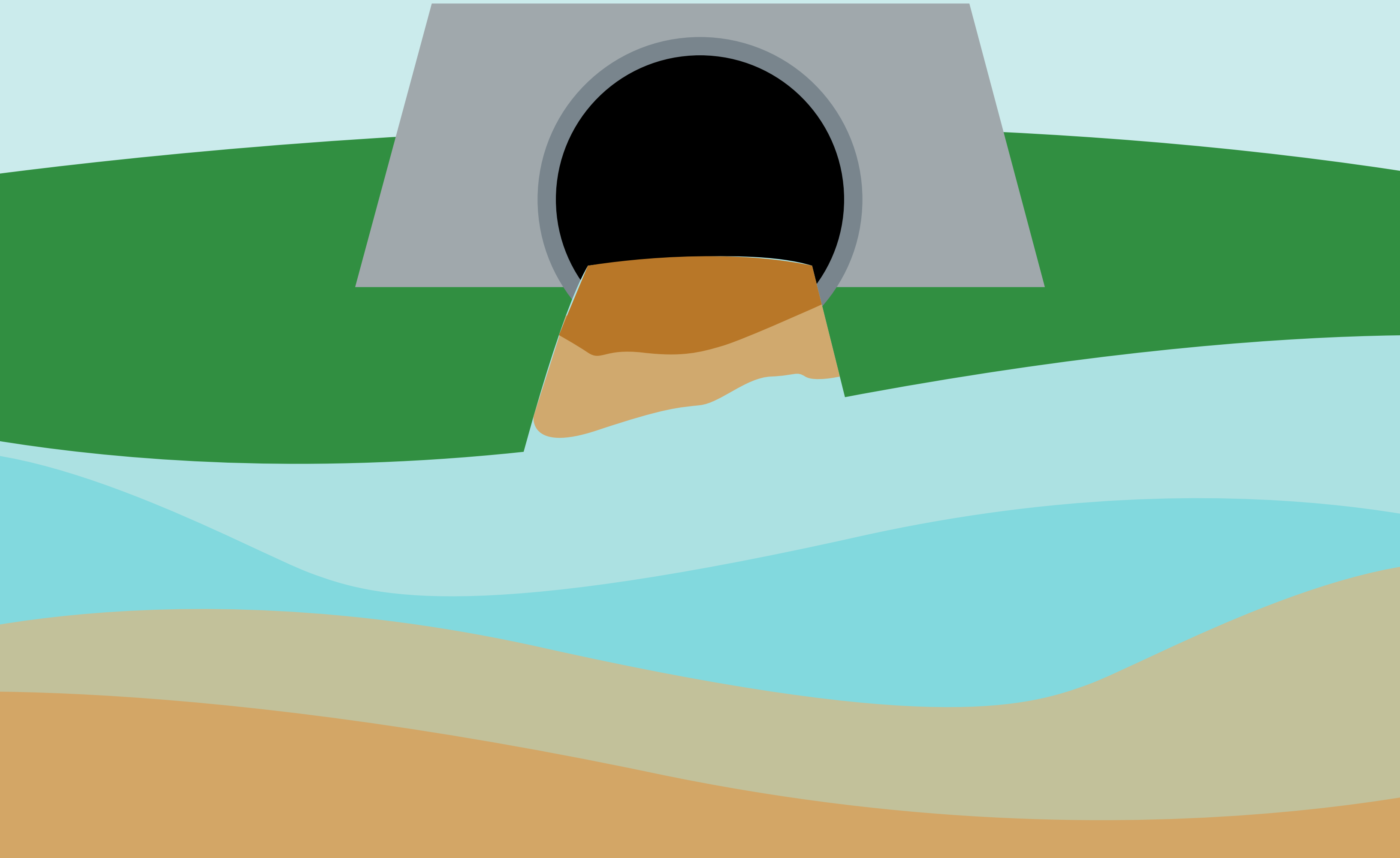
District of Columbia
Office of the State Superintendent of Education

WATER QUALITY AND WASTEWATER MANAGEMENT

High School Environmental Science Instructional Sequence



This high school environmental science instructional sequence was created to support teaching the Next Generation Science Standards through the Biological Sciences Curriculum Study (BSCS) 5E instructional model. Developed by District of Columbia teachers, these lessons include real-world contexts for learning about environmental science through a lens that encourages student investigation of local issues.

The lessons also support Scope and Sequence documents used by District local education agencies:
Unit 1: Ecosystems: Interactions, Energy, and Dynamics
Advisory 1

Acknowledgements:
Molly Smith, Cardozo Education Campus

This curriculum resource can be downloaded online:
https://osse.dc.gov/service/environmental-literacy-program-elp

Overview and Goal of the Lesson:

The lesson sequence begins with students investigating the problem of cultural eutrophication. Students test water samples for their ability to transmit light and research the consequences of algal blooms. To address solutions to the problem, students model the wastewater treatment process and monitor the water's improvement as it moves through the system. The students specifically address one cause of cultural eutrophication by practicing a chemical engineering technique: removing phosphates from wastewater using chemical precipitation. A field trip to the Blue Plains Wastewater Treatment Facility takes place during this unit.

Essential Question(s):

- How are human interactions impacting biodiversity in ecosystems?
- What technologies are required to produce less pollution and waste in an effort to prevent ecosystem degradation?
- How are anthropogenic changes disrupting ecosystems and threatening the survival of some species?
- How are Earth's surface processes and human activity impacting the Chesapeake Bay and Anacostia watersheds?

Big Ideas:

Resource availability has guided the development of human society.

- The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources.
- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.
- When evaluating solutions, it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural, and environmental aspects.

NGSS Emphasized and Addressed in this Lesson Sequence:

PERFORMANCE EXPECTATIONS	SCIENCE AND ENGINEERING PRACTICES	DISCIPLINARY CORE IDEAS	CROSSCUTTING CONCEPTS
HS-LS2-7. Design, evaluate, and refine a solution for reducing impacts of human activities on the environment and biodiversity. **ESS3-4.** Evaluate or refine a technological solution that reduces impacts of human activities on natural systems. **HS-PS1-2.** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. *(secondary)* **HS-ETS1.** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.	**Constructing Explanations and Designing Solutions** • Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. **Connections to Nature of Science Scientific Investigations Use a Variety of Methods** • Science investigations use diverse methods and do not always use the same set of procedures to obtain data • New technologies advance scientific knowledge.	**ETS1.A Defining and Delimiting Engineering Problems** • Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. E**SS2.C. The Roles of Water in Earth's Surface Processes** • The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. **Systems and System Models** • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. **Connections to Engineering, Technology, and Applications of Science** **Influence of Science, Engineering, and Technology on Society and the Natural World** • New technologies can have deep impacts on society and the environment, including some that were not anticipated.

PERFORMANCE EXPECTATIONS	SCIENCE AND ENGINEERING PRACTICES	DISCIPLINARY CORE IDEAS	CROSSCUTTING CONCEPTS
	Scientific Knowledge is Based on Empirical Evidence Science arguments are strengthened by multiple lines of evidence supporting a single explanation	**ESS3.C: Human Impacts on Earth Systems** • The sustainability of human societies and the biodiversity that supports them requires responsible management of natural resources. • Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. **LS2.C. Ecosystem Dynamics, Functioning, and Resilience** • Anthropogenic changes in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. **ETS1.C Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. **ETS1.B: Developing Possible Solutions** • When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural, and environmental aspects. **PS1.B Chemical Reactions** • The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	**Science is a Human Endeavor** • Science is a result of human endeavors, imagination, and creativity. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

Materials

ITEM	QUANTITY	PURPOSE
SMARTBOARD slides of fish kills, dead zones, other signs of local waters degradation	1/class	Warm-up for engage lesson
River water	~500 mL/group	eutrophication lab
Tap water	~250 mL/group	eutrophication lab control
Plant fertilizer (Miracle Gro-type)	0.5 g/ group	eutrophication lab
Other possible contaminants or disruptions for eutrophication lab	assorted for class	eutrophication lab: provide materials for investigation into causes of water quality decline
Measuring device: light meter, Vernier colorimeter, turbidity tester (mini Secchi disk)	1 for class or 1 per group, depending upon type of device	collecting comparative data from algal bloom experiment
Articles or links to information on eutrophication	as needed per student	research causes and effects and solutions for cultural eutrophication
Cause-effect template and cut out statements	1 set per pair of students	organizer for causes and effects and solutions of cultural eutrophication
3 1-liter bottles, straws or tubing, clay, clamps or paper clips, cheesecloth, rubber bands, stoppers	1/group	wastewater treatment system
Yeast, vegetable oil, glucose/dextrose, bits of plastic and paper, water, grass clippings or other vegetation	~300 mL/group	simulated wastewater
Yeast culture	50 mL/group	simulated microbes for wastewater lab
0.1 M NaOH solution	30 mL/group	wastewater treatment lab
Alum solution prepared from $Al_2(SO_4)_3 * 12\ H_2O$ (add 1 part alum to 10 parts water)	100 mL/group	wastewater treatment lab
glucose test strips	6-8/group	wastewater treatment lab
$Na_3PO_4 * 12\ H_2O$ (sodium phosphate dodecahydrate)	~1 g /lab group	source of phosphate for elaborate activity
$FeSO_4 * 7\ H_2O$ (iron II sulfate heptahydrate)	~2 g /lab group	to precipitate phosphate for elaborate activity
$MgSO_4 * 7\ H_2O$ (magnesium sulfate heptahydrate)	~2 g /lab group	to precipitate phosphate for elaborate activity
$CuSO_4 * 5\ H_2O$ (copper II sulfate pentahydrate)	~2 g /lab group	to precipitate phosphate for elaborate activity
$CaCl_2$ (anhydrous calcium chloride)	~1 g /lab group	to precipitate phosphate for elaborate activity
Printed pages from or online access to Carolina Biological Supply catalog for each "phosphate precipitator" listed above	several sets per class	reference for health, flammability, and reactivity and cost for elaborate activity
Funnels, filter paper	1/group	phosphate precipitation lab for elaborate activity
Beakers	2-3 /group	phosphate precipitation lab for elaborate activity
Electronic scale OR pan balance	1/class 1/group	phosphate precipitation lab for elaborate activity
Goggles	1/student	phosphate precipitation lab for elaborate activity
Distilled water	~250 mL/group	phosphate precipitation lab for elaborate activity

5E Lesson Sequence

Total Duration: Six 80-minute blocks				
5E Model Stage	Duration	Teacher and Student Actions		Notes
Engage	30 minutes	What Teacher Does	1. Teacher presents pictures for WARM-UP of Chesapeake Bay dead zones, algal blooms, and fish kills. Question to students: How did this happen? 2. Teacher will provide samples of water that have varying amounts of algal growth. Students will be shown how to use the available light transmittance device such as a mini-Secchi disk column, light meter, or colorimeter. 3. Teacher will prompt students to think of water systems that they have encountered that have different levels of clarity. 4. Teacher will introduce scientific vocabulary.	**Important resource for use throughout lesson:** www.dcwater.com/clean-rivers-project In order to engage with one of the issues related to eutrophication, students will test water samples for level of light transmittance/ turbidity using a mini-Secchi disk or light meter (see Supporting Document 1 for images of the mini-Secchi disk). Students will discuss, with note-taking, the ways that water quality impacts the economy, environment, and health of the residents of the District of Columbia. Refer to *A Problem with Phosphates … and How Chemistry Can Help* for background and sample procedure (Supporting Document 2).
		What Students Do	1. Students will test the relative amounts of light that pass through the water samples. 2. Students will generate questions about why the water may be more or less cloudy and discuss possible consequences of lower light transmittance in natural water systems.	
Explore 1 Eutrophication	40 minutes	What Teacher Does	1. Teacher will provide materials to set up and run algal bloom experiment. 2. Teacher will ask students to test different factors affecting growth.	See Supporting Document 3: *Eutrophication Lab* The short Fuse School animation is an overview of the eutrophication process caused by nutrients from fertilizer runoff. It presents the consequences of not addressing the situation and can help students develop their own investigation.[1]
		What Students Do	1. Students will follow general guidelines to set up algae bloom experiment. Collect baseline data using colorimeter, light sensor, or mini-Secchi disk, or take pictures for later comparison. 2. Students will discuss possible outcomes with reasoning. 3. Students will continue to collect data for several days and compare amount of algae growth/light transmittance in nutrient-rich water compared to less enriched water.	
Explain 1	60 minutes	What Teacher Does	1. Teacher will provide hard copies and online references as necessary for research on causes and effects of cultural eutrophication. Provides eutrophication cause and effect and solutions papers and template.	NOAA written description (Search NOAA Nutrient Pollution - Eutrophication)[2] Khan academy video[3] Students create a *graphic organizer* that incorporates the causes and effects of the steps of the process of eutrophication (Supporting Document 4). Additionally, the description of an engineering solution is delineated.
		What Students Do	1. Students research causes and effects of eutrophication online or by reading provided articles. In pairs, students place the cause/effect/solutions papers in order. 2. Students will explain in writing or verbally the causes and effects of eutrophication and specify solutions to the problem.	

5E Model Stage	Duration	Teacher and Student Actions		Notes
Explore 2	80 minutes	What Teacher Does	1. Teachers will provide materials for creating a model wastewater treatment facility. 2. Teacher will provide instructions for setting up the model and testing the water at each stage of treatment.	See Supporting Document 5: students will create a model that demonstrates the process of treating municipal wastewater. Sample "wastewater" will be tested at each step to determine the effectiveness of the treatments. Students will have the opportunity to vary the process. They will be prompted to provide their rationale for methods during the process and then during the explanation stage.
		What Students Do	1. Students work in groups to model wastewater treatment and evaluate effective methods for waste removal.	
Explain 2	30 minutes	What Teacher Does	1. Teacher provides whiteboards or other means for students to diagram their water treatment process.	
		What Students Do	1. Students will diagram their final set up and annotate with the purpose and results of material removal at each step.	
Elaborate	80 minutes	What Teacher Does	1. Teacher provides materials for phosphate removal experiment: metal ions such as Ca^{2+}, Fe^{2+}, Mg^{2+}, Cu^{2+}; lab equipment and Na_3PO_4. 2. Teacher provides MSDS and chemical catalogue sheets (hard copies or on line references) and explains how to determine the cost and safety of the chemical options. 3. Teacher provides lab procedure for reacting the chosen cation with PO_4^{3-}.	See Supporting Document 7: *How Can Phosphate Contamination Be Addressed?* The teacher will determine the level of quantitative data collection based on time and prior student experience. Chemical quantities (stoichiometry) may be possible. Cost comparisons and safety considerations are applicable in this model of water treatment. Students will reference associated links to Minnesota chemical phosphate removal.[4]
		What Students Do	1. Students first test the reactions of provided metal ion solutions with the phosphate ion (PO_4^{3-}) to determine the feasibility of precipitation. Cost and safety data will be reviewed to determine the practicality of using specific ions of "phosphate removal" at a wastewater treatment plant. 2. Students carry out the experiment per instructions and test for complete removal.	

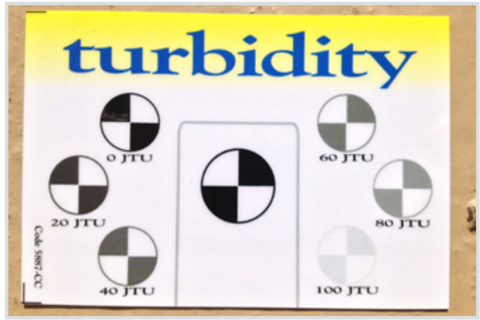
Stage	Duration	Teacher and Student Actions		Notes
Evaluate	160 minutes	What Teacher Does	1. Teacher provides scaffolded guidance for writing a report that delineates the problem of eutrophication and addresses possible solutions.	In the role-playing scenario, students will collaborate to write and report on a solution to eutrophication. They will use researched and experimental data and choose to make an oral or visual persuasive presentation of a cost-benefit analysis of treating wastewater. For example, students may choose to create persuasive argument for mock council meeting, write a newspaper article with interviews from water treatment engineers, or create an infographic or brochure. Alternative demonstrations of mastery of the material are encouraged, especially those creating action plans.
		What Students Do	1. Students have the option of presenting their findings and recommendations for wastewater treatment in several formats. 2. Students role play as DC Council members and employees of DC Water to explain the cost, safety, and environmental imperatives for wastewater quality. 3. Students write a newspaper article that covers the "council meeting." 4. Students create an infographic or brochure that explains the benefits and costs of a particular wastewater treatment. 5. Students create an alternative method for demonstrating mastery.	

Footnotes

1 www.youtube.com/watch?v=6LAT1gLMPu4
2 www.oceanservice.noaa.gov/education/kits/estuaries/media/supp_estuar09b_eutro.html
3 www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/v/eutrophication-and-dead-zones
4 www.pca.state.mn.us/sites/default/files/wq-wwtp9-02.pdf

SUPPORTING DOCUMENTS

Supporting Document 1: Images of sample turbidity tester from LaMotte kit



Supporting Document 2: A Problem with Phosphates … and How Chemistry Can Help (sample handout)*

*measuring instructions found after Background

A problem with phosphates … and how chemistry can help

Investigation objectives:

- Relate phosphate contamination to water quality
- Carry out the phosphate removal in the lab (carried out in elaborate stage)
- Compare the cost, safety, and effectiveness of the tested ions (carried out in elaborate stage)

Background:

The sources of **phosphates** at wastewater treatment plants are human waste and some cleaning agents such as dishwasher and laundry detergents. The polyatomic ion, PO_4^{3-} (sometimes referred to as orthophosphate), is often added to drinking water supplies to protect the inside of the pipes from corrosion. However, phosphates are also a plant nutrient and so they act as a fertilizer. When phosphates go down the drain and into the sewer system and eventually into the Potomac River (our source of drinking water), they create a problem by helping the algae in the water grow very fast. **Eutrophication** is the name of this destructive process by which algae grows rapidly and then dies causing an overall decline in water quality.

Why is rapid algae growth a problem?

First, water plants growing at the bottom of the river need to have sunlight in order to carry out photosynthesis. If the water has a lot of algae growing in it, not enough light can pass through the water to get to the plants at the bottom. Besides hiding baby fish and other small organisms, underwater plants purify water. Not only does this help the river system, but the cleaner the river water, the easier (and cheaper) it is to make it clean enough for us to drink. Water plants also produce oxygen during photosynthesis. Obviously, animals living in the water appreciate this! Algae also produce oxygen during photosynthesis, but rapid growth, called an algal bloom, is followed by rapid death and decay. During this part of the process, as bacteria digest the algae, they also consume oxygen at a high rate.

Investigate the problem: Test water samples to see how much light can get through. This is an indirect method of testing the amount of algal growth in the water samples. The testing method described below uses a Vernier colorimeter. Other methods of comparing the relative amount of light passing through water samples (and hence indirectly comparing algal density) can be used. One simple way is to create or purchase a mini-Secchi tube as shown in the photos above (Supporting Document 1).

Procedure for using LabQuest and colorimeter for light transmittance data collection:

1. Use the dropper to fill the plastic cuvette almost to the top with the control sample (pure water).
2. Hold the cuvette on the ribbed sides and wipe the flat sides dry with the tissue.
3. Insert the cuvette into the colorimeter so that the flat sides line up with the small white triangle.
4. Record the transmittance value on the LabQuest interface below.
   The control should be close to 100 percent since nothing in the sample is blocking the light—all of the light is going through the water.
5. Repeat with the other water samples and record the values.

Control (tap water):________ Sample A:__________ Sample B:__________

- If less light is transmitted though the water, less light can pass to the underwater plants.
  The lower the amount of light the underwater plants have, the less likely they are to survive.
  - Is more light transmitted through sample A or B?
  - Which sample is blocking more light from passing through?

Draw two diagrams showing plants growing at the bottom of a river—one with murky water and one with clear water. Use arrows to show how much sunlight is passing through the water to get to the plants. Label each diagram.

There is another big problem with all of that extra algae.

When the algae die, they decay. The bacteria that are involved in the decay process use up lots of oxygen that is dissolved in the water. That leaves less oxygen in the water for the creatures that need it.

- What kinds of organisms use the oxygen (O_2) that is dissolved in the water?

Supporting Document 3: Eutrophication Lab

Eutrophication Lab

Purpose: To investigate the effect of increased nutrients or other disruption from human activity on the ability of a natural water system to transmit light. High light transmittance is one indicator of relative water quality.

Materials: 2 x 250 mL river water samples, tap water, three jars or beakers, fertilizer, droppers, some form of turbidity tester: Vernier colorimeter or turbidity sensor or homemade mini-Secchi disk* column. (This can be used to record relative turbidity, not necessarily quantitatively. Taking pictures of the water samples each class period is another way to observe the effects of increased nutrients on algal growth.)

***To make a mini-Secchi disk tester:**
Obtain a vial that has a diameter between 2-3 cm.
Cut a circle out of white paper that is about that same size diameter.
On the circle, use a black marker to draw the pattern of a Secchi disc.
Tape the circle to the bottom of the vial.

***To use the mini-Secchi disk tester:**
Each day (or designated time period) pour the same amount of each sample into the vial.
Compare the relative visibility of the Secchi disk to each of the samples.
Students may draw the observed results each test day in order to make a long-term comparison. Remind them that all observations are significant and that their current data collections will be helpful at the end during analysis.

(Below is an example for students choosing to test a fertilizer such as one purchased at a garden store. A similar procedure may be followed for any question the students are addressing. Ensure that they are only changing one variable.)

Procedure:

1. Pour 250 mL of river water into TWO separate beakers or clear jars.
2. Pour 250 mL of tap water into a third beaker.
3. Label the beakers as follows: river water + nutrients*, river water with no added nutrients, tap water + nutrients. Include student names on all beakers!
4. Test and record the initial turbidity of each of the samples as instructed by the teacher.
5. Add 0.5 g of fertilizer to each of the two beakers labeled **+ nutrients**.
6. Place all jars in an equally sunny window or under a grow light.
7. Test and record the turbidity of each sample each class period for about one week.

Analysis and evaluation:

Evaluate the results of the experiment using a CER (sample response)

Guiding question: What are long-term effects of increased nutrients <u>in a water system</u>?

Example:

Claim: When nutrients are added to river water, there is increased algae growth that causes the water to become more cloudy.

Evidence: The turbidity, a measure of the relative clarity of water, of the river water sample with added nutrients increased at a higher rate compared to river water without added nutrients and the control

Evidence: The amount of light that can pass through a sample of water containing higher levels of turbidity (from algae) is less than that of less turbid water as measured by_________________.

Reasoning: Water with increased turbidity will not allow as much light to pass through it. This is a problem for water grasses that need sunlight to photosynthesize. The health of water grasses impacts the amount of dissolved oxygen available and the amount of habitat for small or immature water animals.

Supporting Document 4: Eutrophication Graphic Organizer

Eutrophication: causes, consequences, and solutions—teacher notes

Below is a list of the causes and effects of, and one solution to the process of cultural eutrophication. Cut out each of the statements and organize the information in the event boxes provided on the next pages. Work with one or two others.

To begin, first identify each event as a part of the problem (P) or part of the solution (S).

P Nutrients from incomplete treatment at wastewater treatment plants enter water system.	P Fertilizers containing phosphates are washed into streams, rivers, and lakes.	S Water leaving the waste water treatment facility does not contain phosphate.	P Water plants die and no longer produce oxygen.
P Algae grows rapidly and then dies at a higher rate.	P The amount of bacteria consuming the decaying algae increases.	P Murky water blocks light and photosynthesis is inhibited (not allowed).	S Algae grows at normal rate.
P Bacteria consume (use) large amounts of O_2.	P Animals in deoxygenated water (water with low levels of O_2) suffocate.	S Phosphate precipitate is removed by filtering it out of mixture.	S Water system begins to recover; water plants grow and produce oxygen.
S Bacteria growth decreases.	S Phosphate ion is reacted with cation to form precipitate.	P Water becomes murky (cloudy) from algae, bacteria, and decaying matter.	P Sewage from animal farms and storm water runoff enters river.

Original situation: Clear, oxygenated water provides healthy water ecosystem.
Problem: Cultural eutrophication

Root cause of cultural eutrophication	**Series of effects/chain of events**			
Events 1, 2, 3	**Events 4, 5, 6**	**Events 7, 8**	**Event 9**	**Event 10**
Sewage from animal farms and storm water runoff enters river. Nutrients from incomplete treatment at wastewater treatment plants enter water system. Fertilizers containing phosphates are washed into streams, rivers, and lakes as runoff.	Algae grows rapidly and then dies at a higher rate. The amount of bacteria consuming the decaying algae increases. THEREFORE: Water becomes murky (cloudy) from algae, bacteria, and decaying matter.	Bacteria consume (use) large amounts of O_2. Murky water blocks light and photosynthesis is inhibited (not allowed).	Water plants die and no longer produce oxygen.	Animals in deoxygenated/anoxic water (water with low levels of O_2) suffocate.

Solution: Phosphate* nutrient is removed at wastewater treatment facility.

Planned technical solution		**Process of restoration**		**Restoration outcome**
Processes 1 and 2	**Allow Event 3**	**Cause Event 4**	**Cause Event 5**	**Cause Event 6**
Phosphate ion is reacted with cation to form precipitate. THEN: Phosphate precipitate is removed by filtering it out of mixture.	Water leaving the waste water treatment facility does not contain phosphate.	Algae grows at normal rate. Bacteria growth decreases.	Water plants grow and produce oxygen.	Clear, oxygenated water provides healthy water ecosystem.

Supporting Document 5: Setting up a model wastewater treatment plant

The Carolina clip and pdf links below describe the way to use the Wastewater Treatment Kit from Carolina Biological. However, any plastic bottles and other readily available materials can be used. See photos for equally effective modified system.

- http://bit.ly/2yuMcoe
- http://bit.ly/2yuc8Si
- http://bit.ly/2gpCNti
- http://bit.ly/2gpKaRq

Water Environment Foundation document about wastewater treatment:

- http://bit.ly/2xLxDuq

U.S. Environmental Protection Agency's primer on municipal wastewater systems:

- http://bit.ly/2yucVTg

Flocculation:

- http://bit.ly/10VDjBQ

Setting up a model wastewater treatment plant

Purpose: Students will create a model that demonstrates the process of treating municipal wastewater. Sample "wastewater" will be tested at each step to determine the effectiveness of the treatments.

Materials for system: three one-liter bottles, sand, gravel, fine screen or cheesecloth, straws, modeling clay, alum, clamp/binder clip, ring stand and clamps

Overview of preparing system materials:

1. Cut the bottoms off of three plastic bottles.
2. Loosely cover the open top of one bottle with cheesecloth or netting and hold in place with tape or binder clips. This is the pretreatment screen.
3. On that same bottle, cut a straw-sized hole about an inch away from the capped end. Use clay to secure a straw or tubing (to keep it from leaking) in the hole. Put a clamp or binder clip on the straw to keep water from flowing out. This is the primary settling tank.
4. In the second bottle, repeat the straw placement, including a clamp. This is the secondary treatment. (Yeast will be added to represent the aerobic treatment by microorganisms.)
5. In the third bottle: Remove the cap and cover the opening with cheesecloth held in place with a rubber band. (Students will be responsible for adding layers of filtering materials such as sand of varying coarseness and gravel.) This is an example of further filtration and clarification.

Other materials to prepare ahead of time:

- Wastewater: combine vegetable oil, grass, small pieces of paper, small pieces of plastic from bottles, glucose
- Yeast culture: follow instructions on yeast package
- 0.1 M NaOH solution
- Alum solution prepared from $Al_2(SO_4)_3$ 12 H_2O (add 1 part alum to 10 parts water)

Student Procedure:

1. Obtain the three-bottle set of tanks. Each bottle is different.
2. Set up your system in the way that has been shown.
3. Obtain ~ 300 mL of wastewater.
4. Record observations including appearance, odor, and glucose content.
5. Make sure that the clamps on the straws are secure.
6. Pour the wastewater through the bottle covered by the screen.
7. Allow solids to settle for about 5 minutes.
8. Record observations of materials trapped by the screen and of the materials that passed through.
9. In the meantime, obtain 50 mL of yeast culture and make sure that the next tank is ready to accept the wastewater. DO NOT ADD THE YEAST CULTURE AT THIS POINT.
10. Open the clamp and allow the liquid to flow into the next tank STOPPING before the oil can pass through the straw.

Secondary Treatment: Microbial Action and Aeration

11. Record observations of appearance of wastewater and test initial glucose level using a glucose strip.
12. Add the yeast culture and stir rapidly for several minutes. (Use an aquarium pump and airstone if available.)

13. Check and record the glucose level every 5 minutes for 30 minutes.
14. During this time make a sketch of the apparatus and label the tanks and describe the function of each so far.

(optional) Create a graph and plot the glucose levels versus time. Make sure that axes are labeled and a title is written.

Secondary Treatment: Flocculation and settling

15. Add ~30 mL of 0.1 M NaOH to the liquid in the tank.
16. Add ~ 100 mL of alum solution to the tank and stir for 30 seconds.
17. Allow the solids to settle.

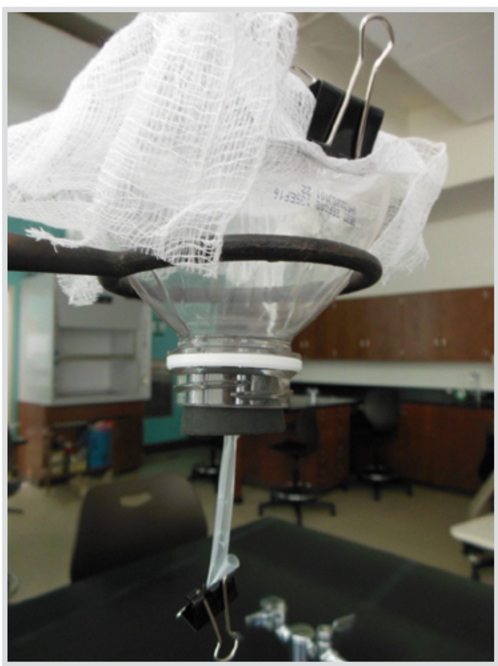
Tertiary Treatment

18. Use the sand and other materials to prepare a filter in the bottle with the cheesecloth around the nozzle.
19. Once the solids have mostly settled, open the clamp and allow the water to flow into the filter that you have designed.

Further Tertiary Treatment Options:

- treat with chlorine (bleach) and test for bacteria on agar plates
- research other treatments used to minimize impacts on water returning to a body of water http://bit.ly/2kTK3z4
- chemically remove phosphates

Photos for modified system using plastic bottles and other readily available materials.



Supporting Document 6: Wastewater Treatment-Phosphate Background with Clarification

During the **drinking water** treatment process, a small amount of phosphate (often referred to as orthophosphate) is added in order to produce a protective coating on the inside of pipes. By doing this, the water flowing through the pipes does not come in direct contact with the metal pipes that can corrode. However, phosphates are also a plant nutrient. When they are introduced to a body of water such as a river, algal growth increases, sometimes in a destructive way, as demonstrated in the eutrophication exploration. Therefore, phosphate levels are monitored at **wastewater** treatment plants, and may be removed by chemical or biological means. In the following activity, a chemical removal will be modeled.

In the following activity students explore a method of removing a contaminant (phosphate) from a water system using chemical engineering practices. Students' prior knowledge of ions, ionic ratios in compounds, and molar conversions are applied to an engineering problem: How can a substance that causes an environmental problem be removed from water before it is released into the Potomac River?

Supporting Document 7: How can phosphate contamination be addressed?

Chemistry to the rescue!

Actions have been taken to lessen the problem of phosphates getting into the water supply. For example, fewer cleaning products contain phosphates these days. Another strategy is to remove the phosphates at the wastewater treatment facility. (Our wastewater treatment facility is the Blue Plains Advanced Wastewater Treatment Plant on the Potomac River across from National Airport.)

How can an environmental engineer remove the phosphates before they get into the river?

When phosphates (PO_4^{3-}) bind to certain positive ions, they are insoluble and so they form solid precipitates in solution. When solid precipitates form in a solution, they settle to the bottom of the container and can be removed from the water. The precipitate can also be separated by filtration.

Determining the appropriate chemical quantities to capture the phosphates can be calculated. A simple way to determine whether all phosphate ions have been removed from a sample is to add an additional small amount of the selected metal cation solution. If no further precipitation is observed, the sample is relatively free of PO_4^{3-} ions.

There are some ions that work better than others to remove the phosphates because some ions react more readily with phosphates than others. Through chemical experimentation, you and your classmates will determine the best way to remove phosphates from a sample of wastewater. In addition to the effectiveness of the cations, the cost and safety of the different compounds will be investigated

Select a cation

The **source** of phosphate ions is Na_3PO_4. It will dissolve in water and is considered the wastewater in this model. Use the chart below to determine the mass of the compound that will react with 1.00 g of $Na_3PO_4 \cdot 12\ H_2O$. To ensure full reaction, each of the quantities is about double the amount that theoretically would be needed. The hydrated forms of the chemicals are most likely available in a high school lab.

mass of $Na_3PO_4 \cdot 12\ H_2O$	mass of $CuSO_4 \cdot 5\ H_2O$	mass of $FeSO_4 \cdot 7\ H_2O$	mass of $MgSO_4 \cdot 7\ H_2O$	$CaCl_2$ (anhydrous)
1.00 g	2.00 g	2.00 g	2.00 g	1.00 g

Experimental Method

Materials: sodium phosphate, other chosen compound (from above), distilled water, three beakers, graduated cylinder, filter paper, funnel, ring stand, stirring rod, balance, scoop

Procedure:
(Read all of the steps before beginning.)

1. Place a clean beaker on the balance. Click zero.
2. Measure out 1.00 g sodium phosphate.
3. Add about 100 mL of distilled water to the beaker. Stir to dissolve.
4. Place a DIFFERENT clean beaker on the balance. Click zero.
5. Measure out the correct quantity (from chart) of the other compound.
6. Add about 100 mL of distilled water to the beaker and stir to dissolve.
7. Combine the two solutions in one beaker.
8. Measure the mass of a piece of filter paper.
9. Write your name in pencil on the filter paper.
10. Fold the paper in half and then in half again. Open the filter paper part way to make a cone.
11. Set the cone in a funnel and put the funnel in the ring stand.
12. Set a clean beaker under the funnel and begin pouring the mixture through the filter.
13. Check for compete removal: Add a small amount of the compound solution OR a very small amount of solid compound to the filtrate (the liquid that has passed through the filter). Observe carefully to see if any more precipitate forms. If no additional precipitate (cloudiness) forms, all of the phosphate has been removed. It can enter the Potomac River without boosting algal growth.

Optional Analysis:

14. When all the water has passed through the filter, remove the paper and the solid from the funnel and place it in a spot designated by the teacher. It will dry overnight.
15. When the solid is dry, weigh the filter paper and the solid together on the balance.
16. Record the mass.
17. Subtract the mass of the filter paper to find the mass of the solid alone. This is the amount of solid that will need to be sent to the landfill.

Data Table:

Substance/Material	Mass (g)
filter paper	
Na_3PO_4	
reactant	
filter paper + product	
product	
qualitative observations	

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