An Analysis of Pollution in the York River watershed

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at George Mason University

by

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George Mason University, 2017

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Fall Semester 2019
George Mason University
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Dedication

This is dedicated to my loving friends and family.

Acknowledgements

I would like to thank the many friends, relatives, and supporters who have made this happen. My loving family that assisted me in my research. Drs. Fuhrmann, Rice, and Komwa were of invaluable help. Finally, thanks go out to the College of Science for providing a clean, quiet, and well-equipped repository in which to work.

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List of Abbreviations

BMPs…………………………………………………….....Best Management Practices
CBF………………………………………………………..Chesapeake Bay Foundation
ENVI…………………………………………...Environment for Visualizing Images
EPCRA………………………..Emergency Planning and Community Right-to Know Act
ESRI ....Environmental Systems Research Institute
ETM……………………………………………………..Estuarine Turbidity Maximum
GHG……………………………………………….……Green House Gasses
GIS ....Geographic Information Systems
N .... Nitrogen
P...Phosphorus
PCBs…………………………………………………………Polychlorinated biphenyls
POI .... Point of Interest
RSC………………………………………………..Regenerative Stormwater Conveyance
STAC……………………………………...Science and Technical Advisory Committee
TMDL……………………………………………………...Total Maximum Daily Load
US EPA…………………………………United States Environmental Protection Agency
VGI ....Volunteered Geographic Information
VIMS……………………………………………………Virginia Institute of Marine Science
VA DEQ…………………………………Virginia Department of Environmental Quality
WIP…………………………………………………...Watershed Implementation Plans

Abstract

AN ANALYSIS OF POLLUTION IN THE YORK RIVER WATERSHED

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George Mason University, 2019

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This study addresses the lack of a proper mapping assessment of field-level pollution sources for the implementation of pollution management practices. Phosphorus and nitrogen entering streams and rivers contribute to eutrophication as well as greenhouse gas (GHG) production in the York River. Not only do nitrogen and phosphorus enter the river, but manmade chemicals, such as polychlorinated biphenyls (PCBs) do as well. An environmental analysis of the potential contribution of the reduction of nutrients from nonpoint and point sources of pollution to the Chesapeake Bay originating in the York River, Virginia was conducted. The research focuses on three objectives each in their own chapter: 1) What are the main sources of water pollutants in the York River?; 2) How has the water pollution of the York river changed between 1986 and 2013?; and 3) What is the rate of algae bloom expansion and the increase in invasive algae species in the York River? This study finds that the York River has rapidly increased in its pollution over the past twenty-seven years and finds evidence of large amounts algae blooms and loss of animal and fish species in the surrounding area. The study is inconclusive about urban development. Future work in the increase of human

development along the river needs to be conducted in order to isolate causes and contributions to the rapid increase of pollution into the York River.

1. Introduction and Background

The Chesapeake Bay is approximately 4,500 sq. miles that is home to roughly 18.2 million people as of 2010. The Bay and its tributaries contain food sources such as fishes, crabs, clams, and oysters. The Bay also contains certain pollutants such as nitrogen and phosphorus, which leads to depleted oxygen, chlorophyll, and water clarity issues (https://www.chesapeakebay.net/state/population, 2019). The York River watershed is more densely populated than the other watersheds due to its size and rapid increase of human population during the time period of 1986-2013. Nitrogen and phosphorus are essential nutrients for organisms, which is essential for plant growth in many ecosystems. The York River is especially sensitive to eutrophication, or excessive inputs of nitrogen and phosphorus because the removal of nitrogen limitation can lead to large scale algae blooms. When these blooms die off, bacteria in the water break down the organic matter from the algae and consume oxygen in the water column. This process results in very low oxygen levels, which is defined as hypoxia. In the United States, large areas of the Chesapeake Bay experience hypoxia due to algae blooms. The extent, duration, and number of these events has increased with the rapid human development around the York River. Watershed nitrogen and phosphorus accumulation is the primary driver of algae blooms. Nitrogen and phosphorus sources include the chemicals from vehicle exhaust, infrastructure, and agricultural and residential fertilizer. Nitrogen in organic matter that is swept up by smaller rivers on the way to the York River is often assumed to be too difficult to manage or too insignificant to contribute to the increase in hypoxia, however this is the opposite in the coastal areas with large amounts of urbanization.

1.1 Geography of the York River Watershed

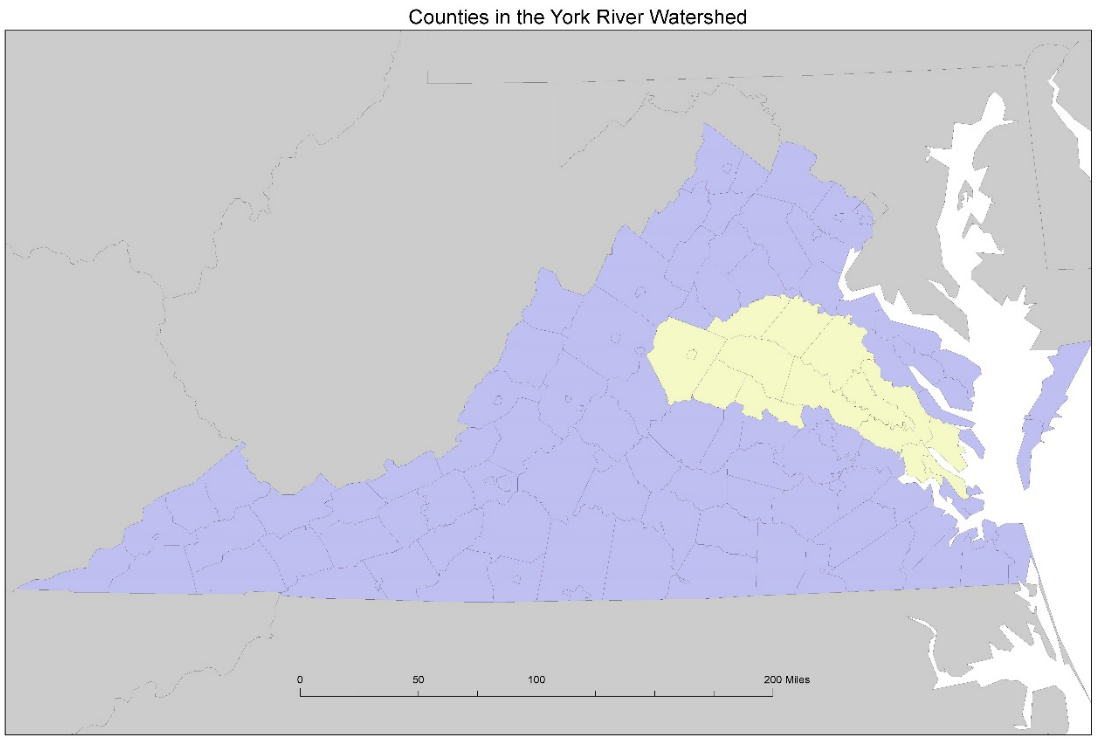

Figure 1. Location of the York River Watershed

The American Council of Science and Health states that the manufacture and industrial uses of PCBs in the United States date back to 1929 (https://www.acsh.org/news/2003/01/01/whats-the-story-pcb). With few exceptions (e.g. microscopic oils, electrical transformers and capacitors), the Toxic Substance Control Act of 1976 banned the use of Polychlorinated Biphenyls (PCBs) (Environmental Protection Agency, 2018). About 550,000 tons of PCBs were manufactured between 1929 and 1977. The major uses of PCBs include electrical insulating-coolant fluids in electrical transformers and capacitors, flame retardants, hydraulic fluids, surface coating materials, pesticide extenders, plasticizers, lubricants, adhesives, dyes, ink and dye carriers, carbonless copy paper, paint additives, sound damping materials, freezer and refrigerator motors, fiberglass, foam rubber, water proofing materials, impregnation fluids, and chlorinated solvents. Over 200 chemical processes can produce PCBs as by-products.

Polychlorinated Biphenyls (PCBs) have significant ecological and human health effects. Harmful effects of PCBs include neurotoxicity, reproductive and developmental toxicity, immune system suppression, liver damage, skin irritation, and endocrine disruption (Illinois Department of Health, 2009).

1.2 Sources and Types of Pollution in the York River Watershed

According to a Pulp & Paper Mill Effluent Environmental Fate & Effects by Dennis L. Borton, Timothy Hall, Robert Fisher, Jill Thomas, The York watershed is estimated to be 70% forested, 20% agricultural, and 10% urban (Borton, 2004). Human population growth, land-use, waste generation, and environmental pollution are largely related to point sources of pollution in the York watershed. Examples of these include landfills, wastewater treatment plants, abandoned mines, refineries, factories, gas stations, power plants, and other sources. What is sometimes unknown to the general public is that land use patterns in and around the York watershed impact the water quality. Not only the River itself but other rivers, lakes, streams, ponds, etc. that feed into the York River. Waste disposal or waste management sites, energy plants, landfills, composting sites, and atmospheric deposition may add harmful chemicals to natural waters. The public usually sees these sites as ways to curb environmental hazards but in fact, increase pollution due to particles from these areas seeping into the River. The rate at which the water moves, as well as addition of chemicals in to River, and the circulation of nutrients in the waters, are all affected by agricultural cultivation, the cutting down of forested land, land development and construction, the operation and maintenance of structures and facilities such as dams, bridges, and factories. In order to consider how much pollution is released into the York River Watershed, the Virginia Department of Environmental Quality has compiled a total of number of lbs. each known county releases into the environment thanks to the Emergency Planning and Community Right-to Know Act (EPCRA). Due to the amassing of data for the public, the Virginia Department of Environmental Quality was unable to provide a total amount data for the counties of Orange, King and Queen, and Gloucester. On-site releases of Nitrogen and Phosphorus in the York River Watershed are displayed in Table 1 (Virginia DEQ, 2017).

Table 1. Chart Showing the on-site release in lbs. from the counties in the York River Watershed (Virginia DEQ, 2017)

County Name	Total on-site Releases, lbs.	Total Air Releases, lbs.	Total Land Releases, lbs.	Total Water Releases, lbs.
Orange	N/A	N/A	N/A	N/A
Louisa	84,719	84,719	0	0
Spotsylvania	106	106	0	0
Caroline	221	0	0	221
Hanover	724,159	657,922	0	66,237
King William	7,093,969	0	0	0
James City	430,514	430,514	0	0
King and Queen	0	0	0	0
York	293,842	279,626	9,510	4,706
Gloucester	N/A	N/A	N/A	N/A

While point sources are regulated under the Clean Water Act, animal farms and agricultural runoff of nitrogen and phosphorus usually loosely regulated. Policies are made to encourage the adoption of agricultural best management practices (BMPs) to reduce the runoffs and include payments for environmental services. Nutrient trading between different sources can allow for significant cost savings and provide economic efficiencies. Wastewater treatment facilities must spend larger amounts to reduce nutrient pollution when compared to those of agricultural producers. Additionally, nutrient trading provides major benefits such as restoration of fishing habitats, reduced erosion, and the reduction of eutrophication.

Nutrients are critical in watershed environments for the development of organisms such as the staple food item phytoplankton for fish to eat and survive. High inputs of nutrients are also harmful and may have major impacts forming eutrophication. The nutrients that enter estuaries from the watershed increase nutrient concentration above the equilibrium. Higher levels of nutrients increase phytoplankton production which produces large amounts of algae. This in turn reduces the light availability in the water and increases sedimentation of organic matter. The new conditions of lower light availability reduce the ability for submerged aquatic vegetation to be productive and deliver oxygen into the water. After a short period of time, the increase in the decomposition of organic material can reduce the levels of oxygen, leading to anoxic conditions. This result of reduced light, oxygen, and habitat leads to massive changes in the species populations such as plankton and fish. In order to stop this from occurring, the Chesapeake Bay Foundation partnered with the Environmental Protection Agency (EPA) and the Virginia Department of Environmental Quality (DEQ) have been able to sort the sources of nitrogen and phosphorus pollution into certain categories. Those categories are shown in Figures 2 and 3.

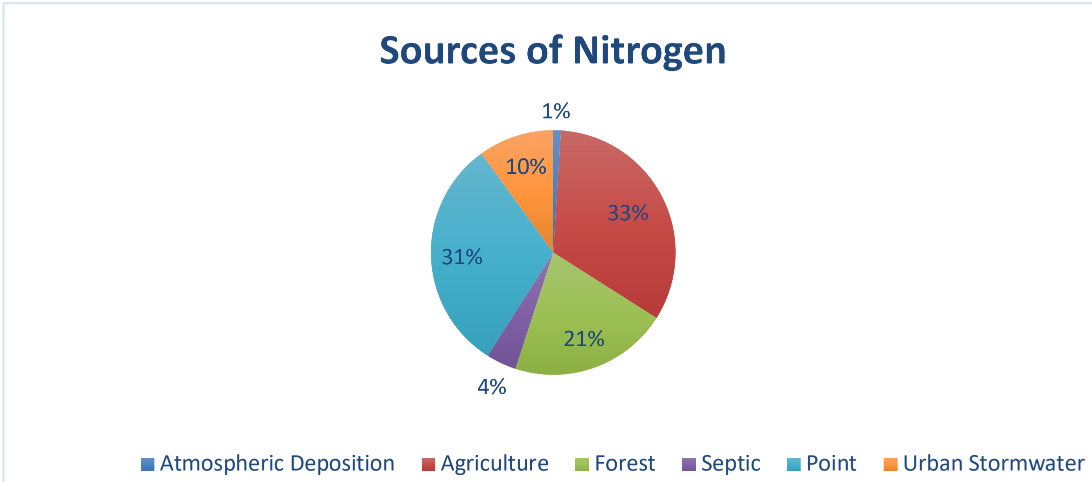

Figure 2. Sources of Nitrogen nutrient pollution affecting Chesapeake Bay. [Hampton Roads Planning District Commission]

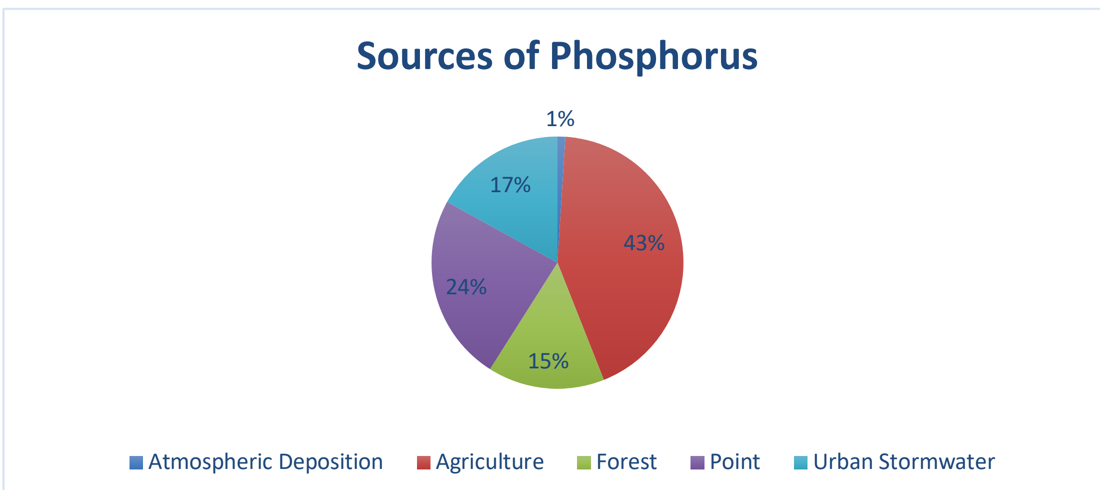

Figure 3. Sources of Phosphorus nutrient pollution affecting Chesapeake Bay. [Hampton Roads Planning District Commission]

1.3 Farm Pollution and Total Maximum Daily Load

Agricultural practices use nutrients as inputs in the production process, applied as components of fertilizers for the growing of their crops. Nutrients are also introduced in animal waste, both as fertilizer and as a byproduct of livestock. Nutrients not taken up by plants usually end up transported from the surface via runoff or through the ground via throughflow and ultimately end up in bodies of water, or in this case, the York River. Farm practices influence the amount of nutrients that enters the watershed. On December 29, 2010, the EPA established the Chesapeake Bay Total Maximum Daily Load (TMDL), as a comprehensive “pollution diet” for the Bay (EPA, 2019). The TMDL establishes a limit on nutrient pollution loads in the Bay and its watersheds. The loads are associated with desired water quality standards that are stated by the EPA. However, in a report by Claudia Copeland, a specialist in Resources and Environmental Policy in 2012, points out that “states can but are not required to regulate nonpoint sources to achieve goals set out in a TMDL” (Copeland, 2012). The TMDL set Bay watershed annual limits of 186 million pounds of nitrogen; a 25% reduction from current loads, 12.5 million pounds of phosphorus; a 24% reduction, 6.5 billion pounds of sediment per year; a 20% reduction (EPA, 2019). The problem is that the EPA does not prescribe how regulated parties must achieve these reductions. If a party does not achieve these reductions, what usually follows is a fine. The problem with these fines is that they are usually just slaps on the wrists for the major companies who would rather pay the fines rather than spending more money fixing the problem. Besides companies, states are responsible for developing their own Watershed Implementation Plans (WIP). The overall Bay TMDL is designed to bring pollutant levels in the Bay under state regulation standards, where the water is safe to fish and swim in. Specifically, the TMDL load reduction targets will meet quality standards for dissolved oxygen, water clarity, nitrogen, phosphorus, and chlorophyll, which can be used as an indicator of algae levels.

According to the United States Department of Agriculture (USDA), there are 43,225 farms in Virginia. The number of farms and average acreage for Virginia counties within the York River Watershed are shown in Table 2. Agriculture, being the largest contributor of non-point source pollution, has led to numerous steps being implemented to reduce the use and manage fertilizers are other important pollutants in the Bay. There are numerous ways to achieve this, known as best management practices (BMP). These include more nutrient management planning and planting of buffer zones. Implementation of Best Management Practices (BMPs) is a key component of state Watershed Implementation Plans (WIPs) to meet the TMDL goals (Chesapeake Bay TMDL, 2019).

Table 2. Number of Farms and Average Size Acre Size in Counties Along the York River

County Name	Number of Farms	Average Acre Size
Orange	417	228
Louisa	431	159
Spotsylvania	338	123
Caroline	222	279
Hanover	567	157
King William	90	527
James City	72	92
King and Queen	151	320
York	40	23
Gloucester	166	157

The highest proportion of earnings from agriculture these counties are grains, oilseeds, dry beans, dry peas, poultry, and eggs. Data from the USDA shows that the number of farms and number of total acres of farming have decreased steadily over the years in the counties around the York River, yet the rate of pollution of nitrogen and phosphorus have increased over fifty percent.

1.4 Nutrient Trading

In their September 6, 2006 meeting, The Virginia State Water Control Board approved Article 4.02 of the Code of Virginia establishing the Chesapeake Bay Watershed Nutrient Credit Exchange Program. While most nutrient pollution from non-point sources and is largely unregulated, companies along the York River can buy and sell their credit to a company that needs to buy them because they could not meet the pollution regulations. This in turn will allow for an economic solution by incentivizing companies to produce less pollution so that they can make a profit off it (Nutrient Trading, 2019). Larger companies tend to use this to escape fines or monetary costs to fix their sources of pollution they produce on a monthly or yearly basis. When it comes to farms, smaller farms tend to have issues with nutrient trading. They must weigh the costs of whether they can afford the BMPs and TMDLs. In a doctoral dissertation by Emily Pindilli (George Mason University, 2015) the average costs of BMPs can range from $380 to $453 for an average 50-acre farm.

1.5 Nitrogen and Phosphorus in the Watershed

Nitrogen and phosphorus are nutrients that are natural parts of aquatic ecosystems. Nitrogen is also the most abundant element in the Earth's atmosphere. Nitrogen and phosphorus support the growth of aquatic plants, which provide food and habitat for aquatic species in the York River. Each pollutant follows a certain cycle on the Earth, however one small change in the cycle could have lasting impacts on the surrounding environment (Figure 4). The phosphorus cycle is an extremely slow process that is often influenced by the weather of the surrounding area.

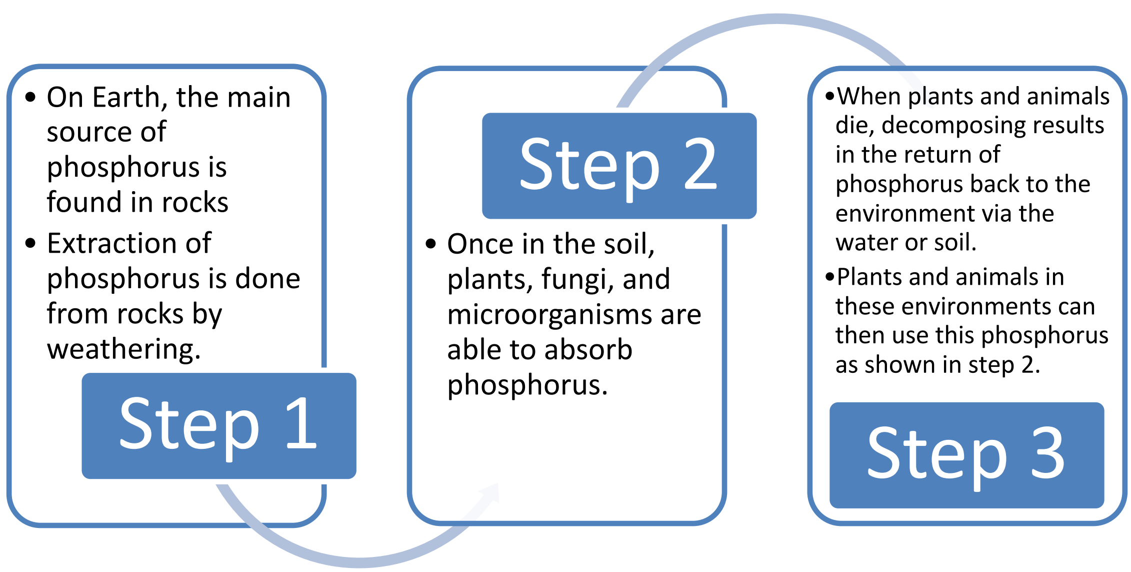

Figure 4. Steps of the Phosphorus Cycle

The nitrogen cycle on the other hand, is not as slow as the phosphorus cycle (Figure 5). However, there are more steps that are required in the nitrogen cycle. The Earth's atmosphere is about 78% nitrogen, about 21% oxygen, and about 1% other gases. Nitrogen is an inert in its gaseous form and is harmless until it forms bonds with other elements possibly making dangerous compounds such as nitrous oxide and gases.

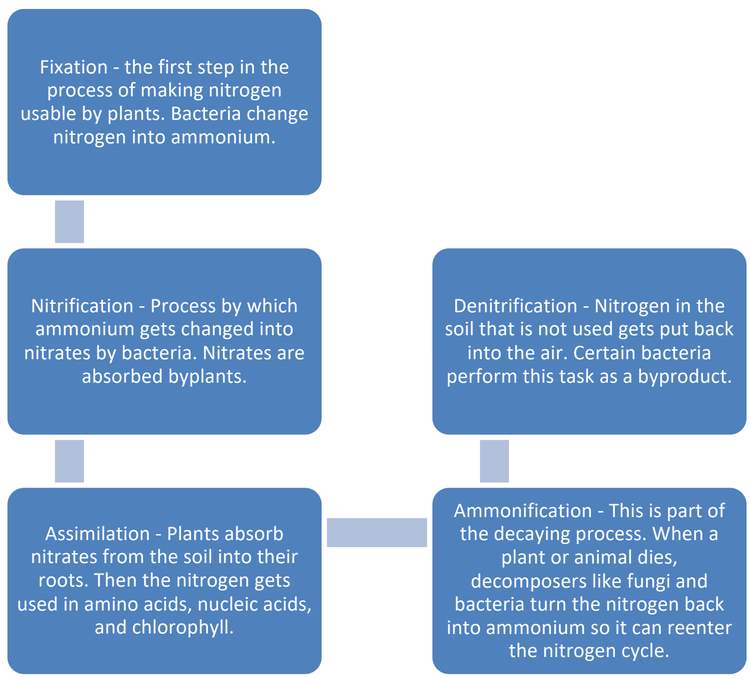

Figure 5. Nitrogen Cycle

Human activity has greatly altered the cycle. An example of this is done by adding nitrogen into the soil with fertilizer. The soil becomes dependent on the fertilizer for its nutrition, effectively cutting out the nitrification process.

1.6 Eutrophication

Eutrophication occurs when a body of water becomes overwhelmed with minerals and nutrients, which in turn produce excessive growth of algae. This process often results in the depletion of oxygen of the water. An example of eutrophication is the blooming of large patches of algae on the surface of the water. Eutrophication often occurs when the discharge of nitrogen or phosphorus flow into an aquatic system, or in this case, the York River. Eutrophication usually follows certain steps:

1. With farming, farmers apply more nutrients into the soil in hopes reap a greater harvest
2. Over time, some of the excess nutrients leach into the surrounding soil where they can remain until they get drained into the water body, usually by weather.
3. The excess nutrients combine in the water and form an algae bloom.
4. The algae bloom blocks the light of the sun from reaching the bottom of the river.
5. The plants beneath the algae bloom die because they cannot get sunlight to perform photosynthesis.
6. The algae bloom dies and sinks to the bottom of the lake where bacteria decompose the remains and use up the oxygen.
7. Because there is no oxygen, fish and other aquatic species, suffocate to death.

An article published by William G. Reay from the Virginia Institute of Marine Science shows that the York River has two areas estuarine turbidity maximum. An estuarine turbidity maximum, or Estuarine Turbidity Maximum (ETM), is the zone of highest turbidity resulting from turbulent movement of sediment and flocculation, a process where the particles disperse form larger-size clusters of particulate matter into smaller particles in a body of water. Research has also shown that with higher water salinity, eutrophication tends to occur easier even when the nutrient level in the water is not sufficiently high.

A way to curve the growth is to take the nitrogen and phosphorus from the water treatment plants and turn it into organic fertilizer and use that to sell to farmers allowing for the reuse of the particles without introducing new ones. Another method that is currently being used in France and the Netherlands is taking the particles and using it for road building along the waterways, decreasing the amount of building materials needed to construct new roads and cutting the cost of moving the particles to a new location so that they do not reenter the waterway.

2. Literature Review

After the Clean Water Act passing in the early 1970s, numerous studies in and round the Chesapeake Bay have been done to monitor its health. Since the publication of the Chesapeake Bay Report Card in 1986, research has been done at stations along each of the main watershed tributaries to monitor the state of the Bay and its health. The areas that are included in this report card are: overall health index, dissolved oxygen, nitrogen, phosphorus, chlorophyll a, water clarity, aquatic grasses, benthic community, blue crab, bay anchovy, and striped bass. Each of these areas are monitored by multiple stations up and down the tributaries near the Bay. While areas around the Bay and the Bay itself have been slightly improving in these categories, the York River has fallen behind and either decreased or stagnated in these categories since 1986.

Previous research from the 1986 report card has shown that the York River is the leader in the amount of phosphorus that it produces compared to the other tributaries. This in turn can be used to see why there has been a massive increase in dissolved oxygen and algae blooms along the York River. The River has seen a fifty percent increase in the amount of pollution that has entered the Bay in the past decade. This data seems to contradict the statement of the Chesapeake Bay Foundation stating that all areas of the Bay and its tributaries are seeing a reduction of pollutants and an increase in water health.

The Chesapeake Bay Program Science and Technical Advisory Committee (STAC), released a report detailing past research that has been done on the Chesapeake

Bay, in one such research article in the report, research has shown that the Bay has seen a significant increase in temperature in the water. At the mouth of the York River near VIMS pier, the temperature of the water has shown to be at least one degree Celsius warmer than the main Bay. The article further reports how the killing of the whelk, which are marine snails, is associated with the first recorded bloom of the toxin producing *Alexandrium monilatum* (Chesapeake Bay Foundation, 2009). *Alexandrium monilatum* is one of the species of red algae that can multiply into blooms that are sometimes called "red tide." Normally this type of algae is seen in warmer waters such as Florida or the Gulf of Mexico, but as research has shown, there has been an increase in water temperature in the Chesapeake Bay allowing for new plant and animal species to migrate and live in the area.

2.1 Chesapeake Bay Foundation

Emerging in the early 1970s, the Chesapeake Bay Foundation (CBF) noticed that Maryland and Virginia had just enacted their tidal wetland protection acts. The legislation was largely untested. In wetland permit hearings, CBF staff biologists began to press for strict enforcement of Maryland's Act, strengthening the hand of state government to do so. Within a couple of years, tidal wetland loss fell by more than 90 percent. In December of 1983, the Governors of Maryland, Virginia, and Pennsylvania and the Mayor of the District of Columbia met at a major conference that also included staff from CBF, other environmental organizations, and the research laboratories. Their task was to hammer out what would become the first interstate Chesapeake Bay Agreement. Foundation staff members participated in the negotiations for the goals hammered out in the Agreement.

They supported many of the program initiatives posed by the states, but when Virginia's financial commitment to the cleanup proved to be modest, CBF pressed for additional financial resources. Two months later, the state's General Assembly expanded the program.

Research completed on fisheries shows that crab populations dropped modestly in the 1990s. Ever since the 2000s, numbers increased slightly. The steady growth of underwater grasses and the shrinking of low-oxygen dead zones should help the crab population in coming years. Once abundant, American shad remained at all-time lows. The oyster population remained at low levels, and wild fishery harvests were down dramatically, especially in the northern part of the Chesapeake Bay. But some individual oyster restoration projects reached important milestones, including the restoration of some rivers' oyster population. In addition, oyster aquaculture continues to thrive, providing both ecological and economic benefits to the region.

Studies were also completed for the surrounding habitats of the York River. Underwater grasses increased slightly over the time period of 1986-2013. While we are still far short of our restoration goal, 2002 and 2009 marked the highest acreage of underwater grasses ever recorded. However, from 2010 to 2011, the acres of underwater grasses in the Bay and its tidal rivers decreased by roughly 20 percent. Experts agree that extreme weather conditions contributed to the decline. These weather conditions included Hurricane Irene and Tropical Storm Lee which lead to heavy rainfall.

The major part of the series of research projects done on the York River area deals with pollution. More significant rainstorms have occurred over the time period.

That meant that more pollution ran off farm fields and city streets into the Bay and its rivers and streams. That's what happened in the summer of 2011, with record rainfall levels resulting in the phosphorus, nitrogen, and water clarity scores dropping. It's a lesson for the future. However even with the additional pollution loads, there are signs that the Bay is better able to deal with the extreme weather. For instance, a recent study suggests that the Bay is starting to help itself by slowing down the process that exacerbates the summer dead zone, leading to more oxygen in bottom waters.
Storms and algal blooms spurred by these additional nutrients disrupted water clarity. That was a set-back. The federal government could undermine progress. The Trump administration plans to roll back Clean Air Act regulations that would have reduced nitrogen loads to the Chesapeake Bay.

Each year the CBF gives scores based off the rating of each section of its report in pollution, fisheries, and habitats. While certain types of fish have seen growth over the course of the 1986-2013 period, oyster and shad populations have stayed relatively low. Pollution has increased in the average nitrogen per year; however, the average phosphorus levels have decreased over the time period.

2.2 Environmental Protection Agency and Watershed Pollution

Environmental Protection Agency (EPA) works with federal and state agencies, non-profit organizations and academic institutions to coordinate restoration of the Chesapeake Bay and its watershed through the Chesapeake Bay Program, a unique regional partnership including EPA, six states, and the District of Columbia. EPA researchers are helping with past research projects. They and their partners are applying rigorous scientific methods to quantify the effects and benefits of York River restoration. In a foundational study, agency researchers and their collaborators explored the current literature of stream restoration studies to develop a typology of approaches and analyze their impacts on nutrient retention. The work provided important insight for those planning restoration projects as well as the need for additional, long-term studies to inform future progress. EPA ecologist Paul Mayer has been conducting some of the longest running studies of stream restoration to date, much of it deals the Chesapeake Bay watershed. He and his partners are particularly interested in assessing and monitoring levels of key pollutants before and after restoration, with a focus on nitrogen and phosphorous. Mayer also serves on an expert panel assembled by the Chesapeake Stormwater Network to update and adjust the protocol to define nutrient removal rates for stream restoration projects (EPA, 2019). The EPA has explored the effectiveness of a technique called regenerative stormwater conveyance (RSC) that triggers filtration by routing stream flow over a series of shallow pools lined with substrates of permeable sand overlying a mixture of organic materials such as wood chips. This work has been done in laboratory studies simulating the techniques that are used in the streams. Even though regenerative stormwater conveyance started to be used at the end of the time period in this study, this was one of the first studies known to combine different field studies with laboratory analysis. The researchers were able to carefully compare different conditions and composition of sand mixtures. What they found is that regenerative stormwater conveyance can be an important choice for stormwater management and one of the best management practices for nutrient reduction. However, this approach along certain points of the York River can work, it does not work across all parts of the York watershed due to different conditions. One major important finding is that there may be tradeoffs in better managing nitrogen versus phosphorous because variations to the RSC approach may improve nitrogen retention while allowing phosphorous to travel faster down the York River. Because of this, researchers need to carefully select which restoration approaches to implement and determine what is more effective without causing any additional negative impacts.

2.3 WorldMinds

WorldMinds: Geographical Perspectives on 100 Problems is a book that includes 100 short essays reveal and exemplify the conceptual and topical richness of contemporary North American geography. The diverse chapters of WorldMinds well illustrate some of the key geographical perspectives that contribute usefully to the broader understanding of common problems. In chapter 66, “Non-Point Sources: Historical Sedimentation and 20th Century Geography” by Dr. L. Allan James, he describes that with the passage of the Clean Water Act Amendment in 1987, study of non-point sources has grown in relevancy. The amendment represented the first substantial federal mandate to study, manage, or migrate off-site impacts of land use. In chapter 92, “Geospatial Contributions to Watershed-Scale Surface Water Quality Modeling”, Drs. J. M. Shawn Hutchinson, John A. Harrington Jr., Luke J. Marzen describe GIS and remote sensing has allowed geographers a better way to map areas that are vulnerable to non-point source pollution. They also describe focusing on pollutant transport and mapping them much like what is being done in this research with My study focusing on the GIS plotting of buoy data. Mapping pollutant transport allows for the increase in prospects for achieving water quality management goals in the most effective way considering costs of doing so.

2.4 Richmond School of Law

In a paper published by Noah M. Sachs, titled *A Strategy to Protect Virginians From Toxic Chemicals,* provides the emergence of the Emergency Planning and Community Right-to Know Act (EPCRA) of 1986. This Act passed by Congress in the wake of the 1984 Union Carbide plant disaster in Bhopal, India. This Act is used in full effect in Virginia because citizens have a right to know about the release and the management of toxic chemicals in the Commonwealth. The Act requires that facilities that manufacture, process, or otherwise use any of nearly 600 toxic chemicals and 30 chemical categories report annually on the amount of each toxic chemical released from their facilities. Due to EPCRA, data was available about what industries were producing the largest amounts of Nitrogen and Phosphorus along the York River. Due to the data being released, the Commonwealth found that the number of Nitrate Compounds released into the water totaled 16,249,549 lbs., which makes up 97% of all chemicals released into the water. Two key facts listed in the paper by Sachs are that the York River ranks 41st among national waterways in releasing Cancer Causing Chemicals into the water (6,524 lbs.) and ranks 46th among national waterways with releasing developmental toxins into the water (1,320 lbs.).

2.5 USGS

In a study by USGS biologist Barry H. Rosen, when dealing with algae that at levels about one-half as salty as seawater, Microcystis aeruginosa cell walls began to weaken and leak their toxin, called microcystin. The research also found that phytoplankton biomass and productivity generally decline through the late fall and early winter in association with reduced water temperatures, available nutrients and light.

2.6 Hypothesis

It is hypothesized that, over the past two decades, Pollution in the York River has increased by over fifty percent as a result of increased human development in the region. The following section outlines the data that will be used to explore this hypothesis and to determine whether or not it is supported by the available data.

3. Data and Methodology

This chapter presents the Research Method which divided into research design, counties and sample, instrumentation, validity and reliability, data collection and data analysis. This research used experimental design to investigate the factor and the ways to improve pollution among the counties in the York River watershed.

3.1 Research Design

The design of this research is quantitative design, investigating the effects of five water quality variables; namely, nitrogen, phosphorus and other sources of pollution; on the dependent variable human development. This section will explain the design of this study.

3.2 Counties and Sampling Design

This research is conducted in south-eastern Virginia. This research sample comprised the counties of Albemarle, Caroline, Charlottesville, Fluvanna, Gloucester, Goochland, Hanover, James City, King and Queen, King William, Louisa, New Kent, Orange, Spotsylvania, York, and Williamsburg.

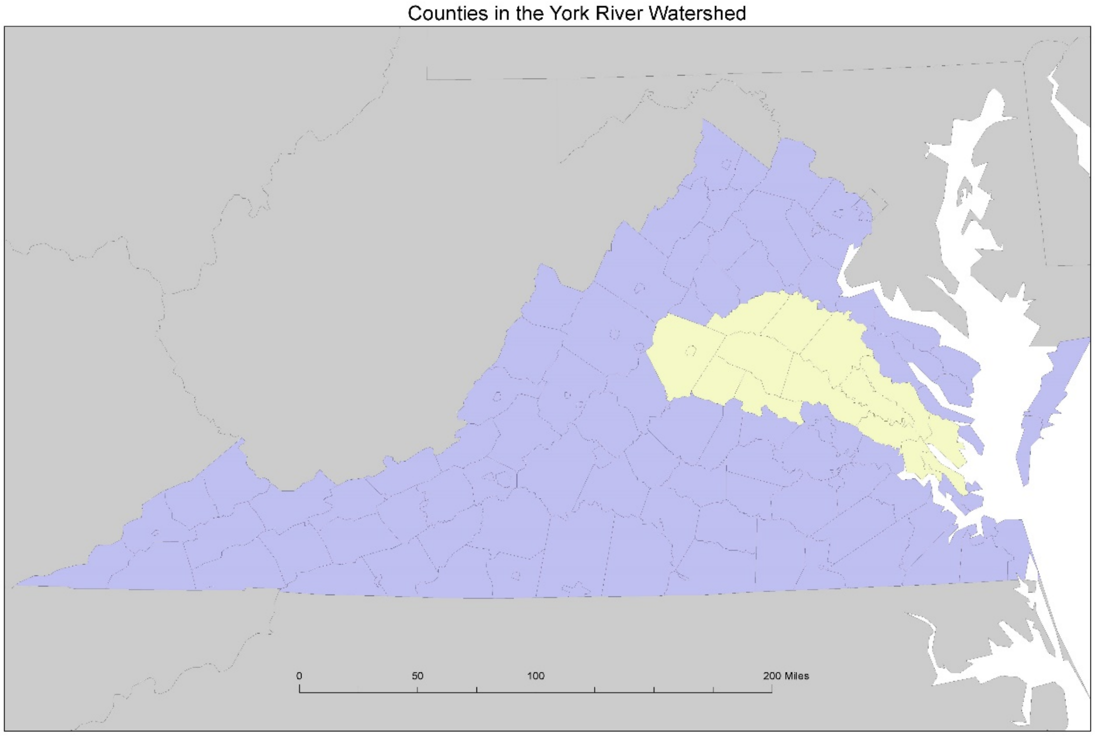

Figure 6. York River Watershed.

This research includes both private and public human development and their projects, as well as the loss of habitat for the local wildlife.

3.2.1 Counties/Major Cities

The counties of this study refer to the total number of counties and major cities and their data in the form of a thorough count of all elements the findings of the study seek to represent. A clearly defined population ensures that the results and findings apply to the correct category of elements in the watershed. Considering that the study basically assesses the factors that affect the sources of pollution in the York River watershed and other ways of combating pollution through research and environmental works, the population of the study is all areas of York River Watershed. In order to be able to pay closer attention to sources of pollution in a thorough assessment of human development, the multiple case study strategy presents the sources of the two selected pollutants that are the focus under study. Whereas one pollutant is large and widely known in the York River watershed, the other is comparably small in knowledge and destructive capabilities.

3.2.2 Sampling method

Due to limited resources, there is almost always the need to sample more areas for any investigation. It may be added that it is not practical to use the Bay area to conduct the survey since that process takes a lot of effort and consumes a lot of time. Therefore, we are focused on the "sample", or York River part picked from the whole set of the Bay data. The size of the sample may impact on the extent of significance of relationship between variables of the study. Whereas a small sample size may not be representative, a sample size too large can create the perception of significance of a non-existing relationship. Irrespective of these, it is representative to select a sample size appropriate for the study with the use of a method that offered each other equal chance of selection. It must be noted that the sources of pollution were conveniently selected due their easy access to the data by the researcher.

3.3 Sources of Data Collection

For this research, there are two main sources of data exist. These sources of data are primary and secondary data sources. Both data sources contribute to the objectives and helped generate conclusions and recommendations.

3.3.1 Primary Sources

Primary data is data that is collected by a researcher from first-hand sources, using methods like surveys, interviews, or experiments. It is collected with the research project in mind, directly from primary sources. The buoy data is primary data, collected by the University of Maryland Center for Environmental Science.

3.3.2 Secondary Sources

Secondary Data Sources may be referred to as data that is not originally gathered by the study and help in some way to arrive at a conclusion for the study. Secondary data sources are derived from data that is already in existence. Secondary data for this study was acquired from a variety of online databases of journals, books, year projects by past research of organizations. Secondary data was very instrumental in gathering primary data to in the bid to find solutions to the study's research questions. Secondary data sources for this study include the WorldMinds book, Richmond School of Law, EPA, and USGS.

3.4 Data Analysis Techniques

Quantitative data analysis was done with the help of ArcGIS software version 10.5.1, Microsoft Office Excel 2017, and Abode Illustrator. Quantitative data collected was first entered Microsoft Excel 2017 to pave way for easy analysis. Descriptive aspects of the findings were presented with the help of tables and graphs alongside other descriptive statistical indicators. Qualitative data was entered in by the researcher. This significantly reduced the amount of data available for analysis. The data was divided to two parts which is part one and part two. The part one explains about nitrogen, phosphorus, and other pollution sources. Firstly, we count the number of recording buoys, and sort them according to the amount of nitrogen and phosphorus pollution levels. Secondly, we divided the data to three main things according listed in research question.

3.4.1 Central Feature tool

In ArcGIS, this feature is associated with the smallest accumulated distance to all other features in the dataset is the most centrally located feature. This feature is selected and copied to a newly created Output Feature Class. It is possible to have more than one feature sharing the smallest accumulated distance to all other features. When this happens, all the features are highlighted in the Output Feature Class. Accumulated distances in this research are measured using Euclidean distance.

If the focus was to map the county with the largest number of farms or county with the greatest farm average size by acres for example, ArcGIS could calculate the central feature for a multiple polygon feature class, those variables to identify which part of the watershed is the center. The Central Feature tool is useful for finding the center when you want to minimize distance (Euclidean or Manhattan distance) for all features to the center.

3.4.2 Trend Surface Analysis

Trend surface analysis is to represent a surface by a simple polynomial function so that we can easily understand its global structure. Trend surface analysis describes the spatial structure of a surface by a small set of variables and their associated coefficients. It uses geographic coordinates as predictors in regression analysis and helps determine what larger trends exist (in this case, at the scale of the entire watershed). For example, in this research, the state of Virginia population map has a trend is strong east-west, but not north-south.

3.5 Limitations of methodology

It may be observed first and foremost that the present study is geographically limited and confined to the York River watershed. An important limitation however is the limited amount of time offered to complete the present study by the researcher. A timetable was maintained in order to overcome such limitations pertaining to interim submissions and maintenance of other milestones necessary to complete the study in time. It was critical to establish a timetable with pre-determined achievable milestones to keep track of vital activities that are fundamental in meeting necessary deadlines of project. The research's timetable of twenty-seven years also served as a major obstacle in this area. Other implications of the methodology to findings are discussed in the next chapter.

4. Results and Discussion

In this chapter, the primary and secondary data collected are summarized. Whereas quantitative data collected with the help of the research buoys is presented with the help of tables, graphs and brief explanations, qualitative data narrated concurrently will answers some of the research questions, as discussed in the previous chapter. Where relevant, relationships are tested for significance between variables towards providing answers to the proposed research questions. The chapter begins with a discussion of the counties with their primary and secondary data collection; it then proceeds to discuss findings in context of the research questions. After the presentation of data findings, discussions and implications of findings to theory and practice are also discussed. Other implications of the methodology and limitations are as well discussed.

4.1 Counties

This section addresses impacts, and data collected for the watershed which includes fourteen counties and the independent cities in the watershed. The counties determine the land usage within their jurisdictions and have individual impacts on the water quality within the watershed. Part of analysis includes a calculation of the farm density in each country, which is included below. The York River and its tributaries is shown in Figure 7 and the population density of the State of Virginia is shown in Figure

8. A dot density map of the farms is shown in Figure 9. It shows that most Virginia's farms are in the western part of the state.

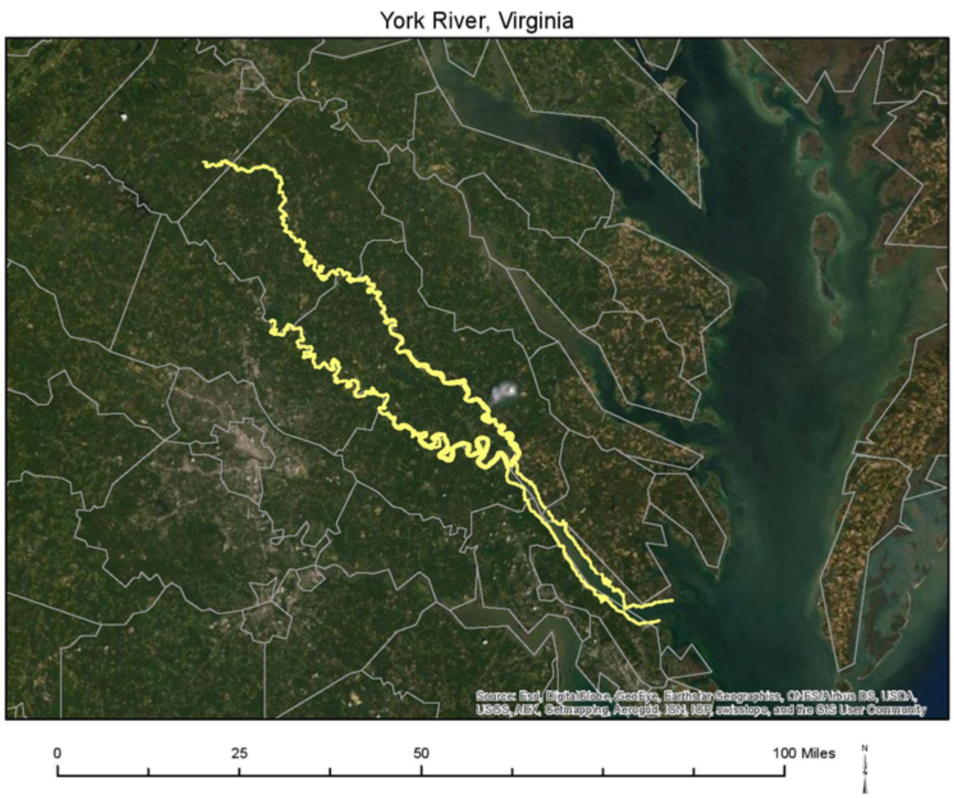

Figure 7. Counties Along the York River

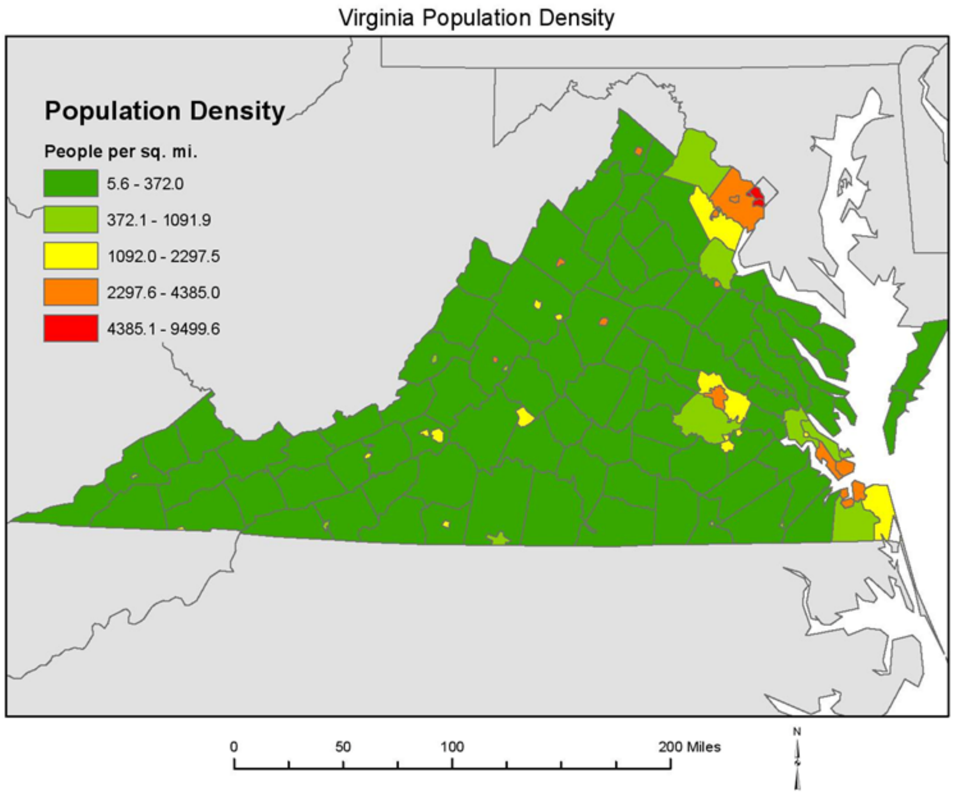

Figure 8. Virginia Population Density

Virginia Farm Dot Density

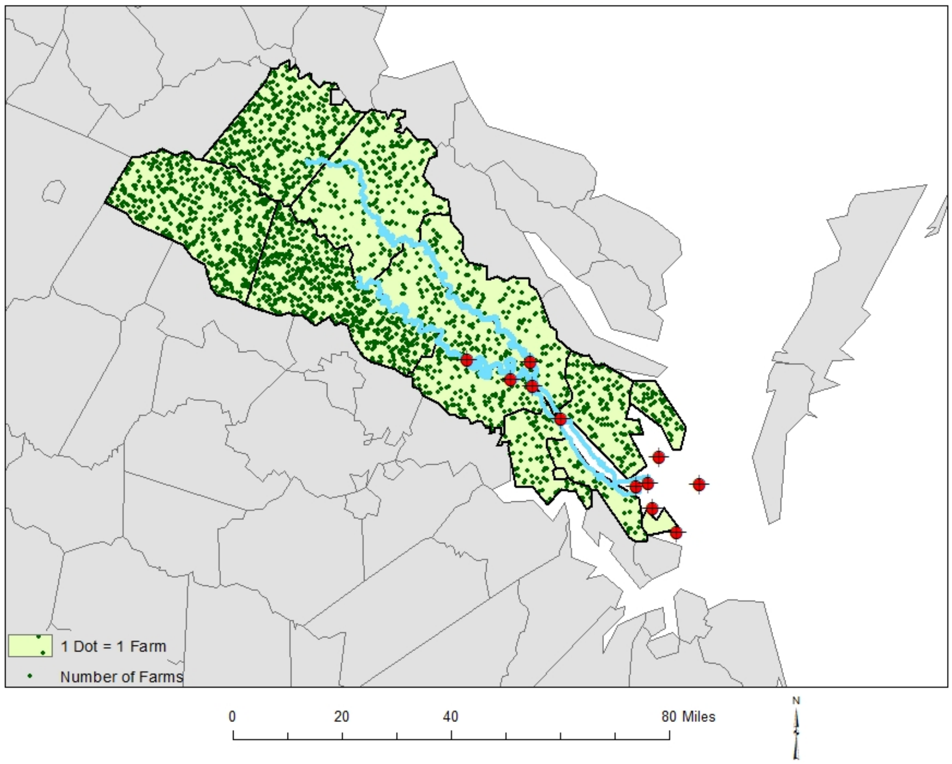

Figure 9. Virginia Dot Density

4.2 Descriptive data:

Key areas of investigation in the research that affect pollution levels include human, physical, and economic factors. Data presented is therefore presented under these subheadings. There was the need to investigate the level of internal consistency between items under the same dimensions. Figure 10 shows the placement and location of the buoys, which are the source of water quality measurement data.

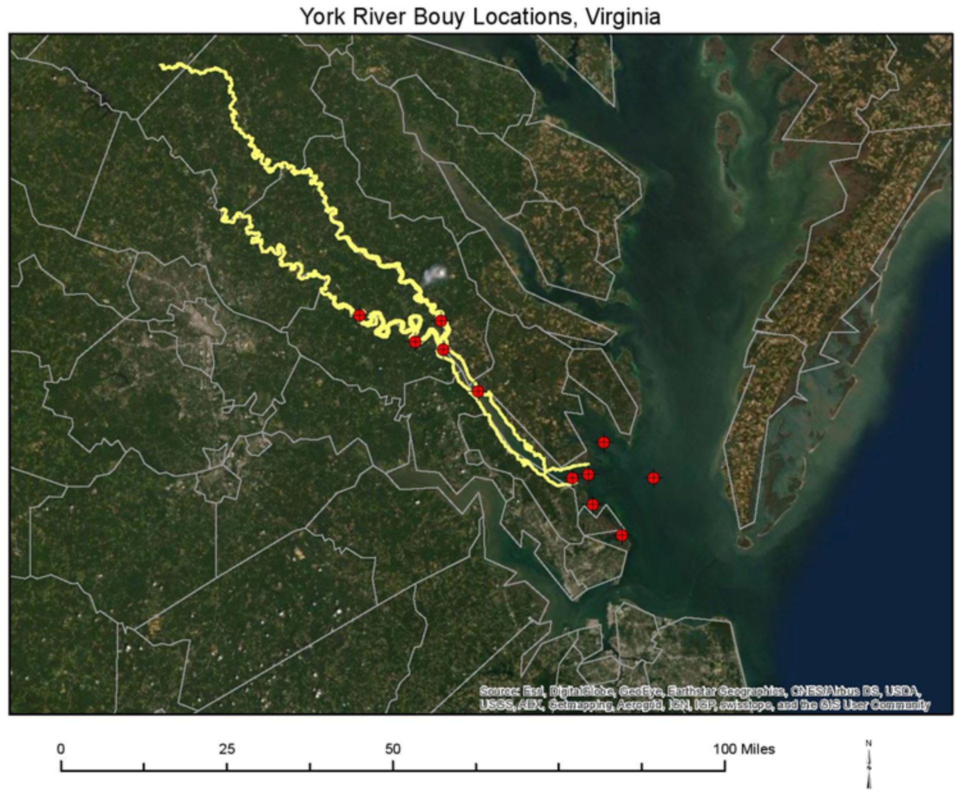

Figure 10. York River Buoy Locations

4.3 Nitrogen

Figure 11 shows the nitrogen data at the eleven buoy locations. The area in which the rivers converge is where the most concentrations of nitrogen are with an outlier just north of Hampton.

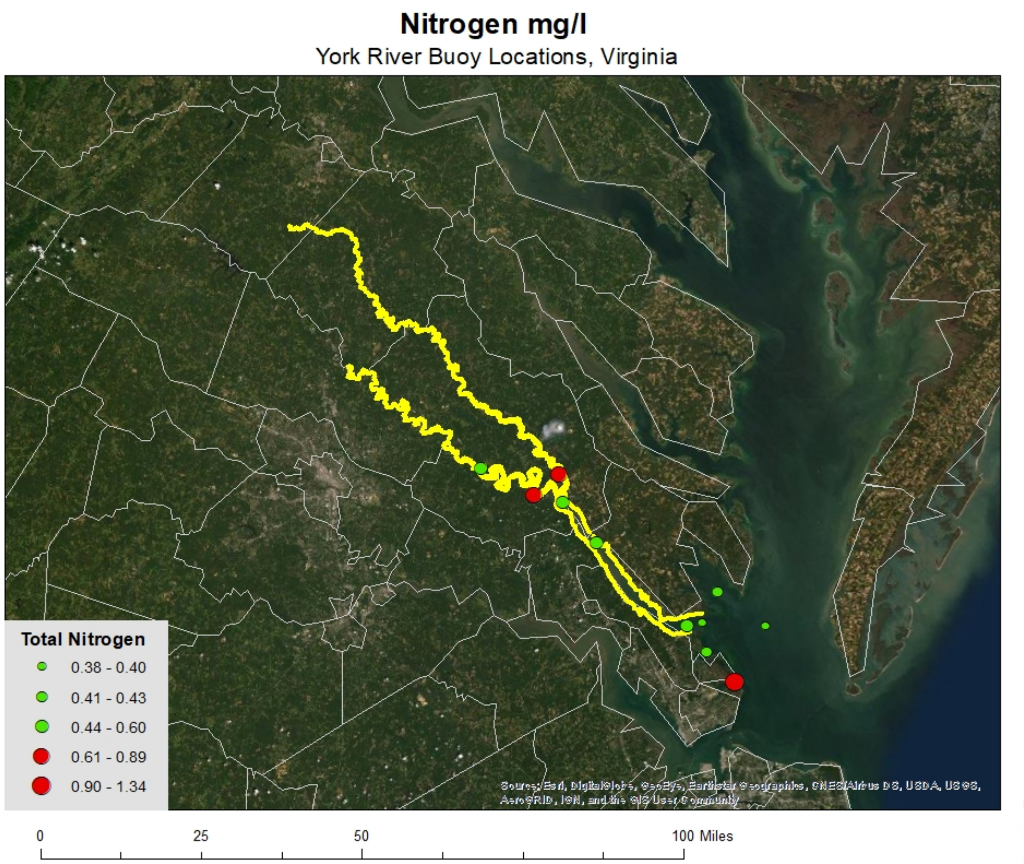

Figure 11. York River Watershed Nitrogen, Buoy Sample Locations, mg/L

The University of Maryland Center for Environmental Science has stated that for each reading of the buoy that the limit is .6 mg/l. Appropriate reference levels of nitrogen are 2.2 mg/L total per month. In general, most fish species will grow and thrive within a nitrogen with values below 2.2 mg/L (ppm). If levels go above 2.2 mg/L per month they may stop feeding, become stressed and possibly lead to catastrophic fatalities. Figure 12 shows levels over the 27-year period, with 21 years out of compliance.

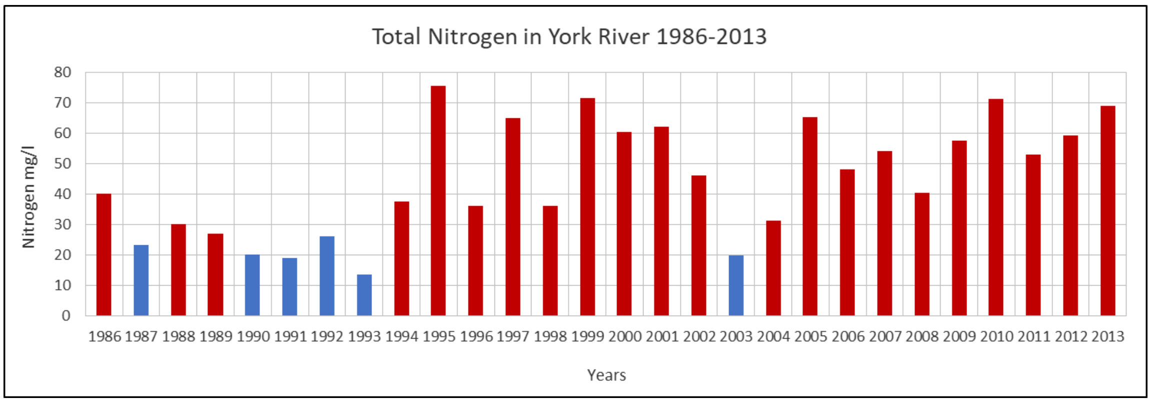

Figure 12. York River Watershed Total Nitrogen, 1986-2013

4.4 Phosphorus

Figure 13 shows the phosphorus data at the eleven buoy locations. The area in which the rivers converge is where the most concentrations of phosphorus are.

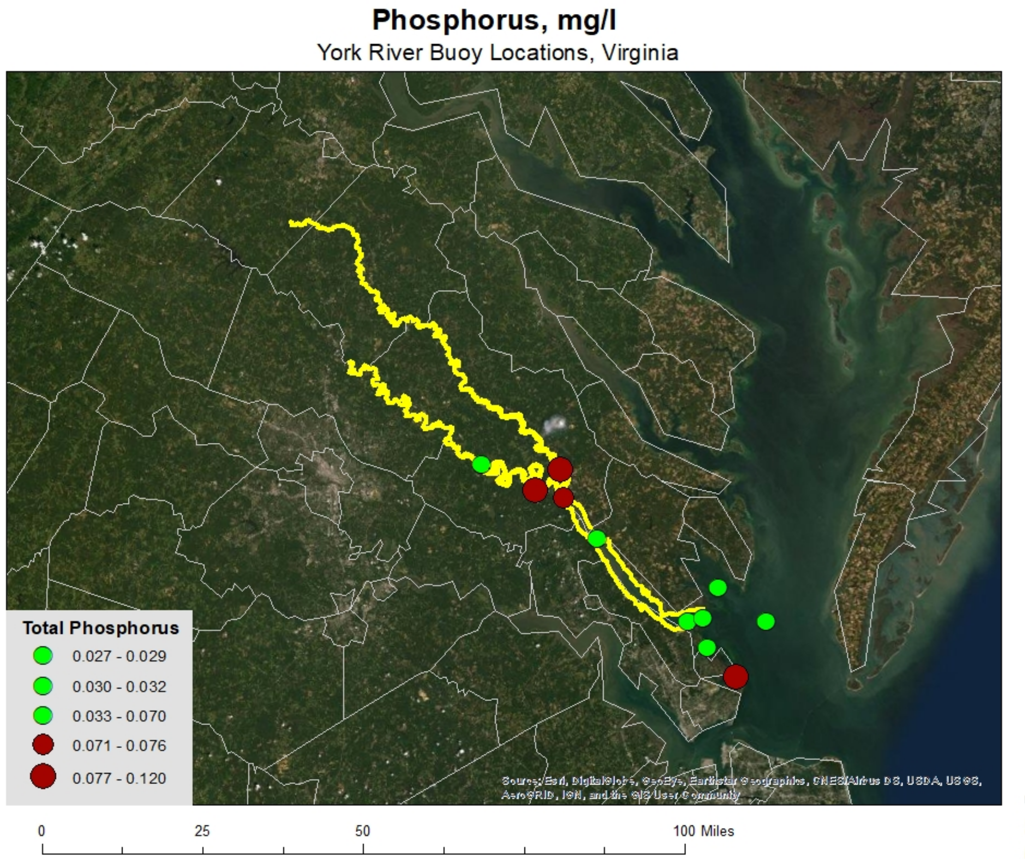

Figure 13. York River Watershed Phosphorus, Buoy Sample Locations, mg/L

The University of Maryland Center for Environmental Science has stated that for each reading of the buoy that the limit is .7 mg/l. EPA limit for nitrogen in the watershed 1 mg/L total phosphorus as a monthly average. In general, most fish species will grow and thrive within a nitrogen range of around <1 mg/l (ppm) per month. However, if levels go above 1 mg/L per month they may stop feeding, become stressed and possibly lead to catastrophic fatalities. Figure 14 shows levels over the 27-year period, with 25 years out of compliance.

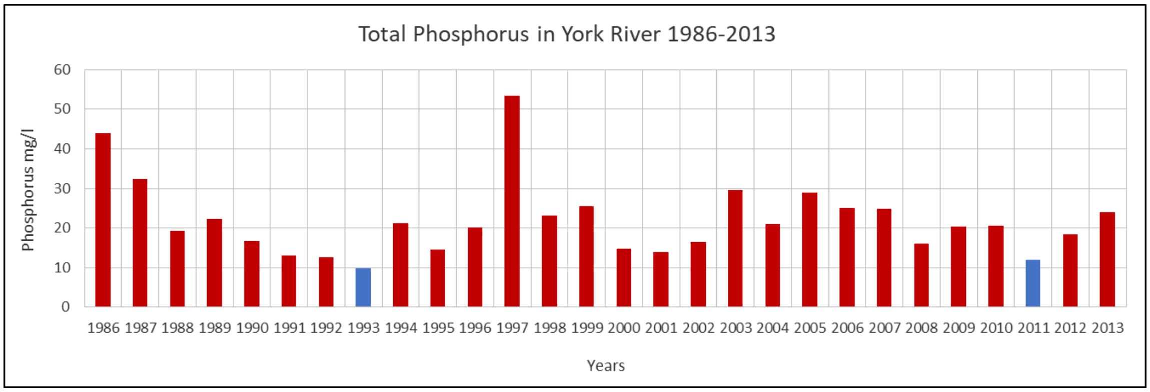

Figure 14. York River Watershed Total Phosphorus, 1986-2013

4.5 Dissolved Oxygen

Figure 15 shows the dissolved oxygen data at the eleven buoy locations. The area in which the York River enters the Chesapeake Bay is where the most concentration of dissolved oxygen is.

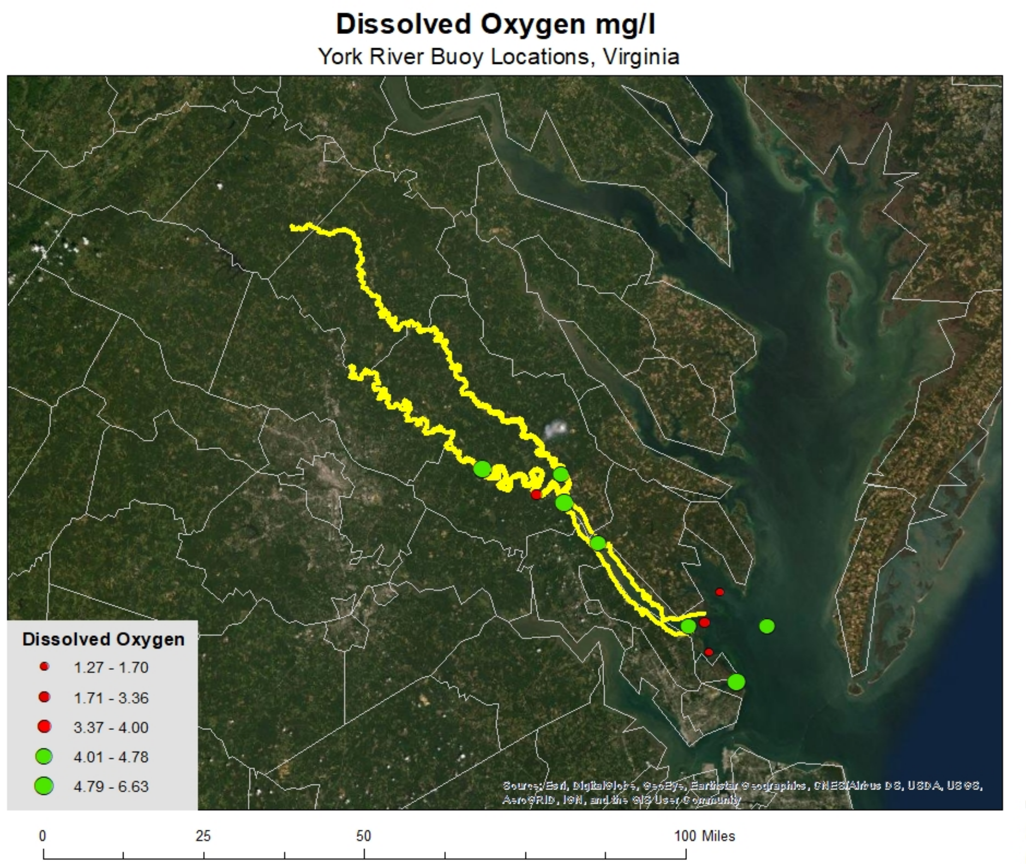

Figure 15. York River Watershed Dissolved Oxygen, Buoy Sample Locations, mg/L

The University of Maryland Center for Environmental Science has stated that for each reading of the buoy that the limit is <4 mg/l. The average range of dissolved oxygen is 5-12 mg/L (ppm) per month. In general, most fish species will grow and thrive within a DO range of 5-12 mg/L (ppm). However, if levels drop below 4 mg/L per month they may stop feeding, become stressed and possibly lead to catastrophic fatalities. Figure 16 shows levels over the 27-year period, with 11 years out of compliance.

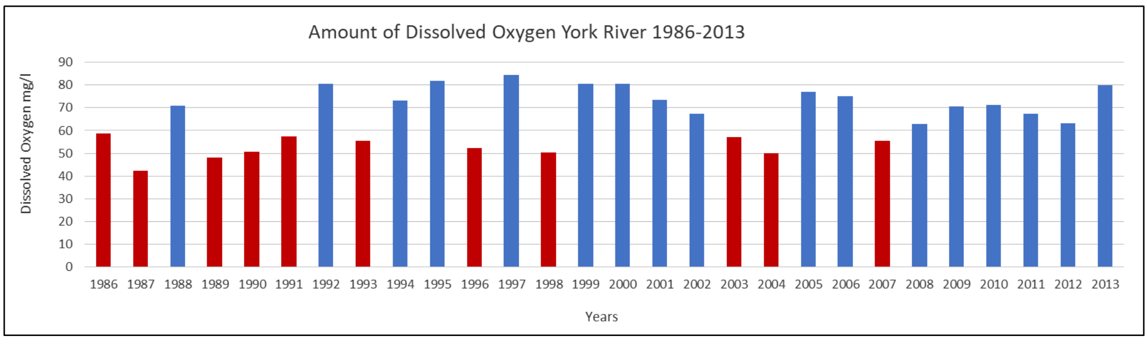

Figure 16. York River Watershed Dissolved Oxygen, 1986-2013

4.6 Water Clarity

Figure 17 shows the water clarity data at the eleven buoy locations. The area in which the York River enters the Chesapeake Bay are where the higher levels water clarity are.

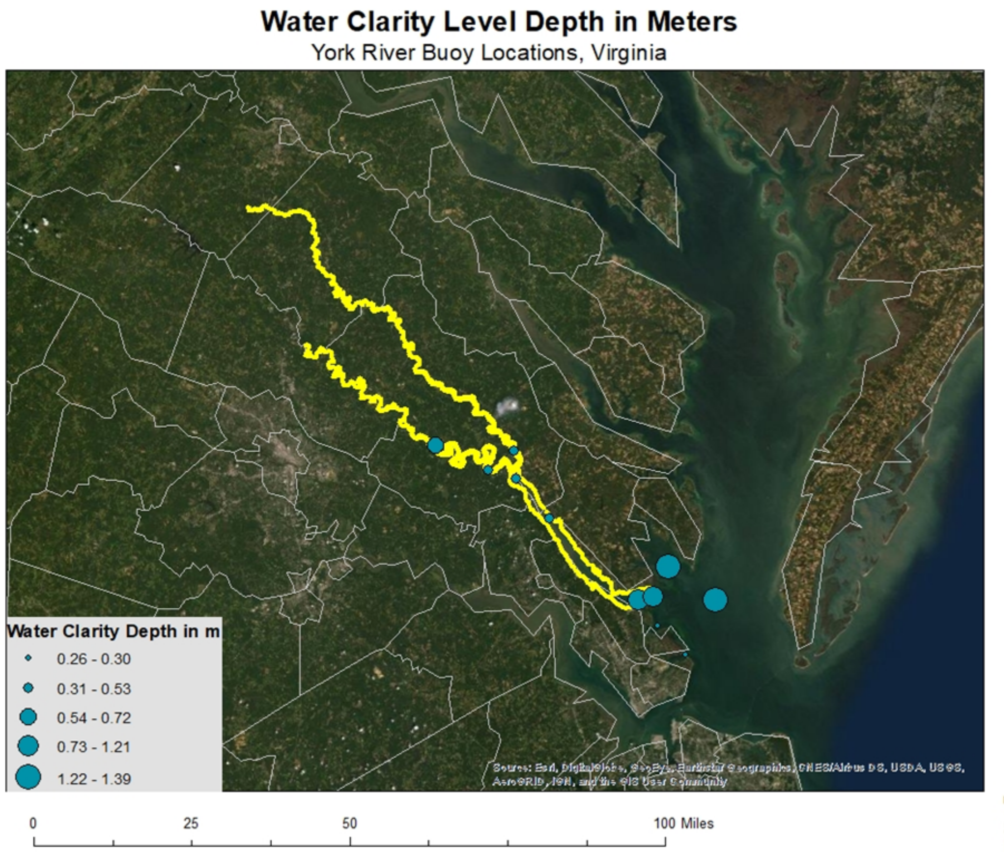

Figure 17. York River Watershed Water Clarity, Buoy Sample Locations, in meters

The University of Maryland Center for Environmental Science has stated that for each reading of the buoy that the limit is areas with <2 m, which is considered eutrophic water. The average range of water clarity is 2 m for each month, which is used to derive an annual water clarity estimate (Figure 17). In general, most fish species will grow and thrive water clarity range of above 2 m. However, if levels drop below 2 m per month they may stop feeding, become stressed and possibly lead to catastrophic fatalities. Figure 18 shows levels over the 27-year period, with all years out of compliance. However, 2013 was not measured.

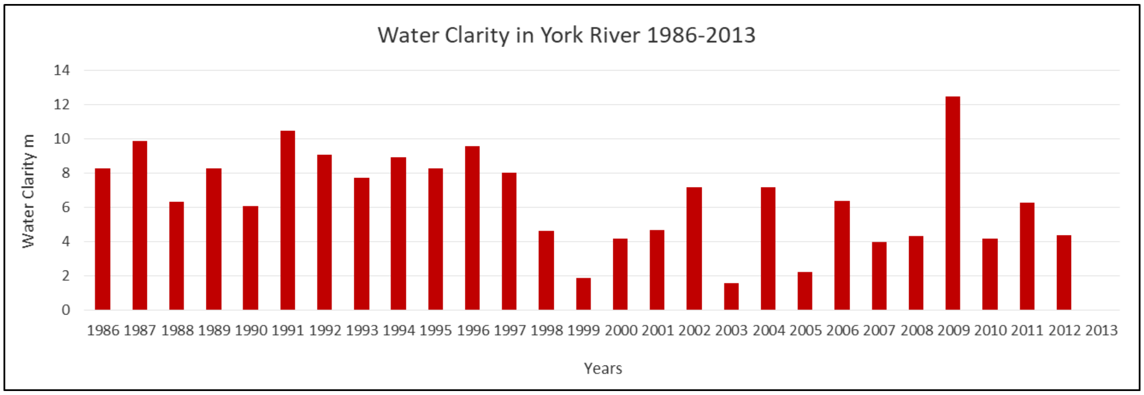

Figure 18. York River Watershed Water Clarity, 1986-2013

4.7 Chlorophyll

Figure 19 shows the chlorophyll data at the eleven buoy locations. The area in which the rivers converge to the area in which the York River enters the Chesapeake Bay are where the most concentrations of chlorophyll are.

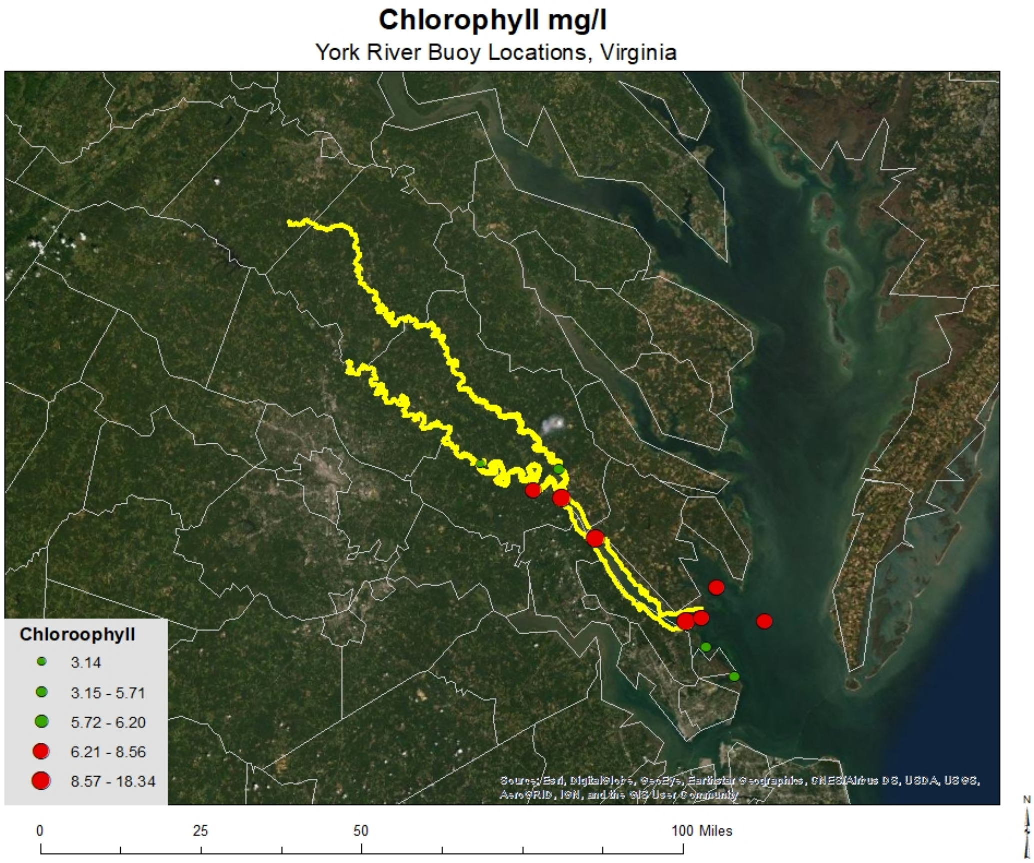

Figure 19. York River Watershed Chlorophyll, Buoy Sample Locations, m

The University of Maryland Center for Environmental Science has stated that for each reading of the buoy that the limit is 6.2 mg/l. The average range of chlorophyll is 15 to 20 mg/L per year. In general, most fish species will grow and thrive water clarity range below 15 to 20 mg/L (ppm). However, if levels go above 15 to 20 mg/L per year, they may stop feeding, become stressed and possibly lead to catastrophic fatalities. Figure 20 shows levels over the 27-year period, with 26 years out of compliance.

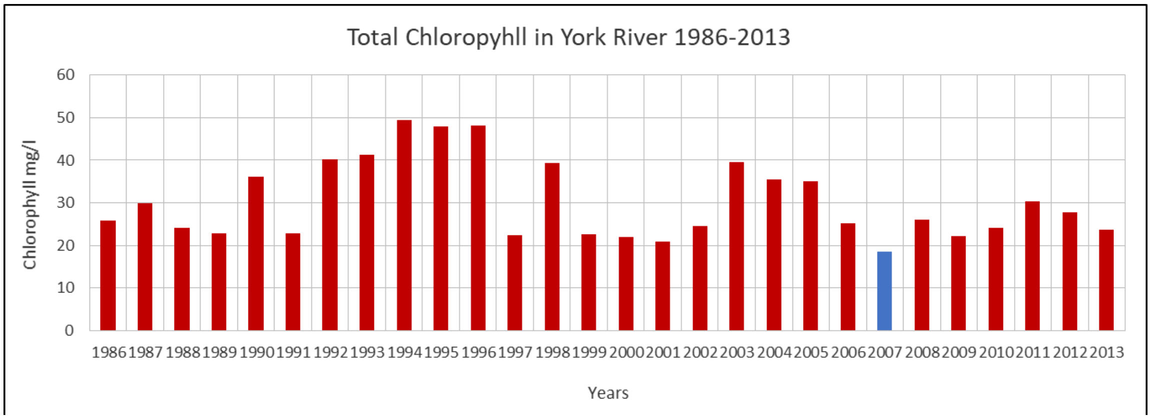

Figure 20. York River Watershed Chlorophyll, 1986-2013

4.8 Trend Surface Analysis

Trend surface analysis is a statistical technique that offers a simple geographic extension to regression analysis, where the location components of the observations are used as independent variables to test the significant of the observation locations. The independent location variable components (latitude, longitude) are used to predict the value at that location. The value is used as the dependent variable. This analysis tests the suite of water quality variables measured at the buoy locations (nitrogen, phosphorus, chlorophyll, water clarity) to determine whether geographic location is a significant predictor. The significant predictors (and their coefficients) can be interpreted as direction slope coefficients for a plane fit through the data. Chorley and Haggett (1965) presented the general technique, and Bailey and Gatrell (1995) provide useful models and examples of the technique. The trend surface procedure used in this work is the standard first-order model, where location variables are used in the standard form. Bailey and Gatrell cover several versions of trend surface analysis where the predictors are changed to create a higher-order polynomial fit for the surface. While these higher-order models are often better fits, they are difficult to interpret.

4.8.1 Virginia Cities and Population

A general trend surface analysis for the Cities of Virginia is shown below. As seen in figure 21, the largest cities are in the southeast, and there are generally few cities of any size in the western parts of the state. When these cities are modeled with a trend surface using a first-order model, we would expect a simple plane to be sloped from the southeast (high point) to the west and to a lesser extent, to the north, where the presence of several small cities creates both low and high values.

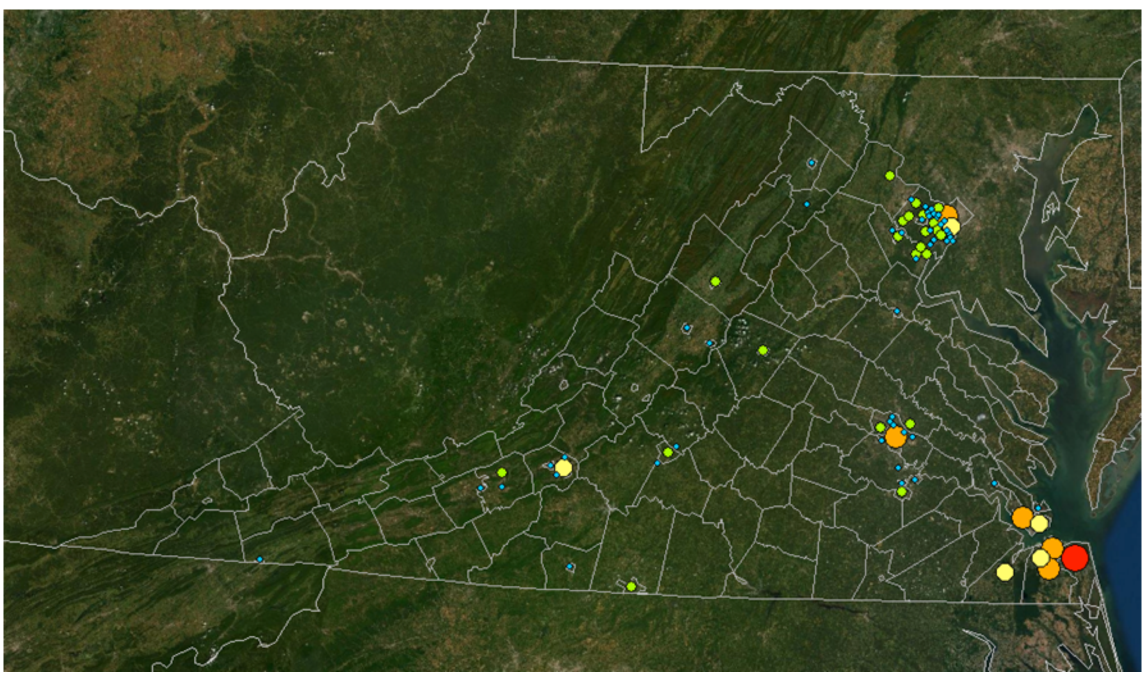

Figure 21. Cities in Virginia, 2014 (source: Price, Mastering ArcGIS, 8th edition)

Table 3. Trend Surface Analysis of Virginia City Population

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.52482583							
R Square	0.27544215							
Adjusted R Square	0.25662246							
Standard Error	58187.7255							
Observations	80							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	9.9108E+10	4.9554E+10	14.6358537	4.1003E-06			
Residual	77	2.6071E+11	3385811397					
Total	79	3.5982E+11						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-530739.79	115090.008	-4.6115193	1.5629E-05	-759913.27	-301566.3	-759913.27	-301566.3
POINT_X	0.3761507	0.07568851	4.96972	3.9556E-06	0.22543562	0.52686578	0.22543562	0.52686578
POINT_Y	-0.2662964	0.07222143	-3.687221	0.00042017	-0.4101076	-0.1224851	-0.4101076	-0.1224851

As noted in Table 3, the trend surface analysis for Virginia city population shows that the location variables used as predictors are both highly significant, with the X direction (east-west) showing a t test statistic of 4.96 and associated p-value of 0.0000039556, and the Y direction (north-south) showing a student's t-test statistic of -3.68 and a p-value of 0.00042017. The p-values lead us to conclude that the location variables are both good predictors for Virginia city population. The R-squared value for this analysis is 0.5248, suggesting that the location variables can be used to explain 52.48% of the variation in city population. The coefficients (X = 0.376; Y=-0.266) is sloped downward toward the west (population decreases as X decreases) and to a lesser extent, toward the north (population decreases slightly as Y increases). This trend can be imagined when looking at Figure 21, which shows a graduated circle map of Virginia city population.

With this general procedure outlined, the water buoy dataset will be analyzed in similar fashion, to determine whether the locations of the buoys are significant predictors for the water quality values nitrogen, phosphorus, chlorophyll, dissolved oxygen, and water clarity. For these variables, location may be a good predictor if the values are higher upstream or higher downstream.

4.8.2 Trend surface Analysis Results: Chlorophyll

A trend surface analysis for the variable chlorophyll looks at whether the location of the buoys is a significant predictor of the water chlorophyll level. A preliminary look at the values, plotted as graduated symbols on a map of the watershed, shows that the highest levels may be downstream, although both high and low levels are present in both upstream and downstream locations. Water chlorophyll levels are highest in areas with algae present, which can lead to lower dissolved oxygen, lower water clarity, and poor conditions for aquatic wildlife.

The general results (table 4) show that only 9.1% of the variation in Chlorophyll can be described with the buoy locations (latitude and longitude). This R-squared value is quite low and indicates that the relationship between the predictors (buoy latitude and longitude) and the dependent variable (chlorophyll) is very weak. As expected, the student's t-test statistic is low for each predictor (Latitude = 0.00308, Longitude = 0.09576) and associated p-values (0.9976, 0.92606) are greater than 0.1 and therefore insignificant at an alpha level of 0.1.

Table 4. Trend Surface Analysis of Chlorophyll

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	**0.09054863**							
R Square	0.00819905							
Adjusted R Square	-0.2397512							
Standard Error	5.42034232							
Observations	11							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	1.94304395	0.97152198	0.03306734	0.96760493			
Residual	8	235.040887	29.3801109					
Total	10	236.983931						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	132.321357	513.859264	**0.25750505**	**0.80328872**	-1052.6402	1317.28295	-1052.6402	1317.28295
Latitude	0.08603177	27.900892	**0.00308348**	**0.99761525**	-64.25354	64.425604	-64.25354	64.425604
Longitude	1.65298728	17.2617382	**0.09576019**	**0.92606636**	-38.152652	41.4586269	-38.152652	41.4586269

4.8.3 Trend surface Analysis Results: Dissolved Oxygen

A trend surface analysis for the variable dissolved oxygen looks at whether the location of the buoys is a significant predictor of the water oxygen level. A preliminary look at the values, plotted as graduated symbols on a map of the watershed, shows that the highest levels may be downstream, although both high and low levels are present in both upstream and downstream locations. Dissolved oxygen levels are lowest in areas with algae present, lower water clarity, and poor conditions for aquatic wildlife.

The general results (table 5) show that only 34.0% of the variation in dissolved oxygen can be described with the buoy locations (latitude and longitude). This R-squared value is quite low and indicates that the relationship between the predictors (buoy latitude and longitude) and the dependent variable (dissolved oxygen) is very weak. As expected, the t-test statistic is low for each predictor (Latitude = -0.548, Longitude = -0.823) and associated p-values (0.598, 0.4344) are greater than 0.1 and therefore insignificant at an alpha level of 0.1.

Table 5. Trend Surface Analysis of Dissolved Oxygen

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.33987493							
R Square	0.11551497							
Adjusted R Square	-0.1056063							
Standard Error	1.81463555							
Observations	11							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	3.44046051	1.72023025	0.52240552	0.61201485			
Residual	8	26.3432173	3.29290216					
Total	10	29.7836778						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-168.60046	172.031069	-0.9800582	0.35576195	-565.30482	228.103893	-565.30482	228.103893
Latitude	-5.1217599	9.3407293	-0.5483255	0.5984321	-26.66152	16.4180005	-26.66152	16.4180005
Longitude	-4.7554836	5.77892721	-0.8229008	0.43440609	-18.081714	8.57074642	-18.081714	8.57074642

4.8.4 Trend surface Analysis Results: Water Clarity (Turbidity)

As indicated earlier, water clarity at each sample buoy location was tested using a Secchi disc (Figure 6), lowered into the water and whose depth was recorded when it disappeared. The graduated circle map for Water Clarity is shown in Figure 16. It does show a relatively clear pattern which higher values in the mouth of the York River estuary, near the confluence of the York River with the Chesapeake Bay. The water clarify in upstream locations is poorer, with lower values. This indicates a higher level of water turbidity, due to sediments, algae, and other solids being suspected in the water column. Table 6 indicates that 65.4% of the variation in water clarity can be explained by latitude and longitude variables. This means that the relationship between the buoy locations (latitude and longitude) and water clarity is strong. The trend surface analysis results in a statistically significant student's t-test statistic for longitude (2.2806, associated p-value = 0.05200), and a nearly significant t-test statistic for latitude (1.8055, associated p-value = 0.108). The intercept for the trend surface analysis is also significant, with a t-test statistic of 2.226 and associated p-value of 0.00566. The coefficient for significant predictor (longitude) is 2.594. This means that as longitude increases (as the sample sites move east), the water clarity levels increase significantly. This is consistent with the visual evidence from the graduated circle map for water clarity (Figure 16).

Table 6. Trend Surface Analysis of Water Clarity

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.65445722							
R Square	0.42831425							
Adjusted R Square	0.28539281							
Standard Error	0.35712068							
Observations	11							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	0.76440783	0.38220392	2.99685094	0.10681432			
Residual	8	1.02028142	0.12753518					
Total	10	1.78468925						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	75.3645803	33.8557524	2.22604949	0.05664502	-2.7069248	153.436085	-2.7069248	153.436085
Latitude	3.31905743	1.83825759	1.80554534	0.1086282	-0.9199722	7.55808703	-0.9199722	7.55808703
Longitude	2.59401626	1.13729415	2.28086662	0.05200094	-0.0285888	5.21662127	-0.0285888	5.21662127

4.8.5 Trend surface Analysis Results: Nitrogen

A trend surface analysis for the variable nitrogen looks at whether the location of the buoys is a significant predictor of the water nitrogen level. A preliminary look at the values, plotted as graduated symbols on a map of the watershed, shows that the highest levels may be downstream, although both high and low levels are present in both upstream and downstream locations. Water nitrogen levels are highest in areas with algae present, which can lead to lower dissolved oxygen, lower water clarity, and poor conditions for aquatic wildlife.

The general results (table 7) show that only 34.0% of the variation in nitrogen can be described with the buoy locations (latitude and longitude). This R-squared value is quite low and indicates that the relationship between the predictors (buoy latitude and longitude) and the dependent variable (nitrogen) is very weak. As expected, the t-test statistic is low for each predictor (Latitude = -0.987, Longitude = -1.02) and associated p-values (0.3523, 0.3374) are greater than 0.1 and therefore insignificant at an alpha level of 0.1.

Table 7. Trend Surface Analysis of Nitrogen

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	**0.34077545**							
R Square	0.11612791							
Adjusted R Square	-0.1048401							
Standard Error	0.29767897							
Observations	11							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	0.09313941	0.0465697	0.52554169	0.61032012			
Residual	8	0.70890215	0.08861277					
Total	10	0.80204155						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-16.912384	28.22056	**-0.599293**	**0.5655587**	-81.989112	48.164344	-81.989112	48.164344
Latitude	-1.5132012	1.53228491	**-0.9875456**	**0.35229829**	-5.0466565	2.02025416	-5.0466565	2.02025416
Longitude	-0.9672796	0.94799482	**-1.0203427**	**0.33742723**	-3.1533596	1.21880035	-3.1533596	1.21880035

4.8.6 Trend surface Analysis Results: Phosphorus

A trend surface analysis for the variable phosphorus looks at whether the location of the buoys is a significant predictor of the water phosphorus level. A preliminary look at the values, plotted as graduated symbols on a map of the watershed, shows that the highest levels may be downstream, although both high and low levels are present in both upstream and downstream locations. Water phosphorus levels are highest in areas with algae present, which can lead to lower dissolved oxygen, lower water clarity, and poor conditions for aquatic wildlife.

The general results (table 8) show that only 52% of the variation in phosphorus can be described with the buoy locations (latitude and longitude). This R-squared value is quite low and indicates that the relationship between the predictors (buoy latitude and longitude) and the dependent variable (phosphorus) is very weak. As expected, the t-test statistic is low for each predictor (Latitude = -1.648, Longitude = -1.504) and associated p-values (0.31, 0.17) are greater than 0.1 and therefore insignificant at an alpha level of 0.1.

Table 8. Trend Surface Analysis of Phosphorus

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.52462535							
R Square	0.27523175							
Adjusted R Square	0.09403969							
Standard Error	0.03156336							
Observations	11							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	2	0.00302661	0.0015133	1.51900558	0.27592855			
Residual	8	0.00796996	0.00099625					
Total	10	0.01099657						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-4.9319721	2.9922693	**-1.6482381**	**0.13791628**	-11.832158	1.96821324	-11.832158	1.96821324
Latitude	-0.1761038	0.16247052	**-1.0839122**	**0.30998637**	-0.5507615	0.19855392	-0.5507615	0.19855392
Longitude	-0.1511554	0.10051735	**-1.503774**	**0.17104881**	-0.3829488	0.08063805	-0.3829488	0.08063805

5. Conclusions and Future Work

As the state of the Chesapeake Bay is becoming more and more uncertain in the future due to budget cuts and temperature increases, research must be continued to map the state of the Bay. With the future will come the rising of water levels, increase in the water temperature, reduction of old animal species and the introduction of new animal species that will migrate as the temperature increases. Even with the ninety percent decrease in the Chesapeake Bay Foundation's budget by President Donald Trump, the monitoring of Bay is going to be more difficult than it ever has been. Luckily over the past few years has seen the introduction of open-source maps that have allowed for other private organizations and citizens to contribute to the mapping of the Bay and its pollutants.

The seasonality of the samples from the buoys may lead to some bias in the results, as they only capture data between April and October. There may be some Fall, Winter, and early Spring dynamics that are not being captured. The locations of the buoys along the river are not uniform, and there is some uncertainty about their representativeness, especially along with upstream tributaries, which lack buoy coverage. Figure 13 shows elevated Phosphorus levels near the junction of the upstream tributaries and the York River. While some of the spatial dynamics, or lack thereof, are captured in the Trend Surface Analysis (Chapter 4), some of the spatial dynamics are not clear. The nature of the Phosphorus levels and their spatial distribution is one such dynamic that should be explored further.

Open-source data is a rapidly growing industry that allows for individuals to gather and report data to a central database and using that data, the database will be able to provide a map to show the general public and researchers areas in which pollutants have increased, decreased, or remained stagnant. Goodchild (2005) address the nature of information sharing communities, which may soon include the sharing of environmental data. Rice et al. (2014, 2016) and Qin et al. (2016) discuss how geocrowdsourcing may be used within data generation and data collection processes, which will likely come to fruition in areas related to environmental sampling. Rice et al. (2012) profile some environmental crowdsourcing activities. Doing so will allow this database to be easily accessible to all interested parties. Examples of these open source datasets are: ESRI, NASA's Socioeconomic Data and Applications Center (SEDAC), Open Topography, UNEP Environmental Data Explorer, and NASA Earth Observations (NEO) (gisgeography, 2019).

Several areas of research are can be done to analyze and further research the results of the study. The approaches presented here should be further tested with different avenues of data analysis such as remote sensing to map the extent of year to year algae growth with infrared data. A primary area of further research should be examining more methods and techniques to improve the time and effort required to implement these and future heuristics with different GIS software and remote sensing programs such as ENVI (Environment for Visualizing Images).

Further research can be done do identify the anomaly year of 1997 with its high values in dissolved oxygen and record phosphorus with a low value in chlorophyll.

Research presented by the Chesapeake Bay Foundation could also suggest methods to identify clusters of points or areas of interest using buffer zones that could be used in future heuristics. While this research focuses on just the York River, it is limited to a small area of the larger Chesapeake Bay Watershed. Using the data and methods from this research and implementing them for each of the other main tributaries of the Bay would provide a greater scope of understanding of the overall health of the Bay while focusing on each tributary.

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