MODULE 1: SEA-LEVEL RISE AND FLOODING BASICS

MODULE & LESSON TIMING: There are four lessons in Module 1. Each lesson should be able to be completed in one or two class periods, with student readings before or during.

WHAT TO EXPECT: Module 1 introduces the causes and impacts of sea-level rise and flooding.

1.1 Frozen in Time: Ice Cores and Earth's Recent Climate Changes – climate change (page #4)

1.2 Rising Waters: The Ocean Is Getting Too Big for Its Beaches – causes of sea-level rise (page #18)

1.3 High Tide Flooding: Rainboots Required Even on Sunny Days? – types of flooding (page #30)

1.4 Climate Change Anomalies and Suffering Economies – economics and interpreting sea-level rise modeling (page #45)

TEACHER BACKGROUND RESOURCES:

Videos

- Introductory video about sea-level rise in the northern Gulf of Mexico
  - "The Basics: Northern Gulf Sea-Level Rise" https://vimeo.com/322867969
- Introductory video about sea-level rise and storm surge in the northern Gulf of Mexico
  - "Amplified Storm Surge: Northern Gulf Sea-Level Rise" https://vimeo.com/323815181
- Introductory video about global and local sea-level rise by NOAA
  - NOAA Ocean Today, "Global vs Local Sea Level" https://oceantoday.noaa.gov/globalvslocalsealevel/welcome.html
- Case study videos about responding to sea-level rise exacerbated hazards sea-level rise in the northern Gulf of Mexico
  - "Responding to Hazards in Mississippi" https://vimeo.com/322242202
  - "Responding to Hazards in Alabama" https://vimeo.com/322242513

Educational Resources

- Lesson about sea-level rise by NOAA National Ocean Service
  - "Is sea level rising?" https://oceanservice.noaa.gov/facts/sealevel.html
- Additional digital activity by NOAA with real-time NOAA data for students to explore sea-

MODULE 2: NATURAL SOLUTIONS

MODULE & LESSON TIMING: There are 3 lessons in Module 2. Each lesson should be able to be completed in one or two class periods, with student readings before or during.

WHAT TO EXPECT: Module 2 examines sea-level rise resilience through natural solutions.

TEACHER BACKGROUND RESOURCES:

Educational Resources

- Informational booklet on plants found in coastal wetlands by MS Extension
  - "Coastal Wetland Restoration Plant Fact Sheets" http://extension.msstate.edu/sites/default/files/publications/publications/p3356.pdf
- Informational guide for plants found in coastal wetlands by USDA
  - Coastal & Shoreline: Gulf of Mexico" https://www.nrcs.usda.gov/wps/portal/nrcs/detail/plantmaterials/technical/publications/?cid=stelprdb1044274
- Infographic about the benefits of living shorelines by NOAA Ocean Service
  - "What is a living shoreline?" https://oceanservice.noaa.gov/facts/living-shoreline.html

Readings

- Website with resources on the benefits of living shorelines, and images of different types
  - "What is a living shoreline" http://floridalivingshorelines.com/what-is-a-livingshoreline/
- Database of existing living shorelines including maps of projects across the US
  - Living Shorelines Academy: https://www.livingshorelinesacademy.org/
- Informational guide for creating a rain garden
  - Rain Gardens: http://extension.msstate.edu/rain-gardens
- Informational guide for integrating water conservation in landscaping including the use of rain gardens

MODULE 3: ORDINANCE AND POLICY SOLUTIONS

MODULE & LESSON TIMING: There are 3 lessons in Module 3. Each lesson should be able to be completed in one to two class periods, with student readings before or during.

WHAT TO EXPECT: Module 3 examines sea-level rise resilience through ordinances and policies.

TEACHER BACKGROUND RESOURCES:

Videos

- Introductory video on "Working with Natural Systems in Fairhope, Alabama" (6-minute video)
  - Alabama: https://vimeo.com/322236377
  - Mississippi: https://vimeo.com/322236734
- TED Radio Hour about sea-level rise and community impacts (13-minute video)
  - "Colette Pichon Battle: How Can We Prepare For The Next Hurricane Katrina?": https://www.npr.org/2021/02/26/971498925/colette-pichon-battle-how-can-we-prepare-for-the-next-hurricane-katrina

Readings

- Informational page from the National Hurricane Center about the SLOSH model
  - Sea, Lake, and Overland Surges from Hurricanes (SLOSH): https://www.nhc.noaa.gov/surge/slosh.php
- Informational page with Frequently Asked Questions about ADCIRC:
  - https://adcirc.org/home/adcirc-faq/
- Resource to find news articles about climate change.

MODULE 4: COMMUNITY PLANNING

MODULE & LESSON TIMING: There are 3 lessons in Module 4. Each lesson should be able to be completed in one class period, with student readings before or during.

WHAT TO EXPECT: Module 4 examines sea-level rise resilience by "putting it all together" through community planning.

4.1 Sea-Level Rise Risk & Reward – sea-level rise resilience planning (page #5)

4.2 Stakeholder Roll Call – stakeholder participation (page #19)

4.3 Kingtown – Planning with a Purpose – community planning (page #30)

TEACHER BACKGROUND RESOURCES:

Videos

- Introductory case study video "Master Planning in South Padre Island, Texas" (5-minute video)
  - Alabama: https://vimeo.com/318492225
  - Mississippi: https://vimeo.com/322234446
- Planning for Rising Seas: Northern Gulf Sea-Level Rise (5-minute video)
  - https://vimeo.com/323815494
- Science Friday segment on flooding
  - Cities are starting to rethink their how water is collected, stored, and conserved and how they can make their communities more resilient. Engineers and architects are looking to nature for inspiration by replacing dams and pipes with green roofs and other green infrastructure. City planners are designing parks based on how the natural ecology of the landscape handled the water. Instead of trying to hold back the floods, they're welcoming the water and finding ways to turn it into fresh, useable water.
  - https://www.sciencefriday.com/segments/turning-flood-water-into-freshwater/ (34 minutes)
- Video, Florida Keys road adaptation planning project (8 minutes):
  - https://www.youtube.com/watch?v=qJ7xOP_BAeo&feature=youtu.be

Readings

- Introduction to Stakeholder Participation, NOAA's Office for Coastal Management:
  - https://coast.noaa.gov/data/digitalcoast/pdf/stakeholder-participation.pdf

MODULE 4: COMMUNITY PLANNING

MODULE & LESSON TIMING: There are 3 lessons in Module 4. Each lesson should be able to be completed in one class period, with student readings before or during.

WHAT TO EXPECT: Module 4 examines sea-level rise resilience by "putting it all together" through community planning.

TEACHER BACKGROUND RESOURCES:

Videos

- Introductory case study video "Master Planning in South Padre Island, Texas" (5-minute video)
    - Alabama: https://vimeo.com/318492225
    - Mississippi: https://vimeo.com/322234446
- Planning for Rising Seas: Northern Gulf Sea-Level Rise (5-minute video)
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    - https://www.sciencefriday.com/segments/turning-flood-water-into-freshwater/ (34 minutes)
- Video, Florida Keys road adaptation planning project (8 minutes):
    - https://www.youtube.com/watch?v=qJ7xOP_BAeo&feature=youtu.be

Readings

- Introduction to Stakeholder Participation, NOAA's Office for Coastal Management:
    - https://coast.noaa.gov/data/digitalcoast/pdf/stakeholder-participation.pdf

- Flooding is the natural hazard with the greatest economic and social impact in the United States, and these impacts are becoming more severe over time. Catastrophic flooding from recent hurricanes, including Superstorm Sandy in New York (2012) and Hurricane Harvey in Houston (2017), caused billions of dollars in property damage, adversely affected millions of people, and damaged the economic well-being of major metropolitan areas. Flooding takes a heavy toll even in years without a named storm or event. Major freshwater flood events from 2004 to 2014 cost an average of $9 billion in direct damage and 71 lives annually. These figures do not include the cumulative costs of frequent, small floods, which can be similar to those of infrequent extreme floods. Dr. Lauren Alexander Augustine discussed some of the findings of the National Academies of Sciences, Engineering, and Medicine's recent report "Framing the Challenge of Urban Flooding in the United States."
    - National Academies of Sciences, Engineering, and Medicine. 2019. Framing the Challenge of Urban Flooding in the United States. Washington, DC: The National Academies Press. https://doi.org/10.17226/25381. https://www.preventionweb.net/files/73798_25381.pdf
    - There are four dimensions of urban flooding:
        - 1. The physical dimension represents the built and natural environments.
        - 2. The social dimension represents the people, where they live, who in the community is impacted, what those impacts look like, etc.
        - 3. The information dimension looks at a variety of issues such as what data are needed to understand the flood risk, how to communicate risk, how people interpret information about risk, etc.
        - 4. The actions and decisions dimension considers what needs to be done about urban flooding, how decisions are made, how flooding is managed, etc.
- Article on flooding "The Growing Thread of Urban Flooding: A National Challenge": https://cdr.umd.edu/sites/cdr.umd.edu/files/urban-flooding-report-online.pdf.
    - Galloway, G. and Brody, S. 2018. The Growing Threat of Urban Flooding: A National Challenge. University of Maryland, College Park and Texas A&M University, Galveston Campus. Accessed February 3, 2020.
    - This report was based on a national survey of municipal flood and stormwater managers and professionals, and found:
        - 83% of respondents experienced urban flooding in their communities.
        - 65% of respondents indicated that most of the damages from these floods were not covered by the National Flood Insurance Program (NFIP) because the community was located well outside the areas of the FEMA floodplains and located in areas that were not considered at risk for floods.
        - 41% of respondents indicated that their communities do not have funding to address their urban flooding problem.
        - 32% of respondents stated that there is a lack of political will to address the urban flooding problem.

        - Respondents believed only 34% of elected officials and 28% of the public were concerned about urban flooding in their communities.
    - Some of the report's conclusions include:
        - Urban flooding is a local government issue, but it is everyone's problem. How do we put communities in a better position to be able to deal with urban flooding?
        - The division of responsibility for urban flooding is fragmented. There is too much stove-piping within government and between agencies and organizations. There is no coordinated approach for dealing with urban flooding.
        - Infrastructure is aging and inadequate, and it is getting worse.
        - There is no federal agency charged with coordinating the federal support of urban flooding.
        - The economic and social impacts of urban flooding are immense. The lowest income groups are being hit hardest.
        - Government is not communicating the urban flooding risk very well, and the data needed to understand the risk are lacking.
- Article about sea-level rise community impacts "Norfolk Wants to Remake Itself as Sea Level Rises, but Who Will Be Left Behind?" https://insideclimatenews.org/news/21052018/norfolk-virginia-navy-sea-level-rise-flooding-urban-planning-poverty-coastal-resilience/
- A discussion surrounding the language of sea-level driven migration and why our words matter. "Reframing the Language of Retreat" https://eos.org/opinions/reframing-the-language-of-retreat
- Article "Flooded: How Natural Disasters Lead to Predatory Lending in the Rio Grande Valley" https://shelterforce.org/2020/11/06/flooded-how-natural-disasters-lead-to-predatory-lending-in-the-rio-grande-valley/
- Article about the Pointe-au-Chien Tribe
    - https://gulfofmexicoalliance.org/2020/09/pointe-au-chien-tribe-a-success-story/
- Article "Protection for the Rich, Retreat for the Poor," How the United States' implementation of climate change adaptation programs is exacerbating inequality and breeding a new form of climate gentrification: https://www.hakaimagazine.com/news/protection-for-the-rich-retreat-for-the-poor/
- Article "California Has A New Idea For Homes At Risk From Rising Seas: Buy, Rent, Retreat" https://www.npr.org/2021/03/21/978416929/california-has-a-new-idea-for-homes-at-risk-from-rising-seas-buy-rent-retreat

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4.1 Sea-Level Rise Risk & Reward

AGE RANGE
9th—12th grade

TIME REQUIRED
70 minutes

ACTIVITY OVERVIEW
Engage: Discussion Question

Explore: SLR Risk & Reward

Explain: Reflections

Elaborate: Adaptation Pathways Reading

Evaluate: Discussion Question

MATERIALS
Dice (one per group)
Candy or tokens (>5 per student)
Group Set-Up page
Group Worksheet

BASED ON:
"Game of Futures" by Dani Boudreau Tijuana River National Estuarine Research Reserve

LESSON TOPIC: Integrating sea-level rise resilience into planning.

ACTIVITY SUMMARY: Students will play a dice game that simulates making adaptations to plan for future sea-level rise.

OBJECTIVES:

Students will be able to:
- Understand the need to plan adaptation strategies with location-specific sea-level rise information.
- Determine if adaptation strategies are effective at reducing impacts under different climate scenarios.

LESSON BACKGROUND: The dice game sets up student groups as communities. Each student makes individual choices that may impact the whole community. Through the gameplay, students decide how much they will prepare their home for sea-level rise. The future sea-level rise impact is determined by rolling the dice. As the game progresses, students pay money if their adaptation strategy did not protect their home from sea-level rise impacts, but students will also have an opportunity to update their strategy.

The game includes a version of an insurance payout. Homeowners or renters insurance covers losses and damages to an individual's residence. The individual pays a certain amount based on the value of their home to the home insurance company each month, called the premium. In return, the insurance company agrees to pay a certain amount of money to cover expenses if there is a catastrophic event. In the case of a catastrophic event, the homeowner files a claim with the insurance provider. The insurance provider sends someone to assess the damage, and after filing paperwork, the homeowner will receive a payment to cover damages.

The student reading builds off the game by introducing the concept of adaptation pathways. The reading outlines the technique used to mitigate damage from future sea-level rise impacts by utilizing multiple solutions that build on one other. These adaptation strategies are organized into a pathway that can be followed, and additional mitigation actions added as conditions change. This becomes a proactive planning tool to add policy change and mitigation actions by following the observed sea-level rise rather than projections. Adaptation strategies are not one size fits all but they can build on previously implemented strategies. By using numerical modeling of physical processes, like wind and waves, scientists can get an idea of how adaptation strategies will behave in a future climate. There is uncertainty regarding the impacts of sea-level rise, but we can still plan for the future by effectively considering the uncertainty and preparing to respond to a range of scenarios.

The dice outcomes may seem predictable in the game, and that is because some outcomes, like sea-level rise scenarios, are more likely than others. Scientifically speaking, the range of sea-level rise scenarios cover all scientifically plausible scenarios. Having a large range of sea-level rise scenarios does not mean that scientists do not know what they are doing. It shows the range of possible outcomes. There are three major reasons for the scenarios. The first is that we do not know how much carbon will be in the atmosphere because the rate of global carbon emissions changes with policies put in place by different governments. The second is the natural variability built into the scenarios. The third is that scientists are still studying ice sheet melt, and the models used to measure the volume of ice sheets and their rate of melting is relatively new and getting more accurate constantly. With these reasons in mind, the range of sea-level rise scenarios shows the range of scientifically possible scenarios for future sea-level rise with low scenarios following a low-end range of natural variability and an extreme scenario following catastrophic ice melt. *The Module 3 lesson 3.2 Assets at Risk involves a discussion on sea-level rise projections that can be connected to this lesson.*

Just as with the dice, is it helpful to plan for sea-level rise by considering scenarios based on their probabilities of occurring. The likelihood of each sea-level rise scenario depends in part on the amount of carbon gas in the atmosphere. Carbon emission scenarios, also known as Representative Concentration Pathways or RCPs, represent different potential futures based on policies and actions of people globally. The table below explores the probability of each sea-level rise scenario under three different RCPs: RCP2.6 is a dramatic reduction of carbon currently in the atmosphere; RCP4.5 is a modest decrease in global carbon emissions; and RCP8.5 is continuing on the current global emissions trajectory. As stated above, the scenarios, low through extreme, cover the range of scientifically plausible scenarios. Probabilities help us understand the likelihood of each scenario occurring. For example, under RCP8.5, it is 100% likely that we will exceed the Low scenario by 2100, while there is a very low probability (0.1% chance) that we will exceed the Extreme sea-level rise scenario by 2100.

Probabilities of occurrence help determine which scenario best supports your risk tolerance in planning. For example, although the High scenario has a low probability of occurring, you may want to plan for it when protecting long-term investments with low risk-tolerance. For instance, a military base or water treatment facility would have a low risk-tolerance because they serve critical functions to a large number of people, have interdependent systems with other critical services, and cannot be easily moved or adapted to future conditions once built

Likelihood of sea-level rise scenarios:

Global Sea Level Rise Scenario	RCP2.6 dramatic reduction of carbon emissions	RCP4.5 modest reduction in carbon emissions	RCP8.5 no change in carbon emissions
Low	94%	98%	100%
Intermediate low	49%	73%	96%
Intermediate	2%	3%	17%
Intermediate-high	0.4%	0.5%	1.3%
High	0.1%	0.1%	0.3%
Extreme	0.05%	0.05%	0.1%

Source: Collini et al, 2018

VOCABULARY:

Adaptation	The process of adjusting to new (climate) conditions in order to reduce risks to valued assets.
Adaptation Planning	Preparing a natural or urban area for the effects of climate change with the intention of reducing risk or exposure.
Adaptive Capacity	The ability of a person, asset, or system to adjust to a hazard, take advantage of new opportunities, or cope with change.
Critical Facilities and Services	Man-made structures/improvements which, because of their function, size, service area, or uniqueness, are paramount to day-to-day function (e.g., hospitals, power plants, wastewater treatment facilities, emergency response, etc.).

Risk Communication	Process of informing people about potential hazards to their person, property, or community.
Social Vulnerability	Risk that a community will lose its ability to maintain social interactions, cultural institutions, and/or a standard of living. Negative impacts on communities due to stresses on human physical, mental, or cultural health, which consider socioeconomic factors like poverty level, access to transportation, and living conditions.

ENGAGE:

Ask students: What do you think about when making an important decision? Is it important to know the possible outcome(s) when you are planning? Would they want to know future sea-level rise when building a beach house?

EXPLORE:

Students will play the Sea-Level Rise Risk & Reward game.

<u>Game Procedure:</u>

1. Divide class into groups of 5. In a group of 5, one player will act as scorekeeper and the others will each get one turn to roll the dice.
    - Note: If you do not use dice in your classroom you can have students use a phone or computer to "roll the dice" by asking Siri to "roll two dice" or the teacher can pre-roll numbers.
2. Each student is given 5 pieces of candy or tokens. This represents the total money an individual has to repair, maintain, or modify the adaptation strategy as climate change is experienced.
3. Each student in a group will choose an adaptation strategy (below) to implement. They are planning to protect their home for approximately the next 30 years, through 2050.

    ADAPTATION STRATEGIES:
    You own your house on the coast. To make your home resilient to sea-level rise you can choose from the following possible options in the short term. Pay the candy/tokens to the bank.

    A. Do nothing (cost = 0 candy)
        - **Teacher talking point:** in this strategy the home is left as is.

B. Nourish the beach in front of your home to accommodate scenario 1 (cost = 1 candy)
    - **Teacher talking point:** nourishing the beach in front of the home replaces sand lost from erosion and this land will act as a barrier to sea-level rise.

C. Build a dune in front of your house to accommodate scenarios 1 & 2 (cost = 2 candy)
    - **Teacher talking point:** a dune with dune grasses will offer protection to the home from erosion and water inundation

D. Elevate your house to accommodate scenarios 1,2 & 3 (cost = 3 candy)
    - **Teacher talking point:** elevating the home raises it above base flood elevation (or higher) and will allow water to come underneath but not impact the home

E. Relocate your house inland to accommodate scenarios 1, 2, 3 & 4 (cost = 4 candy)
    - **Teacher talking point:** the home will be relocated away from the water but still within the community. This allows the home to be protected from sea-level rise impacts but also maintain community social connections and contribute to taxes.




Images: Top left, beach renourshiment; top right, sand dunes; bottom left, elevated house; bottom right, relocation.

4. Player One rolls two dice, once. Determine the scenario outcome (Step 5). Player One's roll affects all students in their group.
    - The probability of the dice sum outcome is linked to the probability of future sea-level rise scenarios for the northern Gulf of Mexico (Mississippi, Alabama, and NW Florida).

- This sea-level rise scenario outcomes in this game are representative of likelihoods with no change in carbon emissions. You may choose to share this with your students when they are selecting Adaptation Strategies.
    1. **100%** Low 0.8ft (~0.2m)
    2. **96%** Intermediate-Low 1.0ft (~0.3m)
    3. **17%** Intermediate 1.5ft (~0.5m)
    4. **1.3%** Intermediate high 2.0ft (~0.6m)

5. The sum of the two dice determines what scenario they are in.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Year 2050	7	6 or 8	4, 5, 9, 10	2, 3, 11, 12

   Payout!
   a. If students adequately protected their home from the scenario they rolled, they keep their candy/token and get 2 bonus candy/token. The bonus candy/token reflects homeowners saving income.
   b. If students did not adequately protect their home from the scenario they rolled, they pay the bank with 1 candy/token for each level of scenario of difference. (Ex: If they protected to Scenario 1 but rolled Scenario 2, they pay 1 candy/token. If they protected to Scenario 1 but rolled Scenario 4, they pay 3 candies/tokens.)
6. Repeat with Player Two rolling the dice.
7. Before Player Three rolls there is an opportunity for an Insurance Payment. If any of the players lost candy/tokens due to the scenario outcome in Round One, they get to collect one less candy/token than they lost. (Ex: If they paid 1 candy/token, they would not collect insurance. If they paid 3 candy/token, they would collect 2 candy/token from insurance.) This represents the process of insurance payments, where partial damage is covered through insurance and it happens months-years after the damage.
8. Repeat Step 4 with Player Three rolling the dice.
9. There is an opportunity at this point in the game for students to change their original Adaptation Strategy to one of the other 5 choices. **Discuss with students**: Is my strategy effective?
    - Is everyone's strategy still effective with the sea-level rise scenarios?
    - What strategies are successful in the new scenario? Why or why not?
    - If not successful, can it be altered to be effective in the scenario?
10. Repeat Step 4 with Player Four rolling the dice.
11. Players count their remaining candy/tokens.

EXTENSION*:* There are two game extension opportunities to add to the game. RESOURCE VULNERABILITY starts the game off with each individual having different resources. This option would work well for 1) classes playing a second round or 2) for teachers to use the first time with an advanced class. HIGH-TIDE FLOODING COMMUNITY IMPACT is a game option that allows teachers to add an element into the game while it is currently being played. There are three real life scenarios for teachers to select from.

RESOURCE VULNERABILITY

When the game is played with Resource Vulnerability, individuals in the community start the game with different resources. To determine which players will have limited resources each player will roll one die. The die outcome is the number of candy/tokens that player starts the game with. (Ex: If they rolled a 1, they only get 1 piece of candy/token.)

Social vulnerability is a combination of factors that determine how resilient a community is when confronted by external stresses, potentially from a hazard like sea-level rise. The Social Vulnerability Index (SVI) employs U.S. Census Bureau data to identify communities at higher risk. The SVI ranks on 15 social factors, including poverty, disability, minority status, lack of vehicle access, and crowded housing. These are then grouped into four themes: socioeconomic status, household composition, race/ethnicity/language, and housing/transportation. Our game will rank students randomly and is used as a starting point for discussion of resource vulnerability. The SVI fact sheet can be found online: https://svi.cdc.gov/factsheet.html

HIGH-TIDE FLOODING COMMUNITY IMPACT

When the game is played with High-Tide Flooding Community Impact, the community group must work together to fund infrastructure improvements. This extension can be introduced to the game at any point by the teacher to heighten game-play and stimulate community-level conversations. There are three real-life simulated options below for the teacher to select from. Each of the following community impacts affect everyone regardless of their chosen Adaptation Strategy. The community cost for each improvement is 10 candies/tokens, and this can be divided across individuals however each community group decides, for example, communities may decide that everyone contributes an equal share. In the case that some individuals do not have enough money the community may decide that other individuals cover the difference.

Road Access: The main road to enter the community is inaccessible for one third of the year due to high-tide flooding. Since the flooding blocks access for the whole community, the community must collectively raise the funds to elevate the road.

Storm Water Infrastructure: The storm drains along community roads no longer drain rainwater away fast enough during thunderstorms. Sometimes the storm drains back up with water during a high tide even without a rainstorm. The outflow pipe directs water from the streets into the bay. This system needs to be improved so that the exit point is not covered by water during the tidal cycle.

Power Station: The facility that provides power for the community is vulnerable to storm surge inundation and needs to be relocated. Moving the power station will allow the community to be more resilient to future storms. This relocation will be a partnership between the power company and the community, so the community will help pay a portion of the relocation cost.

EXPLAIN:

Wrap-up and reflections

Begin by determining who the individual and group “winners” are. If multiple people or groups seem to have been successful, begin a discussion around why those individuals/groups were successful.

Discuss with students what lessons were learned throughout the process.

- If you did not choose an expensive adaptation when you had the resources, how did that impact you later in the game? Would you change your strategy if you did it again?
- What strategies seemed to be the most resilient?
- Community vs. individual successes?
- What did you struggle with throughout the game?
- Is the adaptation to relocate an easy choice in real life?
- Was there one scenario that seemed to be particularly difficult for individuals or community?
- Who has the most candy left and why? Even though relocation protects against all scenarios, it also cost the most and may not even have been necessary.
- Do the outcomes seem a little predicable? Is sea-level rise predictable?
  - With this final discussion topic remind them that we have the sea-level rise projections for the range of scenarios from Low to Extreme. We can use this information to make plans for our homes and communities.

Connect to facts:

- Every $1 spent on mitigation funding can save the nation $6 in future disaster costs.
    - National Institute of Building Sciences. Natural Hazard Mitigation Saves: 2017 Interim Report
- For every $1 a private property owner spends installing a living shoreline instead of a bulkhead they will save $6 in avoided maintenance, replacement, and storm repair costs over 60 years.
    - Sicangco, Camille, et al. *Cost-Benefit Analysis of a Small-Scale Living Shoreline Project*. MASGP-21-054
- As sea-level rises, the benefits for installing a living shoreline also rise. Rising seas decreases the lifespan of bulkheads, increasing maintenance cost and replacement frequency.
    - Sicangco, Camille, et al. *Cost-Benefit Analysis of a Small-Scale Living Shoreline Project*. MASGP-21-054

The Sea-Level Rise Risk & Reward game allows students to start thinking about how planning now prepares individuals and communities for future conditions.

ELABORATE:

Students read the excerpt about adaptation strategies. This mirrors the game-play, because as conditions change you can follow the adaptation pathway and make the largest/most expensive adaptations only when they are needed, yet preliminary planning and investment is required for these approaches to work.

Excerpt from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. Climate Change.

EVALUATE:

Ask students: What is an adaptation pathway? Why is it important to have a mitigation plan that might change?

FUTURE SCENARIO NARRATIVES:

1. Low: 0.8ft (~0.2m)
2. Intermediate-Low: 1.0ft (~0.3m)
3. Intermediate: 1.5ft (~0.5m)
4. Intermediate-High: 2.0ft (~0.6m)

ADAPTATION STRATEGIES:

You own your house on the coast. To make your home resilient to sea level rise you can choose from the following possible options in the short term. Pay the candy/tokens to the bank.

A. Do nothing (cost = 0 candy)
B. Nourish the beach in front of your home to accommodate scenario 1 (cost = 1 candy)
C. Build a dune in front of your house to accommodate scenarios 1 & 2 (cost = 2 candy)
D. Elevate your house to accommodate scenarios 1,2 & 3 (cost = 3 candy)
E. Relocate your house inland to accommodate scenarios 1, 2, 3 & 4 (cost = 4 candy)

GAME-PLAY

SEA-LEVEL RISE SCENARIOS:

The sum of the two dice determines what scenario you are 30 years into the future:

	Scenario 1 - Low	Scenario 2 – Intermediate-Low	Scenario 3 - Intermediate	Scenario 4 – Intermediate-High
Year 2050	7	6 or 8	4, 5, 9, 10	2, 3, 11, 12

ROUND PAYOUT:

a. If students adequately protected their home from the scenario they rolled, they keep their candy and get 2 bonus candy.
b. If students did not adequately protect their home from the scenario they rolled, they pay the bank with 1 candy for each level of scenario of difference. (Ex: If they protected to Scenario 1 but rolled Scenario 2, they pay 1 candy. If they protected to Scenario 1 but rolled Scenario 4, they pay 3 candy.)

INSURANCE PAYOUT:

If any of the players lost candy/tokens due to the scenario outcome in Round One, they get to collect one less candy/token than they lost. (Ex: If they paid 1 candy, they would not collect insurance. If they paid 3 candy, they would collect 2 candy from insurance.)

STUDENT PAGE | Sea-Level Rise Risk & Reward – Group Worksheet

	Player 1: *Name*	Player 2: *Name*	Player 3: *Name*	Player 4: *Name*	Player 5: *Name*
Strategy: *Check a box*	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E
Round One Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Round Two Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Insurance Payment If you lost $$ in Round One *Check a box*	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______
Round Three Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Strategy change? *Check a box*	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______
Round Four Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Final Count:	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*

Adaptation Pathway - Sequential implementation of adaptation strategies as a policy pathway

Due to the uncertainty in future climate conditions, including the amount of sea-level rise and coastal response to those conditions, and due to relative effectiveness of individual strategies for different rates of sea-level rise, it is important to develop a strategic plan that is also adaptive. Haasnoot et al. (2013) describes dynamic adaptive policy pathways: a set of possible actions that may be implemented sequentially and in response to changing conditions. When the current action is no longer able to meet the intended objective, which in this study is to lessen the damage to a coastal community from a hurricane and rising seas, a tipping point is reached and a new action must be chosen.

Using the sea-level rise scenarios and adaptation strategies analyzed in this study, a policy pathway is created for Bay Head (Fig. 5). According to computer modeling simulations, strategy A reduces erosion (i.e., improves habitability) for sea-level rise = +0.2 m but not for sea-level rise = +1.0 m and higher. Strategy A is also the least expensive option in terms of initial costs based on the amount of sediment required to raise the beach (Fig. 2). However, a tipping point is reached as sea levels rise from +0.2 to +1.0 m, and a new strategy must be chosen. The preferred pathway routes to strategy B (Fig. 5) such that, as sea levels rise above +0.2 m, both the beach and dune must be nourished to offer protection from future storms at higher sea levels. Since there is more sediment available on the beach and dunes for transport (Fig. 2), erosion is reduced, island habitability is improved, but initial costs are higher due to the additional sediment required to build the dune. Also, the larger dunes only protect against ocean-side waves and surge, and the back barrier remains vulnerable to flooding and erosion by bay-side surge.

As sea levels continue to rise, back-barrier vulnerability becomes too large and another tipping point is reached. Strategy D is required to continue protection of the island for sea-level rise greater than +1.0 m. Although raising the island is an extreme adaptation strategy, it was implemented in Galveston, TX, USA, a developed barrier island located on the Gulf of Mexico. After a devastating hurricane in 1900, Galveston built a 16-km-long seawall and raised the island by up to 4 m (Bartee 2001). Over the last century, Galveston has survived several strong tropical storms including Hurricane Ike (2008), which has been largely attributed to the seawall and grade raising (Bartee 2001). As sea-level rise increases above 1.0 m in Bay Head, strategy D is the only option considered here that prevents complete erosion of the back barrier for extreme sea-level rise. Although it has the highest initial costs, a life cycle cost analysis for each strategy may reveal that periodic renourishment over several decades of sea-level rise could have greater costs than the initial cost of strategy D. Additionally, the analyses may reveal that it makes more sense to strategically relocate some of the infrastructure and aspects of the community.

Excerpt from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. Climate Change.

(a)

Strategy (sediment volume added, m³)	Beach raised by SLR	Dune raised by SLR	Seawall raised by 0.5 m	Seawall raised by 1.0 m	Seawall raised by 2.0 m	Back barrier raised to minimum elevation
EC						
A (8,32,71)	X					
B (11, 68, 145)	X	X				
C (11, 68, 145)	X	X	X	X	X	
C1.0 (10, 67, 144)	X	X	X	X	X	
C2.0 (7, 64, 141)	X	X	X	X	X	
D (13, 128, 322)	X	X				X
E (13, 128, 322)	X	X	X			X
E1.0 (12, 127, 321)	X	X		X		X
E2.0 (9, 124, 318)	X	X			X	X

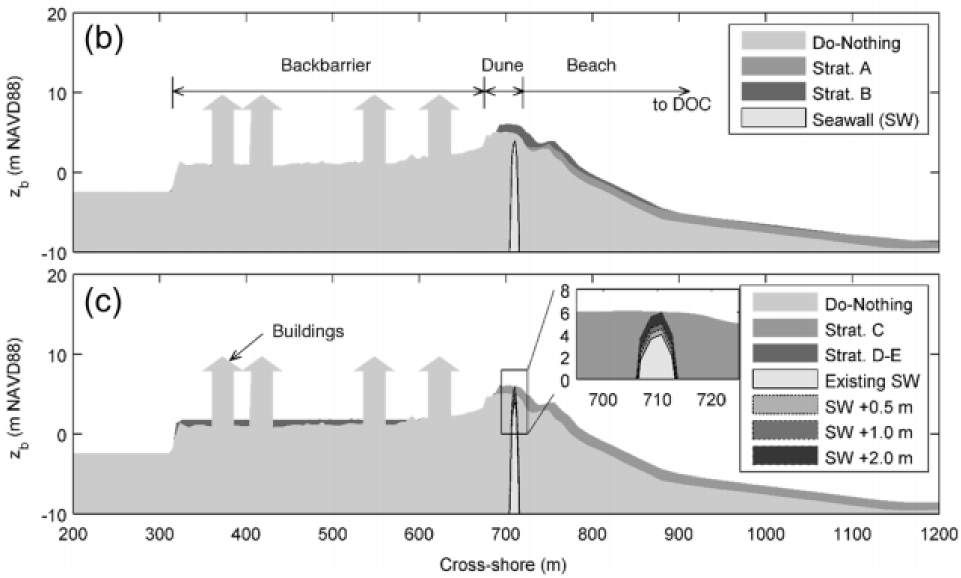

Fig. 2 Characteristics of adaptation strategies (**a**) and representative cross-shore profiles for SLR = +1.0 m: **b** EC elevation (z_b) and strategies A–B; **c** EC z_b and strategies C–E. Initial volumes are per unit width. Buildings are peaks in data and the seawall is represented by *shaded regions* at cross-shore distance 785 m. *SW* denotes seawall, and *DOC* is the depth of closure

Image: Figure 2 from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels title. *Climatic Change.*

Fig. 5 Policy pathway for Bay Head under SLR scenarios

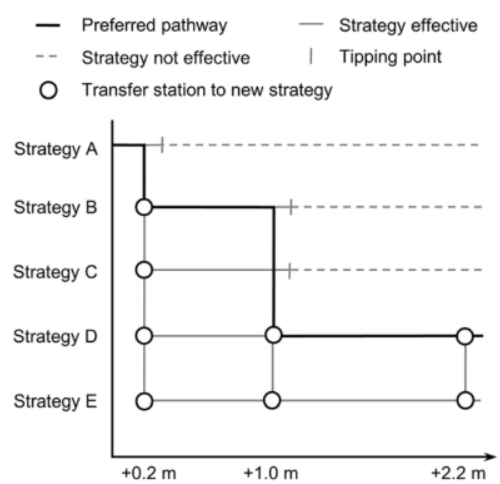

Image: Figure 5 from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. *Climatic*

STUDENT PAGE | Sea-Level Rise Risk & Reward

DO NOW:

Describe how you currently think about sea-level rise in regards to living along the coast.

EXIT TICKET:

Why is having a mitigation plan that changes helpful for community resilience?

4.2 Stakeholder Roll Call

AGE RANGE

9th—12th grade

TIME REQUIRED

60 minutes

ACTIVITY OVERVIEW

Engage: Case Study Videos
Explore: Stakeholder Categories
Explain: Role Play Preparation
Elaborate: "Council Meeting"
Evaluate: Presentations

MATERIALS

Student Worksheet
Student Role Cards
Computers

BASED ON:

Resources from Planning and Facilitating Collaborative Meetings by NOAA Office for Coastal Management

LESSON TOPIC: Stakeholder participation

ACTIVITY SUMMARY: Students will role play as community stakeholders responding to local high tide flooding.

OBJECTIVES:

Students will be able to:

- Categorize types of stakeholders.
- Explore the benefits of including a wide range of stakeholders.
- Discuss solutions to high tide flooding.

LESSON BACKGROUND: A collaborative process (also referred to as collaborative decision making, facilitated processes, consensus building, participatory decision making, systematic problem solving, etc.) engages multiple stakeholders in cooperative deliberations in order to address issues and solve problems. The issues addressed may be internal to organizations or in the public arena. The collaborative process often improves the relationship of involved parties, encourages high quality input, and aids in the construction of mutually acceptable agreements. Public agencies use collaborative processes to build consensus and gain strong support for proposed solutions to public issues.

When collaborative processes are conducted properly, participants obtain a clear understanding of the issue and have analyzed all relevant facts together—before jointly developing solutions that represent the whole group's best thinking about the optimal decision. A consensus decision is reached when everyone says, "I can live with this decision, and I will support its implementation." A collaborative process should be designed to get to this point—even if the consensus is that the group agrees to use one of the other decision-making methods to reach the final agreement.

While science can serve as a rational foundation for natural resource management or community planning, in many cases it is those groups impacted by the decisions that decide how acceptable a decision is and influence how effective the implementation will be. Peoples' experiences and culture, understanding of an issue, and support of an agency can shape their support for and compliance with coastal resource management decisions and policies.

Involving stakeholders in decision-making can accomplish the following:

- Produce better outcomes or decisions
- Garner public support for agencies and their decisions
- Bring to light important local knowledge
- Increase public understanding of natural resource issues or management decisions
- Reduce or resolve conflicts between stakeholders
- Ensure implementation of new programs or policies
- Increase compliance with natural resource laws and regulations
- Help agencies understand flaws in existing management strategies or potential unintended consequences from new decisions
- Create new relationships among stakeholders

Practitioners of stakeholder participation will jokingly define a stakeholder as "anybody who wants to be." There is much truth to this broad definition. Stakeholders are generally those who have an interest in or are affected by a decision. Stakeholders are also those who have influence or power in a situation. Stakeholders' interests in an issue can be monetary, professional, personal, or cultural, and can arise from a host of other motivations.

From the Planning and Facilitating Collaborative Meetings by NOAA Office for Coastal Management Training Manual

VOCABULARY:

Collaborative	A collaborative process (also referred to as collaborative decision making, facilitated processes, consensus building, participatory decision making, systematic problem solving, etc.) engages multiple stakeholders in cooperative deliberations in order to address issues and solve problems.

Community Planning	Public participatory process where future goals and objectives for the community are identified, priorities for project funding and implementation are set, and current policies are evaluated/revised.
Stakeholders	An individual or group that has an interest in any decision or activity of an organization.

ENGAGE:

Show the case study video to the class. This 5-minute video follows the city of Covington, Louisiana as they make a plan for preparing for flooding.

Alabama version: https://vimeo.com/322242513

Mississippi version: https://vimeo.com/322242202

Introduce the community issue for this lesson:
Azaleaville is located on the coast along the northern Gulf of Mexico. The north part of Azaleaville is unincorporated county and there are two neighboring cities to the east and to the west. In the early 19th century, a local seafood industry developed in Azaleaville. In 1838, the city constructed a lighthouse to guide fishermen safely home. Azaleaville's seafood market increased steadily throughout the 20th century, and the local fishing community survived dozens of hurricanes and tropical storms. More recently, however, the Deepwater Horizon Oil Spill in 2010 and the adverse environmental impacts of the opening of the Bonnet Carré spillway have severely reduced the seafood industry. On August 29th, 2005, Hurricane Katrina hit the coast near Azaleaville as a category 3 storm and caused a record high storm surge of 27.8 feet (8.47 meters) with sustained winds of 120 mph. Storm damage from Katrina left many empty lots and vacant businesses. Azaleaville has been slow to rebuild in part because of the cost required to comply with building codes for buildings to be above base flood elevation and due to the high cost of flood insurance. Although rain, wind, and storm surge from tropical storms and hurricanes pose the most severe flooding threats, riverine and flash flooding from local and upriver thunderstorms have recently increased in Azaleaville. There is a 47% chance that Azaleaville will experience a flash, coastal, or riverine (non-hurricane) flood in any given year, and flooding can occur anytime during the year.

Sea-level rise is leading to more days of high tide flooding in Azaleaville. The main road leading to the high school is blocked by flood water often during the year but especially in September, October, and November. This flooding is already happening now, and with future sea-level rise projections the number of flooding days will increase. This flooding is preventing buses and cars from entering the school drop off area and the parking lot for students who drive to school is reduced by half. A Community Meeting was called to convene with a diverse group of stakeholders, who serve and/or represent different community sectors in Azaleaville.

EXPLORE:

In this lesson, students will take on roles of specific community members to address a community issue. Before they can begin their "Community Meeting" they must identify the stakeholders (the people involved with the issue). Students read the excerpt from Stakeholder Participation from NOAA's Office for Coastal Management as the Student Reading.

Using the Student Worksheet chart, students can work individually or in pairs to generate a list of stakeholders who are impacted by the Azaleaville high-tide flooding blocking access to the high school.

EXPLAIN:

Divide students into groups of 5-6. Students will be given a role to play for the Community Meeting of how the community will address the high-tide flooding at the high school. Students should take a few minutes to think about the person they will be playing and how that person would handle the high-tide flooding at the high school. **Alternative:** Use the activity as a whole class exercise instead of separating into individual groups. Multiple students would then be in each stakeholder group and would be encouraged to speak up.

> **EXTENSION:** Students can be assigned their role ahead of time and be required to research that role by speaking to individuals in that role in their community. You can also have the students think of this activity as a drama/play and they can dress up for their role.

The specific Community Meeting goals are to better understand:

- The risks and impacts of floods on the community
- Actions the community is taking now and could take in the future to mitigate future floods
- Challenges the community continues to face related to flood mitigation
- What the community needs to enable them to make informed decisions about flood mitigation
- How the community is funding their flood mitigation activity

Note: These cards at the end of the section are formatted to be printed on Avery5390 Name Badge Inserts (2-1/4" x 3-1/2").

First Responder

- Your career is devoted to keeping others safe.
- You respond first to emergencies making sure to enforce the law and provide medical help.
- You are aware that the flooding by the high school might lead to students walking across busy roads with more chance of accidents.

Local Government Official

- You are committed to your region and work to serve the best interests of both residents and businesses.
- You have a good working relationship with other levels of government and your city's first responders.
- You understand that a strong school system draws parents to move to your town and increases tax revenue and your ability to provide critical services to the town.

Principal

- You are the principal of the high school.
- The principal is responsible if anything happens to the students while on school property.
- You want to ensure easy access to the school for students and you promote a well-rounded education.

Teacher

- You work as a teacher at the high school and you have a strong community network.
- You live nearby the school and walk to work along the road that is often flooded.

Local Resident - Fisherman

- You are a working professional with no children, you work at the fishing docks and live across town from the high school.
- You are worried huge construction projects to flood proof the city will impact your day to day life or could cause flooding in new places that will negatively impact you.

Local Resident - Parent

- You are a parent with two children in the high school, and you work near the school and drop your kids off on your way to work.
- You are concerned about the safety of dropping your children off at school on the busy road.

High School Student

- You are a student at the high school and drive yourself to school.
- You are concerned about driving through the flooded road and about the lack of parking.

ELABORATE:

In their groups, students will play their role and discuss at the Community Meeting their thoughts for mitigating the high-tide flooding by the high school. They should be presenting their thoughts for mitigating the flooding impacts while also persuading other members to support their idea.

Review the following class discussion norms to ensure a successful Community Meeting:

- Allow everyone a chance to speak
- Actively listen

- Listen respectively
- Constructively critique ideas, not individuals
- Be open to changing your perspectives based on what you learn from others

Guide the discussion with the following questions:

- How does flooding impact your community?
- What are the main flood risks in your community?
- What actions has your community already taken to mitigate floods?
- What are your plans for future mitigation actions?
- What are examples of how your community coordinates flood mitigation efforts across the public, private, and/or nonprofit sectors or across jurisdictions?
- How can your community fund your flood mitigation activities?
- What are the main barriers or challenges that obstruct your ability to take action to mitigate against floods?
- How complex is the solution?
- Is there an opportunity for public engagement?

At the end of the time have them decide on the “winning” solution or combination of solutions. The “winning” solution or combination of solutions is agreed upon by the group. Note to the class there is also a cost to doing nothing. There can also be litigation against the school district to contend with regardless of the action taken so the city and/or school district attorney will likely be involved.

Note to teachers: allow the students to come up with the ideas for solutions on their own. All ideas are encouraged. As a group facilitator you can provide options as necessary. These may include:

- Road elevation or pedestrian path elevation
- Additional rain gardens or water absorbing areas
- Improvements to the storm water drains or updating old infrastructure
- Road detours leading to the high school
- Elevating the high school
- High school relocation
- Adjusting the start dates of school, i.e. school break or virtual over the heavy flooding

EVALUATE:

Bring all the students back together to present the winning solution from each group.

Extension: ask students what **their** decision would have been and how does that compare with the role they played.

FIRST RESPONDER

- Your career is devoted to keeping others safe.
- You respond first to emergencies, making sure to enforce the law and provide medical help.
- You are aware that the flooding by the high school might lead to students walking across busy roads with more chance of accidents.

LOCAL GOVERNMENT OFFICIAL

- You are committed to your region and work to serve the best interests of both residents and businesses.
- You have a good working relationship with other levels of government and your city's first responders.
- You understand that a strong school system draws parents to move to your town and increases tax revenue and your ability to provide critical services to the town.

PRINCIPAL

- You are the principal of the high school.
- The principal is responsible if anything happens to the students while on school property.
- You want to ensure easy access to the school for students and you promote a well-rounded education.

TEACHER

- You work as a teacher at the high school and you have a strong community network.
- You live nearby the school and walk to work along the road the is often flooded.

LOCAL RESIDENT - FISHERMAN

- You are a working professional with no children, you work at the fishing docks and live across town from the high school.
- You are worried huge construction projects to flood proof the city will impact your day to day life.

LOCAL RESIDENT - PARENT

- You are a parent with two children in the high school, and you work near the school and drop your kids off on your way to work.
- You are concerned about the safety of dropping your children off at school on the busy road.

HIGH SCHOOL STUDENT

- You are a student at the high school and drive yourself to school.
- You are concerned about driving through the flooded road and about the lack of parking.

STUDENT PAGE | Stakeholder Roll Call

In the following chart, generate a list of stakeholders who are impacted by the Azaleaville high-tide flooding blocking access to the high school.

Stakeholder Category	Stakeholder – name of group or individual
Those who are directly affected	
Those with decision-making authority	
Those who have resources or skills that may be needed	
Those who will be implementing the results or outcomes	
Those who will actively oppose the process	
Those who will actively support the process	

STUDENT PAGE | Stakeholder Roll Call

Azaleaville high-tide flooding brainstorm:

What is your role in the community: ____

How are you impacted by the high-tide flooding at the school?

What do you propose that your community do to address the high-tide flooding? (Use the space below to brainstorm a few different options).

Draft your proposal to the community:

a) State how this high-tide flooding is impacting your role:

b) State your suggestion for addressing the issue:

c) Explain why your suggestion is the most effective for your community:

Stakeholder Participation

"The public's attitudes, perceptions, beliefs, and knowledge can have a profound effect on the success of coastal resource management. While science can serve as a rational foundation for management, in many cases it is those groups impacted by resource management decisions that decide how acceptable a decision is and influence how effective management will be. Peoples' experiences and culture, understanding of an issue, and support of an agency can each shape their support for and compliance with coastal resource management decisions and policies. Over the past several decades, traditional top-down, agency-driven decision-making in natural resource management has generally moved toward processes that involve stakeholders (those who have an interest in or are affected by a decision) and acknowledge the importance of public attitudes, perceptions, beliefs, and knowledge. Specifically, involving stakeholders in natural resource management decisions can accomplish the following:

- Produce better outcomes or decisions
- Garner public support for agencies and their decisions
- Bring to light important local knowledge about natural resources
- Increase public understanding of natural resource issues or management decisions
- Reduce or resolve conflicts between stakeholders
- Ensure implementation of new programs or policies
- Increase compliance with natural resource laws and regulations
- Help agencies understand flaws in existing management strategies
- Create new relationships among stakeholders

Of course, stakeholder participation can also pose challenges. Involving stakeholders can be costly, time consuming, labor-intensive, and confrontational - and can ultimately delay decision-making. Additionally, if improperly managed, stakeholder participation can create new conflicts or escalate existing ones."

Excerpt from "Resources from Planning and Facilitating Collaborative Meetings" by NOAA Office for Coastal Management.

STUDENT PAGE | Stakeholder Roll Call

DO NOW:

What is high-tide flooding?

EXIT TICKET:

Why is it important to bring all members of the community together to discuss flooding and sea-level rise resilience? "In your opinion, which stakeholder presented the best argument and why?"

4.3 Kingtown – Planning with a Purpose

AGE RANGE

9th—12th grade

TIME REQUIRED

80 minutes

ACTIVITY OVERVIEW

Engage: Kingtown Introduction
Explore: Stakeholders
Explain: Discussion
Elaborate: Resilience Planning
Evaluate: Impact Discussion

MATERIALS

Student Worksheet
Computers

BASED ON:

This lesson is used with permission from Museum of Science Boston, NOAA, Arizona State University, and Northeastern University.

LESSON TOPIC: Community planning for sea-level rise resilience.

ACTIVITY SUMMARY: Students will explore Kingtown and different sea-level rise resilience plans.

OBJECTIVES:

Students will be able to:

- Explore resilience plan strategies for a city impacted by sea-level rise.
- View results and impacts of different sea-level rise resilience strategies.

LESSON BACKGROUND: The Climate Hazard Resilience Forum was developed in partnership with Arizona State University and Northeastern University and supported by a NOAA Environmental Literacy Grant. This deliberative forum brings the participants through the resilience planning process for various generic cities in specific contexts. Each city is based on a real place and uses real data but was anonymized for unbiased deliberation. Participants learn and discuss stakeholder values, consider trade-offs of various resilience strategies, make a final resilience plan, and then experience visualizations of how their plan will affect the city and the people who live there. The fictional towns are visualized through online ArcGIS StoryMaps created by Northeastern University. To learn how to use StoryMaps for this forum, access the training video through this link: https://www.youtube.com/watch?v=55e2tiLpvcs&feature=youtu.be.

Kingtown is a fictional town used to demonstrate sea-level rise resilience. In Kingtown, sea levels have risen by about a foot over the last century. Some high-tide flooding occurs, even when there are no precipitation or strong wind events. These floods may be only a foot or two deep, but can cause roadways to be impassable, flood basements in low-lying areas with saltwater, or negatively impact coastal ecosystems.

Kingtown is now prone to flooding on the streets at high tides and during coastal storms. This matters because the structures we build to protect ourselves are built for the sea level people experienced a century or more ago. When we have high tide and waves from storms on top of sea-level rise, water washes onshore. This means Kingtown is at increased risk to flood impacts and needs to become more resilient.

Students will use visualizations to explore potential vulnerabilities to city infrastructures, social networks, and ecosystems from sea level rise, then discuss potential strategies for addressing the threat, focusing on the priorities and needs of relevant stakeholders. Students will then make recommendations for increasing their city's community resilience.

VOCABULARY:

Conservation Planning	Specific to maintain natural values and assets in a specific landscape or seascape with competing uses, values, and other threats and opportunities.
Equity	The fair and just practices and policies that ensure all community members can thrive. Equity is different than equality in that equality implies treating everyone as if their experiences are exactly the same.
Historic Preservation	Utilizing planning to protect historic sites and resources (e.g., monuments, buildings) from hazards related to climate change (e.g., acid rain, increased erosion, extreme weather).
Land Use	Management of land, including the social and economic potential that the land use provides (e.g., grazing, timber, and conservation).
Managed Retreat	The purposeful, coordinated movement of people and buildings away from risks. At the same time, natural coastal habitat is enhanced seaward of a new line of defense. Also referred to as strategic relocation or managed realignment.

ENGAGE:

In this lesson, students will be able to work in groups to determine a resilience strategy for the town of Kingtown. The town and all information is available on the website: https://arcg.is/15rSzD . Through this web portal, students will be able to see the effects of their chosen resilience plan.

Start the lesson by showing the students Kingtown on the "Kingtown" tab. Scroll through the infrastructure and the last image of sea-level rise impacts on the city.

EXPLORE:

Assign students one of the stakeholders from the “Stakeholders” tab: Emergency Room Doctor, Local Resident, Oyster Farmer, Power Plant CEO, Transit Worker, and Economic Development Director. They have 5 minutes to read over the different perspectives.

Students will then discuss in their groups the different stakeholder perspectives, and the demographics of the city on the “Demographics” Tab. There are three strategies for dealing with the impacts of sea-level rise in Kingtown: Keep Water Out, Living with Water, and Managed Retreat. Each strategy has a Plan A (larger and more expensive) and a Plan B (smaller scale and less expensive). Students can explore these options by clicking through the named tabs. As a group, they will prioritize the values of what to protect from sea-level rise impacts and how they will do it with their limited resources. (15 minutes)

EXPLAIN:

Come together as a class to share which resilience plan each group chose. Look at the results of one resilience plan option. There are 17 possible outcomes so choose one not picked by any of the groups. The tab “Submit Resilience Plan” shows the images of each plan option on the left side, and when those are clicked you are brought to a new story map that reflects changes to the community based on the plan. Walk through all the impacts with the group on the new story map (10 minutes)

ELABORATE:

Groups go back to working together to explore the impacts from their chosen resilience plan. (20 minutes)

EVALUATE:

Groups share the resilience plan they chose as well as the impacts to Kingtown based on their decision. Ask them to reflect on what the ramifications of these impacts might mean for the residents living in the town. The new maps for each resilience plan has information describing the changes, and students can summarize this information to present to the class. Students can also be asked to compare their personal decision to that of their assigned stakeholder. (10 minutes)

STUDENT PAGE | Kingtown – Planning with a Purpose

As a group prioritize the values: Economic, Environmental, and Social. Next to each strategy in the chart below is a star ranking of how the strategy will impact Economic, Environmental, and Social values. Decide which value is the most important to you to protect.

Your group is allotted 3 coins for your resilience plan selection.

Plan A costs 2 coins and Plan B costs 1 coin. You cannot spend all three coins on one strategy, and you do not have to spend all three. **Decide as a group which resilience plan you choose on the following page.**

My Resilience Plan 1

KEEP WATER OUT	LIVING WITH WATER	MANAGED RETREAT
Plan A	Plan A	Plan A
$ $	$ $	$ $
Plan B	Plan B	Plan B
$	$	$

What resilience plan would you make for Kingtown? Why did you choose this plan?

Mark the empty coin spaces to choose a plan. Remember you only have three coins and can't use all three on one strategy!

STUDENT PAGE | Kingtown – Planning with a Purpose

DO NOW:

Suggest a method for a community to equitably discuss the possibility of managed retreat in a Community Meeting.

EXIT TICKET:

Which value below is most important to you? Explain.

- Keep Water Out
  - Economic – 2 stars
  - Environmental – 3 stars
  - Social – 3.5 stars
- Living with Water
  - Economic – 2.5 stars
  - Environmental – 4 stars
  - Social – 2 stars
- Managed Retreat
  - Economic – 3 stars
  - Environmental – 4.5 stars
  - Social – 2 stars

- Flooding is the natural hazard with the greatest economic and social impact in the United States, and these impacts are becoming more severe over time. Catastrophic flooding from recent hurricanes, including Superstorm Sandy in New York (2012) and Hurricane Harvey in Houston (2017), caused billions of dollars in property damage, adversely affected millions of people, and damaged the economic well-being of major metropolitan areas. Flooding takes a heavy toll even in years without a named storm or event. Major freshwater flood events from 2004 to 2014 cost an average of $9 billion in direct damage and 71 lives annually. These figures do not include the cumulative costs of frequent, small floods, which can be similar to those of infrequent extreme floods. Dr. Lauren Alexander Augustine discussed some of the findings of the National Academies of Sciences, Engineering, and Medicine's recent report "Framing the Challenge of Urban Flooding in the United States."
    - National Academies of Sciences, Engineering, and Medicine. 2019. Framing the Challenge of Urban Flooding in the United States. Washington, DC: The National Academies Press. https://doi.org/10.17226/25381. https://www.preventionweb.net/files/73798_25381.pdf
    - There are four dimensions of urban flooding:
        - 1. The physical dimension represents the built and natural environments.
        - 2. The social dimension represents the people, where they live, who in the community is impacted, what those impacts look like, etc.
        - 3. The information dimension looks at a variety of issues such as what data are needed to understand the flood risk, how to communicate risk, how people interpret information about risk, etc.
        - 4. The actions and decisions dimension considers what needs to be done about urban flooding, how decisions are made, how flooding is managed, etc.
- Article on flooding "The Growing Thread of Urban Flooding: A National Challenge": https://cdr.umd.edu/sites/cdr.umd.edu/files/urban-flooding-report-online.pdf.
    - Galloway, G. and Brody, S. 2018. The Growing Threat of Urban Flooding: A National Challenge. University of Maryland, College Park and Texas A&M University, Galveston Campus. Accessed February 3, 2020.
    - This report was based on a national survey of municipal flood and stormwater managers and professionals, and found:
        - 83% of respondents experienced urban flooding in their communities.
        - 65% of respondents indicated that most of the damages from these floods were not covered by the National Flood Insurance Program (NFIP) because the community was located well outside the areas of the FEMA floodplains and located in areas that were not considered at risk for floods.
        - 41% of respondents indicated that their communities do not have funding to address their urban flooding problem.
        - 32% of respondents stated that there is a lack of political will to address the urban flooding problem.

        - Respondents believed only 34% of elected officials and 28% of the public were concerned about urban flooding in their communities.
    - Some of the report's conclusions include:
        - Urban flooding is a local government issue, but it is everyone's problem. How do we put communities in a better position to be able to deal with urban flooding?
        - The division of responsibility for urban flooding is fragmented. There is too much stove-piping within government and between agencies and organizations. There is no coordinated approach for dealing with urban flooding.
        - Infrastructure is aging and inadequate, and it is getting worse.
        - There is no federal agency charged with coordinating the federal support of urban flooding.
        - The economic and social impacts of urban flooding are immense. The lowest income groups are being hit hardest.
        - Government is not communicating the urban flooding risk very well, and the data needed to understand the risk are lacking.
- Article about sea-level rise community impacts "Norfolk Wants to Remake Itself as Sea Level Rises, but Who Will Be Left Behind?" https://insideclimatenews.org/news/21052018/norfolk-virginia-navy-sea-level-rise-flooding-urban-planning-poverty-coastal-resilience/
- A discussion surrounding the language of sea-level driven migration and why our words matter. "Reframing the Language of Retreat" https://eos.org/opinions/reframing-the-language-of-retreat
- Article "Flooded: How Natural Disasters Lead to Predatory Lending in the Rio Grande Valley" https://shelterforce.org/2020/11/06/flooded-how-natural-disasters-lead-to-predatory-lending-in-the-rio-grande-valley/
- Article about the Pointe-au-Chien Tribe
    - https://gulfofmexicoalliance.org/2020/09/pointe-au-chien-tribe-a-success-story/
- Article "Protection for the Rich, Retreat for the Poor," How the United States' implementation of climate change adaptation programs is exacerbating inequality and breeding a new form of climate gentrification: https://www.hakaimagazine.com/news/protection-for-the-rich-retreat-for-the-poor/
- Article "California Has A New Idea For Homes At Risk From Rising Seas: Buy, Rent, Retreat" https://www.npr.org/2021/03/21/978416929/california-has-a-new-idea-for-homes-at-risk-from-rising-seas-buy-rent-retreat

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4.1 Sea-Level Rise Risk & Reward

AGE RANGE
9th—12th grade

TIME REQUIRED
70 minutes

ACTIVITY OVERVIEW
Engage: Discussion Question

Explore: SLR Risk & Reward

Explain: Reflections

Elaborate: Adaptation Pathways Reading

Evaluate: Discussion Question

MATERIALS
Dice (one per group)
Candy or tokens (>5 per student)
Group Set-Up page
Group Worksheet

BASED ON:
"Game of Futures" by Dani Boudreau Tijuana River National Estuarine Research Reserve

LESSON TOPIC: Integrating sea-level rise resilience into planning.

ACTIVITY SUMMARY: Students will play a dice game that simulates making adaptations to plan for future sea-level rise.

OBJECTIVES:

Students will be able to:

- Understand the need to plan adaptation strategies with location-specific sea-level rise information.
- Determine if adaptation strategies are effective at reducing impacts under different climate scenarios.

LESSON BACKGROUND: The dice game sets up student groups as communities. Each student makes individual choices that may impact the whole community. Through the gameplay, students decide how much they will prepare their home for sea-level rise. The future sea-level rise impact is determined by rolling the dice. As the game progresses, students pay money if their adaptation strategy did not protect their home from sea-level rise impacts, but students will also have an opportunity to update their strategy.

The game includes a version of an insurance payout. Homeowners or renters insurance covers losses and damages to an individual's residence. The individual pays a certain amount based on the value of their home to the home insurance company each month, called the premium. In return, the insurance company agrees to pay a certain amount of money to cover expenses if there is a catastrophic event. In the case of a catastrophic event, the homeowner files a claim with the insurance provider. The insurance provider sends someone to assess the damage, and after filing paperwork, the homeowner will receive a payment to cover damages.

The student reading builds off the game by introducing the concept of adaptation pathways. The reading outlines the technique used to mitigate damage from future sea-level rise impacts by utilizing multiple solutions that build on one other. These adaptation strategies are organized into a pathway that can be followed, and additional mitigation actions added as conditions change. This becomes a proactive planning tool to add policy change and mitigation actions by following the observed sea-level rise rather than projections. Adaptation strategies are not one size fits all but they can build on previously implemented strategies. By using numerical modeling of physical processes, like wind and waves, scientists can get an idea of how adaptation strategies will behave in a future climate. There is uncertainty regarding the impacts of sea-level rise, but we can still plan for the future by effectively considering the uncertainty and preparing to respond to a range of scenarios.

The dice outcomes may seem predictable in the game, and that is because some outcomes, like sea-level rise scenarios, are more likely than others. Scientifically speaking, the range of sea-level rise scenarios cover all scientifically plausible scenarios. Having a large range of sea-level rise scenarios does not mean that scientists do not know what they are doing. It shows the range of possible outcomes. There are three major reasons for the scenarios. The first is that we do not know how much carbon will be in the atmosphere because the rate of global carbon emissions changes with policies put in place by different governments. The second is the natural variability built into the scenarios. The third is that scientists are still studying ice sheet melt, and the models used to measure the volume of ice sheets and their rate of melting is relatively new and getting more accurate constantly. With these reasons in mind, the range of sea-level rise scenarios shows the range of scientifically possible scenarios for future sea-level rise with low scenarios following a low-end range of natural variability and an extreme scenario following catastrophic ice melt. *The Module 3 lesson 3.2 Assets at Risk involves a discussion on sea-level rise projections that can be connected to this lesson.*

Just as with the dice, is it helpful to plan for sea-level rise by considering scenarios based on their probabilities of occurring. The likelihood of each sea-level rise scenario depends in part on the amount of carbon gas in the atmosphere. Carbon emission scenarios, also known as Representative Concentration Pathways or RCPs, represent different potential futures based on policies and actions of people globally. The table below explores the probability of each sea-level rise scenario under three different RCPs: RCP2.6 is a dramatic reduction of carbon currently in the atmosphere; RCP4.5 is a modest decrease in global carbon emissions; and RCP8.5 is continuing on the current global emissions trajectory. As stated above, the scenarios, low through extreme, cover the range of scientifically plausible scenarios. Probabilities help us understand the likelihood of each scenario occurring. For example, under RCP8.5, it is 100% likely that we will exceed the Low scenario by 2100, while there is a very low probability (0.1% chance) that we will exceed the Extreme sea-level rise scenario by 2100.

Probabilities of occurrence help determine which scenario best supports your risk tolerance in planning. For example, although the High scenario has a low probability of occurring, you may want to plan for it when protecting long-term investments with low risk-tolerance. For instance, a military base or water treatment facility would have a low risk-tolerance because they serve critical functions to a large number of people, have interdependent systems with other critical services, and cannot be easily moved or adapted to future conditions once built

Likelihood of sea-level rise scenarios:

Global Sea Level Rise Scenario	RCP2.6 dramatic reduction of carbon emissions	RCP4.5 modest reduction in carbon emissions	RCP8.5 no change in carbon emissions
Low	94%	98%	100%
Intermediate low	49%	73%	96%
Intermediate	2%	3%	17%
Intermediate-high	0.4%	0.5%	1.3%
High	0.1%	0.1%	0.3%
Extreme	0.05%	0.05%	0.1%

Source: Collini et al, 2018

VOCABULARY:

Adaptation	The process of adjusting to new (climate) conditions in order to reduce risks to valued assets.
Adaptation Planning	Preparing a natural or urban area for the effects of climate change with the intention of reducing risk or exposure.
Adaptive Capacity	The ability of a person, asset, or system to adjust to a hazard, take advantage of new opportunities, or cope with change.
Critical Facilities and Services	Man-made structures/improvements which, because of their function, size, service area, or uniqueness, are paramount to day-to-day function (e.g., hospitals, power plants, wastewater treatment facilities, emergency response, etc.).

Risk Communication	Process of informing people about potential hazards to their person, property, or community.
Social Vulnerability	Risk that a community will lose its ability to maintain social interactions, cultural institutions, and/or a standard of living. Negative impacts on communities due to stresses on human physical, mental, or cultural health, which consider socioeconomic factors like poverty level, access to transportation, and living conditions.

ENGAGE:

Ask students: What do you think about when making an important decision? Is it important to know the possible outcome(s) when you are planning? Would they want to know future sea-level rise when building a beach house?

EXPLORE:

Students will play the Sea-Level Rise Risk & Reward game.

Game Procedure:

1. Divide class into groups of 5. In a group of 5, one player will act as scorekeeper and the others will each get one turn to roll the dice.
    - Note: If you do not use dice in your classroom you can have students use a phone or computer to "roll the dice" by asking Siri to "roll two dice" or the teacher can pre-roll numbers.
2. Each student is given 5 pieces of candy or tokens. This represents the total money an individual has to repair, maintain, or modify the adaptation strategy as climate change is experienced.
3. Each student in a group will choose an adaptation strategy (below) to implement. They are planning to protect their home for approximately the next 30 years, through 2050.

    ADAPTATION STRATEGIES:
    You own your house on the coast. To make your home resilient to sea-level rise you can choose from the following possible options in the short term. Pay the candy/tokens to the bank.

    A. Do nothing (cost = 0 candy)
        - **Teacher talking point:** in this strategy the home is left as is.

B. Nourish the beach in front of your home to accommodate scenario 1 (cost = 1 candy)
    - **Teacher talking point:** nourishing the beach in front of the home replaces sand lost from erosion and this land will act as a barrier to sea-level rise.

C. Build a dune in front of your house to accommodate scenarios 1 & 2 (cost = 2 candy)
    - **Teacher talking point:** a dune with dune grasses will offer protection to the home from erosion and water inundation

D. Elevate your house to accommodate scenarios 1,2 & 3 (cost = 3 candy)
    - **Teacher talking point:** elevating the home raises it above base flood elevation (or higher) and will allow water to come underneath but not impact the home

E. Relocate your house inland to accommodate scenarios 1, 2, 3 & 4 (cost = 4 candy)
    - **Teacher talking point:** the home will be relocated away from the water but still within the community. This allows the home to be protected from sea-level rise impacts but also maintain community social connections and contribute to taxes.




Images: Top left, beach renourshiment; top right, sand dunes; bottom left, elevated house; bottom right, relocation.

4. Player One rolls two dice, once. Determine the scenario outcome (Step 5). Player One's roll affects all students in their group.
    - The probability of the dice sum outcome is linked to the probability of future sea-level rise scenarios for the northern Gulf of Mexico (Mississippi, Alabama, and NW Florida).

- This sea-level rise scenario outcomes in this game are representative of likelihoods with no change in carbon emissions. You may choose to share this with your students when they are selecting Adaptation Strategies.
    1. **100%** Low 0.8ft (~0.2m)
    2. **96%** Intermediate-Low 1.0ft (~0.3m)
    3. **17%** Intermediate 1.5ft (~0.5m)
    4. **1.3%** Intermediate high 2.0ft (~0.6m)

5. The sum of the two dice determines what scenario they are in.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Year 2050	7	6 or 8	4, 5, 9, 10	2, 3, 11, 12

   Payout!
    a. If students adequately protected their home from the scenario they rolled, they keep their candy/token and get 2 bonus candy/token. The bonus candy/token reflects homeowners saving income.
    b. If students did not adequately protect their home from the scenario they rolled, they pay the bank with 1 candy/token for each level of scenario of difference. (Ex: If they protected to Scenario 1 but rolled Scenario 2, they pay 1 candy/token. If they protected to Scenario 1 but rolled Scenario 4, they pay 3 candies/tokens.)
6. Repeat with Player Two rolling the dice.
7. Before Player Three rolls there is an opportunity for an Insurance Payment. If any of the players lost candy/tokens due to the scenario outcome in Round One, they get to collect one less candy/token than they lost. (Ex: If they paid 1 candy/token, they would not collect insurance. If they paid 3 candy/token, they would collect 2 candy/token from insurance.) This represents the process of insurance payments, where partial damage is covered through insurance and it happens months-years after the damage.
8. Repeat Step 4 with Player Three rolling the dice.
9. There is an opportunity at this point in the game for students to change their original Adaptation Strategy to one of the other 5 choices. **Discuss with students**: Is my strategy effective?
    - Is everyone's strategy still effective with the sea-level rise scenarios?
    - What strategies are successful in the new scenario? Why or why not?
    - If not successful, can it be altered to be effective in the scenario?
10. Repeat Step 4 with Player Four rolling the dice.
11. Players count their remaining candy/tokens.

EXTENSION: There are two game extension opportunities to add to the game. RESOURCE VULNERABILITY starts the game off with each individual having different resources. This option would work well for 1) classes playing a second round or 2) for teachers to use the first time with an advanced class. HIGH-TIDE FLOODING COMMUNITY IMPACT is a game option that allows teachers to add an element into the game while it is currently being played. There are three real life scenarios for teachers to select from.

RESOURCE VULNERABILITY

When the game is played with Resource Vulnerability, individuals in the community start the game with different resources. To determine which players will have limited resources each player will roll one die. The die outcome is the number of candy/tokens that player starts the game with. (Ex: If they rolled a 1, they only get 1 piece of candy/token.)

Social vulnerability is a combination of factors that determine how resilient a community is when confronted by external stresses, potentially from a hazard like sea-level rise. The Social Vulnerability Index (SVI) employs U.S. Census Bureau data to identify communities at higher risk. The SVI ranks on 15 social factors, including poverty, disability, minority status, lack of vehicle access, and crowded housing. These are then grouped into four themes: socioeconomic status, household composition, race/ethnicity/language, and housing/transportation. Our game will rank students randomly and is used as a starting point for discussion of resource vulnerability. The SVI fact sheet can be found online: https://svi.cdc.gov/factsheet.html

HIGH-TIDE FLOODING COMMUNITY IMPACT

When the game is played with High-Tide Flooding Community Impact, the community group must work together to fund infrastructure improvements. This extension can be introduced to the game at any point by the teacher to heighten game-play and stimulate community-level conversations. There are three real-life simulated options below for the teacher to select from. Each of the following community impacts affect everyone regardless of their chosen Adaptation Strategy. The community cost for each improvement is 10 candies/tokens, and this can be divided across individuals however each community group decides, for example, communities may decide that everyone contributes an equal share. In the case that some individuals do not have enough money the community may decide that other individuals cover the difference.

Road Access: The main road to enter the community is inaccessible for one third of the year due to high-tide flooding. Since the flooding blocks access for the whole community, the community must collectively raise the funds to elevate the road.

Storm Water Infrastructure: The storm drains along community roads no longer drain rainwater away fast enough during thunderstorms. Sometimes the storm drains back up with water during a high tide even without a rainstorm. The outflow pipe directs water from the streets into the bay. This system needs to be improved so that the exit point is not covered by water during the tidal cycle.

Power Station: The facility that provides power for the community is vulnerable to storm surge inundation and needs to be relocated. Moving the power station will allow the community to be more resilient to future storms. This relocation will be a partnership between the power company and the community, so the community will help pay a portion of the relocation cost.

EXPLAIN:

Wrap-up and reflections

Begin by determining who the individual and group "winners" are. If multiple people or groups seem to have been successful, begin a discussion around why those individuals/groups were successful.

Discuss with students what lessons were learned throughout the process.

- If you did not choose an expensive adaptation when you had the resources, how did that impact you later in the game? Would you change your strategy if you did it again?
- What strategies seemed to be the most resilient?
- Community vs. individual successes?
- What did you struggle with throughout the game?
- Is the adaptation to relocate an easy choice in real life?
- Was there one scenario that seemed to be particularly difficult for individuals or community?
- Who has the most candy left and why? Even though relocation protects against all scenarios, it also cost the most and may not even have been necessary.
- Do the outcomes seem a little predicable? Is sea-level rise predictable?
    - With this final discussion topic remind them that we have the sea-level rise projections for the range of scenarios from Low to Extreme. We can use this information to make plans for our homes and communities.

Connect to facts:

- Every $1 spent on mitigation funding can save the nation $6 in future disaster costs.
  - National Institute of Building Sciences. Natural Hazard Mitigation Saves: 2017 Interim Report
- For every $1 a private property owner spends installing a living shoreline instead of a bulkhead they will save $6 in avoided maintenance, replacement, and storm repair costs over 60 years.
  - Sicangco, Camille, et al. *Cost-Benefit Analysis of a Small-Scale Living Shoreline Project*. MASGP-21-054
- As sea-level rises, the benefits for installing a living shoreline also rise. Rising seas decreases the lifespan of bulkheads, increasing maintenance cost and replacement frequency.
  - Sicangco, Camille, et al. *Cost-Benefit Analysis of a Small-Scale Living Shoreline Project*. MASGP-21-054

The Sea-Level Rise Risk & Reward game allows students to start thinking about how planning now prepares individuals and communities for future conditions.

ELABORATE:

Students read the excerpt about adaptation strategies. This mirrors the game-play, because as conditions change you can follow the adaptation pathway and make the largest/most expensive adaptations only when they are needed, yet preliminary planning and investment is required for these approaches to work.

Excerpt from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. Climate Change.

EVALUATE:

Ask students: What is an adaptation pathway? Why is it important to have a mitigation plan that might change?

FUTURE SCENARIO NARRATIVES:

1. Low: 0.8ft (~0.2m)
2. Intermediate-Low: 1.0ft (~0.3m)
3. Intermediate: 1.5ft (~0.5m)
4. Intermediate-High: 2.0ft (~0.6m)

ADAPTATION STRATEGIES:

You own your house on the coast. To make your home resilient to sea level rise you can choose from the following possible options in the short term. Pay the candy/tokens to the bank.

A. Do nothing (cost = 0 candy)
B. Nourish the beach in front of your home to accommodate scenario 1 (cost = 1 candy)
C. Build a dune in front of your house to accommodate scenarios 1 & 2 (cost = 2 candy)
D. Elevate your house to accommodate scenarios 1,2 & 3 (cost = 3 candy)
E. Relocate your house inland to accommodate scenarios 1, 2, 3 & 4 (cost = 4 candy)

GAME-PLAY

SEA-LEVEL RISE SCENARIOS:

The sum of the two dice determines what scenario you are 30 years into the future:

	Scenario 1 - Low	Scenario 2 – Intermediate-Low	Scenario 3 - Intermediate	Scenario 4 – Intermediate-High
Year 2050	7	6 or 8	4, 5, 9, 10	2, 3, 11, 12

ROUND PAYOUT:

a. If students adequately protected their home from the scenario they rolled, they keep their candy and get 2 bonus candy.
b. If students did not adequately protect their home from the scenario they rolled, they pay the bank with 1 candy for each level of scenario of difference. (Ex: If they protected to Scenario 1 but rolled Scenario 2, they pay 1 candy. If they protected to Scenario 1 but rolled Scenario 4, they pay 3 candy.)

INSURANCE PAYOUT:

If any of the players lost candy/tokens due to the scenario outcome in Round One, they get to collect one less candy/token than they lost. (Ex: If they paid 1 candy, they would not collect insurance. If they paid 3 candy, they would collect 2 candy from insurance.)

STUDENT PAGE | Sea-Level Rise Risk & Reward – Group Worksheet

	Player 1: *Name*	Player 2: *Name*	Player 3: *Name*	Player 4: *Name*	Player 5: *Name*
Strategy: *Check a box*	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E
Round One Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Round Two Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Insurance Payment If you lost $$ in Round One *Check a box*	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______
Round Three Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Strategy change? *Check a box*	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______
Round Four Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Final Count:	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*

Adaptation Pathway - Sequential implementation of adaptation strategies as a policy pathway

Due to the uncertainty in future climate conditions, including the amount of sea-level rise and coastal response to those conditions, and due to relative effectiveness of individual strategies for different rates of sea-level rise, it is important to develop a strategic plan that is also adaptive. Haasnoot et al. (2013) describes dynamic adaptive policy pathways: a set of possible actions that may be implemented sequentially and in response to changing conditions. When the current action is no longer able to meet the intended objective, which in this study is to lessen the damage to a coastal community from a hurricane and rising seas, a tipping point is reached and a new action must be chosen.

Using the sea-level rise scenarios and adaptation strategies analyzed in this study, a policy pathway is created for Bay Head (Fig. 5). According to computer modeling simulations, strategy A reduces erosion (i.e., improves habitability) for sea-level rise = +0.2 m but not for sea-level rise = +1.0 m and higher. Strategy A is also the least expensive option in terms of initial costs based on the amount of sediment required to raise the beach (Fig. 2). However, a tipping point is reached as sea levels rise from +0.2 to +1.0 m, and a new strategy must be chosen. The preferred pathway routes to strategy B (Fig. 5) such that, as sea levels rise above +0.2 m, both the beach and dune must be nourished to offer protection from future storms at higher sea levels. Since there is more sediment available on the beach and dunes for transport (Fig. 2), erosion is reduced, island habitability is improved, but initial costs are higher due to the additional sediment required to build the dune. Also, the larger dunes only protect against ocean-side waves and surge, and the back barrier remains vulnerable to flooding and erosion by bay-side surge.

As sea levels continue to rise, back-barrier vulnerability becomes too large and another tipping point is reached. Strategy D is required to continue protection of the island for sea-level rise greater than +1.0 m. Although raising the island is an extreme adaptation strategy, it was implemented in Galveston, TX, USA, a developed barrier island located on the Gulf of Mexico. After a devastating hurricane in 1900, Galveston built a 16-km-long seawall and raised the island by up to 4 m (Bartee 2001). Over the last century, Galveston has survived several strong tropical storms including Hurricane Ike (2008), which has been largely attributed to the seawall and grade raising (Bartee 2001). As sea-level rise increases above 1.0 m in Bay Head, strategy D is the only option considered here that prevents complete erosion of the back barrier for extreme sea-level rise. Although it has the highest initial costs, a life cycle cost analysis for each strategy may reveal that periodic renourishment over several decades of sea-level rise could have greater costs than the initial cost of strategy D. Additionally, the analyses may reveal that it makes more sense to strategically relocate some of the infrastructure and aspects of the community.

Excerpt from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. Climate Change.

(a)

Strategy (sediment volume added, m³)	Beach raised by SLR	Dune raised by SLR	Seawall raised by			Back barrier raised to minimum elevation
			0.5 m	1.0 m	2.0 m	
EC						
A (8,32,71)	X					
B (11, 68, 145)	X	X				
C (11, 68, 145)	X	X	X	X	X	
C1.0 (10, 67, 144)	X	X	X	X	X	
C2.0 (7, 64, 141)	X	X	X	X	X	
D (13, 128, 322)	X	X				X
E (13, 128, 322)	X	X	X			X
E1.0 (12, 127, 321)	X	X		X		X
E2.0 (9, 124, 318)	X	X			X	X

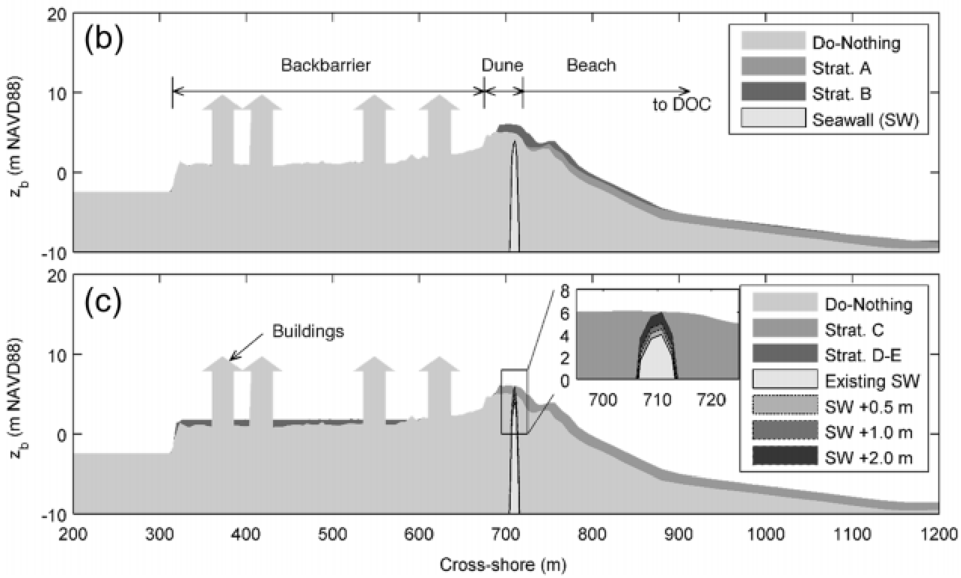

Fig. 2 Characteristics of adaptation strategies (**a**) and representative cross-shore profiles for SLR = +1.0 m: **b** EC elevation (z_b) and strategies A–B; **c** EC z_b and strategies C–E. Initial volumes are per unit width. Buildings are peaks in data and the seawall is represented by *shaded regions* at cross-shore distance 785 m. *SW* denotes seawall, and *DOC* is the depth of closure

Image: Figure 2 from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels title. *Climatic Change.*

Fig. 5 Policy pathway for Bay Head under SLR scenarios

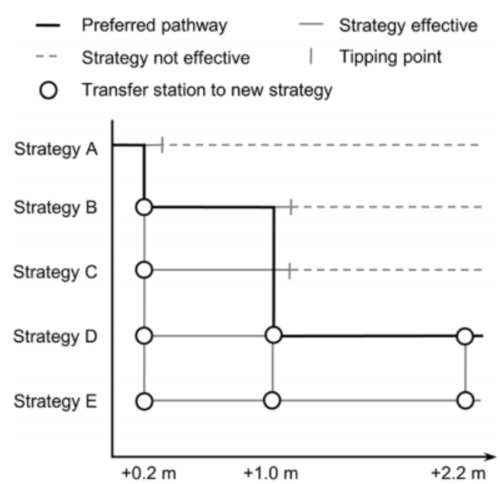

Image: Figure 5 from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. *Climatic*

STUDENT PAGE | Sea-Level Rise Risk & Reward

DO NOW:

Describe how you currently think about sea-level rise in regards to living along the coast.

EXIT TICKET:

Why is having a mitigation plan that changes helpful for community resilience?

4.2 Stakeholder Roll Call

AGE RANGE
9th—12th grade

TIME REQUIRED
60 minutes

ACTIVITY OVERVIEW
Engage: Case Study Videos
Explore: Stakeholder Categories
Explain: Role Play Preparation
Elaborate: "Council Meeting"
Evaluate: Presentations

MATERIALS
Student Worksheet
Student Role Cards
Computers

BASED ON:
Resources from Planning and Facilitating Collaborative Meetings by NOAA Office for Coastal Management

LESSON TOPIC: Stakeholder participation

ACTIVITY SUMMARY: Students will role play as community stakeholders responding to local high tide flooding.

OBJECTIVES:

Students will be able to:

- Categorize types of stakeholders.
- Explore the benefits of including a wide range of stakeholders.
- Discuss solutions to high tide flooding.

LESSON BACKGROUND: A collaborative process (also referred to as collaborative decision making, facilitated processes, consensus building, participatory decision making, systematic problem solving, etc.) engages multiple stakeholders in cooperative deliberations in order to address issues and solve problems. The issues addressed may be internal to organizations or in the public arena. The collaborative process often improves the relationship of involved parties, encourages high quality input, and aids in the construction of mutually acceptable agreements. Public agencies use collaborative processes to build consensus and gain strong support for proposed solutions to public issues.

When collaborative processes are conducted properly, participants obtain a clear understanding of the issue and have analyzed all relevant facts together—before jointly developing solutions that represent the whole group's best thinking about the optimal decision. A consensus decision is reached when everyone says, "I can live with this decision, and I will support its implementation." A collaborative process should be designed to get to this point—even if the consensus is that the group agrees to use one of the other decision-making methods to reach the final agreement.

While science can serve as a rational foundation for natural resource management or community planning, in many cases it is those groups impacted by the decisions that decide how acceptable a decision is and influence how effective the implementation will be. Peoples' experiences and culture, understanding of an issue, and support of an agency can shape their support for and compliance with coastal resource management decisions and policies.

Involving stakeholders in decision-making can accomplish the following:

- Produce better outcomes or decisions
- Garner public support for agencies and their decisions
- Bring to light important local knowledge
- Increase public understanding of natural resource issues or management decisions
- Reduce or resolve conflicts between stakeholders
- Ensure implementation of new programs or policies
- Increase compliance with natural resource laws and regulations
- Help agencies understand flaws in existing management strategies or potential unintended consequences from new decisions
- Create new relationships among stakeholders

Practitioners of stakeholder participation will jokingly define a stakeholder as "anybody who wants to be." There is much truth to this broad definition. Stakeholders are generally those who have an interest in or are affected by a decision. Stakeholders are also those who have influence or power in a situation. Stakeholders' interests in an issue can be monetary, professional, personal, or cultural, and can arise from a host of other motivations.

From the Planning and Facilitating Collaborative Meetings by NOAA Office for Coastal Management Training Manual

VOCABULARY:

Collaborative	A collaborative process (also referred to as collaborative decision making, facilitated processes, consensus building, participatory decision making, systematic problem solving, etc.) engages multiple stakeholders in cooperative deliberations in order to address issues and solve problems.

Community Planning	Public participatory process where future goals and objectives for the community are identified, priorities for project funding and implementation are set, and current policies are evaluated/revised.
Stakeholders	An individual or group that has an interest in any decision or activity of an organization.

ENGAGE:

Show the case study video to the class. This 5-minute video follows the city of Covington, Louisiana as they make a plan for preparing for flooding.

Alabama version: https://vimeo.com/322242513

Mississippi version: https://vimeo.com/322242202

Introduce the community issue for this lesson:
Azaleaville is located on the coast along the northern Gulf of Mexico. The north part of Azaleaville is unincorporated county and there are two neighboring cities to the east and to the west. In the early 19th century, a local seafood industry developed in Azaleaville. In 1838, the city constructed a lighthouse to guide fishermen safely home. Azaleaville's seafood market increased steadily throughout the 20th century, and the local fishing community survived dozens of hurricanes and tropical storms. More recently, however, the Deepwater Horizon Oil Spill in 2010 and the adverse environmental impacts of the opening of the Bonnet Carré spillway have severely reduced the seafood industry. On August 29th, 2005, Hurricane Katrina hit the coast near Azaleaville as a category 3 storm and caused a record high storm surge of 27.8 feet (8.47 meters) with sustained winds of 120 mph. Storm damage from Katrina left many empty lots and vacant businesses. Azaleaville has been slow to rebuild in part because of the cost required to comply with building codes for buildings to be above base flood elevation and due to the high cost of flood insurance. Although rain, wind, and storm surge from tropical storms and hurricanes pose the most severe flooding threats, riverine and flash flooding from local and upriver thunderstorms have recently increased in Azaleaville. There is a 47% chance that Azaleaville will experience a flash, coastal, or riverine (non-hurricane) flood in any given year, and flooding can occur anytime during the year.

Sea-level rise is leading to more days of high tide flooding in Azaleaville. The main road leading to the high school is blocked by flood water often during the year but especially in September, October, and November. This flooding is already happening now, and with future sea-level rise projections the number of flooding days will increase. This flooding is preventing buses and cars from entering the school drop off area and the parking lot for students who drive to school is reduced by half. A Community Meeting was called to convene with a diverse group of stakeholders, who serve and/or represent different community sectors in Azaleaville.

EXPLORE:

In this lesson, students will take on roles of specific community members to address a community issue. Before they can begin their "Community Meeting" they must identify the stakeholders (the people involved with the issue). Students read the excerpt from Stakeholder Participation from NOAA's Office for Coastal Management as the Student Reading.

Using the Student Worksheet chart, students can work individually or in pairs to generate a list of stakeholders who are impacted by the Azaleaville high-tide flooding blocking access to the high school.

EXPLAIN:

Divide students into groups of 5-6. Students will be given a role to play for the Community Meeting of how the community will address the high-tide flooding at the high school. Students should take a few minutes to think about the person they will be playing and how that person would handle the high-tide flooding at the high school. **Alternative:** Use the activity as a whole class exercise instead of separating into individual groups. Multiple students would then be in each stakeholder group and would be encouraged to speak up.

> **EXTENSION:** Students can be assigned their role ahead of time and be required to research that role by speaking to individuals in that role in their community. You can also have the students think of this activity as a drama/play and they can dress up for their role.

The specific Community Meeting goals are to better understand:

- The risks and impacts of floods on the community
- Actions the community is taking now and could take in the future to mitigate future floods
- Challenges the community continues to face related to flood mitigation
- What the community needs to enable them to make informed decisions about flood mitigation
- How the community is funding their flood mitigation activity

Note: These cards at the end of the section are formatted to be printed on Avery5390 Name Badge Inserts (2-1/4" x 3-1/2").

First Responder

- Your career is devoted to keeping others safe.
- You respond first to emergencies making sure to enforce the law and provide medical help.
- You are aware that the flooding by the high school might lead to students walking across busy roads with more chance of accidents.

Local Government Official

- You are committed to your region and work to serve the best interests of both residents and businesses.
- You have a good working relationship with other levels of government and your city's first responders.
- You understand that a strong school system draws parents to move to your town and increases tax revenue and your ability to provide critical services to the town.

Principal

- You are the principal of the high school.
- The principal is responsible if anything happens to the students while on school property.
- You want to ensure easy access to the school for students and you promote a well-rounded education.

Teacher

- You work as a teacher at the high school and you have a strong community network.
- You live nearby the school and walk to work along the road that is often flooded.

Local Resident - Fisherman

- You are a working professional with no children, you work at the fishing docks and live across town from the high school.
- You are worried huge construction projects to flood proof the city will impact your day to day life or could cause flooding in new places that will negatively impact you.

Local Resident - Parent

- You are a parent with two children in the high school, and you work near the school and drop your kids off on your way to work.
- You are concerned about the safety of dropping your children off at school on the busy road.

High School Student

- You are a student at the high school and drive yourself to school.
- You are concerned about driving through the flooded road and about the lack of parking.

ELABORATE:

In their groups, students will play their role and discuss at the Community Meeting their thoughts for mitigating the high-tide flooding by the high school. They should be presenting their thoughts for mitigating the flooding impacts while also persuading other members to support their idea.

Review the following class discussion norms to ensure a successful Community Meeting:

- Allow everyone a chance to speak
- Actively listen

- Listen respectively
- Constructively critique ideas, not individuals
- Be open to changing your perspectives based on what you learn from others

Guide the discussion with the following questions:

- How does flooding impact your community?
- What are the main flood risks in your community?
- What actions has your community already taken to mitigate floods?
- What are your plans for future mitigation actions?
- What are examples of how your community coordinates flood mitigation efforts across the public, private, and/or nonprofit sectors or across jurisdictions?
- How can your community fund your flood mitigation activities?
- What are the main barriers or challenges that obstruct your ability to take action to mitigate against floods?
- How complex is the solution?
- Is there an opportunity for public engagement?

At the end of the time have them decide on the “winning” solution or combination of solutions. The “winning” solution or combination of solutions is agreed upon by the group. Note to the class there is also a cost to doing nothing. There can also be litigation against the school district to contend with regardless of the action taken so the city and/or school district attorney will likely be involved.

Note to teachers: allow the students to come up with the ideas for solutions on their own. All ideas are encouraged. As a group facilitator you can provide options as necessary. These may include:

- Road elevation or pedestrian path elevation
- Additional rain gardens or water absorbing areas
- Improvements to the storm water drains or updating old infrastructure
- Road detours leading to the high school
- Elevating the high school
- High school relocation
- Adjusting the start dates of school, i.e. school break or virtual over the heavy flooding

EVALUATE:

Bring all the students back together to present the winning solution from each group.

Extension: ask students what **their** decision would have been and how does that compare with the role they played.

FIRST RESPONDER

- Your career is devoted to keeping others safe.
- You respond first to emergencies, making sure to enforce the law and provide medical help.
- You are aware that the flooding by the high school might lead to students walking across busy roads with more chance of accidents.

LOCAL GOVERNMENT OFFICIAL

- You are committed to your region and work to serve the best interests of both residents and businesses.
- You have a good working relationship with other levels of government and your city's first responders.
- You understand that a strong school system draws parents to move to your town and increases tax revenue and your ability to provide critical services to the town.

PRINCIPAL

- You are the principal of the high school.
- The principal is responsible if anything happens to the students while on school property.
- You want to ensure easy access to the school for students and you promote a well-rounded education.

TEACHER

- You work as a teacher at the high school and you have a strong community network.
- You live nearby the school and walk to work along the road the is often flooded.

LOCAL RESIDENT - FISHERMAN

- You are a working professional with no children, you work at the fishing docks and live across town from the high school.
- You are worried huge construction projects to flood proof the city will impact your day to day life.

LOCAL RESIDENT - PARENT

- You are a parent with two children in the high school, and you work near the school and drop your kids off on your way to work.
- You are concerned about the safety of dropping your children off at school on the busy road.

HIGH SCHOOL STUDENT

- You are a student at the high school and drive yourself to school.
- You are concerned about driving through the flooded road and about the lack of parking.

STUDENT PAGE | Stakeholder Roll Call

In the following chart, generate a list of stakeholders who are impacted by the Azaleaville high-tide flooding blocking access to the high school.

Stakeholder Category	Stakeholder – name of group or individual
Those who are directly affected	
Those with decision-making authority	
Those who have resources or skills that may be needed	
Those who will be implementing the results or outcomes	
Those who will actively oppose the process	
Those who will actively support the process	

STUDENT PAGE | Stakeholder Roll Call

Azaleaville high-tide flooding brainstorm:

What is your role in the community: ____

How are you impacted by the high-tide flooding at the school?

What do you propose that your community do to address the high-tide flooding? (Use the space below to brainstorm a few different options).

Draft your proposal to the community:

a) State how this high-tide flooding is impacting your role:

b) State your suggestion for addressing the issue:

c) Explain why your suggestion is the most effective for your community:

Stakeholder Participation

"The public's attitudes, perceptions, beliefs, and knowledge can have a profound effect on the success of coastal resource management. While science can serve as a rational foundation for management, in many cases it is those groups impacted by resource management decisions that decide how acceptable a decision is and influence how effective management will be. Peoples' experiences and culture, understanding of an issue, and support of an agency can each shape their support for and compliance with coastal resource management decisions and policies. Over the past several decades, traditional top-down, agency-driven decision-making in natural resource management has generally moved toward processes that involve stakeholders (those who have an interest in or are affected by a decision) and acknowledge the importance of public attitudes, perceptions, beliefs, and knowledge. Specifically, involving stakeholders in natural resource management decisions can accomplish the following:

- Produce better outcomes or decisions
- Garner public support for agencies and their decisions
- Bring to light important local knowledge about natural resources
- Increase public understanding of natural resource issues or management decisions
- Reduce or resolve conflicts between stakeholders
- Ensure implementation of new programs or policies
- Increase compliance with natural resource laws and regulations
- Help agencies understand flaws in existing management strategies
- Create new relationships among stakeholders

Of course, stakeholder participation can also pose challenges. Involving stakeholders can be costly, time consuming, labor-intensive, and confrontational - and can ultimately delay decision-making. Additionally, if improperly managed, stakeholder participation can create new conflicts or escalate existing ones."

Excerpt from "Resources from Planning and Facilitating Collaborative Meetings" by NOAA Office for Coastal Management.

DO NOW:

What is high-tide flooding?

EXIT TICKET:

Why is it important to bring all members of the community together to discuss flooding and sea-level rise resilience? "In your opinion, which stakeholder presented the best argument and why?"

4.3 Kingtown – Planning with a Purpose

AGE RANGE

9th—12th grade

TIME REQUIRED

80 minutes

ACTIVITY OVERVIEW

Engage: Kingtown Introduction
Explore: Stakeholders
Explain: Discussion
Elaborate: Resilience Planning
Evaluate: Impact Discussion

MATERIALS

Student Worksheet
Computers

BASED ON:

This lesson is used with permission from Museum of Science Boston, NOAA, Arizona State University, and Northeastern University.

LESSON TOPIC: Community planning for sea-level rise resilience.

ACTIVITY SUMMARY: Students will explore Kingtown and different sea-level rise resilience plans.

OBJECTIVES:

Students will be able to:

- Explore resilience plan strategies for a city impacted by sea-level rise.
- View results and impacts of different sea-level rise resilience strategies.

LESSON BACKGROUND: The Climate Hazard Resilience Forum was developed in partnership with Arizona State University and Northeastern University and supported by a NOAA Environmental Literacy Grant. This deliberative forum brings the participants through the resilience planning process for various generic cities in specific contexts. Each city is based on a real place and uses real data but was anonymized for unbiased deliberation. Participants learn and discuss stakeholder values, consider trade-offs of various resilience strategies, make a final resilience plan, and then experience visualizations of how their plan will affect the city and the people who live there. The fictional towns are visualized through online ArcGIS StoryMaps created by Northeastern University. To learn how to use StoryMaps for this forum, access the training video through this link: https://www.youtube.com/watch?v=55e2tiLpvcs&feature=youtu.be.

Kingtown is a fictional town used to demonstrate sea-level rise resilience. In Kingtown, sea levels have risen by about a foot over the last century. Some high-tide flooding occurs, even when there are no precipitation or strong wind events. These floods may be only a foot or two deep, but can cause roadways to be impassable, flood basements in low-lying areas with saltwater, or negatively impact coastal ecosystems.

Kingtown is now prone to flooding on the streets at high tides and during coastal storms. This matters because the structures we build to protect ourselves are built for the sea level people experienced a century or more ago. When we have high tide and waves from storms on top of sea-level rise, water washes onshore. This means Kingtown is at increased risk to flood impacts and needs to become more resilient.

Students will use visualizations to explore potential vulnerabilities to city infrastructures, social networks, and ecosystems from sea level rise, then discuss potential strategies for addressing the threat, focusing on the priorities and needs of relevant stakeholders. Students will then make recommendations for increasing their city's community resilience.

VOCABULARY:

Conservation Planning	Specific to maintain natural values and assets in a specific landscape or seascape with competing uses, values, and other threats and opportunities.
Equity	The fair and just practices and policies that ensure all community members can thrive. Equity is different than equality in that equality implies treating everyone as if their experiences are exactly the same.
Historic Preservation	Utilizing planning to protect historic sites and resources (e.g., monuments, buildings) from hazards related to climate change (e.g., acid rain, increased erosion, extreme weather).
Land Use	Management of land, including the social and economic potential that the land use provides (e.g., grazing, timber, and conservation).
Managed Retreat	The purposeful, coordinated movement of people and buildings away from risks. At the same time, natural coastal habitat is enhanced seaward of a new line of defense. Also referred to as strategic relocation or managed realignment.

ENGAGE:

In this lesson, students will be able to work in groups to determine a resilience strategy for the town of Kingtown. The town and all information is available on the website: https://arcg.is/15rSzD . Through this web portal, students will be able to see the effects of their chosen resilience plan.

Start the lesson by showing the students Kingtown on the "Kingtown" tab. Scroll through the infrastructure and the last image of sea-level rise impacts on the city.

EXPLORE:

Assign students one of the stakeholders from the “Stakeholders” tab: Emergency Room Doctor, Local Resident, Oyster Farmer, Power Plant CEO, Transit Worker, and Economic Development Director. They have 5 minutes to read over the different perspectives.

Students will then discuss in their groups the different stakeholder perspectives, and the demographics of the city on the “Demographics” Tab. There are three strategies for dealing with the impacts of sea-level rise in Kingtown: Keep Water Out, Living with Water, and Managed Retreat. Each strategy has a Plan A (larger and more expensive) and a Plan B (smaller scale and less expensive). Students can explore these options by clicking through the named tabs. As a group, they will prioritize the values of what to protect from sea-level rise impacts and how they will do it with their limited resources. (15 minutes)

EXPLAIN:

Come together as a class to share which resilience plan each group chose. Look at the results of one resilience plan option. There are 17 possible outcomes so choose one not picked by any of the groups. The tab “Submit Resilience Plan” shows the images of each plan option on the left side, and when those are clicked you are brought to a new story map that reflects changes to the community based on the plan. Walk through all the impacts with the group on the new story map (10 minutes)

ELABORATE:

Groups go back to working together to explore the impacts from their chosen resilience plan. (20 minutes)

EVALUATE:

Groups share the resilience plan they chose as well as the impacts to Kingtown based on their decision. Ask them to reflect on what the ramifications of these impacts might mean for the residents living in the town. The new maps for each resilience plan has information describing the changes, and students can summarize this information to present to the class. Students can also be asked to compare their personal decision to that of their assigned stakeholder. (10 minutes)

As a group prioritize the values: Economic, Environmental, and Social. Next to each strategy in the chart below is a star ranking of how the strategy will impact Economic, Environmental, and Social values. Decide which value is the most important to you to protect.

Your group is allotted 3 coins for your resilience plan selection.

Plan A costs 2 coins and Plan B costs 1 coin. You cannot spend all three coins on one strategy, and you do not have to spend all three. **Decide as a group which resilience plan you choose on the following page.**

My Resilience Plan 1

KEEP WATER OUT	LIVING WITH WATER	MANAGED RETREAT
Plan A	Plan A	Plan A
$ $	$ $	$ $
Plan B	Plan B	Plan B
$	$	$

What resilience plan would you make for Kingtown? Why did you choose this plan?

Mark the empty coin spaces to choose a plan. Remember you only have three coins and can't use all three on one strategy!

DO NOW:

Suggest a method for a community to equitably discuss the possibility of managed retreat in a Community Meeting.

EXIT TICKET:

Which value below is most important to you? Explain.

- Keep Water Out
  - Economic – 2 stars
  - Environmental – 3 stars
  - Social – 3.5 stars
- Living with Water
  - Economic – 2.5 stars
  - Environmental – 4 stars
  - Social – 2 stars
- Managed Retreat
  - Economic – 3 stars
  - Environmental – 4.5 stars
  - Social – 2 stars

- Connected Coastlines is a nationwide climate reporting initiative in coastal states hosted by the Pulitzer Center: http://connected-coastlines.pulitzercenter.org/

- Article about how climate change is speeding gentrification in some of America's most flooding vulnerable cities.
    - "High ground, high prices": https://www.cnn.com/interactive/2021/03/us/climate-gentrification-cnnphotos-invs/

RECOMMENDED CURRICULUM CITATION:

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3.1 Whose Law Is It Anyways?

AGE RANGE

9th—12th grade

TIME REQUIRED

60 minutes

ACTIVITY OVERVIEW

Engage: Discussion Question
Explore: Student Reading
Explain: Discussion
Elaborate: Government Research
Evaluate: Discussion

MATERIALS

Student Reading
Student Worksheet
Computers

BASED ON:
The Great State by iCivics and Follow That Legislation by Katie Crosby, Colleton County High School

LESSON TOPIC: Levels of government

ACTIVITY SUMMARY: Students will explore their local type of government.

OBJECTIVES:

Students will be able to:

- Demonstrate an understanding of the structure and function of government.
- Explain the impact of state agencies and commissions on citizens' lives and property.
- Describe the role of state governments in providing services and regulating activity.

LESSON BACKGROUND: There are three major levels of government that we are going to explore to better understand who is creating the laws, policies, and ordinances that impact sea-level rise adaptation, mitigation, and resilience: local, state, and federal.

State governments work almost exactly like the U.S. federal government. There are three branches of state and federal government: an executive branch, a legislative branch, and a judicial branch. At the state level, the head of the executive branch is called the governor, for the federal government it is the President of the United States. Every state except one, Nebraska, also has a bicameral legislature, meaning that the legislature is made up of two chambers. In most states, those chambers are called the Senate and the House of Representatives. A state's judicial branch normally includes a high court, often called the Supreme Court, and a system of lower courts. These lower courts include trial courts and appeals courts. A state's three branches interact just like the three branches at the federal level. The purpose of having three branches is to balance power so that no one branch or person becomes too powerful. The state's legislature passes laws, a state's governor can veto laws that are passed and the executive branch enforces the laws, and a state's high court has the power to decide whether state laws violate the state's constitution and to interpret how those laws should be enforced.

VOCABULARY:

Adoption	The act of accepting and entering new ordinance into the Code of Laws as a result of a majority vote in favor of the proposed ordinance.
Amendment	A change to the existing language in the ordinance.
Coastal Hazard	Physical phenomena that expose a coastal area to risk of property damage, loss of life and environmental degradation.
Coastal Resilience Index	A questionnaire for communities to assess their level of preparedness for extreme events.
Federalism	The division of powers among the local, state, and national governments.
Infiltration	The process by which water on the ground surface enters the soil.
Motion	A new idea or action.
Ordinance	An authoritative rule or law; a public injunction or regulation.
Policy	Definite course or method of action; a high-level plan embracing the general goals and acceptable procedures of a governing body.
Resilience	The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.

ENGAGE:

Play the "Freddy the Fish Teaches About Stormwater" video for students: https://www.youtube.com/watch?v=jjPfLhJbdc0&feature=emb_logo (4.5 minutes).

Explain to students that as sea-level rises, the drains for stormwater might be blocked with rising seas. Ask students to brainstorm who might need to be involved in decision making to ensure stormwater systems can be adapted to sea-level rise.

EXPLORE:

Have students read the "Levels of Government" reading.

With the attention of the whole class, read a series of yes or no questions. Ask the class to answer "Yes" or "No," alternatively students could each have a set of index cards one with "Yes" and one with "No" that they would vote with. Use each question as an opportunity to quickly discuss and follow up with additional questions about the material.

1. Do state governments have anything in common with the federal government? (Yes — they both have three branches)
2. Do state lawmakers represent citizens from a certain area of the state? (Yes — those areas are called districts)
3. Can a state governor veto bills passed by the state legislature? (Yes)
4. Does each state have its own constitution? (Yes)
5. Is a state's legislature the only place or way laws can be adopted? (No — in many states, citizens can put laws on the ballot through the initiative process and municipalities can enact their own laws)
6. Can states always afford all the services they need to provide? (No — often they receive money from the federal government)
7. Do local governments provide any services? (Yes — schools, libraries, police, water, and many others)

Students will work on computers to research the type of government in their town or city and complete the questions below. Some of the cities along coastal Mississippi and Alabama are linked below.

Biloxi, Mississippi: https://www.biloxi.ms.us/pdf/GMAcitycontact.pdf
Bay Saint Louis, Mississippi: https://www.baystlouis-ms.gov/
Foley, Alabama: https://cityoffoley.org/#
Mobile, Alabama: https://www.cityofmobile.org/government/

Name of Town or City:
Type of local government:
Name of Mayor:
Members of the town/city council:
Time, day, and location of council meetings:

EXPLAIN:

The nation relies heavily on the economy of the Gulf coast.

Ports & Shipping – 2018 (Data from: 2018 National Economic Impact of the U.S. Coastal Port System by Martin Associates)

- $321.1 billion in federal, state, and local tax revenues
- $1.4 trillion in wages and local consumption
- 26% of Gross Domestic Product

Fishing – 2016 (Data from: *Fisheries Economics of the United States Volume 11* by NOAA)

- $212 billion in sales
- 1.7 million jobs
- $100 billion to the GDP

Culture (Data from: *State of the U.S. Ocean and Coastal Economies* by National Ocean Economics Program). Tourism & recreation accounts for:

- 28% of the coastal GDP
- 72% of coastal employment
- 41% of wages paid

Our coastal communities are valuable, but they are also vulnerable to sea-level rise. Ecosystems, communities, and economies all affect one another. So, we must give attention to all three areas to have safe and robust coastal communities, healthy natural resources, and a balanced system to ensure our communities, economies, and ecosystems can bounce back from current and future stresses. This is known as coastal community resilience.

Healthy Economy

- Working waterfronts
  - Seafood
  - Tourism
  - Ports
- Agriculture
  - Food security
- Small businesses

Healthy Environment

- Habitat protection and restoration
- Water resources
- Living resources
- Coastal planning

Healthy Society

- Education
- Public safety
  - Health
  - Physical
  - Mental
- Infrastructure
- Housing
  - Insurance

The Coastal Resilience Index (http://masgc.org/assets/uploads/publications/662/coastal_community_resilience_index.pdf) is a questionnaire for communities to assess their level of preparedness for extreme events. This helps communities discuss and discover their coastal hazard-related vulnerabilities. It is a self-assessment tool developed by the Mississippi-Alabama Sea Grant Consortium and NOAA's Coastal

Storms Program. To complete the index, community leaders get together and use the tool to guide discussion about their community's resilience to coastal hazards. The Index provides a simple, inexpensive method for community leaders to perform a self-assessment of their community's resilience to coastal hazards, identifying weaknesses a community may want to address prior to the next hazard event and guiding community discussion. The Index is not intended for comparison between communities.

The Index uses information that is readily available and asks mainly "yes" or "no" questions. It consists of an eight-page guiding document, and includes six sections (critical facilities and infrastructure, transportation issues, community plans and agreements, mitigation measures, business plans, and social systems). The Index can be completed in less than three hours.

At the community level, local governments work with stormwater management, flood insurance, beach closures, storm surge, saltwater intrusion, hypoxic zones, harmful algal blooms, and sea-level rise. The Index is a way to identify issues such as sea-level rise that can exacerbate weaknesses where communities are not as prepared as they might need to be.

ELABORATE:

Local governments are on the frontlines of responding to sea-level rise. A number of tools are available to local governments to reduce the vulnerability of local coastal communities to flooding and sea level rise.

Zoning overlays, development setbacks, and buffer zones can be used to shift development to protect vulnerable coastal areas, accommodate rising sea levels, reduce flood risks, and lower flood insurance rates for residents and local businesses. Enacting building codes, subdivision ordinances, construction standards, and building design standards that consider future flooding frequency, depths, and extents can reduce potential damages during current and future flooding events as sea level rises.

Examples of places approaching the issue of sea-level rise through policy include using strategies of regulatory documents:

- The Comprehensive Plan
- The Code of Ordinances, mostly Building and Land Development Codes
- Stormwater Technical Standards Manual, for Public and Private
- Local Building Code Amendments
- The Transportation Technical Manual
- The Local Mitigation Strategy
- The Post-Disaster Redevelopment Plan

- The Environmental Protection Commission
- Regional Water Management District policies and guidelines

Examples of this in action from locations across the United States:

Commit to planning and permitting toward future sea level and groundwater height scenarios (comprehensive plan)

- Guarantee life-expectancy of projects
- Reduce risk for future taxpayers

Consider secondary impacts of sea-level rise (comprehensive plan)

- Hurricane storm surge and drainage issues are or will be increased
- In addition to the impact to property and structures, there are environmental and social issues to address

Mapping and inventory of susceptible infrastructure (comprehensive plan)

- Publicly owned utilities, infrastructures, and buildings
- Coastal shoreline protection

Develop flexible coastline space (comprehensive plan)

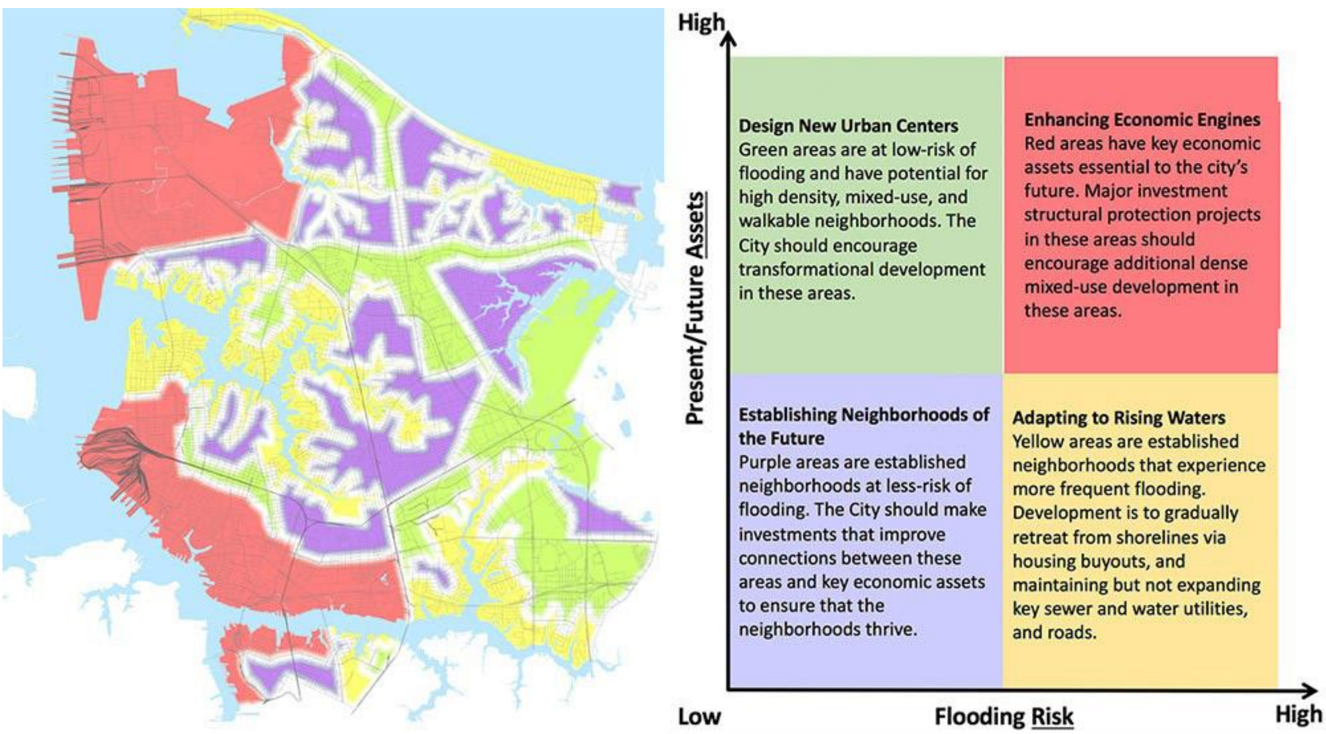
- Allows for habitat migration
- Reduces wave action and erosion
- Allows for adaptation depending on future scenarios
- Equity of coastal access
- Value to adjacent properties

Consider building height (bottom and top) (land development code, building code)

- FEMA Flood Insurance Rate Map and state building codes

Create overlay zones (land development code, comprehensive plan)

- FEMA Flood Insurance Rate Map zones
- Zones V, A, Coastal A (also a velocity zone), X
- A Protection Zone
- An Accommodation Zone
- A Managed Relocation Zone
- Can associate other stipulations, tax incentives, funding sources and disclosure policies with agreed upon planning and land development overlay zone
- Norfolk divided the city into 4 planning zones (corresponding image below)



Establish (erosion based) setbacks (land development code)

- Accommodate for future conditions
- Use historic erosion rates

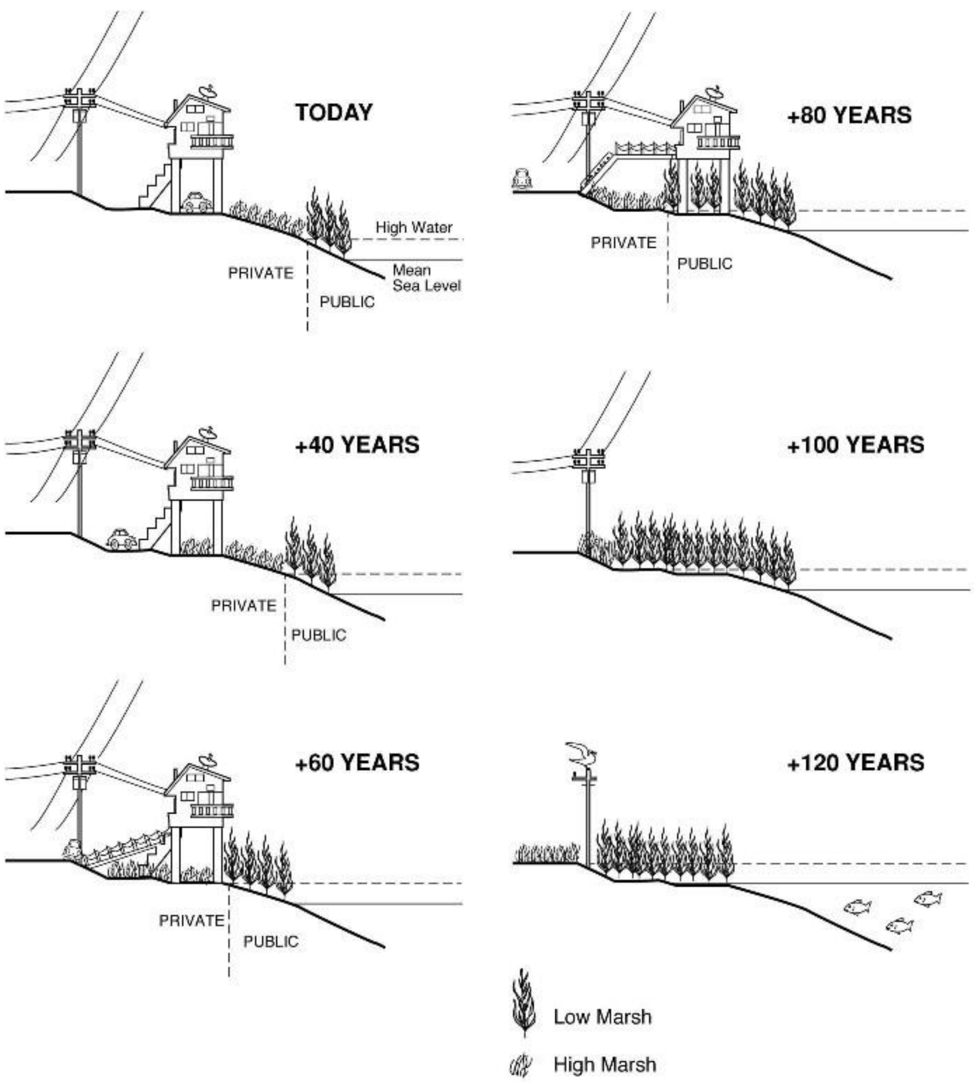
Establish sea wall standards (land development code, building code)

- Create build-to standards
- In Broward County, structures must be at least 5 feet above NAVD88 (local mean sea level). The height applies to all new or substantially repaired or rehabilitated seawalls, banks, and berms
- Sea walls must be in good repair or face fines

- Work towards the removal of sea walls to aid in habitat migration and ecosystem functionality

Options for managed relocation (land development code, comprehensive plan)

- Planning and engagement is important
- Working within property rights
- Incentivize development in non-vulnerable locations
- Rolling easements (corresponding image below)
    - Municipality purchases future land rights
    - Must allow coastline to migrate
    - Preserve for conservation or for future public access



Real estate disclosures (land development code, comprehensive plan)

- For properties that have been impacted by flooding
- If a property falls within an overlay zone, whether from FEMA or otherwise

Broward County, Policy 2.21.7 https://www.broward.org/climate/pages/usace.aspx

Owners must include:
"This real estate is located in a tidally influenced area. The owner may be required by county or municipal ordinance to meet minimum tidal flood barrier elevation standards during construction or substantial repair or substantial rehabilitation of seawalls, banks, berms, and similar infrastructure or when required to abate nuisance flooding."

Information adapted from the presentation "Opportunities for Regulatory Response" by Brian Cook, ASLA, PLA. Brian Cook's affiliations and contact information follows: Visiting Assistant Research Professor, Florida Center for Community Design + Research, School of Architecture + Community Design, University of South Florida email: brianraycook@usf.edu, 4202 E. Fowler Ave HMS 301, Tampa, FL 33620-8340

Students will think about the issue of storm water management and **write an initiative** that their local government could adopt to increase sea-level rise resilience.

EVALUATE:

Discuss with the class the difficulty in accessing the information and talk about what they already knew and if anything surprised them during their local government research.

STUDENT PAGE | Whose Law Is It Anyways?

Research your local government to complete the following questions.

Name of Town or City:

Type of local government:

Name of Mayor:

Members of the town/city council:

Time, day, and location of council meetings:

In low-lying localities, rising water tables, increased inundation, and increasingly high-intensity rainfall events are already impacting the function of traditional stormwater management systems and will reduce the effectiveness of some stormwater practices in the future. Many localities have traditional stormwater management systems like culverts, drainpipes, & detention basins that are already generating street flooding due to backflow of tidal waters into low-lying pipes and drainage ditches.

Green infrastructure practices like cisterns, rain gardens, bioswales, permeable pavement, green roofs, and bioswales meet water quality goals and reduce stormwater runoff, flooding, and combined sewer overflows. All system upgrades and retrofits should plan for sea-level rise adaptation by incorporating more storage and infiltration to minimize flooding. Infiltration is the return of surface water to groundwater.

Write an initiative that your local government could adopt to increase sea-level rise resilience through stormwater management.

Levels of Government

There are three major levels of government that we are going to explore to better understand who is creating the laws, policies, and ordinances that impact sea-level rise adaptation, mitigation, and resilience: local, state, and federal.

State governments work almost like the U.S. federal government. There are three branches of state and federal government: an executive branch, a legislative branch, and a judicial branch. At the state level, the head of the executive branch is called the governor, for the federal government it is the President of the United States. Every state except one also has a bicameral legislature, meaning that the legislature is made up of two chambers. In most states, those chambers are called the Senate and the House of Representatives. A state's judicial branch normally includes a high court, often called the Supreme Court, and a system of lower courts. These lower courts include trial courts and appeals courts. A state's three branches interact just like the three branches at the federal level. The purpose of having three branches is to balance power so that no one branch or person becomes too powerful. The state's legislature passes laws, a state's governor can veto laws that are passed, the executive branch enforces the laws, and a state's high court has the power to decide whether state laws violate the state's constitution and to interpret how those laws should be enforced.

Each state is divided into legislative districts that contain roughly the same number of citizens. Citizens in each district elect representatives to serve in the state legislature. That means the state legislators represent the citizens who live in their district.

The head of a state's executive branch is the state governor. The governor has the power to veto bills passed by the state's legislature. A state's executive branch also includes many departments. States usually have their own departments of education, transportation, health, and other services. These departments carry out the laws passed by the state's legislature.

Just like the U.S. has the Constitution, each state's constitution describes how the state's government must operate. In addition to the state constitution and the state legislative branch, there are usually other ways that state-wide laws can be made in a state. In many states, the initiative process allows citizens to draft laws they would like to see adopted. If citizens collect enough signatures, the law will be placed on the ballot for state citizens to vote on. The referendum process works the same way but is used to let citizens vote on a law already passed by the state legislature. No matter how a state law is adopted, the law only applies inside that state.

State governments provide many services to state citizens. These include things like police, fire safety, roads, schools, and parks. One of the biggest services is maintaining the state's infrastructure—the basic support structures that serve a geographic area, such as transportation, communication, and power systems. These services cost money and are paid for with taxes collected from citizens. When states cannot afford to provide all the services citizens need, they use federal grants, which are sums of money designated for a certain purpose such as improving an airport or providing health care to low-income households.

Local governments, such as cities and counties, get their power from the state government. The state decides what services cities and counties are responsible for providing and what kinds of laws cities and counties are allowed to make. A municipality is a city, town, or county with a state-granted charter to make decisions. Because local governments are the closest to citizens, often they are the ones that can most easily provide services. Municipal governments provide services such as schools, libraries, police, water, and trash collection, while also regulating zoning and city ordinances. Local governments must follow both state and federal laws when providing these services and not all municipal governments have all of these powers.

Large municipalities generally follow one of three types of government: council-manager, mayor-council, and commission. In council-manager, there is a city council that oversees general administration and policy procedure. The council appoints a professional city manager for daily administrative operations and a mayor is often chosen from the council. In mayor-council the mayor is elected separately from the city council and has significant administrative and budgetary authority. The mayor will have “weak” or “strong” authority depending on the balance of political power between the mayor and the council. In commission governments, voters elect individual commissioners to a governing board where they are responsible for a specific aspect such as public works, police, or health. Though these are the three most common forms of municipal government, government structure is not always distinct with combinations of roles and authority. For example, in coastal Mississippi there are Aldermen, who are elected members of a municipal council.

State and local governments work together on topics like enforcing building codes that specify exactly how buildings must be constructed. However, local governments are often at the forefront of resilience strategies because of their local authority. An ordinance is the term for a law passed by a local government. Ordinances address local issues from sign sizes to sea-level rise resilience. The process for passing an ordinance is determined by each state.

The process for passing an ordinance starts with an idea. This idea may come from the local council, mayor, a local citizen, or be in response to state or federal actions. The idea is then introduced by the city council as a proposed ordinance. The proposed ordinance is discussed by the city council and researched by specialized committees. There is generally at least one public hearing of the proposed ordinance to provide local citizens an opportunity to comment. Once public hearings and final discussions are complete, the city council votes on the proposed ordinance. In forms of local government with a “strong” mayor, the mayor would need to approve the ordinance. The ordinance would then go into effect based on specific locality processes and details of the ordinance.

STUDENT PAGE | Whose Law Is It Anyways?

DO NOW:

What group of people are creating the laws, policies, and ordinances that impact sea-level rise adaptation, mitigation, and resilience?

EXIT TICKET:

How can you be involved in local government?

3.2 Community Assets at Risk

AGE RANGE
9th—12th grade

TIME REQUIRED
60 minutes

ACTIVITY OVERVIEW
Engage: Discussion Question
Explore: SLR 2-Pagers
Explain: Range of SLR Scenarios Discussion
Elaborate: Community Asset Worksheet
Evaluate: Discussion Questions

MATERIALS
Community Asset Worksheet
SLR 2-Pagers

BASED ON:
Material from the NOAA Adaptation Planning For Coastal Communities workshop.

LESSON TOPIC: Municipal decision makers

ACTIVITY SUMMARY: Students evaluate community resources and the risks those resources may face.

OBJECTIVES:

Students will be able to:

- Analyze their community assets.
- Make informed decisions for community resilience.

LESSON BACKGROUND: Sea-level rise scenarios show the range of possible outcomes. There are three major reasons for the scenarios:

1) We do not know how much carbon will be in the atmosphere.
    a. The rate of carbon emissions across the globe changes with policies put in place by different governments. Example: the Paris Agreement.
2) There is natural variability.
    a. Nature is dynamic; for example, each year it is not the same temperature on August 1st. That natural "wiggle" or range must be integrated into the scenarios
3) Scientists are still studying the ice sheet melt.
    a. Models used to measure the volume of ice sheets and their rate of melting is relatively new and constantly getting more accurate.

By understanding the possible outcomes of sea-level rise, communities can prepare for the future. Planning and implementing an adaptation plan is scalable and can start with a smaller project and lead to more. The integration of climate change adaptation planning into related policies and projects brings it into the mainstream.

VOCABULARY:

Assets	People, resources, ecosystems, infrastructure, and the services they provide. Assets are the tangible and intangible things people or communities value.
Built Infrastructure	Human-made buildings and structures such as bridges, roads, stormwater systems, wastewater treatment plants, buildings.
Climate Stressor	A condition, event, or trend related to climate variability and change that can exacerbate hazards or the impact of hazards.
Community Rating System (CRS)	The National Flood Insurance Program's (NFIP) Community Rating System (CRS) is a voluntary incentive program that encourages community floodplain management activities that go above and beyond standards required by the NFIP. In return citizens of that community receive flood insurance discounts.
Critical Facilities and Services	Man-made structures/improvements which, because of their function, size, service area, or uniqueness, are paramount to day-to-day function (e.g., hospitals, power plants, wastewater treatment facilities, emergency response, etc.).
Drinking Water	Water that is safe to drink or to use for food preparation without risk of health problems. Also known as 'potable water'.
Energy Infrastructure	Large-scale facilities allowing for the transport of energy (e.g., electricity, oil, and natural gas) from producer to consumer and for management and direction of energy flow.
Green and Blue Infrastructure	Plant- and water-based natural systems as infrastructure for communities (i.e., protection against flooding or improving soil, air, and water quality) in order to benefit both nature and people.
Managed Retreat	The purposeful, coordinated movement of people and buildings away from risks. At the same time, natural coastal habitat is enhanced seaward of a new line of defense. Also refered to as strategic relocation or managed realignment.

Mitigation	Processes that can reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing them from the atmosphere.
Natural Resources	Materials or substances that occur in nature and can be used for economic gain.
Non-climate Stressor	A change, trend, event, or action unrelated to climate that can exacerbate hazards (e.g., marine debris impacts on coastal habitats).
Probability	The likelihood of something occurring, in this case hazard events. Probabilities have traditionally been determined from the historic frequency of events. With changing climate and the introduction of non-climate stressors, the probability of hazard events also changes.
Projections	Potential future climate conditions calculated by computer-based models of the Earth system. Projections are based on sets of assumptions about the future (scenarios) that may or may not be realized.
Resilience	The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.
Risk	The potential total cost if something of value is damaged or lost, considered together with the likelihood of that loss occurring. Risk is often evaluated as the probability of a hazard occurring multiplied by the consequence that would result if it did happen.
Transportation	System (e.g., bus, roadways, subways, etc.) for moving passengers or goods from one place to another.
Uncertainty	A state of incomplete knowledge. Uncertainty about future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the challenges with predicting decisions that society will make.
Utilities	Services (e.g., light, power, or water) provided by a public utility.
Vulnerability	The propensity or predisposition of assets to be adversely affected by hazards. Vulnerability encompasses exposure, sensitivity, potential impacts, and adaptive capacity.
Wastewater	Water that is adversely affected in quality by human influence (e.g., agricultural runoff, surface runoff, and most commonly sewage).

ENGAGE:

Open NOAA Sea Level Rise Viewer: https://coast.noaa.gov/slr/. Explore, with students, the area along the coast near your school. The slider bar with "MHHW" refers to Mean Higher High Water, meaning that it is referencing sea-level rise impact on high tide. Some locations have blue map pins with water drops, these open photos and show simulations of sea-level rise.

Ask students who makes the choices for policies and ordinances in their town. Ask students what information would be helpful for these decision makers to have when they make plans for sea-level rise. This should set them up to explore the sea-level rise scenario projections and the days of future flooding and should call back to Module 1. *It is not necessary to have completed Module 1 for this activity.*

EXPLORE:

For this activity students will work in groups using a Sea-Level Rise 2-Pager for a local region of their choice. 2-pagers will be available with curriculum material for our local region. Students will examine their 2-pagers to familiarize themselves with the contents.

Alternative: teachers can prepare additional 2-pagers ahead of time or reference www.localSLR.org for students to view projections of sea-level rise in other locations in the U.S.

EXPLAIN:

With the class lead a discussion about what the scenario graph is showing.

Introduce the global scenario graph with multi-colored lines for future sea-level rise projections.

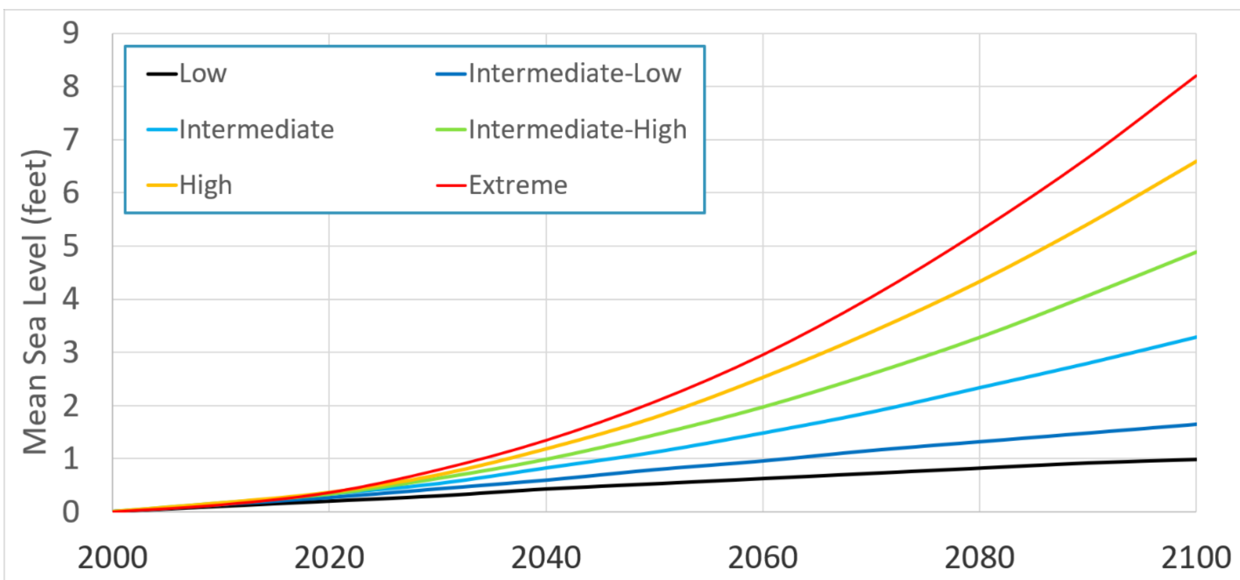


Image: global scenarios for sea-level rise. Source: Collini et al. 2018

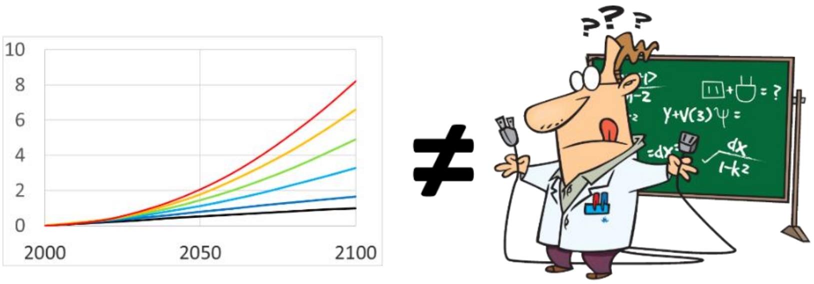


Image: Having a large range of sea-level rise scenarios does not mean that scientists do not know what they are doing. It shows the range of possible outcomes. Source: Northern Gulf of Mexico Sentinel Site Cooperative

There are three major reasons for the scenarios:

1) We do not know how much carbon will be in the atmosphere.
    a. The rate of carbon emissions across the globe changes with policies put in place by different governments. Example: the Paris Agreement.
2) There is natural variability.
    a. Nature is dynamic; for example each year it is not the same temperature on August 1st. That natural "wiggle" or range has to be integrated into the scenarios
3) Scientists are still studying the ice sheet melt.
    a. Models used to measure the volume of ice sheets and their rate of melting is relatively new and getting more accurate constantly.

With those three reasons in mind, the graph shows the range of scientifically possible scenarios for future sea-level rise. Low scenarios follow a low-end range of natural variability and the extreme scenario follows catastrophic ice melt.

To plan for sea-level rise it is helpful to narrow down the scenarios by understanding probabilities. Looking at the scenario likelihood chart, the greater the percentage the more likely that scenario will occur based on change in carbon emissions. As you can see in the chart, the likelihood of an extreme sea-level rise scenario occurring is very low – 0.1%-0.05%.

Global Sea Level Rise Scenario	RCP8.5 no change in carbon emissions
Low	100%
Intermediate-low	96%
Intermediate	17%
Intermediate-high	1.3%
High	0.3%
Extreme	0.1%

Image: likelihood of sea-level rise scenarios. Source: modified from Collini et al, 2018

Once you understand the probability of a scenario occurring you can identify your risk tolerance. Risk tolerance is the degree of uncertainty that you are willing to accept in respect of negative impacts to your community, structures, and people. This level will change based on considerations such as the location, cost or value, function served, adaptability, and length of time.

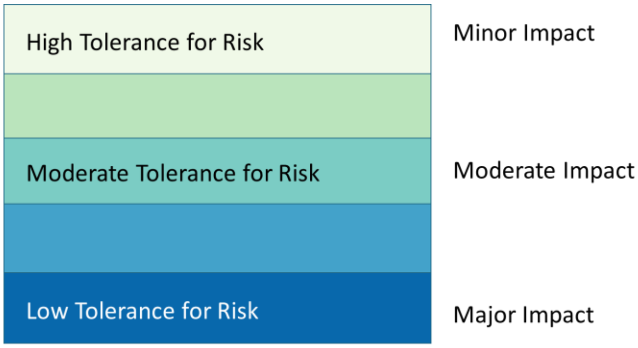


Image: Flood risk tolerance compared to impact level. Source: Northern Gulf of Mexico Sentinel Site Cooperative

Thinking in terms of building a new structure in your community:

If you are building a new hospital, this will require a large expense, its function is critical for providing care in your community. The hospital cannot be easily moved or adapted once it is built, and you want the hospital to be present for a long time. Building a hospital has a low tolerance for risk, meaning that you have a lot put into the building, do not have the flexibility to let anything negative happen, and cannot easily move it out of harm's way. Because of these considerations, a hospital would have a low tolerance for risk. To minimize the likelihood that your hospital would be impacted by sea-level rise over the course of its life, you would want to plan to the higher sea-level rise scenarios. This does not mean that the hospital will never experience flooding, but greatly reduces the likelihood that it will flood under any of the possible sea-level rise scenarios.

Sea level rise scenario	Likelihood
Low	100%
Intermediate-low	96%
Intermediate	17%
Intermediate-high	1.3%
High	0.3%
Extreme	0.1%

Low chance of happening, but would have a big impact

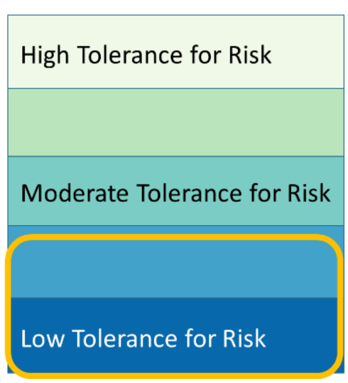


Image: Structures and areas with a low tolerance for risk should plan for high or extreme sea-level rise scenarios. Source: Northern Gulf of Mexico Sentinel Site Cooperative

If you are buying a new home there is a moderate expense required compared to something like a new power plant or hospital, it is critical for one family, other facilities are not dependent on the home, and you would want the home to be present for a mid-term length of time. Buying a home has a moderate tolerance for risk. You would not want a negative impact on the structure, but it does not support a wide community and the cost is not millions of dollars. In this case, this would be considered a moderate tolerance for risk. A person would want to plan for sea-level rise scenarios that are still less likely to occur but would not be as costly to adapt to as the higher sea-level rise scenarios.

Sea level rise scenario	Likelihood
Low	100%
Intermediate-low	96%
Intermediate	17%
Intermediate-high	1.3%
High	0.3%
Extreme	0.1%

Moderate chance of happening, would have a moderate impact

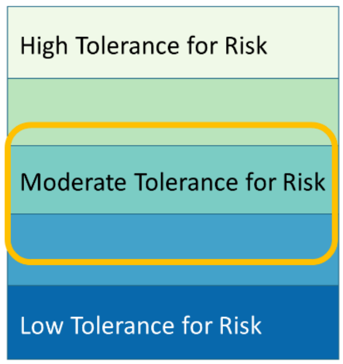


Image: Structures or areas with a moderate tolerance for risk should plan for the intermediate or intermediate-high sea-level rise scenarios. Source: Northern Gulf of Mexico Sentinel Site Cooperative

If you are building a shed there is a minor expense, the structure does not provide a critical function, it is relatively easy to move, and it is only needed for the short-term. The shed has a high tolerance for risk, meaning that not a lot of functionality or cost would be lost if something negative occurred. In a case like this your risk tolerance is high and you would only want to plan for the amount of sea-level rise that you are certain is going to occur. The low and intermediate-low scenarios are very likely to happen.

Sea level rise scenario	Likelihood
Low	100%
Intermediate-low	96%
Intermediate	17%
Intermediate-high	1.3%
High	0.3%
Extreme	0.1%

High chance of happening, would have a low impact

Image: Structures or areas with a high tolerance for risk should plan for the low or intermediate-low sea-level rise scenarios. Source: Northern Gulf of Mexico Sentinel Site Cooperative

The next step to narrowing down sea-level rise scenarios is to link the flood risk tolerance with probabilities.

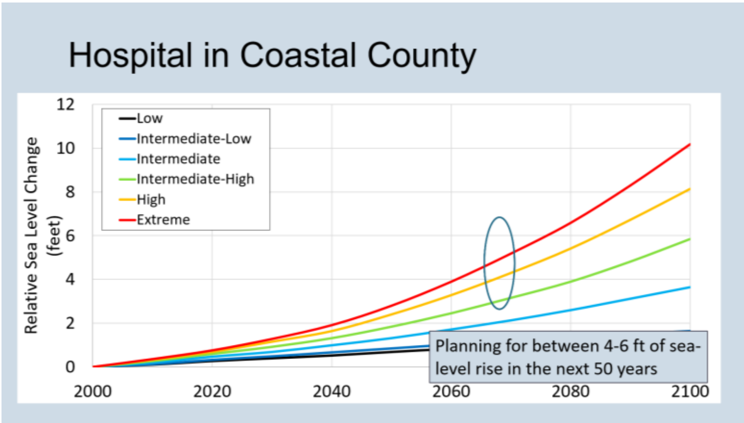


Image: Using the sea-level rise and likelihood scenarios to focus on how much sea-level rise to plan for. In this example a coastal county will build a hospital to last longer than 50 years. This structure has a low tolerance of risk, so they plan for the high or extreme scenarios. Following the x-axis to approximately 2070 (50 years in the future), then looking at the y-axis for feet of sea-level rise change on the high (yellow) and extreme (red) trend lines shows that the hospital should plan for 4-6 feet of sea-level rise. Source: Northern Gulf of Mexico Sentinel Site Cooperative.

ELABORATE:

Students will work in small groups and use the information from the sea-level rise projection graphs to work as community decision makers to plan for sea-level rise resilience. This chart is the same tool that is used by resilience professionals through the Adaptation Planning Framework. Working through this activity, models to students how professionals work through adaptation planning in our communities. In this activity students are thinking of assets as separate components. Eventually the individual assets need to be thought of in a holistic view because they fit together to create a whole community. Set up the "why" of the activity: communities have limited resources, personnel, and funding - unfortunately it is not realistic for communities to immediately upgrade all vulnerabilities. Thinking critically about all the stresses on valuable infrastructure allows resilience professionals to strategically plan the most needed resilience adaptations first.

EXTENSION:

The first chart "**Identifying Community Assets**" can be completed as a class through group discussion. Additionally, the lesson can be extended by having students complete a "Climate Issue Statement" using their responses from their assessment chart.

Climate stressors are conditions or trends that are related to climate variability and can exacerbate hazards.

- Increasing frequency and intensity of drought conditions can be a climate stressor for forests and crops. Rising sea level is another climate stressor.

Non-Climate stressors are changes or trends that are unrelated to climate but that can exacerbate hazards.

- Altering drainage patterns and replacing open land with roads and buildings are non-climate stressors for flooding hazards. Population growth along exposed coasts is another non-climate stressor.

EVALUATE:

Students complete reflection questions about the asset related to the sea-level rise projections from the first part of this activity.

How will future flooding impact your community asset?

How will the sea-level rise projections impact your asset? Is there a difference in impact between low and intermediate projections?

EXTENSION: Students present Climate Issue Statements.

STUDENT PAGE | Assets at Risk

As decision makers it is important to understand the assets that strengthen and support your community. In the following chart **list two assets in each sector and for each category**. Be as specific as possible for your community. Rather than "bridge" use "Pascagoula River High Rise Bridge." Keep in mind that your assets might fit in more than one category.

Identifying Community Assets		
	High Value	High Consequence if Impacted
Built Infrastructure Bridges, roads, stormwater systems, wastewater treatment plants, buildings, etc. 		
Natural Resources Beaches, rivers, wetlands, parks, etc. 		
People, Commerce, and Culture Citizens, health services, historical landmarks, economy, recreation and tourism, etc. 		

Decision makers need to narrow down their focus. **Choose <u>one</u> asset**. Use the following chart to describe characteristics of the assets.

Characterizing an Asset		
Asset:		
Circle the sector your selected asset belongs in		
Built Infrastructure 	**Natural Resources** 	**People, Commerce, and Culture** 
Circle the area that best applies to your selected asset		
Site (small)	**Region (medium)**	**Extensive (large)**
Characterize Stressors		
Non-climate Stressors	**Climate Stressors**	**Top climate Stressor Trend**
List all:	*List all:* *What is the top climate stressor?*	*Is the top climate stressor already occurring?* **Yes** or **No** *Circle the expected trend of the top climate stressor?* **Increase** **Decrease** **Stay the same**

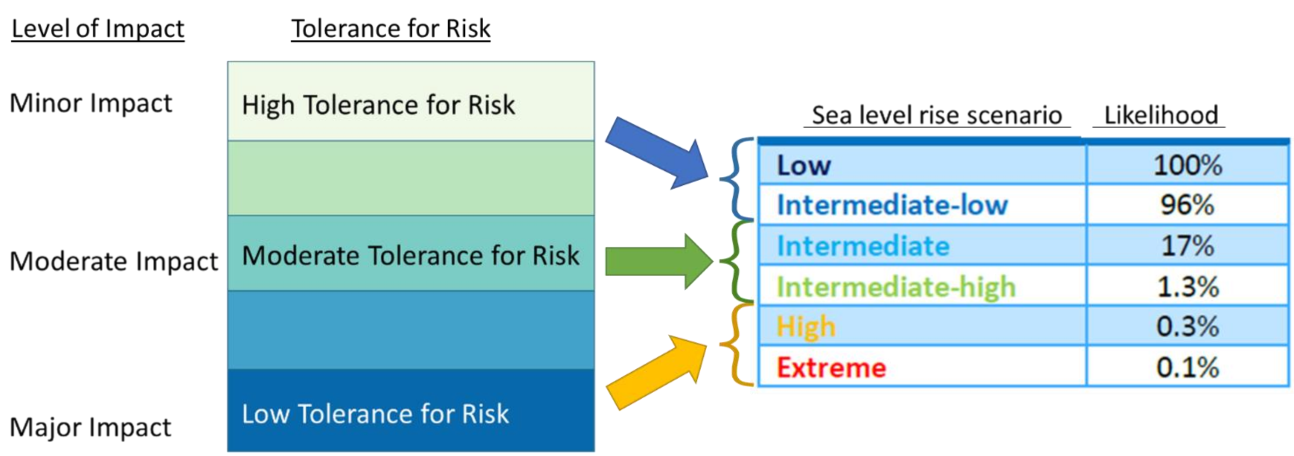
Now that you have the list of stressors to your asset, think about what consequences there may be if your asset was damaged or lost. If you think of consequences not listed write them in under “Other.” **Circle all potential consequences if your community asset is damaged or lost.**

Potential Consequences		
Circle all potential consequences if your community asset is damaged or lost.		
Economic	**People & Society**	**Environmental**
Movement of goods impaired	Damage to housing and displacement of people	Biodiversity or species loss
Movement of people impaired	Loss of recreation opportunities	Habitat fragmentation and/or loss
Employment centers disrupted	Residents unable to obtain key services	Loss of flood protection benefits
Disproportionate impacts on certain business sectors	Disproportionate impacts on certain community members	Water quality decline
Lost revenue	Loss of cultural or historical resources	Loss of carbon absorption function.
Increased maintenance or repair costs	Personal injury or loss of life	*Other:*
Other:	Overall decline in quality of life	
	Other:	

If your asset is damaged the consequences will fall in a range of minor to severe impact. Think about your asset and how much relies on it functioning. **Circle the overall potential level of impact.**

Severity of Consequences Using the descriptions below, identify the overall potential level of impact	
Rating	**Description**
Minor	Financial costs to the community are possible but would be minimal. No expected loss of life, minimal decline in quality of life, and little disruption to livelihoods. Property and ecosystem damage might occur, but could be repaired without substantial cost or time.
Moderate	Some financial costs to the community are possible and would be moderate. No expected loss of life, but there could be a decline in the quality of life and some disruption to livelihoods. Recovery of property and ecosystem damage would take longer and be more costly.
Major	Large financial costs or significant inconveniences would be incurred the community. The possibility of loss of life or livelihood exists. Significant, and potentially permanent, property or ecosystem damage might occur.

Using your selected "Severity of Consequences" **circle the level of impact, the tolerance for risk, and the sea-level rise scenario and likelihood you should plan for.**



EXTENSION:

As a decision maker at the community level, you need to convince the other members of your community and other leaders why it is important to protect an asset from the climate change risks you have identified. Using the information you collected throughout the lesson, add them into the template below. This will be your Climate Issue Statement.

Climate Issue Statement		
Tell the story of why this is important to address. Use the information from the lesson.		
	Insert value statement for asset – why should people care	
	is already experiencing	
Asset		*Non-climate stressor(s)*
and is susceptible to		.
	Top climate stressor	
Consequences would likely be		and could include
	Severity of consequences	
	,	and
Economic	*people and society*	
	. Therefore, we should consider strategies and actions that	
environmental		
Summarize risk tolerance approach.		

STUDENT PAGE | Assets at Risk

DO NOW:

How does your local government address sea-level rise and flood resilience?

EXIT TICKET:

What are the three main reasons for sea-level rise scenarios?

3.3 Flooding Pains and Dream House Gains

AGE RANGE

9th—12th grade

TIME REQUIRED

70 minutes

ACTIVITY OVERVIEW

Engage: FEMA Floodplain Map
Explore: GOMSurge.org
Explain: Student Reading
Elaborate: Student Beach House
Evaluate: Beach House Ordinances

MATERIALS

Computers
FEMA Floodplain Map
Student Worksheet
Student Reading

LESSON TOPIC: Floodplains and ordinances

ACTIVITY SUMMARY: Students explore flooding hazards and municipal flood ordinances.

OBJECTIVES:

Students will be able to:

- Explore digital tools for viewing flood and storm surge risk.
- Identify areas along the coast that are vulnerable to sea-level rise and storm surge.
- Identify flood ordinances for buildings.

LESSON BACKGROUND: The FEMA Flood Map Service Center: https://msc.fema.gov/portal/home is the public source for flood hazard information produced to support the National Flood Insurance Program (NFIP).

FEMA identifies flood hazards on floodplain maps for community members to understand their specific risk. Special Flood Hazard Areas (SFHA) are the areas that have a 1% annual chance of a flood exceeding that depth and extent. SFHA are labeled as: Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30. In the SFHA, a base flood elevation is identified to set standards of recommending building practices. The areas between the 1% annual exceedance probability flood and the 0.2% annual exceedance probability flood are moderate flood hazard areas and labeled as Zone B or Zone X (shaded). The areas outside of the special flood hazard area are at minimal flood risk and are labeled as Zone C or Zone X (unshaded).

Scientists and our governments are able to use the information available to develop models that help us prepare for the impacts of sea-level rise and flooding.

FEMA uses a model called SLOSH which stands for Sea, Lake and Overland Surges from Hurricanes (SLOSH). This model is a computerized numerical model developed by the National

Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field that drives the storm surge.

Other researchers use ADCIRC (Advanced Circulation Model) and couple it with SWAN (Simulating WAves Nearshore). ADCIRC simulates circulation and storm surge generation whereas SWAN simulates waves. When these two models are coupled, you are able to capture the complex interactions between waves and currents and the effects of both on storm surge.

SLOSH and ADCIRC+SWAN are two common models used to generate the 1% annual chance exceedance probability, sometimes known as the 100-year floodplain or the SFHA.

To make projections of sea-level rise impacts on our coastal communities, scientists use models to add in the interactions of different processes. For example, understanding how wind and waves erode sand from a coastline and change the shape allows the projection of how sea-level rise impacts might be altered with a different coastline shape. A model commonly used for this is XBeach, which simulates morphological change, including erosion and deposition, and has its own circulation and wave module. This is one of the most advanced models in terms of simulating storm impacts, and it is a high-resolution model. It can resolve processes on very small scales and it can simulate flow and sediment transport around infrastructure.

VOCABULARY:

Buildings and Structures	Structures built for permanent use (e.g., a dwelling) or that is built by putting parts together and that usually stands on its own (e.g., a house, tower, bridge, etc.).
Built Environment	Basic structures and facilities (e.g., buildings, roads, and power supplies) needed for a community.
Ordinances/Codes	Laws and regulations passed and enforced by a municipality in order to maintain safety and preserve community standards.
Planning and Land Use	Process of designing potential futures for a community, city, etc. Land use is a type of planning that is implemented through zoning, which can change management of land and lead to impactful changes.

ENGAGE:

Show students the two images of the same location on Dauphin Island, Alabama fifteen years apart. **Ask** students what might be impacting the changing shoreline. **Ask** students if they think there are any guidelines for people building their homes. What might those guidelines be? **Ask** students at which point do communities need to discuss if there is no more land for their homes. This can start a discussion about the need for managed retreat in some areas.

Image: West end of Dauphin Island, Alabama, in 2000. Yellow outline is the outline of the main land mass in 2000. The yellow arrows are pointing to houses that can be used as benchmarks for the next figure. Imagery from Google Earth. Source: Embracing the dynamics of shorelines. Eric Sparks. Mississippi-Alabama Sea Grant Consortium. Apr 04, 2018.

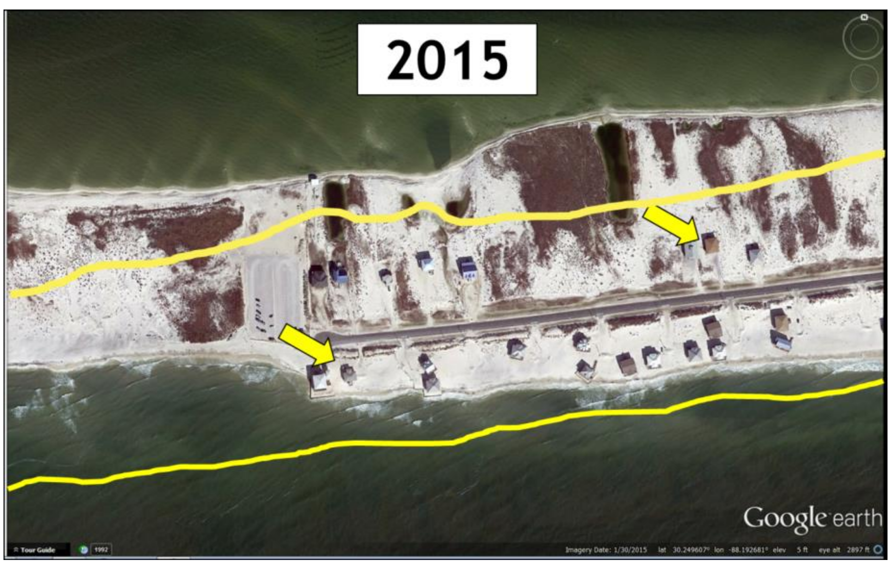


Image: West end of Dauphin Island, Alabama, in 2015. Yellow outline is the outline of the main land mass in 2000. The yellow arrows are pointing to houses that can be used as benchmarks from the previous figure. Imagery from Google Earth. Source: Embracing the dynamics of shorelines. Eric Sparks. Mississippi-Alabama Sea Grant Consortium. Apr 04, 2018.

Show the video Amplified Storm Surge: Northern Gulf Sea-Level Rise (4.5 minutes): https://vimeo.com/323815181. This video introduces storm surge in the Northern Gulf of Mexico and introduces the tool GOMsurge.org that will be used later in the lesson.

Display the FEMA floodplain (https://msc.fema.gov/portal/home) map that includes the school location. Identify the zone in which the school is located.

Ask the students why is it important to understand floodplains? How could you use this map to make decisions?

EXPLORE:

Floodplain management works to mitigate coastal hazards and respond to disasters. Students will explore the features on the www.gomsurge.org website, and work through problem sets for potential future scenarios.

Students answer questions using Claim-Evidence-Reasoning. The claim is the statement that answers the question. The evidence is the data used to support the claim. The reasoning is the explanation of "why" and "how" the evidence supports the claim.

Procedure:

1) Students go to www.gomsurge.org and scroll down to the "Stillwater Storm Surge" section.
    a. These images indicate 1% annual chance probability of storm surge inundation, showing the area where water pushed in by a hurricane will go. The data was developed by examining models of astronomic tide, wind and wave, and hurricane storm surge. These 1% annual chance data (commonly referred to as 100-year floodplains) were developed to assess the effects of future coastal change on storm surge under different sea-level rise scenarios.
2) The slider bar in the middle of the page can be moved to display two different sea-level rise projections, the Low and the Intermediate-High projections, for 1% annual chance probability of storm surge inundation in 2100. The right side of the screen displays the Intermediate-High projection of 1.2 meters, or 3.9 feet, increase of sea-level rise from 2000. The left side of the screen displays the Low projection of 0.2 meters, or 0.7 feet. Deeper water is indicated by brighter purple color.

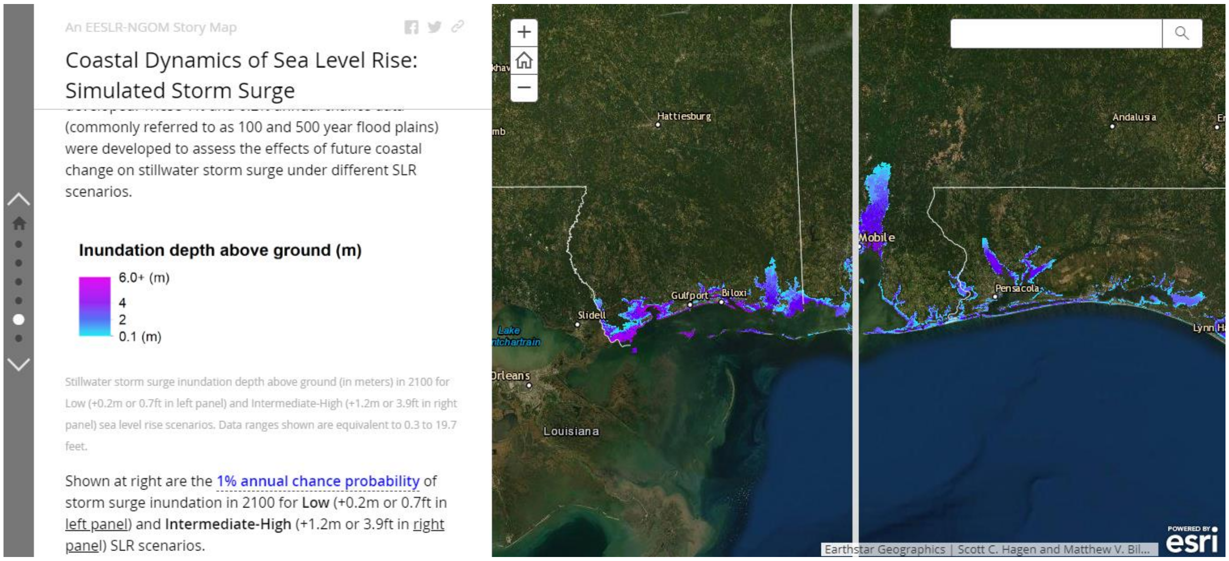


Image: a screen capture of the Stillwater Storm Surge section of gomsurge.org with the inundation depth color gradient visible. The color range is indicative of water depth in meter, lighter blue at the low end of 0.1m and brighter purple indicating water 6m and deeper. Source: www.gomsurge.org

3) Enter the following location into the search bar: 1815 Popps Ferry Road, Biloxi, MS. Zoom out until the colored inundation is visible. Answer the following questions about the area:
   a. Does water reach the specific building? (marked by a blue square on the left panel).
   b. What changes in water do you observe in the area? Does the water reach new areas? Do existing areas have deeper water?
4) Searching on the map find a location with a river leading to the Gulf of Mexico. Answer the following questions:
   a. What changes in water do you observe in the river inland and the river where it meets the Gulf of Mexico?
5) Search the map for a location with a large city close to the coast. Answer the following questions:
   a. What changes in water do you observe in the city compared to areas outside of the city?
6) Compare the differences in water inundation area and depth change from the river location to the city location. Why might you observe these differences?

EXPLAIN:

Marshes and bayous with plants are able to absorb more water than concrete. Explain that rivers can carry storm surge water farther inland, but that natural marsh and plant shorelines can help protect homes. Additionally, discuss how the floodplain is becoming larger as sea-level rises, putting more homes, businesses, and infrastructure at risk. *Connect back to Module 2 Lesson 1 about marshes if it was covered.*

Students read "100-Year Flood" reading.

ELABORATE:

Provide students with this prompt and building choices on the student worksheet.

Build your (dream) home! You are now the proud owner of property along the Gulf coast and now you get to design the home you hope to live in for many years. Your home is in the perfect location for outdoor recreation, and being close to the beach and bayous. Make a choice between the options given for each step. Once you have selected all the option make a sketch of your home.

> **EXTENSION**: Students explore houses with different structures before taking the house quiz. Using foam board, or another water-resistant material, students cut out general models of houses: a non-elevated house, a house on stilts, an elevated house with 2 solid walls, an elevated house with 2 lattice walls, an elevated house with 4 solid walls. Recreating an activity from Module 2 Lesson 2 with the water pans, students create a shoreline with clay on one side of a plastic container and place their home one top. They then create waves in the container and compare how each house is impacted.

EVALUATE:

Communities share information with residents about how to prepare for and protect their buildings from floods. The "Flood Damage Prevention Ordinance" for Coastal Communities is an ordinance that promotes public health, safety, and general welfare to minimize losses due to floods. The provisions designated to protect public and private buildings from flood conditions are:

(1) anything vulnerable to flooding needs be protected against flood damage at the start of construction;
(2) uses that are dangerous to health, safety, and property, or uses that lead to increased flood height, water velocity, or erosion will be restricted or prohibited;

(3) any filling, grading, dredging and other development which may increase flood damage or erosion are controlled;
(4) flood barriers that are constructed and unnaturally divert flood water or increase flood hazards in other areas are prevented or regulated;
(5) control the alteration of natural floodplains, stream channels, and natural protective barriers which are involved in the accommodation of flood waters.

Using the "Flood Damage Prevention Ordinance" for Coastal Communities the class will score their homes to how well they aligned with ordinances in place to protect against flooding damages.

Question 1 – How to elevate

Article 4 Provisions for Flood Hazard Reduction, Section A General Standards

(4) Elevated Buildings - All New construction or substantial improvements of existing structures that include ANY fully enclosed area located below the lowest floor formed by foundation and other exterior walls shall be designed so as to be an unfinished or flood resistant enclosure. The enclosure shall be designed to equalize hydrostatic flood forces on exterior walls by allowing for the automatic entry and exit of flood waters.

(a) Designs for complying with this requirement must either be certified by a professional engineer or architect or meet the following minimum criteria:

(i) Provide a minimum of two openings having a total net area of not less than one square inch for every square foot of enclosed area subject to flooding;

What this means: All structures below base flood elevation must have at least two openings near the ground to allow water to flow through and relieve pressure from floodwater on the walls of the structure. This not only helps protect the building from being damaged but allows floodwaters to drain more quickly. It also means that structures at this level are expected to flood regularly and it should not be used as a living area or furnished as such.

Article 4 Provisions for Flood Hazard Reduction, Section F Coastal High Hazard Areas (V-Zones).

(2) All new construction and substantial improvements of existing structures shall be elevated on piles, columns, or shear walls parallel to the flow of water so that the bottom of the lowest supporting horizontal structural member (excluding pilings or columns) is located no lower than one foot above the base flood elevation level.

What this means: Walls and supports of structures must be built parallel to the flow of floodwaters so water can pass by and through them with ease. It also means that the structures must be built at least one foot above base flood elevation.

Score your home for Question 1: 2 points for raised on piles/stilts, 2 points for raised with 2 solid walls allowing ocean breeze underneath, 1 point for raised with 2 solid walls blocking ocean wind from question 1. No points for other options.

Question 2

Article 4 Provisions for Flood Hazard Reduction, Section B Specific Standards. In ALL Areas of Special Flood Hazard designated as A1-30, AE, AH, A (with estimated BFE), the following provisions are required:

> *(1) New construction and substantial improvements - Where base flood elevation data are available, new construction or substantial improvement of any structure or manufactured home shall have the lowest floor, including basement, elevated no lower than one foot above the base flood elevation. Should solid foundation perimeter walls be used to elevate a structure, openings sufficient to facilitate the unimpeded movements of flood waters shall be provided in accordance with standards of Article 4, Section A(4), "Elevated Buildings."*

What this means: The lowest floor of any structure must be one foot above the projected height of base flood evaluation, generally the 1% annual exceedance probability. This lowers the likelihood that damage or injury will occur in the event of a flood.

Score your home for Question 2: 1 point for raised to a foot higher than the 1% annual exceedance probability from question 2. No points for other options.

Question 3

Article 4 Provisions for Flood Hazard Reduction, Section C Floodways.

> *(1) Floodway: Located within Areas of Special Flood Hazard established in Article 2, Section B, are areas designated as floodway. A floodway may be an extremely hazardous area due to velocity floodwaters, debris or erosion potential. In addition, the area must remain free of encroachment in order to allow for the discharge of the base flood without increased flood heights. Therefore, the following provisions shall apply:*
>
> > *(a) The community shall select and adopt a regulatory floodway based on the principle that the area chosen for the regulatory floodway must be designed to carry the waters of the base flood, without increasing the water surface elevation of that flood more than one foot at any point;*

What this means: In communities of high risk of flood, a floodway must be designed in the area to allow floodwater to flow through and exit the community. This will reduce flooding in homes and allow water to drain from the neighborhood more efficiently.

Score your home for Question 3: 1 point for leaving the drainage ditches from question 3. No points for other options.

Question 4

Article 4 Provisions for Flood Hazard Reduction, Section D Building Standards for Streams Without Established Base Flood Elevations (Approximate A-Zones). Located within the Areas of Special Flood Hazard established in Article 2, Section B, where streams exist but no base flood data have been provided (Approximate A-Zones), the following provisions apply:

> *(2) No encroachments, including structures or fill material, shall be located within an area equal to the width of the stream or twenty-five feet, whichever is greater, measured from the top of the stream bank, unless certification by a registered professional engineer is provided demonstrating that such encroachment shall not result in any increase in flood levels during the occurrence of the base flood discharge.*

What this means: Structures must not be built too close to streams because if the water level in the stream were to rise up to the structure, the building could block some of the water flowing down the stream. Additionally, damage to the structure could occur.

Score your home for Question 4: 1 point if you built 25 feet away from the stream in question 4. No points for other options.

Question 5

Article 4 Provisions for Flood Hazard Reduction, Section F Coastal High Hazard Areas (V-Zones). Located within the areas of special flood hazard established in Article 2, Section B, are areas designated as Coastal High Hazard areas (V-Zones). These areas have special flood hazards associated with wave action and storm surge; therefore, the following provisions shall apply:

> *(1) All new construction and substantial improvements of existing structures shall be located landward of the reach of the mean high tide.*

What this means: No structures can be built within the area that is covered by the average high tide. They must be further inland. During storm surge, water levels can rise even higher than high tide, so this keeps buildings at a safer distance and height from storm surge.

Score your home for Question 5: 1 point if you built inland from the highest water level, and 2 points if you built behind the dunes in question 5. No points for option a.

Question 6

Article 4 Provisions for Flood Hazard Reduction, Section F Coastal High Hazard Areas (V-Zones).

> *(4) All pile and column foundations and the structures attached thereto shall be anchored to resist flotation, collapse, and lateral movement due to the combined effects of wind and water loads acting simultaneously on ALL building components, both (non-structural and structural). Water loading values shall equal or exceed those of the base flood. Wind loading values shall be in accordance with the most current edition of the Standard Building Code*

What this means: Structures must be anchored so they do not float away or blow away during times of flood or high winds. This helps prevent people from completely losing their home.

Score your home for Question 6: 1 point if you built a house with strong foundation to resist flooding from question 6. No points for other options.

Question 7

Article 4 Provisions for Flood Hazard Reduction, Section F Coastal High Hazard Areas (V-Zones).

> *(6) All space below the lowest horizontal-supporting member must remain free of obstruction. Open lattice work or decorative screening may be permitted for aesthetic purposes only and must be designed to wash away in the event of abnormal wave action without causing structural damage to the supporting foundation or elevated portion of the structure. The following design specifications are allowed:*
>
> > *(a) No solid walls shall be allowed, and;*
> >
> > *(b) Material shall consist of lattice or mesh screening only.*
> >
> > *(c) If aesthetic lattice work or screening is utilized, any enclosed space shall not be used for human habitation, but shall be designed to be used only for parking of vehicles, building access, or limited storage of maintenance equipment used in connection with the premises.*

What this means: The open space below an elevated building can be used for parking or storage but not for living space. Any decorative screening needs to wash away in flood water to prevent damage to the building.

Score your home for Question 7: 2 points if you elevate and use it for parking, 2 points if you decorated the piles with latticework from in question 7. No points for other options.

Question 8

Article 4 Provisions for Flood Hazard Reduction, Section F Coastal High Hazard Areas (V-Zones).

> *(10) There shall be no alteration of sand dunes or mangrove stands which would increase potential flood damage*

What this means: Natural barriers to floodwater such as sand dunes or mangroves shall not be removed in order to build a structure if it would risk increasing damage caused by flooding. These natural structures provide a buffer for communities, protecting them from water and wind.

Score your home for Question 8: 1 point if left the dunes as they were in question 8. No points for other options.

Total your score:

If your score was between 0-3. You are a student of community ordinances.

If your score was between 4-7. Not bad – you are a potential municipal government official.

If your score was between 8-10. Excellent – you are an expert floodplain manager.

Discuss with the students what their ranking was on their dream house. **Ask** how might they have made changes if they knew the ordinances from the beginning?

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Floodplain management works to mitigate coastal hazards and respond to disasters. Students will explore the features on the www.gomsurge.org website, and work through problem sets for potential future scenarios.

Procedure:

1) Go to www.gomsurge.org and scroll down to the "Stillwater Storm Surge" section.
    a. These images indicate 1% annual chance probability of storm surge inundation, showing the area where water pushed in by a hurricane will go.
2) The slider bar in the middle of the page can be moved to display two different sea-level rise projections, the Low and the Intermediate-High projections, for 1% annual chance probability of storm surge inundation in 2100. The right side of the screen displays the Intermediate-High projection of 1.2 meters, or 3.9 feet, increase of sea-level rise from 2000. The left side of the screen displays the Low projection of 0.2 meters, or 0.7 feet. Deeper water is indicated by brighter purple color.
3) Enter the following location into the search bar: 1815 Popps Ferry Road, Biloxi, MS. Zoom out until the colored inundation is visible. Answer the following questions about the area:
    a. **Does water reach the specific building**? (marked by a blue square on the left panel).

    b. What changes in water do you observe in the area? Does the water reach new areas? Do existing areas have deeper water?

4) Searching on the map **find a location with a river leading to the Gulf of Mexico**. Answer the following questions:
    a. What changes in water do you observe in the river inland and the river where it meets the Gulf of Mexico?

    Claim (write a sentence that states what happens along the river)

    Evidence (provide data that supports your claim about what happens along the river)

    Reasoning (write a statement that connects your evidence to your claim about what happens along the river)

5) Search the map for **a location with a large city close to the coast**. Answer the following questions:
   a. **What changes in water do you observe in the city compare to areas outside of the city?**
      Claim (write a sentence that states what happens to water in the city)

      Evidence (provide data that supports your claim about what happens to water in the city)

      Reasoning (write a statement that connects your evidence to your claim about what happens to water in the city)

6) Compare the differences in water inundation area and depth change from the river location to the city location. **Why might you observe these differences?**

   Claim (write a sentence that states what happens to water inundation area and depth in the city compared to the river)

   Evidence (provide data that supports your claim about what happens to water inundation area and depth in the city compared to the river)

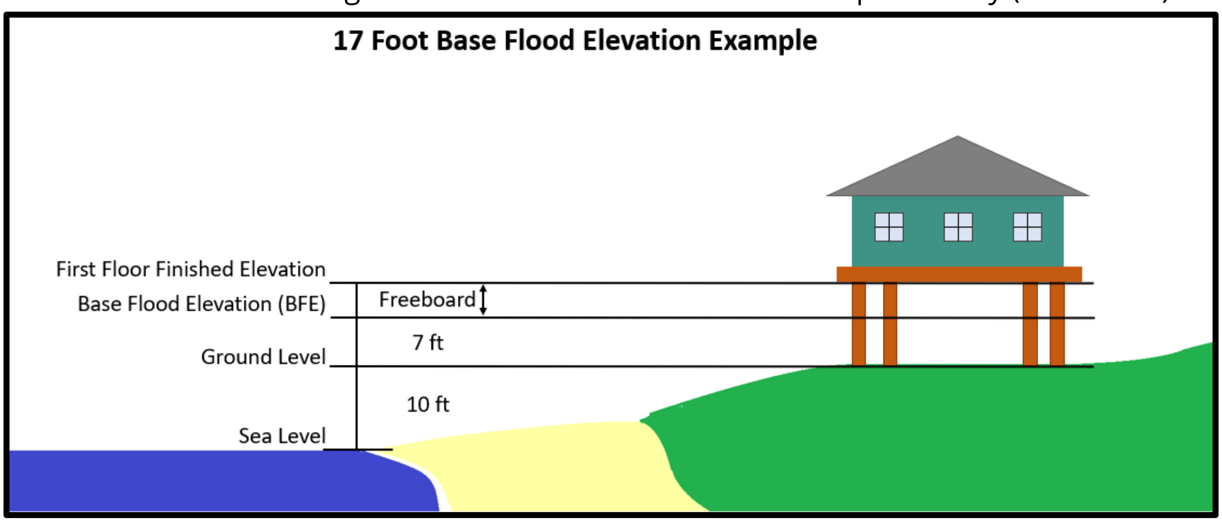
   Reasoning (write a statement that connects your evidence to your claim about what happens to water inundation area and depts in the city compared to the river)

Build your (dream) home! You are now the proud owner of property along the Gulf coast and now you get to design the home you hope to live in for many years. Your home is in the perfect location for outdoor recreation, being close to the beach and bayous. Make a choice between the options given for each step. Once you have selected all the option make a sketch of your home.

1. How do you want to elevate your home, if at all?
    a. No elevation
    b. Raised on piles/stilts
    c. Raised with 2 solid walls allowing ocean breeze underneath
    d. Raised with 2 solid walls blocking ocean wind
    e. Raised with 4 solid walls



2. How high do you want to elevate your home?
    a. No elevation
    b. Raised to the level of the 1% annual exceedance probability
    c. Raised to a foot higher than the 1% annual exceedance probability (Freeboard)



3. There are drainage ditches on the road leading to your home.
    a. You fill these in
    b. You leave them

4. How close do you build your home to your small backyard stream?
    a. Right next to it so you can easily access it for fishing, boating, or swimming
    b. You want a little space, so you build 25 feet away
5. How close to the beach do you build your home?
    a. Right at the lowest water level
    b. Inland from the highest water level
    c. Behind the dunes



6. You want to protect your home and belongings from floods. So you:
    a. Build a floating house, when water level rises your house floats up and away.
    b. Build a house with strong foundation to resist flooding impacts.
7. What do you use the underneath of your house for?
    a. You didn’t elevate so there is no underneath
    b. You elevated and use it for parking
    c. You elevated and set up the space as a spare bedroom
    d. You decorated the pilings with latticework
    e. You decorated the pilings with rustic wooden beams that also help support the overall structure




8. You can almost see the beach from your house, but there are sand dunes with beach grass in the way.
    a. You cut an access path and build a boardwalk from your house to the beach through the dunes
    b. You leave the dunes as they are and map out the quickest road to access the beach

Using the "Flood Damage Prevention Ordinance" for Coastal Communities your teacher will share the ordinances in place to protect against flooding damages.

Score your home for Question 1:

2 points for raised on piles/stilts, 2 points for raised with 2 solid walls allowing ocean breeze underneath, 1 point for raised with 2 solid walls blocking ocean wind from question 1. No points for other options.

Score your home for Question 2:

1 point for raised to a foot higher than the 1% annual exceedance probability from question 2. No points for other options.

Score your home for Question 3:

1 point for leaving the drainage ditches from question 3. No points for other options.

Score your home for Question 4:

1 point if you built 25 feet away from the stream in question 4. No points for other options.

Score your home for Question 5:

1 point if you built inland from the highest water level, and 2 points if you built behind the dunes in question 5. No points for option a.

Score your home for Question 6:

1 point if you built a house with strong foundation to resist flooding from question 6. No points for other options.

Score your home for Question 7:

2 points if you elevate and use it for parking, 2 points if you decorated the piles with latticework from in question 7. No points for other options.

Score your home for Question 8:

1 point if left the dunes as they were in question 8. No points for other options.

Total your score:

If your score was between 0-3: You are a student of community ordinances.

If your score was between 4-7: Not bad – you are a potential municipal government official.

If your score was between 8-10: Excellent – you are an expert floodplain manager.

100-Year Flood

Sea-level rise impacts ways in which water interacts with our coastal communities. With increased sea-level rise, the number of days we experience nuisance flooding increases and storm surge can travel farther inland and flood areas with deeper water. One term used to describe large flood events is the 100-year flood. Many federal, state, and local laws and ordinances are designed around the 100-year flood. To better understand this term, it is helpful to understand the history of the National Flood Insurance Program.

The National Flood Insurance Program provides flood insurance to homeowners, renters, and businesses, works at the community level to improve floodplain management regulations, and develops maps of flood hazard zones. A floodplain is a nearly flat area of land that is naturally subject to flooding. Communities use floodplain management to reduce the risk of current and future flooding by taking corrective and preventative measures to increase their resilience. In the 1960's there was widespread flooding along the Mississippi River but there was a lack of private flood insurance and the standard homeowner insurance policy does not cover flood damage. This led to large amounts of flood losses to communities and increases in federal disaster assistance needed. In response to this the United States government added the National Flood Insurance Program to be managed by the Federal Emergency Management Administration (FEMA). To designate the areas at high-risk for flooding and therefore most in need of flood insurance, the National Flood Insurance Program used the 1% annual exceedance probability (AEP) floodplain. The annual exceedance probability floodplain is a measure of chance that flooding will be at least that high/far each year. The 1% annual exceedance probability floodplain describes the areas that have a 1 in 100 chance, or 1% probability, of being flooded each year. The phrase 1-percent annual exceedance probability leads to the term 100-year flood.

The 100-year floodplain has a 1% chance of flooding every year but, like flipping a coin, you could get heads three times in a row. When you look at the risk of something in the 1% annual exceedance probability floodplain over multiple years, the risk increases. For example, there is a 26% chance a house will flood over the course of a typical 30-year mortgage. If a high school senior has lived in the same house in the 100-year floodplain for their entire life, there is a 16% chance that they would experience flooding at least once. These values (26% and 16%) are based on the probability theory that accounts for each of the mentioned years having a 1% chance of flooding. The estimates for the 1% AEP floodplain come from measurements by scientists and engineers measuring the height and flow of water. However, the accuracy of 1-percent annual exceedance probability depends on the data available, any changes in land use, river drainage, or climate change.

As our communities talk more about larger floods and increasing their protection from flooding, they may use the term 500-year flood. The corresponds to an annual exceedance probability of 0.2% or 1 in 500 chance of a flood happing each year.

With the growing need to prepare for flooding there is also the need for clear communication regarding risk. Hydrologists (the scientists that study distribution, circulation, and physical properties of water, at the United States Geological Survey) are transitioning away from the terms 100-year and 500-year flood to define floods in terms of the annual exceedance probability, such as the 1% annual exceedance probability. This helps communicate that the occurrence of a large flood does not mean that you are flood-free for the next 99 years.

FEMA identifies flood hazards on floodplain maps for community members to understand their specific risk. Special Flood Hazard Area (SFHA) is the area that will be inundated by the 1% annual exceedance probability flood. Special Flood Hazard Areas are labeled as: Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30. The areas between the 1% annual exceedance probability flood and the 0.2% annual exceedance probability flood are moderate flood hazard areas and labeled as Zone B or Zone X (shaded). The areas outside of the special flood hazard area are at minimal flood risk and are labeled as Zone C or Zone X (unshaded).

Base Flood Elevations (BFEs) are the elevation to which floodwater is anticipated to rise during the 1% AEP flood for your location. The Base Flood Elevation is a regulatory requirement for the elevation and floodproofing of structures. Some states require building to at least Base Flood Elevation as defined by FEMA, but some municipalities go above and beyond and require building higher than Base Flood Elevation, known as freeboard. Federal, state, and local governments use the 1% AEP floodplain as the regulating standard for flood insurance and building codes. It can also be considered in zoning, and other policies and practices.

With our changing climate and sea-level rise coupled with changes in land use and impervious surfaces, our historic flood patterns are changing. The 1% annual exceedance probability is including a larger area and deeper water as sea levels rise. By understanding our risk, we are able to prepare our communities, homes, and businesses for current and future flooding.

Source: Robert R. Holmes, Jr. and Karen Dinicola, US Geological Survey, 100-Year Flood – It's All About Chance. April 2010. General Information Product 106

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DO NOW:

How can you narrow down sea-level rise scenarios to focus on when starting a construction project?

EXIT TICKET:

What is a 100-year flood?

    - Water Conservation in Your Landscape: http://extension.msstate.edu/sites/default/files/publications/publications/p3146.pdf
- Article by Mississippi State University Extension about rain gardens
    - “Rain gardens are good water management tools” http://extension.msstate.edu/news/feature-story/2018/rain-gardens-are-good-water-management-tools
- Informational booklet about the home watershed including tips for reducing runoff, conserving water, and reducing pollution
    - “Managing Your Home Watershed” https://extension.msstate.edu/sites/default/files/topic-files/healthy-soils-and-water/managing_your_home_watershed.pdf
- Information from City of Durham about rain gardens
    - “Rain Gardens” https://durhamnc.gov/787/Rain-Gardens
- Information from Alabama Cooperative Extension System about rain gardens
    - “Rain Gardens” https://www.aces.edu/blog/topics/landscaping/rain-gardens/
- Step by step guide to building a rain garden by This Old House
    - “How to Build a Rain Garden to Filter Run-Off” https://www.thisoldhouse.com/gardening/21016338/how-to-build-a-rain-garden-to-filter-run-off
- NPR article about Mobile-Tensaw Delta habitats.
    - “On A Tour Of 'America's Amazon,' Flora, Fauna And Glimpses Of Alabama's Past” https://www.npr.org/2020/12/06/943088103/on-a-tour-of-americas-amazon-flora-fauna-and-glimpses-of-alabamas-past
- Informational website with introductory educational information on how to develop a coastal restoration project from concept to proposal.
    - “Coastal Restoration Toolkit” https://restoreyourcoast.org/coastal-flooding/

RECOMMENDED CURRICULUM CITATION:

Vedral, Sonia, Collini, Renee C., Miller-Way, Tina, Rellinger, Alison N., Sempier, Tracie T., Smallegan, Stephanie M., Sparks, Eric. (2021). Sea-Level Rise in the Classroom. MASGP-21-056

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2.1 Tides and Wetlands

AGE RANGE

9th—12th grade

TIME REQUIRED

90 minutes

ACTIVITY OVERVIEW

Engage: NERR Image

Explore: NOAA Tides

Explain: Discussion

Elaborate: Salt Marsh Profile

Evaluate: Discussion

MATERIALS

Computers
Graph Paper
Wetland Plant Cards
Tape

BASED ON:

"Water Going Up, Water Going Down" from NERR TOTE & Mock Marsh

LESSON TOPIC: Wetlands and wetland plants

ACTIVITY SUMMARY: Exploration of local tidal patterns and the distribution of northern Gulf of Mexico wetland plants.

OBJECTIVES:

Students will be able to explain that:

- Estuaries are dynamic ecosystems with variability in physical and biological components.
- Estuaries support an abundance of life and a diversity of habitat types.
- Salt marshes are dominated by a variety of plant species and influenced by tides.
- Plants that live in salt marshes tolerate different levels of flooding and this tolerance level determines where the plant lives in the marsh.
- Rising sea levels may change the plant species distribution and composition in salt marshes, impacting the entire marsh ecosystem.

LESSON BACKGROUND:

TIDES

Tides are caused by the gravitational attraction of the moon and sun on water in the ocean and in very large lakes. Tides originate in the ocean and move toward coastlines as very long-period waves, giving the appearance of regular rise and fall of the sea surface. High tide occurs when the highest part of the wave, the crest, reaches the coast, and low tide occurs when the lowest part, the trough, reaches the coast. The gravitational pull of the moon is greater than the sun, and the moon plays a larger role in producing tides.

The position of the moon and the sun in relation to Earth cause variations in the heights of tides. During new moon and full moon, the sun, moon, and Earth form a line and we experience the greatest tidal amplitude with highest high and lowest low tide. This is termed “spring tide.” When the position of the moon is at a right angle to the Earth and sun we experience “neap tide” with tides with the least amplitude. Spring tide and neap tides occur twice each month.

The physical geography of the coastline influences tidal patterns in different locations. There are three basic tidal patterns: semi-diurnal, mixed semi-diurnal, and diurnal. Semi-diurnal means that there are two high tides and two low tides each day. Mixed semi-diurnal means that the high and low tides differ in height. Diurnal means that there is only one high tide and one low tide each day. Along the Mississippi and Alabama coasts, we experience diurnal tides.

ESTUARIES

Estuaries are the transition zone between freshwater environments and marine environments. Estuaries are fed by one or more freshwater rivers or streams and are open to the ocean, and the water is a mixture of fresh and salt water - often termed “brackish.” Wetland habitats might be present in estuaries. A salt marsh is a type of wetland that is flooded and drained by salt water brought in by tides. Tides affect the height of water within estuaries and salt marshes since they are open to the ocean.

Plants that live in salt marshes are affected by abiotic factors including water level and salinity, as well as competition among plant species. Marshes generally have three vegetation zones: low marsh, high marsh, and upland edge. The plants that grow in each zone are determined by their ability to tolerate water level and salinity. The more flooding-tolerant plants are located in the lower marsh zones.

With sea-level rise, wetlands and marshes will erode. High water levels will flood farther inland and new wetlands can form. However, the rate of new wetland growth may be less than the rate of wetland loss as many developed areas with hard structures like bulkheads and roads prevent the marsh from moving inland.

Understanding coastal processes allows for the use of natural systems to reduce flooding and sea-level rise impacts in coastal to urban areas. Wetlands and coastal marshes along the northern Gulf of Mexico provide many natural solutions. Wetlands act as speed bumps for storms, slowing the storms as they come ashore, 15 ft of marsh can absorb 50% of incoming wave energy. One square mile of salt marsh stores the carbon equivalent of 76,000 gal of gas annually. Marshes trap sediments from tidal waters, allowing the marsh to grow in elevation as sea level rises.

VOCABULARY:

Abiotic	A nonliving condition or thing, as climate or habitat, that influences or affects an ecosystem and the organisms in it.
Biomass	Organic matter derived from living, or recently living organisms.
Biotic	Biotic components, or biotic factors, can be described as any living component that affects another organism or shapes the ecosystem.
Carbon Sink	Anything that absorbs more carbon that it releases.
Carbon Storage	Capture and storage of carbon dioxide before release to the atmosphere (also known as 'carbon sequestration') through natural and/or anthropogenic (i.e., human) processes in order to mitigate climate change.
Diurnal Tide Cycle	An area has a diurnal tidal cycle if it experiences one high and one low tide every lunar day. Many areas in the Gulf of Mexico experience these types of tides.
Dynamic	Characterized by continuous action or change.
Ecosystems	All the living things in a particular area as well as components of the physical, non-living environment with which they interact (e.g., air, soil, water, and sunlight).
Elevation	Height above or below a fixed reference point.
Estuary	Estuaries and their surrounding wetlands are bodies of water usually found where rivers meet the sea. A mixture of fresh water draining from the land and salty seawater.
Forestry	Science and practice of planting, managing, and caring for forests.
Inundation	To flood; cover or overspread with water.
Invasive Species	Introduced, non-native organism (e.g., disease, parasite, plant, or animal) that rapidly expands its range, displacing other species, and causes harm to the environment, the economy, or to human health.
Mixed Semidiurnal Tide Cycle	An area has a mixed semidiurnal tidal cycle if it experiences two high and two low tides of different size every lunar day. Many areas on the western coast of North America experience these tidal cycles.

Salt Marsh	A salt marsh or saltmarsh, also known as a coastal salt marsh or a tidal marsh, is a coastal ecosystem in the upper coastal intertidal zone between land and open saltwater or brackish water that is regularly flooded by the tides.
Seagrass	Seagrasses are flowering plants which grow in marine environments.
Sediment	Fragmented organic and inorganic material, typically occurring due to erosion or weathering, that is easily transported by water, wind, or ice.
Semidiurnal Tide Cycle	An area has a semidiurnal tidal cycle if it experiences two high and two low tides of approximately equal size every lunar day. Many areas on the eastern coast of North America experience these tidal cycles.
Sequestration	The net removal of CO2 from the atmosphere by plants and micro-organisms and its storage in vegetative biomass and in soils.
Subsidence	Sinking of the ground due to underground movement or soil compaction and/or degradation; most often caused by the removal of water, oil, natural gas, or mineral resources from the ground by draining, pumping, fracking, or mining activities.
Tide	Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the moon and the sun, and the rotation of the Earth.
Transect	A transect is a line across a habitat or part of a habitat. It can be as simple as a string or rope placed in a line on the ground. The number of organisms of each species along a transect can be observed and recorded at regular intervals.
Wetland	Wetlands are areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season.
Wetland Change	When coastal wetlands, especially estuarine and marine wetlands, are naturally or unnaturally altered by high energy events such as erosion and inundation from sea level rise and storms.

ENGAGE:

Watch with students the introductory video "What is an estuary?" (2 minutes) about estuaries and the National Estuarine Research Reserves (NERRs): https://oceanservice.noaa.gov/facts/estuary.html

Display a map of the NERRs and show Weeks Bay NERR in Alabama and Grand Bay NERR in Mississippi. Ask students what estuaries might be stressed by given their location on the coast next to the Gulf of Mexico. Answers to highlight: storms, tides, sea-level rise.

Alternative: Show students the short video of rapid erosion at Grand Bay NERR: https://www.youtube.com/watch?v=S6TGEmu9dcA (1 minute 25 seconds)

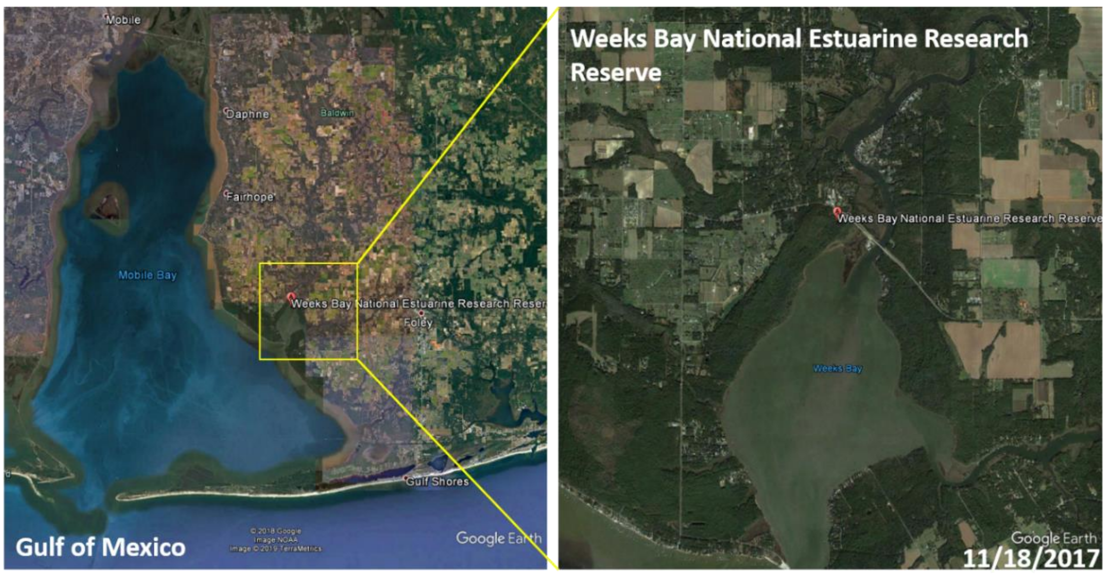


Image: Google Earth image of Weeks Bay NERR in Alabama.

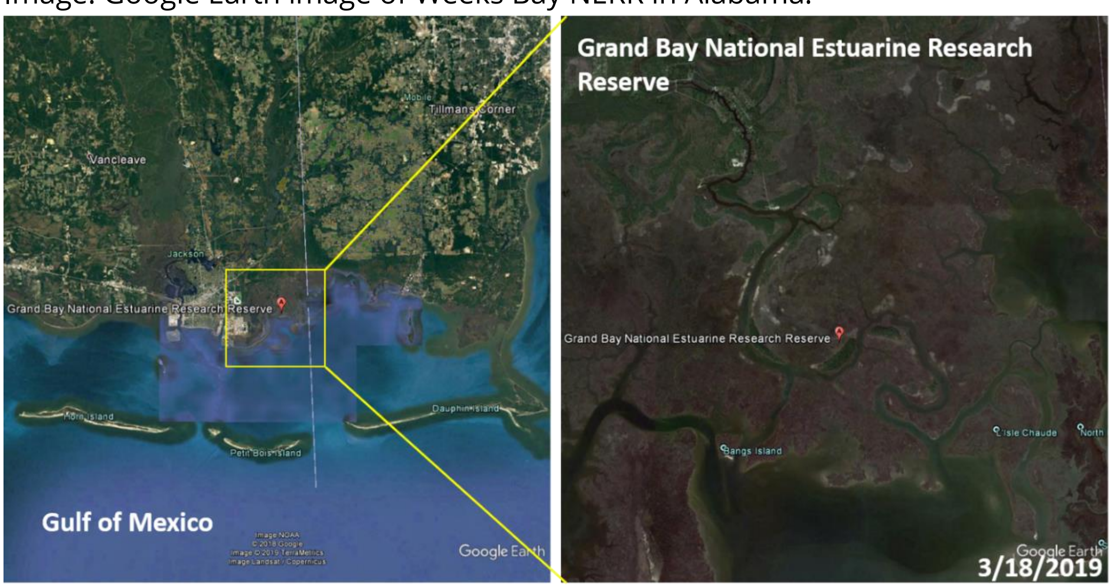


Image: Google Earth image of Grand Bay NERR in Mississippi.

EXPLORE:

Activity description: students will use NOAA's Tides and Currents website to explore tidal data from tide stations in Alabama and Mississippi.

Materials: access to computers with internet access and graph paper.

Procedure:

1. Open NOAA's Tides and Currents website: http://tidesandcurrents.noaa.gov/. Click on a state to be directed to local tides and currents information.
2. In the Legend on the right side make sure only "Water Level and Met" and "Water Levels" pins are checked. Locations in Alabama and Mississippi are given below, but students may work on stations located on other United States coasts. Ensure that at least one student group has selected a location outside of the northern Gulf of Mexico to allow for comparisons at the end.

Alabama:
Weeks Bay, Mobile Bay, AL;
Dauphin Island, AL;
Dog River Bridge, AL;
East Fowl River Bridge, AL;
Coast Guard Sector Mobile, AL;
Mobile State Docks, AL;
Chickasaw Creek, AL;
West Fowl River Bridge, AL;
Bayou La Batre Bridge, AL.

Mississippi:
Grand Bay NERR, Mississippi Sound, MS;
Pascagoula NOAA Lab, MS;
Bay Waveland Yacht Club, MS

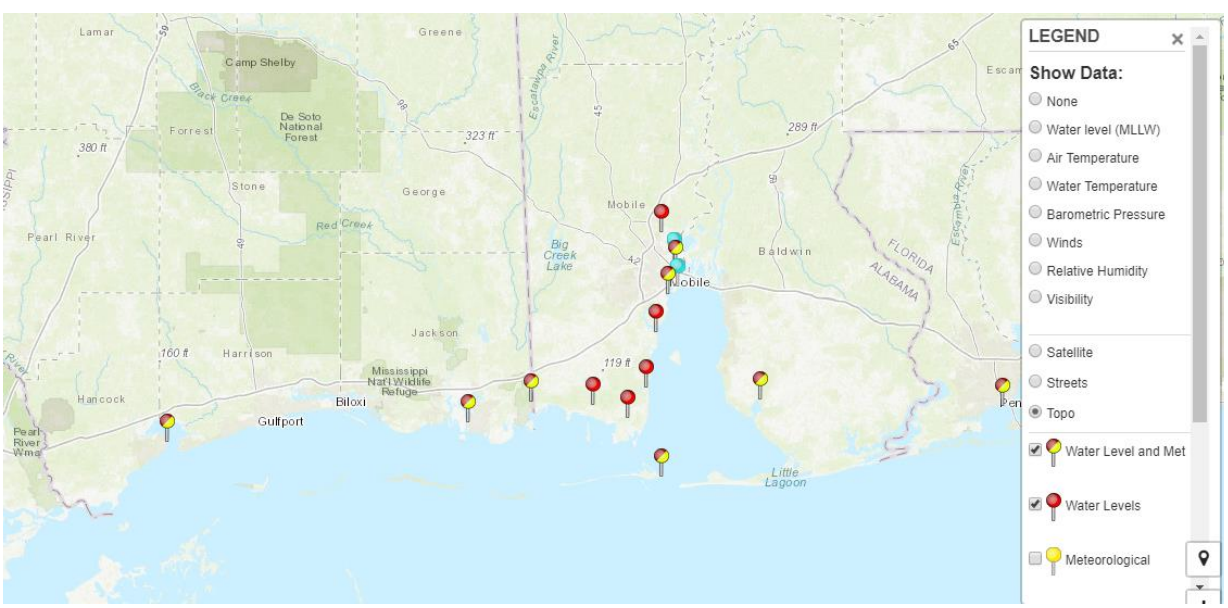


Image: Mississippi and Alabama display from NOAA Tides and Current website. Source: https://tidesandcurrents.noaa.gov/map/index.html

3. Students can access the tidal height data by clicking on the pin, then clicking on "More Data" in the dialog box that opens, and clicking on "Water Levels."

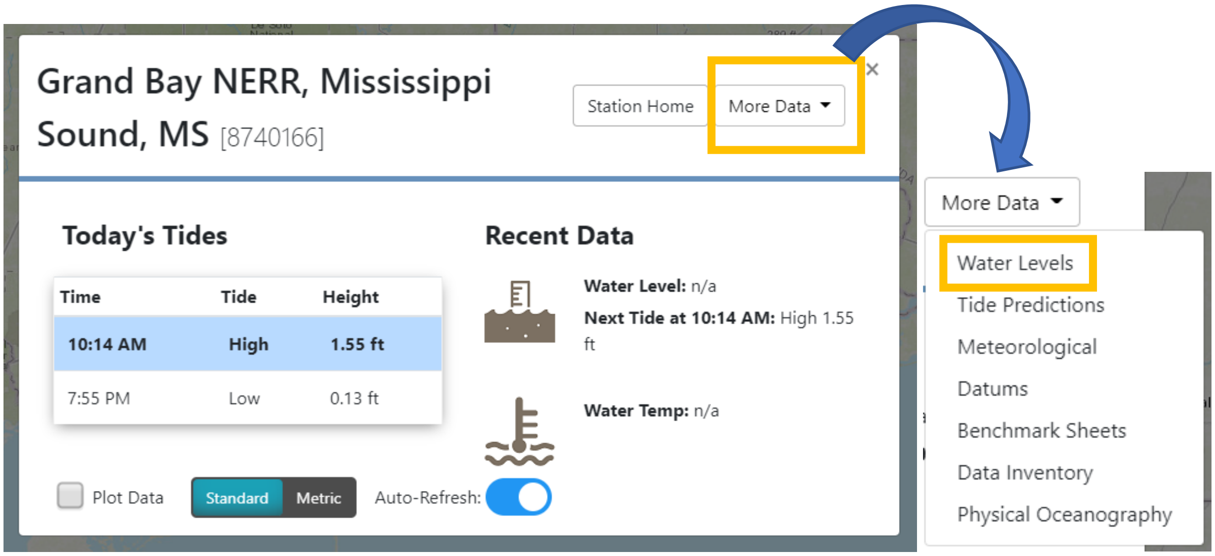
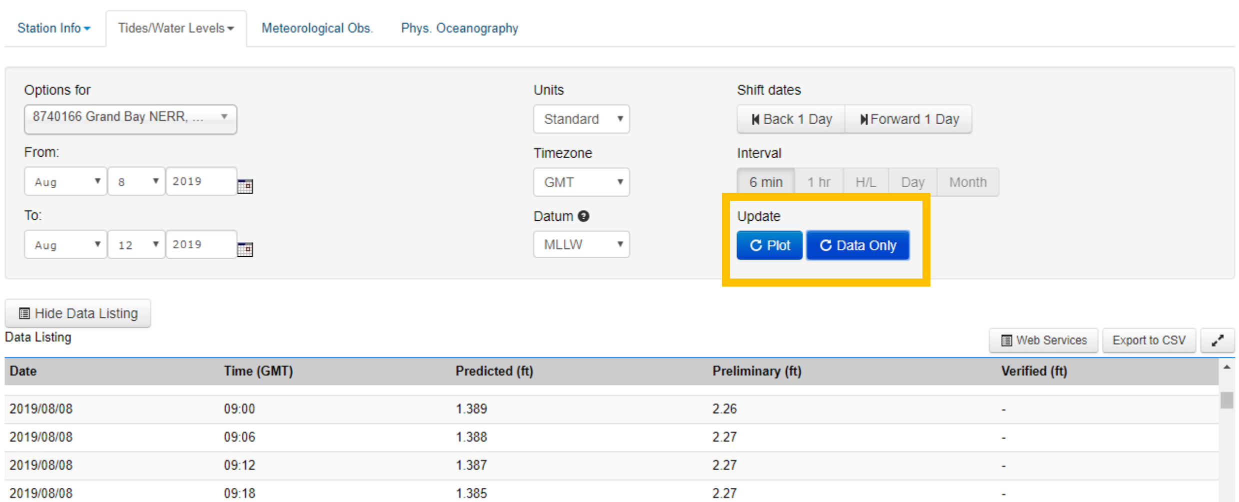


Image: The dialog box that opens when a tidal gauge pin is clicked. Source: https://tidesandcurrents.noaa.gov/map/index.html

4. Have students examine a range of time with tide data for their station. They select the range of time using the date selection and access the data by clicking the "Data Only" button.



5. Using the graph paper have students create a line graph of the tidal change at their location. Record the water height every two hours for at least a three-day length of time.
6. Have students calculate the tidal range - this is the difference in tide height from the low tide to the high tide.

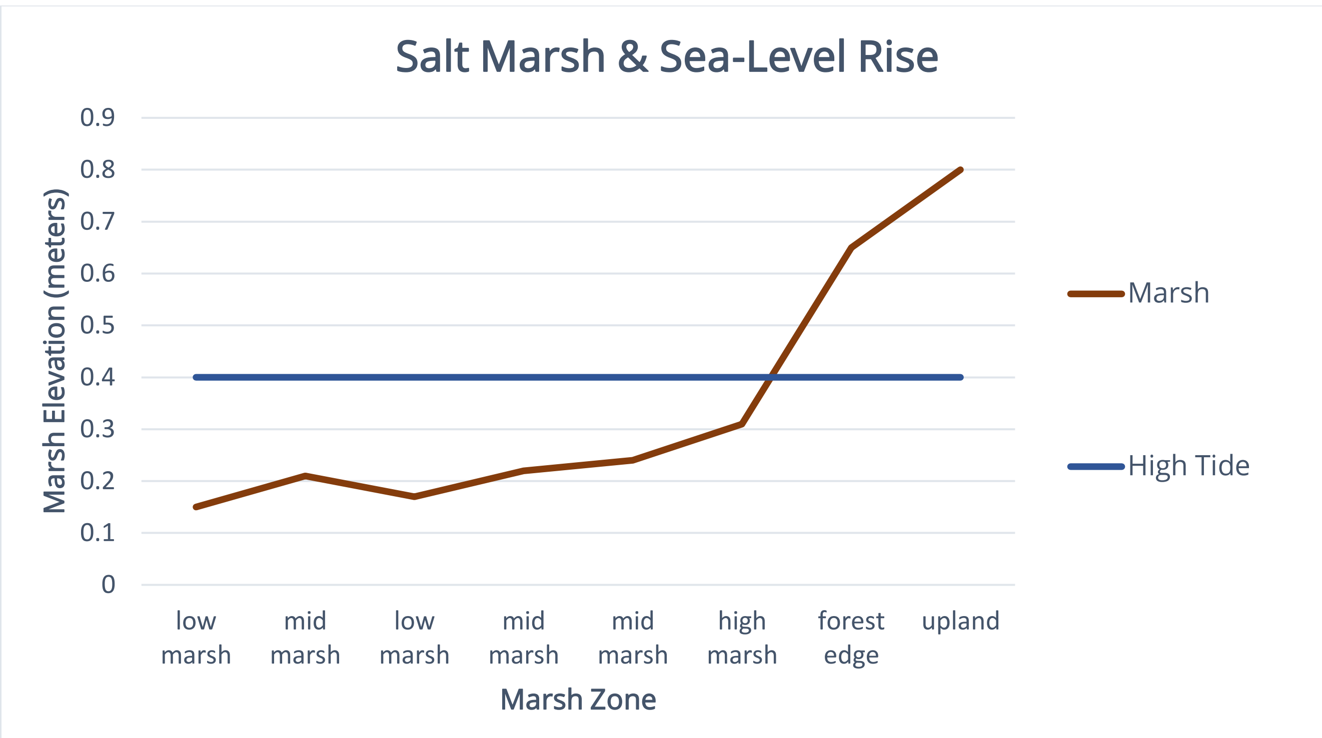
EXPLAIN:

Discuss the trends in tides that students found from graphing the tidal range. Compare graphs from locations with diurnal and semi-diurnal tides. In the Gulf of Mexico, we have a small tidal change, but the east coast has relatively large changes in their tides.

Guide students into thinking about how tidal changes might influence coastal wetland habitats.

Note: at this point the lesson can be paused for the day.

Across the board, or along one wall with string, create the graph below showing high tide, and marsh elevation. This could also be projected onto the wall.



This is a mock transect of a northern Gulf of Mexico marsh.

- The marsh elevation follows the brown line
- Current High Tide Elevation: 0.4 meters
- Current Sea-Level: 0

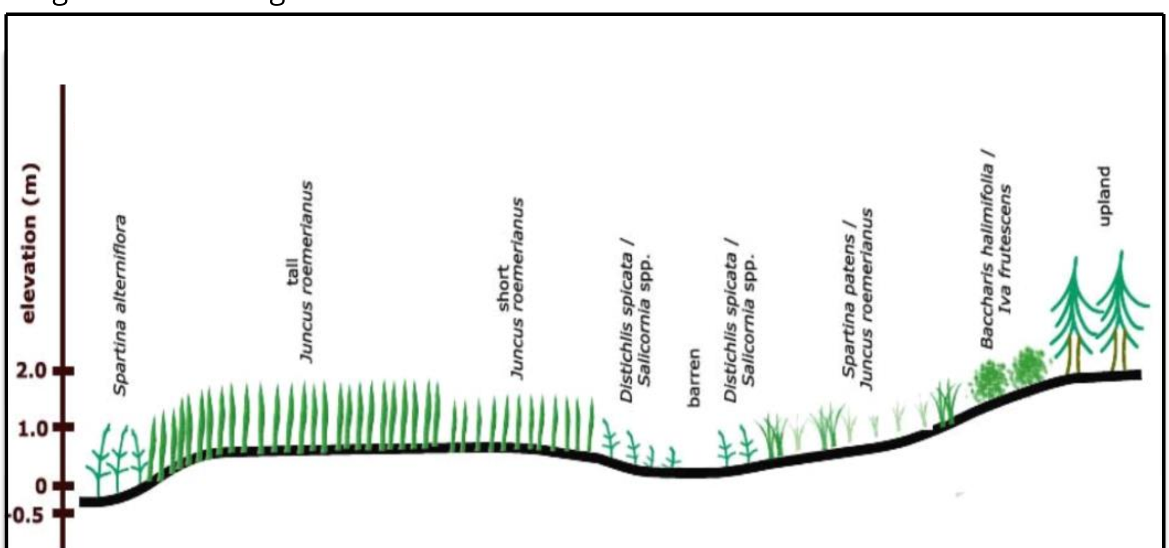
ELABORATE:

Materials: Enlarged version of the Salt Marsh Profile, Preserved specimens or cutout copies of the "Coastal Wetland Restoration Plant Fact Sheets" http://extension.msstate.edu/sites/default/files/publications/publications/p3356.pdf

This activity will have students exploring the plants commonly found in salt marshes in Mississippi and Alabama and understanding the marsh zones.

Procedure:

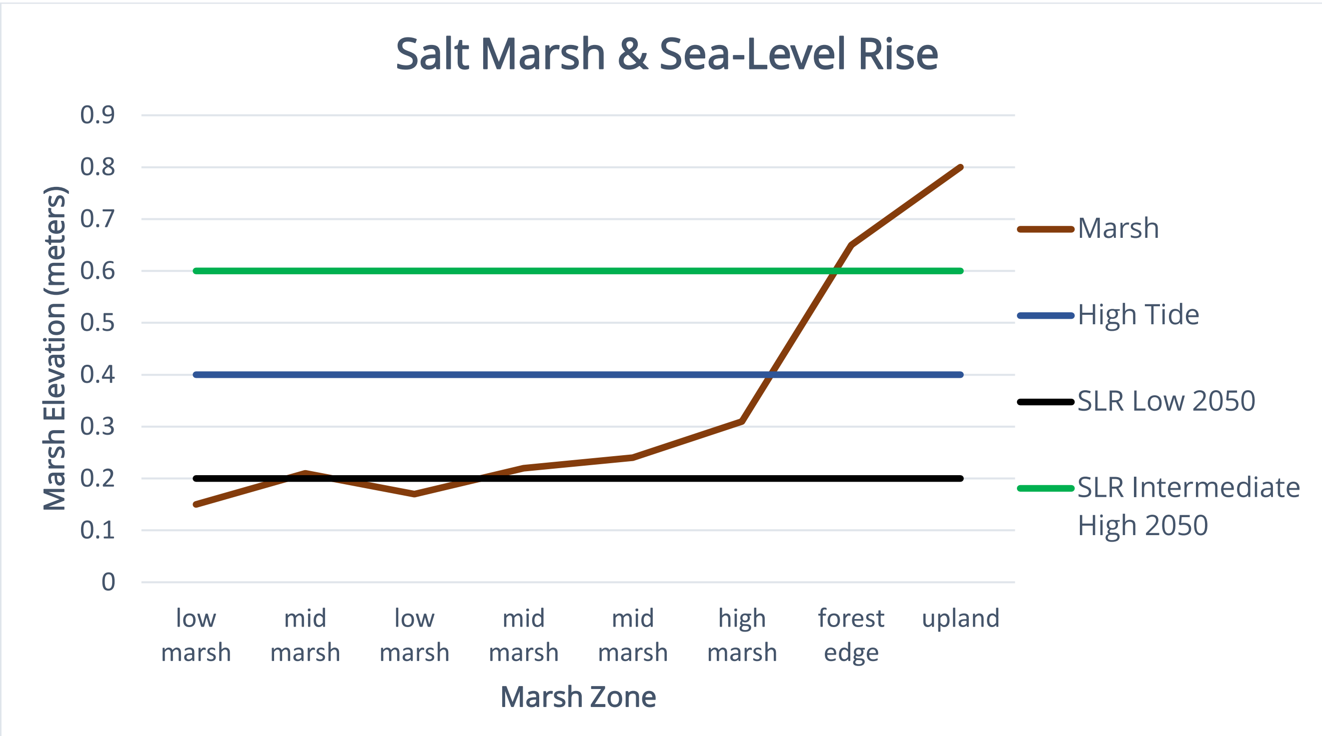
1. Discuss the different vegetation zones of the marsh and have students brainstorm what might impact where plants can grow in a marsh (low marsh = plants have to withstand more or constant flood inundation of salt water; high marsh and upland edge = plants will rarely be exposed to water inundation from incoming tides).
2. Ask students what kind of adaptations they think plants living in a salt marsh might have. This can include things like the ability to excrete, exclude or sequester the salt, rhizomes, or developed aerenchyma to channel to get air to the roots.
3. Using identification cards or preserved specimens, have students identify the common salt marsh plants. Common name in regular text, scientific name in italics.
    a. Low marsh: smooth cordgrass *Spartina alterniflora,* Black needlerush *Juncus roemerianus*
    b. High marsh: Black needlerush *Juncus roemerianus,* Saltmeadow cordgrass *Spartina patens,* Bulrush *Schoenoplectus americanus,* Salt grass *Distichlis spicata*
4. Discuss with students the adaptations that each plant has that allows it to survive in the marsh and determine the marsh zone the plant is located.
5. After discussing the salt marsh plants, place them in the marsh zone displayed on the graph, using the below image for marsh zone reference.



Credit: wetlandextension.ifas.ufl.edu

Image: Marsh profile showing elevation gradient graphic. Source: UF/IFAS Wetlands Extension.

7. Once all the plants have been placed, display the graph below with additional lines showing the projected sea-level rise by 2050 under the Low and Intermediate High scenarios. These sea-level rise projections show the change in low tide.
8. If needed, change the location of the plants based on the water levels from sea-level rise.
9. Students can use corresponding worksheet for notes.



- The marsh elevation follows the brown line
- Current High Tide Elevation: 0.4 meters
- Current Sea-Level: 0
- Sea-Level under the Low Scenario in 2050: 0.2 meters
- Sea-Level under the Intermediate High Scenario in 2050: 0.6 meters

Sea-level rise poses a challenge for marsh plants. Greater and more frequent inundation of the marshes leads to flooding stress and brings salt water into the higher marsh zones. In the northern Gulf of Mexico, we are experiencing sea-level rise at rates greater than the global average, so our marshes are being faced with this challenge now. The plants living in salt marshes have two options for keeping pace with sea-level rise: landward migration or vertical accretion. For landward migration, salt marsh plants move upslope into upland habitat. For vertical accretion, salt marsh plants trap sediment and vertically build up the land to stay above water with sea-level rise. Both of these pathways are relatively slow processes.

Landward migration is a process where the marsh zones shift upslope. However, landward migration is limited by steep slopes or barriers like human-built sea walls, parking lots, roads, or houses. This creates “coastal squeeze”, where the natural movement of the coastal habitat is prevented by physical barriers on the upslope side (see image below). Vertical accretion allows salt marshes to move up vertically as sea-level rises. This process occurs as salt marsh plants physically reduce the speed of water, which allows sediment particles to settle out and accumulate around the base of marsh plants. However, vertical accretion is limited by changes in marsh plant abundance and sediment supply; as plant biomass decreases there are less plants to slow the water velocity and accumulate sediment.

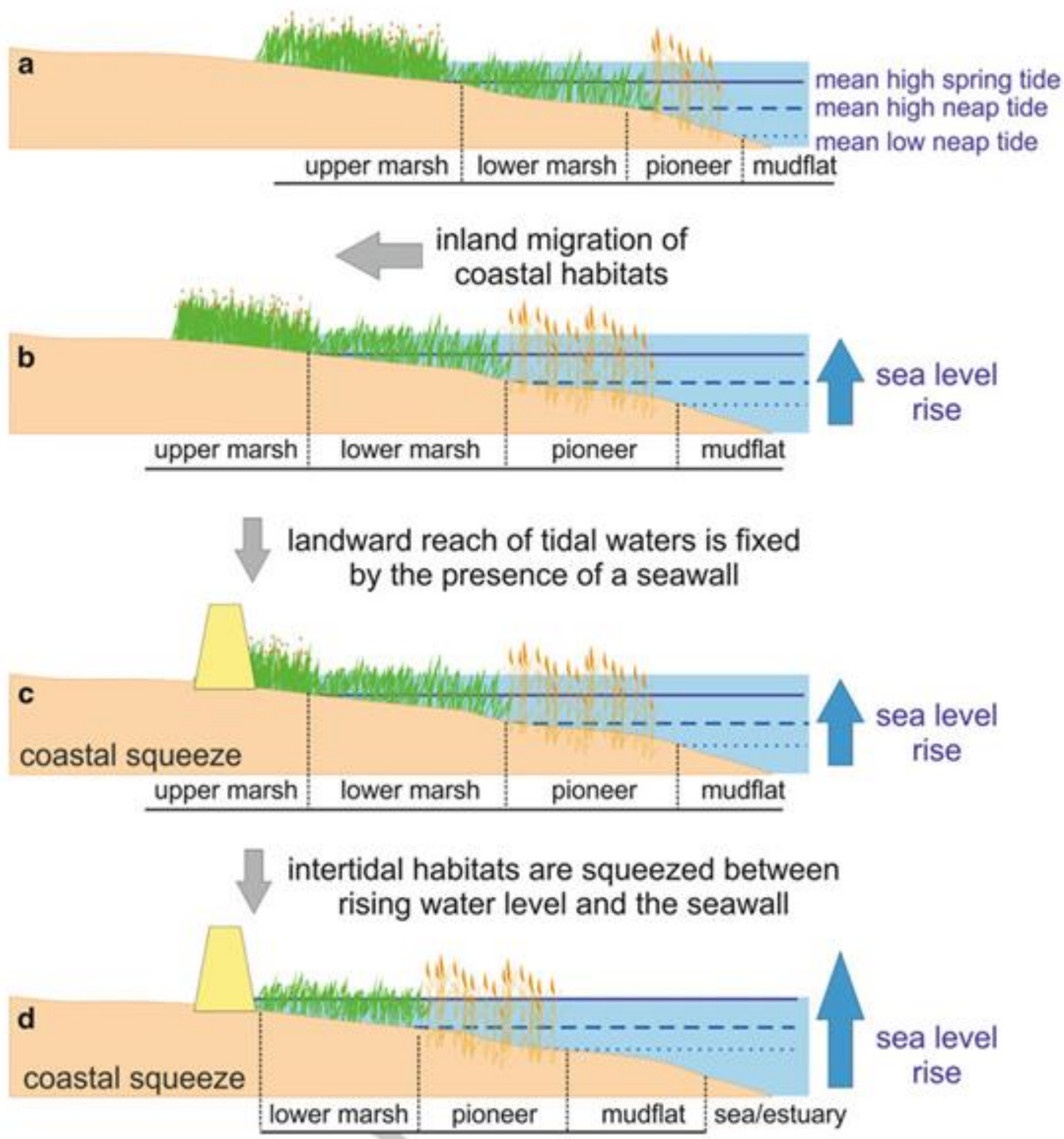


Image: The elevation in relation to the tidal range is one of the key factors determining the type of intertidal habitat that may develop in a particular location (a). Natural habitats tend to migrate inland as a response to rising sea levels (b). As a result of this migration the intertidal area may expand or reduce depending, for example, on the coastal topography. Hard engineering structures will invariably fix the landward limit of intertidal areas (c), which will be reduced in extent as sea levels rise and more land becomes permanently inundated (d). The loss of coastal habitats due to rising sea levels in front of artificially fixed shorelines is known as coastal squeeze. Image source: Esteves, L.S., 2015. Coastal squeeze. *In*: Kennish, M.J., ed. *Encyclopedia of Estuaries 2016 ed.* Dordrecht: Springer.

As marsh plants try to adapt to sea-level rise, many human-made stressors can reduce their ability to adapt. With wetland restoration and resilient sea-level rise actions, we can provide pathways for marshes and the animals that rely on them to keep pace with sea-level rise and continue to provide flood protection and other valuable services.

EVALUATE:

Ask: How does the tide influence salt marshes and the plants that grow there?

The incoming tide floods the marsh with brackish water, which is a mixture of salt and fresh water. Most plants cannot tolerate being regularly flooded or exposure to salt water, so salt marsh plants must have special adaptations that allow them to grow there. The frequency and duration of tidal inundation will determine where certain species of plants can grow.

Ask: How might sea level rise impact the marsh zones and subsequently the plants that grow there?

As marshes become more frequently flooded or hold more standing water, plants that are less salt or flood tolerant may die back and be replaced by the very few tolerant species that inhabit the low marsh.

Introduction to Estuaries and Wetlands

Along the Gulf of Mexico, we have many areas that provide habitat for animals. An estuary is the area where freshwater meet the saltwater ocean. The mixture of fresh and salt water is often called “brackish” water. Since estuaries are located along the coast, they are impacted by tides. As the water level of an estuary rises and falls, the water level and chemistry changes create a wide range of habitats. The marsh and seagrasses along the coast slow the moving water, allowing sediment and food particles to settle to the bottom. The maze of grasses provide many hiding places to small fish and crabs, giving estuaries the name “nursery of the sea.”

Types of coastal estuaries include brackish or freshwater marshes, salt marshes, seagrass beds, and oyster reefs. Some coastlines may only have a soft shoreline of sand. Wetlands are what their name implies, areas of land that are wet enough to influence the plants and soils. Wetlands can be found inland or along the coast.

A salt marsh is a type of wetland that is flooded and drained by salt water brought in by tides. Tides affect the height of water within estuaries and salt marshes since they are open to the ocean. Plants that live in salt marshes are affected by abiotic factors including water level and salinity, as well as competition among species. Marshes generally have three vegetation zones: low marsh, high marsh, and upland edge. The plants that grow in each zone are determined by their ability to tolerate flooding (or inundation) and salt water. The more flood tolerant plants will be located in the lower marsh zones. The high marsh and upper marsh edge are generally only flooded by the tide during spring tides or during storms. Sometimes the high marsh area has a high salt concentration due to evaporation, which can lead to the formation of salt pannes.

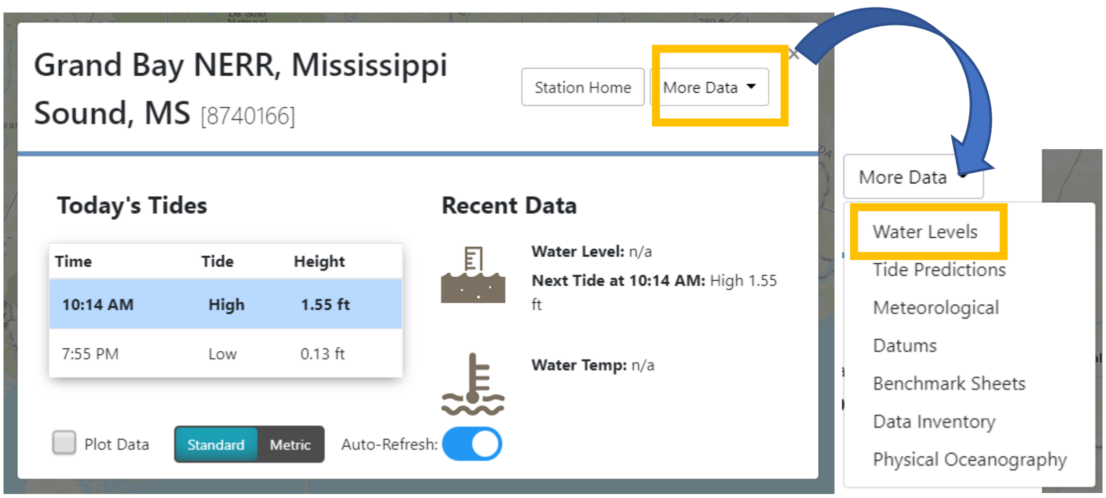
Most plants have one of three adaptations to deal with the salt from tidal influences: excrete the salt through specialized glands, exclude the salt at the roots, or sequester the salt in its leaves. Black needlerush (*Juncus roemerianus*) is the most common salt marsh plant in Mississippi and Alabama and has adaptations to handle anaerobic (i.e., no oxygen) conditions, as well as wide ranges of pH fluctuations. Saltmarsh cordgrass (*Spartina alterniflora*) thrives in the lower elevations of the marsh and alongside tidal creeks because of its tolerance to a high level of salinity. It excretes the excess salt onto the blades of the grass, which you can see as small crystals. Most salt marsh plants have an underground system of stems called rhizomes. These send out shoots, anchor the plant in unstable sediment, and help the plants survive in the harsh conditions of a salt marsh.

An essential component of a salt marsh is peat, the ‘ground’ of a marsh, providing the foundation for plants and animals living there. Often several feet thick, waterlogged, and composed of decomposing plant material, peat is low in oxygen, leading to a condition known as hypoxia. Certain bacteria thrive in hypoxic conditions, emitting the characteristic rotten egg smell associated with salt marshes. Examining a handful of peat shows the abundance of organic matter as well as its capacity to hold water. This ability of peat to act like a sponge means that marshes play a vital role in soaking up excess water during storm events, resulting in diminished flooding along the coast.

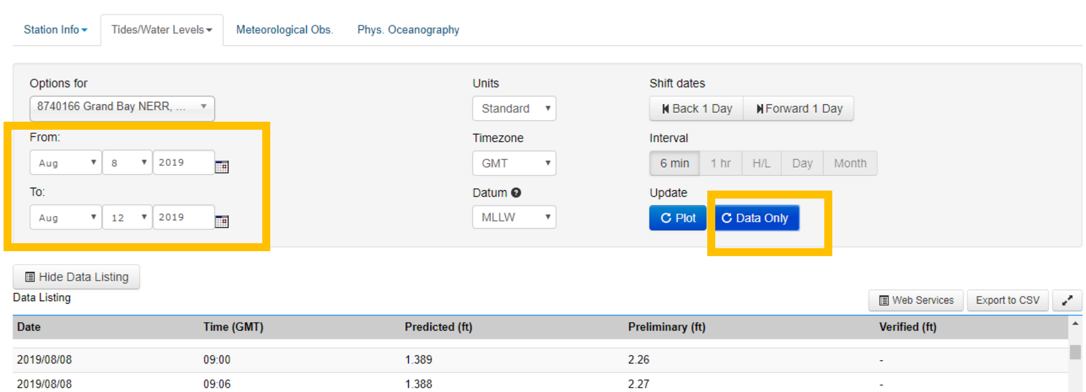
NOAA's Tides and Currents Investigation

What is your assigned tide station? ______________________________

1. Go to http://tidesandcurrents.noaa.gov/ and search for your tide station by checking the "Water Level Met" and "Water Levels" pins in the right-side Legend.
2. Access the tidal height data by clicking on the tide station pin.
3. Click on "More Data" in the dialog box that opens, then click "Water Levels."



4. Select a range of time (at least 3 days) and click the "Data Only" button.



5. On graph paper record the water height every two hours for at least a three-day length of time. Create a line graph of the tidal change.
6. Calculate the tidal range:
   a. What is the height of the **high tide**? ______________________
   b. What is the height of the **low tide**? ______________________
   c. Tidal range = High tide minus low tide → ____________________

STUDENT PAGE | Tides and Wetlands

Answer the following questions based on the marsh plant and sea-level rise activity.

1. When you first placed your plants, what plant did you place nearest the water's edge? How did you decide where to place your plants in your mock marsh habitat?

2. What is the difference in elevation between the mean high tide line and sea level projection for 2050, and for the accelerated rate by 2050?

3. When you moved your marsh plants where did you decide to place them and why?

4. What happened to the marsh as a result of sea-level rise?

5. How might marshes be able to adapt to sea-level rise?

6. What management activities could we do to allow marshes to adapt to sea level rise?

STUDENT PAGE | Tides and Wetlands

DO NOW:

Draw a coastline.

EXIT TICKET:

How does sea-level rise impact coastal wetlands in undeveloped and developed areas?

2.2 Living with Living Shorelines

AGE RANGE

9th—12th grade

TIME REQUIRED

90 minutes

ACTIVITY OVERVIEW

Engage: Shoreline Images
Explore: Water Pan Demos
Explain: Discussion
Elaborate: Reading
Evaluate: Discussion

MATERIALS

Clear plastic containers (4 per group)
Sand (1 bag per ~8 containers)
Playdoh Dough (1 tub per group)
Water
Plastic aquarium grass
2 small vinyl siding samples
Small mesh bags
Small pebbles/rocks inside
Rubber bands
Small paint scrapers
Towels
Saran /Plastic Wrap
Rulers
Masking Tape
Wet/Dry Erase Markers

BASED ON:

"Shifting Shorelines" from North Carolina Coastal Federation

LESSON TOPIC: Living shorelines

ACTIVITY SUMMARY: Students compare erosion from waves and storms on four different beach types.

OBJECTIVES:

Students will be able to:

- Identify components of a living shoreline and built stabilization structures.
- Understand coastal erosion and erosion control methods.
- Describe benefits of living shorelines to animal habitat and economic benefit.

LESSON BACKGROUND: Shorelines are the first line of defense against storms in the Gulf of Mexico. A healthy coast helps to protect our communities. Coastal erosion results in loss of land and can be caused by wind, waves, storms, boat wakes, and rising water levels. Some techniques to protect the coast from erosion are human built structures like bulkheads and seawalls. These structures provide a barrier to water stressors, but they require expensive maintenance and during strong storms they can fail. Additionally, hardened structures can often lead to loss of natural intertidal habitat and all of the benefits they provide. Natural shoreline protection can come in the form of oyster reefs and wetlands. These act as speed bumps to storms, slowing them down and reducing erosion. Living shorelines is a broad term that covers a variety of shoreline construction & protection techniques that harnesses the ability of natural habitats to provide shoreline protection, through using natural elements like native marsh grasses and oyster shells to stabilize the shore. Another benefit of living shorelines is that they offer habitat for animals like fish, crabs, and oysters. Oysters are filter feeders and help clean the water they are in, so using oyster shells in living shorelines promotes oyster reef growth to clean the water while also preventing erosion. Marsh grasses provide habitat for fish to hide while they are young. Adult fish will venture into the Gulf of Mexico. The Gulf of Mexico is the second largest area of fish landings in the United States, second only to Alaska. Commercial fisheries in the Gulf of Mexico have an economic impact through job creation, including processors, dealers, retailers, restaurateurs that transport seafood from the ocean to our plate. Utilizing living shorelines helps to affordably and sustainably protect our coasts while also supporting fisheries and clean water.

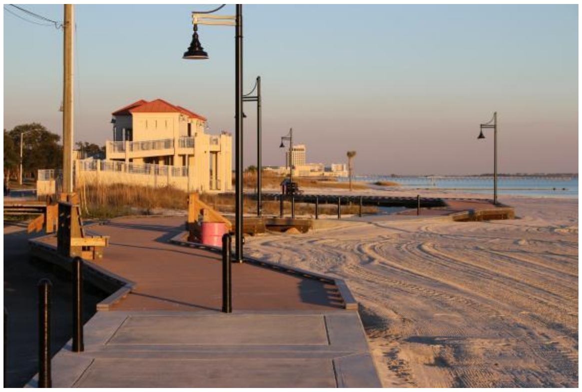
Mississippi State University Coastal Conservation and Restoration Program has developed larger scale living shoreline education tanks. At several locations along the MS and AL, coast there are living shoreline education tanks – also called SWASH tanks – Gulf Coast Research Laboratory Marine Education Center, Pascagoula River Audubon Center, Grand Bay National Estuarine Research Reserve, Mississippi Aquarium, and Dauphin Island Sea Lab Estuarium. Each tank is actually a set of three tanks that each have a different type of shoreline on one side. Those shoreline types are bulkhead, natural shoreline, and living shoreline (with breakwater). On the other end of the tank is a paddle connected to a lever. When the lever is pushed it creates an equal-sized wave in each tank that then crashes into the different shoreline types. You will notice that the wave dissipates quickest (i.e., the water gets calmer – faster) in the natural shoreline and living shoreline tanks than the one with the bulkhead. The bulkhead is essentially a flat wall that reflects waves instead of dissipating them, which can cause erosion on neighboring shorelines. The natural or living shoreline tanks have several characteristics that help dissipate wave energy and reduce potential erosion – those are a gentler slope, vegetation, and a breakwater. This demonstration shows that the more natural shorelines you have, the more waves will be dissipated.

VOCABULARY:

Coastal Processes	Physical, biological, and geological processes and affecting coastlines and coastal habitats.
Ecosystem Service Valuation	Quantifying the benefits that humans receive from natural systems; often utilizes economic value.
Erosion	Process wherein sediments are broken down and worn away by waves, currents, wind, and/or precipitation.
Habitat Management	Manipulating an ecosystem in order to suit a purpose, especially to balance environmental and human activities.
Living Shoreline	A living shoreline is a protected and stabilized shoreline that is made of natural materials such as plants, sand, or rock.
Restoration	Manipulation of the physical, chemical, or biological characteristics of a site with the goal of returning previous function(s). Includes ecological, ecosystem, and habitat restoration.
Rhizome	A rhizome is a modified subterranean plant stem that sends out roots and shoots from its nodes.

ENGAGE:

Display the images of the sand beach, wetland salt marsh, living shoreline planted with marsh grass and oyster reef, hardened shoreline near city, and bulkhead. Have students discuss the benefits of each type of shoreline. Then ask students to rank the images according to how well they think the type of shoreline will protect upland habitat.



West Biloxi Beach Boardwalk. Source: GulfCoast.org

A natural shoreline at Guana Tolomato Matanzas National Estuarine Research Reserve. Source: Melody Ray-Culp, US Fish and Wildlife Service

A living shoreline in Panama City, Florida. Source: Florida Living Shorelines

Hardened shorelines in South Florida. Source: Florida Living Shorelines

Hardened bulkhead shoreline in Scarborough, ME. Source: Maritime Construction and Engineering, LLC

EXPLORE:

Activity Overview: water pan demos - Students will explore how various shoreline stabilization methods influence coastal erosion and the surrounding habitat. They will rotate through four stations: a bare sand shoreline, a hard structure protection method, a living shoreline with planted marsh grasses, and a living shoreline with both planted marsh grasses and a constructed oyster reef. While rotating through the stations in small groups, students will simulate wave energy and observe which method works best to protect estuarine shores.

Materials:

- Clear plastic containers (11 in X 16 in, 15 Qt.), enough for students to work in groups of 3
- Playdoh or Crayola Dough (1 tub per group)
- Saran /Plastic Wrap

- Sand (1 bag per ~8 containers)
- Plastic aquarium grass used in fish tanks
- 2 small vinyl siding samples from Lowes Hardware (for bulkhead/seawall)
- Small mesh bags with small pebbles/rocks inside (for oyster reef)
- Rubber bands
- Small paint scrapers or dust pans (as many as plastic containers)
- Water (enough to fill each contained ½ way)
- Rulers (one for each station)
- Wet/Dry Erase Markers or Masking Tape (one for each station)
- Towels

Procedure:

1. Divide students into groups of 2-3. Each group will build a shoreline. Depending on your class size there may be duplicate shorelines.
    - All: Make a one-inch layer of playdoh along the bottom of the plastic container from the edge to 1/3 of the way. Place a sheet of plastic wrap over the playdoh, to help with cleanup. Add sand on top of the playdoh and form a gentle slope to create a beachfront/shoreline. Add water to the opposite end of the container so it reaches roughly ¼ of the sandy shore. The only sand shoreline is complete, all other shorelines continue with the following directions.
    - Bulkhead/seawall: Add the small vinyl siding samples and place them side by side. Stick them down into the playdoh.
    - Living shoreline with plants: Add aquarium plants and bury down in the sand/playdoh a bit to represent plant roots. You may need to cut the aquarium plants so they fit in your container correctly.
    - Living shoreline with plants and oyster reef: Add plants and then place pebble bags slightly in front of plants. You may need to use rubber bands around the pebble bags to make the reef more streamline.

Image: From left to right, sand only, bulkhead, living shoreline with plants, living shoreline with plants and oyster reef. Image showing the complete shoreline setups.

2. Rotate student groups through the shoreline stations to observe wave action and erosion. At each station have students record the following:
    - Their prediction/hypothesis for amount of erosion they expect from the type of shoreline.
    - The number of millimeters of erosion they measure after making waves.
3. When a group arrives at a shoreline have them mark the end of the shoreline (the coast) with tape on the outside of the container.
   Alternative: students trace the edge of the shoreline with a dry or wet erase marker. If you want to prevent the students from writing directly on the bin, each group can tape a transparent paper (sheet protector or laminated page) to the bin to draw the "before" shoreline in one color permanent marker and the "after" shoreline in another color permanent marker. These transparent pages can be kept to compare all bins at the end of the lesson.
   One student per group will make 20 waves in the water using the paint scraper.
4. Using the ruler, the group will measure the distance from the coast to their piece of tape. *Alternative*: students measure the distance to their traced line. This will show the amount of erosion. Before the group rotates to the next station have them repair the shoreline back to the original condition and remove the tape/erase the line.
5. Groups continue rotating until each group has been to each type of shoreline at least once.

Image: Marker on the outside of the container showing original shoreline shape compared to new shoreline share.

Tips for resetting the activity between classes:

- Have extra sand on hand to replace
- Use fresh playdoh if it has dried out
- Have dump buckets for used water and sand

EXPLAIN:

With groups all together discuss with students what they saw and how it might translate to what we experience on the Gulf Coast.

- Which shoreline eroded the most during the wave experiment?
- Which shoreline offered the most protection from erosion?
- What happened to the sand? Where did it go? Why did this happen?
- What do you think would happen if a hurricane came to the shorelines? At this point the teacher or a student can simulate a hurricane on each shoreline with strong waves.
- What do you think the different shorelines would look like a year after the hurricane? (Plants and living shorelines are able to recover naturally).
- How do you think the plants and oyster reefs can help keep the surrounding water clean? (plants can help filter any pollutants coming from the mainland, and the oyster reefs will attract new oysters, which naturally help clean and filter water)
- What other benefits do they provide?

ELABORATE:

Students read “Living with Living Shorelines” and then look over living shoreline resources available to homeowners.

Protection your property and the environment: A homeowner’s guide to living shorelines in Alabama. Martin SE, Sparks EL, Temple NA, Firth DC. 2017. http://extension.msstate.edu/sites/default/files/publications/publications/P3063.pdf

Protection your property and the environment: A homeowner’s guide to living shorelines in Mississippi. Martin SE, Sparks EL, Temple NA, Firth DC. 2017. http://extension.msstate.edu/sites/default/files/publications/publications/P3062.pdf

Living shorelines can be implemented as a buffer in many areas: homes, bridges, roads, and more.

Discussion questions for students:

- How do we rely on wetlands?
    - They offer protection from erosion. They buffer the coastline during storms, thus protecting our structures. They are a nursery habitat for fish and crabs and help contribute to the large seafood industry in the Gulf of Mexico.
- What plant grows in a salt marsh?
    - Common salt marsh plants along the northern Gulf of Mexico inclide: smooth cordgrass *Spartina alterniflora*, Black needlerush *Juncus roemerianus,* Saltmeadow cordgrass *Spartina patens*, Bulrush *Schoenoplectus americanus*, and Salt grass *Distichlis spicata*
- Where are salt marshes located?
    - Salt marshes are wetlands located along the coast and influenced by tides.
- What organisms rely on salt marsh habitat?
    - Blue crab, shrimp, red drum, osprey, blue heron, periwinkle snails, and many more.
- What is a rhizome and what is the function?
    - A rhizome is a horizontal underground root. It spreads to produce new clones of the plant.
- Why are salt marshes threatened?
    - Salt marshes are threatened from upland sources like human development and runoff, and from sea-level rise.
- Why are sea walls not as good as natural shorelines?
    - Sea walls and hardened structures are not able to adapt and change over time. Also, due to their impermeability they redirect wave energy and can increase erosion in adjacent locations.

- Name 3 benefits of restoring natural shorelines on private properties.
    - Restoring natural shorelines on private property can help reduce erosion, support healthy coastal ecosystems, and boost local economies.
- Which was more efficient at protecting the shoreline, the 50 percent coverage area or the 100 percent coverage area?
    - The area planted at 50 percent coverage was the most efficient as it performed just as well as the area plated at 100 percent but cost less to install.
- Which would be cheaper and less labor intensive (less hard work)?
    - The 50 percent coverage.
- What is a breakwater?
    - A nearshore breakwater is a structure used to help reduce wave energy before it hits the marsh. Depending on the site, these breakwaters can be made of temporary materials, such as biodegradable coir logs or short, board fences, or longer-term materials, such as loose stone, concrete structures, or oyster shell cages.

Connect the outcomes of the water pan demonstration to coastal building ordinances in Module 3 (Lesson 3.3) and Module 4 (Lesson 4.1).

EVALUATE:

Return to the images from the start of the lesson. Ask students if their thoughts changed on the erosion protection.

Ask students: What causes erosion? What are examples of different shorelines? Which shoreline offered the most protection from erosion? Which shoreline offered the most habitat to animals?

STUDENT PAGE | Reading – Living with Living Shorelines

Salt marshes are coastal wetlands common throughout the globe and visible just about any time you drive over a bridge along the coast. Found in estuaries, where rivers meet the ocean, these wetlands stabilize the shoreline, act like kidneys to filter nutrient pollution, and offer food and shelter for birds and fish. Black needlerush is one of the dominant species of grass-like perennial foliage native to the Gulf and Atlantic coasts. It grows moderately fast, forming a deep, fibrous root system and dense above-ground canopy that provide habitat for waterfowl, muskrats, nongame birds, and organisms that are the base of the food chain for fish, shrimp, crabs and other commercially important seafood. The hardy root system essentially grabs and holds sediment in place, which, in turn, slows down shoreline erosion.

Salt marshes are rapidly disappearing as people build hard structures, such as seawalls and bulkheads, to help lessen erosion. Human development in these wetlands all over the world is causing large losses of marshland, but the most dramatic losses in the United States are happening in the northern Gulf of Mexico, which includes Mississippi, Texas, Louisiana, Alabama, and Florida. Natural shorelines are much better at providing a long-term solution for lessening coastal erosion. Sea walls and other hard structures deteriorate from exposure to saltwater, and many must be replaced every 10 to 30 years.

Restoring natural shorelines on private property can help reduce erosion, support healthy coastal ecosystems, and boost local economies. In fact, scientists have conservatively estimated that coastal marshes provide more than $20 billion worth of shoreline stabilization and storm protection services in the United States alone. The majority of our shoreline is small, privately owned tracts of property.

Resent research explored the most economical and effective method of salt marsh restoration for small-scale projects. Restoring natural shorelines on private property can help reduce erosion, support healthy coastal ecosystems, and boost local economies.

In the study, scientists from Mississippi State University, the University of South Alabama, Dauphin Island Sea Lab, the University of Connecticut, The Nature Conservancy, and the Grand Bay National Estuarine Research Reserve planted black needlerush in two different designs at the Grand Bay National Estuarine

Black needlerush lines many Mississippi and Alabama coastal areas and protects them from erosion. Extensive root systems protect bayou and bay shorelines from low to moderate wave energy. (Photo by MSU Extension Service/Eric Sparks)

Research Reserve in Moss Point, Mississippi. They harvested the marsh plants from a nearby marsh and used this donor area as a control site for comparison. Transplants were planted in one design area at 100 percent coverage. The second design area was planted at 50 percent coverage, which was less costly and labor-intensive. After two years, both design areas performed similarly. The area planted at 50 percent coverage was the most efficient as it performed just as well as the area planted at 100 percent but cost less to install.

The techniques used in living shorelines are extremely site specific, but an essential aspect of the construction is a nearshore breakwater to help reduce wave energy before it hits the marsh. Depending on the site, these breakwaters can be made of temporary materials, such as biodegradable coir logs or short, board fences, or longer-term materials, such as loose stone, concrete structures, or oyster shell cages. Temporary breakwaters are intended to persist long enough for plants to get established or rerooted. In higher wave energy environments, the more permanent breakwaters may be needed for sustained shoreline protection in conjunction with the shoreward salt marsh.

Reading adapted from publications by Dr. Eric Sparks: Salt marsh plants offer valuable shoreline service, Sparks EL. 2018. Research helps landowners reduce erosion and support ecosystems. Sparks EL, Cebrian J. 2016. Salt marsh plants offer valuable shoreline service, Sparks EL. 2018.

Shoreline #1: ____________________________________

Draw a picture of what the shoreline looks like before any wave action:

Write your hypothesis for what you think will happen when waves come up to this shoreline?

Place a piece of tape on the outside of the container where the sand stops.

One student per group will make 20 waves in the water using the paint scraper.

Marks where the sand stops with another piece of tape.

Use a ruler to measure how far the sand traveled from the first piece of tape to the last piece of tape. How many millimeters did the shoreline move back from the start of the experiment to the end? ____________________________________

Draw a picture of what the shoreline looks like after all 20 waves:

Before you rotate to the next station, repair the shoreline back to the original condition and remove the tape.

Was your hypothesis supported by the data? Explain.

Shoreline #2: ______________________________________

Draw a picture of what the shoreline looks like before any wave action:

Write your hypothesis for what you think will happen when waves come up to this shoreline?

Place a piece of tape on the outside of the container where the sand stops.

One student per group will make 20 waves in the water using the paint scraper.

Marks where the sand stops with another piece of tape.

Use a ruler to measure how far the sand traveled from the first piece of tape to the last piece of tape. How many millimeters did the shoreline move back from the start of the experiment to the end? ______________________________________

Draw a picture of what the shoreline looks like after all 20 waves:

Before you rotate to the next station, repair the shoreline back to the original condition and remove the tape.

Was your hypothesis supported by the data? Explain.

Shoreline #3: ______________________________________

Draw a picture of what the shoreline looks like before any wave action:

Write your hypothesis for what you think will happen when waves come up to this shoreline?

Place a piece of tape on the outside of the container where the sand stops.

One student per group will make 20 waves in the water using the paint scraper.

Marks where the sand stops with another piece of tape.

Use a ruler to measure how far the sand traveled from the first piece of tape to the last piece of tape. How many millimeters did the shoreline move back from the start of the experiment to the end? ______________________________________

Draw a picture of what the shoreline looks like after all 20 waves:

Before you rotate to the next station, repair the shoreline back to the original condition and remove the tape.

Was your hypothesis supported by the data? Explain.

Shoreline #4: ____

Draw a picture of what the shoreline looks like before any wave action:

Write your hypothesis for what you think will happen when waves come up to this shoreline?

Place a piece of tape on the outside of the container where the sand stops.

One student per group will make 20 waves in the water using the paint scraper.

Marks where the sand stops with another piece of tape.

Use a ruler to measure how far the sand traveled from the first piece of tape to the last piece of tape. How many millimeters did the shoreline move back from the start of the experiment to the end? ____

Draw a picture of what the shoreline looks like after all 20 waves:

Before you rotate to the next station, repair the shoreline back to the original condition and remove the tape.

Was your hypothesis supported by the data? Explain.

DO NOW:

Describe the following terms:

Landward Migration

Vertical Accretion

EXIT TICKET:

What characteristics make a shoreline more resilient to wave action?

2.3 Puddles to Gardens

AGE RANGE

9th—12th grade

TIME REQUIRED

90 minutes

ACTIVITY OVERVIEW

Engage: Rain Garden Introduction
Explore: Tour of Potential Locations
Explain: Drainage Calculations
Elaborate: Rain Garden Planning
Evaluate: Presentations

MATERIALS

Student Worksheet
graph paper
pencil
tape measure
long handle shovel
ruler
hose or watering can

BASED ON:

"Rain Gardens" by Kids Gardening

LESSON TOPIC: Community implementation of rain gardens

ACTIVITY SUMMARY: Students explore the mathematics involve with planning a rain garden.

OBJECTIVES:

Students will be able to:

- Understand the impact of stormwater runoff and water pollution on the environment.
- Explore the ability of plants to absorb and filter water.
- Design a rain garden for their school.

LESSON BACKGROUND: In suburban and urban settings, much of the rain that falls hits impervious surfaces such as roofs, parking lots, and roads, where it cannot be absorbed. It becomes runoff, moving across the ground to areas where it can be absorbed or into local waterways, either directly or via storm sewers. In urban settings, as little as 15% of the water may be absorbed where it falls and up to 55% will run off. Not only does this result in lower groundwater reserves which endangers drinking water supplies and can ultimately cause land to sink (subsidence), it also creates a significant amount of water to deal with above ground.

Although rain is an important contributor for recharging local waterways, the problem with runoff from urban environments is what the runoff is carrying. As the water moves across surfaces such as streets, parking lots, and roofs, it picks up all sorts of pollutants, from nutrients like nitrogen and phosphorous that fuel algal blooms to pesticides, herbicides, oil, grease, heavy metals, and harmful bacteria. These pollutants can kill water life and interfere with the delicate balance of the aquatic ecosystem.

A rain garden is a garden planted in a low area to encourage water collection. This design enables rain gardens to trap stormwater before it becomes runoff and filter it before it's absorbed into the soil. The plants in a rain garden have high tolerance for excess moisture and the increased levels of nutrients often found in stormwater. Rain gardens are most useful if situated downhill from impervious surfaces, such as rooftops and roads, and are designed to collect runoff from those surfaces. They slow down the flow of stormwater by collecting it in the sunken garden area and allowing it to absorb into the soil rather than cause erosion and carry pollutants into our waterways.

Note: this lesson has the option to explore an area outside after a rain and to use tools to collect soil samples and plant. Consider safety measures you need to put in place.

VOCABULARY:

Conservation Planning	To maintain natural values and assets in a specific landscape or seascape with competing uses, values, and other threats and opportunities.
Stormwater Runoff	Rain that falls on streets, parking areas, sports fields, gravel lots, rooftops or other developed land and flows directly into nearby lakes, and rivers.

ENGAGE:

Introduce the students to this lesson by observing a rain event or by walking around the school following a rain event. If your class time overlaps with an active rainstorm have the student watch the rain. Ask students: What happens to the water once it hits the ground? If your class time occurs after a rainstorm has passed, take the students outside to observe areas of flowing or standing water. Ask students: How is the water from rain managed at our school? If no periods of rain coincide with your class, ask them to recall rain experiences at school or home.

Make the connection of rain gardens to wetland plants. Rain gardens bring the benefits of wetlands -water filtration, reducing runoff, limiting erosion, and providing animal habitat – to areas beyond the coast.

EXPLORE:

Materials:

- graph paper
- pencil
- tape measure
- long handle shovel
- ruler
- hose or watering can

Procedure:

1. Divide students into pairs or small groups.
2. Take the class on a tour of the school ground to identify a good location to build a rain garden, looking for an area lower in elevation and at least 10 ft away from buildings. The garden should not be placed over a septic system or under mature trees to protect the roots.
    a. This lesson will only be for the students to plan the garden, but if your supplies allow and your school is willing, you may be able to implement your garden. Make sure to call your local utilities hotline to have them mark any underground lines on the property before you dig your garden.
3. Once you identify a possible site, test the drainage of the soil. It is important for the garden to contain well-draining soil so that the collected water dissipates within two to four days. If water sits for too long, plant roots will suffocate, and insect breeding will become a problem. Ideal rain garden soil is comprised of 20-25% leaf mulch or compost, sandy soil, and topsoil.
    a. To test the drainage of the soil in each a potential rain garden location:
        i. Dig a hole 6 inches wide and 18 inches deep in each location
        ii. Fill each hole with water and measure depth with a ruler.
        iii. Check on water depth every hour and record results.
    b. If all the water drains within a few hours, the site has excellent drainage. If the water drains within 24 hours, then it is still an acceptable site for a rain garden. If the water has not drained in 48 to 72 hours, then you should choose a different location.

Rain Garden Examples:

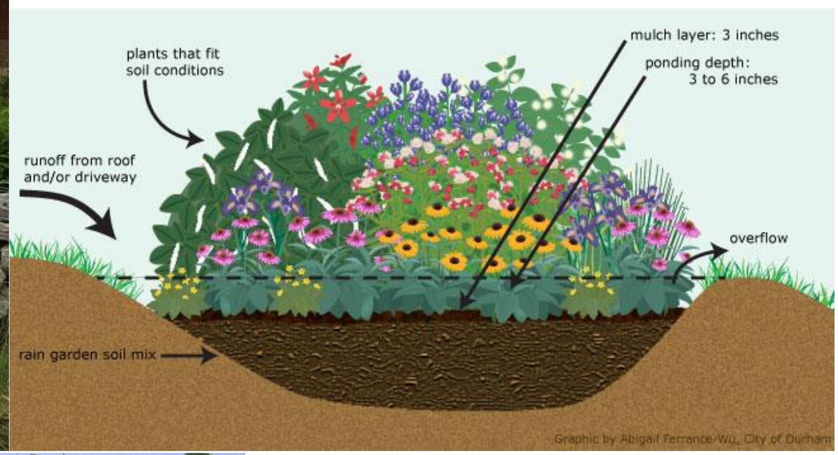


Image: Rain gardens, such as the one at the Mississippi State University Landscape Architecture Facility (left), are designed to channel and filter excess rainwater. Diagram on the right is from City of Durham, NC. Bottom shows rain garden picture overlaid with diagram of water flow, from Alabama Cooperative Extension System.

EXPLAIN:

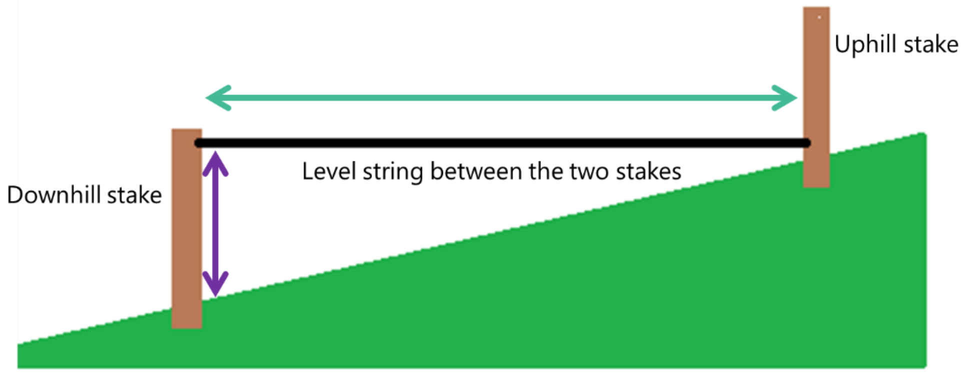
To design an effective rain garden, students will need to consider the drainage from the test earlier as well as the slope. Calculations can be conducted inside, and then include an outside exploration.

How to Calculate Drainage Area:

To determine the size of the area that will drain into the rain garden, measure the amount of impervious surfaces surrounding the location of your rain garden.

length (ft) x width (ft) = _____________ft ^{2} (drainage area)

How to Determine the Slope or Necessary Depth of the Rain Garden:



1. Place a stake at the uphill end for the rain garden and another at the downhill end.
2. Level the string between the two stakes.
3. Measure the total length of the string (teal arrow) and height of the string at the downhill stake (purple arrow) in inches.
4. Divide the height by the length of the string and multiply the result by 100. This is the slope as a percentage.

Slope = (height/length) x 100

The slope into the rain garden will help you figure out how deep the soil in your garden needs to be. Once you have calculated the slope, use the chart to identify the appropriate soil depth for your rain garden.

Slope	Depth
<4%	3-5 inches
5-7%	6-7 inches
8-12%	8+ inches

How to Determine the Soil Type in Your Rain Garden:

1. Grab a handful of moist soil and roll it into a ball in your hand.
2. Place the ball of soil between your thumb and the side of your forefinger and gently push the soil forward with your thumb, squeezing it upwards to form a ribbon about ¼" thick.
3. Try to keep the ribbon with a uniform thickness and width. Repeat the motion to lengthen the ribbon until it breaks under its own weight. Measure the ribbon and evaluate according to these specifications:
    a. Sand: soil does not form a ribbon at all
    b. Silt: soil forms a weak ribbon <1.5 inches before breaking
    c. Clay: soil forms a ribbon >1.5 inches long

EXTENSON: A more in-depth soil texture analysis can be conducted as part of this lesson by following "The Jar Test" procedure.

Materials:

- Straight edged, clear jar
- Permanent marker
- Ruler
- Timer
- 1 tablespoon of powdered dishwashing detergent
- Mesh sieve or old colander

Procedure:

1. Using a mesh sieve or old colander, sift the soil to remove any debris, rocks, and large organic matter (leaves, sticks, roots, etc.).

2. Fill the jar ⅓ full of the soil to be tested

Jar filled a ⅓ of the way full with soil. Andrew Jeffers, ©2018, Clemson Extension

3. Fill the remainder of the jar with clean water and leave some space at the top.

4. Add 1 tablespoon of powdered dishwashing detergent.

5. Cap the jar and shake vigorously until the soil turns into a uniform slurry.

6. Set on a level surface and time for one minute.

7. Place a mark the outside of the jar, showing the coarse sand layer settled at the bottom of the jar.

Jar showing the coarse sand layer settled at the bottom of the jar.
Andrew "Drew" Jeffers, ©2018, Clemson Extension

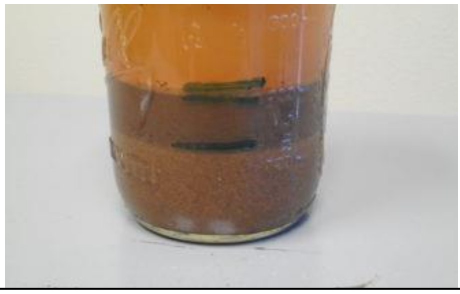
8. Leave the jar in a level spot for 2 hours.

9. Mark the top of the next settled layer with the permanent marker. This is the silt layer.

Jar showing the silt layer.
Andrew "Drew" Jeffers, ©2018, Clemson Extension

10. Leave the jar on a level spot for 48 hours.

11. Mark the top of the next settled layer with the permanent marker. This is the clay layer that has settled on top of the silt layer.



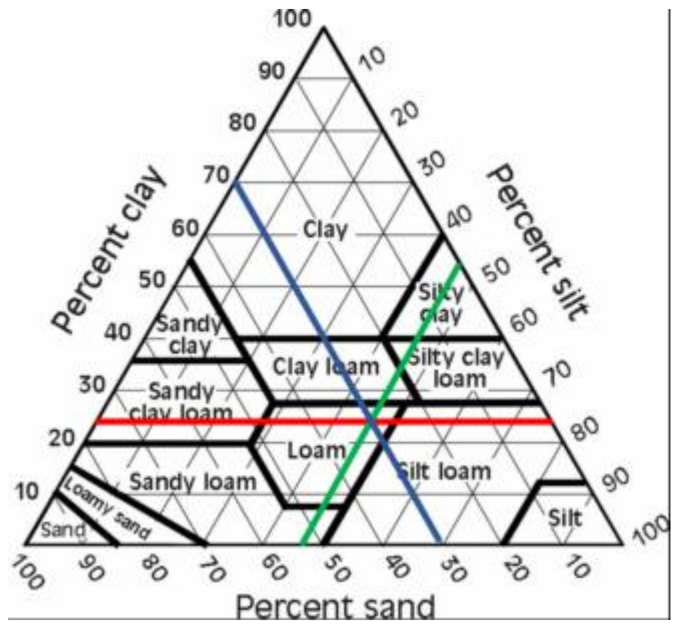
Jar showing the clay layer.
Andrew "Drew" Jeffers, ©2018, Clemson Extension

12. Using a ruler, measure and record the height of each layer, and the total height of all three layers. Use the soil texture analysis worksheet below to record results.

Using a ruler, measure and record the height of each layer, and the total height of all three layers. Andrew “Drew” Jeffers, ©2018, Clemson Extension

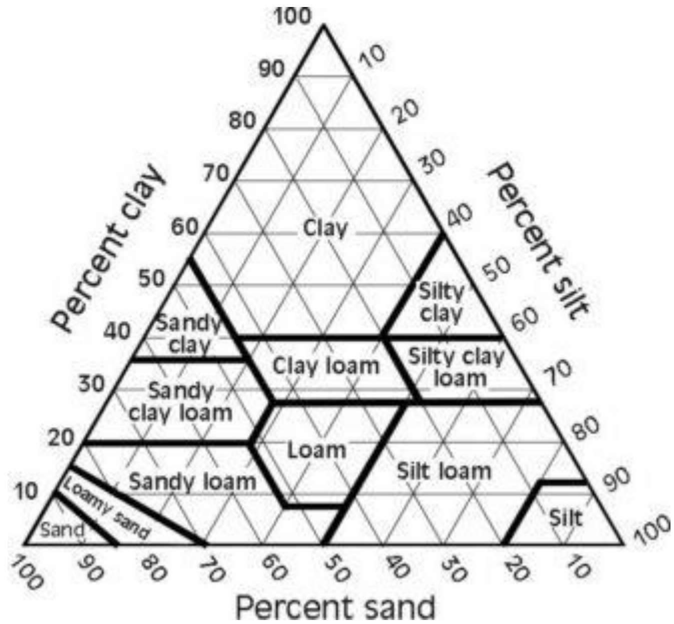
Procedure for using a soil texture triangle to estimate the soil type:

1. Use the soil texture triangle to estimate the soil type for the site.
2. The clay percentages are listed on the left side of the triangle. Lines corresponding to clay percentages extend from the percentages reading left to right (see red line).
3. The silt percentage is on the right side, with lines extending downwardly, diagonally right to left (see green line).
4. The sand percentage is on the right side, with lines extending upwardly, diagonally right to left (see blue line).
5. Track the lines with the percentages measured and find the spot on the triangle where all three lines intersect. The region where these lines intersect indicates the soil type present. The example shown represents a loam soil texture.



Soil Texture Analysis “The Jar Test” Worksheet:

Insert your measurements from the jar in the spaces below:



Height of sand layer _______inches / cm

Height of silt layer _______inches / cm

Height of clay layer _______inches / cm

Total height of layers _______inches / cm

% SAND=(sand height)/(total height) x 100 =__________ % SAND

% SILT=(silt height)/(total height) x 100 =___________ % SILT

% CLAY=(clay height)/(total height) x 100 =___________ % SILT

Adapted from: Soil Texture Analysis “The Jar Test” Procedure by Andrew "Drew" Jeffers, Spartanburg Cooperative Extension, Horticulture and Natural Resource Agent, Clemson University

Note: the lesson can be paused here for the day.

How to Determine the Size Factor of Your Rain Garden:

1. Locate the soil type of your rain garden on the left hand column of the table below.
2. Locate the depth you calculated for your rain garden in the second row of the table below.
3. Identify where the soil type and depth intersect in the table to find the proper size factor for your garden.
4. Use this number in the equation below to determine the appropriate size of your rain garden.

Soil Type	Depth		
	3-5 inches	6-7 inches	8+ inches
Sand	0.19	0.15	0.08
Silt	0.34	0.25	0.16
Clay	0.43	0.32	0.20

How to Determine the Size of Your Rain Garden:

Size Factor x Drainage Area = Rain Garden Area

Example: Suppose a rain garden was determined to have a drainage area of 1,000ft^2. It has a slope of 5%, requires a depth of 6-7 inches, and has clay soil. To determine the recommended size of the rain garden: 0.32 (Size Factor) x 1,000 ft^2 (Drainage Area) = 320ft^2 (Rain Garden Size)

ELABORATE:

Students continue to work in groups to plan out their rain garden. Have students plan the size of their rain garden and select plants. They can map out their garden using graph paper. Graph paper also comes in poster size, and can be used by students to create a larger scale plan. The design of the garden can be varied between students but should include the following components:

1. Ponding area or depression. To help capture runoff, the garden base should be shaped like a saucer with the middle deeper than the edges. The land leveling between the middle (generally 6" deep) and edges should be gradual so that water is spread out throughout the garden. Because of this shape, the edges of the garden will usually be drier than the middle which will need to be considered when selecting plant materials.
2. Well-draining soil. Well-draining soil is important to ensure quick absorption of runoff. During planting and maintenance, it is important to avoid compacting the soil, which will decrease its effectiveness.

3. Tough plants. Plants chosen for the rain garden must be able to tolerate extremes of wet and dry soil. Rain gardens are typically planted with shrubs and perennials. Because the rain garden functions better with deep rooting plants, annuals are not part of the usual design. Native plants are often the best choices because they will be well suited to the environmental conditions of your climate.
4. Mulch. Mulch is needed to protect the soil from erosion and insulate the garden from extreme wet and dry conditions. Shredded bark mulch is preferable because it does not wash away as easily as lighter bark chips.
5. A grass buffer strip. A grass buffer strip around the garden is important to slow the speed at which the runoff enters the garden and to decrease soil erosion.
6. A berm. A berm made from at least six inches of soil or rocks helps to keep the runoff in the garden long enough to allow it to be absorbed into the soil. Make sure that if your garden does overflow, the overflow will head to storm drains rather than towards structures.

Students may use this list as a resource to select suitable plants for rain gardens in the Gulf South. Information from Mississippi State University Extension.

Small and Large Trees			**Perennials**	
Common name	**Scientific name**		**Common name**	**Scientific name**
Swamp red maple	*Acer rubrum var. drummondii*		Joe pye weed	*Eupatorium fisulosum*
Bald cypress	*Taxodium distichum*		Cardinal flower	*Lobelia cardinalis*
Green ash	*Fraxinus pennsylvanica*		Stokes aster	*Stokesia laevis*
Swamp black gum	*Nyssa sylvatica var. biflora*		Rose mallow	*Hibiscus lasiocarpus*
Willow oak	*Quercus phellos*		Texas star hibiscus	*Hibiscus coccinea*
Black willow	*Salix nigra*		Louisiana iris	*Iris spp*
Sweet bay magnolia	*Magnolia virginiana*		Boltonia	*Boltonia asteroids*
Pond cypress	*Taxodium ascendens*		Coreopsis	*Coreopsis lanceolata*
Mayhaw	*Crataegus opaca*		Swamp sunflower	*Helianthus angustifolius*
Ironwood	*Carpinus caroliniana*		Blue flag iris	*Iris virginica*
Wax myrtle	*Myrica cerifera*		Blazing star	*Liatris spicata*
			Cinnamon fern	*Osmunda cinnomomea*
Shrubs			Royal fern	*Osmunda regalis*
Gallberry holly	*Ilex glabra*		Goldenrod	*Solidago canadensis*
Yaupon holly	*Ilex vomitoria*		Ironweed	*Vernonia spp.*
Dwarf palmetto	*Sabal minor*		Obedient plant	*Physostegia virginiana*
Chokeberry	*Aronia arbutifolia*		Horsetail	*Equisetum hyemale*
Buttonbush	*Cephalanthus occidentalis*			

Summersweet	*Clethra alnifolia*		**Grasses and Sedges**	
Sweetspire	*Itea virginica*		River oats	*Chasmanthium latifolium*
Titi	*Cyrilla racemiflora*		Blue sedge	*Carex glauca*
Buckwheat tree	*Cliftonia monophylla*		Woolgrass	*Scirpus cyperinus*
			Muhly grass	*Muhlenbergia capillaries*
			Panic grass	*Panicum virgatum*
			Little bluestem	*Andropogon virginicus*
			Spikerush	*Eleocharis spp.*

For any additional assistance needed for planning a rain garden please reach out to your local extension service. Mississippi educators can reach out to Christine E.H. Coker, Ph.D., GRP.

Email address: christine.coker@msstate.edu
Title: Associate Research and Extension Professor of Urban Horticulture
Mississippi State University Coastal Research and Extension Center
Beaumont Horticultural Unit

EVALUATE:

Students can present their rain garden design to the class, making sure to answer the following questions:

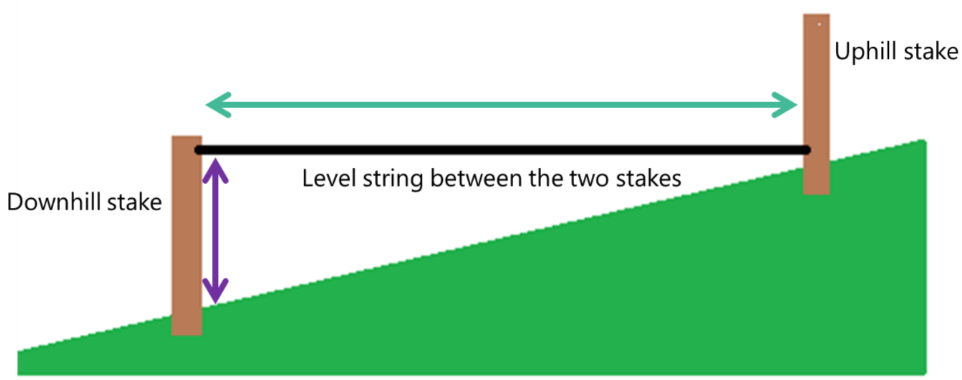
- What is the impact of stormwater on rivers, streams, and lakes?
- What are some ways each individual can reduce their impact on local waterways?
- State some reasons to mitigate stormwater runoff.
- State the purpose of rain gardens.
- State your scenario conclusions.
- Showcase your garden design.
- Showcase a listing of selected plants and why they were selected for use in the rain garden.

How to Calculate Drainage Area:

To determine the size of the area that will drain into the rain garden, measure the amount of impervious surfaces surrounding the location of your rain garden. *Make sure to pay attention to units.*

length (ft) x width (ft) = ____________ft ^{2} (drainage area)

How to Determine the Slope or Necessary Depth of the Rain Garden:



1. Place a stake at the uphill end for the rain garden and another at the downhill end.
2. Level the string between the two stakes.
3. Measure the total length of the string (teal arrow) and height of the string at the downhill stake (purple arrow) in inches.
4. Divide the height by the length of the string and multiply the result by 100. This is the slope as a percentage.

Slope = (height/length) x 100

The slope into the rain garden will help you figure out how deep the soil in your garden needs to be. Once you have calculated the slope, use the chart to identify the appropriate soil depth for your rain garden.

Slope	Depth
<4%	3-5 inches
5-7%	6-7 inches
8-12%	8+ inches

How to Determine the Soil Type in Your Rain Garden:

1. Grab a handful of moist soil and roll it into a ball in your hand.
2. Place the ball of soil between your thumb and the side of your forefinger and gently push the soil forward with your thumb, squeezing it upwards to form a ribbon about ¼" thick.
3. Try to keep the ribbon with a uniform thickness and width. Repeat the motion to lengthen the ribbon until it breaks under its own weight. Measure the ribbon and evaluate according to these specifications:
    a. Sand: soil does not form a ribbon at all
    b. Silt: soil forms a weak ribbon <1.5" before breaking
    c. Clay: soil forms a ribbon >1.5" long

How to Determine the Size Factor of Your Rain Garden:

1. Locate the soil type of your rain garden on the left hand column of the table below: Sand, Silt, or Clay.
2. Locate the depth you calculated for your rain garden in the second row of the table below: 3-5 inches, 6-7 inches, or 8+ inches.
3. Identify where the soil type and depth intersect in the table to find the proper size factor for your garden.
4. Use this number in the equation below to determine the appropriate size of your rain garden.

Soil Type	Depth		
	3-5 inches	6-7 inches	8+ inches
Sand	0.19	0.15	0.08
Silt	0.34	0.25	0.16
Clay	0.43	0.32	0.20

How to Determine the Size of Your Rain Garden:

Size Factor x Drainage Area = Rain Garden Area

Example: Suppose a rain garden was determined to have a drainage area of 1,000ft^2. It has a slope of 5%, requires a depth of 6-7 inches, and has clay soil. To determine the recommended size of the rain garden: 0.32 (Size Factor) x 1,000 ft^2 (Drainage Area) = 320ft^2 (Rain Garden Size)

DO NOW:

Compare the benefits of living shorelines and bulkheads.

EXIT TICKET:

How do plants help reduce flooding?

level rise

  - Data in the Classroom: https://dataintheclassroom.noaa.gov/content/sea-level
- Additional sea-level rise educational activities from NOAA National Ocean Service
  - "Sea Level Rise" https://oceanservice.noaa.gov/education/sea-level-rise/welcome.html
- Article with five steps for teaching climate change
  - "How to teach climate change in a non-scary way" https://www.tes.com/news/how-teach-climate-change-non-scary-way
- Online module with introduction to climate change
  - "ClimatEdu" Climate education made by students, for students: https://climatedu.org/

Readings

- Additional resources for talking about climate change
  - Frameworks Institute, "How to Talk about Climate Change and the Ocean": http://www.frameworksinstitute.org/assets/files/PDF_oceansclimate/climatechangeandtheocean_mm_final_2015.pdf
- Informational NOAA webpage about sea-level rise with graphs and images
  - NOAA Climate, "Climate Change: Global Sea Level": https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level
- Infographic about sea-level rise by NASA
  - https://climate.nasa.gov/climate_resources/125/infographic-sea-level-rise/
- StoryMap about the financial impact on city and state locals from the "Ellicott City Flash Flood"
  - https://www.arcgis.com/apps/Cascade/index.html?appid=0496f01f99604990b10519b5b144040f & https://apps.npr.org/ellicott-city
- Article from NASA, "NASA-led Study Reveals the Causes of Sea Level Rise Since 1900"
  - https://climate.nasa.gov/news/3012/nasa-led-study-reveals-the-causes-of-sea-level-rise-since-1900/
- Article on connection of sea-level rise and stormwater management, "In Norfolk, sea level rise reduces some stormwater system capacity by 50%, data shows"
  - https://www.pilotonline.com/news/environment/vp-nw-fz20-sensor-stormwater-flooding-norfolk-20210103-t4jofv7hbff3dgcposbf7z7p5m-story.html?fbclid=IwAR29Mph9-3Myduj1oXMIPmJeWs035z0K_9Vb9LZDlu3TSoStrO0ac6tnx-Y
- Article on the differences of sea-level rise impacts on marginalized communities, "Mexico explains decision to flood poor, Indigenous areas"
  - https://apnews.com/article/floods-mexico-898bd6f13f6a5c2e1a4dc2b0217def62

RECOMMENDED CURRICULUM CITATION:

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1.1 Frozen in Time: Ice Cores and Earth's Recent Climate Changes

AGE RANGE

9th—12th grade

TIME REQUIRED

100 minutes

ACTIVITY OVERVIEW

Engage: Connect-it!
Explore: Ice core graphing
Explain: Discussion
Elaborate: Carbon dioxide concentrations
Evaluate: Discussion

MATERIALS

"Vostok, Antarctica, Ice Core Data" worksheet for each student
"Carbon Dioxide Concentration and Temperature Rate of Change" for each student
Graph paper
Colored pencils
Connect-It Cards

BASED ON:

"Getting to the Core" EPA

LESSON TOPIC: Climate change

ACTIVITY SUMMARY: Students will graph data from Antarctic ice core samples.

OBJECTIVES:

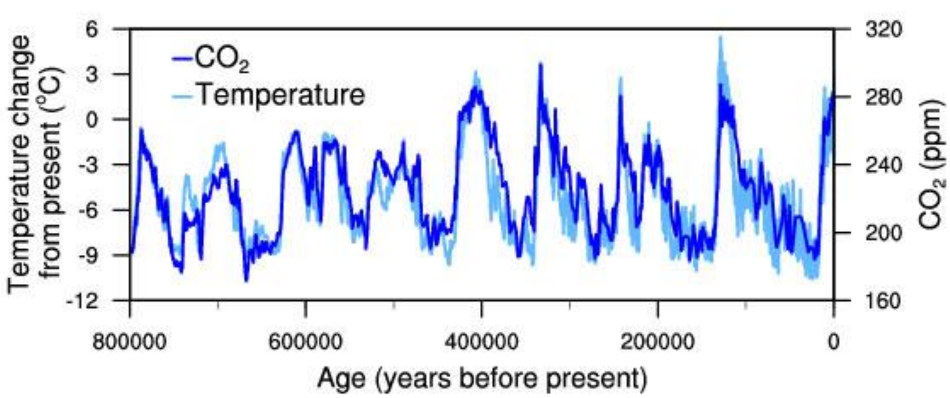
Students will be able to explain that:

- Ice core data shows Earth's record for hundreds of thousands of years.
- As carbon dioxide increases, so does temperature.
- Past patterns can help understand future scenarios.
- Changes and rates of change to systems can be quantified over short or long time periods.

LESSON BACKGROUND: Since the start of the Industrial Revolution around 1750, people have burned large amounts of coal, oil, and natural gas to power their homes, factories, and vehicles. Today, most of the world relies on these fossil fuels for their energy needs. Burning fossil fuels releases excess carbon dioxide (CO_2); this builds up in the atmosphere like a blanket and traps heat, warming the Earth. We rely on our atmosphere to trap heat to maintain the temperature on Earth, but our rate of burning fossil fuels is adding too much CO_2, termed a greenhouse gas, and warming the Earth too much.

The Earth's climate has changed many times before. There have been times when most of the planet was covered in ice, and there have also been much warmer periods than we are experiencing today. Over at least the last 650,000 years, CO_2 levels in the atmosphere have increased and decreased in a cyclical pattern. The Earth's temperature has also experienced a similar cyclical pattern characterized by glacial and interglacial periods. During glacial periods (more commonly called ice ages), the Earth has experienced a widespread expansion of ice sheets on land. Intervals between ice ages, called interglacial periods, are marked by higher temperatures. The Earth has been in an interglacial period for more than 11,000 years. Historically, temperature and CO_2 have followed similar patterns and for hundreds of thousands of years, the concentration of CO_2 in the atmosphere cycled between 200 and 300 parts per million (ppm). Today, it's up to nearly 400 ppm, and the amount is still rising.

Before temperatures were recorded with modern instruments, the Earth itself recorded clues about temperature, precipitation, atmospheric gases, and other aspects of the environment in the thick layers of ice that have accumulated in places like Greenland and Antarctica. To reveal these clues to the past, researchers drill into glaciers and ice sheets and remove cylinder-shaped samples of ice called ice cores. Back in the laboratory, scientists can use chemical sampling techniques to determine the age of each layer of ice and the concentrations of different gases trapped in tiny air bubbles within the ice, revealing the composition of the atmosphere in the past. They can also examine the water molecules in the ice to get information about historical temperatures. Trapped pollen and dust provide additional clues about the climate. Ice core records can go back hundreds of thousands of years, and they help scientists find out whether the rapid increase in CO_2 levels and temperature we are currently observing fits a natural pattern or not. The first and deepest ice core drilling occurred at Vostok, a research station located in Antarctica. From the Vostok ice core samples and other ice core drillings, researchers can determine temperature and the amount of trace gases in Earth's atmosphere dating back over 400,000 years ago. Investigating the Earth's air temperature and the amount of CO_2 in the atmosphere over a long time period helps us to better understand the Earth's carbon cycle, its relationship to the greenhouse effect, and its role in regulating the Earth's climate.



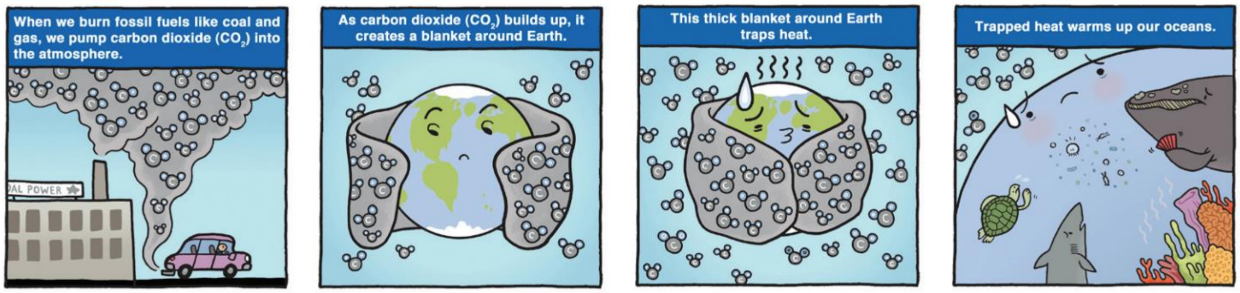
Temperature change (light blue) and carbon dioxide change (dark blue) measured from the EPICA Dome C ice core in Antarctica (Jouzel et al. 2007; Lüthi et al. 2008).

VOCABULARY:

Carbon Emissions	Release of carbon (i.e., carbon dioxide) gas into the atmosphere through direct (e.g., driving cars, shipping industry, airplanes, etc.) or indirect (e.g., food, textiles, etc.) means.
Carbon Storage	Capture and storage of carbon dioxide before release to the atmosphere (also known as 'carbon sequestration') through natural and/or anthropogenic (i.e., human) processes. Carbon storage can mitigate climate change.
Changes in Air Quality	Increases and decreases in pollutants (e.g., particulate matter, sulfates, volatile organic compounds, etc.) and/or changes in the health and safety of the atmosphere. These can be caused by a changing climate (i.e., increasing temperatures result in lower air quality).
Climate	Weather conditions prevailing in general or over a long period.
Climate Change	Long-term change in the average weather patterns that have come to define Earth's local, regional, and global climates.
Climate Scenarios	Projected characteristics of potential future climate(s) (e.g., hotter, wetter).
Emissions Scenarios	Modeled future changes in releases of greenhouse gases into the atmosphere.
Fossil Fuels	A fuel (e.g. coal, oil, or natural gas) formed in the earth from plant or animal remains.
Temperature Anomaly	A difference in temperature, compared with a particular baseline or reference point.
Weather	Day-to-day changes in atmospheric conditions.

ENGAGE:

Demonstrate how the greenhouse effect works by having students explore the Connect-it! Cards: https://climateinterpreter.org/resource/climate-training-activities-connect-it. Discuss the greenhouse effect and the link between temperature and CO_2.



EXPLORE:

1. A student reading *Introduction to Climate and Climate Change* is provided for students to read before the lesson, during the lesson, or after the lesson.
2. Let students see first-hand how scientists are working in the field to collect ice cores. (See https://tinyurl.com/r4erwjj.)
3. **Ask students:** Why are scientists examining ice cores? What information does it provide?
4. Hand out copies of the "Vostok, Antarctica, Ice Core Data" worksheets, two sheets of graph paper per student, and colored pencils. **Discuss what is meant by a temperature anomaly**. [Answer: Temperature anomaly means a departure from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value. For this data set, the reference value is -56 °C.]
5. Students complete the Vostok, Antarctica, Ice Core Data worksheet following the below instructions:
    a. In the space provided in column three, round the carbon dioxide (CO_2) concentration to the nearest whole number. If your students are adept at rounding, you can direct them to skip this step and proceed to graphing.
    b. In the space provided in column five, round the temperature anomaly to the nearest tenth of a degree.
6. Students graph the results following the below instructions:
    a. You will create two graphs: one for CO_2 concentration and one for temperature anomaly.
    b. On both graphs, your x-axis will represent years. Start with 400,000 BC on the left and number as far as the year 0 on the right, counting by intervals of 10,000 years. Label the axis.
    c. On the first graph, the y-axis on the left side of the paper will represent the CO_2concentration using units of parts per million (ppm). Begin with 100 ppm at the

lower end, and number up to 400 ppm, counting by intervals of 10 ppm. Label the axis.

d. On the second graph, the y-axis on the left side of the paper will represent the temperature anomaly in degrees Celsius (°C). Begin with -10.0 °C at the lower end and number up to 2.0 °C, counting by intervals of 0.5 °C. Label the axis.
e. Using different colored pencils, plot the points for CO_2 concentration and temperature anomaly.
f. Write a title on each graph.

EXPLAIN:

When students have finished their graphs **discuss** the following questions as a class:

- What pattern(s) do you notice on the graphs?
  - [Answer: A repeating cycle. When the carbon dioxide concentration goes up, temperature goes up. When the carbon dioxide concentration goes down, temperature goes down.]
- How many peaks (top) can you identify? How many troughs (bottom)? Count the high points as peaks and the low points as troughs.
  - [Answer: Five peaks and four troughs.]
- What is the approximate number of years in one complete cycle? (Hint: A cycle is the time between two peaks or between two troughs.)
  - *[Answer: 100,000 years.]*
- Do peaks represent glacial (cold) periods, or do troughs? How do you know?
  - *[Answer: Troughs, because the temperature is at its lowest.]*

ELABORATE:

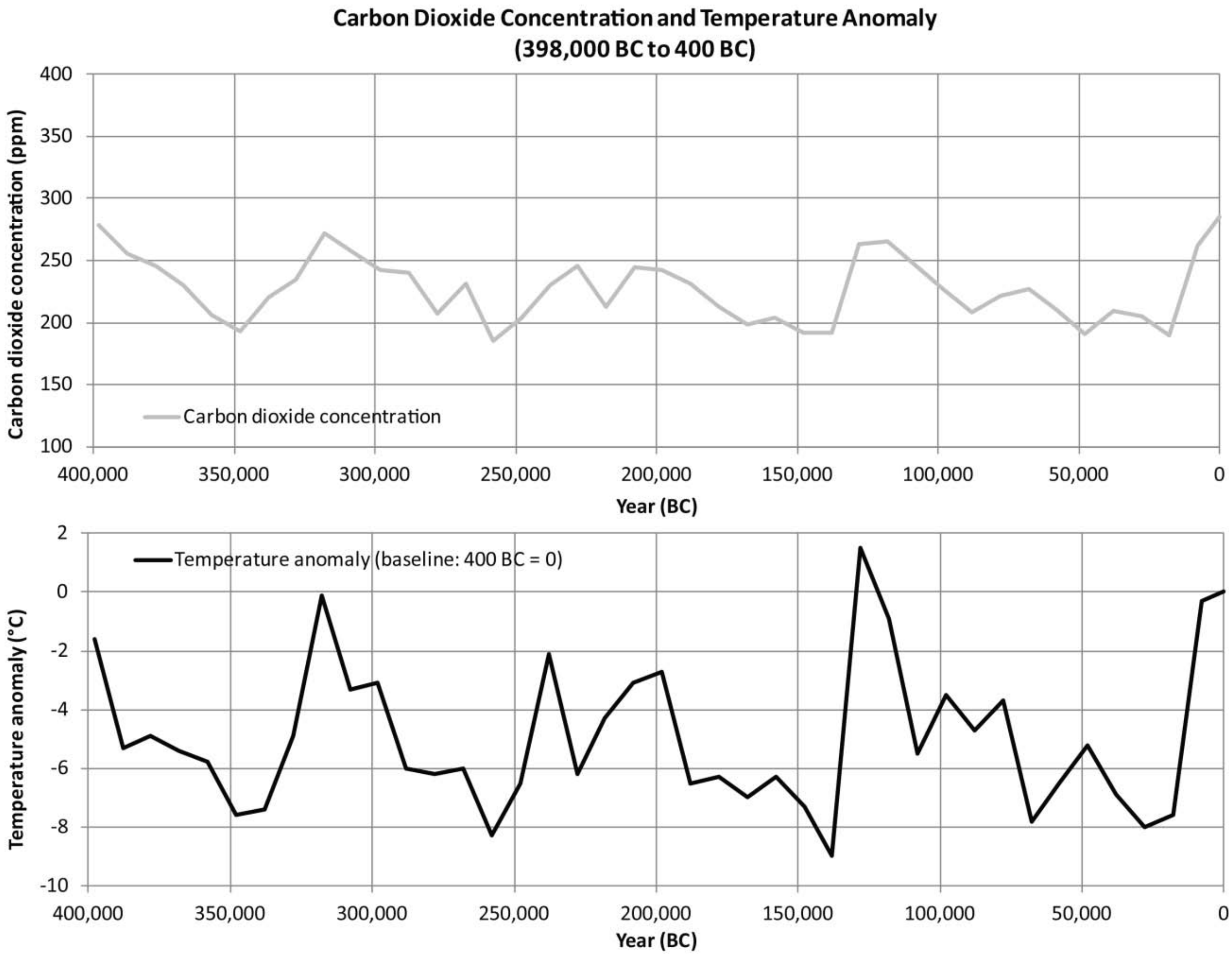
Students will further explore using the “Carbon Dioxide Concentration and Temperature Rate of Change” worksheet. Explain that temperature anomaly values in the first table (398,000 BC to 400 BC) use a different reference value from the temperature anomaly values in the second table (1901 to 2018).

Ask students if choosing a different reference value would change the shape of the trend. Why or why not? *[Answer: No, even if a new reference point is used, the shape and direction of the trend or repeating pattern would stay the same. The overall pattern would just shift up or down.]*

Direct students to use the “Vostok, Antarctica, Ice Core Data” worksheet and their graphs to fill in the blank boxes in the first table (“48,000 BC to 400 BC”) on the “Carbon Dioxide Concentration and Temperature Rate of Change” worksheet. Then ask them to finish filling in the second table (“1901 to 2018”), which has been partially populated with more recent data from another source.

Answer Key:

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
398,000	278	278	-1.64	-1.6
388,000	255.2	255	-5.34	-5.3
378,000	245.9	246	-4.88	-4.9
368,000	229.7	230	-5.42	-5.4
358,000	206.4	206	-5.8	-5.8
348,000	193	193	-7.64	-7.6
338,000	220.4	220	-7.44	-7.4
328,000	234.2	234	-4.9	-4.9
318,000	271.8	272	-0.12	-0.1
308,000	256.3	256	-3.32	-3.3
298,000	241.9	242	-3.08	-3.1
288,000	240.2	240	-6	-6
278,000	207.7	208	-6.17	-6.2
268,000	231.4	231	-5.95	-6
258,000	184.7	185	-8.3	-8.3
248,000	203.9	204	-6.52	-6.5
238,000	230.4	230	-2.12	-2.1
228,000	245.2	245	-6.15	-6.2
218,000	212.2	216	-4.31	-4.3
208,000	244.6	245	-3.07	-3.1
198,000	242.6	243	-2.68	-2.7
188,000	231.4	231	-6.49	-6.5
178,000	213.2	213	-6.34	-6.3
168,000	197.9	198	-7.01	-7
158,000	204.4	204	-6.25	-6.3
148,000	191.9	192	-7.34	-7.3
138,000	192.3	192	-8.99	-9
128,000	263.4	263	1.47	1.5
118,000	265.2	265	-0.86	-0.9
108,000	245.7	246	-5.53	-5.5
98,000	225.9	226	-3.45	-3.5
88,000	208	208	-4.69	-4.7
78,000	221.8	222	-3.66	-3.7
68,000	227.4	227	-7.84	-7.8
58,000	210.4	210	-6.53	-6.5
48,000	190.4	190	-5.18	-5.2
38,000	209.1	209	-6.91	-6.9
28,000	205.4	205	-7.95	-8
18,000	189.2	189	-7.62	-7.6
8,000	261.6	262	-0.28	-0.3
400	284.7	285	0	0



Data source: National Oceanic and Atmospheric Administration (NOAA):
www.esrl.noaa.gov/gsd/outreach/education/poet/Global-Warming.pdf

CARBON DIOXIDE CONCENTRATION AND TEMPERATURE RATE OF CHANGE

Answer Key:

48,000 BC to 400 BC

Length of time: 47,600 years

Variable	Value in 48,000 BC	Value in 400 BC	Change	Rate of change per year
CO_2 concentration (ppm)	190.4 ppm	284.7 ppm	+94.3 ppm	94.3 ppm / 47,600 years = 0.0020 ppm per year
Temperature anomaly (°C)	-5.18 °C	0 °C	+5.18 °C	0.00011 5.18 °C / 47,600 = °C per year

1901 to 2018

Length of time: 117 years

Variable	Value in 1901	Value in 2018	Change	Rate of change per year
CO_2 concentration (ppm)	296.1 ppm	410.8 ppm	114.7 ppm	114.7 ppm / 117 years = 0.980 ppm per year
Temperature anomaly (°C)	-0.16 °C	0.83 °C	+0.99°C	0.99°C / 117 years = 0.0085°C per year

EVALUATE:

Review the graphs and table with students.

Ask students the following questions regarding the parts of the table that they filled in:

- How many years of data are shown in the “48,000 BC to 400 BC” table?
  - [Answer: About 47,600 years.]
- How many years of data are shown in the “1901 to 2018” table?
  - [Answer: 117 years.]
- Did either table, both tables, or neither table show a warming trend? Explain.
  - [Answer: Both. CO_2 concentrations increase and temperature anomaly increases. Both increase at a greater rate more recently.]
- What trend, upward or downward, are we currently experiencing?
  - [Answer: Upward for both CO_2 concentration and temperature anomaly.]
- What is the change in the temperature anomaly between 1901 and 2018?
  - [Answer: +0.99°C]
- In 1971, the globally averaged CO2 concentration was approximately 330 ppm. If the CO2 concentration in 2000 was about 384 ppm, calculate the average rate of increase per year.
  - [Answer: Approximately 1.5 ppm per year.]
- What is happening to the rate of change for CO2 concentrations and temperature anomalies over time?
  - [Answer: The rate of change increases. This is another way of saying that if you graphed the results, the slope of the line would become steeper over time.]
- Why is the temperature data presented as a temperature anomaly? What does this mean?
  - [Answer: A temperature anomaly is the difference from an average, or baseline, temperature. The baseline temperature is typically computed by averaging 30 or more years of temperature data. A positive anomaly indicates the observed temperature was warmer than the baseline, while a negative anomaly indicates the observed temperature was cooler than the baseline.]
- Why was it important to calculate the rate of change for CO_2 concentration and temperature anomaly and not just the absolute change in either parameter?
  - [Answer: The rate of change shows how fast or slow the changes are occurring, so that we can track the changes over time.]
- In your own words, define the relationship over time between CO_2 and temperature.

VOSTOK, ANTARCTICA, ICE CORE DATA

Year (BC)	CO_2 concentration (ppm)	CO_2 concentration rounded to nearest whole number	Temperature anomaly (°C)	Temperature anomaly (°C) rounded to nearest tenth of a degree
398,000	278		-1.64	
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208,000	244.6		-3.07	
198,000	242.6		-2.68	
188,000	231.4		-6.49	
178,000	213.2		-6.34	
168,000	197.9		-7.01	
158,000	204.4		-6.25	
148,000	191.9		-7.34	
138,000	192.3		-8.99	
128,000	263.4		1.47	
118,000	265.2		-0.86	
108,000	245.7		-5.53	
98,000	225.9		-3.45	
88,000	208		-4.69	
78,000	221.8		-3.66	
68,000	227.4		-7.84	
58,000	210.4		-6.53	
48,000	190.4		-5.18	
38,000	209.1		-6.91	
28,000	205.4		-7.95	
18,000	189.2		-7.62	
8,000	261.6		-0.28	
400	284.7		0	

Data source: National Oceanic and Atmospheric Administration (NOAA):
https://www.esrl.noaa.gov/gsd/education/poet/Act-9_POET_GlobalWarmingFinal_Feb2016.pdf

CARBON DIOXIDE CONCENTRATION AND TEMPERATURE RATE OF CHANGE

Remember that the rate of change is equal to the change divided by length of time.

48,000 BC to 400 BC

Length of time: ______ years

Variable	Value in 48,000 BC	Value in 400 BC	Change	Rate of change per year
CO_2 concentration (ppm)				
Temperature anomaly (°C)				

1901 to 2018

Length of time: ______ years

Variable	Value in 1901	Value in 2018	Change	Rate of change per year
CO_2 concentration (ppm)	296.1 ppm	410.8 ppm		
Temperature anomaly (°C)	-0.16 °C	0.83 °C		

Data source: U.S. EPA, Climate Change Indicators in the United States:
https://www.epa.gov/climate-indicators
CO_2 concentrations are from Antarctica (1901) and Hawaii (2019).

STUDENT PAGE | Reading - Introduction to Climate and Climate Change

Weather and climate are distinct. Weather refers to short-term variability of environmental parameters while climate refers to long-term stability of these patterns. Weather is the local and temporary conditions happening at a particular time and place. When describing a region's climate, you are describing conditions over the long term and over an entire region.

Climate is a system of multiple components that include the interactions between the atmosphere, the ocean, and land. These function as an integrated system. Because they are interdependent, changes in one component of the climate system lead to changes throughout the system. The ocean plays a critical role in regulating the climate system.

Climate change refers to changes that exceed the expected levels of variability over decades or more and occur on a global scale. The change in climate is observable and measurable. Climate change is both a natural and a human-caused phenomenon. There are naturally occurring changes in global temperature, however human activities are causing changes that are not attributed to natural variability, also referred to as "anthropogenic climate change".

The primary cause of human-caused, or anthropogenic, climate change is the release of greenhouse gases like carbon dioxide through the burning of fossil fuels. Carbon normally cycles between the land, the oceans, and the atmosphere — but the increased burning of fossil fuels has disrupted this balance by moving enormous amounts of carbon into the atmosphere much faster than the normal cycle. Excess carbon dioxide in the atmosphere acts like a blanket, trapping heat near the planet that would normally be released into space. For over a century, researchers have been studying global processes, the Earth's climate, and the effects of natural processes being altered. They have concluded that carbon emissions from increased fossil fuel use are causing Earth's climate to change.

Carbon dioxide emissions are changing the oceans. Experts noted that carbon dioxide emissions are impacting both the temperature and the acidity of the Earth's oceans. Oceans absorb heat from the atmosphere; as the temperature of the atmosphere warms because of the increased concentration of carbon dioxide, so too does the ocean warm. Due to the critical role the ocean plays in regulating the climate system, changes in the ocean affect the entire planet.

The impacts of climate change are widespread, resulting in a cascade of changes related to increasing atmospheric temperatures. These include sea-level rise and coastal flooding, more extreme weather events, severe drought, species loss, and amplifications of existing weather patterns. These changes will vary by location and while they are long-term, the specifics will be difficult to predict.

Reducing global carbon emissions is key to addressing climate change. Practical short-term ways to mitigate some of the effects of climate change include slowing the rate of carbon dioxide emissions and reducing other human activities that alter the environment. For example, marine systems might be better able to adapt to warming temperatures if pollution and over-fishing were not also stressing these systems. Effective solutions require more than just individual behavior changes. Policy change where governments implement policies that both reduce future carbon dioxide emissions and address the existing impacts of climate change by making investments in new technologies and infrastructure are needed.

Adapted from Volmert, A., Baran, M., Kendall-Taylor, N., Lindland, E., Haydon, A., Arvizu, S., & Bunten, A. (2013). "Just the Earth doing its own thing": Mapping the gaps between expert and public understandings of oceans and climate change. Washington, DC: FrameWorks Institute.

DO NOW:

How do we measure historic Earth conditions?

EXIT TICKET:

What is “The Heat Trapping Blanket” metaphor?

1.2 Rising Waters: The Ocean Is Getting Too Big for Its Beaches

AGE RANGE

9th—12th grade

TIME REQUIRED

90 minutes

ACTIVITY OVERVIEW

Engage: NASA SLR graph
Explore: Land & sea ice melt
Explain: Discussion
Elaborate: Thermal expansion
Evaluate: Discussion and graphs

MATERIALS

Probe thermometer
Heat lamp
Water
Food Coloring
Marker
Plastic bottle
Clear plastic straw
Scissors
Modeling clay
Two clear, plastic food-storage containers, approx. 6in by 6in
Clay (enough to fill about a quarter of each tub with 1-2 inches of clay)
Ice cubes
Ruler

BASED ON:

Lesson based on "What's Causing Sea-Level Rise? Land Ice Vs. Sea Ice" JPL, "Thermal Expansion Model" JPL, and "Thermal Expansion and Sea Level Rise" Centers for Ocean Science Education Excellence.

LESSON TOPIC: Thermal expansion and ice melt

ACTIVITY SUMMARY: Students will explore the two main causes of sea-level rise by recreating ocean water processes through a classroom lab.

OBJECTIVES:

Students will be able to explain that:

- Thermal expansion is the increase in volume of water as a result of increased water temperature.
- Melting land ice contributes to sea-level rise. Not melting sea ice.
- Global sea-level rise is due to warming atmospheric temperatures leading to
  - thermal expansion of ocean water, and
  - addition of water volume from melting land ice.
- Changes in sea-level affect living organisms including humans.

LESSON BACKGROUND: Global sea level has increased by 24 cm since 1880, with 8 cm of that rise occurring since 1993. The rate of sea-level rise since 1900 has been faster than during any other time period in the last 2800 years. The rate of sea-level rise is being driven by global climate change. Sea-level rise impacts coastal areas by increasing the vulnerability of communities to severe storms, erosion of land, inundation of low elevation, salt-water intrusion into aquifers, and increased flooding. Coasts are especially densely populated with about 40% of the world's population living within 100 km of a shoreline. A rise in sea-level of 0.9 meters would permanently inundate areas that 2 million Americans call home.

There are two main factors that drive sea-level rise are a result of a warming atmosphere and ocean. The first factor is thermal expansion of water. As water warms, the molecules vibrate more and take up more space, causing the overall volume of water to expand. The ocean absorbs heat from the atmosphere, and as the ocean warms the water level rises due to thermal expansion. The second factor is melting land ice. Warming atmosphere temperatures melt ice that is stored on land in glaciers and ice sheets and it flows into the ocean, further increasing the volume of water and causing the water level to rise.

Sea level is measured by monitoring stations on the shoreline and at sea. There are over 120 sea level monitoring stations in the U.S. and 240 additional stations worldwide. Sea level has been measured at some stations for more than a century, providing sea level data going back to 1880. In addition to the individual monitoring stations, satellites such as NASA's JASON-3 satellite collect data on sea level. By looking at data from these stations and satellites over periods of 25 years or more, trends can be identified at specific locations along the coast and compared with global trends. This gives scientists useful information about local conditions. Those data can also be used to calculate the global average sea level and study it over time, giving scientists a picture of what's happening to the ocean on a planetary scale.

Sea-level projections and scenarios from: Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, and C. Zervas, 2017: Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. NOAA/NOS Center for Operational Oceanographic Products and Services.

VOCABULARY:

Changes in Temperature	Fluctuations (increases or decreases) in temperature. Climate projections show increasing temperatures across the Gulf of Mexico as well as on average globally.
Land Ice	Land ice in the form of glaciers and ice sheets contains the majority of the world's fresh water and covers about 10 percent of the world's land area.
Sea Ice	Frozen ocean water (e.g., icebergs).
Sea Level	Base level for measuring elevation and water depth on Earth. Because the ocean is one continuous body of water, its surface tends to seek the same level throughout the world. However, winds, ocean currents, river discharges, and variations in gravity and temperature prevent "sea level" from being truly level.
Sea-Level Rise	Increase in sea level caused in part by melting land-based ice and expanding water. Exacerbates existing coastal hazards such as flooding, erosion, inundation, and extreme events. Often abbreviated to SLR.
Thermal Expansion	Increase in linear dimensions of a solid or in volume of a fluid because of a rise in temperature.
Global Sea-Level Rise	Average increase in sea level caused primarily by land-ice melt and water expansion across the entire world.
Relative Sea-Level Rise	Rate of sea-level rise at any given point on the coast. Affected by local processes that can reduce or exacerbate global sea-level rise (e.g., subsidence [ground sinking], tectonic plate movement, etc.).

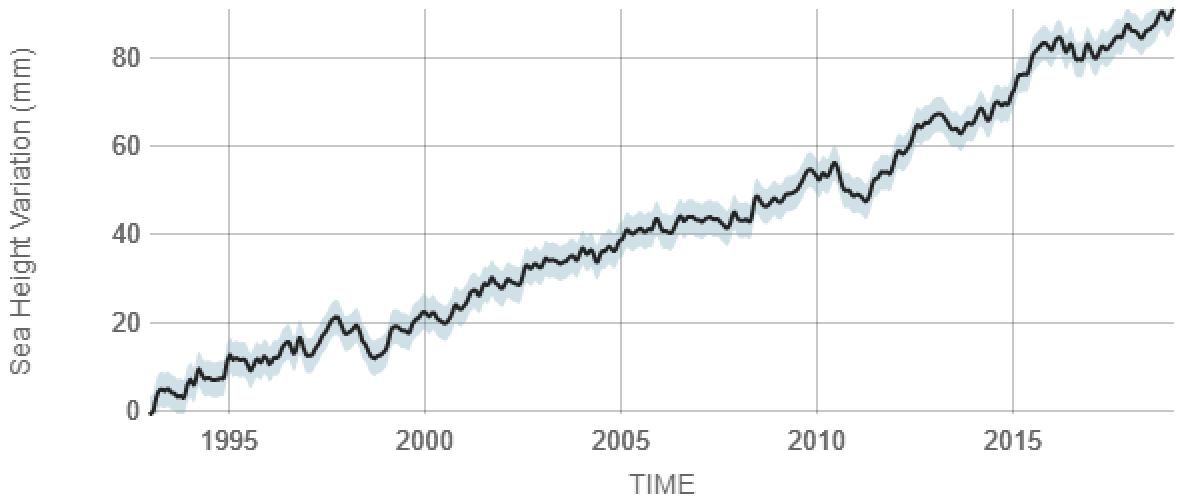
ENGAGE:

Show graph of global sea level from NASA: https://climate.nasa.gov/vital-signs/sea-level/

SATELLITE DATA: 1993-2019

Data source: Satellite sea level observations.

Credit: NASA Goddard Space Flight Center



Source: climate.nasa.gov

Ask students: What is the trend of the data? What would cause sea level to rise? What impact does an increase in temperature have on sea level? What human action contributes to sea-level rise?

EXPLORE:

Activity Overview: In this activity students will compare the added volume of ocean water from melting ice that is on land and melting ice that is in the sea. It can be set up in the classroom using a purchased land model or created using clay. Two trays will be set up with "land" and water. In one tray, ice cubes will be placed in the water and in the other tray the ice cubes will be placed on land. Students record and measure the water level of the tray as the ice melts. The water level will only increase in the tray with the ice on land.

Discuss climate change and sea-level rise with students.
Ask students to identify causes of sea-level rise.
Ask students: What impacts does temperature increase have on water? Target answer: Melting of ice.
Ask students: Where is ice located on Earth? A: Ice sheets on Greenland and Antarctica and glaciers are land ice. Frozen seawater ice and icebergs are sea ice.
Direct students to record their hypothesis for which ice will contribute more to sea-level rise.

Materials

Two clear, plastic food-storage containers, approx. 6 inches by 6 inches
Clay (enough to fill about a quarter of each tub with 1-2 inches of clay)
Tray of ice cubes
Ruler
Water
Permanent marker or tape

Procedure

1. Press clay into one side of the plastic tub, making a ledge. Repeat exactly on other container.
   a. Consider adding push pins along the edge of the clay to represent cities or landmarks.
2. In one container place as many ice cubes as can fit on the clay ledge to represent land ice.
3. In the other container place the same number of ice cubes on the bottom of the container not on the clay to represent sea ice.
4. Pour water in the sea-ice container until the ice floats. The clay ledge should remain out of the water.
5. Pour an equal amount of water into the land-ice container without touching the ice cubes.
6. Use the rule to measure the water level in millimeters in each tub. Mark the water level on the outside of the containers with the marker or tape.
7. At regular intervals measure the water and record the water level. Allow the ice in both containers to melt completely. Using a heat lamp will speed this up.
8. Allow the ice to melt while you move onto the other activity.

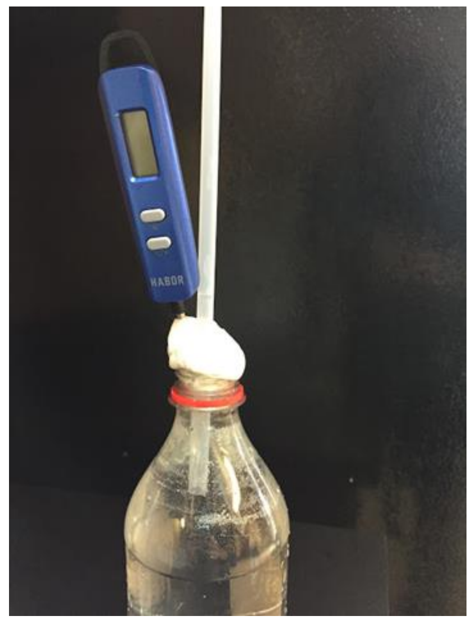
EXTENSION: Follow the same procedure as above but in step 1 switch out the clay for another material, like sand. This will allow for a conversation about different types of land and how the ice will still add to volume of water.

EXPLAIN:

Again, **discuss** climate change and sea-level rise with students. If students did not mention thermal expansion before, explain that in addition to ice melt, there is another phenomenon that contributes to sea-level rise. The following activity will demonstrate that phenomenon.

ELABORATE:

Activity Overview: In this activity students will observe thermal expansion of water. This activity can be set up in a classroom using either science lab equipment (flask and clear glass tube) or using everyday items (water bottle and straw). As the water is heated under a lamp the level in the straw rises, demonstrating thermal expansion.



Materials
Probe thermometer
Heat lamp
Water
Food Coloring
Marker
Plastic bottle
Clear plastic straw
Scissors
Modeling clay

Procedure
1. Completely fill the plastic bottle with water and food coloring to improve visibility.
2. Surround the thermometer and straw with modeling clay a few inches from the bottom of the straw. Do not block the straw with clay.
3. Place the clay into the bottle and press to seal to edges. The water should rise up the straw.
4. Mark the water level using the marker on the straw. Record the temperature of the water.
5. Place a heat lamp approximately 5 inches away from the bottle. Direct the light towards the middle of the water, not at the top.
6. Have students make hypothesis for how the water level will change when the lamp is turned on.
7. Turn on the lamp. Record the temperature and mark the water level after 5-10 minutes.

Ask students: What happened to the water level? What was the impact of the lamp?
A: The water level rose. The lamp added heat energy and increased the temperature of the water.
Ask students: Why did the water level rise as the temperature increased?
A: The lamp adding heat energy to the water resulted in the water molecules moving around more and taking up more space. Each molecule taking up more space increased the volume of water in the bottle and the only place to move was up the tube/straw. This is thermal expansion.

EVALUATE:

Record the measurements from the ice-melt activity to create a line graph representing water level in each tub.
Ask students: Under which ice conditions did the water level rise more? A: The container with the land-ice.
Ask students: Why did this happen? A: The sea-ice was already adding its volume to the water, but the land-ice was adding new water so it increased the total volume as more melted.
Ask students: What does this mean on a global scale? A: Ice melting from land-ice increases global sea-level.

MELTING LAND AND SEA ICE

Which type of ice (land or sea) will contribute more to sea-level rise?

Hypothesis:

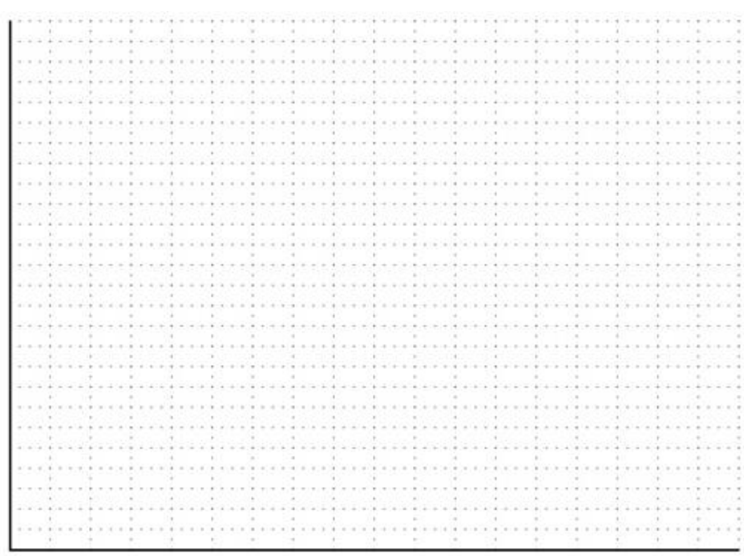
Record the water level in millimeters at the indicated time increments in the chart below:

Time	Land Ice Water Level (mm)	Sea Ice Water Level (mm)
0 min		
10 min		
20 min		
30 min		

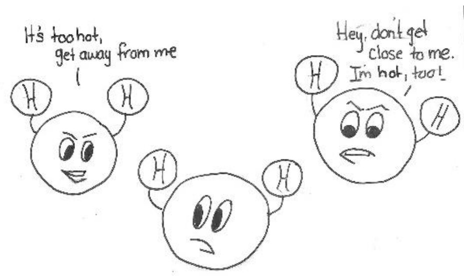
Describe the results from the melting ice lab:

Explain whether or not your hypothesis was supported by the data:

Graph: Create a line graph with time in minutes on the x-axis, water level in millimeters on the y-axis, and the land and sea ice containers represented by different lines.



THERMAL EXPANSION OF WATER



Credit: Kate Tagai, Island Institute

What impact will the heat lamp have on the water in the bottle?

Hypothesis:

Record the water temperature at the indicated time increments in the chart below:

Time	0 min	5 min	10 min	15 min
Water Temperature (°C)				

Describe the results from the thermal expansion lab:

Explain whether or not your hypothesis was supported by the data:

Global sea level is an average level of the surface of the global ocean. Sea level varies from place to place due to shifting surface winds, the expansion of warming ocean water, and the addition of melting land ice. The sea level measurement of specific locations is called local or relative sea level. A local change can be caused by an increase in sea surface height, or by a decrease in land height. Over relatively short time spans (hours to years), the influence of tides, storms, and decadal oscillations (e.g., El Niño and La Niña) dominates sea level variations. Over longer time spans (decades to centuries), the influence of climate change is the main contributor to sea level change in most regions.

Sea level is measured using tide gauges and satellites. Tide gauges measure relative sea level, so they include changes resulting from vertical motion of both the land and the sea surface. Before computers were used to record water levels, special "tide houses" sheltered permanent tide gauges. The instrumentation—including a well and a mechanical pen-and-ink recorder—was housed inside and a tide staff was attached outside. Essentially a giant measuring stick, the tide staff allowed scientists to manually observe tidal levels and then compare them to readings taken every six minutes by the recorder. The computer age led to tide gauges that used microprocessor-based technologies to collect sea-level data. Today's recorders are more sophisticated. Some send an audio signal down a narrow "sounding tube" and measure the time it takes for the reflected signal to travel back from the water's surface. Others are on the sea floor and measure the pressure and density of the water to account for the depth of the water. Since the late 20th century, satellite measurements of the height of the ocean surface relative to the center of the Earth (known as geocentric sea level) show differing rates of geocentric sea level change around the world.

Over many coastal regions, vertical land motion is small. However, in some regions, vertical land motion has had an important influence. For example, the steady fall in sea level recorded in Stockholm is caused by uplift of this region after the melting of a large (>1 km thick) continental ice sheet at the end of the last Ice Age, between ~20,000 and ~9000 years ago. Land subsidence, the gradual settling or sinking of land, is common in many coastal regions, particularly in large river deltas like Louisiana. Subsidence can occur because of natural processes, such as the compaction of soil, or due to human processes, such as the extraction of groundwater or oil/natural gas from underground.

Melting ice from glaciers or the Greenland and Antarctic ice sheets lead to sea level rise, but it is not uniform throughout the world. Melting results in regional differences in sea level due to processes like changes in ocean currents, winds, the Earth's gravity field, and land height. Large ice sheets are so massive that they have gravitational pull on the surrounding water. When the ice sheets melt, the gravitational attraction between the ice sheets and ocean water is reduced. As the ocean water relaxes away from the ice sheets, it moves to new areas in the ocean and causes sea level to rise in greater amounts compared to the global average value.

In summary, a variety of processes drive height changes of the ocean surface and land elevation, resulting in different patterns of sea level change at local to regional scales. The combination of these processes produces a complex pattern of total sea level change, which varies through time as the relative contribution of each process changes. The global average of sea level change reflects climatic processes and represents a good estimate of sea level change across many coastal locations, but the rate and amount of sea-level rise will differ among regions.

Adapted from: Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

NOAA. What is a tide gauge? National Ocean Service website, https://oceanservice.noaa.gov/facts/tide-gauge.html, 06/25/18.

STUDENT PAGE | Rising Waters

DO NOW:

What is one impact of increased carbon dioxide in the atmosphere?

EXIT TICKET:

Why does melting sea ice not contribute to sea-level rise?

1.3 High Tide Flooding: Rainboots Required Even on Sunny Days?

AGE RANGE

9th—12th grade

TIME REQUIRED

70 minutes

ACTIVITY OVERVIEW

Engage: NPR podcast
Explore: Days of future flooding
Explain: Discussion
Elaborate: Coastal dynamics
Evaluate: Writing assignment

MATERIALS

Days of future flooding graphs

Computers

LESSON TOPIC: Types of flooding

ACTIVITY SUMMARY: Students explore high tide flooding projections in their local regions.

OBJECTIVES:

Students will be able to explain that:

- High tide flooding and other hazards will be exacerbated by sea-level rise.
- Flooding will not be the same in every city.
- Natural hazards will continue to have an effect on human society.

LESSON BACKGROUND: Flooding occurs when water overflows onto land that is usually dry. Communities living along the coast are experiencing flooding events that are caused not just by hurricanes and heavy rain, but by rising sea levels. With increasing sea level, coastal flooding is occurring more often during high tides. High tide flooding can lead to road closures, waterlogged infrastructure, overwhelmed storm drains, and other public inconveniences. High tide flooding is the term used to describe flooding related to minor tidal flooding. This may be from water flooding low elevation coastal roads, overtopping a sea wall, or coming into neighborhoods through storm drains.

Annual occurrences of high tide flooding are increasing throughout communities living along the Gulf of Mexico. Along coastal Louisiana to Texas from 2000 to 2015, the annual frequency of high tide flooding increased from 1.4 days per year to 2.5 days per year. Flood frequency follows a seasonality pattern in part due to astronomical tides and changes in wind and ocean currents. Along the Gulf coast, high tide flooding occurs more often during September–November and again in June–July. With projections of future sea-level rise, it is expected that Gulf coast communities will experience many more high tide flooding events. Under the Intermediate Low projection of 0.5 m global sea-level rise by 2100, the Gulf Coast from Florida to Mississippi is projected to experience 25 days per year of high tide flooding. Under the Intermediate projection of 1 m of global sea-level rise there are 80 days per year projected of high tide flooding.

Storm surge is the rise of water caused by a tropical cyclone (e.g., hurricane or tropical storm), above the tide range. Storm surge happens when water is pushed toward the shore from strong storm winds. Storm surge can cause extreme flooding in coastal areas, bringing water farther inland due to storm winds. The width and slope of the continental shelf impacts storm surge. Here in the northern Gulf, the shallow continental shelf produces greater storm surge, that goes farther inland with potentially extreme water depths. For example, Hurricane Katrina caused severe flooding in three states and pushed over 20ft of water on land. As seas rise, storm surge will go farther inland and generate even deeper flood waters.

VOCABULARY:

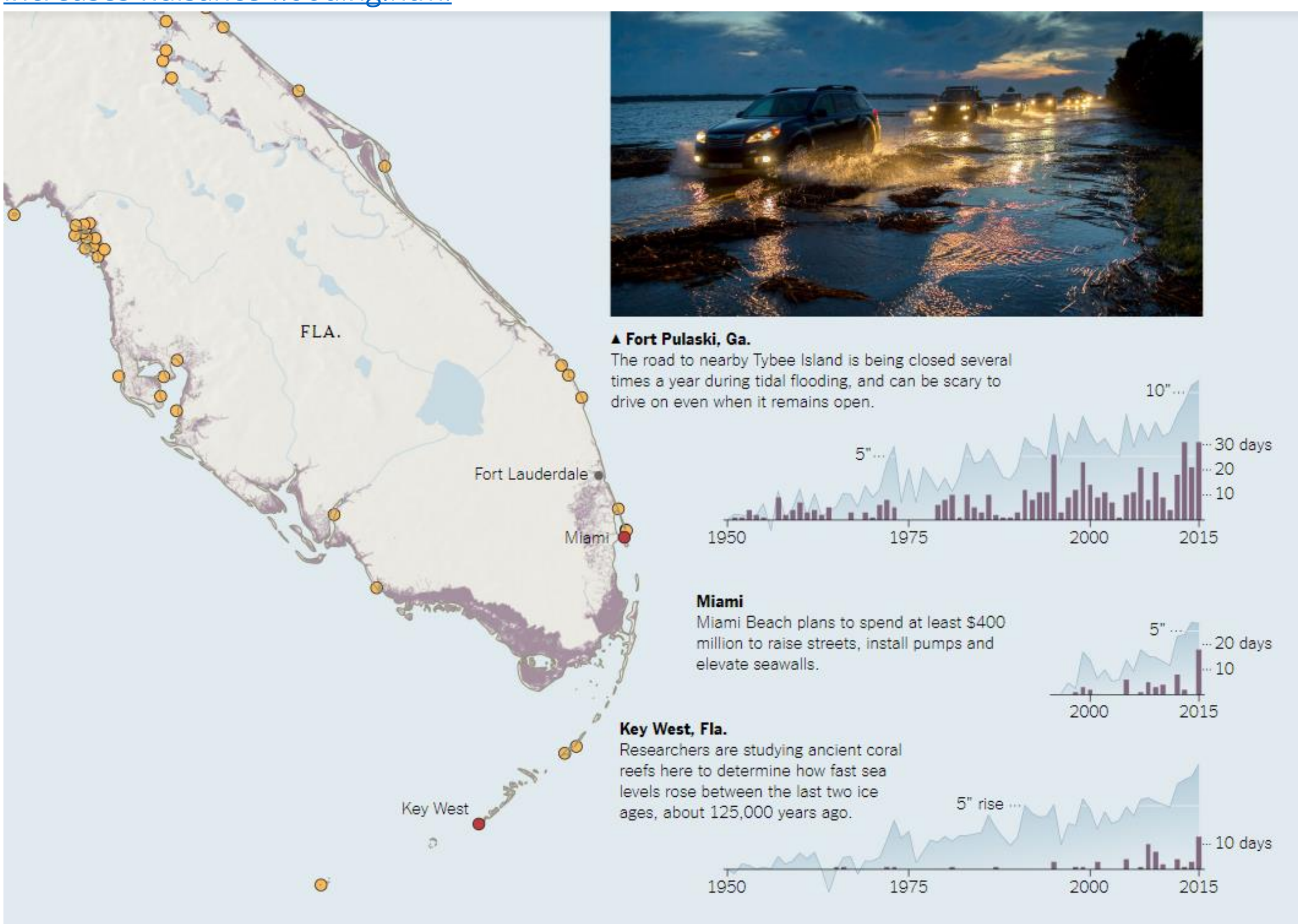
Changes in Precipitation	Fluctuations (increases or decreases) in amount of precipitation. Changes due to climate change vary widely across the Gulf as well as regionally.
Extreme Weather Events	Weather event that is notably different from the typical weather pattern (e.g., severe, unexpected, etc.). Examples include heat waves, heavy rains, droughts and floods, and extreme storms (e.g., hurricanes).
Flooding	Water overflowing its confines and submerging areas that are typically dry; can result in negative impacts on natural and built environment and communities.
High Tide Flooding	Shallow flooding that leads to public inconveniences like frequent road closures, overwhelmed storm drains, and compromised infrastructure. Can interfere with important commerce corridors and processes.
Saltwater Inundation	Flooding of saltwater (i.e., ocean water) onto normally dry land or into normally freshwater (e.g., freshwater aquifers). Can be caused by high tide, sea level rise, storm surge, or other events.
Storm Surge	Abnormal rise of water generated by a storm, over and above the predicted astronomical tide. In coastal areas, often the greatest threat to life and property is from a hurricane or other tropical system.

Stormwater	Rainwater (or melted snow) that becomes surface water. Generally thought of as the precipitation that runs into streets or stormwater drainage systems that must be managed by communities.
Tide Gauge	A tide gauge measures changes in sea level relative to a datum (an established height reference)

ENGAGE:

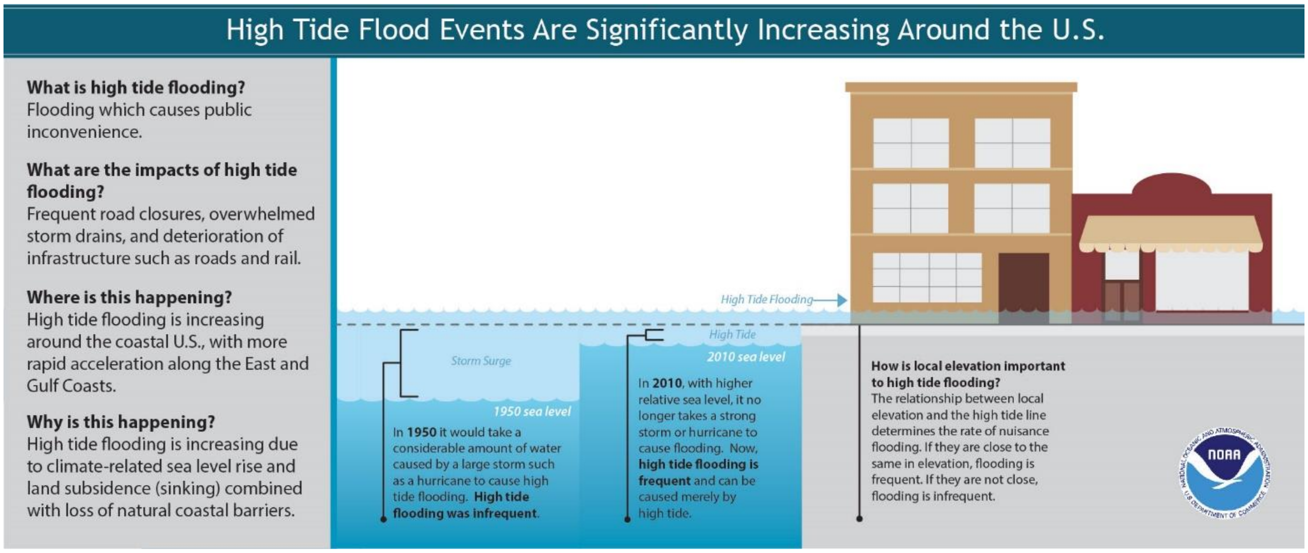
Listen with students to the NPR Science Friday segment from 2/15/2019: [What Does That Parking Lot Puddle Have To Do With Climate Change?](#) (11:19 minutes).

Show students "A Sharp Increase In 'Sunny Day' Flooding" By Jonathan Corum in The New York Times from September 3, 2016 (excerpt below) to observe differences in flooding of cities along the East coast. https://www.nytimes.com/interactive/2016/09/04/science/global-warming-increases-nuisance-flooding.html



Ask students if they have seen or experienced high tide flooding. How did it impact them? **Ask** them why it varies from town to town.

EXPLORE:



Distribute graphs showing the projected days of future flooding with sea level rise to students. These graphs will be provided for coastal counties in Mississippi and Alabama with the curriculum materials. Give different groups in the classroom different locations. At the end of the lessons the groups will pair off with a group with a different location to compare their answers. They should come to the conclusion that different locations have different elevations and may have different numbers of future flooding days, but that they will all experience flooding.

> As an **EXTENSION**, teachers can generate graphs for other areas of the United States using the "Local SLR Two Pager" template: www.localSLR.org

Coastal flooding will become more frequent and occur in more places as sea levels rise. *Minor* flooding is a potential public threat and inconvenient. These graphs are projected frequencies of *minor* flooding caused by high tides under different sea level change scenarios at the NOAA Dauphin Island, AL Tide Gauge (locations matched to graphs). This a good representation of potential future flooding in the area. At Dauphin Island, AL, minor flooding starts when water level is at or above 1.7 feet. Probabilities of *moderate* and *major* flooding, which disrupt commerce, damage private and commercial property, and threaten public safety, are also increasing with sea-level rise, putting more communities and assets at risk.
The graph displays year along the x-axis and days with high tide (nuisance) flooding on the y-axis. The colored bands represent sea-level rise scenarios, low through extreme, which cover the range of scientifically plausible scenarios. The projected days of future flooding are based on the regional sea-level rise scenarios, not the global mean average, so they are location specific.

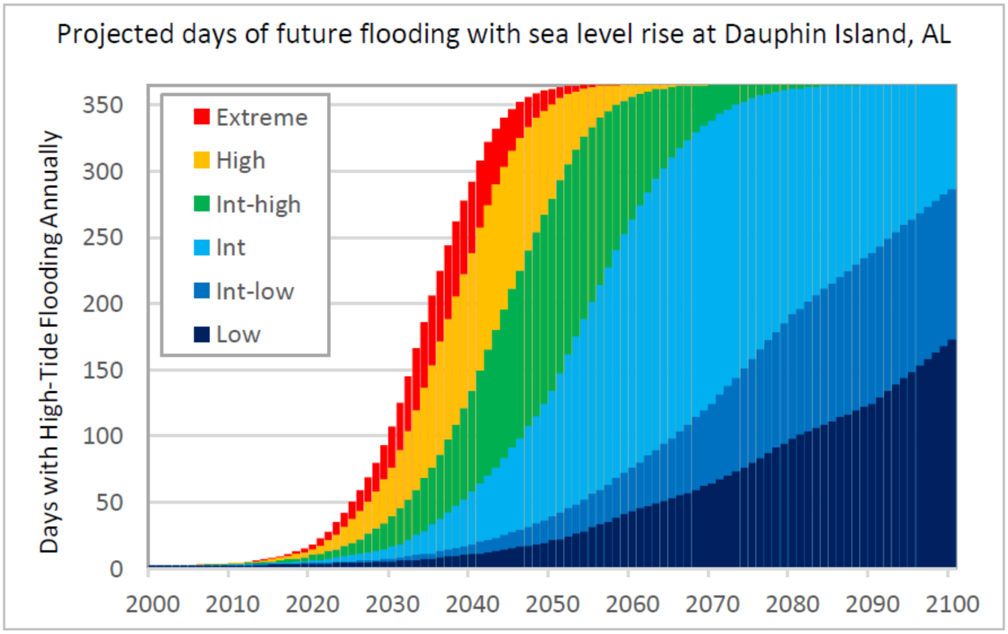
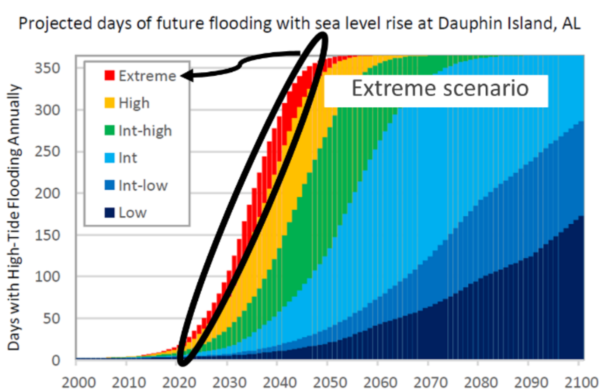
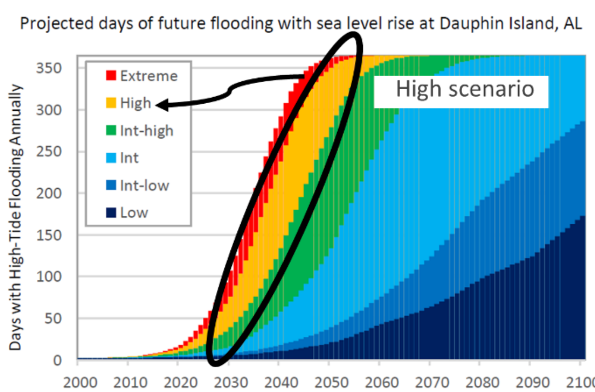


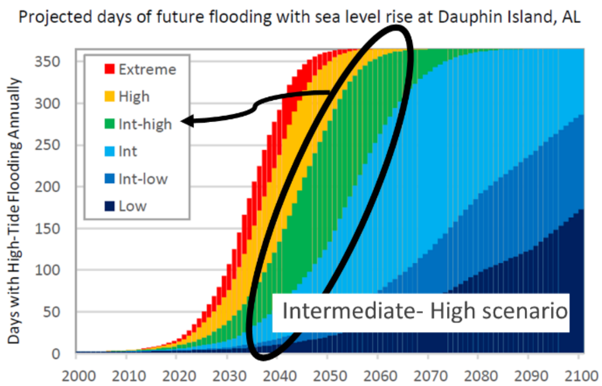
Figure 2: Graph displays the projected future days of minor flooding based on derived levels at Dauphin Island, AL under different sea-level rise scenarios. Data source: NOAA Technical Report NOS CO-OPS 086.

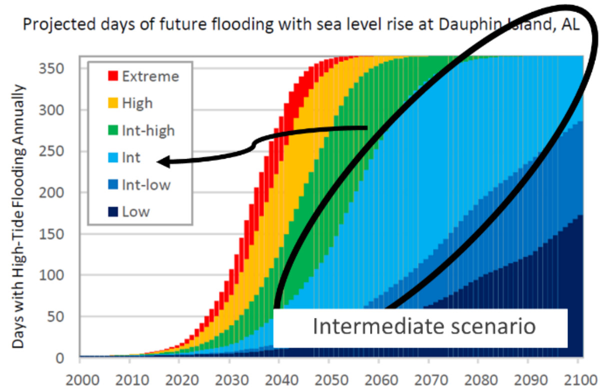
Graph Walk-Through

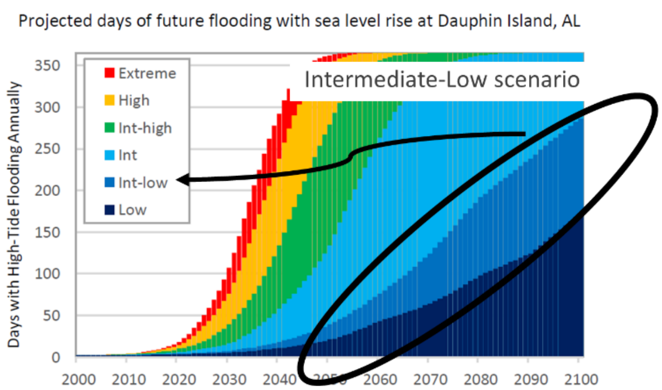
The color key shows the 6 sea-level rise scenarios depicted by a different color. Extreme as red, High as yellow, Intermediate-High as green, Intermediate as light blue, Intermediate-Low as medium blue, and Low as dark blue.

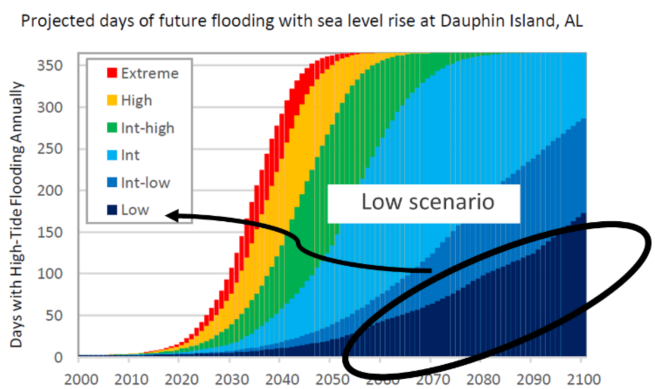






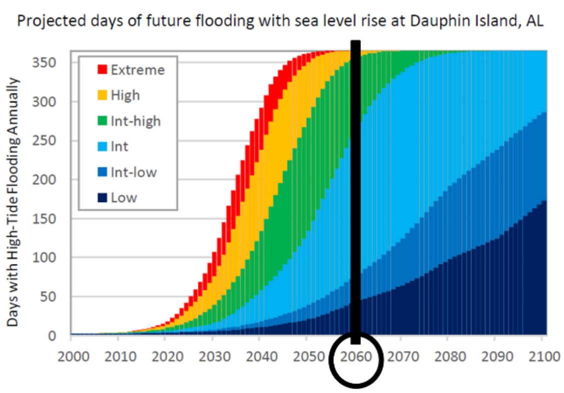




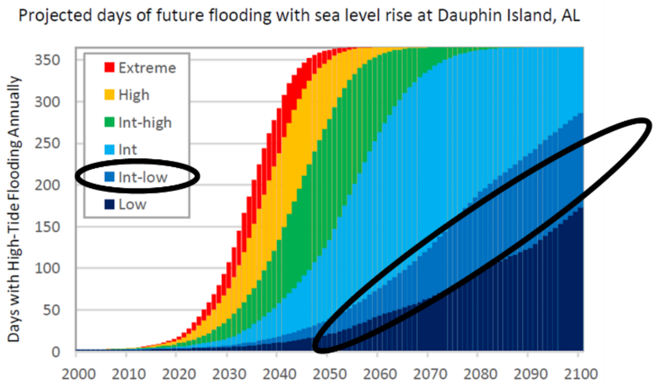


Walk through a practice question: How many days will this location experience high tide flooding with an intermediate-low scenario in the year 2060.

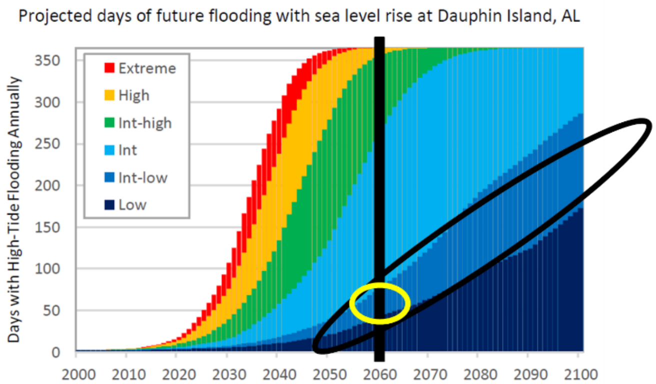
Step 1) Find the year on the x-axis. Drawing a line vertical at that point might help students visualize.



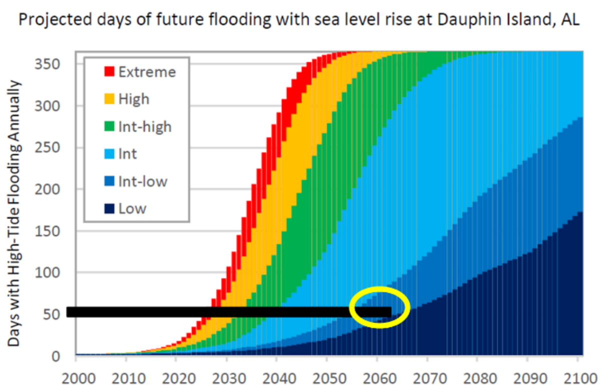
Step 2) Find the color representing the scenario in question. Intermediate-low is the medium blue.



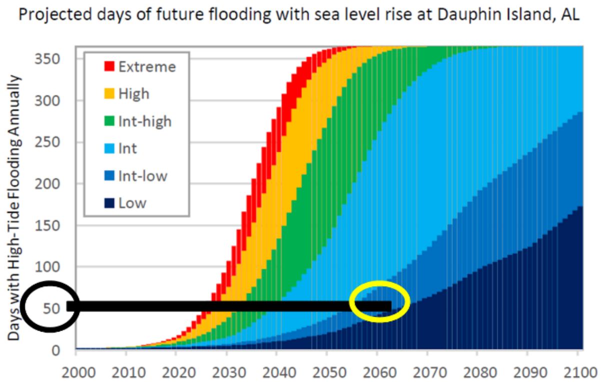
Step 3) Circle the overlap of the year and the scenario. This is the yellow circle in the image below.



Step 4) Find the number of days of flooding in this year and scenario draw a line to the y-axis.



Step 5) Record the number of days on the y-axis where the line intersects.



The answer to this question is that this location will experience 50 high tide flooding days with an intermediate-low scenario in the year 2060.

Student questions:

- Which scenario has the greatest slope? The least slope?
- Using the graph as a resource, in the year 2040, on average, how many days will your location experience high-tide flooding with an intermediate (int) scenario?
- Using the graph as a resource, in what year do all scenarios project at least 100 days of high-tide flooding?
- Using the graph as a resource, what is the earliest year in which a model predicts 100 days of high-tide flooding?

Student groups pair with another group working on a different location to discuss their answers and then talk about what it might mean for their daily lives if the main road to their school was projected to flood 50 days out of the year. What does it mean if these 50 days occur only during the school-year?

EXPLAIN

Discussion: Lead full group discussion of some of the impacts that high tide flooding has on communities (e.g., needing to find alternative routes, being cut-off to certain areas, etc.) This type of flooding is an inconvenience, you might need to wear rainboots more often. There are many low-lying roads near the beach, rivers, canals, or bayous. High tide flooding means these roads might have water covering them each month.

Sea-level rise increases the distance that saltwater travels during tides, high tide flooding, and storm surge. Another impact to coastal regions is saltwater intrusion, when saltwater moves into freshwater aquifers. This can occur more frequently as sea levels rise and as coastal development withdraws freshwater from the ground. Saltwater intrusion into freshwater sources contaminates the drinking water supply for nearby communities. Saltwater causes corrosion of built civil infrastructure. When saltwater intrudes into freshwater marshes the plants that are adapted to survive in freshwater are impacted. These plants might not be able to survive with the salt and may become submerged if the water rises too high too quickly. Saltmarsh plants may move into the marsh and take the place of freshwater plants, allowing saltmarsh migration.

Watch "The Seeds of Ghost Forests" https://www.sciencefriday.com/videos/the-seeds-of-ghost-forests/ to see the impacts of salt-water intrusion on the coasts of North Carolina.

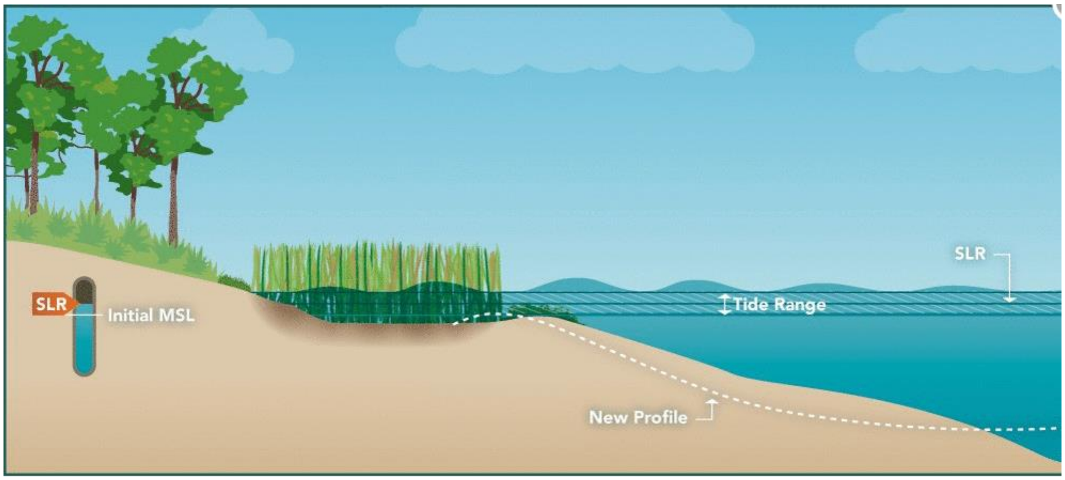
Connect the discussion before about how flooding and sea-level rise impacts human communities, to how it impacts coastal ecosystems. **Ask students**: how do human communities rely on coastal ecosystems?

ELABORATE

Students read the Gulf of Mexico Coastal Flooding reading.

Students use the Coastal Dynamics of Sea Level Rise graphic to see the impacts that sea-level has on changing habitat structure. Discuss that intense one time floods can be damaging, and chronic floods happening more frequently can also have more damaging impacts.

Shoreline changes sliding graphic: GOMmarsh.org and
http://champs.cecs.ucf.edu/CDSLR/index.html



EVALUATE

To conclude the lesson, students pick one of the locations from the projected days of high tide flooding to write a paragraph on potential impacts to human communities and coastal habitats in 50 years' time.

Using the provided Projected Days of Future Flooding answer the following questions:

1. Which scenario has the greatest slope? The least slope?
2. Using the graph as a resource, in the year 2040, on average, how many days will your location experience high-tide flooding with an intermediate (int) scenario?
3. Using the graph as a resource, in what year do all scenarios project at least 100 days of high-tide flooding?
4. Using the graph as a resource, what is the earliest year in which a model predicts 100 days of high-tide flooding?

Discussion

In a group discuss what it might mean for your daily lives if the main road to their school was projected to flood 50 days out of the year. What does it mean if these 50 days occur only during the schoolyear?

Credit: Kate Tagai, Island

STUDENT PAGE | Reading - Gulf of Mexico Coastal Flooding

Flooding is a threat to buildings, property, and lives. Flooding is an overflowing of water onto land that is normally dry, and it can be generated by a wide variety of events such as heavy rains, when ocean waves come on shore, fast snow melt, or dam or levee breaks. Flooding may happen with only a few inches of water, or it may cover a house to the rooftop. It can occur quickly or over a long period and may last days, weeks, or longer. Floods are the most common and widespread of all weather-related disasters.

A coastal flood is the inundation of land areas along the coast and is caused by higher than average high tide and worsened by heavy rainfall and onshore winds blowing landward from the ocean. Places like Gulfport, Bay Waveland, Moss Point, Bayou la Batre, Dauphin Island, and Gulf Shores experience impacts from shallow coastal flooding because of lower elevation.

Credit: Kate Tagai, Island Institute

Storm surge is an abnormal rise in water level in coastal areas, over and above the regular astronomical tide, caused by forces generated from a severe storm's wind, waves, and low atmospheric pressure (e.g., hurricanes). Extreme flooding can occur in coastal areas particularly when storm surge coincides with normal high tide. Along the Gulf coast, storm surge is often the greatest threat to life and property from a hurricane.

High tide flooding, also referred to as nuisance flooding, is the term used to describe flooding related to minor tidal flooding. This may be from water flooding low elevation coastal roads, overtopping a sea wall, or coming back through storm drains. High tide flooding can lead to road closures, waterlogged infrastructure, overwhelmed storm drains, and other public inconveniences.

Inland flooding occurs when moderate precipitation accumulates over several days or intense precipitation falls over a short period. Water from inland flooding will partially be absorbed into the ground or vegetation, and travel along rivers to delta areas on the coast. As the rivers move the excess water to the deltas, it can cause flooding in areas downstream all the way to the coast, even though there was no precipitation in the other locations.

A flash flood is when excessive water fills normally dry creeks or riverbeds and adds water volume to flowing creeks and rivers, causing rapid rises of water in a short amount of time. The water moves very quickly, causing damages and extreme risk to life and property. Densely populated areas are at a high risk for flash floods. The construction of buildings, highways, driveways, and parking lots typically use impervious materials, which increases runoff by reducing the amount of rain absorbed by the ground. This runoff increases the flash flood potential.

People have developed many strategies to keep water from negatively impacting their homes and businesses. Storm drains are used in cities and towns to direct rainfall down and away from roads and buildings. Levees are built along waterways and rivers to prevent high water from flooding the neighboring land. Some people elevate homes, businesses, and roads above common flood levels. Additionally, there are often laws that require building in specific ways or places to minimize flood risk.

Our developed ways of moving water away from homes do pose challenges in certain conditions. During heavy rain, storm drains can become clogged or overwhelmed and flood roads and buildings. As sea level has risen, it has also begun to block storm drain outfalls along the coast, causing inland and flash flooding. Low spots, such as underpasses, underground parking garages, and basements are especially likely to flood. The city of New Orleans experienced massive flooding days after Hurricane Katrina came onshore in 2005 due to the failure of levees along the river designed to protect the city.

Living along the Gulf coast, we experience the impacts from different floods. Proximity to the coast increases the risk of coastal flooding and impacts from storm surge and high tide flooding. But living near the coast means many large and small river systems are nearby (e.g., Mobile-

Tensaw Rivers, Mississippi River) so we also experience the impacts of inland flooding. With sea-level rise, we are already experiencing increased coastal and inland flooding and seeing the need for better prepared communities. Average global sea level has risen 24 cm (8-9 inches) since 1880 but the rate of increase is accelerating. Eight cm of the 24 cm rise has occurred since 1993. Along the low-lying Gulf of Mexico coast, we are highly vulnerable to climate change impacts. We are already experiencing increased flood frequencies from the combined effects of extreme rainfall events and sea-level rise. We need to work towards large-scale methods to improve our region's ability to prepare for more flooding as a result of sea-level rise.

Adapted from: Sever Weather 101 – Floods. The National Severe Storms Laboratory.

Sea-level rise data from: Lewis, K.L.M., D.R. Reidmiller, and C.W. Avery, 2018: Information in the Fourth National Climate Assessment. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1410–1412. doi: 10.7930/NCA4.2018.AP2.

STUDENT PAGE | High Tide Flooding

DO NOW:

What are the two main causes of sea-level rise?

EXIT TICKET:

How does sea-level rise impact high tide flooding?

1.4 Climate Change Anomalies and Suffering Economies

AGE RANGE

9th—12th grade

TIME REQUIRED

90 minutes

ACTIVITY OVERVIEW

Engage: Equal vs equitable
Explore: Reading
Explain: Discussion
Elaborate: Modeling
Evaluate: Discussion and graphs

MATERIALS

Computers

BASED ON:

Lesson adapted from KBS K-12 Partnership Predicting Earth's Future: Building your own climate

LESSON TOPIC: Economics and modeling

ACTIVITY SUMMARY: Students use carbon emission data to create a climate change model.

OBJECTIVES:

Students will be able to:

- Explain what a model is and the basic components that go into constructing a model.
- Explain how climate and sea-level rise models work, including their limitations.
- Understand the connection of sea-level rise and economics.

LESSON BACKGROUND:

ECONOMICS

Rising sea levels impact communities by increasing rates of flooding, exacerbating existing hazards like erosion, and damage community infrastructure. This causes direct impacts on coastal economies through costly damage to individuals, businesses, municipalities, closed businesses, and displaced consumers. It also causes indirect impacts by reducing industry production, increasing real estate pressure, and causing long-term shifts in coastal development patterns.

MODELING

We know that sea level is rising based on measurement data collected from tide gauges and satellites. Scientists use models to estimate how much and how fast sea level will continue rising. There are two different approaches to models: process-based and semi-empirical. Process-based models consider the different physical processes that cause sea levels to rise. Semi-empirical models extrapolate the information contained in measurements of past sea level changes.

Process-based models used for sea-level rise projections quantitatively describe the contributors of sea-level rise: thermal expansion of water and addition of water volume from melting land-ice. Three-dimensional ocean circulation models can be used to model thermal expansion. Determining the rate that heat warms the ocean surface and how deep the water is warmed below the surface are important for this model. One limitation is that as climate change alters ocean circulation, the intensity of ocean mixing changes and leads to uncertainty in the model. Another limitation is the difficulty in measuring the addition of water volume from melting land-ice because there are so many glaciers. The World Glacier Inventory contains ~123,000 glaciers (Radic and Hock 2010). Scientists cannot model the dynamics of each glacier individually. Glaciers are measured using semi-empirical scaling laws to estimate total volume from satellite measured surface area. Due to the uncertainty of glacier volume, this glacier melt could contribute as little as 5 cm (Raper and Braithwaite 2006), around 10 cm (IPCC 2007), or more than 37 cm (for moderate levels of climate change; (Bahr et al. 2009) to sea-level rise by the year 2100. The science to watch is the study of melting land-ice. Every year scientists are improving measurements of melting glaciers and in turn improving the projected range of sea-level rise models.

Semi-empirical models try to extrapolate the link between observed sea-level rise and observed global temperature changes in the past in order to predict the future. The starting point is the simple physical idea that sea level rises faster as it gets warmer. An advantage of semi-empirical projections is that they reproduce the observed past sea-level rise. A limitation is that we cannot be sure that the pattern from the past will continue to hold in the future.

Models are updated with new understanding as our research improves. As the understanding of natural processes, especially the increased understanding of glacier melt, improves, the results are used in process-based models to provide more robust projections of future sea-level rise.

Both types of models put out a range of potential sea-level rise scenarios that provides a framework of possible outcomes based on what we know. This includes accounting for our understanding of models’ limitations, the range of potential future carbon emissions, and natural variability. The range of sea-level rise projections allows communities to plan for a changing coastline.

Background information adapted from: Rahmstorf, S. (2012) Modeling sea level rise. Nature Education Knowledge 3(10):4

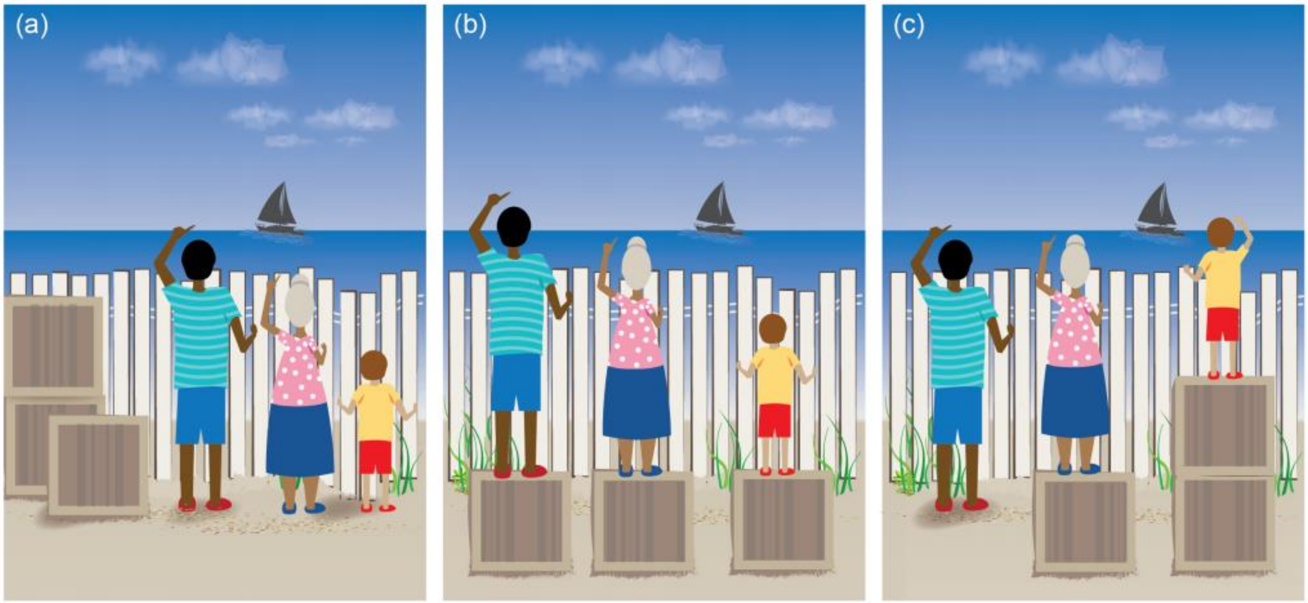
VOCABULARY:

Economics	Economics is a social science concerned with the production, distribution, and consumption of goods and services.
Model	Systematic depiction of current and/or future conditions for different processes. Model climate tool types include theoretical, numerical, and conceptual and can range from simple to complex.
Semi-Empirical Models	A model involving assumptions, approximations, or generalizations designed to simplify calculation or to yield a result in accord with observations.
Process-Based Model	A mathematical representation of one or several processes characterizing the functioning of well-delimited biological systems of fundamental or economical interest.
Visualization	Climate tool type that creates simulations or graphics of current and/or potential future conditions.
Vulnerability	Potential for assets to be adversely affected by hazards. Encompasses exposure, sensitivity, potential impacts, and adaptive capacity.

ENGAGE

Show students the image “Societal Options for Resource Allocation in a Changing Climate” without the figure legend (on the next page). Ask the students what they see in the pictures and what the boxes represent for sea-level rise preparedness.

Societal Options for Resource Allocation in a Changing Climate



Current Conditions and Resources | Equal Distribution of Resources | Equitable Distribution of Resources

Figure 8.5: Society has limited resources to help individuals and communities adapt to climate change. Panel (a) illustrates that there are finite resources available and that individuals and communities are starting from different levels of readiness to adapt. Panel (b) illustrates the option for society to choose an equal allocation of resources where everyone gets the same amount of help, or as illustrated in panel (c), society can choose to distribute resources equitably to give people what they need to reach the same level of adaptation. Source: adapted with permission from Craig Froehle.

EXPLORE

Have students read "Economic Loss Due to Frequent Flooding."
Use Think-Pair-Share with the class to answer questions about the text:
T : (Think) Students "think" about what they know or have learned about the topic.
P : (Pair) Each student should be paired with another student or a small group.
S : (Share) Students share their thinking with their partner. Can be expanded into a whole-class discussion.

Student questions:
How does flooding impact business operation?
Why are businesses important in your community?
What might a business do if high tide flooding occurs more frequently?
What might a homeowner do if high tide flooding impacts their route to school? Work? Recreation?
Why might a family not leave their community even with frequent flooding?

EXPLAIN

We see that sea level is rising and that it will have large impacts, as well as making existing flooding worse. We can investigate the past for measurements recorded by human instruments as well as records stored in ice cores. To prepare our communities for the future of sea-level rise it is important to be able to predict how fast and how much the sea level will rise. Climate change is a result of many factors contributing to increased concentrations of greenhouse gases like carbon dioxide. Sea-level rise results from multiple factors increasing the level of the ocean, like thermal expansion of water and melting land-ice. To predict the future of sea-level rise, scientists take data about the factors contributing to sea-level rise and create models.

Some of these factors are variable while others don't really change even over the course of decades. Scientists must decide which factors to include in their models and how much weight to give to each of them in order to construct a model that can make accurate and precise predictions.

ELABORATE

Students use provided data and spreadsheet/graphing software (Google Sheets or Excel) to model climate impacts.

Tell students: Today, you are a climate scientist working for the Intergovernmental Panel on Climate Change and your job is to prepare a brief report for the United Nations showing the long-term effect of certain carbon emissions policies. You will start by developing a model to predict the average global temperature in the year 2050 and then you will use your model to estimate how much things will change if certain policies are enacted. At the end, you will turn in two things: this worksheet with questions and tables filled in and a copy of all the graphs you make using Google Sheets.

Students will complete the worksheet and create graphs using the data.

EVALUATE

Ask students or review their worksheet:

In what ways do you think your model is accurate?

What other variables do you think would help your model? What other things could influence global temperatures that could be included?

Relate the modeling activity back to economics:

How are economies impacted by climate change and sea-level rise?

How can communities or nations use modeling information to have more resilient economies in the future?

> **EXTENSION**: students can propose two policy changes that the United States could make that would slow the warming trend worldwide.

STUDENT PAGE | Climate Change Anomalies and Suffering Economies

Answer the following questions after reading “Impacts from Increased Flooding.”

1. How does flooding impact business operation?

2. Why are businesses important in your community?

3. What might a business do if high tide flooding occurs more frequently?

4. What might a homeowner do if high tide flooding impacts their route to school? Work? Recreation?

5. Why might a family not leave their community even with frequent flooding?

You are tasked with developing a model to predict the average global temperature in the year 2050. Complete this worksheet and create graphs using a computer.

As you build your climate model, you will have to make several decisions about what data to include in it. To do this, you will make a series of graphs that show the relationship between different climate variables and global temperature and decide which ones make sense to include in your model. Below are descriptions of the data you are using, some going back to 1750 (some data are more limited because we only started collecting the data more recently):

You can access the data here: https://tinyurl.com/y6ozfo3b

(full link: https://docs.google.com/spreadsheets/d/1b4O2APcy-V9gzJg9ZJ8hctDvZfvqg-U9T-Ojnevv4pI/edit?usp=sharing)

Select all the data and copy it into a new spreadsheet document.

Global Temp: The average land surface temperature of the Earth based on interpolations from weather stations all over the Earth (data source: Berkley Earth)

Catastrophic Volcanos: Number of catastrophic volcanic eruptions around the world during that year (a "catastrophic" volcanic eruption is a volcanic eruption rated at a 3 or higher on the Volcanic Eruption Index) (data source: National Centers for Environmental Information)

Aerosol Optical Depth: A general measure of the concentration of aerosols (small particles found in dust, smoke, and ash) in the atmosphere that can shade out sunlight (source: National Centers for Environmental Information)

Sunspot Number: The average number of sunspots on the sun in a given year (data source: National Centers for Environmental Information)

CO_2 Concentration: The average global atmospheric CO_2 concentration during in a given year (data source: Institute for Atmospheric and Climate Science)

Cattle in USA: The total number of cows in the USA during in a given year (data source: National Agricultural Statistics Service)

Step 1: Variability Over Time

To model what will happen in the future you will need to determine if the variables follow a pattern. For each variable, use Google Sheets make a graph showing how it changes over time (you will make six graphs for this part). Be sure to label your axes and give each graph a title. A line graph would be a good way to represent these data.

After making your six graphs, fill in the table below, briefly describing the trend in the data (is it increasing, decreasing, or staying the same over time), variability (is the trend fairly constant over time or does it vary widely from year-to-year), and general notes on the pattern that you see.

Variable	General Trend	Variability	Notes
Global Temperature			
Volcanic Eruptions			
Sunspot Number			
CO_2 Concentration			
Cattle in USA			
Aerosol Optical Depth			

Step 2: Relationship with Temperature

After determining if the variables follow a pattern, you need to examine how they affect global temperature. Now use Google Sheets to make series of graphs that show the relationship between each variable (x-axis) and the global temperature (y-axis), then fill in the table below. Be sure to label your axes and give each graph a title.

Note: Since you aren't looking at change over time, it's not appropriate to use a line graph here. You will have to visualize your data with a scatterplot.

Fill in the table below to indicate the relationship between that variable and global temperature (are they positively related, negatively related, or unrelated) and the strength of any relationship (is it a strong relationship or just a weak one with a lot of variation).

Variable	Direction of Relationship	Strength of Relationship	Notes
CO_2 Concentration			
Sunspot Number			
Cattle in USA			
Aerosol Optical Depth			
Volcanic Eruptions			

Step 3: Building Your Model

Now we need to decide which variables to include in your model. Based on the relationship between global temperature and each variable, decide whether or not you think it would be important to include that variable in your model (Circle Yes or No) and briefly justify your decision.

CO_2 Concentration	YES	NO
Sunspot Number	YES	NO
Cattle in USA	YES	NO
Aerosol Optical Depth	YES	NO
Volcanic Eruptions	YES	NO

You know two things about each variable: how it changes over time and how it is related to average global air temperature. Now it's time to put your model together. For each of the variables you chose to include in your model, look back at your graphs from Step 1 and extrapolate the trend forward to the year 2050 to see what that value is. (Remember, you only need to include the variables you decided to include in your model from above)

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Variable: ________________________________ Value in 2050: __________

Now look at your graphs from Step 2 and make a prediction for what the temperature is likely to be in 2050 based on 2050 values you determined above.

Variable: _______________________________ Predicted Temp in 2050: __________

Variable: _______________________________ Predicted Temp in 2050: __________

Variable: _______________________________ Predicted Temp in 2050: __________

Variable: _______________________________ Predicted Temp in 2050: __________

Variable: _______________________________ Predicted Temp in 2050: __________

Lastly, calculate an average of the predicted temperatures from each of the variables above to determine your final prediction.

Your prediction for average global air temperature in 2050: ___________________

In what ways do you think your model is accurate?

What other variables do you think would help your model? What other things could influence global temperatures that could be included?

ECONOMIC LOSS DUE TO FREQUENT FLOODING

Coastal flooding has increased across much of the United States. Sea-level rise is causing more frequent flooding outside of extreme weather conditions. Flood damage causes negative impacts to property and buildings, but it also extends to impacting business and community life. Researchers Hino, Belanger, Field, Davies, and Mach (2019) studied the impacts on business caused by high tide flood events in Annapolis, Maryland. In 2017, Annapolis had high tide flooding occur on 63 days, particularly affecting the historic downtown area. For us living along the Gulf of Mexico from Florida to Mississippi, by 2050 we will experience high tide flooding on average between 25 to 80 days each year. Understanding effects in similarly impacted communities will help us plan for impacts in our communities. The research in Annapolis, Maryland demonstrates that high tide flooding does affect their local economic activity, and the number of people visiting the historic downtown was reduced by 1.7% during flood events. Future sea-level rise will further increase the number of high tide flooding days. With just 3 inches of additional sea-level rise, the increased frequency of high tide floods would reduce visits by 3.6%, resulting in negative impacts from reduced tourism and economic exchanges. When businesses are closed, it reduces revenues that support the community through sales tax, lodging tax, and other sources. Without this revenue, the budgets of cities, towns, and counties will be reduced, minimizing the amount of services (e.g., police, fire fighters, schools, road repairs, etc.) the municipalities can provide to their residents. Understanding how frequent flooding leads to economic loss will help guide local adaptations to prepare for climate change impacts.

SOCIETAL IMPACTS DUE TO SEA-LEVEL RISE

Climate change and sea-level rise pose risks to coastal communities around the world. Researchers Martinich and colleagues (2013) used an analytic tool to identify geographic areas in the contiguous United States that may be more likely to experience disproportionate impacts of sea-level rise and to determine if and where socially vulnerable populations would bear disproportionate costs of adaptation. They identified socially vulnerable coastal communities in four regions of the United States: North Atlantic (Maine through Virginia), South Atlantic (North Carolina through Monroe County, Florida), Gulf (Collier County, Florida through Texas), and Pacific (California through Washington). To evaluate if the communities threatened with sea-level rise would have the economic ability to adapt to the changes, they combined the vulnerable community output with a sea-level rise model. Their results show that under the mid sea-level rise scenario with around 67cm of rise by 2100, approximately 1,630,000 people are potentially affected by sea-level rise. Of the people affected, about 332,000 (~20%) are among the most socially vulnerable. Areas of higher social vulnerability are much more likely to be abandoned than protected in response to sea-level rise. In the Gulf region over 99% of the most socially vulnerable people are living in areas that are unlikely to be protected from sea-level rise inundation. In comparison, of the least socially vulnerable group in the Gulf region, only 8% of people live in areas unlikely to be protected. These results demonstrate the need to consider economic barriers of communities facing sea-level rise impacts.

First reading adapted from: Hino, M., Belanger, S., Field, C., et al. Science Advances (2019) 8: EAAU2736 https://doi.org/10.1126/sciadv.aau2736

Second reading adapted from: Martinich, J., Neumann, J., Ludwig, L. et al Mitigation and Adaptation Strategies for Global Change (2013) 18: 169. https://doi.org/10.1007/s11027-011-9356-0

STUDENT PAGE | Climate Change Anomalies and Suffering Economies

DO NOW:

Draw a downtown "Main Street." Then draw how high tide flooding might impact the area.

EXIT TICKET:

How does sea-level rise impact the economy?

SEA-LEVEL RISE IN THE CLASSROOM CAPSTONE PROJECT

WHAT TO EXPECT:

The Capstone Project is to be completed by students using the Sea-Level Rise in the Classroom curriculum to expand their understanding of community resilience. There are notes throughout this document with suggestions for scaffolding the project to fit your classroom needs. The project can be given as in-class work or as independent research and shortened or lengthened depending on the school calendar.

The capstone walk-through videos introduce the different layers and elements of the town maps. Review these with your students to orient them to the digital tool.
Waterside Village walkthrough: https://vimeo.com/583124304
Sunrise Bayou walkthrough: https://vimeo.com/583124192

The case study videos provide examples for how to identify, understand, and address sea-level rise impacts in each of the capstone towns.
Waterside Village case study: https://vimeo.com/583124213
Sunrise Bayou case study: https://vimeo.com/583124132

SET-UP:

There are two towns developed for this project: Sunrise Bayou and Waterside Village. Sunrise Bayou is a small coastal bayou town surrounded by marsh and rivers. Waterside Village is a larger coastal port city protected by barrier islands. These towns are representative of real locations along the Gulf Coast. Information about the town is provided through the town maps: population, income, social vulnerability, storm surge inundation from a category 3 hurricane, and 3-foot sea-level rise projections.
Students will work in groups of 3 to 5 to develop a resilience strategy for their assigned town.
Waterside Village: https://arcg.is/0j5eyC
Sunrise Bayou: https://arcg.is/1K8KCq
if the links do not work, copy and paste them into your browser

STUDENT INTRODUCTION:

Your team has been selected to head the Resilience Coalition for your town [Sunrise Bayou or Waterside Village]. You have grown up in this town and have a deep understanding of its history. Using your knowledge of the range of resilience strategies employed in other cities across the Gulf and around the world you must develop a strategy to help your city become more resilient to sea-level rise impacts. Your resilience strategy must help your community prepare for, absorb, recover from, and more successfully adapt to impacts of rising sea levels. Use information provided in the town map to identify the area of concern and resilience actions.

In addition to detailing your resilience strategy you must also include the process used to enact the strategy – how will you get input from the community? As your group prepares a resilience strategy keep in mind: What is the ethical thing to do? Are all members of the community being considered? What is the best action for the overall town? What resources are required and where will they come from?

Teacher note: One way to accomplish this is to have students create a pros and cons list for their strategy after they've developed a draft of their plan. This will help them identify who is left out, what facilities are not being helped or still vulnerable, etc. and give them a clear direction on how to make improvements to their plan.

Your capstone project will include a written response, and a corresponding presentation (Powerpoint, Sway, Prezi, video, website, etc.). As a group you will choose your target audience; are you presenting your plan to decision makers or are you presenting to educate local citizens?

RESILIENCE CONCERNS:

As your team works to develop your resilience plan, think about the following questions. Select a minimum of [X] to address with your resilience plan.

Teacher Note: scaffold the number of resilience concerns that each group needs to address to fit your class needs.

How does your resilience plan…

- protect critical facilities under current and future conditions? (Module 1)
- communicate future and current flood risk from multiple sources? (Module 1)
- protect natural resources? (Module 2)
- prepare and adapt for shoreline changes? (Module 2)
- ensure clean drinking water under current and future conditions? (Module 3)
- use ordinances and policies (Module 3)
- protect critical facilities under current and future conditions? (Module 3)

The list continues on the next page

- protect culturally significant locations under current and future conditions? (Module 4)
- protect residences under current and future conditions? (Module 4)
- prepare for resident evacuation and reentry? (Module 4)
- communicate early flood warning to residents? (Module 4)
- support first responders? (Module 4)

WRITTEN RESPONSE:

Teacher note: the length of the plan can be customized to your class but recommend ~2 pages per team member including one non-text component per student.

Introduction – your team should **prioritize** the issues for your town and then begin the document with a compelling argument you believe will engage your community. As you learned in the Kingstown exercise, everything cannot be a priority. Using the lessons from the modules, you must make decisions based on economic, environmental and social considerations for these towns. The introduction should also provide an overview of what the town is already doing to combat SLR and flooding issues. At the end of this section readers should understand what the plan is trying to accomplish and why.

The Plan – your team must convey your plan for the town in a written format. Your team must also determine the most effective means to present your plan considering the use of tables, infographics, flow charts and other alternatives to large blocks of text to make the plan more accessible to your reader.

Teacher note: Help your students focus on SLR and flooding issues. In classroom testing, many students wanted to focus on hurricane/storm surge plans. Remind students that storm surge issues due to SLR are only one of the issues their community may face.

Office and Google applications include many templates for tables and charts. You may choose to utilize free online tools like Canva or Piktochart to create graphics.

Be sure to consider the questions you selected from the list above as you create the resilience plan for your community.

Also consider the financial viability of your choices. As you learned in several modules, solutions have a wide range of associated cost. While you're not expected to know actual costs of implementing your plan, you should be mindful of presenting solutions that would be economically viable. Assume your community cannot implement every higher cost idea you've learned about in the modules.

At the end of this section readers should understand what action(s) the plan is recommending and what the outcome of those actions will be.

Stakeholder Engagement – Using the tools from Module 4, your team needs to include a plan for soliciting feedback from your community. In this section, provide details of how you will reach your community. At the end of this section readers should understand how best they or other members of your community can weigh in on and contribute to the actions described in the previous section.

PRESENTATION:

Teachers note: Students will prepare a 10-minute presentation for either a (a) decision maker meeting or (b) community education format. Teachers may alter the length of these presentations to better fit their classroom schedule. Teachers may elect to have students all complete one type of presentation or give the groups the option to choose their format.

These presentations offer an opportunity for students to role play as decision makers or community members and evaluate their peers. This is also an excellent opportunity to invite other teachers/administrators or guests from the community to participate as audience members.

Your presentation should include highlights from your written document. Your written document will inherently be more comprehensive than what you can accomplish in a short presentation. Therefore, a large part of your task is determining the most important information to communicate to the audience to which you're presenting. To know what information is important, you need to know who your audience is and what is important to them. The following section outlines some of the broad goals of two common types of meeting formats Resilience Coalitions must conduct.

Decision maker meeting format goals:

- Identify what risks the plan is intended to address
- Explain how this will benefit the community in terms that are meaningful for those decision-makers
    - This can include things like reduced damage to public and private property, reduced risk of loss of life, financial savings, or strong businesses
    - Identify specific sections/neighborhoods of the community this will benefit
- Communicate how much and/or what kind of effort and resources are required to accomplish what is in the plan
- Identify how the community will be engaged
- You want to leave decision-makers feeling confident in what the plan is and how the plan will help them and/or their community

Community education format goals:

- Introduce the risk(s) the plan is intended to address in a captivating way
- Identify how implementing the plan will address those risks
- Identify any additional ways it could benefit the community members in attendance
- Identify how they can get involved
- Do not overwhelm with too much information – these interactions are typically very brief
- Ensure you do not use too much jargon and present the plan at a level everyone can understand
- You want to leave the community members feeling confident in the plan and their ability to affect change
- DO NOT leave community members feeling hopeless or overwhelmed by the risks or the solutions

Presenting tips: your presentation should not feel like you are just reading your document to the audience. The infographics, flow charts, etc. that you have used in your document will be an important component of your presentation. You should avoid large blocks of text and consider the use of things like bulleted lists to present text when necessary.

RECOMMENDED CURRICULUM CITATION:

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EVALUATION RUBRIC

Overall Project	Low Quality (1)	Average Quality (3)	High Quality (5)	Score
Effort is consistent	Lack of evidence to demonstrate the amount of effort put forth and/or that the project wasn't started early and/or effort was not consistent.	Evidence demonstrates that the project was started with a somewhat consistent effort.	Evidence demonstrates that the project was started early and/or consistent effort has been made.	
SLR Resilience Strategy Clearly Described	The project lacks a sea-level rise resilience strategy and/or the strategies are not explained in detail.	The sea-level rise resilience strategy is somewhat described and explained.	The sea-level rise resilience strategies are clearly described and explained in detail.	
Depth of Background Research	Lacks the use/definition of important scientific terminology. Did not supply good sea-level rise solutions.	Uses and defines most important scientific terminology. Provides/explains legitimate solutions for this issue, including what people are already doing.	Uses and defines important scientific terminology. Explains in detail legitimate solutions for this issue, including what people are already doing.	
Clarity and Comprehension	Posture and speaking clearly were areas of weakness at several points. Student is unable to accurately answer questions posed by classmates.	Has good posture and voice clarity for most of the presentation. Student is able to accurately answer most questions posed by classmates.	Faces the class, speaks clearly, stands up straight throughout the presentation. Student is able to accurately answer all reasonable questions posed by classmates about the topic.	
Defense (Triple Points)	The project lacks a meaningful defense for your decision	The project explains a somewhat defense for the decision made.	The project explains a strong defense for the decision made.	
Time Used (Double Points)	Student not using their time appropriately in class.	Student was somewhat utilizing the time given in class.	Student was focused and utilized their time extremely well in class.	
Comments				

For all other document formats, supplemental materials, and PowerPoints please visit the [curriculum's Google Drive folder].