

A continuing study of the water quality in the Pasquotank Watershed in Northeastern North Carolina

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Abstract- The Pasquotank River Watershed is found in Northeast North Carolina beginning in the Great Dismal Swamp at the Virginia/North Carolina border and flows into the Albemarle Sound. The watershed provides a transition between the Great Dismal Swamp and the waters of the Albemarle Sound. The watershed is surrounded by a variety of landforms including swamps, farmland, and suburban developments. These produce a variety of runoff into the watershed affecting both the aquatic vegetation and marine life in the waters. This project built on the previous analysis of the four tributaries and the Pasquotank River completed in 2011, 2013, 2014, and 2015.

The 2016 Research Experience for Undergraduates Pasquotank River Watershed Team completed one set of tests of the watershed. These test points originated from the 2011 and 2013 research projects with the addition of four points created in 2014 to sample further downstream in the Pasquotank River. The results were compared with previous readings utilizing a Water Quality Index (WQI), a unitless number ranging from 1 to 100 with higher numbers denoting better water quality. The waterways tested were the Pasquotank River, Newbegun Creek, Knobbs Creek, Areneuse Creek, Mill Dam Creek, and Sawyers Creek. These creeks, along with the Pasquotank River, cover a large portion of the watershed and provided a wide area of study for the watershed.

Tests performed in the laboratory on this year's samples include pH, salinity, total dissolved solids, and conductivity. Air/water temperature, dissolved oxygen, wind speed/direction, and turbidity/clarity measurements were taken in the field. The results collected were placed online and displayed in correlation to their position utilizing Google Maps. The data was then compared to the previous projects results.

The overall WQI for all of the tested waterways combined remained in a constant pattern. All of the waterways, except for Sawyers Creek, were at their lowest WQI when being compared to past research ranging from 2011 to 2015. The Lower Pasquotank still has the best water quality index, but

the waterway had a significant decrease in its water quality score. When compared to the results of the 2014 team and the 2015 team, the Lower Pasquotank water quality went from a good Water Quality Index score to a medium Water Quality Index score, dropping 21 points. Newbegun Creek, Areneuse Creek, Mill Dam Creek, Sawyers Creek, Knobbs Creek, and the Pasquotank River all had bad Water Quality Index scores this year.

Keywords: water quality, Pasquotank, watershed, dissolved oxygen, pH, salt, conductivity, clarity, turbidity

I. INTRODUCTION

A. Overview

A watershed can be described as an area or ridge of land that separates waters flowing to different rivers, basins, or seas. [3] Watersheds can be as small as a footprint or large enough to encompass all the land that drains water into rivers that drain into Chesapeake Bay, where it enters the Atlantic Ocean. [5] The reason that watersheds are important is that they affect many different things like the wildlife and food. If a watershed is impaired or unhealthy it will affect how the people around it live. Water can become impaired due to the excess of different nutrients caused by varying factors such as erosion and runoff from waste. [4]

The Pasquotank river basin is a watershed that is fed by several creeks and the Pasquotank River. The focus of this year and previous year's team's research of the river basin were the Pasquotank River, Mill Dam Creek, Areneuse Creek, Sawyers Creek, Knobbs Creek, and Newbegun Creek. The tests completed on these creeks and the river were dissolved oxygen (DO), total dissolved solids (TDS), salinity, conductivity, turbidity, clarity, and pH. After collecting the data from these tests, the data was charted and graphed to seek trends and find comparisons within the waterways over the testing years of 2011, 2013, 2014, 2015, and 2016. The Lower Pasquotank became an addition to the research project in the summer of 2014.

B. Dissolved Oxygen

Dissolved oxygen refers to amount of oxygen that is dissolved in a body of water. Dissolved oxygen is one of the most important factors when it comes to water quality. [7] Many aquatic animals live off of how much DO is in the water. An example of the aquatic life that depends on DO would be fish. If there is not enough, or too much, DO in the water then the fish will die. Oxygen comes from the vegetation that grows along the edges of the stream. In wide streams the oxygen is moved from the side to the middle of the stream by the wind. [7] DO is measured using a wide variety of means, however the team used the MW600 Dissolved Oxygen Meter. This meter measured Dissolved Oxygen in milligrams per liter (mg/l). This measurement was converted to saturation percent to be used in the Water Quality Index calculator.

C. Total Dissolved Solids (TDS)

“Total dissolved solids (TDS) are comprised of inorganic salts and some small amounts of organic matter that are dissolved in water.” [6] The tests were done using the Tracer Pocket Tester for this research. The Tracer Pocket Tester measures TDS in parts per million (ppm). The Water Quality Index calculator uses mg/l, which matches the ppm measurement. A liter of water weighs 1 kg (1 kilogram or 1000 grams) and 1 mg (1 milligram) is equal to 1/1000 of a gram, therefore $1 \text{ mg} = 1/1,000,000$ of a kg.

D. Salinity

“Salinity is the measure of all the salts dissolved in water.” [8] Salinity is important as some aquatic life can only survive at certain salinity levels. The Tracer Pocket Tester was also used for this test. The Pocket Tester measured salinity in parts per million.

E. Conductivity

Conductivity is a measure of water’s capability to pass electrical flow [9]. To test conductivity the Tracer Pocket Tester was used. The instrument measured conductivity in microsiemens (uS). The team converted the measurement to millisiemens for use in the Excel file.

F. pH

pH is the indication of whether the water is acidic or basic. The measurement ranges from 0 to 14 with 7.0 being neutral, 0 being acidic, and 14 being base. pH is affected by the amount of dead vegetation in the water as once the materials decompose they release carbon dioxide which turns into a weak acid. [10]

G. Turbidity

Turbidity is the measurement of the scattered light. Water can become turbid by having high amounts of clay, silt, and organic matter. High water flows can also cause the water to have a high turbidity rating because of all the materials that are carried. [11] Turbidity was measured in inches by a Secchi disk. This data was then converted into Nephelometric Turbidity Units (NTU) as the Water Quality

Index calculator uses NTU as a measurement instead of inches. This was completed by converting the inches into centimeters and then using an NTU conversion chart [2].

H. Clarity

Water clarity is the characteristic of how transparent the water is. Water clarity and turbidity are closely related as a high turbidity reading that means there are more particles in the water causing the water clarity to decrease. [12] Clarity is measured using the white and black side of the Secchi disk. Clarity is also measured in inches.

II. EQUIPMENT

A. Locations

The latitude and longitude of the points were taken from the 2011, 2013, 2014, and 2015 Water Quality Team projects for each waterway. The positions were loaded into the Garmin GPSMAP 60CSx, a handheld Global Positioning System (GPS) device, using the Garmin BaseCamp software [13]

B. Transportation

The canoe was used to travel through each of the small creeks such as Mill Dam Creek, Areneuse Creek, Sawyers Creek, and Knobbs Creek. When traveling on Mill Dam Creek, Areneuse Creek, and Knobbs Creek there was an electric motor attached to the canoe, which made data collection quicker. The LH Viking, a 22 foot Sea Pro boat, was used to travel through the Pasquotank River and Newbegun Creek. During the testing of Newbegun Creek, the kayak was used to travel under a bridge to gather the remaining points of that tributary. One research trip on the Pasquotank River and Newbegun Creek was completed using a 17.5 foot inboard/outboard boat. This trip was completed in less time due to the speed of the smaller boat.

C. Water Temperature

The water temperature was measured using a mercury thermometer attached at the end of a stick. The mercury thermometer measured the water temperature in degrees Celsius. The thermometer was placed at three feet below the surface for one minute for each measurement.

D. Air Temperature/Wind Speed

The Skymate Wind Meter was used to measure wind speed and determine the air temperature. It is an anemometer that measures the wind speed in knots and the air temperature in degrees Celsius. To measure wind speed the anemometer is held directly into the wind. The meter rarely settled completely due to variations in the wind speed. The air temperature was measured by switching the modes.

E. Dissolved Oxygen

The instrument used to measure dissolved oxygen was the MW600 Dissolved Oxygen Meter. This device is calibrated at two points, 100% saturation air and 0% oxygen solution. To calibrate it at a 100% it is best to use the “Open Air” calibration. The first step is to unscrew the membrane,

and expose the probe. Fill the cap with electrolyte and gently dry off the exposed probe. Screw the cap back onto the probe and then hang it pointed towards the ground. Allow for 5 to 10 minutes for it to settle. When the meter settles, press and hold the "CAL" button and turn the 100% adjustment screw left or right until the meter reads 100% saturation. When the calibration procedure is complete, place the plastic cap back on the membrane. [20]

To test the water in the field, remove the plastic cap to expose the membrane. Next, set the probe in the water to the desired depth, which was three feet for this project. Give the device time (1-2 minutes) to reach a stable reading for dissolved oxygen. Once the reading has been taken, place the plastic cap back on to protect the membrane.

F. TDS/Salinity/Conductivity

The Tracer Pocket Tester measures conductivity, salinity, and total dissolved solids (TDS) and is self-calibrating. This pocket tester has two probes on the end which should only be touched by water because if the probes come in contact with anything else, it will cause the readings to be inaccurate.

In order to get the salinity, conductivity, and TDS there are three modes to change between. To accomplish this press and hold "MODE" until SAL, which is for salinity, CON, for conductivity, or TDS, for total dissolved solids, appears at the bottom of the screen. On the screen there is also an indication of the current measurement unit that is being used. In SAL mode, "ppm" will appear in the top left corner and S will appear in the middle. In CON mode, μ S or mS will appear in the middle. In TDS mode, "ppm" will appear in the top left corner. Also allow the pocket tester to settle in order to obtain a reading from each mode.

G. Turbidity/Clarity

The Secchi disk is the tool that measures the clarity/turbidity. The disk has two sides, one being black and white and the other solid black. The black and white side is used for clarity. The solid black side is for turbidity. To measure turbidity and clarity the Secchi disk was lowered until the disk no longer was visible. The disk was then lowered out of sight and raised until it became visible. These two measurements were averaged together.

H. pH

A pH meter was used to take the pH reading of the water samples. The pH meter displays the pH of the water on a small screen located on the front. Before testing the water, the meter needs to be calibrated using different pH tablets ranging from 1.0 to 7.0.

III. SOFTWARE APPLICATIONS

A. Microsoft Excel

Microsoft Excel is a spreadsheet program included in the Microsoft Office. The spreadsheets that can be created can

present tables of values arranged in rows and column that can be manipulated mathematically. This program was used to input data collected from all of testing to perform comparisons, analysis, averaging, and identification of trends. This was completed by creating a graph of all of the data entered. It was also used to provide input to the Water Quality Index calculator.

B. Google Maps

Google Maps is a three-dimensional software feature that allows people to get an accurate reading on a specific location. This is because of the SkyBox Imaging Satellites that are offered for this feature. Google Maps was used to display the map results from the fieldwork and in-house testing.

C. Adobe Dreamweaver

Adobe Dreamweaver is a program used to create a website. The website was used to document the research and to provide data visualization of the data collected.

D. Adobe Photoshop

Adobe Photoshop is a graphics program used for editing different types of images. The program was used to edit photos that could be used for the website.

E. Water Quality Index Calculator

The Water Quality Index is the index that is used to represent overall quality of water. The Water Quality Index calculator is a website that is created by the Water Research Center and uses several factors to determine the health of a waterway. The Water Quality Index ranges from 0 to 100. From 0 to 25 is very bad, 25 to 50 is bad, 50-70 is medium, 70-90 is good, and 90 to 100 is excellent. [1]

F. Google Drive

Google Drive is an online application that allows the storage of documents and other files. The application stores the files in "the cloud". This is important as at any time, or anywhere, the files can be downloaded to a new device. This was good for the development of the final paper and PowerPoint as all of the data could be accessed by any team member.

IV. METHODOLOGY

A. Pre-Field Work

Before the team went out to test the watershed, the points and routes were loaded into the Global Positioning Systems (GPS). Garmin BaseCamp software was used to define the points and the routes used. Once they were established, they were transferred via USB to the Garmin GPSMAP 60CSx. [13]

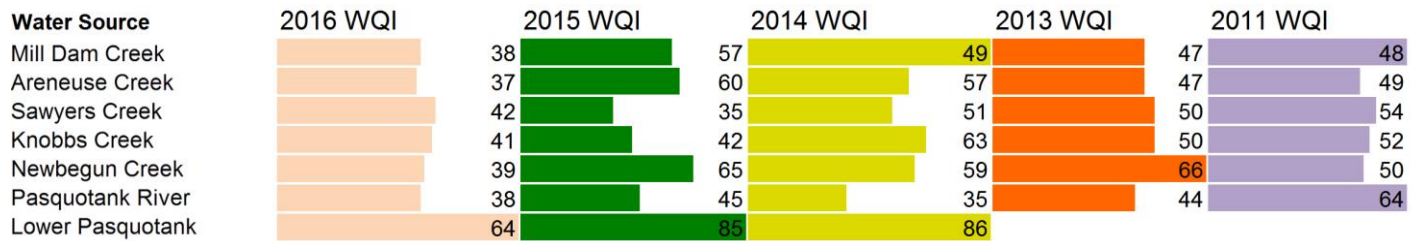


Fig. 1. Average Water Quality Index Comparison between the 2016,2015,2014,2013, and 2011 Projects

The MW600 Dissolved Oxygen Meter was calibrated using a zero oxygen solution and ensuring the meter read zero. The team also performed the “Open Air” calibration procedure.

B. Field Work

When it was time to go out on the water for testing, the canoe, or boat and kayak were loaded with all the supplies needed such as paddles, test equipment, and data recording equipment. All of the test equipment was secured using Velcro straps and tying the straps to the platforms in case the canoe or kayak flipped over, the testing equipment would be secure. At each test point there were several tests performed and recorded and water samples were obtained. The time was written down as a reference for the water samples that were taken as the test results may vary throughout the day. Once the time and the point being tested were recorded, the wind speed/direction and air/water temperature were also recorded. The wind speed and air temperature were recorded using the anemometer, while the water temperature was recorded using a mercury thermometer. Wind direction was determined using the compass on the GPS. Clarity and turbidity were observed using the Secchi disk. The dissolved oxygen measurement was obtained using the DO meter.

C. Post-Field Work

After collecting data from each waterway, in-house tests were completed to obtain the pH, conductivity, salinity, and total dissolved solids readings. The water samples from the field water were poured into small cups for testing. The pH meter was calibrated in distilled water and a pH tablet set for a certain pH reading, an example of this would be a pH reading of 10.0. The pocket tester, which is used to test for salinity, conductivity, and total dissolved solids, is a self-calibrated meter thus there was no need for the team to be calibrated. Each meter was placed in the water sample to obtain readings and then recorded.

D. Offline Data-Visualization

A Microsoft Excel sheet was used to input all the data from the fieldwork and in-house testing. Another Microsoft Excel sheet was used to create graphs of each waterway based on the averages of the water conditions. The data that were inserted into the Microsoft Excel files were dissolved oxygen, corrected dissolved oxygen, pH, clarity, turbidity, salinity, conductivity, total dissolved solids, air temperature, water temperature, wind speed, and wind direction. The graphs that were created from these averages were then used to compare to the previous year’s graphs.

The averages for 2016 were then combined with the previous four years of testing in order to analyze changes occurring.

E. Online Data-Visualization

The 2015 group created an online database and applied that database to Google Maps. This was important so that future groups can input their data into the database and create the same online data-visualization. The data collected in 2016 was converted into a Comma Separated Values (CSV) file for insertion into this database.

V. ANALYSIS

A. Water Quality Index

The overall WQI for all of the tested waterways combined remained in a constant pattern as seen in Figure 1. However, results of this project may have varied due to several changes. A new dissolved oxygen meter was utilized and the method for calibrating the meter was changed. A different WQI calculator was also used as the previously used calculator was a Windows operating system application. All of the waterways, except for Sawyers Creek, were at their lowest WQI when being compared to past research ranging from 2011 to 2015. This may have been due to the high temperature readings during 2016. Turbidity, total dissolved solids, and dissolved oxygen were considerably different from previous years. The water testing for the five years of tests are displayed in Appendix 1. The Lower Pasquotank still has the best water quality index, but the waterway had a significant decrease in its water quality score. When compared to the results of the 2014 team and the 2015 team, the Lower Pasquotank water quality went from a good Water Quality Index score to a medium Water Quality Index score, dropping 21 points. Newbegun Creek, Areneuse Creek, Mill Dam Creek, Sawyers Creek, Knobbs Creek, and the Pasquotank River all had bad Water Quality Index scores this year. Areneuse Creek had the lowest Water Quality Index scores during the 2016 project. Mill Dam Creek, Areneuse Creek, and Newbegun Creek scored lower than any previous years. Sawyers Creek and Knobbs Creek were close in readings due to their size and location.

In-house tests on this year’s samples continued to include pH, salinity, total dissolved solids, and conductivity. Air/water temperature, dissolved oxygen, wind speed/direction, and turbidity/clarity measurements were taken in the field. The results from these readings were placed into an online database where they are correlated to the location of the sample using Google Maps®.

B. Dissolved Oxygen

The dissolved oxygen readings for 2016 experienced a drop in results. The warm temperatures may have been a factor in this drop. All forms of aquatic life use dissolved oxygen in surface water, and dissolved-oxygen concentrations fluctuate with water temperature daily and seasonally [7]. The Lower Pasquotank width played a role in the waterway remaining on the top in dissolved oxygen readings.

C. TDS/Salinity/Conductivity

The total dissolved solids (TDS), salinity, and conductivity readings for 2016 have increased in comparison to the 2015 readings. The distance from Elizabeth City to the Dismal Swam Canal, which is 14 miles, is the reason salinity levels were low in the Upper Pasquotank. Newbegun Creek was high in salinity readings due to the brackish water from the Lower Pasquotank. TDS and conductivity correlates with each other, and the pattern of the readings has been stable throughout every research year.

D. pH

The 2016 readings for pH experienced a slight change. There were four base pH readings this year (7.1-14), which were obtained in Mill Dam Creek, Areneuse Creek, Newbegun Creek, and the Lower Pasquotank. Sawyers Creek, Knobbs Creek, and the Pasquotank River dropped to an acidic pH level category (0-6.99), with Knobbs Creek almost reaching a neutral pH level at 6.95.

E. Clarity/Turbidity

The 2016 readings for clarity and turbidity increased in every waterway tested. Clarity determines how clear the water is while turbidity determines the number of suspended particles is in the water. Mill Dam Creek had the highest reading in both clarity and turbidity, and the Pasquotank River had the lowest readings of clarity and turbidity. Knobbs Creek and Newbegun Creek were very close to one another in clarity readings, but in turbidity readings Sawyers Creek and Knobbs Creek were similar. This year's readings shared the pattern of the 2014 and 2013 research readings.

VI. CONCLUSION

A. Overall

The overall Water Quality Index for the Pasquotank watershed was calculated using the Water Quality Index calculator. The factors that went into the test for each waterway were the Dissolved Oxygen saturation percent, water temperature, pH, TDS, and the NTU measurement of turbidity. It was concluded that the Lower Pasquotank had the highest rating and Areneuse Creek had the lowest. The DO measurements played a large factor in the Water Quality Index scores of these two streams.

B. Variations

The TDS, conductivity, and salinity were all higher this year than they were in previous years. This may have been due to the warm temperatures.

The Google Map of the watershed showed that each point that was near the Pasquotank River shared similar readings. The Lower Pasquotank River and Newbegun Creek also shared similar readings.

VII. FUTURE WORKS

A. Thermometer

The mercury thermometer was a very subjective device and should be replaced with a digital thermometer. It is recommended that the Control Company VWR Waterproof Thermometer, a digital thermometer that is waterproof and shockproof, be acquired for this test. The thermometer ranges from -50 to 300 degrees Celsius. It has the ability to recall its lowest and highest readings over any period [15].

B. Dissolved Oxygen Meter

The MW600 Dissolved Oxygen Meter has been used to measure dissolved oxygen for the past years, but it should be replaced with a waterproof dissolved oxygen meter. The HI98193 is the recommended meter to be acquired for the tests. The HI98193 is waterproof and gives the researchers another water condition to test. The waterproof meter measures dissolved oxygen, barometric pressure, biochemical oxygen demand (BOD), and temperature [16].

C. Secchi Disk

The Secchi disk was used to measure the turbidity and clarity. However, the measurement of the device fluctuates depending on the waterway the device is being used in and the individual that is performing the tests. The device recommended to perform future testing is the Portable Turbidity and Bentonite Check meter because it provides the project with accurate readings and decreases the chances of any interference. The meter also displays the turbidity in Nephelometric Turbidity Units (NTU) units, which is necessary for the Water Quality Index calculator [18].

D. Adding Test

It is recommended that there be more tests performed on the waterways to provide more accurate scores of the Water Quality Index. One of these recommended tests is the test for fecal coliform. The procedure for taking fecal coliform takes 24 to 48 hours to obtain a correct reading. [17]

Another test that could be added is total phosphate. There are various instruments from Hatch ranging from a hand-held device all the way to an instrument that sits on top of a desk comparable to the size of a small laptop. [21]

A test for nitrates could also be added using the "Pocket Colorimeter II, Nitrogen, Nitrate" from Hatch. [19] Nitrates can enter the water by soil erosion or bacteria in the water. [14]

The last test that can be added is the biochemical oxygen demand. The HI98193 is recommended for this test. This meter can also test for dissolved oxygen.

E. Knobbs Creek

Knobbs Creeks contains a navigation obstruction in the form of an old bridge with a large pipe. The canoe must be

carried over the obstructions to obtain access to the upper part of Knobbs Creek. It is recommended that Elizabeth City officials be contacted to see if this obstruction can be removed.

F. Acknowledgement

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REFERENCES

- [1] B. Oram, "Calculating NSF Water Quality Index (WQI)," *Monitoring the Quality of Surface Waters*, 2014. [Online]. Available: <http://www.water-research.net/index.php/water-treatment/water-monitoring/monitoring-the-quality-of-surfacewaters>.
- [2] Chicago River Schools Network, "Turbidity," *Turbidity*. [Online]. Available: http://s3.amazonaws.com/chicagoriver/rich/rich_files/rich_files/502/original/turbidity.pdf.
- [3] Merriam-Webster, "Merriam-Webster," *Merriam-Webster*. [Online]. Available: <http://www.merriam-webster.com/dictionary/watershed>.
- [4] "The Nature Conservancy," *The Importance of Watersheds*. [Online]. Available: <http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/indiana/journeywithnature/watersheds-101.xml>.
- [5] "What is a watershed?," *Watersheds and drainage basins, USGS Water Science School*. [Online]. Available: <http://water.usgs.gov/edu/watershed.html>.
- [6] B. Oram, "Total Dissolved Solids and Water Quality," *Water Research Center*, 2014. [Online]. Available: <http://www.water-research.net/index.php/water-treatment/tools/total-dissolved-solids>.
- [7] "Dissolved Oxygen - Environmental Measurement Systems," *Environmental Measurement Systems*. [Online]. Available: <http://www.fondriest.com/environmental-measurements/parameters/water-quality/dissolved-oxygen/>.
- [8] "Salinity and water quality fact sheet," *Department of the Environment and Energy*. [Online]. Available: <https://www.environment.gov.au/water/quality/publications/factsheet-salinity-and-water-quality>.
- [9] "Conductivity, Salinity & Total Dissolved Solids," *Fundamentals of Environmental Measurements*. [Online]. Available: <http://www.fondriest.com/environmental-measurements/parameters/water-quality/conductivity-salinity-tds/#cond11a>
- [10] "Water Quality, Drinking water, Corrosion and Water pH," *Water Quality, Drinking water, Corrosion and Water pH*. [Online]. Available: <http://www.water-research.net/index.php/ph-in-the-environment>.
- [11] "Turbidity," - *Water Properties, USGS Water Science School*. [Online]. Available: <http://water.usgs.gov/edu/turbidity.html>.
- [12] "Turbidity, Total Suspended Solids & Water Clarity - Environmental Measurement Systems," *Environmental Measurement Systems*. [Online]. Available: <http://www.fondriest.com/environmental-measurements/parameters/water-quality/turbidity-total-suspended-solids-water-clarity/#turbid4>.
- [13] "GPSMAP® 60CSx ," *Garmin*. [Online]. Available: <https://buy.garmin.com/en-us/us/into-sports/discontinued/gpsmap-60csx/prod310.html>
- [14] "Nitrates and Their Effect on Water Quality," *Wheatley River Improvement Group*. [Online]. Available: <http://www.wheatleyriver.ca/current-projects/wrig-pilot-nitrate-study/nitrates-and-their-effect-on-water-quality-a-quick-study/>
- [15] "Thomas Traceable Waterproof Thermometer with Probe Cable -50 to 300 Degree C 4039," *Thomas Traceable Waterproof Thermometer with Probe Cable -50 to 300 Degree C 4039*. [Online]. Available: <https://www.google.com/shopping/product/16936676071866290681?q=scientific+water+thermometer+with+a+probe>.
- [16] "Waterproof Portable Dissolved Oxygen and BOD Meter - HI98193," - *Hanna Instruments*. [Online]. Available: <http://hannainst.com/hi98193-waterproof-portable-do-bod-meter.html>.
- [17] "Total and Fecal Coliform Bacteria Testing," *Drinking Water and Other Waters Bacterial Testing (Fecal / Total Coliform)*. [Online]. Available: <http://www.water-research.net/index.php/water-testing/bacteria-testing/fecal-coliform-bacteria>
- [18] "HI83749 Portable Turbidity and Bentonite Check Meter," - *Hanna Instruments*. [Online]. Available: <https://hannainst.com/hi83749-portable-turbidity-and-bentonite-check-meter.html?id=010002>.
- [19] "Pocket Colorimeter™ II, Nitrogen, Nitrate," *Manufactures Water Quality Testing and Analytical Instruments & Reagents*. [Online]. Available: <http://www.hach.com/pocket-colorimeter-ii-nitrogen-nitrate/product-details?id=7640442955>
- [20] "'Open Air' Calibration Procedure for the MW600 Dissolved Oxygen Meter," *Milwaukee*. [Online]. Available: http://www.milwaukeeinstruments.com/site/pdf/mw600_open_air_calibration.pdf
- [21] "Phosphorus, Total," *Hatch*. [Online]. Available: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0ahukewix5onrtploahxcdh4khzvjc2aqfghqmam&url=http://www.hach.com/asset-get.download.jsa?id=7639983838&usq=afqjoneioqwcsalqoo9yabgyk4ihk_dnda.

Appendix 1

Water Source	D.O.	pH	Water Temp (Celsius)	Air Temp (Celsius)	Clarity Avg (in)	Turbidity Avg (in)	Total Dissolved Solids (ppm)	Salinity (ppm)	Conductivity (milliseimens)
2016 Water Source									
Mill Dam Creek	1.225	7.53	29.75	28.50	28.00	19.00	802.5	570.0	1.15
Arenouse Creek	0.9	7.48	30.00	31.85	27.13	17.73	825.0	590.0	1.89
Sawyers Creek	1.58	6.70	28.60	32.48	19.65	14.15	155.0	109.0	0.23
Knobbs Creek	1.73	6.95	29.80	32.39	23.27	14.03	320.0	226.0	0.46
NewBegun Creek	1.55	7.41	29.25	29.28	24.38	17.87	901.7	642.5	1.31
Pasquotank River	2.43	6.07	28.67	30.96	12.67	9.31	139.3	98.9	0.21
Lower Pasquotank	6.725	7.15	29.75	28.00	24.38	17.75	1432.5	1020.0	2.06
2015 Water Source									
Mill Dam Creek	3.65	6.98	26.88	28.50	20.13	12.06	543.8	390.0	0.79
Arenouse Creek	3.8	6.95	26.00	31.83	25.06	15.52	436.3	310.0	0.63
Sawyers Creek	1.08	6.71	27.50	29.85	9.70	5.05	120.5	85.0	0.18
Knobbs Creek	1.18	6.73	27.08	30.70	15.78	9.08	180.3	127.3	0.27
NewBegun Creek	4.61	7.31	27.29	29.83	18.71	9.73	574.2	622.6	1.25
Pasquotank River	3.29	6.78	28.58	32.68	8.91	4.89	173.8	122.5	0.19
Lower Pasquotank	7.65	7.45	28.13	29.75	21.06	11.50	1106.3	720.0	1.67
2014 Water Source									
Mill Dam Creek	2.1	7.20	23.80	24.70	23.20	11.30	1087.5	773.8	1.56
Arenouse Creek	3.4	7.40	26.10	32.10	24.00	12.20	1057.5	755.0	1.51
Sawyers Creek	3.7	6.70	25.40	27.90	13.10	6.90	158.5	112.5	0.23
Knobbs Creek	4.7	6.90	26.00	27.80	14.60	7.90	271.7	198.4	0.41
NewBegun Creek	3.7	7.60	26.30	30.30	21.70	11.60	901.7	741.7	1.38
Pasquotank River	2.6	6.00	26.90	28.40	9.20	5.30	110.6	77.6	0.41
Lower Pasquotank	7.2	7.40	27.30	30.20	24.90	11.20	1302.5	930.0	1.87
2013 Water Source									
Mill Dam Creek	2.5	7.00	25.50	24.50	24.00	10.50	3263.5	2331.5	4.39
Arenouse Creek	2	7.40	26.00	24.50	22.00	11.00	2455.0	1751.5	3.77
Sawyers Creek	3.5	7.50	28.50	33.00	17.50	9.50	856.0	611.0	1.09
Knobbs Creek	3	7.10	27.00	28.50	25.50	13.00	1314.5	910.0	2.03
NewBegun Creek	5	7.40	27.00	29.00	18.00	9.50	3242.0	2272.5	4.89
Pasquotank River	3	6.40	26.50	30.00	13.00	5.50	815.5	582.5	1.07
2011 Water Source									
Mill Dam Creek	4	5.00	27.80	27.60	32.00	32.00	3203.0	2285.0	5
Arenouse Creek	4	4.00	28.30	28.20	19.00	19.00	2460.0	1758.0	4
Sawyers Creek	4	7.00	25.90	26.30	23.00	15.00	856.0	607.0	1
Knobbs Creek	5	5.00	26.60	28.50	23.00	20.00	1847.0	1325.0	3
NewBegun Creek	4	5.00	27.50	29.70	17.00	17.00	3006.0	2146.0	4
Pasquotank River	5	6.00	26.40	26.00	14.00	14.00	761.0	541.0	1