The Great Bay Eelgrass Game

Written by Chloe Gross, Great Bay National Estuarine Research Reserve, Greenland, NH. Adapted from The Boundary Bay Game by Judy D'Amore, Marine Science Centers, Port Townsend and Poulsbo, WA. FOR SEA—Institute of Marine Science ©2000 J. A. Kolb

SUMMARY

How do human actions impact Great Bay's water quality and eelgrass meadows?

Eelgrass (*Zostera marina*) is an aquatic flowering plant that is a critical part of the Great Bay estuary ecosystem. Eelgrass meadows have been declining since the early 2000s, primarily due to runoff pollution. As a bioindicator and keystone species, the health of Great Bay's eelgrass beds directly relate to the health of the estuary as a whole.
In this game, students assume real world "roles" of individuals who interact with the Great Bay watershed, such as homeowners, farmers, fishers, and developers. Students make decisions based on their role that affect the estuary's water quality and health of its eelgrass beds. Each role card has a corresponding reading about a related topic in the Great Bay watershed.

OBJECTIVES

Students will:

- discuss water quality and eelgrass habitat issues in the local Great Bay watershed
- make reality-based choices that impact water quality and eelgrass habitat in a simulation game adapted for the Great Bay watershed region
- read local articles tied to water quality and eelgrass health concepts
- explain how various social, environmental, and economic factors impact decision-making
- understand that individual actions can have cascading effects on society as a whole

LOGISTICS

Grade Level: 6-12
Subject Areas: Environmental Science, Social Studies
Duration: 1-2 class periods, extension resources available
Setting: Classroom or open floor
Standards: MS-LS2-4, MS-ESS3-4, HS-LS2-6, HS-LS2-7

VOCABULARY

Bioaccumulation
Bioindicator
Estuary
Eutrophication
Limiting nutrient
Keystone species
Non-point source pollution
Point source pollution

HIGHLIGHTS

- Interactive simulation game
- Real world scenarios and local articles
- 23 student role cards, one teacher role card
- Two short answer worksheets
- One data collection, calculation, and synthesis worksheet
- Adaptable for middle and high school students with varying time constraints
  - Extensions and suggested simplifications available

GREAT BAY NATIONAL ESTUARINE RESEARCH RESERVE

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Key Concepts

1. Great Bay is an **estuary** - a place where freshwater and saltwater mix, creating a unique and constantly changing habitat.

2. **Eelgrass** (*Zostera marina*) is an aquatic flowering plant that lives in Great Bay and other estuaries around the world. Eelgrass is a **keystone species** that helps keep the whole estuary ecosystem intact. Eelgrass meadows filter water, keep sediments from washing away, and provide habitat, food sources, and breeding grounds for estuary organisms.

3. Eelgrass is a **bioindicator**. The health of eelgrass beds directly relate to the health of the estuary and its inhabitants as a whole. Great Bay eelgrass beds have been declining since the early 2000s, partly due to runoff pollution. Restoration efforts are underway, but there are still obstacles to overcome. Bioindicators are species, groups of species, or biological communities whose presence, abundance and condition indicate the current and potential future health of that ecosystem.

4. Individuals and groups make decisions that impact the Great Bay estuary. Many decisions are complicated and have tradeoffs that positively or negatively impact Great Bay's water quality and eelgrass meadows.

Vocabulary

Bioaccumulation - the process by which toxins are concentrated in organisms that are higher on the food chain.

Bioindicator - a species whose health indicates the current and potential future health of the rest of its ecosystem.

Eelgrass - *Zostera marina*, an aquatic flowering plant that thrives in clear, salty water.

Estuary - a body of water where saltwater and freshwater mix.

Eutrophication - a process by which there is an overabundance of plant growth due to excess nutrients in a water body.

Limiting nutrient - a nutrient whose abundance determines the growth of plant matter.

Keystone species - a species that the rest of its ecosystem depends on.

Non-point source pollution - pollution that cannot be traced back to a single source.

Point source pollution - pollution that can be traced back to a single source.

Turbidity - the measure of the cloudiness of water.

Teacher Background

Estuaries are some of the most important habitats on the planet. The unique habitat created by the mixing of freshwater from rivers and saltwater from the ocean is rich in biodiversity and productivity. Estuaries have been prized for their commercial, ecological, and cultural importance for centuries.

Great Bay is the largest estuary in NH and is one of 28 estuaries designated by the United States Environmental Protection Agency (US EPA) as having national importance. With each tidal cycle, saltwater travels more than 15 miles inland through the Piscataqua River to reach Great Bay proper. Seven rivers flow into this estuary, including the Salmon Falls, Cocheco, Bellamy, Oyster, Lamprey, Squamscott, and Winnicut rivers. These rivers drain the Great Bay watershed that extends more than 1,000 square miles and includes 37 towns in NH and nine towns in Maine. The large quantities of water that move in and out of the estuary create some of the strongest tidal currents in North America.

Great Bay's habitats are extraordinarily diverse: eelgrass meadows, mudflats, salt marshes, channel bottoms, and rocky intertidal zones, all of which are home to hundreds of bird, fish, and plant species, including 23 that are considered threatened or endangered. Indigenous peoples including the Abenaki and Squamscot groups lived in the Great Bay area long before European settlers arrived in the 1600s. Past and present, these groups have relied on Great Bay's abundant natural resources.

Eelgrass (*Zostera marina*) is an aquatic flowering plant and a critical component of a healthy estuary. Eelgrass is a **bioindicator**, meaning that the health of eelgrass beds directly relates to the overall health of the estuary; eelgrass has been called the "canary in the coalmine" of estuaries. Declines in eelgrass meadows foreshadows the decline of other estuarine life. Since 2002, researchers at the University of New Hampshire have seen the Great Bay estuary lose over half of its healthy eelgrass meadows.

Clear water is critical to eelgrass success. Eelgrass are rooted plants that depend on sunlight to photosynthesize. Cloudy and turbid waters block sunlight from reaching eelgrass blades. Great Bay's turbidity is primarily due to loose sediments and overgrowth of algaes. Severe storms, warming waters, and disease outbreaks - all increasingly fueled by climate change - have also contributed to the decline of eelgrass in Great Bay. While restoration and research projects are underway, more work is needed to reduce nutrient and sedimentation pollution. These efforts are critical to retaining remaining and restored eelgrass meadows in Great Bay.

Point source pollution (pollution that can be traced back to one location, eg. a Water Treatment Plant) and **non-point source pollution** (pollution that cannot be traced back to one location, eg. fertilizers in stormwater runoff leached from multiple lawns) contribute many pollutants, notably nitrogen. Excess nitrogen in water bodies often results in **eutrophication** (the overgrowth of algaes and other nuisance plant varieties). Algae and seaweed - along with sediments and other dissolved organic matter - cloud the water in Great Bay, making it difficult for eelgrass meadows to survive.

The loss of eelgrass has lasting effects. Eelgrass meadows help maintain water quality and decrease water **turbidity** (the measure of the cloudiness of water and a critical metric for measuring eelgrass, ecosystem, and overall estuary health). Eelgrass stabilizes coastal and bottom sediments: its rhizomes grip coastal and bottom sediment and its ribbon-like leaves trap loose particles in the bay's water column in addition to slowing the movement of water. Eelgrass also provide habitats for water-filtering organisms such as oysters. Eelgrass meadows provide food, mating grounds, and habitat for numerous crustaceans, shellfish, fish, amphibians, birds, and mammals. Eelgrass is a **keystone species**, which means that it helps hold its home ecosystem together. Without eelgrass, the estuary ecosystem falls apart.

Activity Overview

The Eelgrass Game is an interactive simulation game geared towards middle and high school students. Students assume the roles of "real world" individuals who interact with the Great Bay watershed, such as homeowners, farmers, fishers, and developers. These roles require students to make decisions that impact the water quality and the health of eelgrass beds in Great Bay, demonstrated by completing "actions" that change the water quality of the simulated "Great Bay." Students then compare their final eelgrass coverage to historic Great Bay eelgrass coverage data and visualize changes over time with a projected GIS map. Students then rate their bay's final water quality to a predetermined gradient and explore what that means for the future of their bay's eelgrass meadows.

Useful Information

Each student receives a "role card" which presents a situation that affects Great Bay's water quality and eelgrass meadows. Each situation has a corresponding "action," many of which result in physical or chemical changes to the composition of the simulated "Great Bay." In this game, every role card scenario has either happened in real-life or is a plausible situation in the Great Bay watershed region. Each card contains the following sections: the "Role," background "Context," "Action," and corresponding "Real World Reference" reading.

Throughout the game, students introduce various materials to the bay. Each material represents a type of pollutant that impacts the water quality and eelgrass health of Great Bay. These include:

- Food coloring to represent visible liquid contaminants such as oil, paint, or illicit industry discharge.
- Clay dust to represent silt and suspended sediments.
- Small items to represent litter.
- Vinegar to simulate invisible contaminants such as nutrient runoff, nitrate, PFAS, or mercury.

Students are prompted at various points in the game to test the bay's water quality using the three methods described below:

1. To simulate a colorimetric analysis, compare the color of a water sample to the Water Quality Standard. Dip one clear vial into "Great Bay" and another into the Water Quality Standard. Visually compare. If the water sample is darker than the standard, the water is considered to be contaminated. Have students mark the comparison as lighter, the same color, or darker than the standard. This provides a simple simulation of a test that might be used to measure the presence of oil or organic contaminants.
2. To measure turbidity, lower the mini secchi disk from the surface of the water. Record the depth at which it is no longer visible (the stem is marked to 20 cm). A secchi disk is a standard piece of water quality equipment used for measuring the turbidity or cloudiness of water.
3. To simulate a test for an invisible contaminant, test the pH of the water with a pH meter or strip of litmus paper. pH is used in this game to show invisible changes to water quality, but is not necessarily used to measure these specific contaminants in the "real world." As students add vinegar, the bay's pH will drop, indicating contamination. If the pH is lower than 6.0, the water is considered to be contaminated for this activity. Students do not need to understand pH for this game; the pH test is meant to simulate chemical analyses that might be used for nutrients or pesticides.

This information is displayed in Figure 3 below. This table is included on card 24 (the teacher role card) and on the student Data Tables reference sheet.

Figure 3 on the student reference sheet	
Simulated pollutant	**Real world examples**
Colored contaminant (Food coloring)	Oil, gasoline, paint
Silt (Clay dust)	Soil from eroding river bank and sediment churned up from bay bottom
Invisible contaminant (Vinegar)	Nutrients or pesticides, PFAS, mercury

Students have role cards that prompt them to make decisions and take actions which directly affect Great Bay's eelgrass populations. For example, a student may have a card that prompts them to add silt to the bay and remove one eelgrass. This demonstrates how the addition of nutrients results in eutrophication that crowds out eelgrass. Take time to answer students' questions. Discussion is encouraged.

The Great Bay Eelgrass Game deals with realistic topics that can have negative consequences for estuary health, eelgrass populations, and human wellbeing. The goal is for students to understand that water quality issues are complicated and multi-faceted. Individuals' and organizations' contributions to pollution vary, as do each's ability to influence and adapt to policy changes. Remind students that while these issues exist, we can help fix them. Pairing serious conversations with humor and fun while offering relatable strategies to help Great Bay can push your students to get the most out of this activity.

Suggested Preparatory Content

The eelgrass game can be used to teach and reinforce a variety of concepts depending on the class and curriculum. For example, concepts related to water chemistry or plant biology could be emphasized along with the central goal of fostering a sense of place and environmental stewardship.

Teachers are encouraged to spend time preparing students for the eelgrass game during a separate class period or through a homework assignment. Played in its entirety, the eelgrass game assigns various readings, short answer and data collection worksheets, and discussion periods over two 50 minute classes. This game is highly customizable, so additional preparation ideas are listed below. Extensions are listed on page 41.

Foster a sense of place. Introduce your students to the Great Bay estuary and its watershed. Ask them what they know about estuaries, specifically Great Bay, and whether they've visited it before. Some example questions include, Have they visited Adams Point or the Great Bay Wildlife Refuge? Have they seen horseshoe crabs or gone fishing in the bay? Have they seen the water as they drive over the General Sullivan Bridge that connects Dover and Newington? A great way of fostering a sense of place is to prompt your students to indicate (such as with a pushpin or sticky note) the location of their home on a large map of the Great Bay watershed. Point out the seven rivers that flow into Great Bay and explain how the twice-daily tides push and pull fresh water from the rivers and salt water from the Atlantic Ocean through the Piscataqua River. Share some of the facts about the bay that you find most interesting. A great general overview of Great Bay is located here: https://greatbay.org/learn/great-bay-101/.

Share the beauty of eelgrass. Seagrasses such as eelgrass live in salt and brackish water below the tide line and are therefore hard to see or touch. The Piscatqua Region Estuaries Partnership page houses videos and other educational resources to illustrate the beauty and importance of eelgrass, located here: https://prepestuaries.org/eelgrass/.

Introduce concepts of pollution and stewardship. Ensure your students are familiar with the terms used in this lesson that are important for your curriculum. For example, students should understand that pollution comes from many sources but it may not be appropriate to discuss limiting nutrients with younger students. For older students, discussing the relationship between the limiting nutrients and eutrophication could substantially boost the content of this game. The recent State of our Estuaries report includes a section about eelgrass, nitrogen, and other indicators of pollution that could be useful context. Located here: https://www.stateofourestuaries.org/.

Use the background readings and preparatory worksheet. The readings linked below contain information about Great Bay's water quality and eelgrass status. These are great resources for students to read before playing the game to help them see the real world context of this activity and understand the complexity of their individual roles.

Additionally, each role card contains a Real World Reference that links to a reading about a topic that is relevant to the specific role. A comprehensive list of the References is located on page 40.

Teachers can use these readings in different ways. For older students, incorporating these preparatory readings and Real World References can greatly boost their experience. For younger students and time-constrained groups, omitting these resources could significantly shorten the duration of this activity.

Consider assigning students their "Role" ahead of time. Ask them to read the articles and complete the preparatory worksheet in class or as homework. During the game, students are prompted to share what they learned about their role, its connection to the corresponding "real-world" example, and the potential impacts of various choices they may make.

Extraordinary Eelgrass. Wildlife Journal. New Hampshire Fish and Game.
https://www.wildlife.state.nh.us/marine/documents/wj-eelgrass.pdf
This NH Fish and Game article provides a great introduction to eelgrass.

A Fish Story. State of our Estuaries. Piscataqua Region Estuaries Partnership. 2023.
https://www.stateofourestuaries.org/setting-the-stage/a-fish-story
This article explains how different parts of the estuary are connected and how a variety of factors affect ecological health. Although some concepts are complex, it provides a great overview of the issues the Great Bay Eelgrass Game teaches.

To Understand Great Bay's Decline (and How to Stop It), Start on the Water. NHPR. 2017.
https://www.nhpr.org/environment/2017-12-19/to-understand-great-bays-decline-and-how-to-stop-it-start-on-the-water
This NHPR article provides a nice overview of the issues facing Great Bay and includes a great graphic about stormwater runoff.

Materials

- A map of Great Bay.
- A large, clear 10 gallon bin filled with water to represent Great Bay.
- A bottle of food coloring, labeled: "*colored contaminant*."
- A bottle of white vinegar, labeled*: "invisible contaminant.*"
- A cup of silt and a scoop.
- A bag of small items to represent trash.
- A clear vial for taking water samples, labeled: "Water Sample."
- A container of tinted water labeled "Water Quality Standard." One drop of food coloring in 1 1/2 quarts of water makes a good water quality standard. Also, a clear vial to use when comparing to the Water Sample.
- A miniature Secchi disk for measuring water turbidity.
- Litmus paper strips or pH meter.
- 10 plastic eelgrass.
- An envelope labeled "Resource Savings Bank." You will use the bank when collecting the students' payments.
- For each student:
    - One student role card per person for a class of 24. If the class is smaller, students could receive two roles, if larger, students could be paired. Simplify as appropriate.
    - Preparatory Questions worksheet.
    - Water Quality Data Table worksheet and Data Tables reference sheet.
    - 5 money units.
    - Post-game Reflection Questions worksheet.

Behind-the-scenes preparation

1. Prepare the students with introductory readings, vocabulary, and context.
2. Provide students access to the introductory readings, worksheets and reference sheet, and role cards. Distribute at appropriate times during the game.
3. Prepare the contaminants, water quality testing equipment, and Resource Savings Bank nearby. Display the map.
4. Fill the clear container with clean water and place it near the map. (Many teachers like to put the bin on a rolling cart so that it can be easily moved aside if the game needs to be continued another day.)
5. Add 10 eelgrass to "Great Bay."

6. Prepare the Water Quality Standard: fill the container labeled "Water Quality Standard" with water. Add 2 drops of food coloring and a 1/8 teaspoon of silt.
7. Decide how to distribute the "money." Some teachers prefer equal distribution among students, while others prefer unequal distribution to give the game a more "real-life" feel. Use discretion to determine what is best for your students.

Instructions for guiding students through the game

Note: The Eelgrass Game takes one to two 50 minute periods to complete, depending on the grade level, content coverage, and depth of discussions. This game can be tailored to be shorter (reducing the number of role cards or content coverage) or longer (use Extension Resources to include more content, foster discussions for each role card, etc.). One recommended timeline includes completing the readings, worksheet, scene-setting, and any desired preparatory content in one period, then playing the game the next day. If you need to interrupt the game, save all props (storing "Great Bay" and other materials on a rolling cart is recommended) and record students' roles and amount of money. If you plan to do this activity with more than one class per day, using separate bins for each class or continuing to add contaminants to the same bin for exaggerated results are two options.

First class period

1. Set the stage. Reference resources in "Teacher Background" (page 3) "Vocabulary" (page 3), "Suggested preparatory content" (page 6) and "Readings, References, and Resources" (page 41). Introduce and discuss new terms and content. If appropriate, distribute the introductory readings for students to read. Discussion is recommended.
2. Distribute a role card and Preparatory Questions worksheet to each student. Have the students read their card's information and articles to complete the worksheet.

Second class period

Before class, ensure everything is set up.

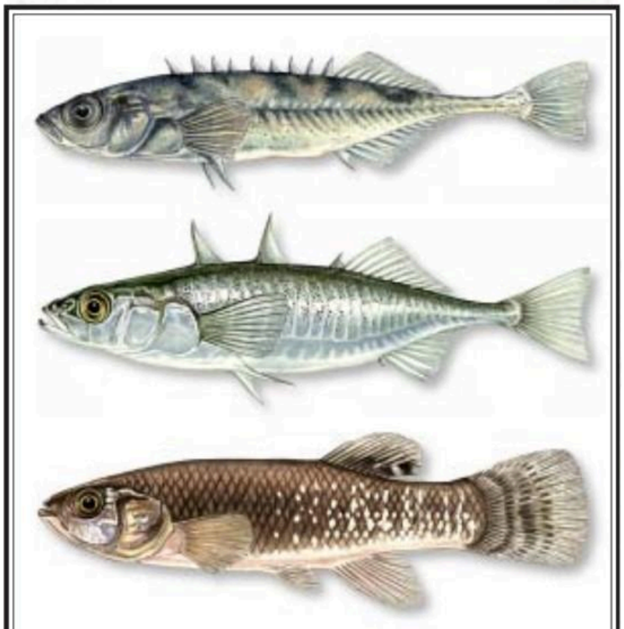
1. Introduce the students to the game. Inform them that they will play the roles of many people who live, work, and play around Great Bay. Show them the materials and demonstrate the three water quality procedures. Alternatively, introduce each action (explain the types of pollutants, water testing methods, voting procedures, etc.) as it arises throughout the game.
2. Distribute the Water Quality Data Table worksheet and Data Tables reference sheet, one per student.
3. Starting with the student who has the role card numbered "1," have the students read aloud their card's Role, Context, and Action. Encourage a short discussion about the various actions the student could take and potential implications, referencing any background reading and classroom content. The goal is for students to realize that most issues are complicated, many factors affect decision-making, and information is constantly changing.

4. Depending on the card's action, take a class vote, have the student make a decision, or discuss the designated action on that student's card. Have the student complete the action (such as adding a scoop of silt to "Great Bay," testing the water quality, or paying money). When testing the water quality, have the students note the measurements in their Water Quality Data Table.
5. Move on to the student with card number "2" and continue the game.
6. The last card - 24 - is for the teacher. Your role is an US EPA official who synthesizes the eelgrass and water quality data to determine the health of Great Bay. Guide the students through the calculation of final eelgrass coverage (one simulated eelgrass = 290 square acres of eelgrass in the "real" Great Bay - determined from Great Bay's peak recorded eelgrass coverage of 2,900 acres in 1996 in Figure 1). Project the GIS map (link on card 24 and in Extension Resources) and display the coverage of the year that most matches the calculated coverage from the simulation.
7. Guide the students through a comparison of the data in their Water Quality Data Table to Figure 2 to determine whether the simulated Great Bay's water quality is "Ideal," "Fair," or "Poor." Discuss what this means for eelgrass populations. What happens if the simulated bay has few eelgrass but good water quality (restoration efforts may succeed)? What happens if the bay has a lot of eelgrass but bad water quality (eelgrass may die in large quantities)?
8. Foster some reflection at the end of the game using an approach that works for your time constraints and student dynamics. This sets the stage for the Reflection Questions worksheet which has questions like,
    a. How did the eelgrass population and water quality change over the game and why?
    b. How did it feel to take the action on your card? Was your decision difficult, and why?
9. Assign the Reflection Questions worksheet.
10. Clean up!

Role Cards

There are 24 cards in this game - 23 student cards and one teacher card. Each student gets one card (adjust distribution as necessary: multiple cards per student or multiple students per card). Each card has a "Role," "Context," "Action," and "Real World Reference." Card 24 has the teacher step into the "role" of an US EPA official who tests the water at the end of the game.

1.



Eelgrass beds serve as fish "nurseries," providing shelter and food for small bottom-dwellers such as (top to bottom) ninespine stickleback, threespine stickleback and mummichog.

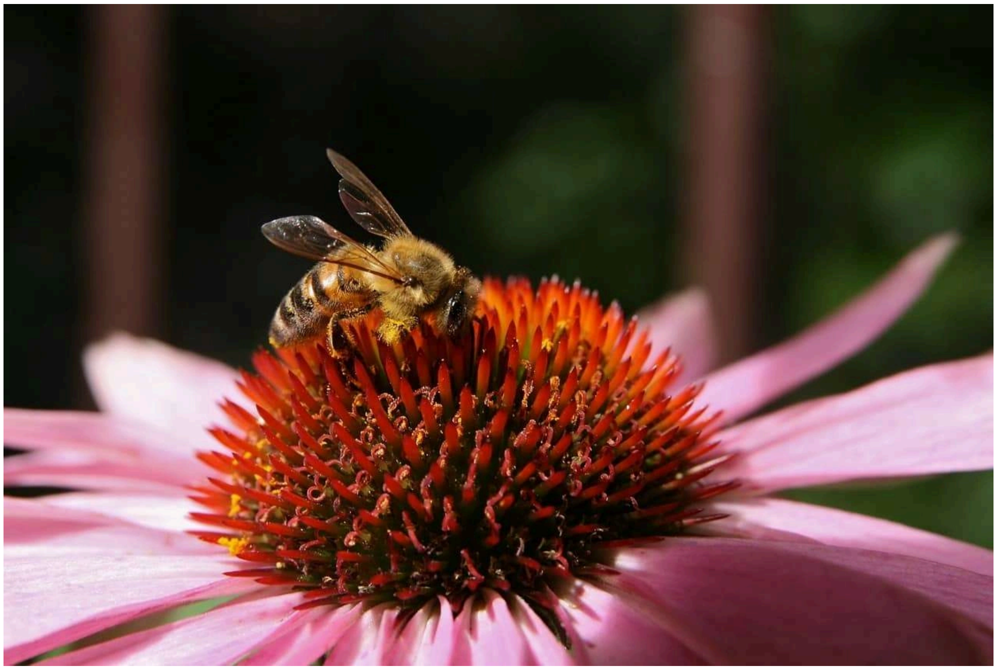
Role: I like to fish on the weekends. I have the best luck near the eelgrass beds in Great Bay, but the fish haven't been biting lately. I've heard that Great Bay is losing its eelgrass beds and that fish depend on those beds for food, but I didn't think it was this bad. Are the fish really gone?

Context: Eelgrass beds are the nurseries of the estuary. They provide food for juvenile fish and small organisms, which in turn attracts larger fish. Many fish reproduce in eelgrass beds because of its protection, and eelgrass rhizomes anchor sediments which create stable shelter for burrowing organisms.

Action: *Test Great Bay's water using all three methods and count the number of eelgrass. Record these figures in the "Test 1" cells on the Water Quality Data Table worksheet.*

Real World Reference: Extraordinary Eelgrass. NH Wildlife Journal Article.

2.



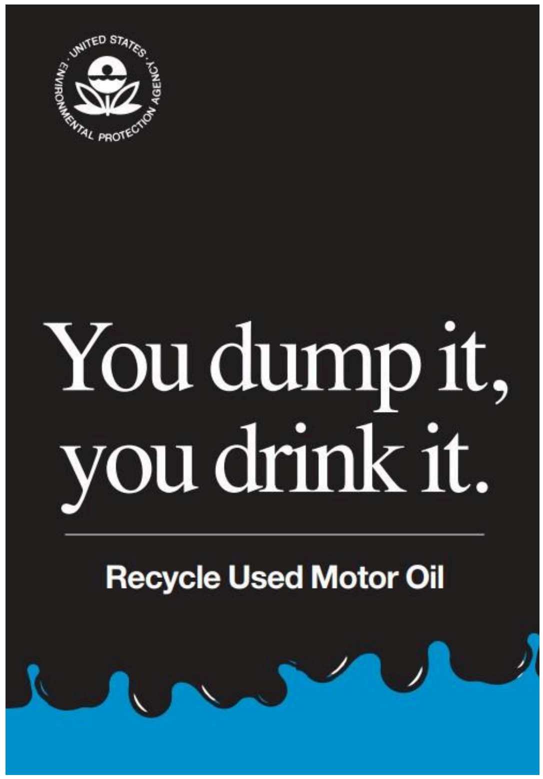
Role: The Homeowners Association where I live requires residents to keep very neat lawns, so I use fertilizers and pesticides to feed my grass and keep weeds at bay. I also have non-native flowers in my garden that can only survive if I use pesticides to kill native insects. I know some of these chemicals wash into stormwater, but I like how everything looks and I could be fined if my lawn is messy.

Context: Lawn fertilizers contain nitrogen, a nutrient that helps plants grow. Unfortunately, these nutrients can easily wash into rivers and bays where they can cause excess growth of algae and seaweed, called **eutrophication**. An abundance of algae can cloud the water and limit the amount of sunlight that can reach eelgrass plants. Bacteria and other decomposers use oxygen to break down dead algae and seaweed matter, but too much decomposition means that there isn't enough oxygen for all the organisms that live in the water. As a **bioindicator**, eelgrass is one of the first species to show signs of distress in toxic conditions.

Action: *Add 1 tablespoon of invisible contaminant to Great Bay.*

Real World Reference: Green Grass & Clear Water. NH Sea Grant Factsheet. 2019.

3.



Role: I change my truck's oil at home. I catch the used oil in a pan, but then I throw it in the trash because I don't want to bring the container to a recycling facility. Somewhere between my garage and the landfill, the oil leaks out of the container and into the Great Bay watershed.

Context: Non-point source water pollution is a major problem for Great Bay. Motor oil is not water soluble, can persist in the environment for a long time, and often contains other toxic compounds. Oil is often seen as a surface pollutant that washes into water bodies, but groundwater can be contaminated too. Spilled motor oil from a single vehicle can contaminate a million gallons of freshwater. Polluted water supplies pose health risks not only for humans, but wildlife and plants too.

Action: *Add 2 drops of colored contaminant to Great Bay.*

Real World Reference: What are the Effects of Oil on Seagrass? Region IV Regional Response Team.

4.

Role: My class visited the University of New Hampshire's Jackson Estuarine Lab at Adams Point. After lunch we left our wrappers on the picnic tables and threw our apple cores in the woods instead of putting our trash in the garbage. The litter washed into Great Bay and the apple core attracted nuisance wildlife. While litter doesn't directly kill eelgrass, it still stresses the whole estuarine ecosystem which makes it harder for eelgrass to survive.

Context: Litter is one of the most visible pollutants in Great Bay. Litter often floats on the surface of the water and can get caught on shorelines and in marshes after high tides. Plastic materials such as wrappers, fishing lines, and styrofoam items do not naturally decompose and therefore remain in the environment for a long time. Though these materials do not decompose, they break down into smaller particles called microplastics that are often ingested by marine animals.

Action: *Dump the bag of trash items to Great Bay.*

Real World Reference: Consider the Source and Microplastics. Great Bay Matters Magazine. 2018.

5.

Role: I have a sailboat that I like to take out on the weekends. I forgot to schedule a pump out of my onboard toilet. I don't want to turn around midday to find a marina with a stationary pump, and the Royal Flush pump out boat is nowhere near me. I release the toilet waste into Portsmouth Harbor because it saves me a lot of time.

Context: Untreated wastewater like sewage and surface runoff can be full of nutrients such as nitrogen. Nitrogen is a **limiting nutrient**, meaning that the growth of plants - such as macroalgae - is controlled by the quantity of the particular nutrient. Great Bay's nitrogen content has increased since the early 2000s, enabling algae and seaweed to become more abundant. Large amounts of seaweed can crowd out eelgrass, and algae clouds Great Bay's water, decreasing the amount of sunlight that can reach the eelgrass beds.

Action: *Add 2 drops of colored contaminant to Great Bay.*

Real World Reference: Great Bay Estuary Faces Pollution Threats. New Hampshire Public Radio. 2010.

6.

Role: I have a thriving aquaculture business in Great Bay. I partner with the University of New Hampshire to restore oyster beds and use the oyster market to boost New Hampshire's economy. One oyster can clean 30 gallons of water per day, but if Great Bay's water is too polluted, my oysters will become contaminated and the state government will close the bay to harvesting. These closures have been occurring more often in recent years and I'm worried that if Great Bay becomes too polluted, the oysters, eelgrass, and other estuary organisms will die. I really hope that I don't go out of business.

Context: Shellfish can become contaminated by water pollutants. Oysters are part of a group of aquatic organisms called filter feeders. These organisms suck in water, filter out microorganisms for their own consumption, and release the "clean" water. Filter feeders often accumulate pollutants and toxins as they filter. Consumption of contaminated shellfish can be harmful for humans - a prime example of **bioaccumulation**. Additionally, polluted water makes it harder for the whole ecosystem to thrive. Great Bay has seen declines in shellfish and eelgrass populations, primarily due to water pollution.

Action: *Test and Great Bay's water using all three methods and count the number of eelgrass. If two or more of the methods show that the water is polluted, remove 1 eelgrass from Great Bay.*

Real World Reference: Oysters, Oyster Restoration and Oyster Aquaculture. State of Our Estuaries Report, 2023. Page 82 - 87.

7.

Role: I work at my town's Wastewater Treatment Plant. Our treated wastewater is released into a tributary that flows into Great Bay and although it's treated, it still has a high nitrogen content. Our system is old and needs to be updated, but a replacement is expensive and will require residents to pay more in taxes and their water bill will increase.

Context: Before its upgrade, the Exeter Wastewater Treatment Plant was a large contributor to the **point source pollution** that flowed into Great Bay. This pollution primarily contained high nitrogen content. Excess nitrogen causes eutrophication that makes it hard for eelgrass to survive. In 2020, Exeter spent $53 million to upgrade the treatment plant and in 2022 the plant received an excellence award for its work on nitrogen pollution.

Action: *Many communities face this problem, so take a class vote. Would your class tax themselves and each other to build a better treatment plant? If the majority votes yes, each person in the class must pay the bank 1 piece of money. If the class votes no, add 2 tablespoons of invisible contaminant to Great Bay and remove 3 eelgrass.*

Real World Reference: Sewage Treatment Plants Part of Pollution Problem in the Great Bay. New Hampshire Public Radio. 2010.

8.

Role: I grow fruits and vegetables on my farm near the Bellamy River. I use chemical fertilizers and pesticides on my crops, and some of these chemicals wash into Great Bay. I know that other farmers have switched to organic farming methods that don't use chemicals, but I also know that they don't produce as many crops anymore. I'm worried I will go out of business.

Context: Many farms use fertilizers and pesticides to enhance crop growth. Synthetic fertilizers are made of specific mineral components such as nitrogen and phosphorus. Oftentimes fertilizers leach from fields and lawns into water supplies. Nitrogen and phosphorus are both **limiting nutrients,** so excess quantities of nitrogen and phosphorus contribute to **eutrophication**. Pesticides are chemicals designed to poison targeted organisms, but they can also poison other animals - and humans - through **bioaccumulation.** Alternative farming methods include fertilizing with compost and using integrated pest management strategies.

Action: *If you decide to farm organically, pay 2 pieces of money for potential crop losses. If you decide against it, add 1 tablespoon of invisible contaminant to Great Bay.*

Real World Reference: Tough times for NH's organic farmers. Valley News. 2021.

9.

Role: I work for the New Hampshire Port Authority. We help maintain deep shipping channels for large vessels moving in and out of Portsmouth Harbor. We received $1.6 million to dredge (remove sediments from the river bottom) a portion of the Piscataqua River to make it easier for large ships to dock here. This will increase the turbidity of the waters that flow in and out of Great Bay, but not dredging will make it harder for ships to dock in Portsmouth which will hurt New Hampshire's economy.

Context: The amount of suspended particulate matter in water is called **turbidity**. Eelgrass thrive in clear waters because they are rooted flowering plants that need sunlight to photosynthesize. Turbid waters prevent sunlight from penetrating the water column and reaching eelgrass leaves. This New Hampshire Port Authority project decided to relocate clean sediments to Salisbury Beach and Plum Island in Massachusetts.

Action: *Take a class vote to decide whether to dredge the harbor or not. If the class chooses to dredge, remove 1 eelgrass, add 1 drop of colored contaminant, and 1 tablespoon of silt to Great Bay. If the class chooses not to dredge, add 1 eelgrass.*

Real World Reference:
'Bigger ships, faster delivery': NH Port Authority gets $1.6M for the basin. Why it matters. Seacoastonline. 2022.

10.

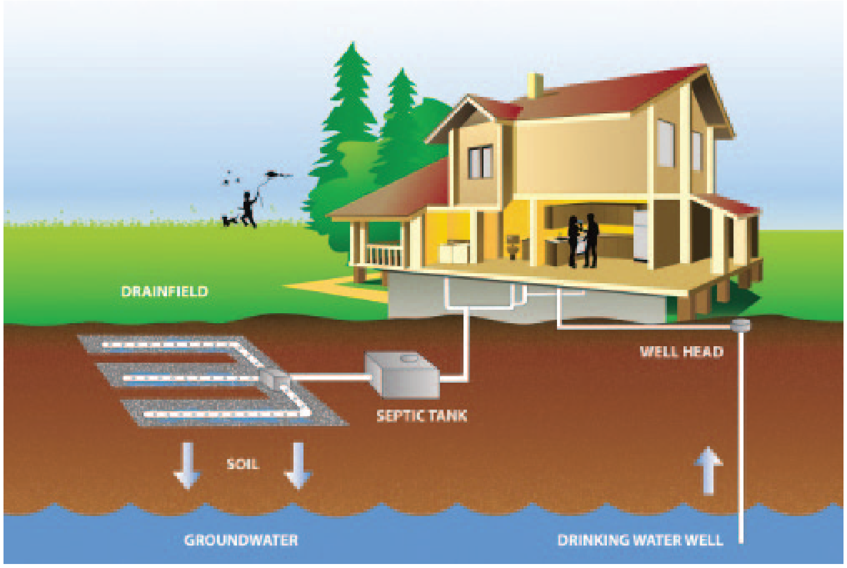
Role: I am a marine scientist at the University of New Hampshire. Part of my work is to research which methods of re-planting eelgrass beds are most effective in Great Bay. These trials, in addition to pollution mitigation projects, are part of an effort to restore eelgrass habitats in the estuary.

Context: Great Bay lost roughly half of its eelgrass population from 2000 to 2020. Efforts to replant eelgrass beds and reduce nutrient runoff and water pollution in Great Bay are underway, but obstacles persist. Eelgrass thrive in cold, clear waters, so warming waters due to climate change make it even more difficult for eelgrass to survive. In addition to requiring eelgrass to double its rate of cellular respiration, warming water temperatures also invite non-native species (such as blue crabs) that damage eelgrass beds.

Action: *Test Great Bay's water using all three methods and count the number of eelgrass. If two or more of the methods show that the water is polluted, remove 1 eelgrass from Great Bay.*

Real World Reference: By transplanting eelgrass, scientists aim to restore balance to Great Bay. NH Bulletin. 2021.

11.



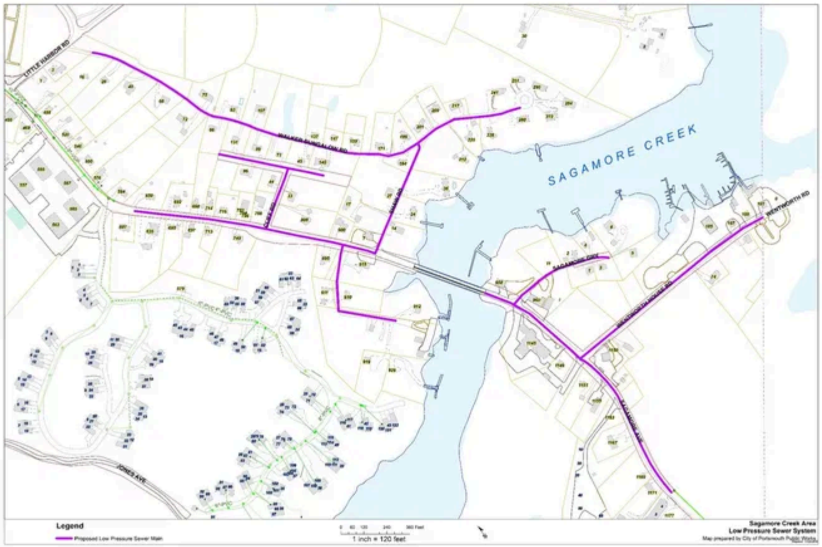
Role: I live near the Bellamy River and have a septic system for my home. My septic system is old and releases nitrogen right now. Replacing my septic is very expensive, but if I don't do this, waste could **leach** into the watershed and contribute to nitrogen pollution. Excess nitrogen and other nutrients cause algae to grow and crowd out eelgrass.

Context: Septic systems release filtered wastewater into the ground. Unfortunately, most septic systems aren't designed to remove nitrogen from wastewater and so some nitrogen is released into the soil around a septic tank and can leach into nearby streams. Nitrogen is a **limiting nutrient**, meaning that the growth of plants - such as macroalgae - is controlled by the quantity of the particular nutrient. Great Bay's nitrogen content has increased since the early 2000s, resulting in an explosion of algae growth. In addition to crowding out eelgrass, algae clouds Great Bay's water, decreasing the amount of sunlight that can reach the eelgrass beds.

Action: *Either pay 2 pieces of money to replace your septic system or add 1 tablespoon of invisible contaminant (e.g., nitrogen) to Great Bay.*

Real World Reference: How Nitrogen from Septic Systems Can Harm Water Quality. Washington State Dept of Health Fact Sheet. 2014.

12.



Role: I am the mayor of a small city in the Great Bay watershed. I know that many of the septic systems in our city are aging and are likely leaking nitrogen into our groundwater and creeks, but it's not clear how to best manage this source of pollution. We could put pressure on these homeowners to upgrade their septic systems, which would be a large and on-going expense for these individuals. Or, we could choose to extend sewer pipes to more of the neighborhoods in our City, which will raise taxes for everyone and cause a lot of disruption as we lay down new pipes under roadways.

Context: About half the homes in NH have individual septic systems that manage their waste, often because there aren't any accessible sewer lines to connect to. Many septic system leak nitrogen which can leach into groundwater and nearby waterways where it can fuel algae blooms, reduce water clarity, and impact eelgrass. The decision to build or expand a municipal sewer treatment system is often controversial because of the expense and hassle.

Action: *Take a class vote. Will the students approve higher taxes to expand the city's sewer system? If they vote yes, everyone must pay 1 piece of money, if this is voted down, everyone that is born between January and May must pay 2 pieces of money to clean and upgrade their personal septic systems. If someone cannot pay, add 2 drops of invisible contaminant to Great Bay.*

Real World Reference:
Dozens of Sagamore Creek residents signing on for sewer hook-up. Portsmouth paying $1.2M.
Seacoastonline. 2022.

13.

Role: I am a student doing a project about eelgrass. I found out that there is a pathogen called *Labyrinthula zosterae* that causes Seagrass Wasting Disease. Warming waters from climate change make it easier for this disease to spread throughout eelgrass meadows. Considering that eelgrass populations are already low, I'm worried about what would happen if the wasting disease spread in Great Bay. I want to write to my state politicians to ask them to fund eelgrass restoration projects, pass pollution restrictions, and fight climate change. Of course, this all costs money, but how much will it cost when we have no eelgrass to keep Great Bay alive?

Context: *Labyrinthula zosterae* is a slime mold that kills eelgrass by colonizing on the surface of the leaves. Seagrass Wasting Disease was responsible for the mass die-off of eelgrass in Great Bay and other Atlantic waters in the 1980s. Great Bay's eelgrass has since recovered, but other issues threaten the plant's existence. *Labyrinthula zosterae* thrive in warm, salty waters - conditions that will become more common due to climate change.

Action: *If you choose to write to your state representatives, plant 1 eelgrass in Great Bay. If you choose not to write, remove 2 eelgrass and add a scoop of silt.*

Real World Reference: Sea Grass Wasting Disease is Fueled by Climate Change. Earth.com 2021.

14.

Role: I just bought a house. I've heard that surface runoff picks up contaminants and washes it all into Great Bay. I know that the water from my gutters ends up in the street, but I could plant a rain garden. I would have to spend part of my weekend digging the garden bed and planting flowers, but then my soil would absorb the runoff and I would have a pretty garden.

Context: Stormwater runoff is a significant source of **non-point source pollution.** Pollutants often lead to murkier water, algae blooms and warmer temperatures which can damage eelgrass. Rain gardens are built to catch water so that it can slowly absorb into the soil. The plants in the garden also filter out contaminants and cool the water temperature. This all helps keep Great Bay clean so that eelgrass can thrive.

Action: *If you choose to create a rain garden, plant 1 eelgrass. If you choose to not plant a rain garden, add 1 drop of invisible contaminant, 1 drop of colored contaminant, and ⅛ teaspoon of silt.*

Real World Reference:
Rain Gardens. New Hampshire Department of Environmental Services.

15.

Role: I serve on my town's Conservation Commission. Unlike many of the surrounding towns, we don't have any specific rules about stormwater management. This makes it difficult to convince property owners and developers to make choices that will help keep Great Bay's water clean. It can be as easy as planting a rain garden that filters and absorbs runoff, but no one wants more regulations.

Context: Stormwater runoff is a significant source of non-point source pollution**.** When rain falls and snow melts on impervious surfaces like roads, parking lots, and buildings, pollutants on the surface leach into streams. These pollutants often lead to murkier water, algae blooms and warmer temperatures which can damage eelgrass. Many towns and cities have rules that require new developments to manage stormwater on their property to minimize the amount of stormwater that runs off.

Action: *Make a choice to either create new stormwater rules and add 1 eelgrass to Great Bay, or add 2 drops of the invisible contaminant and 1 tablespoon of silt to Great Bay.*

Real World Reference:
Stormwater Management Standards and Funding. Piscataqua Region Estuaries Partnership. 2023.

16.

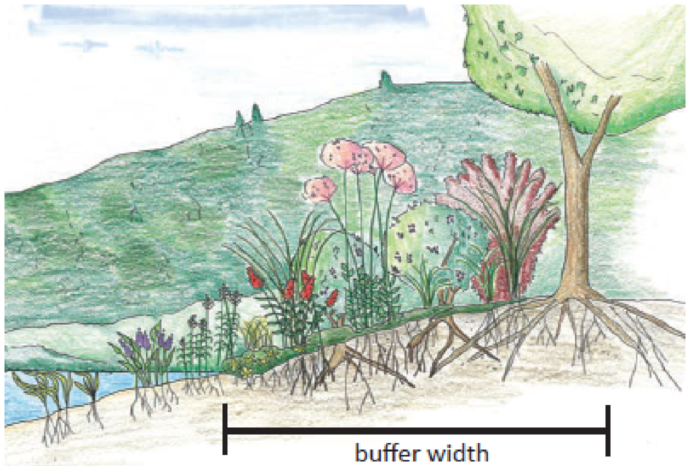
Role: I am a commercial fisherman. The engine on my boat leaks oil into the bilge inside my boat. Water also collects in the bilge, so every so often I have to pump out the mess. If the Coast Guard spotted me dumping the bilge into the water, I would be fined a lot of money, so before I start the bilge pump, I pour detergent into the mix. This makes the oil break up and mix with the water so nobody can see it. I know that this is harmful to the estuary but I don't want to be caught with an oil slick behind my boat.

Context: New Hampshire has a Coastal Spill Response team that responds to situations such as bilge, oil, and fuel tank spills. Oil is not water soluble, can persist in the environment for a long time, and often contains other toxic compounds. Oil is often seen as a pollutant on the surface of the water, but detergents such as soap can disperse the oil particles. Oil coats and smothers eelgrass, especially when the spill is near eelgrass beds. Polluted water supplies pose health risks not only for humans, but wildlife and plants too.

Action: *Add 2 drops of colored contaminant to Great Bay.*

Real World Reference: Spilled Oil In Speedy Piscataqua Would Make For Tricky Clean-Up. NHPR. 2014.

17.



Revised Role: I am a developer and I build residential subdivisions in several towns in the Great Bay watershed. I am proposing to build a new neighborhood that will have excellent views of the Lamprey River. I have learned that some towns have more limited rules about development close to the water's edge and I've also learned how to get a conditional use permit to develop within the protected buffer when needed. Homes with water views sell better and raise more tax revenue for the town. I also believe that people need to see and connect with nature in order to care about it. Why should only a few wealthy people get to have homes with water views? Maybe if we all had views of the Lamprey River or Great Bay we would work harder to protect clean water.

Context: Vegetated buffers filter runoff and prevent harmful particles from entering rivers, wetlands, and other water bodies. These areas also help to slow water movement and cool water temperatures. Without these buffers, pollutants and sediments wash right into the water. This is a big issue for Great Bay. Water that has too many nutrients and too much floating sediment makes it hard for eelgrass to survive.

Action: *The class is the town's planning board and they need to approve your project in the river buffer area. Take a vote. If the class votes to allow you to develop within the river buffer zone add 1 tablespoon of silt and remove 2 eelgrass. If the class denies your permit request, pay 4 pieces of money because you designed a subdivision that you couldn't build.*

Real World Reference: Living with the River: The Importance of Riparian Buffers for Your Land and Your Environment. Connecticut River Joint Commission Fact Sheet.

18.

Role: I work at the Wentworth by the Sea Hotel in New Castle. People from all over the country come to spend their vacations boating, swimming, and fishing on the New Hampshire seacoast. If the rivers, bay, and ocean are polluted, people will stop coming here and I'll go out of business.

Context: Tourism is a critical component of New Hampshire's economy. Tourists funnel millions of dollars of revenue into the state during vacations to the mountains, lakes, and coastal regions of New Hampshire. Beyond preserving ecological integrity, it is economically savvy to keep the state's water bodies healthy, including Great Bay. Maintaining eelgrass meadows are a critical component of the estuary's ecosystem, so efforts to decrease nutrient leaching, wastewater releasing, and stormwater runoff should continue.

Action: *Count the number of eelgrass in Great Bay. If the total number of eelgrass is less than a half of the amount you began with, turn in all your money - you go out of business.*

Real World Reference: 5 Reasons to Visit New Hampshire's Coast this Summer. Outdoor Project. 2018.

19.

Role: I work for the New Hampshire Coast Guard. A yacht caught fire in Portsmouth Harbor near New Castle. Aerial images show that diesel is leaking from the fuel tank on the boat. I have to coordinate with multiple agencies because the boat sank in a difficult position that makes removal dangerous. The leaked diesel hasn't reached any New Hampshire shorelines yet, but if it does, the diesel could smother eelgrass beds, damage nearby ecosystems, and cause unhealthy conditions for human activities. My team needs to decide if we will go forward with the expensive clean up effort of the wreck.

Context: Diesel directly and indirectly harms eelgrass populations. Eelgrass mortality can occur due to smothering, fouling, or asphyxiation from direct contact with oil substances. Juvenile plants are especially susceptible. Diesel pollution can not only block sunlight from reaching eelgrass, but also make eelgrass more vulnerable to other stressors and decrease eelgrass's ability to trap harmful particles in the estuary.

Action: *If you choose to clean up the wreck, tax everyone 1 piece of money to put in the bank. If you choose to leave the wreck, add 3 drops of colored contaminant to Great Bay.*

Real World Reference: Burned yacht 'Too Elusive' pulled from Maine waters, brought to NH. Seacoastonline. 2022.

20.

Role: I serve on the selectboard in Durham. The Mill Pond Dam on the Oyster River (a tributary of Great Bay) is old and unstable. Some residents want to get rid of the dam and others want to build a new one. Getting rid of the dam will drain the historic pond but will create a healthier river ecosystem that will benefit Great Bay. There is grant funding available to pay for the removal, so the town won't have to increase taxes to pay for it. Rebuilding the dam will keep the pond and its recreational, aesthetic, and historic characteristics intact, but will not allow the ecosystem to recover.

Context: The Mill Pond Dam currently obstructs the natural flow of the Oyster River and blocks fish and other aquatic organisms from migrating up and down river to feed and reproduce. In addition, the water behind the dam warms more than it naturally would, and since it flows into Great Bay, it raises the temperature of the bay as a whole. Warmer water temperatures put stress on fish and eelgrass, which makes them more susceptible to disease.

Action: *Take a class vote on whether or not to remove the Mill Pond Dam. If the class votes to remove it, add 1 eelgrass to Great Bay. If the class votes to rebuild it, remove 1 eelgrass.*

Real World Reference: Durham: A community divided by a derelict dam. Seacoastonline. 2022.

21.

Role: I am a State Representative in the New Hampshire legislature. I have to decide whether to vote “yes” or “no” on an eelgrass restoration project. Eelgrass roots help keep shorelines stable. This is becoming more and more important as climate change creates stronger storms, and I know that supporting this project will help protect New Hampshire’s residents and coast. I also know that I am under pressure to decrease New Hampshire’s state spending, and these kinds of projects cost a lot of money.

Context: Eelgrass is both a **keystone species** and a **bioindicator**. Eelgrass meadows protect shorelines from erosion by gripping shoreline sediments, but they also are vulnerable to climate change impacts. Eelgrass rely on clear water for photosynthesis, but increasingly strong storms churn up underwater sediments and wash surface pollutants into Great Bay, making it difficult for eelgrass to survive. This creates a positive feedback loop: turbid water makes it difficult for eelgrass to survive and protect the coast, which means stronger storms from climate change can cause more erosion which increases turbidity.

Action: *Either collect 1 piece of money from everyone and add 1 eelgrass to Great Bay or remove 2 eelgrass.*

Real World Reference: The 'secret weapon' in fight against climate change — planting eelgrass. CBC News. 2022

22.

Role: I am a resident of Durham and I own a large piece of undeveloped land. I and many of my neighbors have been approached by a developer that wants to buy our land to build an oil refinery. There is a group of very concerned citizens working on this; they believe the refinery would destroy New Hampshire's coastline: estuary ecosystems would be crisscrossed by pipelines, and historic farms would be replaced by refinery tanks. The developer claims the refinery would create jobs, reduce taxes and lower gas prices, but they don't have good answers to any of my questions.

Context: In 1974, the town of Durham rejected a proposal for a $600 million oil refinery to be built in Great Bay. At 3,000 square acres, this refinery and tank complex would have been the largest in the world, pumping 400,000 barrels of oil through its systems per day with a capacity of storing 30 million barrels. The plan was highly supported by New Hampshire's governor Meldrim Thompson and Union Leader boss William Loeb. Many local residents vehemently opposed the project and Dudley Dudley of the Save Our Shores group successfully passed a law which upholds New Hampshire's tradition of "home rule" - a legal precedent that grants local residents the final say for developments in their town. In a vote of 1,254 to 144, Durham voted to reject the project.

Action: *Take a class vote. If the class votes against the refinery, tax everyone 1 piece of money for the loss of potential economic benefits. If the class votes for the refinery, add 5 drops of colored contaminant to Great Bay and remove 4 pieces of eelgrass.*

Real World Reference: *Where were you in 1974? 40th Anniversary of oil refinery defeat. Town of Durham News. 2014.*

23.

Role: I just bought a house near Great Bay. I've decided to test the water in my well because I want to make sure it's safe for my family.

Context: Despite efforts to reduce point and nonpoint source pollution, Great Bay still has water quality problems. Recent Wastewater Treatment Plant updates have substantially decreased the quantity of **point source pollutants** in the bay, but it has also revealed how much of the pollution comes from **non-point sources**, including runoff, nutrient leaching, and increased turbidity and sedimentation rates. Groundwater supplies connect to the Great Bay watershed's surface water, so polluted water bodies pose health risks not only for wildlife and plants, but for humans too.

Action: *Test and Great Bay's water with all three methods and count the number of eelgrass. If two or more of the methods show that the water is polluted, pay 1 piece of money to connect to the city water supply.*

Real World Reference: Stormwater runoff problem: Efforts continue to clean up New Hampshire's Great Bay, NHPR. 2023. Link:

24.

Teacher Role: I work for the United States Environmental Protection Agency. Part of my job is to test the water quality in various places around the US. Today I am testing the water in Great Bay. There are many ways to test water quality, but I'm using a Secchi disk, pH reading, visible contaminant comparison, and counting the number of eelgrass present. The results of these tests determine whether Great Bay is safe for human use. These tests are also used to measure the health of the bay's estuarine ecosystem and eelgrass meadows.

Context: There are no conclusive standards for water quality in Great Bay due to the variability of its day-to-day conditions. Ask the students why this could be so (tides, rainstorms, seasons, etc.).

Action: *Count the number of eelgrass in Great Bay. Have the students complete the eelgrass coverage calculation on the Water Quality Data Table sheet. The game started out with 10 eelgrass equalling the peak coverage of 2,900 square acres in 1996. Each individual eelgrass represents 290 acres of eelgrass beds. Multiply the final count of eelgrass by 290 to calculate the game's final eelgrass coverage. Compare the total coverage to the annual totals in Figure 1. Visit the GIS maps at the "Real World Reference." Click the blue "OK" button at the bottom right of the screen, then click the green icon at the bottom left of the next page. This will open up the various GIS layers. Scroll and select the year that most closely represents the game's final eelgrass coverage. The layer will display on the map. Compare to other years, (such as 1996) to note the loss of coverage over time.*

Real World Reference:
1948-2019 Great Bay eelgrass coverage GIS maps. Matt Wood. NH DES.

Note: Figures 1, 2, and 3 are also located on page 38. Distribute this sheet along with the Water Quality Data Table sheet to the students before beginning the game.

Figure 1

Year	Great Bay eelgrass coverage in square acres
1996	2894
1997	-
1998	-
1999	2459
2000	2285
2001	2735
2002	2145
2003	1996
2004	2349
2005	2507
2006	1623
2007	1489
2008	1619
2009	1890
2010	1895
2011	1836
2012	1813
2013	1448
2014	1620
2015	1493
2016	1688
2017	1546
2018	-
2019	1677
2020	-
2021	1352
2022	1481

Action continued: *Next, have the students compare their water quality data to Figure 2, to assess Great Bay's water quality with all three metrics. Ask the students how the water quality impacts eelgrass and how eelgrass health foreshadows the health of the estuary as a whole. Have them hypothesize the "fate" of their Great Bay eelgrass based on the water quality. For example, if the colored contamination is "Fair," and the turbidity is "Poor," the water will be too cloudy for eelgrass to photosynthesize, so even if the bay has lots of eelgrass, the eelgrass meadows will still have a hard time surviving. Discussion is highly recommended.*

Figure 2				
	Colored contamination (comparison to Water Quality Standard)	**Turbidity (Secchi disk)**	**Invisible contamination (pH)**	**Eelgrass coverage (count of plants)**
Ideal	Clear	>12 cm depth	6.5 - 8	8 - 10
Fair	Lighter or same color as standard	8-12 cm depth	5.5 - 6.5	5 - 7
Poor	Darker color than standard	<8 cm depth	Less than 5.5	<6

Summary of the simulated pollutants and what they represent.

Figure 3	
Simulated pollutant	**Real world examples**
Colored contaminant (Food coloring)	Oil, gasoline, paint
Silt (Clay dust)	Soil from eroding river bank and sediment churned up from bay bottom
Invisible contaminant (Vinegar)	Nutrients or pesticides, PFAS, mercury

Preparatory Questions

1. Use the terms watershed, estuary, point source, and non-point source pollution to summarize what you know about Great Bay and its eelgrass health.

3. What is a bioindicator? What does eelgrass health tell researchers about the health of the estuary?

4. Paraphrase the article you read. Describe the issue, possible controversies associated with the topic, and main takeaways.

5. What does your article have to do with Great Bay's water quality and eelgrass meadows?

Water Quality Data Table

	Colored contamination, representing oil and gasoline pollution (comparison to the coloration of the Water Quality Standard) Recorded as "clear," "lighter," "equal color," or "darker"	Turbidity, representing water cloudiness (depth at which Secchi disk is no longer visible) Recorded in cm	Invisible contamination, representing nutrient pollution (pH reading from meter or litmus paper) Recorded as the pH value	Eelgrass coverage, representing eelgrass coverage (count eelgrass individuals) Recorded as the final eelgrass count
Test 1				
Test 2				
Test 3				
Test 4				

Eelgrass Coverage Comparison

1. Calculate the final coverage of eelgrass in Great Bay. One eelgrass = 290 square acres of real Great Bay eelgrass coverage.

2. Compare your final eelgrass coverage to the "real" Great Bay's historic acreage in Figure 1. To which year is your eelgrass coverage most similar?

3. How do you think your bay's water quality will affect your eelgrass meadows? Explain your thinking.

Data Tables Reference Sheet

Figure 1	
Year	**Great Bay eelgrass coverage in square acres**
1996	2894
1997	-
1998	-
1999	2459
2000	2285
2001	2735
2002	2145
2003	1996
2004	2349
2005	2507
2006	1623
2007	1489
2008	1619
2009	1890
2010	1895
2011	1836
2012	1813
2013	1448
2014	1620
2015	1493
2016	1688
2017	1546
2018	-
2019	1677
2020	-
2021	1352
2022	1481

Figure 2				
	Colored contamination (comparison to Water Quality Standard)	**Turbidity (Secchi disk)**	**Invisible contamination (pH)**	**Eelgrass coverage (count of plants)**
Ideal	Clear	>12 cm depth	6.5 - 8	8 - 10
Fair	Lighter or same color as standard	8-12 cm depth	5.5 - 6.5	5 - 7
Poor	Darker color than standard	<8 cm depth	Less than 5.5	<6

Figure 3	
Simulated pollutant	**Real world examples**
Colored contaminant (food coloring)	Oil, gasoline, paint
Silt (clay dust)	Soil from eroding river bank and sediment churned up from bay bottom
Invisible contaminant (vinegar)	Nutrients or pesticides, PFAS, mercury

Reflection Questions

1. Why was it sometimes difficult for people to make decisions in favor of protecting the water quality in this game? What were some long-term social, environmental, and economic costs to individuals or groups as a result of such decisions?

2.What were some motivations that influenced decision making during the game?

3. If your role's situation happened in real life, would your choice be different from the choice you made during? Why?

4. How does water quality impact eelgrass? What happens to the rest of the estuary ecosystem when eelgrass beds die?

5. Provide examples of both point source and non-point source pollution from the eelgrass game and explain the direct and indirect impacts.

4. How did your article about a real-life situation around Great Bay relate to your role card? How does it relate to eelgrass health?

6. Big issues like pollution and habitat degradation can be overwhelming to individuals, but even little choices add up. What can you do to help Great Bay's eelgrass?

Readings, References, and Resources

Below is a list of the references cited in this activity. Some readings are available in PDF format in this google folder.

Background Reading Suggested for All Students

A Fish Story. State of our Estuaries. Piscataqua Region Estuaries Partnership. 2023. Page 10 - 18

Extraordinary Eelgrass. Wildlife Journal. New Hampshire Fish and Game.

To Understand Great Bay's Decline (and How to Stop It), Start on the Water. NHPR. 2017.

Real World References for Role Cards - Alphabetized by Title

'Bigger ships, faster delivery': NH Port Authority gets $1.6M for the basin. Why it matters. Seacoastonline. 2022.

Burned yacht 'Too Elusive' pulled from Maine waters, brought to NH. Seacoastonline. 2022.

By transplanting eelgrass, scientists aim to restore balance to Great Bay. NH Bulletin. 2021.

Consider the Source and Microplastics. Great Bay Matters Magazine. 2018.

Dozens of Sagamore Creek residents signing on for sewer hook-up. Portsmouth paying $1.2M. Seacoastonline. 2022.

Durham: A community divided by a derelict dam. Seacoastonline. 2022.

Green Grass & Clear Water. NH Sea Grant Factsheet. 2019.

Great Bay Estuary Faces Pollution Threats, NHPR. 2010.

How Nitrogen from Septic Systems Can Harm Water Quality. Washington State Dept of Health Fact Sheet. 2014.

Living with the River: The Importance of Riparian Buffers for Your Land and Your Environment. Connecticut River Joint Commission Fact Sheet.

Oysters, Oyster Restoration and Oyster Aquaculture. State of Our Estuaries Report, Piscataqua Region Estuaries Partnership. 2023. Page 82 - 87.

Rain Gardens. New Hampshire Department of Environmental Services.

5 Reasons to Visit New Hampshire's Coast this Summer. Outdoor Project. 2018.

Sea Grass Wasting Disease is Fueled by Climate Change. Earth.com 2021.

Sewage Treatment Plants Part of Pollution Problem in the Great Bay. NHPR. 2010.

Spilled Oil In Speedy Piscataqua Would Make For Tricky Clean-Up. NHPR. 2014

Stormwater runoff problem: Efforts continue to clean up New Hampshire's Great Bay, NHPR. 2023.

Stormwater Management Standards and Funding. State of Our Estuaries Report. Piscataqua Region Estuaries Partnership. 2023. Page 30 - 32.

The 'secret weapon' in fight against climate change – planting eelgrass. CBC News. 2022

Tough times for NH's organic farmers. Valley News. 2021.

What are the Effects of Oil on Seagrass? Region IV Regional Response Team.

Where were you in 1974? 40th Anniversary of oil refinery defeat. Town of Durham News. 2014.

Extension Resources

Seagrasses in Classes, Mount Desert Island Biological Laboratory

Teach Ocean Science, Center of Ocean Science Education Excellence

Great Bay Eelgrass Coverage from 1948-2019 GIS map, New Hampshire Department of Environmental Services

Small Town, Big Oil: The Untold Story of the Women Who Took on the Richest Man in the World—And Won, David W. Moore