NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Shallow Groundwater Monitoring Well at the Flagstaff Arboretum

User's Manual

Northern Arizona University
S San Francisco St.
Flagstaff, AZ 86011

In partnership with:

The Flagstaff Arboretum
4001 S Woody Mountain Rd.
Flagstaff, AZ 86001

Table of Contents

List of Figures

List of Tables

Abstract

This project involves designing and building multiple components for a pilot groundwater monitoring well in Northern Arizona. The goal is to acquire data to analyze the effect climate change has on the surrounding ecosystem. This will be done by outlining the specific components needed for the successful completion of this project. The data collected from the monitoring well is expected to be shared with the Flagstaff Arboretum and community members. This research will show the impacts of climate change to researchers, community members, and policy makers.

Acknowledgements

The team would like to thank the following:

- Dianne McDonnell- Technical Adviser
- Arboretum- Client
- Kristin Haskins- Arboretum Liaison
- NAU School of Informatics, Computing and Cyber Systems (SICCS)

1.0 Introduction

This project involves designing and building multiple components for a pilot groundwater monitoring well in Northern Arizona. The goal is to acquire data to analyze the effect climate change has on the surrounding environment within a shallow aquifer location. Future groundwater monitoring efforts require a design with static water level measurements, therefore installing a protocol for implementing monitoring wells will aim to be easily re-created by other interested parties. The well implementation will take place in a riparian zone which will be informative on the aspects of climate change and how the groundwater can be affected due to the riparian conditions near the well. The water table will vary compared to non-riparian zones.

1.1 Project Purpose

Future groundwater monitoring efforts require a monitoring well design with static water level measurements, therefore installing a protocol for implementing monitoring wells will aim to be easily re-created by other interested parties.

The warmer temperatures due to climate changes increase the water stress demands on trees and may account for greater mortality amongst them. This could account for the greater intraspecific competition for limited water, beetle infestations, and associated pathogens as well [1].

There is a wide variety of evidence on the ecological impacts of recent climate change, from various environments, like ponderosa, mixed conifer and desert climates, amongst others. The responses of both flora and fauna span an array of ecosystems and organizational hierarchies, from the species to the community levels. Although we are only at an early stage in the projected trends of global warming, ecological responses to recent climate change are already clearly visible [2].

The processes described within this manual are designed to explain how to design and build a groundwater monitoring well, along with data collection processes. The location of the pilot groundwater monitoring program performed by the NAU Arboretum Capstone team is located at the Flagstaff Arboretum.

1.2 Background

The monitoring well can be implemented in a shallow aquifer which will most likely be unconfined. The well implementation will take place in a riparian zone, which is the interface between land and a river or stream [3]. This type of zone is described in Figure 1, which shows the differences between riparian, upland, and aquatic areas in climates like that of the state of Arizona's [4]. Figure 2 shows a riparian area in the City of Flagstaff, AZ located at the Rio de Flag.

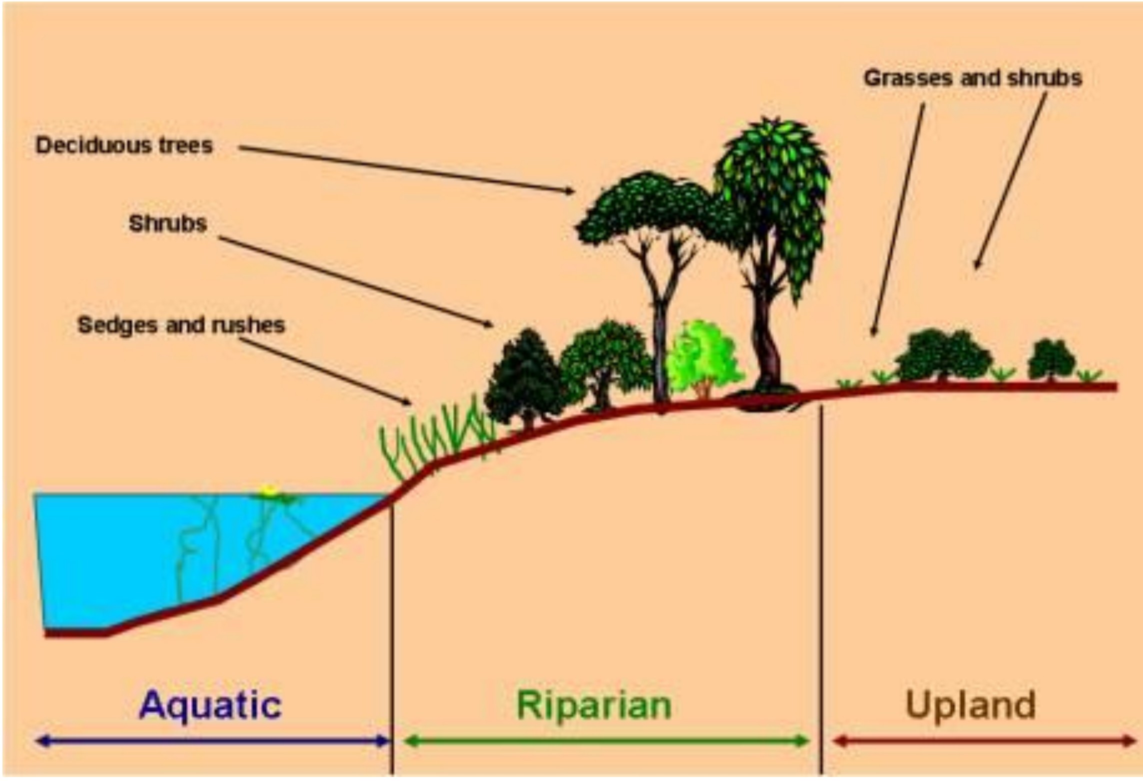


Figure 1: Riparian zone [4]

Figure 2: Rio de Flag, Flagstaff, AZ

In order to complete this project successfully, there are steps that need to be followed to ensure the various tasks required are completed in a timely manner.

2.0 Well Design and Construction

The various tasks that need to be completed for this project are listed as follows:

1. Choose a location
2. Gather all necessary materials
3. Build each necessary component
4. Field work
5. Components implementation
6. Testing
7. Data collection
8. Report findings

Each one of the tasks mentioned above are described in the following sections.

2.1 Choose a Location

As mentioned previously, the location of the monitoring well will be in a riparian location in order to work with a shallow aquifer, therefore making the collection of water samples a simpler process. Figures 3 and 4 show the team's location in an ephemeral wetlands and an unconfined aquifer at the Flagstaff Arboretum, since there was not an opportunity to use a riparian location. An ephemeral wetlands are formed in closed depressions lacking a surface outlet and are wet only seasonally [5], therefore this type of implementation can expect to find water inside the monitoring well during the winter season when the snow melts, and the summer season when monsoons happen.

Figure 3: Well implementation surrounding area, Arboretum constructed ephemeral wetlands

Figure 4: Arboretum team at well implementation location

2.2 Gather all Necessary Materials

In order for the project to be completed successfully, it is important to make sure that all of the materials needed are listed and gathered before starting. The materials needed for the monitoring well along with where to find them are listed in the following sub-sections.

2.2.1 Monitoring Well Components

1) **PVC Pipe**
   Type: Schedule 40
   Diameter: 2 inches
   Length: 10 feet
   This material can be found at a local hardware store
   Ex.: Home Depot, HomCo.
2) **PVC Pipe, Screened**
   Slot size: 0.010 cm
   Diameter: 2 inches
   Length: 2.5 feet
   This material can be found at an online hardware store
   Ex.: EssentialHardware.com
3) **Bentonite**
   Amount: 50 pounds
   This material can be found at a local construction business or herb store.
   Ex.: Winter Sun Herbs
4) **Well cap**
   Material: PVC
   Size: 2 inch
   Quantity: 1
   This material can be found at a local hardware store
   Ex.: Home Depot, Central Arizona Supply.
5) **Well-point**
   Material: PVC
   Size: 2 inch
   Quantity: 1
   This material can be found at an online hardware store
   Ex.: EssentialHardware.com
6) **Silica sand**
   Size: 10-20 micrometers (μm)
   Amount: 100 pounds
   This material can be found at a local hardware store
   Ex.: Home Depot

7) **PVC couplers**
   Size: 2 inch
   Quantity: At least 1*
   This material can be found at a local hardware store
   Ex: Home Depot
   *Based on how many PVC pipes need to be connected

2.2.2 Electrical Components

1) **Arduino UNO Controller**
   Quantity: 1
   This material can be found in an online hardware store and it is used as the microcontroller.
   Ex: Amazon.com
2) **Water Level Sensor (Range: 0-3m)**
   Quantity: 1
   This material can be found in an online hardware store and it is used to collect water depth data.
   Ex: Taobao.com
3) **SanDisk 32GB Ultra Class 10 SDHC UHS-I Memory Card**
   Quantity: 1
   This material can be found in an online hardware store and it is used for data storage.
   Ex: Amazon.com
4) **Virtuabotix SD Card Reader/Writer for Arduino**
   Quantity: 1
   This material can be found in an online hardware store and it is used to develop the function of data storage for Arduino.
   Ex: Amazon.com
5) **DSD TECH HC-06 Wireless Bluetooth Serial Transceiver Support Module Slave and Master Mode For Arduino**
   Quantity: 1
   This material can be found in an online hardware store and it is used to develop the function of data transmission for Arduino.
   Ex: Amazon.com
6) **MB102 Breadboard 830-Point Solderless PCB Bread Board**
   Quantity: 1
   This material can be found in an online hardware store and it is used to expand the ports for Arduino.
   Ex: Amazon.com

7) **Gikfun 9v Battery Holder with ON/OFF Switch for Arduino**
Quantity: 1
This material can be found in an online hardware store and it is used to make the battery portable.
Ex: Amazon.com

8) **Multicolored Dupont Wire**
Quantity: 40
This material can be found in an online hardware store and it is used to do the connection between each electrical part and Arduino.
Ex: Ebay.com

9) **Nine Volts Battery**
Quantity: 1
This material can be found in an online hardware store and it is used as power supply.
Ex: Amazon.com

2.2.3 Tools Needed

1) **3-inch Hand-auger Kit**
This will be used to dig a hole of dimeter of 3 inches and length of approximately 2
meters (6.6 feet). An image of a hand-auger can be seen in Appendix A.

2) **6-inch Hand-auger Kit**
This will be used to dig a hole of dimeter of 6 inches and length of approximately 1 meter (3.3 feet) on top of the first 3-inch hole. An image of a hand-auger can be seen in Appendix A.

3) **Well Pounder**
This will be used to pound the assembled monitoring well into the ground, so it is stable. An image of a pounder can be seen in Appendix B.

4) **Wrench**
This will be used to tighten and/or loosen the hand-auger extensions if needed.

5) **Measuring Tape (~20 feet minimum)**
This will be used for measuring the depth of the holes, so you know when to stop digging.

6) **Laptop with Bluetooth**
This will be used to support the Arduino and Arduino software to program. Also the data and final results will be displayed through the laptop.

7) **Arduino Software**
This will be used to do the coding and test the program.

2.2.4 Cost of Materials

In order to successfully complete the project, the materials mentioned in Chapter 2 needed to be acquired and Table 1 shows each of the materials needed along with their respective costs.

Table 1: Cost Table

Material	Amount	Cost per unit	Total Cost
PVC Pipe (ft)	10	1.63	16.3
PVC Pipe (Screened) (ft)	2.5	8.84	22.1
Bentonite (lbs)	75	0	0
Well Cap	1	0.79	0.79
Well Point	1	8	8
Silica Sand (lbs)	100	0.99	9.97
PVC Coupler*	1	2.18	2.18
Battery Holder	1	10	10
PCB Bread Board	1	5.6	5.6
Bluetooth Module	1	9	9
SD Card Module	2	12	24
32G SD Card	1	14	14
Pressure Transducer	1	18	18
Arduino UNO controller	1	29.9	29.9
Other Expenses:			
Shipping costs			8.95
Overall Cost:			**178.79**

2.3 Build each Necessary Component

Once each of the materials mentioned in the previous sections have been acquired, it is time to start building each of the required components.

For the monitoring well portion of the project, the following steps will help with the assembly of the components.

Step 1) Connect the screened PVC pipe (2.5 ft) with the regular PVC pipe (10 ft) using a coupler.

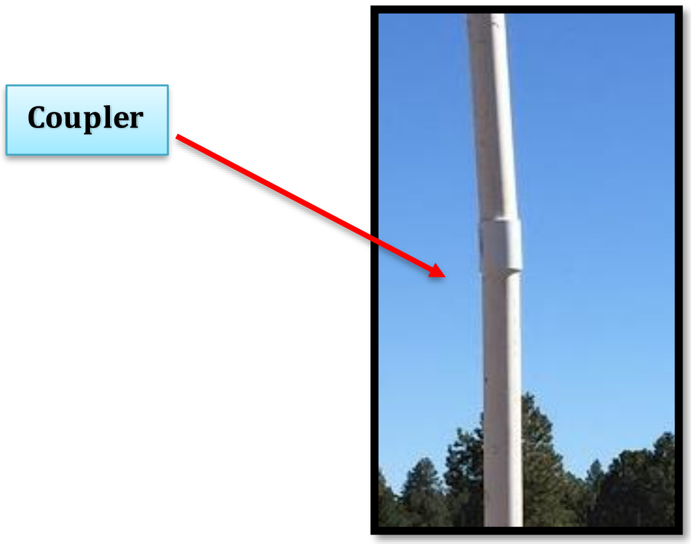


Figure 5: PVC Coupler

Step 2) Insert the well point at the bottom of the open end of the screened PVC pipe.

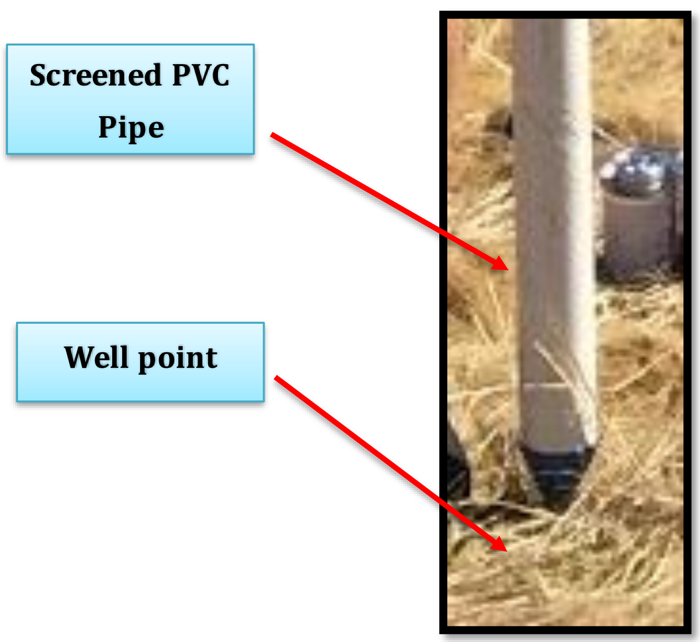


Figure 6: Screened PVC Pipe and Point

Step 3) Use glue if necessary at each of the locations where PVC was connected with couplers.

A completed monitoring well assembly following the steps mentioned above is shown in figure 4.

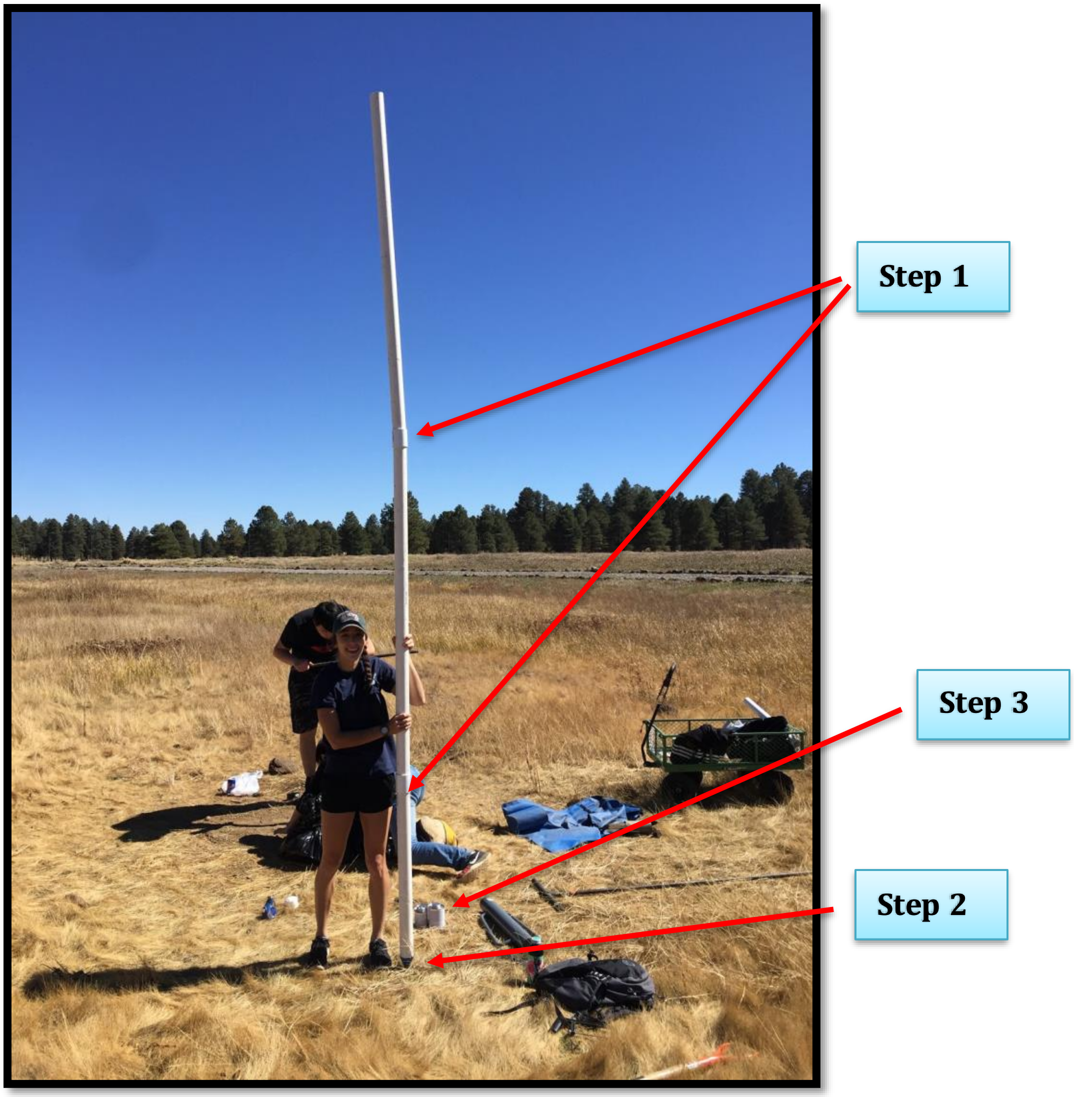


Figure 7: Completed monitoring well assembly

Before build the Water Level Monitoring System, the team needs to prepare and build four electrical components including microcontroller, data collector, data storage and data transmitter.

1) **Microcontroller**

In this manual, microcontroller is arduino UNO controller. Write the code in arduino software then burn the code into arduino UNO controller, so that arduino UNO controller can control water pressure transducer, SD card module and Bluetooth module. This arduino UNO controller is also needed to use multicolored dupont wires to connect with pressure transducer, SD card module and Bluetooth module according to different serial port connection mode.

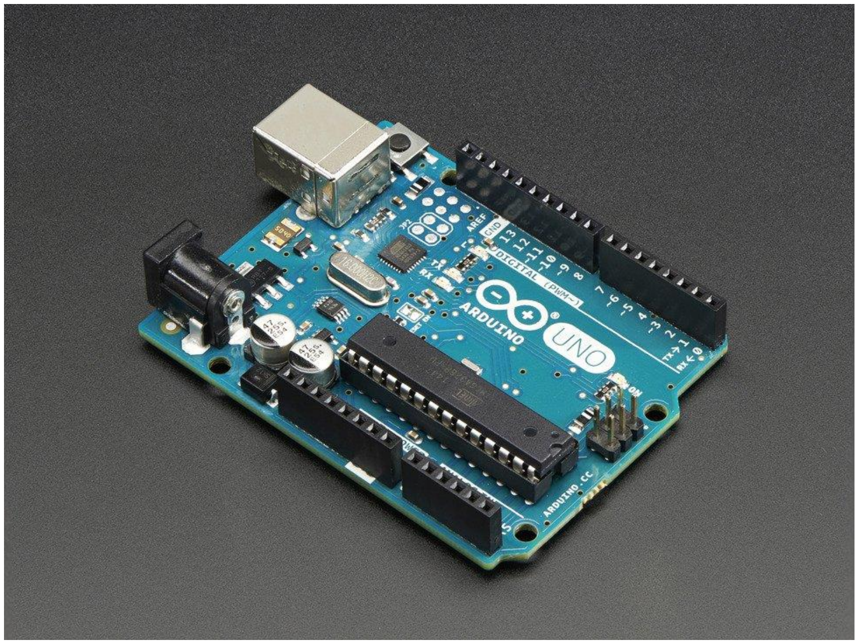


Figure 8: Arduino UNO controller

2) **Data Collector**

The data collector is used to collect the data that in term of water level change from underwater in the monitor well. In this manual, the team customizes a water level sensor with five-meter long three cores' wire. The sensor could detect the water level change from 0 to 3 meters deep depend on our design of the monitoring well. The future teams have other option when customize the similar sensor.

Figure 9: Water level sensor

3) **Data Storage**

The data storage is to store the long-term data that collected by the data collector. All of the data will be saved as text file inside the data storage, so that user can extract long term data from it. In this manual, a SD card module will be implemented with following steps as the component to storage the data. Here we choose the SanDisk 32GB Ultra Class 10 SDHC UHS-I Memory Card and Virtuabotix SD Card Reader/Writer for Arduino as an example.

Step 1) Plug in the SD card into the SD card shelter as a SD card module.
Step 2) Insert the pins that on the SD card module into the PCB bread board.

Step 3) Insert one terminal of Dupont wire into the PCB bread board and correspond to the pins on the SD card module to prepare for the implement of the whole system.

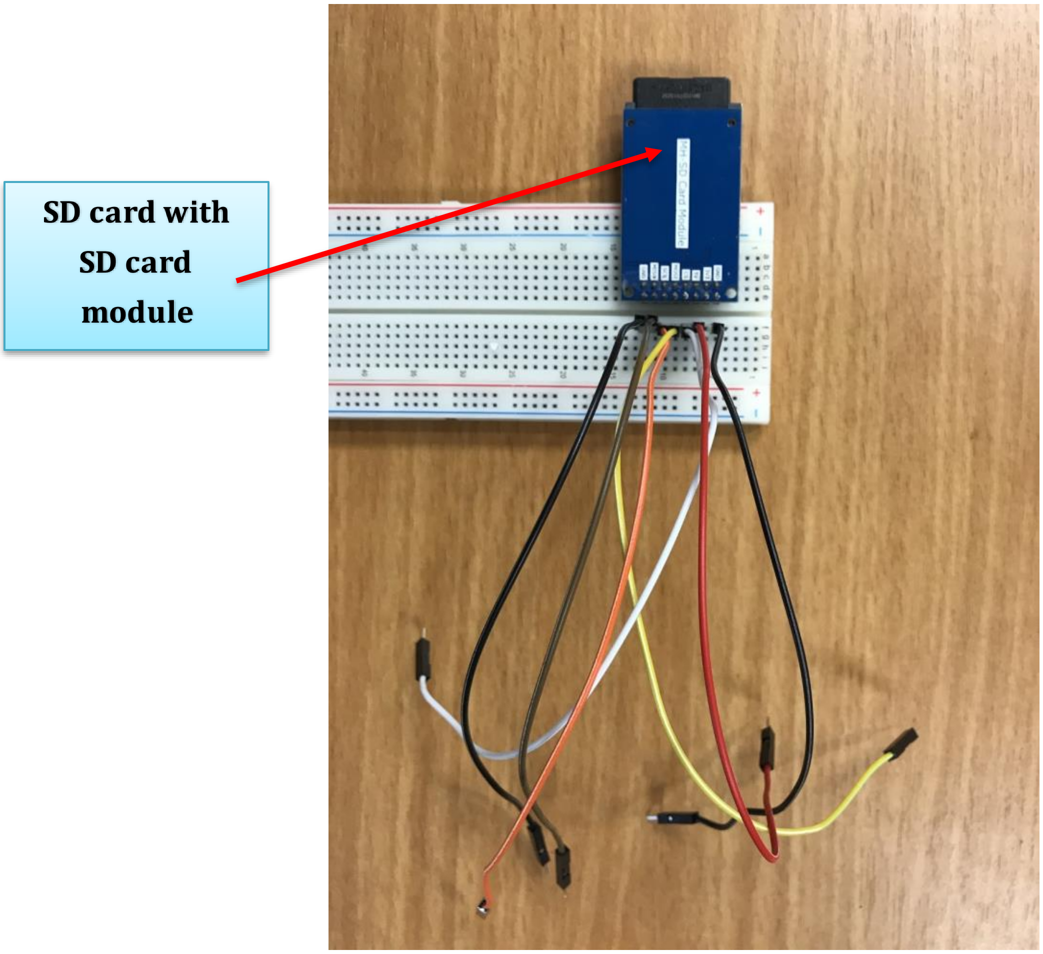


Figure 10: Insert SD card into SD card module with correct wire connection

4) Data Transmitter

The data transmitter is to transfer the data from the SD card to the monitor on the laptop wirelessly. In this manual, the HC-06 Wireless Bluetooth will be used as the transmitter module. Following steps will help to build the data transmitter.

Step 1) Insert the pins that on the Bluetooth module into the PCB bread board. Make sure the pins are using different electrical route than the route used for the data storage.

Step 2) Insert one of the terminal of Dupont wire into the PCB bread board and correspond to the pins on the Bluetooth module.

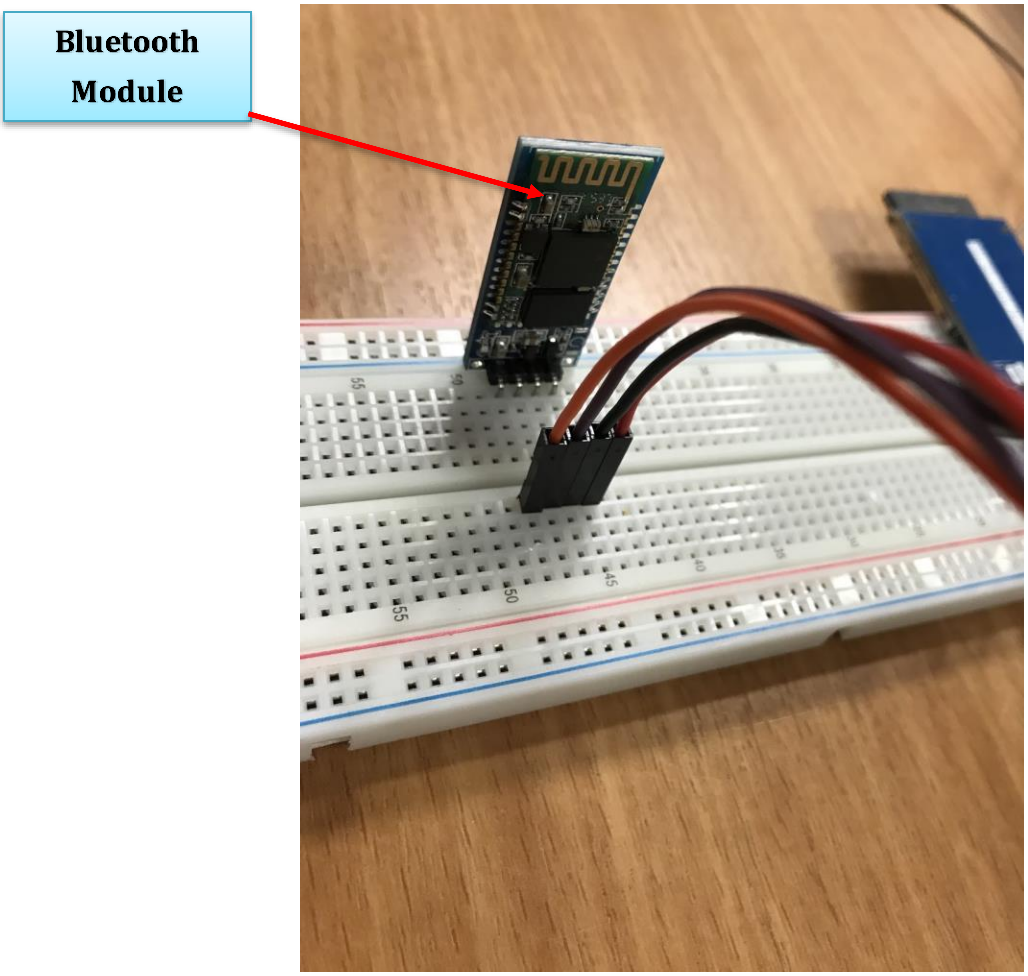


Figure 11: Insert Bluetooth module with correct wire connection

2.4 Well Design and Construction Process

2.4.1 Well Design

The design of the well followed the design presented in the Bosque Ecosystem Monitoring Program, Rio Grande Project [6]. Figure 12 shows a detailed well design.

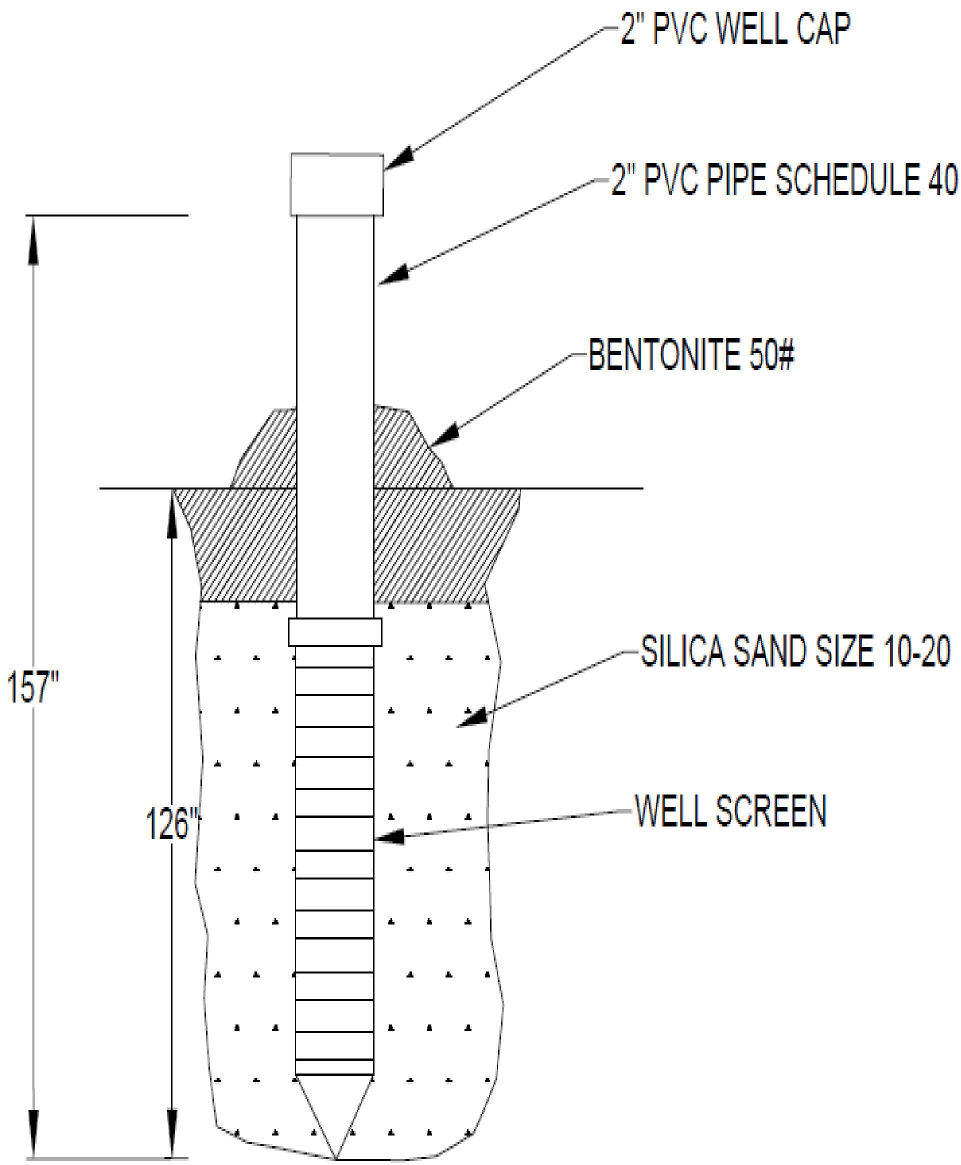


Figure 12: Well Design

2.4.2 Construction Process

The team started to acquire the components needed to build and install the monitoring well. Before assembling the components, the team used a 3-inches hand auger to dig a 3 meters hole. While auguring, soil samples were collected to have them tested to identify the soil horizons, and soil type. Figure 13 shows team members taking turns when using the 3-inches hand augur.

Figure 13: Team members using hand augers for monitoring well hole

The team also augured ¾ meter hole into the existing 3 meters hole using a 6-inches auger. The team used the 6-inches hand augur only to have enough annular space for Bentonite, which is a sort of clay the team used for sealing. Also, Bentonite expands when it gets wet, and that will help in avoiding any contaminants entering the hole. Figure 14 shows a team member using the 6-inches hand auger.

Figure 14: Team member using 6-inches hand auger

The team then started with assembling the well components, which includes PVC pipes, a well screen, PVC Primer and Cement, a well cap, and PVC slip couplers. Both of the PVC Primer and Cement, and the PVC slip couplers were used for some joint connections and to join pipes as needed. Figure 15 shows the acquired monitoring well components.

Figure 15: Monitoring well components

The next step was to input the monitoring well into the augured hole. After inputting the monitoring well into the augured hole, the team used a pounder to pound the assembled monitoring well into the ground, so it is stable. Then, the team started to fill some silica sand into the hole until it reached the top of the well screen. The team used silica sand, because it filters out any fine materials that might accumulate in the well. The last step was to have the rest of the annular space provided to be filled with Bentonite, and cap the well temporarily. The team tried to pack the well tight with Bentonite, so it will be difficult to spin by hand [8]. Figure 16 shows the packed monitoring well.

Figure 16: Packing the monitoring well with Bentonite

2.4.3 Electrical system implementation

After acquiring all the electrical components, the team started with assembling the electrical system, which includes the Microcontroller, Data Collector, Data Storage, Data Transmitter and some other components. Following steps will help with the implementation.

Step 1) According to the following table to connect Arduino to water pressure transducer by using multicolored Dupont wire.

Table 2: Complete pin layout for pressure transducer

Arduino	Pressure transducer
A0	Output
5V	5V
GND	GND

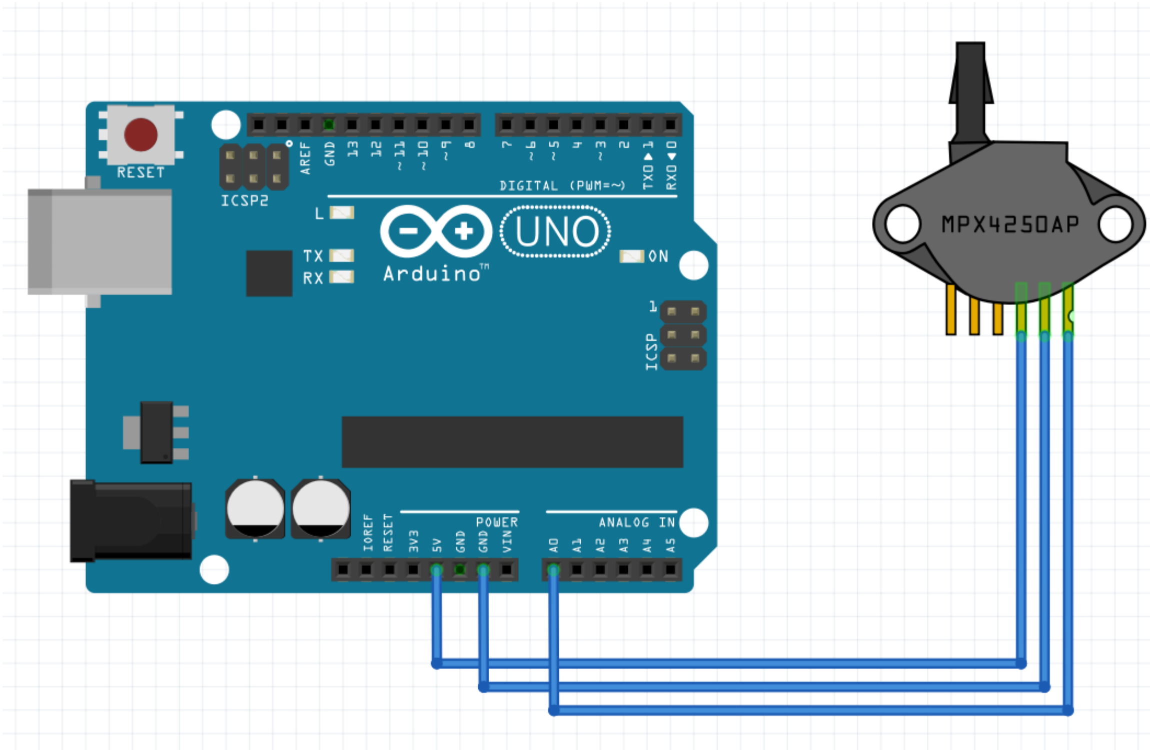


Figure 17: Connect Arduino to water level sensor

Step 2) According to the following table to connect Arduino to corresponding hole of SD card module on the PCB bread board by using multicolored Dupont wire that already on the PCB bread board.

Table 3: Complete pin layout for SD Module

Arduino	SD Module
Pin 4	CS
Pin 11	MOSI
Pin 12	SCK
Pin 13	MISO
GND	GND
5V	5V

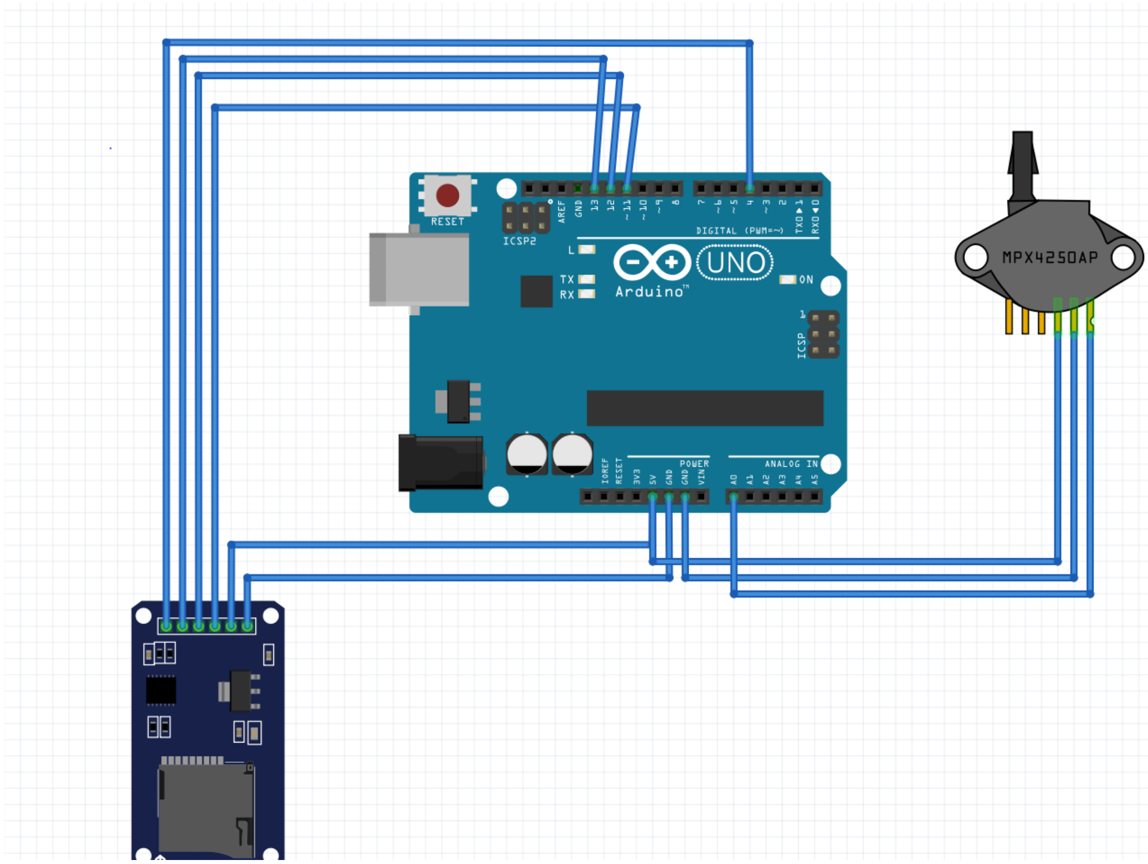


Figure 18: Connect Arduino to corresponding hole of SD card module

Step 3) According to the following table to connect Arduino to corresponding hole of Bluetooth module on the bread board by using multicolored Dupont wire.

Table 4: Complete pin layout for Bluetooth Module

Arduino	Bluetooth Module
RX (Pin 0)	TX
TX (Pin 1)	RX
5V	VCC
GND	GND

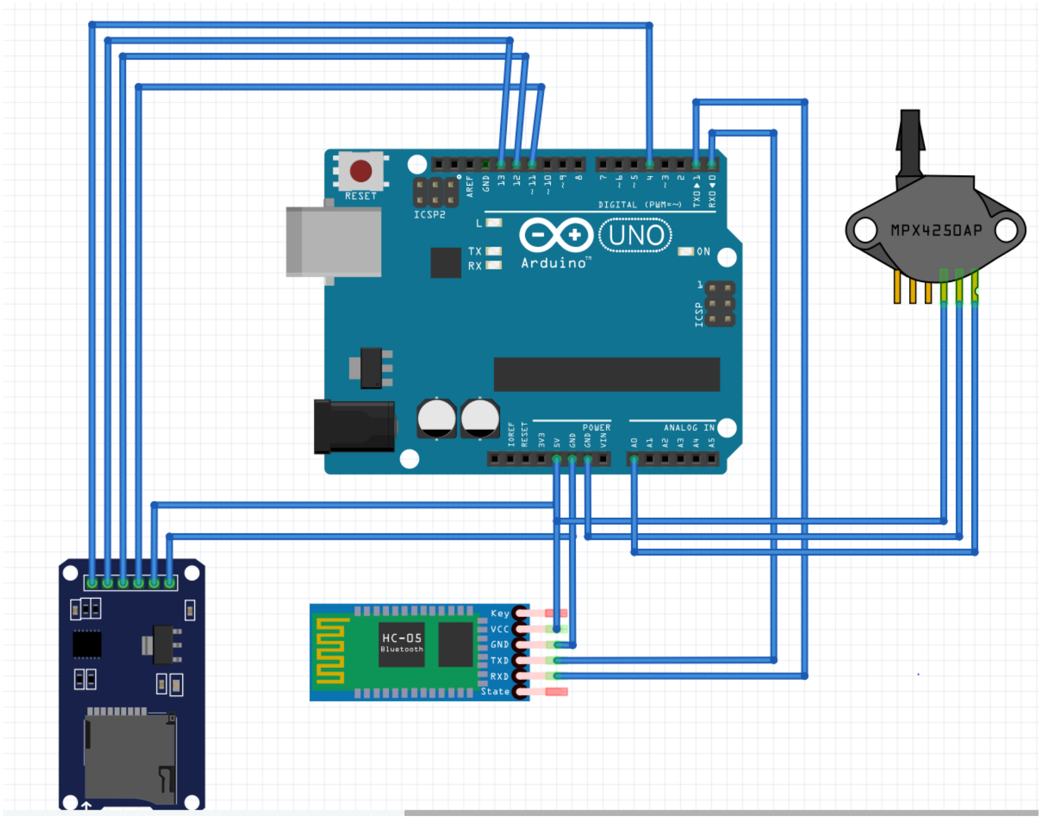


Figure 19: Connect Arduino to corresponding hole of Bluetooth module

Step 4) Insert the battery into the battery holder and connect battery holder to Arduino.

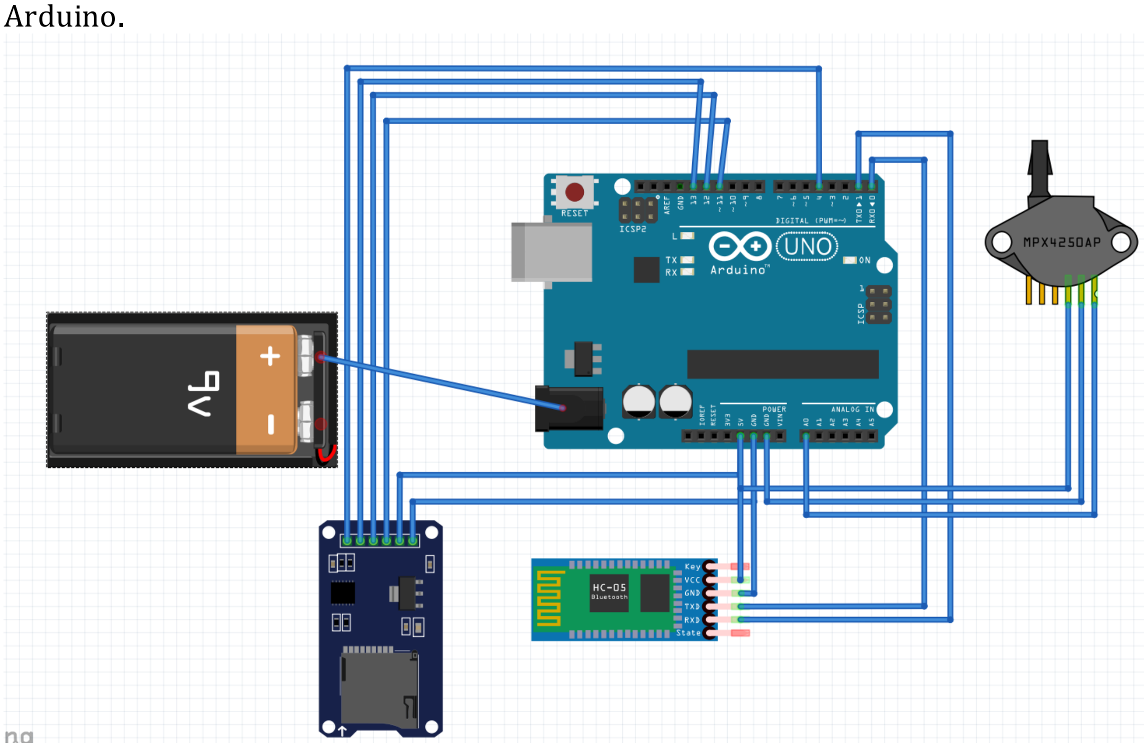


Figure 20: Insert the battery into the battery holder

Figure 21 shows the assembled electrical system. The team used the breadboard to make the connection between each component clearer. The water level sensor showed in above schematic diagrams is not actually the same as the real.

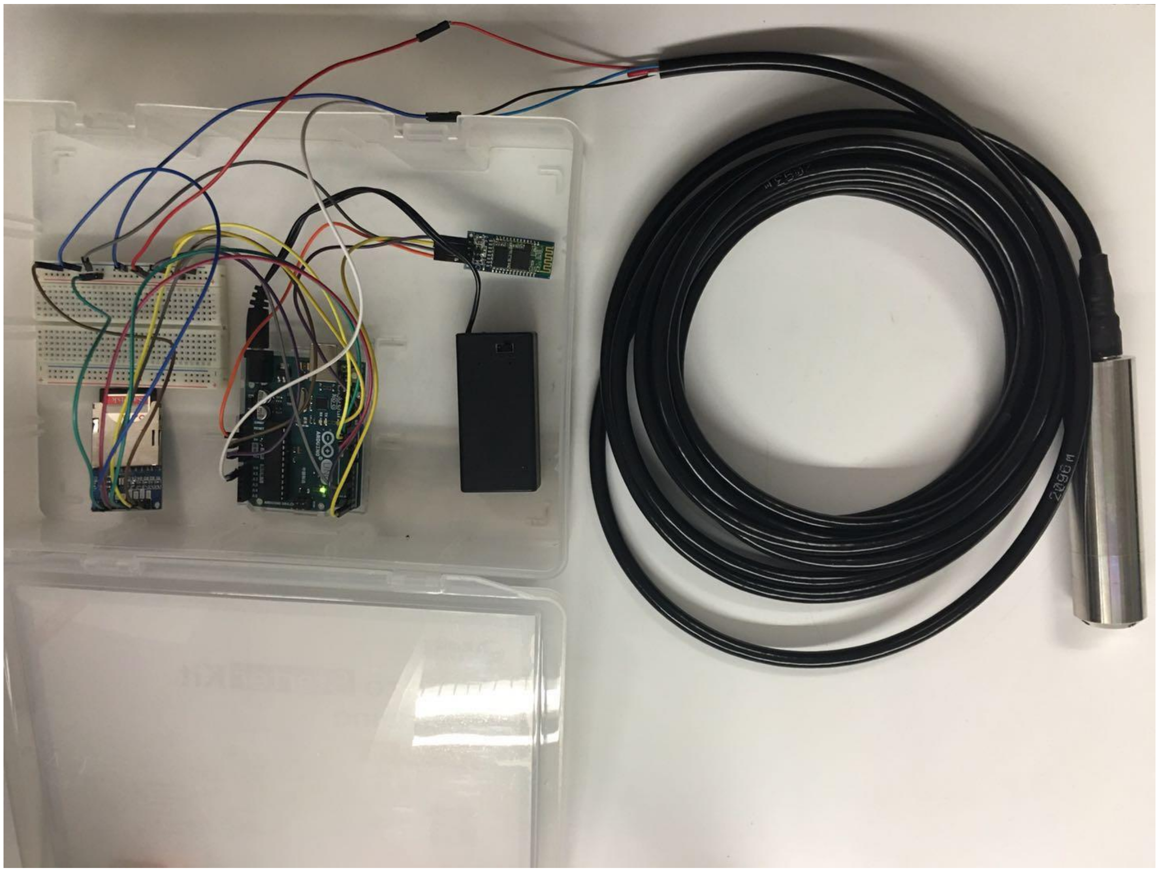


Figure 21: Assembled Electrical System

2.5 Testing

After the successful construction process for each of the components needed for the project, it is necessary to test the components in order to make sure that they are working properly. The testing of the water depth needs to be conducted after the components are determined to be working properly in order to be able to collect data. This also includes the testing of the soil sample acquired from the monitoring well implementation site. These testing processes are described in Sections 3.0 and 4.0, respectively.

2.6 Data Analysis

Once the necessary testing has been completed, data collection and analysis can be conducted in order to be able to report the findings. This includes using the methods described in Sections 3.0 and 4.0 to be able to determine the soil types collected from the well implementation site and the water depth change with respect to time.

2.7 Report Findings

Once the data analysis portion has been completed, it is necessary to report the findings acquired, along with any procedures if required. The team's findings from the data analysis are shown in Sections 3.0 and 4.0. The processes for the successful completion of a project like that of the Arboretum's team is shown throughout this user's manual.

3.0 Soil Samples

In order to determine the type of soil found when excavating monitoring well location, a soil texture analysis must be conducted. The materials needed in order to conduct this analysis are:

- A marking pen
- Mason jars with caps equal to the number of soil samples acquired
- Minimum of 10 sealable plastic bags
- Access to water

The following process can be followed in order to acquire the soil samples.

1) Mark each bag with a description in order to differentiate
2) Check soil samples every time after emptying auger for soil color change
3) When soil color change is detected, write the length at which it was acquired on the specified bag

This process is shown in figure 22.

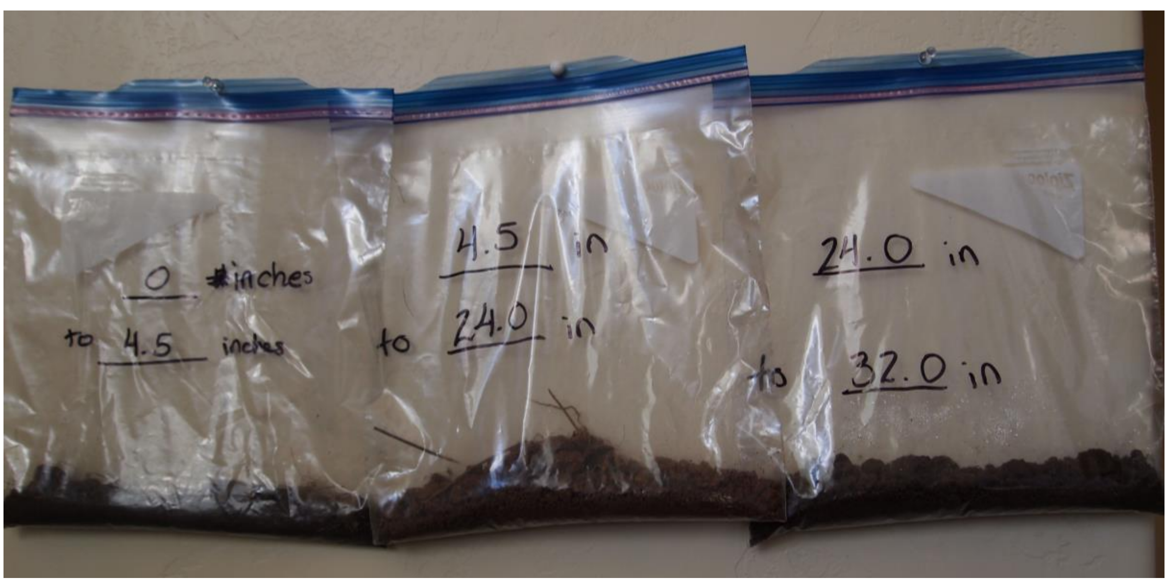


Figure 22: Bags with soil samples and descriptions of lengths at which they were found

Before starting the testing procedure, it is necessary to set up like it is shown in Figure 23.

Figure 23: Soil testing set up

After the set-up process, it is necessary to follow the procedure outlined below:

1) Fill mason jar to halfway point with the soil sample (or use all if you have less soil) (see figure 24)
2) Fill mason jar with enough water to make soil into a mud-type consistency (see figure 25)
3) Let soil settle for 30 seconds and mark jar with a line where the soil sits (see figure 26)
4) Fill the rest of the jar with water and cover with lid (see figure 27)
5) Shake the jar for a minimum of 60 seconds
6) Let jar sit in a place where it can be undisturbed for a period of 48 hours (see figure 28)

Figure 24: Mason jar filled with soil sample to be tested

Figure 25: Jar filling with water for mud-type consistency

Figure 26: Jar marked after 30-second settling

Figure 27: Jar filled with water after 30-second settling period

Figure 28: Soil samples in a location where they will be undisturbed for a period of 48 hours

After the soils have been settling for a period of 48 hours, the type of soil can be determined by following the procedure outlined below:

1) Measure the total height of the soil within the jar
   Use a ruler to measure the total height of the soil within the jar, as is shown in figure 29.
2) Measure the height of each discernible soil layer
   Use a ruler to measure the height of each of the layers within the jar, as is shown in figure 29.
3) Use equation 1 to determine the percentage of each soil type
   Once each soil layer height has been determined, divide each layer height by the total height of the soil within the jar and multiply by 100 to acquire a percentage value for each soil layer.
4) Use Soil Texture Pyramid to determine the type of soil acquired
   Use the United States Department of Agriculture (USDA) soil texture pyramid and follow each side to where each percentage meets.
   *Note: It helps to use a ruler to draw a line across the triangle for each one of the sides for silt, clay and sand in order to clearly see where the lines converge- this indicates what soil classification the sample is.

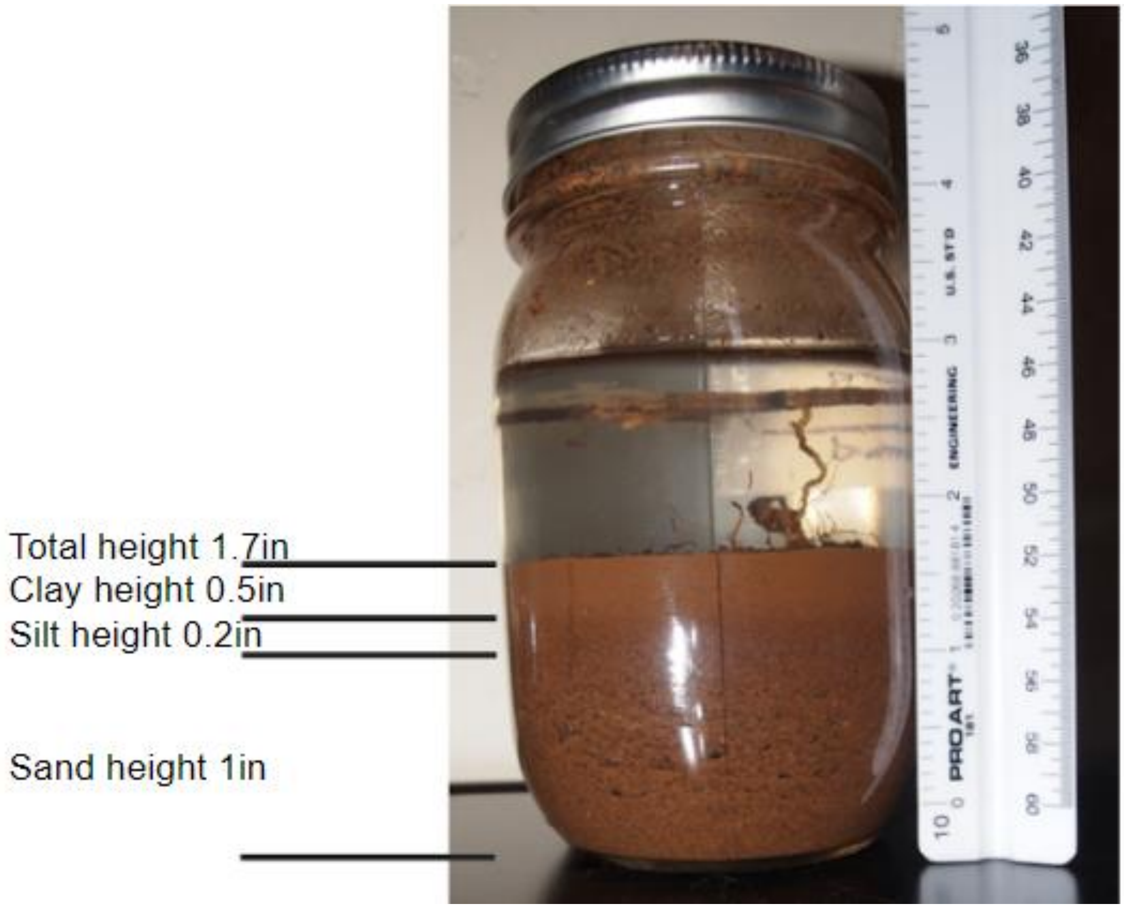


Figure 29: Jar test with soil sample used to determine soil type

Equation 1: Used to determine % sand, % silt and % clay [k2]

$$\frac{Layer\ height}{Total\ height} x100 = \%\ Soil\ of\ Layer$$

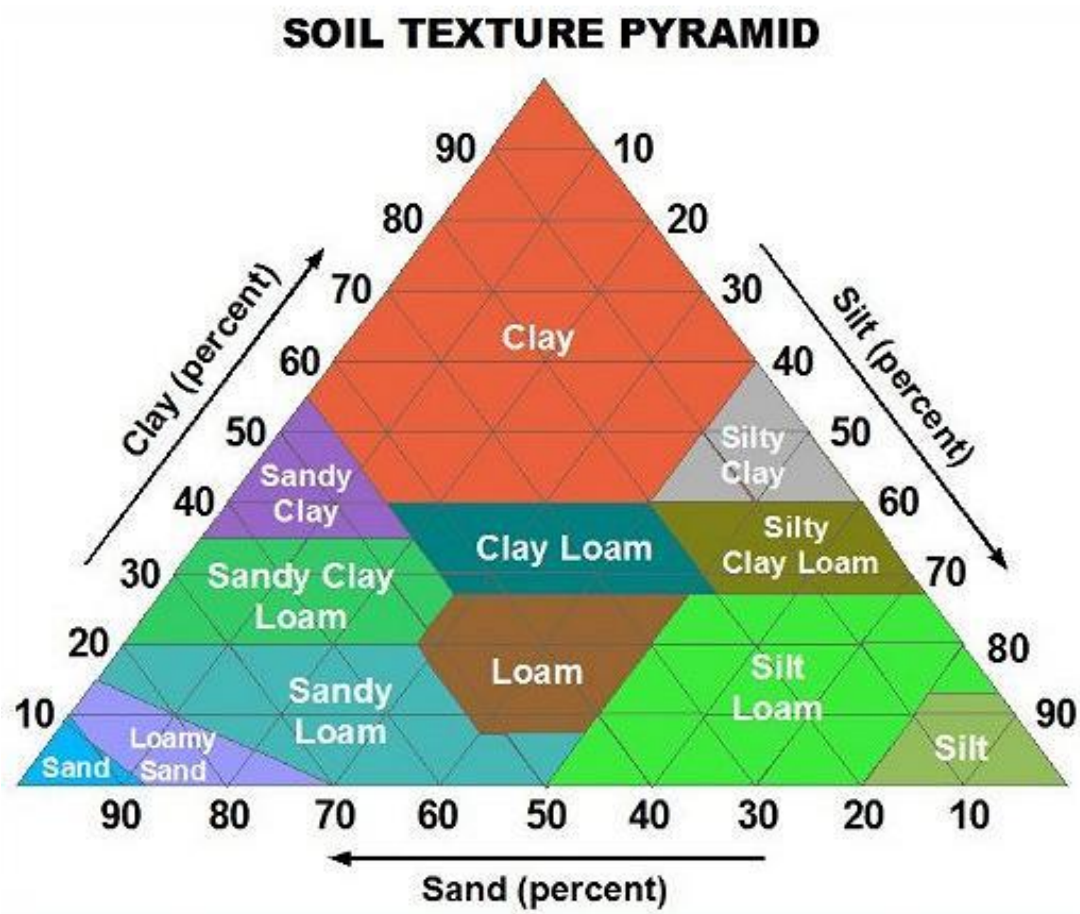


Figure 30: United States Dept. of Agriculture (USDA) Soil Texture Pyramid [7]

After following the steps outlined previously, a table with relevant information for each of the soil types is created in order to keep information organized and classify each of the soil samples acquired from the field testing. These results are shown in Table 5:

Table 5: Soil texture types determined from jar testing

Soil Texture Analysis Results						
Soil Sample	Depth Range (inches)	% Sand	% Silt	% Clay	% Total	Soil Type
1	0 to 4.5	44.4	50	5.6	100	Silt Loam
2	4.5 to 24	58.8	11.8	29.4	100	Sandy Clay Loam
3	24 to 32	50	21.4	28.6	100	Sandy Clay Loam
4	32 to 43	56.3	12.5	31.2	100	Sandy Clay Loam
5	43 to ≥125*	46.7	30	23.3	100	Loam

*Indicates depth at which the team stopped digging

4.0 Electrical Testing

The electrical components testing of the project involved both a simulation process and a data analysis process.

4.1 Simulation

In order to make sure that our monitoring system works under normal condition persistently, the testing of the monitoring system must be carried out repeatedly during the whole process of the project. Since the Arboretum Team hasn't reached any water in the monitoring well in Arboretum Flagstaff, the team decided to do a simulation to prove the function of the monitoring system in the lab. The materials needed in order to implement the simulation are:

- Well assembled monitoring system.
- Laptop with Bluetooth function.
- Arduino software installed.
- Transparent or translucent barrel
- Access to water

Following steps could be followed to do the simulation in the lab.

1) Programming based on C-programming language.
   The programming code for this project showed in figure. The comment for each code is on the right. The codes mainly have three parts involving setup of the program, store the water level data and extract the data. One thing need to mention is that the time period of the detection is one second in this simulation. In order to change the time period, users could edit on line 27 and change the values inside the bracket. The unit for the value is millisecond.

Setup of the program

Store the data

Extract the data

Final_Code §

```
#include <SPI.h>                              // Include the defined function for SD card module.
#include <SD.h>

File mySensorData;                            // Define the file to store the collected data.

void setup()                                  // Set up Arduino UNO controller
{
  Serial.begin(9600);                         // Sets the data rate in bits per second (baud) for serial data transmission.
  pinMode(10,OUTPUT);                         // Sets the pin 10 to be the output pin.
  SD.begin(4);                                // Define the chip selected for SD module.
}

void loop()                                   // Start the loop of the main program.
{ int sensorVal;                              // Define the variable for voltage value collected by the sensor.
  float depth;                                // Define the variable for water depth value.
  mySensorData= SD.open("PTData.txt",FILE_WRITE);  // New or open a file named "PTData" in txt format.
  if (mySensorData)                           // Check if the file is opened.
  {sensorVal=analogRead(A0);                 // Read the voltage value store it in the variable.
    depth= (sensorVal*6.0)/1024.0;            // Transfer the voltage value to water depth value and store it in the variable.
    Serial.print("Sensor Value:");            // Print the real time value on the monitor screen.
    Serial.print(sensorVal);
    Serial.print("Depth = ");
    Serial.print(depth);
    Serial.println(" meters");
    delay(1000);                               // Delay for 1000ms to start next data collection.
    mySensorData.println(depth);               // Store the real time data into the file
    mySensorData.close();                      // Close the file.
  }
  char INBYTE = Serial.read();                 // Define the command to extract the data stored in SD card.
  if( INBYTE == '1' )                          // Check if the command is correct
  {
      mySensorData = SD.open("PTData.txt", FILE_READ);   // Open the file again.
     if (mySensorData)
     {
        Serial.println("PTData.txt:");
        while (mySensorData.available())      // Check is any data is stored.
        {
            Serial.write(mySensorData.read());  // Print all the data stored in SD card.
        }

        mySensorData.close();                 // Close the file.
     }
   }
}
```

2) Fill in the barrel with water till the top.
   Fill the water into the barrel till the top and use the barrel as monitoring well. In the simulation did by Arboretum Team, the full depth of the water is 40cm showed in figure 31.
3) Immerse the water level sensor into the well and pull it up continuously
   Put the water lever sensor into the barrel and pull it up continuously to simulate the groundwater table change. At the same time, the depth value collected by the sensor will be saved in SD card.

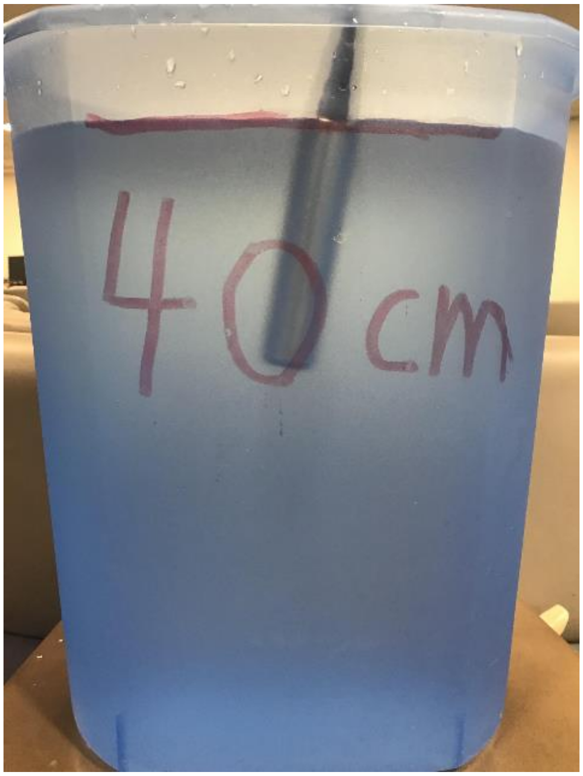


Figure 31: Immerse the water level sensor

4) Connect our device with the laptop via the Bluetooth.

   Input the code "1234" to successfully connect between laptop and Arduino by using Bluetooth module.

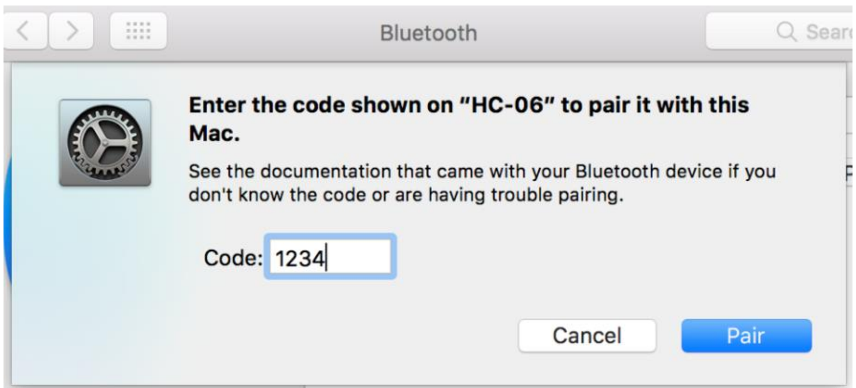


Figure 32: Input the pairing code

Figure 33: Laptop is connected with Arduino

5) Open the serial monitor in the Arduino software and see the real time data. Open the monitor from Arduino software, the real time data shows in it. At the same data, these data will directly save into the SD card based on the coding.

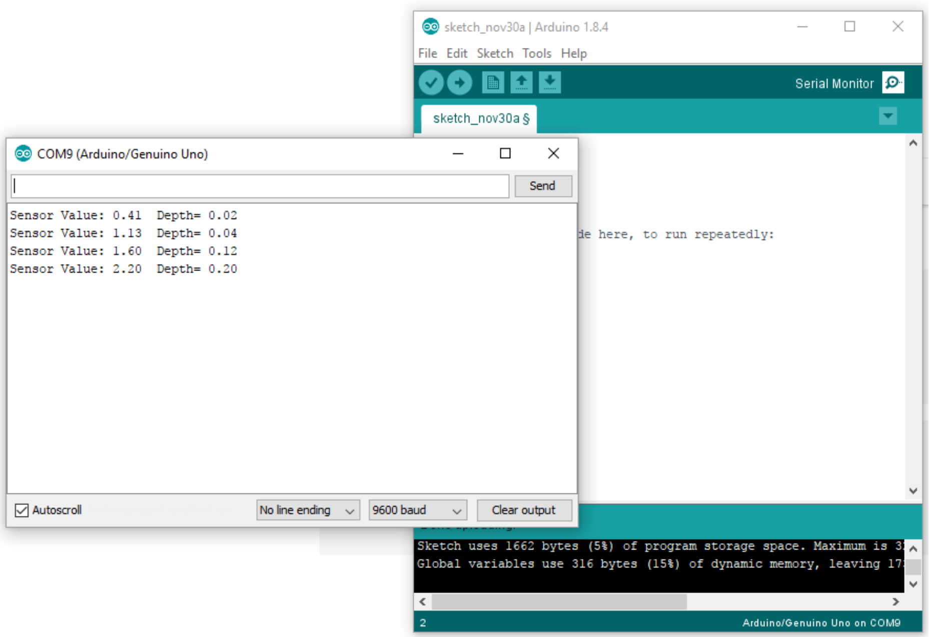


Figure 34: Monitor from Arduino software

6) Input the command code to extract the data stored in SD card. Input the command "1" in the command line at the top of the serial monitor and click send button. The data stored in SD card will appear in the monitor as Figure 35.

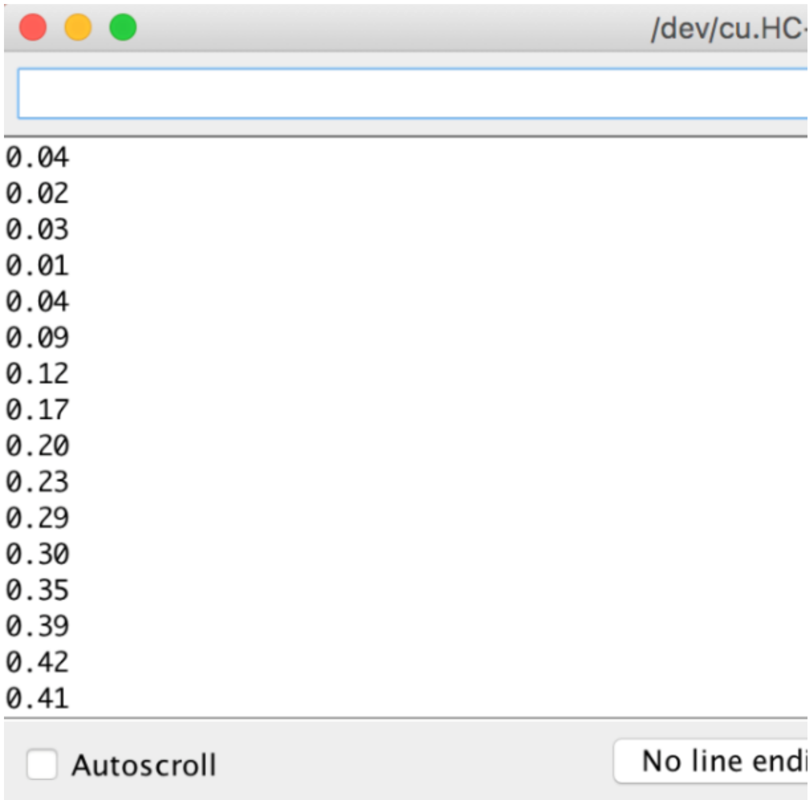


Figure 35: Extract the data stored in SD card

4.2 Data Analysis

Team use Excel to manage and analysis data. Figure 36 is a example what we do in Excel. In this table, it includes data, time of day, groundwater depth, average depth in one day and average depth in one month. After we copy the data from monitor, we paste these data into this table and click the button "Insert Line or Area Chart", then we can get following two diagrams.

	A	B	C	D	E
1	Date	Time	Depth(m)	Average in one day(m)	Average in one month(m)
2		0:00	0.01		
3		1:00	0.03		
4		2:00	0.03		
5		3:00	0.04		
6		4:00	0.03		
7		5:00	0.03		
8		6:00	0.02		
9		7:00	0.02		
10		8:00	0.02		
11		9:00	0.03		
12		10:00	0.03		
13	1-Mar	11:00	0.08	0.13	
14		12:00	0.09		
15		13:00	0.12		
16		14:00	0.18		
17		15:00	0.23		
18		16:00	0.3		
19		17:00	0.33		
20		18:00	0.39		
21		19:00	0.37		
22		20:00	0.3		
23		21:00	0.24		
24		22:00	0.18		
25		23:00	0.1		
26		0:00	0.02		
27		1:00	0.02		
28		2:00	0.02		
29		3:00	0.04		
30		4:00	0.04		
31		5:00	0.02		
32		6:00	0.04		
33		7:00	0.06		
34		8:00	0.07		
35		9:00	0.02		
36		10:00	0.02		
37	2-Mar	11:00	0.02	0.12	
38		12:00	0.03		

Figure 36: Design table in Excel

Team design these two diagrams to help better understand how does the groundwater table change during day and night. These two diagrams give a clear and visual expersission to the reader. Since all of the function are well defined in this two diagrams, when we input the data that we want to above table, we can directly get following two diagrams. Figure 37 shows the relationship between water depth and the time of day. Figure 38 shows the relationship between average water depth and date.

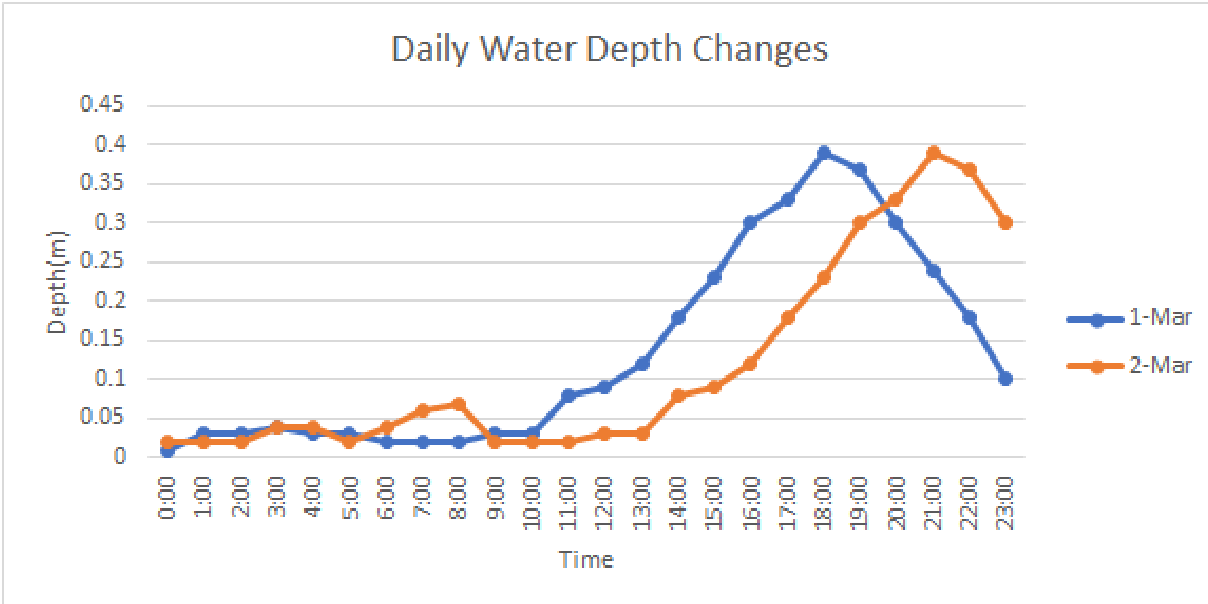


Figure 37: The diagram shows the relationship between water depth and the time of day

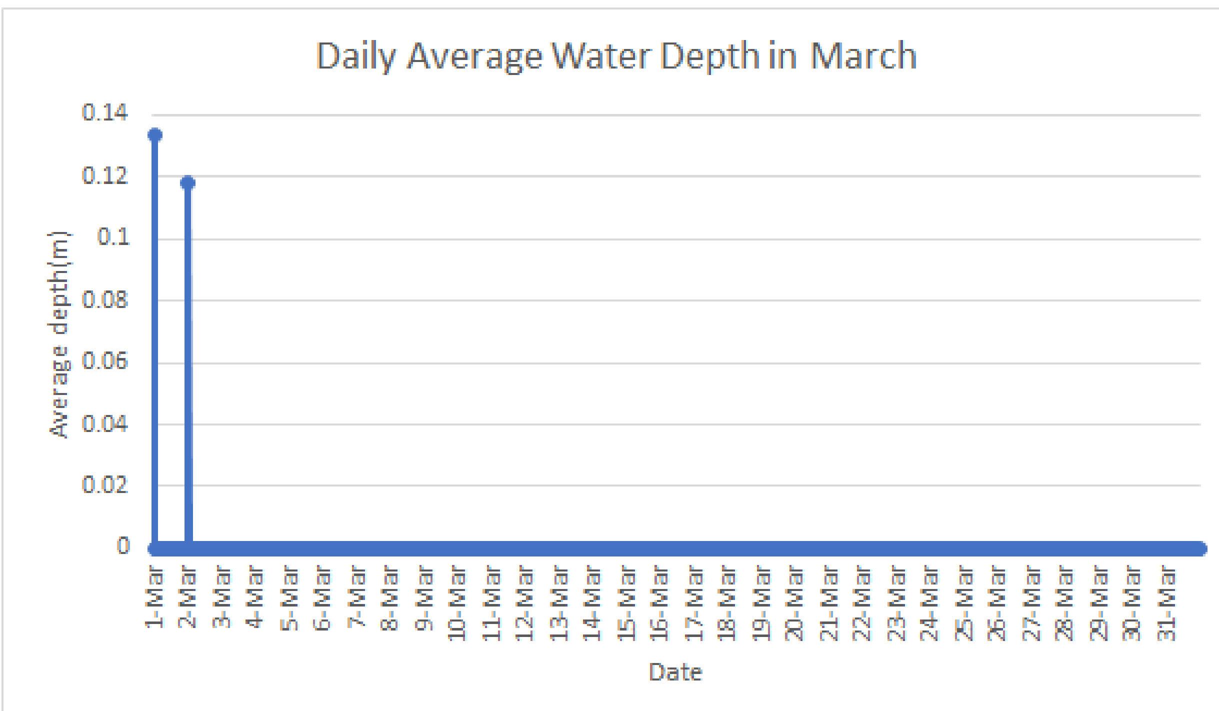


Figure 38: The diagram shows the relationship between average water depth and date

5.0 Budget & Schedule Comparison

5.1 Budget Comparison

In order to successfully determine what the schedule and cost for the project should be, there was research conducted on each component and after careful consideration, the budget and the schedule were modified between the first capstone semester (CENE 476) and the second capstone semester (CENE 486C). These comparisons can be seen in Tables 6 through 9.

Table 6 represents the previous cost table associated with consulting and engineering services.

Table 6: Previous Cost Table

Consulting Services	Total Time (hrs)	Rate (USD/hour)	Estimated Consulting Cost (USD)	Engineering Services	Estimated Engineering Cost (USD)
Project Manager	210.00	44.00	9,240.00	**Site Investigation**	80.00
				Monitoring Well	200.00
				Sampling	50.00
Design Engineer	190.00	32.00	6,080.00	**Static Water Level Detection**	85.00
Senior Engineer	160.00	70.00	11,200.00	**Water Quantity Detection**	90.00
EIT	150.00	60.00	9,000.00	**Data Transmission & Storage**	100.00
Total Labor Cost			**35,520.00**	**Total Engineering Cost**	**605.00**

Table 7 represents the current cost table associated with consulting and engineering services.

Table 7: Current Cost Table

Consulting Services	Total Time (hrs)	Rate (USD/hour)	Estimated Consulting Cost (USD)	Engineering Services	Estimated Engineering Cost (USD)
Project Manager	150.00	80.00	12,000.00	**Site Investigation**	50.00
				Monitoring Well	100.00
				Sampling	100.00
Design Engineer	180.00	80.00	14,400.00	**Static Water Level Detection**	65.00
Senior Engineer	190.00	70.00	13,300.00	**Water Quantity Detection**	50.00
EIT	170.00	60.00	10,200.00	**Data Transmission & Storage**	70.00
Total Labor Cost			**49,900.00**	**Total Engineering Cost**	**435.00**

Both tables show what was changed since the CENE 476 class to the CENE 486 class, which includes having a higher total labor cost, and a lower total engineering cost. In both tables, USD stands for United States Dollars, and EIT stands for Engineer in Training.

5.2 Schedule Comparison

For the schedule of the project, the Arboretum Team developed a schedule in 2017 spring. However, the team faced difficulties during the project and decided to edit the schedule to better suit the actual process.

Table 8 shows the previous project schedule and Table 9 shows the current project schedule. Compare previous project schedule with current project schedule, it is not difficult to find some difference between them. First, in the previous project schedule, team come up with two different ways to do the data transmission which are using GSM/GPRS module and wireless module. In the current project schedule, team not only choose Bluetooth module to do the data transmission based o n the decision table of method selection, but also focus on the data storage which use SD card and SD card module and it is better for long-term data management. Second, when team build the monitoring well in the arboretum and find there is no groundwater in it in this season, team decide to test the electrical monitoring system in the lab. Last, team also do the soil analysis which is not shown in the previous project schedule.

Table 8: Previous Project Schedule

2.0 Scope of Services		
Task	**Sub-Task**	**Sub-Sub-Task**
Site Investigation	Preparation	Investigation
Task 2: Design	Monitoring Well	Design Monitoring Well
		Sampling Equipment
	Water Pressure Transducer	Sensors
		Electric Circuit
		Structure
	Data Collection	
	Data Transmission	Transmission Node
		Arduino UNO Controller
		Wireless Transmission Module
		GSM/GPRS Development Version
Task 3: Building	Building Sampling Well	
	Building Pressure Transducer	
Task 4: Test	Measurement Test of the Water Depth	Pressure Transducer Test
		Monitoring Well Test
Task 5: Project Management	PDT Meetings	
	Technical Coordination Meetings	

Table 9: Current Project Schedule

Schedule		
Task	**Sub-Task**	**Sub-Sub-Task**
Task 1: Site Investigation	Preparation (08/27-09/03)	Investigation
Task 2: Design	Monitoring Well (09/04-09/18)	Design Monitoring Well
		Sampling Equipment
	Water Pressure Transducer (09/04-09/18)	Pressure Transducer
		Wire Extension
	Data Storage (9/19-9/26)	SD Card
		SD Card Module
	Data Transmission (09/19-09/26)	Bluetooth Module
Task 3: Building	Building Sampling Well (09/26-10/17)	
	Building Monitoring System (10/18-10/25)	
Task 4: Test	Soil Analysis (10/26-11/02)	
	Measurement Test of the Water Depth (10/26-11/17)	Monitoring System Test
		Monitoring Well
	Data Analysis (11/03-11/17)	
Task 5: Project Management	PDT Meetings (08/27-11/30)	
	Technical Coordination Meetings (08/27-11/30)	

6.0 Triple Bottom Line

The triple bottom line (TBL) refers to a type of framework that incorporates three dimensions of performance: social, environmental, and financial [8]. The TBL uses the design process in order to be able to successfully complete a project while taking into consideration the social responsibilities it requires, the economic value, and the environmental impacts it may have.

The social aspect of the Arboretum's team project provides a positive impact on the community by making sure that local organizations get more involved with the community. It also provides an opportunity for people to get more involved with the scientific community, along with having educational purposes by involving K-12 students in a project of this type.

The environmental aspect of the Arboretum's team project provides a low impact implementation process. This includes a natural location, therefore causing minimal impact on the surrounding environment along with a compact design that does not need a large amount of space for its implementation and testing.

The economic aspect of the Arboretum's team project is an inexpensive process that involves low-cost materials that are easily acquired, a low maintenance therefore low-cost process and a life cycle that has an implementation, upkeep, and disposal that are simple, therefore low-cost as well.

7.0 Conclusion

After careful consideration, the team determined that this type of project would be better conducted at a different time when there would be a higher probability of water being present in the monitoring well implementation location. This project was developed for the Arboretum Capstone team, and the steps outline within this manual are to be used in order to re-create the processes that the capstone team created. These processes can be modified by the users in order to better suit their needs and purposes. The results acquired by the team were able to demonstrate the various existing conditions at the team's well implementation location, which can then be used in conjunction with pre-existing data in order to determine the effects climate change has on the surrounding environment.

8.0 References

[1] D. Breshears, N. Cobb, P. Rich, K. Price, C. Allen, R. Balice, W. Romme, J. Kastens, M. Floyd, J. Belnap, J. Anderson, O. Myers and C. Meyer, "Regional vegetation die-off in response to global-change-type drought", Proceedings of the National Academy of Sciences, vol. 102, no. 42, pp. 15144-15148, 2005.

[2] G. Walther, E. Post, P. Convey, A. Menzel, C. Parmesan, T. Beebee, J. Fromentin, O. Hoegh-Guldberg and F. Bairlein, "Ecological responses to recent climate change", *Nature*, vol. 416, no. 6879, pp. 389-395, 2002.

[3] "Riparian Areas Environmental Uniqueness, Functions, and Values | NRCS", Nrcs.usda.gov, 2017. [Online]. Available: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=nrcs143_014199.

[4] "Arizona's Riparian Areas", Cals.arizona.edu, 2017. [Online]. Available: https://cals.arizona.edu/extension/riparian/chapt2/p6.html.

[5] Landcareresearch.co.nz. (2017). Ephemeral wetlands. [online] Available at: https://www.landcareresearch.co.nz/publications/factsheets/rare-ecosystems/wetlands/ephemeral-wetlands

[6] "Well Monitoring Directions", *bemp.org*. [Online]. Available: http://bemp.org/wp-content/uploads/2016/01/well-installation-and-monitoring-directions.pdf.

[7] "Soil Texture Calculator | NRCS Soils", Nrcs.usda.gov, 2017. [Online]. Available: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167

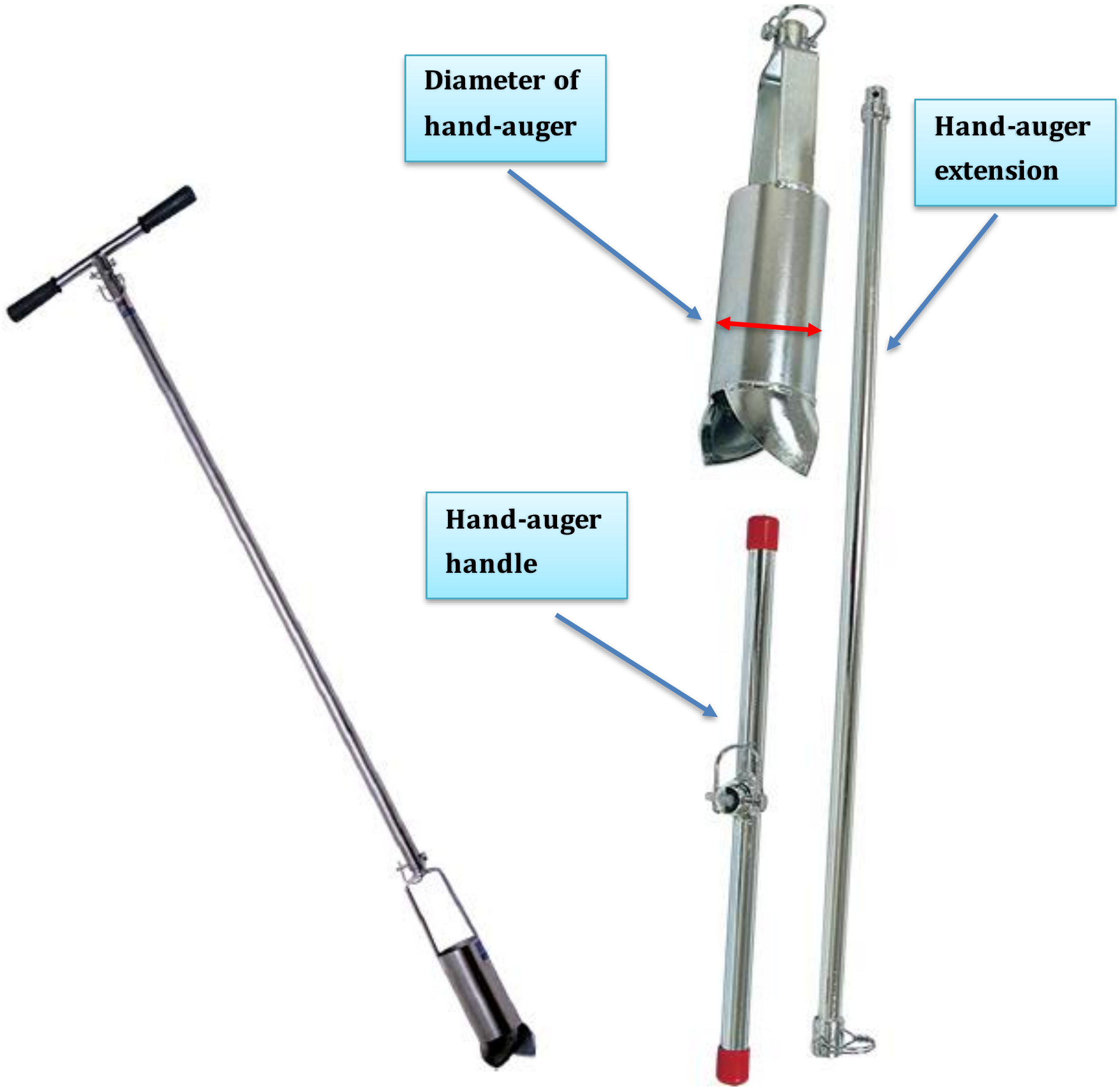
[8] "The Triple Bottom Line: What Is It and How Does It Work?", Ibrc.indiana.edu, 2017. [Online]. Available: http://www.ibrc.indiana.edu/ibr/2011/spring/article2.html.

[9] "Hand Auger Assembly", Testmark.net, 2017. [Online]. Available: http://www.testmark.net/showitem-720.html.

[10] Wardsrental.com, 2017. [Online]. Available: http://www.wardsrental.com/wp-content/uploads/2015/03/femalewelldriver-e1425222406576.jpg.

9.0 Appendices

Appendix A: Hand-auger assembled along with each component [9]



Appendix B: Well pounder [10]