Bringing real world applications for wireless sensor networks into the classroom:

Telemetric monitoring of water quality in an artificial stream

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Contents

Abstract

This research report covers the use of a wireless sensor network (WSN) using the ZigBee protocol to remotely monitor an artificial aquatic ecosystem. Field tests were conducted at the University of North Texas Water Research Facility to compare the accuracy of a high-end standard YSI multi probe system to a cost efficient lab developed sensor cluster, which would be used in the classroom to bring more real-world experiences in engineering to students. Measurements were recorded every 10 seconds for pH, dissolved oxygen, and temperature for a period of 24 hours. Comparison results show a 10 percent degree of variability in dissolved oxygen possibly due to the sensitivity of the DO sensors themselves. On the other hand, temperature and pH measured less than a 5 percent error.

I. Introduction

A freshwater or aquatic ecosystem is defined as the organisms (biotic) and the non-living (abiotic) environment they inhabit. Texas has a large number of water bodies, with 11,247 streams and rivers. The total length of all streams and rivers combined is 191,228 miles however only 40,194 miles of streams and rivers are considered perennial, meaning that they have sustained flow throughout the year [11]. Given the large area, high quality monitoring data are important for tracking and understanding the causes for aquatic ecosystem change [18]. Being able to monitor these changes in an ecosystem demands cutting edge technology and trained professionals who can interpret the data [3].

An artificial aquatic ecosystem provides students the opportunity to change environmental factors that would otherwise be impossible to manipulate in nature. Through collaboration students brainstorm suitable fish tank designs and methods of constructing a classroom tabletop stream system. Students can later monitor changes in water quality by working with PASCO: Passport Water Quality Sensors [17]. These sensors allow for students to monitor pH, temperature, and dissolved oxygen levels in real time allowing students to continuously collect data. Students can then interpret and make inferences of their data and determine the factors affecting the water quality. In more advanced classroom laboratories, students can conduct research to create ZigBee wireless sensor clusters that can be deployed in either their table top stream system or in collaboration with the University of North Texas's Water Research Facility [25]. Incorporating wireless sensor networks expands students understanding to the application of technology as well as giving them a real world experience that they can carry forward into higher education.

The focus of this research project was to incorporate wireless sensor networks to remotely monitor an artificial aquatic ecosystem and to establish a method of collecting data for pH, temperature, and dissolved oxygen. One of the major challenges with collecting meaningful data in the field is the cost of the equipment used to monitor aquatic environments [23]. This cost is a barrier that can prevent researchers from being able to deploy sensors in a dense enough pattern to adequately monitor the environment and requires more extrapolation and estimates back in the lab[4], [10]. As such, our design needed to be low power and cost effective. The Research Experience for Teachers provided a platform for us to expand our personal understanding of electrical engineering and some of the difficulties facing researchers in the field. By putting ourselves into a project where we were forced to grow and learn in an area we were not especially comfortable with allowed us to step out of our roles as teachers and into the shoes of our students. That experience will allow us to create more meaningful lesson plans to bring to our classrooms.

II. Literature Review

The progress in wireless sensor networks has been slow as explained by Corke, Wark, Jurdak, Hu, Valencia and Moore, (2010) in their Environmental Wireless Sensor Networks article. It was proposed that the expectation that there would be wide-use of WSN was triggered by the availability of low-cost microcontrollers and radio transceivers. What this expectation didn't account for was that the WSN is just one part of a complex system that includes internet links, databases and web tools, and that servers would always be available. A gap in any of the aspects of the system leads to gaps in the data.

As technology advances monitoring of the environment will become easier. Environmental research is undergoing a technological revolution as interfaces develop between environmental science, engineering and informational technology as explained by Rundel, Graham, Allen, Fisher and Harmon, (2009) in their Environmental sensor networks in ecological research article. The advances have been made because of decreasing cost, size and weight, and improved reliability, of sensing hardware and software. The internet has allowed increased connectivity to transmit and share data. New designs of WSN allow for observation in near real-time from remote sensing streams. They proposed that Ecological sensor networks are at the core of major new efforts to address issues of global change and stability.

It has been proposed that a WSN could be used to someday help to monitor pollution on a worldwide basis by Hatzikos, Bassiliades, Asmanis and Viahavas, (2007) in their Monitoring water quality through a telematic sensor network and a fuzzy expert system article. They introduced an expert system that monitors seawater quality and pollution through WSN which would collect data from monitor stations. The data is then used to tell whether water is suitable for different uses and if water was determined unsafe, the system would flag an alert.

As concern for the environment increases WSN will become an important means of collecting data. Environmental Sensor Networks (ESNs) will become the standard research tool for future Earth and Environmental Science says Hart and Martinez, (2006) in their article, Environmental Sensor Networks: A revolution in the earth system science? ESNs facilitate the study of fundamental processes and development of hazard response systems.

Development of surface water monitoring network is critical for assessment, restoration, and protection of stream water quality as explained by Ouyang,(2005) in the article: Evaluation of River Water quality monitoring stations by principal component analysis. The study evaluated effectiveness of water quality- monitoring network in a river. It identified principal and non-principal stations. Variations in organic carbon, nitrogen, nitrate, nitrite, pH, salinity, Mg and Ca were identified as most important when evaluating water quality in a stream.

In education, WSN could be in the forefront of advancing student learning and ability to interpret data to bring about positive changes to the environment. There is, no doubt, untapped potential in using technological tools to enhance student's understanding of science concepts, suggested by Metcalf and Tinker,(2004) in their article: Probeware and Handhelds in Elementary and Middle School Science. The article is a report on a study that was part of the Technology Enhanced Elementary Middle and Secondary Science project, which was designed to test the feasibility and educational value of introducing probeware and instructional materials into science, mathematics, engineering, and technology teaching. The study observes the potential of students using portable data collection devices in science. The researchers found specific evidence that the Probeware technology used maximized students' science learning. The study found that the three student groups were able to use the tools to conduct scientific inquiry and engage in scientific discourse.

III. Wireless Sensor Technology

The Arduino microprocessor was developed for artists, designers and 'makers' of all stripes and was intentionally made as easy to program and as low cost as possible. The coding platform (IDE) is based on the Processing development environment. The core libraries for the code are based on versions of the C programming language. The entire project is open source and constantly evolving and developing as enthusiasts and researchers around the world experiment with what the hardware can do. A number of companies also provide sample code for the devices they create that allows for an almost plug-and-play functionality with the Arduino environment [1]. Atlas scientific is one of those companies. Atlas also has the advantage of providing all three types of probes that we intended to integrate into our sensor cluster: pH, temperature and dissolved oxygen. Considering one company had developed all the probes we were interested in and also provided sample code for the microprocessor we intended to use it was not a difficult decision concerning where to order our probes. It also helped that the cost for the Atlas probes was at or below what other companies seemed to offer. By selecting probes from the same source we were able to greatly simplify the task of coding the program since the underlying logic of the probes was similar [2].

The radio transmitter we selected was the XBee because it is inexpensive and has solid support and integration with the Arduino through a custom circuit board known as a shield. The XBee uses the ZigBee protocol. Zigbee is a high level communication protocol that complies with FAA rules for private transmission. It is designed for applications that do not have a demand for high bandwidth and a need to

function in low power systems [13]. Zigbee utilizes a mesh network layout that allows the radios to form ad hoc connections and transmit their data along that web rather than relying on one high power transmitter in the center of the network that is able to reach all the radios.

Advantages in using the ZigBee protocol

The ad hoc nature of the ZigBee protocol also makes the radio network very robust [21]. If a researcher wants to add another sensor cluster to the network all they should have to do it flash the Arduino embedded in the sensor cluster with the program and install the sensor cluster somewhere in the range of the existing wireless sensor network. It should automatically be integrated and add to the data flow. On the other side, if a sensor cluster is lost or destroyed in the field it should not cripple the network or prevent any other sensor clusters from reporting their data since the network should adapt to the loss of that node and continue functioning [8].

IV. Table Top

It has been proven that hands on and real world experiences increase comprehension and retention among students. The problem is that most teachers do not have the resources to bring these experiences into their classroom. With the tabletop model, our goal was to make an affordable model of a stream system that would allow students to monitor the environmental factors such as pH, dissolved oxygen, and temperature. The stream tabletop model cost under $100 and parts for sensor cluster roughly run around $500. From the data collected so far, our stream system is working and the fish have adjusted to their new environment creating niches for themselves and the sensor cluster has been tested and the readings have been close to those of a very expensive YSI unit [24].

Building a classroom table top

Safety is the first measure teachers should take before having students work on any science classroom project. Students should be familiar with the use of handling lab equipment as well as understanding the safety protocols if an accident should occur. Teachers should model the proper use of all lab equipment before allowing students to work with equipment. We designed our classroom tabletop to have a 10 degree drop which allowed for gravity to move water downstream. In order to create our preferred degree in drop, we purchased an 8’ X 11’ sheet of plywood which we had cut into 1’ X 1’ pieces. We cut the top off of (4) 2’ vinyl spouts using a dremel tool and measured and cut out 4” X 3” slots on two sides of our fish tanks where the vinyl spouts would rest. In order to adhere one end of the spout to tank slot, we used inexpensive epoxy-marine waterproof and J-B weld. Before doing this though, we washed the gravel 3 times to drain out any impurities. We then applied the adhesives thoroughly on surfaces allowing them to dry at their recommended time period before applying an additional coat. After settling, we added water and within seconds two tanks began to leak. We drained tanks and sealed leaks using several strips of foil backed repair tape and added a third coat of epoxy and J-B weld. We filled fish tanks and added water conditioning in preparation for fish. After 24 hours we introduced 15 Gambusia minnow fish to tank 4 and 15 others to tank 1. In order to create our desired stream through riffles we added a pump with bubbler. We used a PASCO: Passport Water Quality Sensor to monitor water quality over a period of 3 weeks [17]. We decided to collect readings twice, once in the morning and another in the afternoon, on pH, temperature, and dissolved oxygen. Data was logged in an engineer’s notebook and collaborative google document.

Monitoring and maintaining a classroom table top

Students can use the internet to conduct research on existing fish tank designs that meet their intended goal. Fish tanks come in all shapes and sizes and can get very expensive so students should keep a log of of their supplies with a list of prices as well as the space allocated for constructing their fish tank in the classroom. Once students have come up with a group consensus on the design of their fish tank, they should develop a method in monitoring their aquatic environment to collect data. Determining the dependant variable and independent variables allows for students to observe changes in their test subject while taking into account the factors that influence this change. Three such variables that are readily tested in the classroom are pH, dissolved oxygen, and temperature because they are essential in sustaining aquatic life. Aquatic variables can be monitored using probeware such as PASCO or, if equipment is not available, by water testing supplies from any pet store with aquarium supplies. Whichever monitoring equipment they choose they should be consistent in using this throughout their entire experiment. A logbook is ideal for keeping track of physical changes in their aquatic environment and for collecting daily pH, dissolved oxygen, and temperature readings. A minimum of 2 readings should be taken each day during a 2-3 week experiment. Students should continue noting any change in fish tanks as well as drawing conclusions from their observations to later address as a group and to add to their lab report. Due to the evaporate nature of water, fish tanks will need to be refilled to continue collecting data. Students should keep in mind that any change to the environment should be logged, including the addition of water.

V. Methods

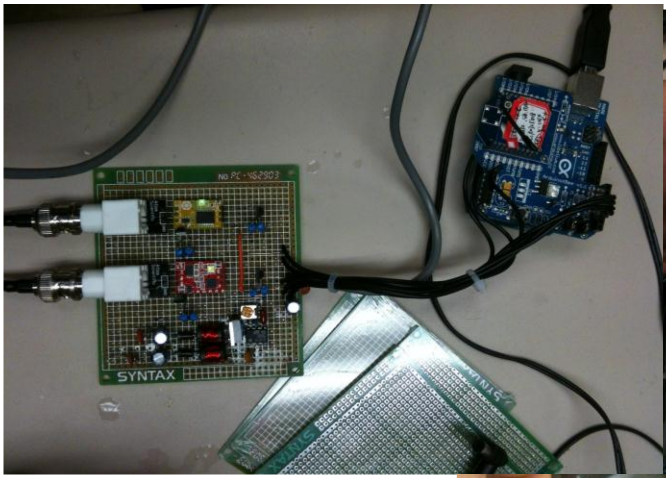
In order to meet the criteria we laid out for our task we needed to find a cost effective microprocessor and radio transmitter [13]. It would also need to run on an accessible OS and transmission protocol so that we could integrate it easily into our sensor cluster regardless of the style and brand of probe we elected to go with. We determined it would also be really nice if there was an active and prolific developer community out there so that we had plenty of resources to draw from. This task would be more than complex enough without us needing to reinvent the wheel. We quickly concluded that the best option was an Arduino microprocessor and an XBee radio.

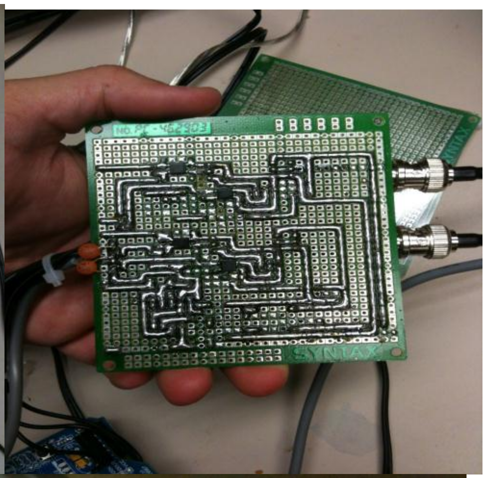
In our application we will be deploying a number of sensor clusters in a field environment that dumps the sensor data to a central data sink. The readings will not be done continuously and will not be large packets so it qualifies as low bandwidth. The tests we have done have all allowed for ground line power to be provided to the units but the ideal would be to have them either battery or solar powered for true field deployment. When used in that manner the low power requirement of the XBee is a decided advantage.

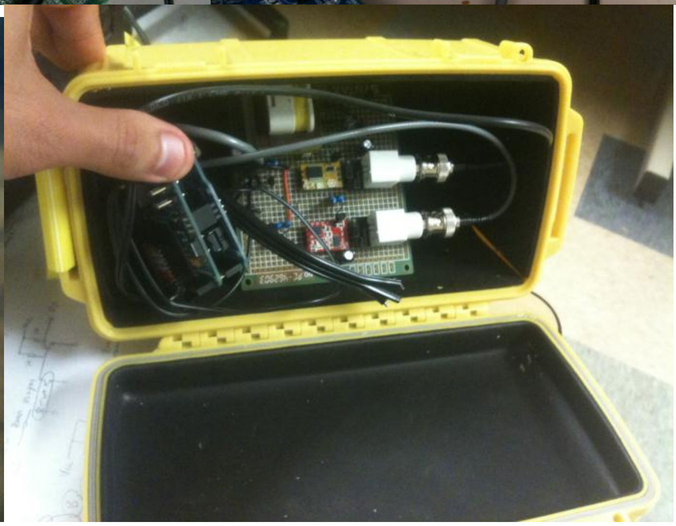
Once the components were identified and assembled the task of assembling a functioning sensor cluster began. We accomplished this task by breaking it down into independent code segments for each component. The first task we tackled was learning to use the XBee to transmit data. We took some time to familiarize ourselves with the IDE for the Arduino UNO that we had at the core of our hardware. Once we were able to build some of the simple circuit projects included with the programming environment we added the XBee and the shield to the Arduino. The control program for the XBee is called XCTU and we started out using that to become familiar with the chipset. Then we switched to the serial monitor built into the arduino programming environment and sent messages back and forth across the room.

Once we were able to transmit data successfully we set our sights on the Atlas Scientific probes. We used a pH sensor, a dissolved oxygen sensor and a field ready temperature sensor. Atlas provides sample code that allows you to run their probes out of the box with an Arduino. We flashed these programs one at a time to the Arduino and tested the probes one at a time. In each case we were able to set up the circuit, load the software and begin taking accurate readings almost immediately.

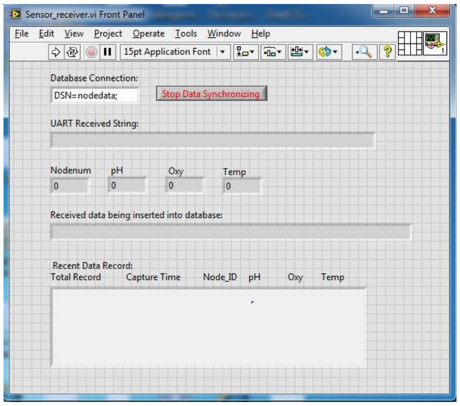
Yixing Gu then took the concept and created a design for the circuit we would deploy. There were four different generations of this circuit as we discovered compatibility issues between the pH and DO sensor that required the addition of a power circuit to ensure that they were not both applying current to the water sample simultaneously. The third version and final version of the circuit are displayed below and the schematics can be found in the appendix.

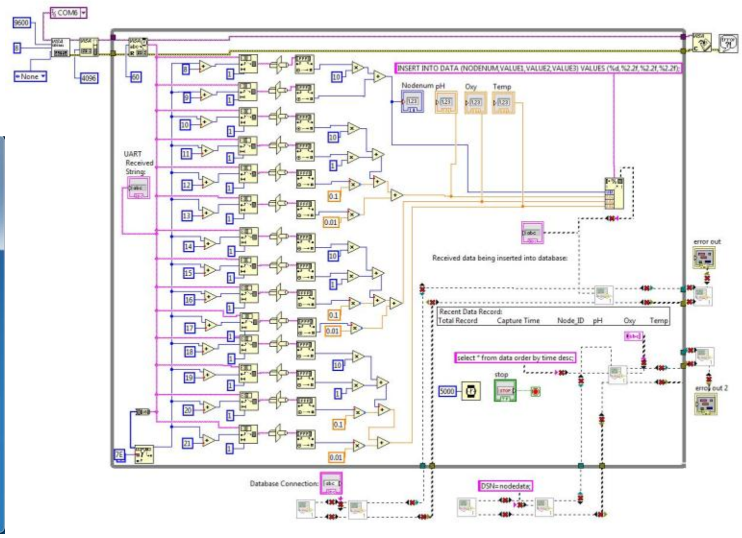




The physical circuit is only half the story, however. All of that hardware has software backing it up and all of that needed to be developed as well. The code that was loaded into the Arduino Uno built into the sensor cluster can be found in the appendix. There is also a LabVIEW program that gathers the data from the sensor cluster and builds an Access database [12]. This will eventually be loaded into an ASP format and fed to the internet.That will not truly provide any added utility at this point but will be very useful once the Water Research Facility has a broadband internet connection established.





Having successfully built a working sensor cluster and data sink we began by deploying it in the lab using our table top artificial stream model. We confirmed that the sensors were collecting data and were able to transmit the data across the hall to the data sink. The data sink was connected to a laptop and produced a table of results like the one that follows. We then put the sensor cluster into a watertight enclosure. We drilled a one inch hole in the bottom of the enclosure to pass through the cables for the probes and the power cords. This hole was then sealed using silicone gel. We deployed the WSN in the field twice. The first time we took the WSN to the water research facility and secured it to the side of a riffle in the artificial stream using a clamp. We monitored the readings for an hour and also deployed several other commercial sensors including the Spark from PASCO and professional grade equipment from YSI. This allowed us to compare our data in a field situation to make sure the readings our cluster gave us were acceptable. The second time we deployed the WSN in the artificial stream it was left to run for a little over twenty-four hours. The sensor cluster was clamped to the side of the riffle the same as the previous outing. The data sink was connected to a laptop and secured inside a shed nearby. An external antenna was mounted on the wall of the shed to improve signal strength. A YSI 6250 v2 was deployed at the same time and in the same relative position as our sensor cluster for comparison purposes.

Initial data from sensor cluster

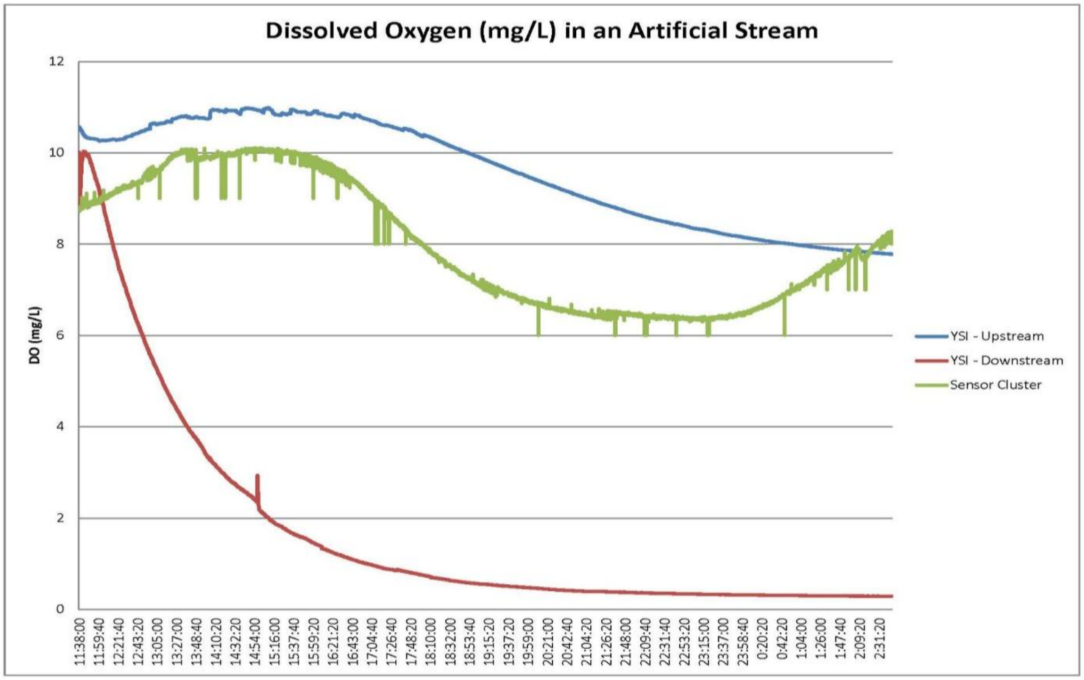
id	time	nodenum	ph	D.O	temp
19969	7/12/2012 11:50:41 AM	12	09.23	09.80	25.94
19968	7/12/2012 11:50:25 AM	12	09.23	09.77	25.94
19967	7/12/2012 11:50:14 AM	12	09.23	09.78	25.94
19966	7/12/2012 11:50:03 AM	12	09.23	09.77	25.94
19965	7/12/2012 11:49:52 AM	12	09.23	09.76	25.94
19964	7/12/2012 11:49:42 AM	12	09.23	09.77	25.94
19963	7/12/2012 11:49:34 AM	12	09.23	09.81	25.94

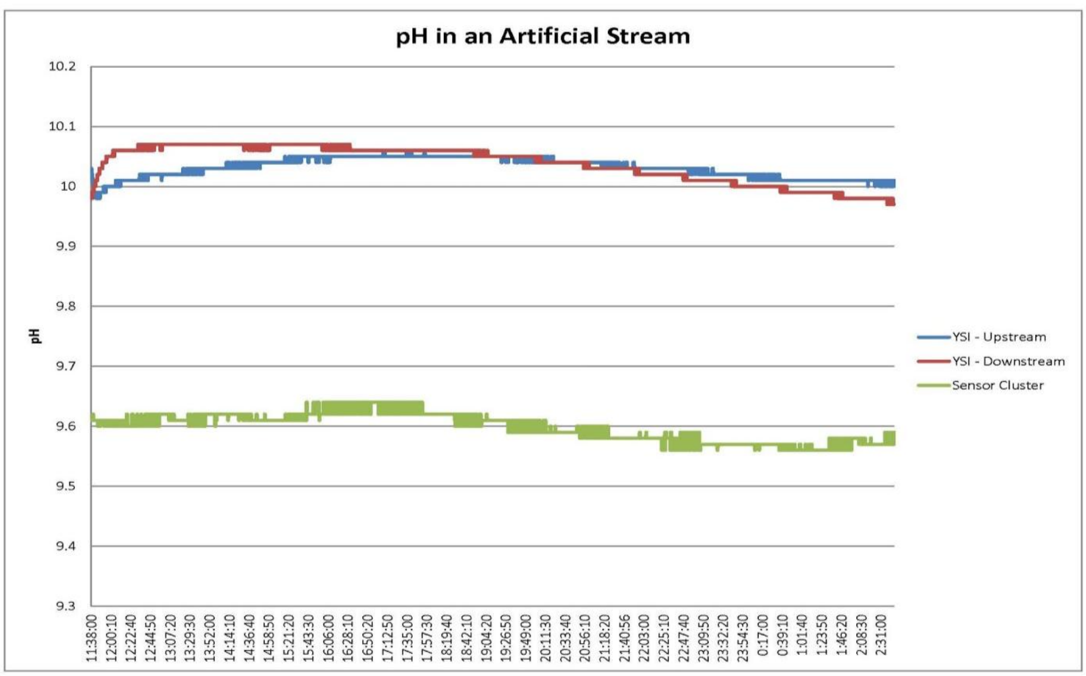
19962	7/12/2012 11:49:26 AM	12	09.23	09.75	25.94
19961	7/12/2012 11:49:16 AM	12	09.23	09.82	25.94
19960	7/12/2012 11:49:10 AM	12	09.23	09.80	25.94
19959	7/12/2012 11:49:08 AM	12	09.23	09.73	25.94
19958	7/12/2012 10:54:41 AM	12	09.23	09.73	25.94
19957	7/12/2012 10:54:32 AM	12	09.23	09.76	25.69
19956	7/12/2012 10:54:23 AM	12	09.23	09.79	25.94
19955	7/12/2012 10:54:14 AM	12	09.23	09.80	25.69
19954	7/12/2012 10:54:01 AM	12	09.23	09.73	25.94
19953	7/12/2012 10:54:01 AM	12	09.23	09.77	25.69

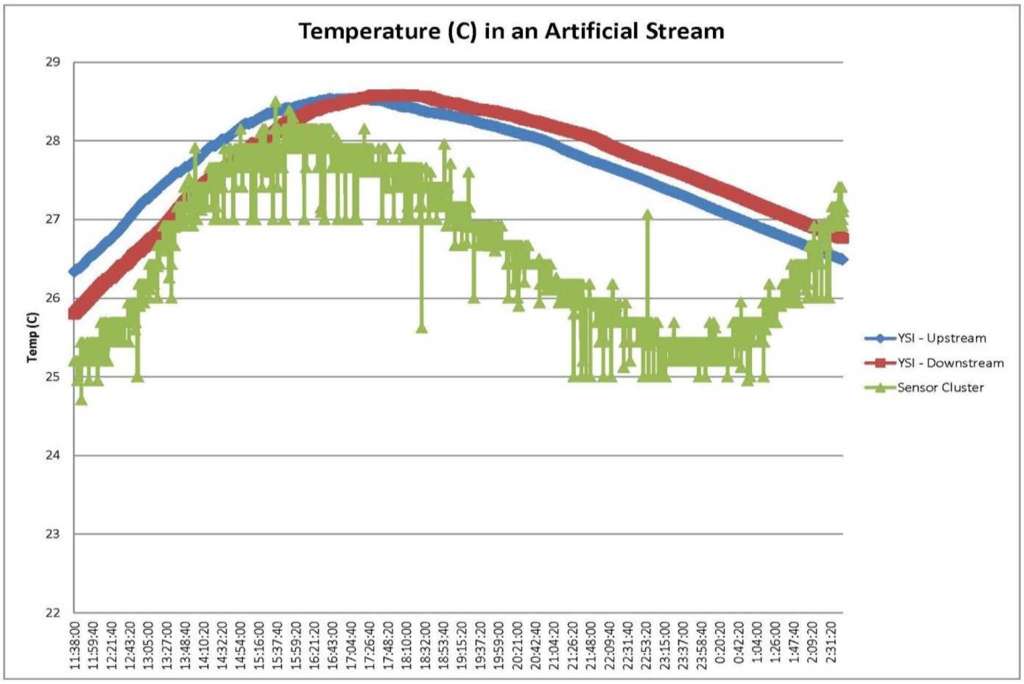
VI. Results

The results we will be using come from a specific deployment we performed beginning on July 16th at approximately 11:30 am and running over night until the next morning. There were two YSI 6920 v2 Sonde deployed along with our sensor cluster. The idea was to bracket our sensor cluster by placing one sonde upstream of our probes and another downstream. The hope was that it would let us identify any variation that might occur due to the location of the probe or stream flow. The data from all three probe sets was loaded into Microsoft Excel to produce the following graphs. To access the raw data for the readings go to http://untret.blogspot.com and look for the link on Week 6 Day

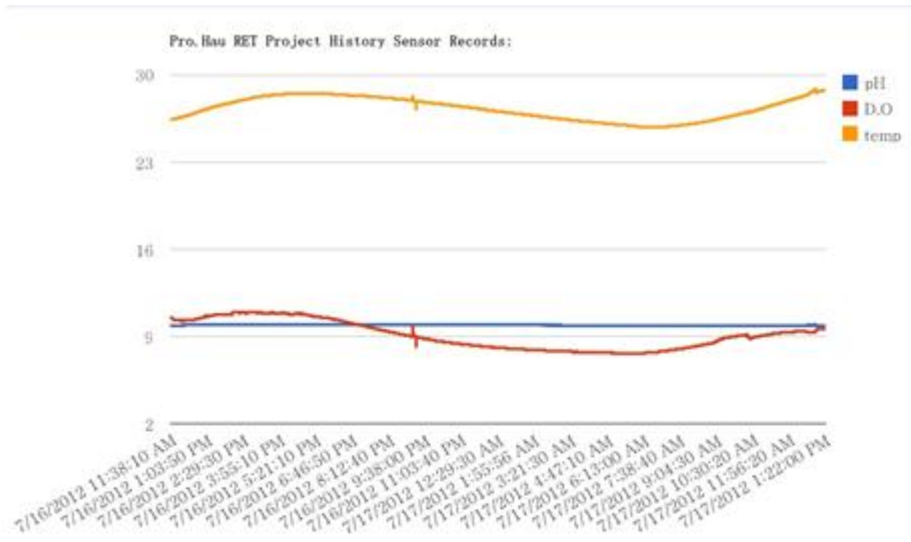
4.


Dissolved Oxygen (mg/L) in an Artificial Stream
DO (mg/L)
YSI - Upstream
YSI - Downstream
Sensor Cluster


pH in an Artificial Stream
pH
YSI - Upstream
YSI - Downstream
Sensor Cluster



Temperature (C) in an Artificial Stream
Temp (C)
29
28
27
26
25
24
23
22
11:38:00
11:59:40
12:21:40
12:43:20
13:05:00
13:27:00
13:48:40
14:10:20
14:32:20
14:54:00
15:16:00
15:37:40
15:59:20
16:21:20
16:43:00
17:04:40
17:26:40
17:48:20
18:10:00
18:32:00
18:53:40
19:15:20
19:37:20
19:59:00
20:21:00
20:42:40
21:04:20
21:26:20
21:48:00
22:09:40
22:31:40
22:53:20
23:15:00
23:37:00
23:58:40
0:20:20
0:42:20
1:04:00
1:26:00
1:47:40
2:09:20
2:31:20
YSI - Upstream
YSI - Downstream
Sensor Cluster


Pro.Hau RET Project History Sensor Records:
30
23
16
9
2
pH
D.O
temp


RET Project History Sensor Records:
30
23
16
9
2
pH
D.O
temp

In order to determine how accurate the readings for our sensor cluster actually are the correlation between the data points for each probe type was determined. We also calculated the percent error for our probes treating the YSI sondes as the standard to determine variation.

	pH	DO	Temperature
Correlation	0.615358	0.807081	0.755728
% Error	4.28714	16.4226	3.93644

VII. Discussion

We began by using the Arduino and the Xbee to build our sensor cluster. Once we connected all three probes to the our wireless sensor cluster, readings on the dissolved oxygen sensor became completely inaccurate and the pH probe began returning unreliable data. It looked like the problem could be solved using code. Yixin Gu built the first of our sensor cluster circuits. When we tested that sensor cluster in a working aquarium we found that the probes all collected data correctly when placed in the water one at a time but the same inconsistency arose when we had multiple probes in the water. At this point Yixin began exploring ways to isolate the pH sensor and dissolved oxygen sensor physically. The final solution involved splitting the DC power supply with a transformer and using a timing chip to control when the pH sensor and dissolved oxygen sensor were on. This seemed to resolve the issue that we were seeing. The implication here is that the issue was tied to the water carrying the current produced by the two sensors and creating interference leading to inaccurate readings.

When we look at the data from the field, we can see that the graphs track very similar patterns for each of the probes. The readings for temperature are all very similar from each of the three probe with a correlation of 0.755728 and a percent error just under 4. That is not surprising because it is the simplest circuit and provides the most straightforward data. Even at that, though, you see some variance. Those differences will be magnified in the pH and dissolved oxygen readings because each of those are temperature dependent. The pH readings are fairly accurate with only 4 percent error, but they fluctuate a good bit and have a relatively low correlation. The values returned by the probes are not that far apart and can definitely be explained by a difference in calibration for the most part. The small amount of difference we see in the pattern of the trend line could be explained by the variance in the temperature graph.

Dissolved oxygen is a more complex reading to explain. Most researchers agree that it is a crucial factor in determining water quality [5]. The problem comes in with the fact that there are a number of variables involved in calculating dissolved oxygen (including temperature and barometric pressure) and the way those are fed to a probe can have a lot of impact. The probe we used in our sensor cluster did not account for barometric pressure at all, so that is one possible source of error. Also, we see that there is a fair amount of variation in our temperature readings which can be magnified when factored into the dissolved oxygen reading. Another thing to consider is the high variability in dissolved oxygen that can be found in aquatic environments in very small pockets. It is not surprising that we see the largest differences in the DO readings based on all of these factors. Even at that we did end up with a strong correlation between our readings and the function sonde at 0.807081. The percent error was by far our highest, though, at 16.4226. It should be noted that the downstream YSI 6290 v2 had a failure in its DO probe shortly after it was placed in the artificial stream so it did not provide any usable data. For the dissolved oxygen comparison we were only able to use the upstream YSI.

VIII. Conclusion

In conclusion, comparisons between our sensor cluster and high tech YSI had a strong correlation. The parts needed to create sensor cluster are cheap and can be ordered through any probeware vendor. There are still some complications that will continue to arise with building monitoring probeware but collaboration can be established through local universities who specialize in sensor networking. Collaboration also brings along benefits to 6-12 grade level schools by teaching students the many applications to technology.

IX. Recommendation

There is still a bit of work that needs to get done before our sensor cluster is ready to deploy in the field. Most of the sensor suite functions well with in parameters but the cluster would benefit from some research into how the data from the dissolved oxygen sensor could be improved. There are also issues with the fact that the sensor cluster currently requires being plugged in to ground power and the data sink must be tethered to a computer. The sensor cluster needs to be converted to run off of battery power and it would be nice if there was a solar panel attached to allow it to recharge. The data sink also needs to have memory added so that the entire program suite can be loaded on board and so that it can log data natively. Having the programs loaded on to the data sink stack itself would free the data sink from needing to be tethered. Adding data logging abilities would ensure that and data collected would not be lost if the transmission signal goes down for any reason.

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XII. Appendix A

Name:___ Date:

Water Quality Activity

Water quality covers a lot of territory and can mean different things to different people. When you are working on this activity today there are specific aspects of the water quality that we want you to look at. The three things we will focus on are: pH, dissolved oxygen and temperature. These three factors can help you determine if plants and animals will be able to survive in the water. The pH is a measure of how active hydrogen ions are in a solution. If the pH is above 7 the solution is considered basic. If it is below 7 it is acidic. Dissolved oxygen (DO) is a very important aspect of water quality because it tells you how much life the body of water could support. All animals require a certain amount of oxygen to be available in the water or they can suffocate. Temperature is also important for a variety of reasons. One reason is simple comfort. Think of how you feel when you are too hot or too cold. What sort of bad things can happen to you if you are exposed to extreme temperature for too long? The same things can happen to animals and plants. It is also important to realize that temperature can affect DO and pH.
That is the idea. Let's collect some data!
There are three beakers at the table. One is ice water, one is room temperature and one is hot. Lets test those and see what we get.
When you look at these readings you should be able see a pattern emerge. See if you can pick out the relationship between the different factors.

	Cold Water	Room Temp Water	Hot Water
pH			
DO			
Temperature			

1) What did you notice about the pH? Did it change from sample to sample?________________
____
__

2) What did you notice about the DO? Did it change from sample to sample?________________
____
__

3) If there was a change in the pH what do you think caused it? ___________________________
____
__

4) If there was a change in the DO what do you think caused it? __________________________
____
__

One of the factors that is tested the most in the field is pH. pH can have a lot of different effects on living creatures. The pH range that seems to be safe for most freshwater animals is between six and nine. Lets test some liquids and see what their pH is. We will use an electronic probe as well as special paper strips used to measure pH. Be sure to read the instructions on how to read the pH strips before you begin this part of the activity.

	pH Probe	pH Strip
Lemon Juice		
Orange Juice		
Vinegar		
Soda		
Baking Soda		
Milk of Magnesia		
Dish Soap		
Detergent		

5) List the things from the table that are acids: ____
____

6) List the things from the table that are bases:____
____

7) Are there any that a fish could live in? ____
____

8) What would happen to water if a lot of vinegar got poured into it? Would be ok in that water?
____
____

9) What would happen to the water if a lot of detergent got poured in it? Would be ok in that water?____
____

There are also a lot of other things that can have a bad impact on water quality that are not mentioned in this activity. Can you think of three things that you see every day that would be bad if it got into your drinking water?

10) 1:______________________ 2: ______________________ 3:_______________________

Appendix B

Aquatic Water Sensor Project Lesson Plan

Investigating Streams and Water Quality

Lesson Objectives:

1. The students will design and build a river system.
2. They will manipulate the flow of water in the system to study the biotic and abiotic factors that influence water quality such as pH, DO, temperature.
3. Students will understand how environmental factors such as climate change, point source and non-point source pollution can affect the well-being of the river system.

Target Grade Level: Middle school through high school; this lesson could be modified for grades K-5th by modifying the levels of questions and hands-on activities.

Middle School Science TEKS:

- 6th Strand E - Organisms & Environments; Knowledge & Skills, #12 - Organisms & Environments, E - Describe Biotic and abiotic parts of an ecosystem in which organisms interact.
- 7th Strand B- Matter & Energy, Strand E- Organisms & Environment; #5- Matter & Energy- (C) Diagram the flow of energy through living systems, including food chains, food webs, and energy pyramids; #8- Earth & Space-(C) Model the effects of human activity on groundwater and surface water in a watershed; #13- Organisms & Environments...living organisms must be able to maintain balance in stable internal conditions in response to external and internal stimuli.
- 8th Strand E- Organisms & Environments; #11- Organisms & Environments... interdependence occurs among living systems and the environment and those human activities can affect these systems.

High School Science TEKS:

- Aquatic Science- (C) Knowledge and skills: 2.G-H; 3.A,E; 4.B; 5.A-D; 6.A; 9.A-C; 10.A-C; 11.A-B; 12.A
- Biology- (C)Knowledge and skills:11.A-C; 12.A-F
- Chemistry-(C)Knowledge and skills: 10A-b & I

Materials Needed:

A. **Project Supplies**

a. Plastic tubs- 20 quart
http://www.walmart.com/catalog/product.do?product_id=8282895&findingMethod=rr
b. Plastic tubing-to fit pump fittings
c. Epoxy-marine waterproof
d. Water pump
http://www.lowes.com/pd_205410-70161-19034_4294765370__?productId=3020301&Ns=p_product_qty_sales_dollar|1
e. gravel
f. water
g. vinyl gutter

B. **Water Testing**
a. Water conditioner
b. Sensors, probes or water quality kits which are used to measure: temperature, pH, dissolved oxygen (DO)
c. water sample containers

Engagement:

A. Videos:

Watershed:
http://video.google.com/videoplay?docid=-856176073243460523
water quality:
http://www.youtube.com/watch?v=nh7Ye3c4o9c
Middle School Level Water quality:
http://www.youtube.com/watch?v=xeH0uklc7ns

B. Student directed questions:

a. How could I build a river system using plastic tubs, tubing and a pump?
b. What kind of design would be best for testing water quality in the stream?
c. What biotic and abiotic factors will I manipulate or evaluate?
d. What supplies will I need?
e. What type of test should I use to assess the water quality of my ecosystem?
f. What factors do I think will influence water quality?

Exploration:

A. Students will research river systems:
a. They will design and construct a simple river system. Includes a rifle and a pool
b. The river system will provide a opportunity for the students to observe how pH, temperature and DO influence water quality.
c. Students will use water quality sensors, probes or kits to collect water data and relate it to the health of their ecosystem.
d. Students will monitor their river system overtime to observe and understand how environmental factors affect the quality of their ecosystem.
e. Students will manipulate variables and predict outcomes.

B. Questions which may be used to encourage and/or focus students' exploration :
a. What type of fish would be best suited for the river system model? Why?
b. What type of substrate will be best suited for our river system? How does the velocity of the water affect the type of substrate?
c. If you were hired to assess the water quality of a stream what steps would you take?
d. How will the number of fish affect the water quality of your system?

Explanation:

A. Use at least 2 higher order thinking questions to solicit STUDENT explanations and help them to justify their explanations. Students will use charts and table to show the data they have collected.

a. What impact do the environmental factors monitored have on an aquatic system? Students will construct a graph of data showing changes in pH, DO, temperature and flow rate over time.

b. How do the abiotic and biotic factors influence the water quality of the system?

c. Using the graphs the students constructed, what were some of the factors that influenced the data collected?

d. How does water quality in a stream impact you, your community, the state and the Gulf of Mexico?

Elaboration:

A. Students will develop a more sophisticated understanding of the concept through the following activities:

a. Students will research river systems, design and build a river system in the classroom and collect water quality data.

b. Students will change variables (number and kinds of fish, substrate, flow of water, and temperature) and predict outcomes.

B. Scientific terminology to be introduced to connect to students' observations.

a. Water quality
b. pH, temperature, DO
c. river system
d. Rate of flow
e. Watershed
f. Rifle, pool, substrate
g. effluent

C. Application of this scientific knowledge in our daily lives:

a. How does your water use affect local river systems?

b. Once you have used the water, what has to be done so that it can be returned to the river?

c. Explain how testing the water can help identify water issues within our watershed? What benefits to our watershed would be obtained by studying water quality?

Evaluation:

How will students demonstrate that they have achieved the lesson objective?

a. Build a working river ecosystem model.
b. Keep a detailed lab journal with pictures, drawings and recorded data.
c. Complete a formal lab report that include graphs and charts of the data and conclusion that will reflect the student's interpretation of the data.
d. Students will present their project to the class

Appendix C

Student Activity: Monitoring water quality in a River System

OBJECTIVE:

- To design and build a river system
- To understand the biotic and abiotic factors that influence water quality in a river system such as: pH, DO, and temperature
- To understand how a watershed can be affected by environmental factors such as: climate change and point source and non-point source pollution
- To predict what human behaviors effect a river system and what changes need to be made to protect our water sources.

Materials:

River System Set Up

- Four plastic tubs
- Gravel and water
- Three sections of vinyl gutter
- Plastic tubing to fit pump fittings
- Water pump
- Marine waterproof epoxy, water-proof tape
- Fish and Plants

Water Quality

- Water conditioner
- Sensors, Probes or water quality kits to measure: temperature, pH, dissolved oxygen(DO)
- Water sample cups

River system materials required

- Four 20-quart plastic tubs
- Three 2ft. lengths of vinyl gutter
- Two- 3ft. long pieces of plastic tubing
- Submersible pump (300 GPM)
- Fish, Water, Plants, food and Gravel
- Scissors for cut plastic and Gutter

In this activity you will:

- Set up a river system:
- Use sensors, probes or water quality kits to monitor water quality conditions: temperature, pH, and DO over a two week period
- Manipulate factors that could affect water quality such as temperature, number of fish and plants, pollutants
- Compare the results of the data collected to determine how the river system was affected by the manipulated factors
- Maintain a journal and record water quality data

Introduction:

River System:

Every river is part of a larger system-a watershed. Rivers are large natural streams of water flowing in channels and emptying into larger bodies of water. The **river source** is

the beginning of a river. A **tributary** is a smaller stream or river that joins a larger or main river. A **floodplain** is relatively flat land stretching from either side of a river. Built of materials deposited by a river, it often is rich in nutrients. A **meander** is a loop in a river channel. **Upstream** is in the direction of the source of the river. **Downstream** is in the direction of the mouth of the river.
Adapted from:
http://www.ccge.org/resources/learning_centre/classroom_activities/river_system.asp

Watersheds
A watershed is defined as an area of land
that drains to a common stream. This water (runoff) carries with it sediment (soil) and other suspended and dissolved materials. The type and amount of these materials are dictated by land uses within each area of the watershed. Watersheds range from largest river basins to smaller stream.

Energy and Food Webs
Energy cycles into, through and out of an ecosystem via plants and animals living in it. In an unshaded river or stream, the sun's energy is added to the ecosystem when aquatic plants photosynthesize. In a shaded stream, the sun's energy enters the ecosystem when leaves from overhanging trees drop into the water. In both cases, plants capture the sun's energy and convert it to a form that aquatic animals can use. energy can leave the aquatic ecosystem as well.

Aquatic Macro-invertebrates

Some aquatics macro-invertebrates, such as clams, are adapted to the quiet pools and lentic (slow-moving) areas of the streams. Most stream macro-invertebrates are benthic (bottom dwelling) and are accustomed to crawling on or attaching to the river bottom. Most benthic macro-invertebrates (BMI) live on and under rocks, logs, roots and other suitable substrates. They are adapted to swiftly moving water. They are also an important food source for your fish.

BMIs as Water Quality Indicators

Stream ecologists can determine the quality of a stream by sampling BMIs from stream bottoms. Most species must have clean water to live.

Ecologists can compare BMI samples from a given stream to those from a similar, clean reference stream. By knowing the water quality and habitat needs of macro-invertebrates, people can use BMIs to determine if a stream has recently been impacted by pollution or habitat disturbance. Bio-assessment can also be used to monitor a stream over time. This is an inexpensive way to assess water quality so that an informed decision can be made on where to spend the money. Sensors are good indicators but only measure what you test. If a problem has been identifies then they can run a more expensive and complete set of tests. Water quality is a snapshot of the river system and monitoring overtime gives us trends and a more complete picture.

Runoff

Creeks in urban areas are vulnerable to impacts of urban runoff. Chemical contaminants can be toxic to aquatic organisms, such as; algae, macro-invertebrates and fish. Without macro-invertebrates, fish have no food. Whether impacts are from chemical toxicity, sediment, urban runoff dramatically alters the food web, ultimately causing collapse of the stream ecosystem.

The Role of Chemical Analysis

Chemical analysis seeks to identify the concentrations of selected chemicals found in the water. By testing such factors as pH, dissolved oxygen, temperature and conductivity, ecologists can assess a stream's health.

Preventing Pollution

Education can go a long way toward improving runoff quality. Some examples:

- Cleaning up trash along streams
- Stenciling storm drains with "No Dumping Flows to River"
- Removing invasive, non-native plants from stream corridors
- Conducting water quality monitoring of local streams
- Reporting illegal dumping into storm drains or creeks

Procedure:

A. River System Set Up

1. Cut gutter in three two ft. sections, cut notches in your plastic tubs to fit gutter. You will cut notches in tubs to account for a 1" gradient from tub 1 to 2 to 3 and 3 to 4. So each notch will be 1" deeper. Epoxy the gutter in the notches in the tubs. Let dry and test for leaks. Use the waterproof tape to seal any leaks.
2. Cut the plastic tubing to fit the pump and to go from tub 1 to tub four.
3. Clean gravel and put gravel in the riffles and the tubs(at least three inches in tubs)
4. Fill tubs with water using tub 4 as a gauge to see it doesn't overflow.
5. Add air pump with tubing to provide air and circulation for your system.
6. Condition the water and introduce fish and plants to your system
7. Monitor water quality and use this as your base line.
8. Monitor water quality on Monday, Wednesday and Friday. Record your data and the factors that were manipulated.

B. Water Quality Journal

Quantitative Data:

1. Set up data tables in your journal- one for water quality (a column for each water condition measured) and one for manipulated factor.
2. Take initial water samples and test for pH, temperature, and DO.
3. Take initial data on fish (number, length and which tank they are in)
4. Feed fish regularly and take water quality data.
5. When changes an environmental factor take readings ad record data.
6. Graph your data

Qualitative Data:

1. Set up an observation section in your journal.
2. Record daily activities and all steps taken when working with system.
3. Record your observations on your river system(water, fish , plant condition).
4. Record all daily observations in your journal.

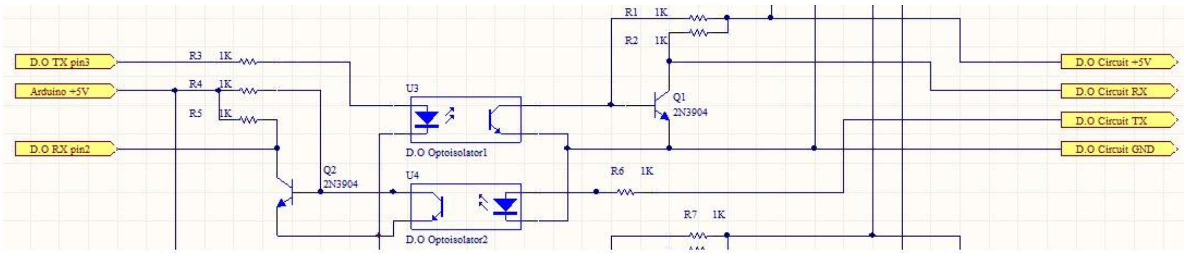
C. Graphs:

1. Compare temperature, pH and DO over time
2. Compare fish population over time.
3. Compare how water quality changed as environmental factors changed.
4. Interpret each data graph and relate it to your overall data set

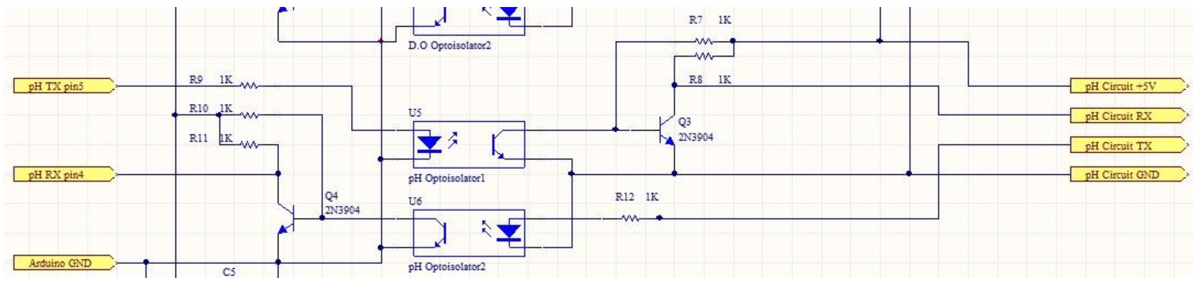
D. Assessment Questions:

1. Describe your river system set up. Explain why this particular set-up could be used to measure water quality.
2. List the water quality tests you used to assess your river system. Explain the purpose of each test and how it relates to the river system.
3. How does the number of fish affect the water quality of the river system?
4. How does changing the temperature affect the water quality of the river system?
5. Why does pH and DO change in the river system?
6. Which factors you tested do you feel are most important to water quality in a river system?
7. What human behaviors have the greatest detrimental effect on your watershed? How can stream monitoring help predict environmental issues?

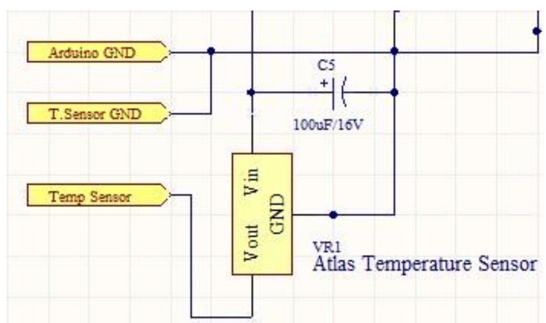
Appendix D



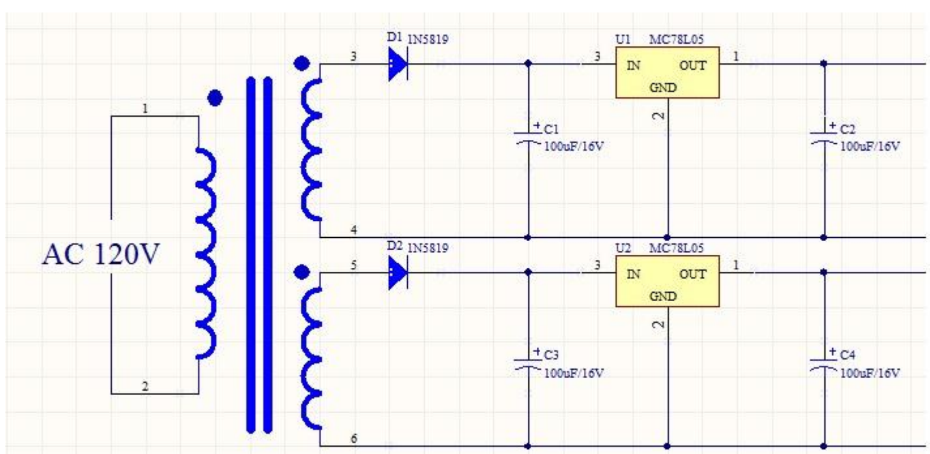
DO Circuit



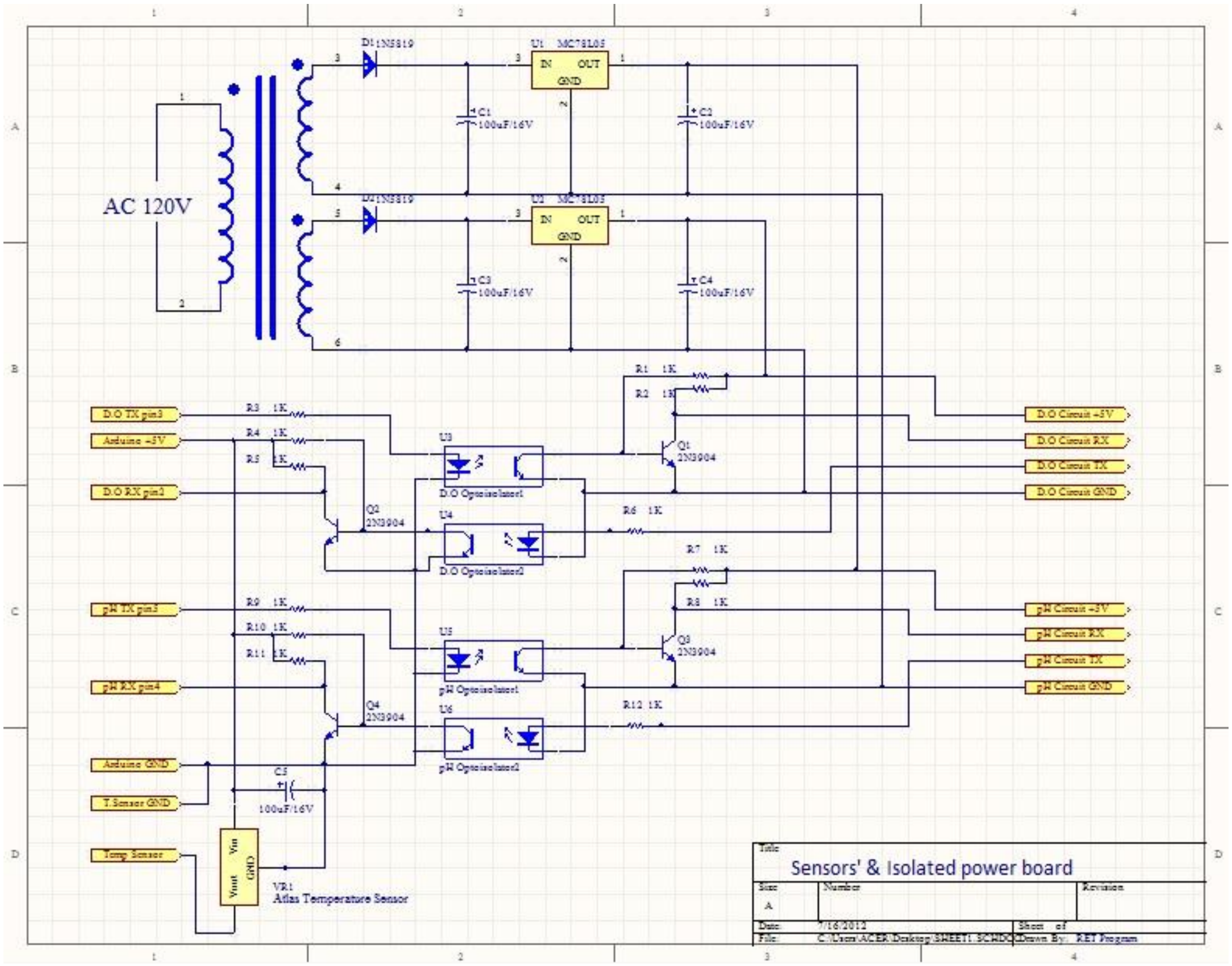
pH Circuit



Temperature Circuit

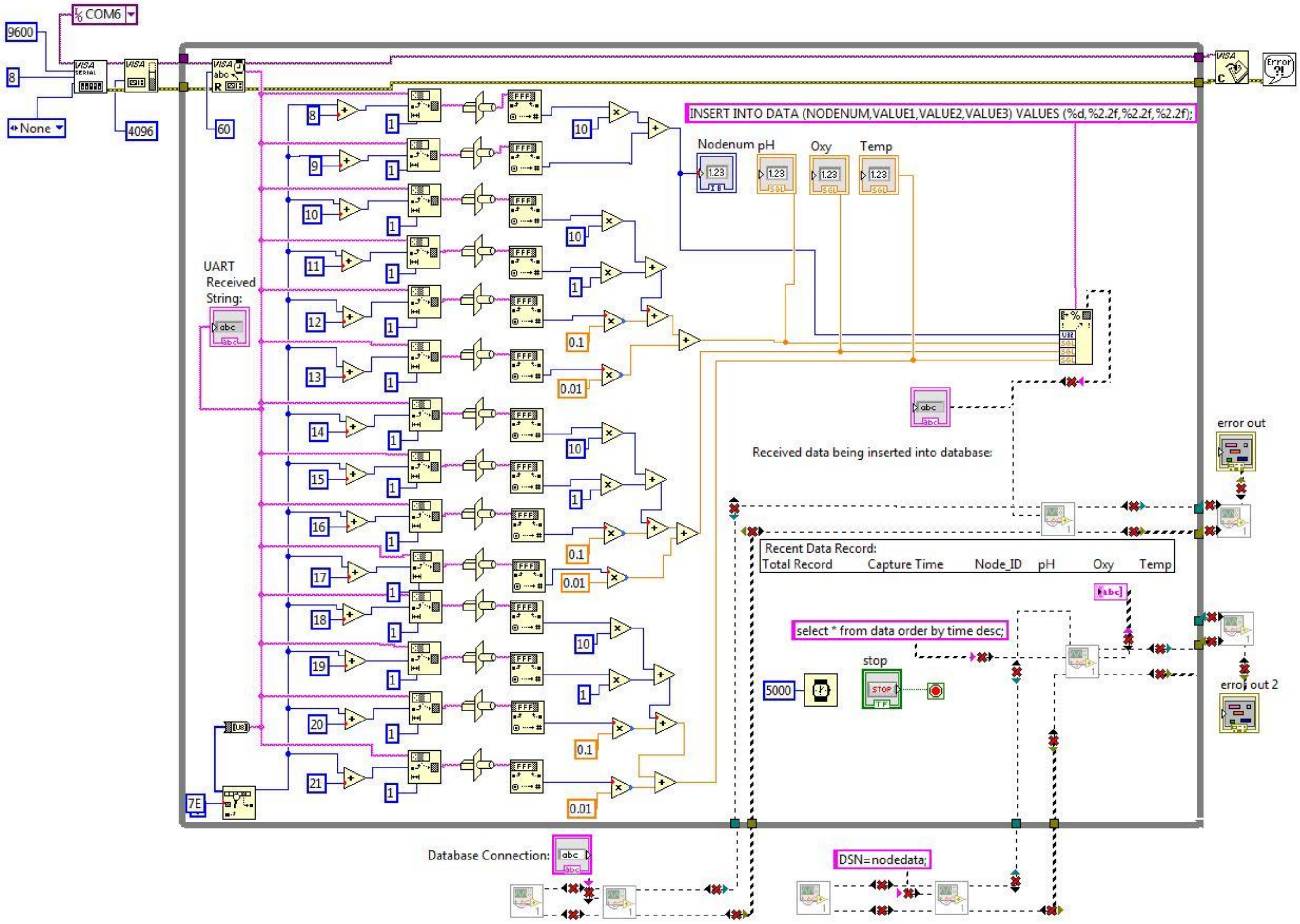


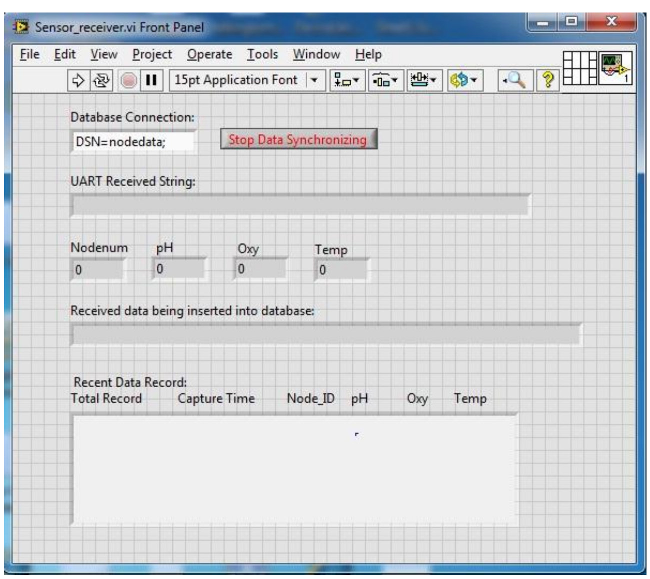
Power Circuit



Complete Circuit

Appendix E


COM6
9600
8
None
4096
60
INSERT INTO DATA (NODENUM,VALUE1,VALUE2,VALUE3) VALUES (%d,%2.2f,%2.2f,%2.2f);
Nodenum
pH
Oxy
Temp
UART Received String:
Received data being inserted into database:
error out
Recent Data Record:
Total Record Capture Time Node_ID pH Oxy Temp
select * from data order by time desc;
stop
5000
error out 2
7E
Database Connection:
DSN=nodedata;


Sensor_receiver.vi Front Panel
File Edit View Project Operate Tools Window Help
15pt Application Font
Database Connection:
DSN=nodedata;
Stop Data Synchronizing
UART Received String:
Nodenum
pH
Oxy
Temp
0
0
0
0
Received data being inserted into database:
Recent Data Record:
Total Record Capture Time Node_ID pH Oxy Temp

Appendix F

```
#include    <SoftwareSerial.h>//add the soft serial libray
SoftwareSerial phport(4,5);   //For   pH,   RX   4,   TX   5
SoftwareSerial xcport(2,3);   //For xc, RX 2, TX 3

String sensorstringph ="";    //a string to hold the data from the Atlas Scienti
String sensorstringxc ="";    //a string to hold the data from the Atlas Scienti
boolean sensor_stringcomplete1 =false;  //ph flag that received all the data fr
boolean sensor_stringcomplete2 =false;  //xc flag that received all the data fr
char  buffer[10];
char phbuffer[4];
char xcbuffer[4];
float sensorph;
float sensorxc;
float v_out;
float temp;

void setup(){                          //set up the hardware
  Serial.begin(9600);                  //set baud rate for the hardware serial
  phport.begin(38400);                 //set baud rate for software serial port
  xcport.begin(38400);                 //set baud rate for software serial port
}

void loop(){                          // main code
  delay(1000);                        // delay 1 second
  digitalWrite(A0,LOW);               // open ADC port
  delay(10);                          // wait 10ms for stability
   v_out =analogRead(0);              // read temp sensor from ADC port A0
                          v_out*=.0048;// standard calculation for temp
  v_out*=1000;
     temp=0.0512  *   v_out   -20.5128;// Temperature reading and convert to deg
  String tempcomp = dtostrf(temp,4,2,buffer);// convert numberic temp to string

  delay(1000);
  phport.print(tempcomp);
  phport.print("\r");                  // send read ph command
  phport.listen();                      // begin to receive
  delay(500);                           // wait for data ready
  while (phport.available())           {// accumulate string
    sensorstringph +=(char)phport.read();
  }
 sensorstringph.toCharArray(phbuffer,6);//converts string to array

  delay(1000);                          // send read oxygen content command
  xcport.print(tempcomp);
  xcport.print("\r");
  xcport.listen();
```

```
  delay(500);
  while (xcport.available()) {
    sensorstringxc +=(char)xcport.read();
  }
 sensorstringxc.toCharArray(xcbuffer,6);//converts string to array

  String tpstring = dtostrf(temp*100,4,0,buffer);
  String phstring = dtostrf(atof(phbuffer)*100,4,0,buffer);
  String xcstring = dtostrf(atof(xcbuffer)*100,4,0,buffer);
  String output= phstring + xcstring + tpstring;
 output.replace(" ","0");
  Serial.println("12"+output);
 sensorstringph="";                          // clear varible for next loop
 sensorstringxc="";


}
```

Appendix G

code to create the .asp database

```
<html>


<head>

<meta http-equiv="Content-Type" content="text/html; charset=gb2312">

<meta http-equiv="refresh" content= "30">,

<title>Nodedata-test</title>

</head>

<%

Set Conn=Server.CreateObject("ADODB.Connection")

ConnStr="provider=microsoft.jet.oledb.4.0;data source=" & server.mappath("nodedata.mdb")

Conn.open connstr


set rs=server.CreateObject("adodb.recordset")

sql="select * from data order by time desc"

rs.open sql,conn,1,1

%>

<p align="center"><font face="Candara" size="5">2012 NSF Research Experiences

for Teachers @ UNT</font></p>

<p align="center"><font face="Candara" size="4">---Real-Time Experiment Data---</font></p>


<table align=center border="1" width="680" rowspan=5>

	<tr>

		<td align="center"  width=120><font face="Candara"  size="3">Node-
number</font></td>

		<td align="center" width=120><font face="Candara"  size="3">pH</font></td>
```

```
                    <td align="center" width=120><font face="Candara"  size="3">Oxygen
Content</font></td>
                    <td align="center" width=160><font face="Candara"  size="3">Water Temp</font></td>
                    <td align="center" width=160><font face="Candara"  size="3">Capture
time</font></td>
          </tr>

<%
cot=0
do while not rs.eof
response.write "<tr align=center>"
response.write "<td>"&rs("nodenum")&"</td>"
response.write "<td>"&rs("value1")&"</td>"
response.write "<td>"&rs("value2")&"</td>"
response.write "<td>"&rs("value3")&"</td>"
response.write  "<td>"&rs("time")&"</td></tr>"
cot=cot+1
rs.movenext
loop
%>
</table>
```

code to create graphic representation of data

```
<%
Set Conn=Server.CreateObject("ADODB.Connection")
ConnStr="provider=microsoft.jet.oledb.4.0;data source=" & server.mappath("nodedata.mdb")
Conn.open connstr

set rs=server.CreateObject("adodb.recordset")
sql="select * from data order by time"
rs.open sql,conn,1,1

%>
<html>
  <head>
    <script type="text/javascript" src="https://www.google.com/jsapi"></script>
    <script type="text/javascript">
          google.load("visualization", "1", {packages:["corechart"]});
          google.setOnLoadCallback(drawChart);
          function drawChart() {
          var data = google.visualization.arrayToDataTable([
          ['Time', 'pH', 'D.O','temp']
        <%
                                do while not rs.eof
            response.write ",['"
          response.write rs("time")
          response.write "',"
          response.write rs("value1")
```

```
response.write ","
response.write rs("value2")
response.write ","
response.write rs("value3")
response.write "]"
//response.write "</br>"
rs.movenext
loop
                                        %>
 ]);

  var options = {
   title: 'RET Project History Sensor Records:'
      };

                                        var chart = new
google.visualization.LineChart(document.getElementById('chart_div'));
   chart.draw(data, options);
     }
   </script>
    </head>
    <body>    <div id="chart_div" style="width: 900px; height: 500px;"></div>
     </body>
      </html>
```