

Aquatic Nutrient Levels and Climate Change

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Research Background:

Water Quality and Nutrients

For a quick run-down of nitrogen, phosphorus, and how they're cycled through the ecosystem, here is a great "crash course" summary video: <u>https://www.youtube.com/watch?v=leHy-Y_8nRs</u>



Nitrogen and phosphorus are critically important elements that sustain and comprise all life on Earth. For this lesson, we'll discuss the importance of these naturally-occurring nutrients in the aquatic environment. Nitrogen enters aquatic systems as part of the **nitrogen cycle**, whereby atmospheric nitrogen is incorporated into food webs after being fixed by bacteria (Fig. 2). While the atmosphere contains a large reservoir of nitrogen, the **phosphorus cycle** does not include a prominent gaseous phase. Instead,

phosphorus is distributed throughout the environment primarily from the weathering of phosphate-containing rocks and soils. This phosphorus is eventually dissolved into aquatic systems, either directly from geological features or from terrestrial food webs (Fig. 3).

These nutrients are essential to the growth of aquatic primary producers (i.e., phytoplankton, periphyton, and macrophytes), which serve subsequent important roles in the environment. **Macrophytes** (aquatic plants) often serve as nurseries for young fish and crustaceans and as well as foraging grounds for other animals. They also stabilize aquatic sediment, keep stream microhabitats intact during high flow events and maintain water clarity. Additionally, all aquatic primary producers generate oxygen and organic material and comprise the foundation of aquatic food webs. These aquatic food webs affect the health of the Earth's environment, ultimately affecting human health and society at large.



Fig. 1. Fleming, Jay. "Striped Bass." *Chesapeake Quarterly*. Maryland Sea Grant. https://www.chesapeakequarterly.net/V16N2/main1/

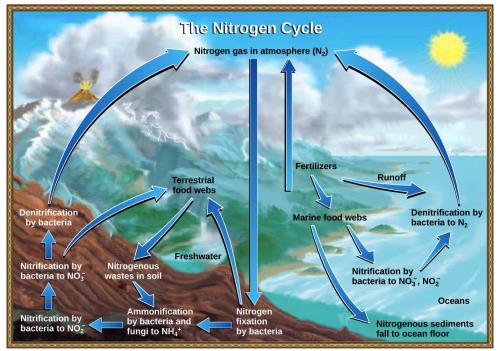


Fig. 2. Nitrogen cycle. Image attribution: *Biogeochemical cycles: Figure 4* by OpenStax College, Biology, CC BY 4.0. Modification of work by John M. Evans and Howard Perlman, U.S. Geological Survey. https://www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/a/the-nitrogen-cycle

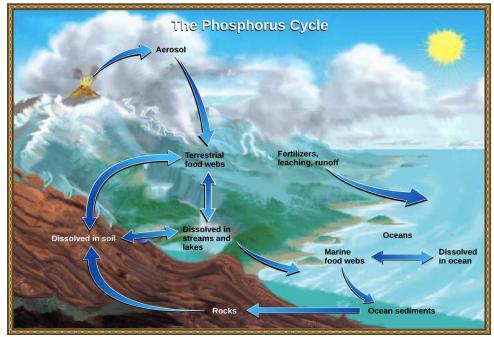


Fig. 3. Phosphorus cycle. Image attribution: *Biogeochemical cycles: Figure* 5 by OpenStax College, Biology, CC BY 4.0. Modification of work by John M. Evans and Howard Perlman, U.S. Geological Survey. https://www.khanacademy.org/science /biology/ecology/biogeochemical-cycles/a/the-phosphorous-cycle

Anthropogenic Drivers of Nutrient Pollution

To learn more about nutrient pollution and its causes, check out the following EPA video: https://www.youtube.com/watch?v=vCicSNnKUvM

Nitrogen and phosphorus can also enter aquatic environments through **anthropogenic** (human-related) **inputs**. The primary sources of anthropogenic inputs of nitrogen and phosphorus into watersheds are discussed below.

Input types

<u>Run-off</u>

Rain events over urban areas containing lawn fertilizers, certain soaps/detergents, and animal waste can carry excess nutrients into water bodies. The presence of **impervious surfaces** (hard, non-porous surfaces such as concrete) and certain types of landscaping can increase the amount of runoff that occurs.



Fig. 4. Stormwater Runoff. RVAH20. City of Richmond Department of Public Utilities. http://www.rvah2o.org/storm-water

Farming

Agriculture is one of the largest sources of nutrient pollution. Fertilizers containing high amounts of phosphorus and nitrogen for crop growth can be washed from fields during rain events. Common agricultural effects on the land such as soil erosion and de-vegetation additionally removes barriers that would otherwise prevent run-off



Fig. 5. "Nitrogen-Runoff-Illustration-orig." *Edisto Riverkeeper.* Waterkeeper Alliance. http://www.edisto riverkeeper.org/stormwater--agricultural-runoff.html

Wastewater treatment

Sewer systems do not always operate properly or remove enough nitrogen and phosphorus before discharging into waterways. Additionally, some systems can become overwhelmed with excess rain.

Fossil fuels

Use of fossil fuels for things such as electric power generation, industry, and transportation have increased the amount of nitrogen in the air. These human-related inputs are often much greater than natural inputs and cause an unnatural excess of nitrogen and phosphorus in aquatic systems, also known as **nutrient pollution**. According to the EPA, nutrient pollution is one of the most widespread, costly, and challenging environmental problems today, and results in numerous adverse effects on water quality.

One of these harmful effects is increased algal blooms. Algal blooms in aquatic environments are entirely normal - however, when increased nutrients cause excessive growth, it can overwhelm an aquatic system and result in **eutrophication**.

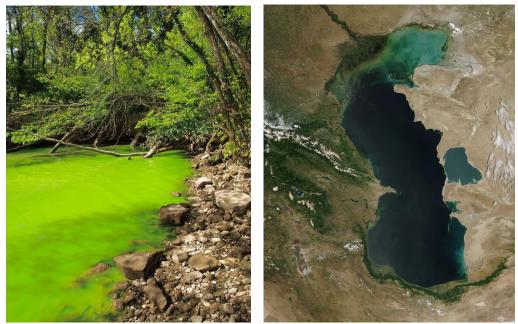


Fig 6. Left: Eutrophication in the Potomac River, Virginia, caused by dense blooms of cyanobacteria, a type of algae. Credit: Alexandr Trubetskoy, own work. Right: Eutrophication in the northern Caspian Sea, between Asia and Europe, evident from orbit. Credit: NASA.

Eutrophication occurs when severe algal growth blocks light that is needed for aquatic plants, such as seagrasses, to grow. When the algae and seagrass die, they decay. In the process of decay, the oxygen in the water is used up and leads to low levels of dissolved oxygen in the water. These low levels of oxygen (**hypoxia**), or no oxygen at all (**apoxia**), kills fish, crabs, oysters, and other aquatic animals, causing a **dead zone**.

One example is one of the largest dead zones in the world - the Gulf of Mexico. The actions of humans dramatically increased the flux of phosphorus and nitrogen from the Mississippi River into the Gulf, and the massive dead zone only continues to grow every year.

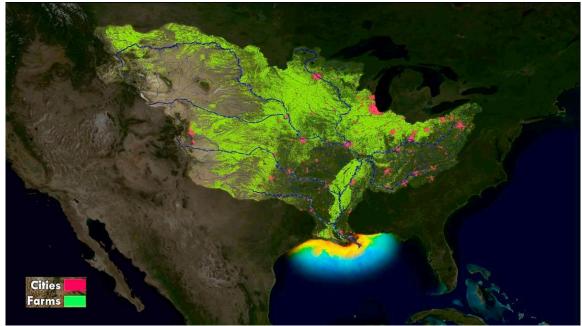


Fig. 7. Gulf of Mexico Dead Zone. *Dealing with Dead Zones: Hypoxia in the Ocean*. National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/podcast/feb18/nop13-hypoxia.html This image from a NOAA Environmental Visualization Lab animation shows how runoff from farms (green areas) and cities (red areas

This image from a NOAA Environmental Visualization Lab animation shows how runoff from farms (green areas) and cities (red areas) drains into the Mississippi.

Adverse Effects on Humans

Nutrient pollution can also have negative consequences on human wellbeing. For instance, some species of algae that are involved in algal blooms are toxic. Direct exposure to these algae through ingestion or contact through swimming can result in health problems including rashes, stomach illness, and respiratory problems. A compound of nitrogen called nitrate, often present in fertilizers, can also contaminate drinking water and result in illness, particularly in infants.

Even when nutrient pollution does not result in direct health effects on humans, the degradation of the aquatic ecosystem can negatively impact human economies through negative effects on fisheries and loss of revenue from recreational water activities.

Climate Change Effects on Nutrients

Climate change is anticipated to exacerbate the availability and transport of nutrients into water bodies, possibly worsening them and increasing harm to aquatic environments (Coffey et al., 2018). In particular, the east coast of the United States is expected to receive more rainfall with climate change. Increases in precipitation may then result in elevated nutrient pollution in streams and rivers through increased erosion, which will enhance the release of nutrients from soils, and increased runoff from urban areas and farmland.

Increased precipitation may also cause **Combined Sewer Overflow events** (CSOs), which occur when sewer systems built to collect both wastewater and rainfall runoff cannot handle the volume of water entering the system. When these systems overflow, untreated sewage and storm water is discharged into a nearby water body.

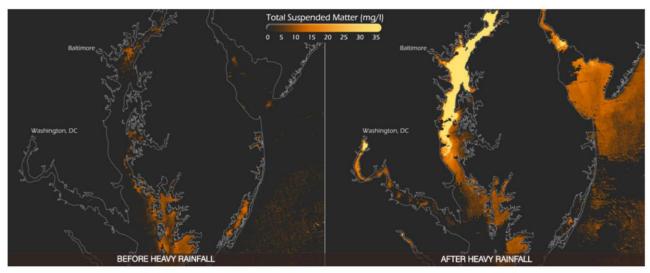


Fig.8. Nutrient Pollution and Rainfall. *What is Nutrient Pollution?*. National Oceanic and Atmospheric Administration, June 25 2018, https://oceanservice.noaa.gov/facts/nutpollution.html.

Visualization of the Chesapeake Bay, part of the largest watershed in the Northeast. This illustration shows the amount of suspended matter (e.g., silt, mud, debris) in waterways before (left) and after (right) areas in this region received exceptionally heavy rainfall in 2011. All of this rain and runoff eventually made its way into the Chesapeake Bay.

Together, these phenomena are expected to drive adverse impacts associated with nutrient pollution, discussed above, possibly magnifying existing problems or creating new areas of concern.

TMDLs and Other Mitigation Efforts

Several policy and management actions are being taken to monitor water quality and combat nutrient pollution. For example, Section 303(d) of the **Clean Water Act (1972)** authorizes state and federal agencies to assist in listing impaired waters and developing **Total Maximum Daily Loads (TMDLs)** for these water bodies. A TMDL establishes the maximum amount of a pollutant allowed in a waterbody and serves as the starting point or planning tool for restoring water quality.

What is Linear Regression and What is it used for?

A linear regression is a powerful yet simple statistical tool that can be used as a means of predictive analysis. Linear regression is used to compare two variables using a y=a+bx equation. In this equation, the dependent variable is y, the intercept is a, the slope is b, and the independent variable is x.

A linear regression works by creating a model (and line of best fit) that accounts for as much variation in the data as possible. In other words, the model creates a line that ensures the least amount of error between the real data and the model line. If this model outputs a significant P-Value (typically p < 0.05) and a high R^2 value, then the model can be used to understand trends and possibly predict future of the data.

Scientist and Research Introduction:

Scientist Introduction



Fig. 9. Dr. Paul Bukaveckas. *Paul Bukaveckas*. WordPress, http://wp.vcu.edu/pabukaveckas/

Scientific Data Introduction

Dr. Paul Bukaveckas is an ecosystem ecologist and associate professor who has been at Virginia Commonwealth University's Center for Environmental Studies in Richmond, Virginia since 2003. As a scientist whose research focuses on rivers and estuaries, Dr. Bukaveckas's location in Richmond is advantageous as it places him in close proximity to the lower reaches of the Chesapeake Bay watershed. In particular, Dr. Bukaveckas is interested in investigating the variables that control algal blooms in the James River. His research on nutrient runoff has served as a basis for water management decisions and policy for Virginia's state government.

At 348 miles, the James River is the longest river in Virginia and one of the 150 major rivers flowing into the **Chesapeake Bay**. Located in the eastern U.S., the Chesapeake Bay is the largest estuary in the country and the third largest estuary in the world. In part due to its size, it has also historically been greatly affected by nutrient pollution. Along the bay's extent, there are hundreds of wastewater treatment plants, agricultural areas, and developed lands that contribute to nutrient loading in the bay, which has resulted in large scale declines of seagrass beds and the loss of fisheries.

These effects were so dire, that in 2009 President Obama signed an executive order that recognized the Chesapeake Bay as a national treasure. The order requested the federal government to lead in the effort to restore water quality in the bay and resulted in the U.S.

Environmental Protection Agency establishing TMDLs for the Chesapeake Bay watershed in 2010.

Dr. Bukaveckas and associates conducted a study between 2007 and 2014 in the James River Estuary, which receives a large majority of runoff from the Appomattox and James Rivers. Discharge from the river into the estuary was monitored daily and water samples for nutrient analysis (including nitrogen and phosphorus) were collected weekly-monthly.

According to the EPA report that set the TMDLs for rivers flowing into the Chesapeake Bay, the additive total nitrogen (TN) TMDLs for the entire James River and the Appomattox River together is 15,792,660 kgs/yr. For total phosphorus (TP), the additive TMDLs come to 1,634,559 kgs/yr.

This research measured several water quality variables, but this lesson will only examine nitrogen and phosphorus concentrations and how they relate to discharge.



Fig. 10. Faunce, Kaycee. "Virginia's Scenic James River" [map]. (ca. 1:1,465,000). April 2019. Using: ArcGIS Pro [GIS software]. Version 2.2.0. Redlands, CA: Environmental Systems Research Institute, Inc., 2018. Special credit to John Nelson for Physical Geography Atlas and Hachures styles: https://www.esri.com/arcgisblog/author/j_nelson/

Scientific Question

Keeping in mind what we've learned about nutrients and climate change effects, how will nitrogen and phosphorus react to varying discharge in the James River Estuary?

Hypothesis

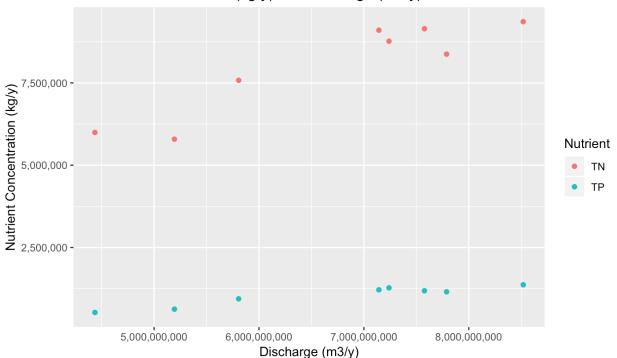
If discharge increases in the James River Estuary, then nitrogen and phosphorus concentrations will also increase.

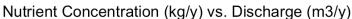
Data Findings:

As a scientist, you configured the data with the programming language R inside the open source RStudio platform. Below are several figures and regressions you must now interpret as a scientist. Study them closely, see what conclusions can be drawn, and answer the questions under each figure.

Graph 1: Nutrient Concentration (kg/y) vs. Discharge (m³/y)

Graph 1 is a scatterplot of river discharge in cubic meters per year against nutrient concentrations in kilograms per year. "TN" stands for total nitrogen and "TP" stands for total phosphorus.





1. Why might you want to plot this data as a scatterplot to begin?

Visualizing your data initially as a scatter plot can make you comfortable first manipulating the data and give you an idea of general trends. For example, you can observe if relationships appear linear, if one variable seems to be increasing at a higher slope than another, if the variables are cyclical in nature, etc.

2. What conclusions can you draw from this figure? What could be some implications from those conclusions?

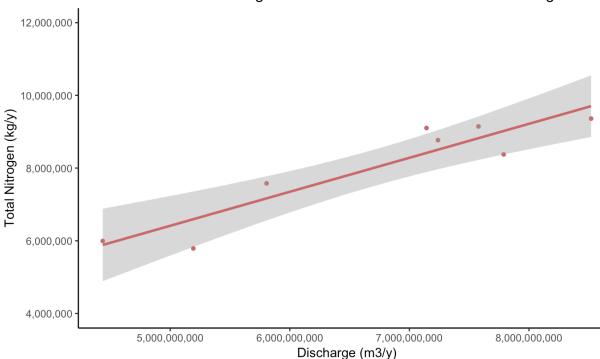
First and foremost, the relationship between discharge for both total nitrogen AND total phosphorus appear linear in nature. This could theoretically mean discharge and nutrient concentration are dependent upon each other and share a linear relationship; however, additional testing needs to be completed in order to see if this relationship is statistically significant. Additionally, nitrogen appears to be at a higher level in the ecosystem than phosphorus. This ecologically follows the norm and could affect how the specific TMDL for nitrogen is designated and managed.

3. Why might Nitrogen be more sensitive in an environment then Phosphorous?

While conclusions drawn from this figure can give us a good idea of a relationship(s) that may exist, those relationships may not be statistically significant. Therefore, a linear regression must be completed to specifically test statistical significance.

Graph 2: Total Nitrogen (kg/y) v. Discharge (m³/y)

Graph 2 is a linear regression specifically examining discharge in kilograms per year vs. nitrogen concentration (TN) in kilograms per year. $R^2 = 0.8352$ P Value = 0.0009317 Equation = 1,738,000 + 0.0009349x



Linear model of total nitrogen concentration as a function of discharge

1. What conclusions can you draw from this figure? Was this relationship significant? Why? Specifically reference the P-value and R² value.

This linear regression is highly significant, with a P-value of 0.0009317 (< 0.05) and a R² value of 0.8352 This means that 86% of our variation in our data is explained by the model. Therefore, we can expect there is a very high probability that increasing discharge also increases nitrogen concentration.

2. The additive TMDLs for total nitrogen (TN) in the James and Appomattox Rivers is 15,792,660 kgs/yr. If you can, mark this point on your graph as a horizontal line. Are there any further conclusions you can draw now?

The TMDL is well above the values represented in this linear regression, which means that the amount of nitrogen in the sampled area is well below the TMDL. This could be an indication that nitrogen is not impairing the system, and management techniques are assisting in keeping it below a harmful level.

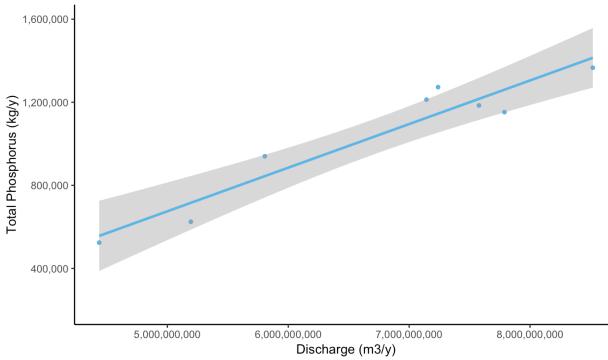
Graph 3: Total Phosphorous (kg/y) v. Discharge (m³/y)

Graph 3 is a linear regression specifically examining discharge in kilograms per year vs. phosphorus concentration (TP) in kilograms per year.

 $R^2 = 0.9003$

P Value = 0.0002017

Equation = -374683.9614353 + 0.00021x



Linear model of total phosphorus concentration as a function of discharge

 What conclusions can you draw from this figure? Was this relationship significant? Why? Specifically reference the p-value and R² value. Yes, this was a significant relationship. The p-value was 0.0002017 (< 0.05) and the there was also a high R² value. According to the R2 value, 90% of the variation in our data is explained by this model. Therefore, we can expect there is a very high probability that increasing discharge also increases phosphorus concentration. 2. The additive TMDLs for total phosphorus (TP) in the James and Appomattox Rivers is 1,634,559 kgs/yr. If you can, mark this point on your graph as a horizontal line. Are there any further conclusions you can draw now?

The line for the TP TMDL is above where the y-axis ends. However, our data stops not very far below where the maximum limit is, as set by the EPA. This is concerning if future climate scenarios deliver more rain events to these watersheds, because it means we are more likely to go above the TMDL limit.

Final Questions:

1. What were the overall findings of the study?

Through our analysis and interpretation, we found that the TN and TP levels for the James and Appomattox Rivers are both below the thresholds set by the EPA TMDLs. However, the very strong linear relationship we observed between discharge and these nutrient levels is concerning, given what we know about how climate change is expected to affect precipitation amounts in this part of the United States. The TP levels especially are approaching the maximum limit, which means this may be more at risk for going over with additional future rainfall, without significant intervention through management strategies.

2. Was the hypothesis supported by the data? Use specific evidence from the figures to explain why or why not. If you feel the data was inconclusive, explain why.

Yes, our hypothesis was supported by the data. Both linear regressions produced very significant P-values and high R2 values between both nutrients considered and discharge.

3. How will these findings affect your decision as a scientist? What will you tell management groups concerning the recommended federal limits on nutrients? Keep in mind the TMDL guidelines and how changes might affect stakeholders.

The data for both nitrogen and phosphorus showed that they never cross the TMDL. Phosphorus, however, gets fairly close with large discharge events. With increasing extreme precipitation events in Virginia due to climate change, it is possible that in the future the TMDL for phosphorus will be exceeded during an extreme precipitation event. In preparation for the future, we would recommend prevention through government regulation where possible. However, depending on how strict, these management actions have the potential to impact agriculture industry and infrastructure, and may cause a pushback. 4. Do you think some anthropogenic sources contribute more than others to nutrient pollution specifically in the James River? Why or why not?

Yes, some anthropogenic sources may include agriculture, sewage and urban runoff. The James River runs near the urban city of Richmond, Virginia and may see more sewage and runoff pollution due to its proximity. Richmond has a combined sewer system and therefore CSOs are common (i.e. they occur with every precipitation event greater than or equal to 1-inch rainfall).

5. <u>Your next steps as a scientist</u>: Science is an ongoing process. What new question do you think should be investigated? What future data should be collected to answer your question?

Students answers may vary. For example:

- How might these numbers change in other rivers of Virginia, or rivers in other states?
- How does an increase in nutrients during high discharge events affect the presence of algal blooms? Data collection will include chlorophyll data for the region along with nutrient data. Chlorophyll a (CHLa) data is used as a representation of phytoplankton abundance

Key Terms		
Nitrogen and phosphorus	Nitrogen cycle	Phosphorus cycle
Macrophytes	Anthropogenic inputs	Impervious Surfaces
Nutrient pollution	Eutrophication	Нурохіа
Apoxia	Combined Sewer Overflow events (CSOs)	Dead Zone
Clean Water Act (1972)	Total Maximum Daily Loads (TMDLs)	Chesapeake Bay
Linear Regression	Y = a + bx	

Information References

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Spatial Data References

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