying wastewater data.

Quarry Trails Wetland Design [Spring 2020]
- Conducted onsite research of the client needs for a quarry restoration in a Columbus Metro park.
- Designed a stormwater treatment wetland as a solution to runoff from a residential area upstream.
- Utilized AutoCAD and GIS to accurately model the wetland and its ecological services.

Advanced Energy Vehicle [Spring 2018]
- Built a small scale AEV to provide the city of Columbus with a public transportation solution.
- Conducted research to improve AEV's aerodynamics, energy efficiency, and braking accuracy.
- Updated a website with R&D progress.

EXTRACURRICULAR INVOLVEMENT
- FABENG Mentor Program, Mentor [Fall 2020-present]
- Buck-I-Serv, Trip Leader [Fall 2019-present]
- ASABE, Member [Fall 2019-present]
- Ohio State AWARES, Mentee [Fall 2019-Spring 2020]
- Ohio State Welcome Leader, Member [Fall 2018]
- Longboarding Club, Member [Fall 2017-Spring 2019]

Rylee Kohr

ryleekohr@gmail.com
2668 E. Teresa Dr. Martinsville, IN 46151
765-318-3683

EDUCATION

Ohio State University, Columbus, OH
B.S. Food, Agriculture, and Biological Engineering,
Specialization in Biological Engineering May 2021

RELATED EXPERIENCE

Software Design Project Ohio State University (August – December 2017)
-Collaborated with 4 students develop two computer games of the students' choice
- Created these games using MATLAB software as well as a website that displays the production process
- Completed all of the requirements for the games and received an A with extra credit

Advanced Energy Vehicle Project Ohio State University (January – December 2018)
- Collaborated with 4 students to develop a working vehicle using an Arduino and other parts
- Coded the vehicle using Arduino software and created 3-d models using Solidworks as well as a website that displays the process of creating the advanced energy vehicle
- Completed all of the requirements for the final run and received an A

Capstone: WaterHub Ohio State University (August 2020 – May 2021)
-Collaborated with 4 other students, the Ohio State's Facilities Operations and Development office, and Sustainable Water to design and implement the sensors placement and data collection for the Upcoming WaterHub so EPA wastewater requirements can be met and maintained while the facility is showcased as a living learning lab.

INTERNSHIPS

Seaboard Energy – Biodiesel Production Intern (Summer 2019)
- Perform tests to the lab
- Ensure the biodiesel is within the specifications set for market
- Assisted piloting an anerobic biodigester to treat wastewater

QUALIFICATIONS

Computer and Technical:
- Solid understanding of Solidworks, Matlab AUTOCAD
- Extensive use of Microsoft Word, Excel, and PowerPoint

Coursework Includes:
- Engineering: Fundamentals of Engineering 1 and 2, Engineering Economics, Fluid and Thermo Dynamics, and Instrumentation
- Mathematics: Calculus 2 and 3 for Engineers, Linear Algebra, Statistics
- Science: Physics, Chemistry, Biology, and Organic Chemistry, Molecular Genetics, Entomology
-Sustainable Waste Management
-Urban Stormwater Control
-Phytotechnology and Phytoremediation

OTHER JOB EXPERIENCE

Old Navy, Brand Associate (August 2019- Present
Office of Postdoctoral Affairs, Student Assistant (September 2017 – Present)

Current Address:
58 Chittenden Ave.
Columbus, OH 43201

Jake Grim

grim.99@osu.edu or jakegrim1998@gmail.com
(419) 439-8516

Permanent Address:
B466 County Road 17B
New Bavaria, OH 43548

EDUCATION

The Ohio State University College of Engineering — **Columbus, Ohio**
Bachelor of Engineering — *Expected Graduation Date: May 2021*
Agricultural Engineering, Soil and Water — *GPA: 3.1/4.0*

WORK EXPERIENCE

Scotts Miracle-Gro — **Marysville, Ohio**
Lawns R&D Intern — *June 2020 - August 2020*
- Tasked with researching nanotechnology's impact on Scotts' liquid fertilizers
- Maintained, collected, analyzed, and reported data from different test trials
- Analyzed the collected data through ARM program and came to a conclusion that a small greening impact was evident, but the product needs further researching
- Suggested focusing research on turf grass growth instead of greening

Advanced Agrilytics — **Southwest, Ohio**
Intern — *May 2019 - August 2019*
- Scouted and soil sampled fields in surrounding area for farm owners
- Sought out early signs of crop diseases, crop deficiencies, and bug damage on crops
- Successfully prevented advancements of crop damage by reporting these findings

Grim Farms — **New Bavaria, Ohio**
Self-employed — *2012 - Present*
- Plant, harvest, and market corn and bean crops on cash rented land
- Participate in H2Ohio program including nutrient management program, conservation crop rotation, cover crops, and drainage water management

Hill Asphalt Paving — **Napoleon, Ohio**
Manual Laborer — *May 2018 - August 2018*
Tenneco, Inc. — **Napoleon, Ohio**
Manual Laborer — *May 2017 - August 2017*

INVOLVEMENT

Capstone Project – Waterhub and Wastewater reclamation and reuse — **Columbus, Ohio**
Project Co-Leader — *August 2020 - Present*
- Coordinating the research of sensors, water sampling, and hydroponics in order to treat and reuse water for a power plant at the Ohio State University

American Society of Agricultural and Biological Engineers (ASABE) — **Columbus, Ohio**
Engineers' Council Representative and Active Member — *May 2017 - December 2019*
- Represented ASABE at the Engineers' Council meetings and at Involvement Fairs
- Reported back and notified members of upcoming events and volunteer opportunities
- Volunteered at Farm Science Review preparing food for attendees

Ohio State Women's Practice Player — **Columbus, Ohio**
Practice Player — *Seasons: 2018, 2019*
- Scrimmaged against players in game like situations and drills

Skills
- Experience with: AutoCAD, Solidworks, ArcMap, HEC-RAS, ARM Software, Excel, Microsoft Teams
- Programming: Matlab, Simulink

A2. Original Problem Statement

Project: WaterHub wastewater reclamation and reuse

Sponsor: OSU Energy and Sustainability

The Ohio State University has implemented a Sustainability Program, with an aggressive sustainability goal to reduce potable water consumption by 5% every 5 years, resetting the baseline every 5 years. Currently, the university uses 1.2 billion gallons of water per year, which is down by 4 million gallons four years ago. The biggest user on campus is the power and chiller plants that together use approximately 270 million gallons of water per year. That number will increase with the addition of the Combined Heat and Power Plant in the next few years. To continue to meet or exceed our goal of potable water usage, the university is currently partnered with Sustainable Water to investigate wastewater reuse as a non-potable source of water for the power plants. Sustainable Water (SW) is a water management consulting firm and water infrastructure developer that specializes in the design build of district-scale and ecologically engineered wastewater treatment solutions. Sustainable Water has a system called the WaterHub which mines our sewers harvesting the polluted water, treating it through a system of biological and ecological processes, and then sends the treated water to the energy facilities. The project would involve technical analyses to support making a business and ecological case for a WaterHub. The goal of this project is to use the provided data to develop a wastewater system design for energy plant reuse. The design would be an ecologically based wastewater treatment and reuse system. The system may include reciprocating wetlands or hydroponic systems. The design will be such that it will be energy efficient and aesthetically pleasing. In addition, new technologies and equipment packages, such as high-performance screens, membranes, ultrafiltration, and/or reverse osmosis, may be required to meet the water quality requirements of the energy facilities where the water will be reused.

A3. Auto Sampler Quote

xylem
Let's Solve Water

O·I·Analytical | Global Water | WTW | SI Analytics | -ebro- | ROYCE TECHNOLOGIES | BS Bellingham + Stanley

Telephone: OI Analytical: 800-653-1711 / 979-690-1711
Global Water/WTW/SI/ebro : 800-876-1172 / 979-690-5560 | Royce: 800-347-3505 / 979-690-5556 | B + S: 800-678-8573 / 678-804-5730

Customer Number: 10634
Jake Grim
The Ohio State University
1960 Kenny Road
Research Foundation Building
Columbus OH 432101063
UNITED STATES

Phone:
Fax:

Quotation

Reference Number: E000073463	**Page 1 of 2**
Quote Date: 4/13/2021	**Expiry Date:** 5/13/2021
Terms: NET 30 DAYS	**Currency:** USD

Sales Contact: Laura Warne	**Territory:**

Customer Type:

Qty/Unit	Item	Description	Unit Price	Extended Price
0.00 EA	**CU0000**	**WS700 Water Sampler, 1 Pump** Shipping Dimensions: 24" X 24" X 14" Shipping Weight: 35 LBS ***Price is not reflected in total amount***	**1,875.00**	**0.00**
0.00 EA	**CL0500**	**WS700-IBO Ice Bag Water Sampler** 24x12x24 ***Price is not reflected in total amount***	**1,950.00**	**0.00**
0.00 EA	**CU1000**	**WS705 Improved Water Sampler, 1 Pump** 24" X 24" X 14" ***Price is not reflected in total amount***	**1,945.00**	**0.00**
0.00 EA	**CD0500**	**WS700R Refrigerated Water Sampler 115VAC** WS700R Refrigerated Water Sampler 115VAC. Size 32" X 24" X 24" (PLEASE NOTE THAT THIS ITEM IS NOT CE APPROVED AND CAN NOT SHIP TO COUNTRIES REQUIRING CE CERTIFICATION) SHIPPING WEIGHT: 60LBS SHIPPING DIMENSIONS: 24X24X32 IN ***Price is not reflected in total amount***	**2,333.00**	**0.00**
0.00 EA	**CT0000**	**WS750 Water Sampler, 2 Pump** Shipping Dimensions: 24" X 24" X 14" Shipping Weight: 22 LBS ***Price is not reflected in total amount***	**2,098.00**	**0.00**