Sandwich Climate Change and Coastal Resiliency Curriculum Framework

Developed to support Sandwich Public Schools STEM Academy Curriculum
7th and 8th Grade

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WOODS HOLE GROUP FORWARD

Dear Sandwich Science Teachers,

I am excited to share with you the *Sandwich Climate Change and Coastal Resiliency Curriculum* for the 7th and 8th grade STEM Academy. The lesson plans contained in this curriculum document support existing curricula from the *2016 Massachusetts Science and Technology/Engineering (STE) Curriculum Framework.* This document also serves to supplement existing climate change lesson plans by incorporating localized climate change data and applied science investigations for the Town of Sandwich.

Coastal towns, like Sandwich, are extremely vulnerable to the impacts of storm surge, flooding, sea level rise, and other coastal hazards. In turn, Sandwich is committed to building community resilience and reducing vulnerability to the impacts of climate change. The town has invested significant resources and time to develop a detailed understanding of its evolving and dynamic coastline, and has explored unique and diverse strategies to restore, protect, and enhance these natural assets for the enjoyment and benefit of all.

In 2018, the Town of Sandwich was awarded a Planning Grant from the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) to implement the Municipal Vulnerability Preparedness (MVP) Program's Community Resilience Building (CRB) framework. The CRB workshop resulted in a list of implementable actions and certified the Town of Sandwich as an MVP community. As a certified MVP community, the Town of Sandwich was eligible to apply for MVP Action Grants to implement prioritized actions from the workshop. One of the top priorities from the CRB workshop was to "Develop an Education Outreach Strategy on Climate Change and Beaches/Dunes". In 2019, the Town of Sandwich received an MVP Action Grant to develop an educational communications platform for the Town's coastal resilience program. With a goal of reaching the student demographic, a series of lesson plans aimed at communicating the local impacts of climate change and developing adaptation solutions was identified as a priority of the successful completion of this project.

I would like to thank everyone that was involved in the development of this curriculum. I believe educating students about local climate change and resiliency efforts will not only help bridge the gap in science communication but will inspire the next generation of young people to have a profound respect for our world now and into the future.

Sincerely,

Brittany Hoffnagle, M.S.
Environmental Scientist
Woods Hole Group

ACKNOWLEDGEMENTS

The Sandwich Climate Change and Coastal Resilience Curriculum was the result of grant funding from the Municipal Vulnerability Preparedness program through Massachusetts's Executive Office of Environmental Affairs (EEA) in 2019. The MVP program is designed to help communities reduce vulnerability to climate-related hazards and build community resilience. EEA also launched the ResilientMA Climate Change Clearinghouse which is the primary source for all information and data related to climate change for the State of Massachusetts. Past and future climate change data used in the development of this curriculum was derived from ResilientMA.org.

The Massachusetts Coast Flood Risk Model results used throughout this curriculum were developed by Woods Hole Group and funded by Massachusetts Department of Transportation. This sophisticated hydrodynamic model aims to assess the impacts of storm surge and sea level rise to municipal and state infrastructure throughout the State now and into the future.

Woods Hole Group would like to thank Dave DeConto and the Sandwich Department of Natural Resources in their support of this curriculum development completed under the 2019 MVP action Grant.

The framework of this curriculum would not be possible without the support of Sandwich Public Schools and the STEM academy. In particularly, I wish to say thank you to the following Sandwich STEM Academy contributors:

Betty Hyde-McGuire- 7-12 Science & Engineering Department Chair
Amy Ferreira- 8th Grade Science Teacher
Chris Harlow- 7th Grade Science Teacher

INTRODUCTION

The lessons developed herein cover the topics of coastal geology, human impact on the natural world, weather and climate differences, coastal resiliency and adaptation strategies, and future climate change science. The lesson plans contained in this document aim to supplement existing climate change and coastal science curriculum. Integrating local knowledge of the coastal processes affecting Sandwich's coast and examining localized climate change data in the context of regional and global climate trends are importance in educating students about their Town and the natural world around them.

The lessons herein serve as a framework for teaching your students about local coastal process and climate change impacts in the Town of Sandwich. Each lesson contains an introduction activity which exposes the students to the topic or prompts the students to explore an online platform that will be utilized further in the lesson. The main lesson section of each plan provides detail on how to effectively teach the subject matter with all associated resources and critical thinking questions. Each lesson incorporates a conclusion activity which ranges from classroom discussions to student creative projects. Following the lesson plans is a list of suggested project-based learning capstones. This list provides suggestions for creative student projects that cross over to other curriculum standards and utilizes available school technology.

The suggested activities, probing questions, associated resources, and critical thinking questions which exist in each lesson plan serve as recommendations for teaching the students. The teacher has total discretion and flexibility to teach students these lessons in their current format or make changes that better suit their classroom needs. As the teacher, you will know the appropriate level of questions to ask and understand the education needs your students require. These lesson plans in their current state, can but utilized as a unit and be taught in successive order as each lesson utilizes information from previous lessons. However, based on the natural teaching schedule, lessons can be dispersed throughout the year to be complimentary to existing lessons plans.

Significant educational context and narratives are included in many of these lesson plans that serve as important background knowledge for you. The science and materials included in these lesson plans can be complex and the more you are familiar with the information, the better the dissemination to the students will be.

And remember- this curriculum was a collaborate effort from Sandwich science teachers and a scientist and should be used as a reliable resource from your bag of tricks!

7TH GRADE LESSON PLANS

Understanding the Changes along Sandwich's Coastline

Time: 1.5hours

Standards: 7.MS-ESS2-2. Construct an explanation based on evidence for how Earth's surface has changed over scales that range from local to global in size. Example of changes occurring over small, local spatial scales include earthquakes and seasonal weathering and erosion.

Question: How has Sandwich's coastline changed through time and how might these changes affect the Town?

Objective: Students will use available orthoimagery[1] to describe how Sandwich's coastline has changed through time, make inferences on what caused these changes and how they might affect the Town.

Background: Students should have a basic understanding of coastal processes (i.e. accretion/erosion) and how these processes can reshape the environment on the local and regional scale.

Materials: Sandwich locus map, Cape Cod Chronology Viewer (Option A), Google Earth Pro (Option B). Personal student device with internet access.

Vocabulary: erosion, deposition, locus map, historical maps, aerial photos, orthoimagery

Introduction:

The Town of Sandwich, located on the southwestern edge of Cape Cod Bay, has a very dynamic coastline consisting of a barrier beach system and extensive marsh ecosystem. Sandwich's coastline has evolved through time for a variety of reasons which students will better understand throughout this lesson. Students will observe how the coastline has changed but first they should become familiar with Sandwich's coastline to better observe the change on the local level.

Share the Sandwich Locus Map figure with the students. This figure will orient the students to a variety of focus points along the Town's Coastline. Understanding the local environment will allow the students to better describe the observed changes they will see in this lesson.

Locations seen in the Sandwich Locus Map include:

1. Scusset Beach	2. Cape Cod Canal
3. Town Neck Beach	4. Entrance to Old Harbor
5. Sandwich Marina	6. Freeman Ave
7. Bay Beach Lane	8. Town Neck Beach Spit
9. Cape Cod Canal North Jetty	10. Cape Cod Canal South Jetty
11. Town Neck Road	12. Cape Cod Bay
13. Town Neck Beach Dune	14. Sandwich Marsh
15. Old Harbor Creek	

Alternative: Google Earth Pro or online mapping platforms like Google Maps, Bing etc. can also be used to help orient the students to the Town's Coastline. The Locus map can still be used by the Teacher as a reference if an online platform is the more appropriate option for student use.

Sandwich Locus Map

Main Lesson:

The students will now use historical maps and aerial photos to observe how Sandwich's Coastline has changed over time. Aerial photos are a type of ortho-photo that is taken of the earth's surface from aircraft such as planes, helicopters or even drones. Orthophotos can also be taken by satellites placed in earth's orbit.

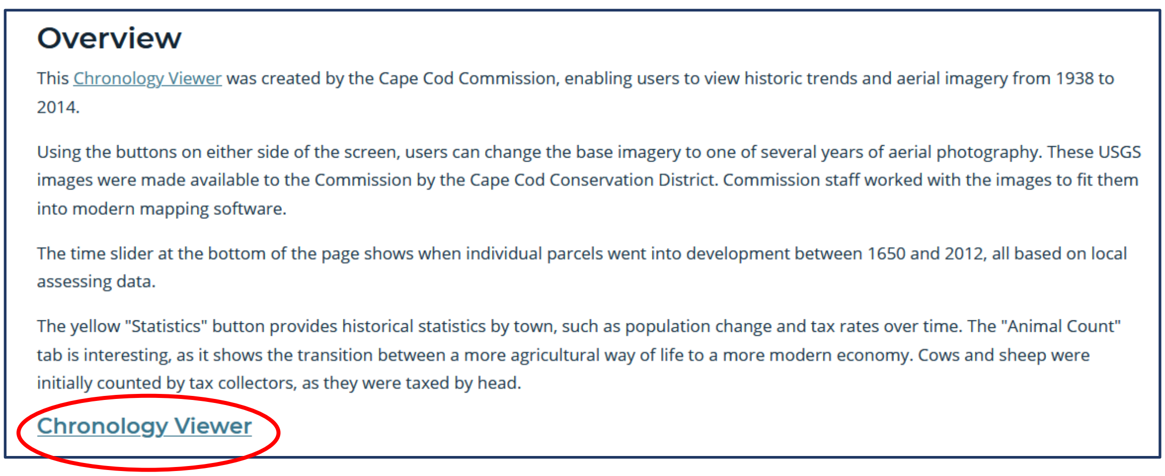
Aerial photography taken through time can aid a viewer in describing how local landforms have changed over time. Based on available technology there are two options to complete this lesson:

Option A: Cape Cod Chronology View developed by Cape Cod Commission

Cape Cod Commission has a Cape Cod Chronology viewer that shows historical maps and aerial photographs from Cape Cod starting from the year 1890 (historical map) and through 2014. Link is provided below:

https://www.capecodcommission.org/our-work/cape-cod-chronology-viewer/[2]

Once you enter the website you will be directed to an overview page describing the creation and use of the viewer. Once the website has been entered, click on the linked Chronology Viewer as seen circled in red in the figure below:



Overview

This Chronology Viewer was created by the Cape Cod Commission, enabling users to view historic trends and aerial imagery from 1938 to 2014.

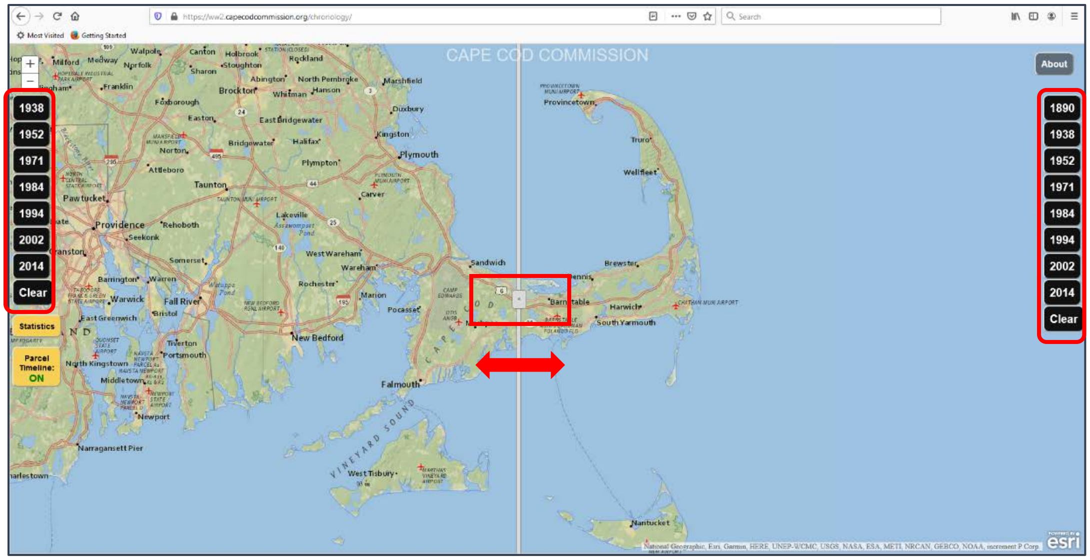
Using the buttons on either side of the screen, users can change the base imagery to one of several years of aerial photography. These USGS images were made available to the Commission by the Cape Cod Conservation District. Commission staff worked with the images to fit them into modern mapping software.

The time slider at the bottom of the page shows when individual parcels went into development between 1650 and 2012, all based on local assessing data.

The yellow "Statistics" button provides historical statistics by town, such as population change and tax rates over time. The "Animal Count" tab is interesting, as it shows the transition between a more agricultural way of life to a more modern economy. Cows and sheep were initially counted by tax collectors, as they were taxed by head.

Chronology Viewer

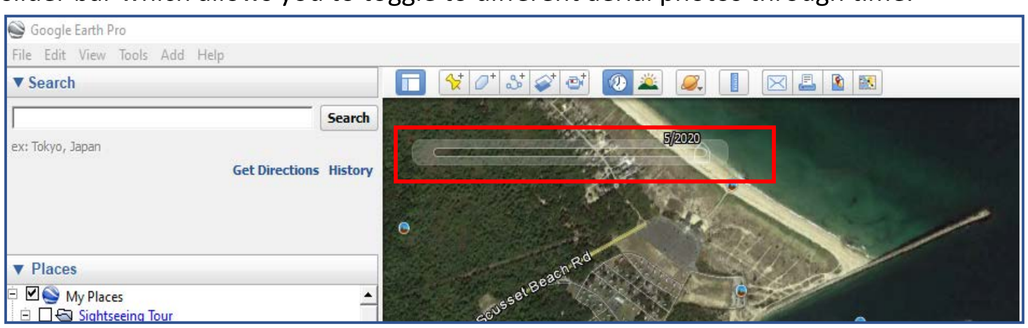
The viewer allows you to select which photograph years the viewer wants to compare seen on the left and right (figure below). There is a slider bar in the middle that can be moved from left to right to see changes that occur between two different years. There are also zoom in and zoom out buttons in the top left corner. Use these buttons to zoom in to Sandwich. You can also use your cursor to move the map to the area that you are interested in (i.e. Sandwich coastline).



Option B: Google Earth Pro

Google Earth Pro is a mapping platform that is free to download to any device and is useful in becoming more acquainted to any geography in the world. Google Earth Pro is useful in learning local roads, important local places and even the elevation and terrain characteristics of a locale. Google Earth Pro also provides the benefit of looking at historical imagery but is more limited in the years available (1991-Present) than the Cape Cod Chronology viewer.

To access the historical imagery in Google Earth Pro, click on View from the top menu bar and select Historical Imagery. A bar at the top of the window will appear showing a slider bar which allows you to toggle to different aerial photos through time.



Clicking on the left or right areas will change the aerial photo from different years to see the landform changes along Sandwich's coastline.

Students will then use the aerial photo platform to complete the lesson. Allow the students to take a few minutes to interact with the aerial photos and discuss amongst themselves what changes they see. The goal of this exercise is for students to describe the physical changes that are seen and make educated guesses on why they may be occurring.

The following worksheet provides an example of the critical thinking questions that students could answer while comparing the various historical aerial photos. For each question there is a reference example answer to be used by the teacher.

1. While looking at the earliest available aerial photo and using the Locus map as a reference, describe Sandwich's Coastline. Note the existence of various features, the degree of development along the coastline or even the width of the beach.
   Ex: 1938- 1. Scusset Beach had a creek channel that went across the beach face. There are no houses built along the coast.

2. After looking at the various other aerial photos, fill out the table below to describe how the coast has changed through time in comparison to the earliest aerial photo.

Year Comparison (i.e. 1893- 2014)	Describe the changes you see
Ex. 1952-1994	1. A lot of houses were built right along the beach by 1994 2. The beach in 1952 looks wider. 3. The tidal creek inlet looks to be in a different position.

3. Describe a few of the processes that might contribute to these observed changes

   Ex. Erosion of sediment along Town Neck Beach.

4. What are some possible impacts to the Town of Sandwich if the coastline were to experience large scale erosion or sand deposition events?

   Ex. If Town Neck Beach were to erode, there could be an increase in flooding to the Town. If sand were to deposit in the tidal creek inlet there could be reduced tidal flushing.

5. Do you think humans could have contributed to any of these observed changes? Why or why not?

   Ex. Yes, there were houses and jetties/groins built right along the coastline.

Conclusion:

After the students have completed the table and questions, students can volunteer to share some of their identified changes through time guided by the display of the aerial photos on a big screen.

Resources:

Below is a list of URLs associated with the various resources found in this lesson plan.

1. Orthophoto Wikipedia
   -https://en.wikipedia.org/wiki/Orthophoto

2. Cape Cod Chronology Viewer
   -https://www.capecodcommission.org/our-work/cape-cod-chronology-viewer/

Impacts of Coastal Structures on Coastal Processes

Time: 1.5 hours

Standards: 7. MS-ETS1-2. Evaluate competing solutions to a given design problem using a decision matrix to determine how well each meets the criteria and constraints of the problem. Use a model of each solution to evaluate how variations in one or more design features, including size, shape, weight, or cost, may affect the function or effectiveness of the solution.

7.MS-ETS3-4(MA). Show how the components of a structural system work together to serve a structural function. Provide examples of physical structures and relate their design to their intended use.

Question: Why are manmade structures (e.g. Cape Cod Canal, jetties, or groins) built along the coast and what role do these structures have on erosion and deposition of sand on Town Neck Beach in Sandwich?

Objective: After searching for and reviewing a variety of resources (i.e. news article), students will explore the pros and cons of coastal man-made structures.

Background: Students should have a basic understanding of coastal processes (i.e. deposition/erosion, currents) and the ability to evaluate the effectiveness of an engineered and designed structure.

Materials: Personal student device with internet, literature options, Sandwich Locus Map

Vocabulary: coastal zone, longshore currents, stabilization structures, sediment and sediment transport, erosion, deposition

Introduction:

The coastal zone is a very dynamic environment situated between the ocean and land. This area experiences change from coastal processes that occur. Waves, wind, and longshore currents can transport sediment (e.g. sand) from one location to another reshaping the coastline on a variety of temporal scales. The use of jetties, groins and other shoreline stabilization structures are just a few ways that humans try to manage the coastline to prevent undesired changes, especially along developed coastlines.

Sandwich has a variety of manmade structures along its coastline including the Cape Cod Canal, the Cape Cod Canal Jetties, and several shore perpendicular groins along the length of the beach. Utilize the Sandwich Locus Map below to orient the students to these structures along the coast. (See red boxes in the Locus Map below)

Have a short classroom discussion on the purpose of these coastal structures and existence of the Cape Cod Canal. Probing questions could include:

1. What is the purpose of these coastal structures?
2. Why was the Cape Cod Canal built?

Asking these questions can facilitate their creativity and critical thinking skills, but also give you background of what they already know about coastal structures and coastal processes.

Next, the students will be introduced to the history of the Cape Cod Canal which significantly altered the coastline of Sandwich.

The construction of the Cape Cod Canal started in the early 1900's and opened by 1914. In the 1930's, under new Federal ownership (US Army Corps of Engineers), the canal was modified further to be straighter and deeper (see: US Army Corps Cape Cod Canal History[1] for more information). The Cape Cod Canal was built not only to expedite the shipping time between major shipping ports of Boston and New York, but to also navigate away from the treacherous waters of the outer cape where hundreds of shipwrecks have occurred throughout history. The Cape Canal is an engineering feat that connected Cape Cod Bay to Buzzards Bay between two historical low-lying tidal rivers (Scusset River and Monument River) and now includes two long jetties at the Cape Cod Bay entrance and an armored approached channel in Buzzards Bay.

Have the students view the video or read this US Army Corps Article at the links below and answer these two questions.

Video: History Channel- Building the Cape Cod Canal[2]

Article: US Army Corps Cape Cod Canal History[1]

Questions:

1. What are some reasons for the construction of the Cape Cod Canal?
   Ex. To expedite travel between major ports and to create a haven for shops protected from treacherous weather conditions.

2. What engineering and construction strategies were used to complete the canal?
   Ex. Connecting two historical low-lying tidal rivers, dredging, wooden dikes to hold back water.

Main Lesson:

Overall: The students will now conduct some research to learn about the difference between various shoreline stabilization structures and explore their intended purpose and possible impacts to sediment dynamics. Students should be able to complete their own research but here are some resources that you can provide if needed:

1. Coastal Processes, Hazards, and Society[3]
2. National Park Service- Coastal Engineering[4]
3. Shoreline Stabilization Structures[5]

On the local Level: Currently, Sandwich is undertaking a few investigative studies to better understand the sediment dynamics of the area. The Town Neck Beach and dune system located south of the canal is experiencing extensive erosion and impacts from past nor'easters. The north jetty prevents the natural transport of sediment alongshore. The Town is looking into ways to nourish and bolster the current beach and dune system. A potential sand source for the nourishment is from Scusset Beach located on the northern side of the Canal. Since the north jetty traps sediment that moves alongshore, Scusset Beach has a significant deposition of sand material that could be used to re-nourish Town Neck Beach. If not for this interruption of longshore sediment transport by the jetties, this sand material would have naturally replenished Town Neck Beach. Consequently, Town Neck beach is sediment starved and more vulnerable to erosion from the local coastal processes occurring. Another study is looking at the hydrology and hydrodynamics of the Old Harbor Tidal Creek. Sand that has eroded from Town Neck Beach has bypassed the entrance to Old Harbor and deposited into the Old Harbor Creek Channel potentially reducing the tidal flushing of the entire salt marsh system. Another important study is the Section 111 to further investigate the specific role the jetties (under US Army Corps of Engineers federal management) may have had on the sediment dynamics and erosion issues Sandwich experiences. The students will now look at some resources to learn about the local coastal structures in Sandwich and the sediment issues that Sandwich is experiencing. The students should look at the following sources of information linked below

1. Sandwich Story Map[6]- This Source will introduce the students to some of the erosion issues that Sandwich is experiencing and some of the projects that are being done to address these concerns.
2. Cape Cod Times Article[7] – A news article that explores the role that Cape Cod Canal jetties played on the erosion along Town Neck Beach.
3. CapeCod.com Article[8]—An article reporting on the Army Corps study that assessed the role that the Cape Cod Canal Jetties play on the erosion along Sandwich beaches.

Based on this research, the students should be able to answer the following sample questions.

1. What is the purpose of a shoreline stabilization structure?
   Ex. The main purpose of a shoreline stabilization is to protect structures that have been built in an environment that is experiencing sand loss (e.g. beach house). These stabilization structures alter how waves, currents, and sand movement affect an area.

2. What is the difference between Jetties and Groins?
   Jetties are often very long and are intended to maintain open shipping and/or navigational channels (i.e. Cape Cod Canal jetties).

   Groins are typically much shorter structures built along a beach intended to trap sand at that location.

3. What materials are used to construct these types of structures?
   Ex. Shoreline stabilization structures can be built from wood, steel, concrete, or rocks/boulders; just to name a few.

4. Create a list of pros and cons of having shoreline stabilization structures along the coastline.

Pros of Coastal Stabilization Structures	Cons of Stabilization Structures
Ex. - Can keep sand from moving into a shipping channel - Maintain a straight tidal creek channel - Etc.	Ex. - Sand downdrift of a structure can erode - Beaches downdrift of a structure do not have a sand supply - Etc.

5. What are some of the issues that Sandwich is experiencing along its coastline? (From the Story Map)

Ex. Sand is being deposited along Scusset Beach. Town Neck Beach and dune south of the South Cape Cod Canal is eroding. Sand is transported into the Old Harbor Creek inlet.

Critical Thinking Questions:

1. Could it be possible the coastal structures are contributing to the issues Sandwich is experiencing along the coast? Why or why not?
   Ex. This is an opinion piece, but students could use the Army Corps article as support to saying yes.

2. What impacts can erosion of Sandwich's coast have on the entire Town? (Could Use Story Map for support)
   Ex. Erosion of a beach and dune could result in Town-wide flooding. If roads or buildings in town flood, emergency services could be impacted.

Resources:

Below is a list of URLs associated with the various resources found in this lesson plan.

1. US Army Corps of Engineers Cape Cod Canal History
   -https://www.nae.usace.army.mil/Missions/Recreation/Cape-Cod-Canal/History/
2. History Channel- Building the Cape Cod Canal
   -https://www.history.com/topics/us-states/a-challenging-story-the-cape-cod-canal-video
3. Coastal Processes, Hazards, and Society
   -https://www.e-education.psu.edu/earth107/node/1060
4. Series: Coastal Engineering- Hard Structures
   -https://www.nps.gov/articles/groins-and-jetties.htm
5. Shoreline Structures
   -http://www.beachapedia.org/Shoreline_Structures
6. Town of Sandwich Coastal Resilience Program
   -https://storymaps.arcgis.com/stories/0cc1b190abbc40058219d66b2f355eaa
7. Cape Cod Times Newspaper Article: US. Army Corps
   -https://www.capecodtimes.com/news/20160303/us-army-corps-canal-jetties-exacerbate-sandwich-erosion
8. CapeCod.com Article: Army Corps Report
   https://www.capecod.com/newscenter/army-corps-report-confirms-canal-jetty-woes-for-sandwich-beaches/

Sandwich Coastal Shoreline Change Analysis

Time: 2.5 hours

Standards: 7.MS-ESSE-2. Construct an explanation based on evidence for how Earth's surface has changed over scales that range from local to global in size. Example of changes occurring over small, local spatial scales include earthquakes and seasonal weathering and erosion.

7. MS-ETS104. Generate and analyze data from iterative testing and modification of a proposed object tool, or process to optimize the object, tool, or process for its intended purpose.

Question: How quickly is sandwich's coastline changing? Is the beach eroding? Is the beach accreting?

Objective: The students will calculate, and graph shoreline rates based on historical shorelines from the Town of Sandwich.

Background: Students should have a basic understanding of coastal process (accretion/erosion) and be able to graph and analyze data.

Materials: Personal Student device with internet, graph paper or appropriate graphing resources.

Vocabulary: accretion, erosion, shoreline change, historical shorelines.

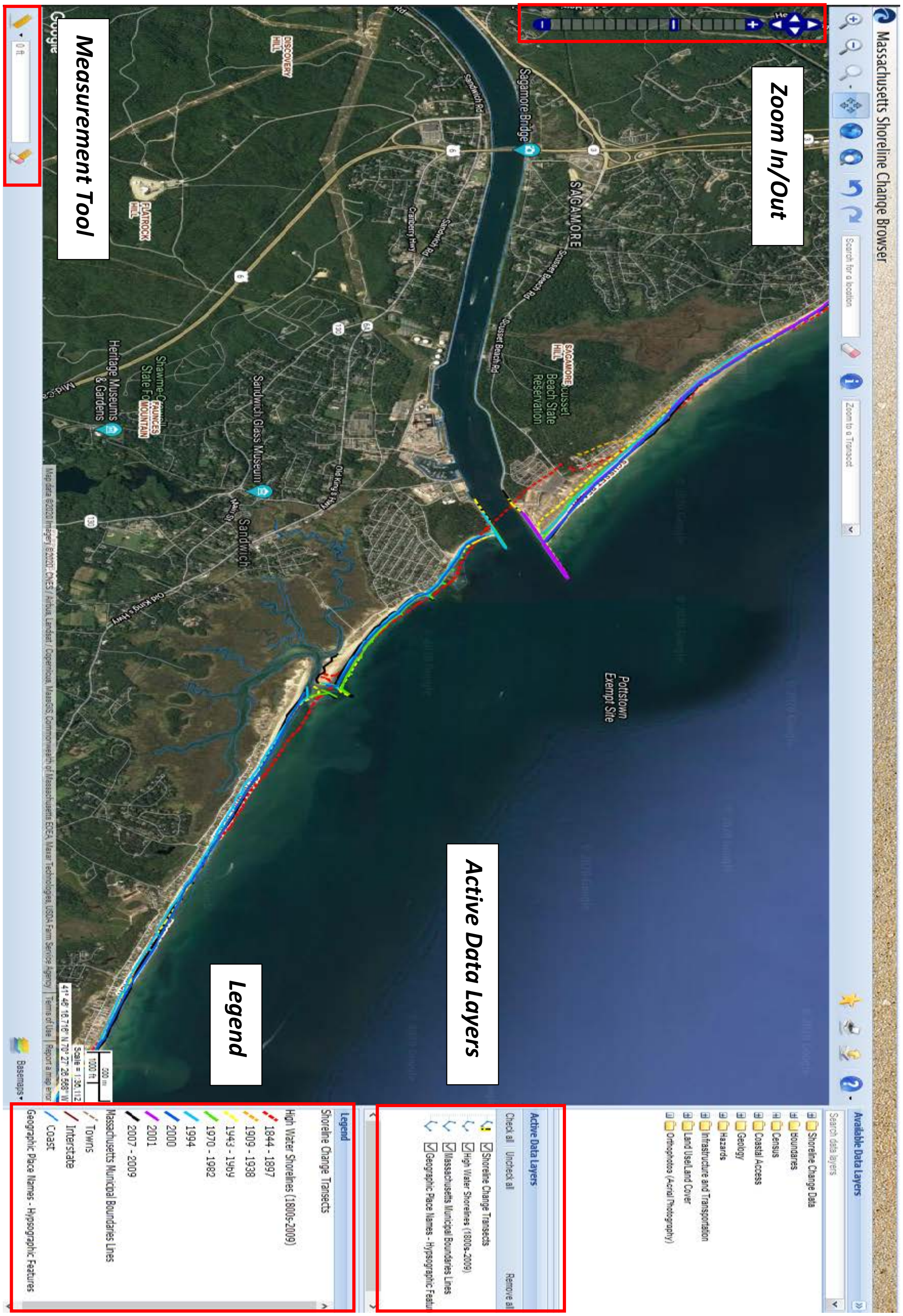
Introduction:

Shoreline change analyses are one important way to understand how the coastline changes especially when informing management decisions. Historical shorelines are often digitized from historical aerial photos or documented by detailed on-the-ground surveys. The digitized shorelines represent the high-water line position. Changes in the position of the high-water line can indicate changes to the beach. Using the distance between each high-water line through time can help to determine shoreline change rates to understand the temporal changes of the coastline.

Massachusetts Coastal Zone Management (CZM) is a governmental agency that leads in the policy, planning and technical assistance on coastal and ocean issues. They have developed the Shoreline Change Project to identify erosion prone areas along the Massachusetts coast. CZM has an online interactive viewer that displays the historical shorelines that are included in the CZM Shoreline Change Project inventory. Use the following link to access the viewer:

Coastal Zone Management Shoreline Change Project[1]

This viewer is an interactive map that you can zoom in and out to any specific geographic location. On the left-hand side there are buttons that you can use to zoom in and out. On the bottom left hand corner there is a measurement tool. On the right-hand column is the *Active Data Layers* that allows you to click on/off the layers you want to look at. On the bottom right there is a *Legend* identifying the year of each shoreline. Use the figure below to orient yourself to the viewer.


Massachusetts Shoreline Change Browser
Zoom In/Out
Measurement Tool
Active Data Layers
Legend
Available Data Layers
Shoreline Change Data
Boundaries
Census
Coastal Access
Geology
Hazards
Infrastructure and Transportation
Land Use/Land Cover
Orthophotos (Aerial Photography)
Check all
Uncheck all
Remove all
Shoreline Change Transects
High Water Shorelines (1800s-2009)
Massachusetts Municipal Boundaries Lines
High Water Shorelines (1800s-2009)
1844 - 1897
1909 - 1938
1943 - 1969
1970 - 1982
1994
2000
2001
2007 - 2009
Towns
Interstate
Coast
Geographic Place Names - Hypsographic Features
Sagamore Bridge
SAGAMORE
Sandwich
Sandwich Glass Museum
Heritage Museums & Gardens
Pottstown Exempt Site
Basemaps

Have the students in small groups visit the Shoreline Change View for a few minutes. Have the student move to the Sandwich area and zoom in to the coastline. Once the students zoom into the coast the yellow *Shoreline Change Transects* might be visible. Students should unselect the *Shoreline Change Transects* located in the *Active Data Layers* area.

Students should answer the following questions after interacting with the Viewer.

1. How many high-water lines are in the viewer?
   Ex. 8 for transect 1, 7 for transect 2, and 6 for transects 3-7.

2. Which high water line is from the earliest point in time? Which is the most recent shoreline shown?
   Ex. 1844-1897 – earliest 2007-2009—most recent

3. What is the span of time between the earliest and most recent high-water lines?
   Ex. Approximately 165 years

Main Lesson:

The students will now have an opportunity to understand how quickly the shoreline is changing along the coastline of Sandwich by conducting their own shoreline change analysis.

Typically, shoreline change analysis is completed by calculating change rates along shore perpendicular transects. At each transect, the distance between each high-water line is measured which will be used to calculate the rate of change and assess whether the beach at each transect is eroding or accreting sand.

In this lesson students will work in groups to calculate the shoreline change rates along one (1) transect. Following this lesson plan, Reference A includes base maps that show seven (7) transects positioned along the coastline in Sandwich that you will assign to a group of students. You should take some time to project the CZM shoreline change viewer onto the white board and walk the students through how they will use these transects to calculate the shoreline change rates.

How to instruct the students to measure the distances between shorelines:

1. Project the CZM shoreline view on the white board so the entire class can see the shorelines along Sandwich's coast.
2. Zoom into the area as seen in the image below which shows transects 1 and 2.

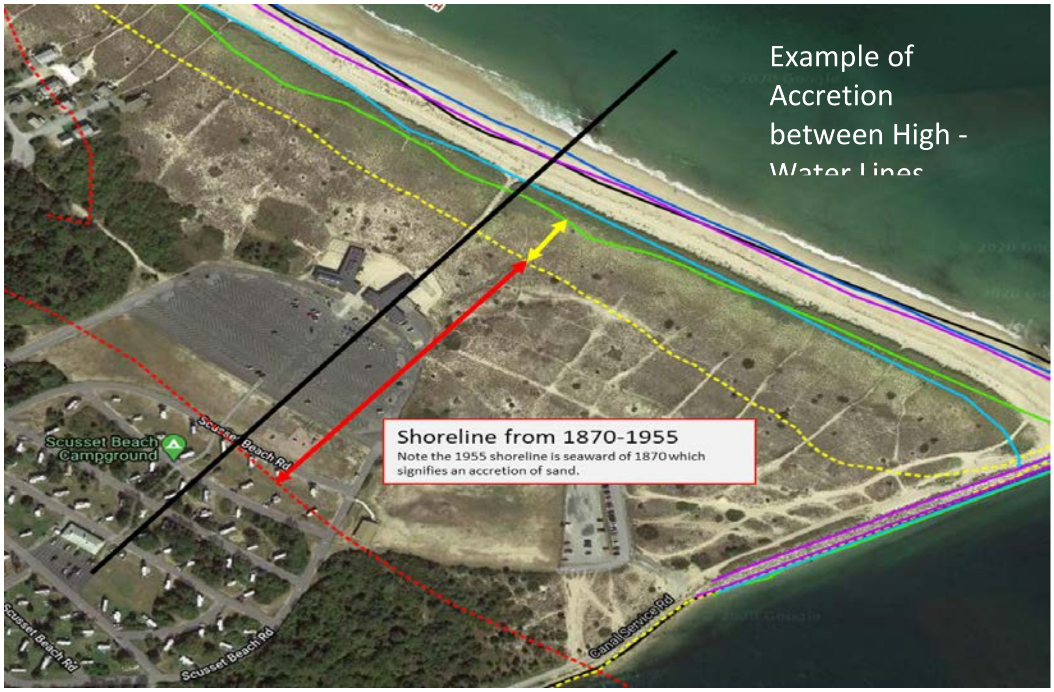
3. Draw a shore perpendicular dotted line on the white board like transect 1 and 2 in the image above. (Make sure this transect crosses over each shoreline that can be in the viewer). You could also trace a few of the shorelines that intersect the dotted line using various colors of white board markers.
4. Inform the students that they will be measuring the distance between each shoreline along a transect. Keep in mind, that their personal device will not show a transect but they should do their best to measure the distance between the shorelines along a straight line if possible.

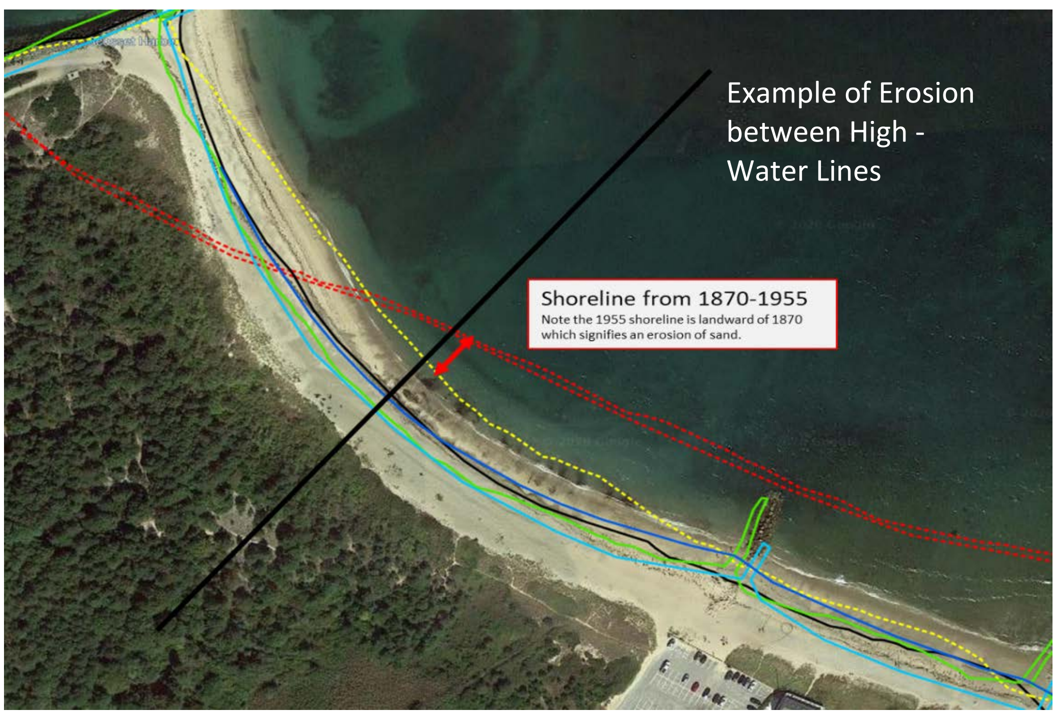
5. Students will be filling out the following data table (see worksheet):

Year of High Water Line	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion
1870 (1844-1897)	--	--	--	--
1924 (1909-1939)				
1955 (1943-1969)				
1976 (1970-1982)				
1994				
2000				
2001				
2008 (2007-2009)				
What is the Minimum Shoreline Rate Change				
What is the Maximum Shoreline Rate Change				
Average Shoreline Rate Change				

6. Orient the students to the table. Some high-water shorelines include a range of years (e.g. 1844-1897). In earlier times, shorelines were either digitized from multiple historical maps or delineated by an on-foot surveyor. On-foot surveying would often take many years to complete. To simplify the dates of the shoreline, the time frame for analysis is represented by the midpoint year (e.g. 1870 is the midpoint between 1844 and 1897).
7. There are some shorelines in the table that are *NOT* at each transect location. Students who are working on a transect should cross out the line in the table of the time period that is not represented by a high-water line in the viewer. For transects 2 students should cross out the 1924 shoreline and for transects 3 through 7 students should cross out the 1924 and 2001 shorelines.
8. The students should then calculate the number of years between the high-water lines cross their transect. For example, considering that 1924 is not present for Transect 2, the number of years should then be calculated between 1955 and 1870 (85 years), 1976 and 1955 (21 years) and so on.
9. The distance between two time periods will be recorded in the "Distance from earliest shoreline". Use the ruler measurement tool in the bottom left hand corner of the viewer to draw a line between the 1884-1897 high water line to the 1909-1939. The box in the bottom left corner will tell you the distance between these two high water lines. Proceed to show them how to measure between the 1943-1969 to 1909-1939 high water line, etc. To start a new measurement, you will have to click on the *Clear Measurement* button at the bottom left corner of the viewer.

10. One important detail the students need to understand is whether the beach is eroding or accreting sand at each location. If the more recent year of a comparison of two mean high waters is more seaward then the earliest year in the comparison, then the measured distance should be positive (✚). If the more recent year is more landward than the earliest year in the comparison, the measured distance should be negative (—). Use the images below as a reference.





11. Once the distances are measured the students will then calculate the rate of change by dividing the distance between two time periods by the number of years in that time frame.

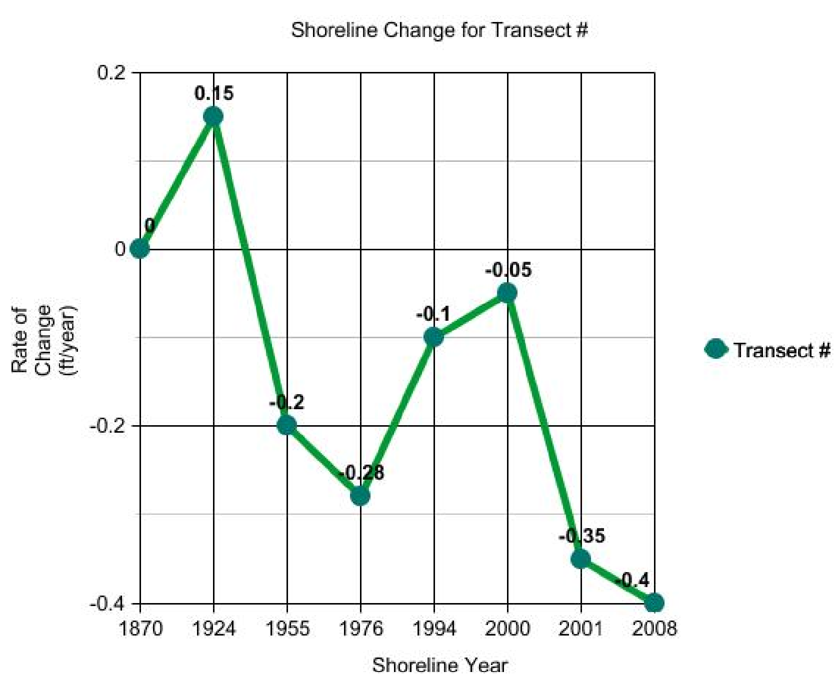
$$Rate\ of\ change = \frac{Distance\ between\ shorelines\ (feet)}{Number\ of\ years\ between\ shorelines}$$

12. Based on the rate of change the students should comment if that particular time frame was experiencing erosion or accretion. A positive rate of change means that beach was accreting sand and a negative rate of change means the beach was eroding sand.
13. Students will also determine the minimum, maximum, and average rate of change for the data. Lastly, assign each of these metrics with erosion or accretion like they did for each individual time period.
14. The students should now work in their group to measure the high-water lines and complete the data table. A table of calculate results for each transect are in Reference B to be used to check the data students have calculated. Expect to see minor differences due to measuring inaccuracies.
15. The last step of this main lesson is to have the students graph the results. You can choose to either have them graph on paper or they can use an online web platform to automate the process.

    Option A- Kids Zone- Create a Graph[2]

    Option B- Google Docs

    The graph should enable them to identify the independent (x-axis; shoreline year) and the dependent variable (y axis; rate of change) from their data collection. An example graph is pictured below.



16. After creating the graph, the students should be able to answer the following questions:

    What is the general trend of change along your transect? Is it eroding or generally accreting sand? (From the graph above)

    Ex. This particular transect is generally experiencing erosion. In the beginning, there is an accretion event by by 1976 there is a lot of erosion. The among of erosion slows by 2000 but then increases significantly by 2008, etc.

    What period shows the fastest rate of erosion? The Slowest? (From the graph above)

    Ex. The fast rate of erosion is in 2008 (-.4 ft/yr). The slowest is 2000 (-0.05 ft/yr)

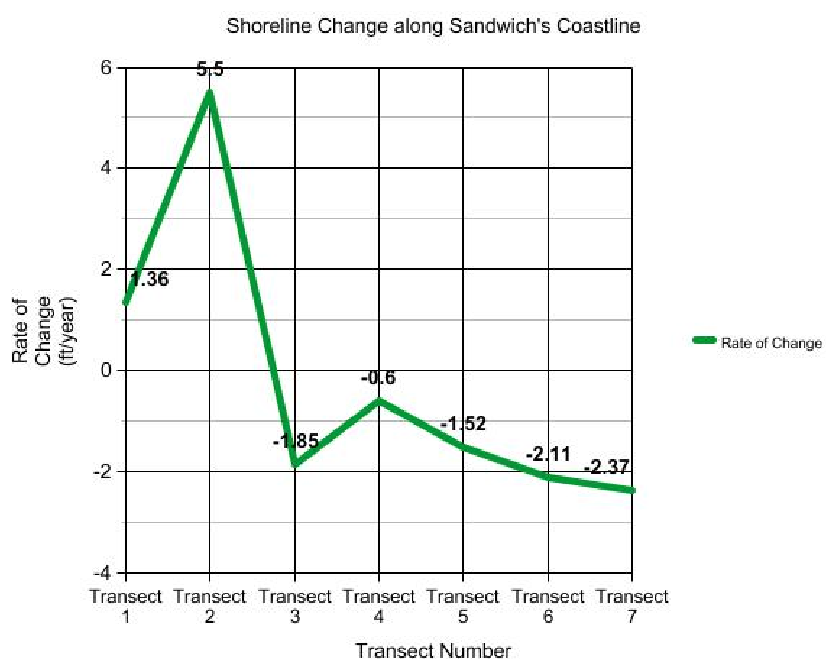
    What period shows the fastest rate of accretion? The slowest? (From the graph above)

    Ex. This question does not really apply to this graph.

Note: Reference C includes an example worksheet the students can use to complete this lesson.

Conclusion:

To conclude this lesson, have a class discussion about the overall trends of the entire Sandwich coastline. Have the students report the average rate of change of their transect to the class. Use graph paper or one of the online graphing platforms to graph the students data for all transects. This will provide the rate of change along the coastline and allow the students to make observations of what areas of town are accreting and eroding. Example graph is below.



After the graph is created and displayed for the class to see here are a few prompting questions to ask the students.

What area of town is the beach accreting sand? How do you know?

Ex. Scusset Beach is accreting sand because the rates of change are positive.

What area of Sandwich is eroding? How do you know?

Ex. Town Neck Beach and south of the Cape Cod Canal are eroding because the rates of change are negative.

How do you think Sea Level Rise and Climate Change would affect how quickly Sandwich's coast will change?

Ex. If sea level rise increases, the high-water line would shift more landward signifying a loss of land.

Does this analysis support the theory that the Cape Cod Canal Jetties are affecting the normal sediment transport processes along the coast? Why or Why not?

Ex. Yes, Scusset Beach is accreting sand because of the positive rates of change along transect 1 and 2 which supports the idea that the jetties are trapping sand and depriving Town Neck Beach from sand. Starving Town Neck Beach of sand leaves it vulnerable to erosion which is supported by the negative rates of change determined from this analysis.

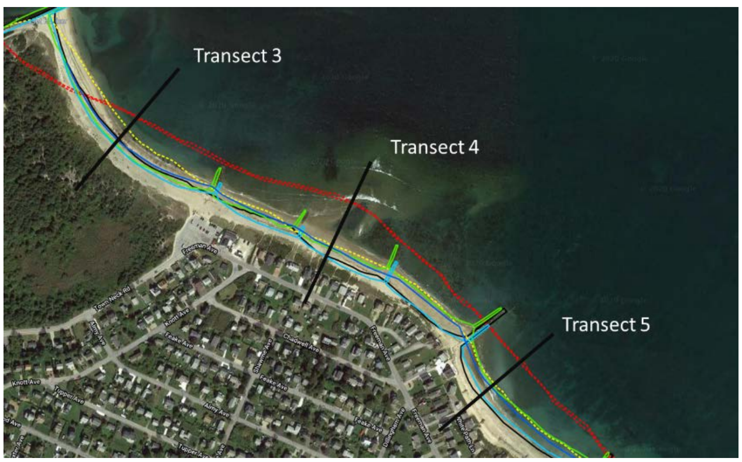
Resources:

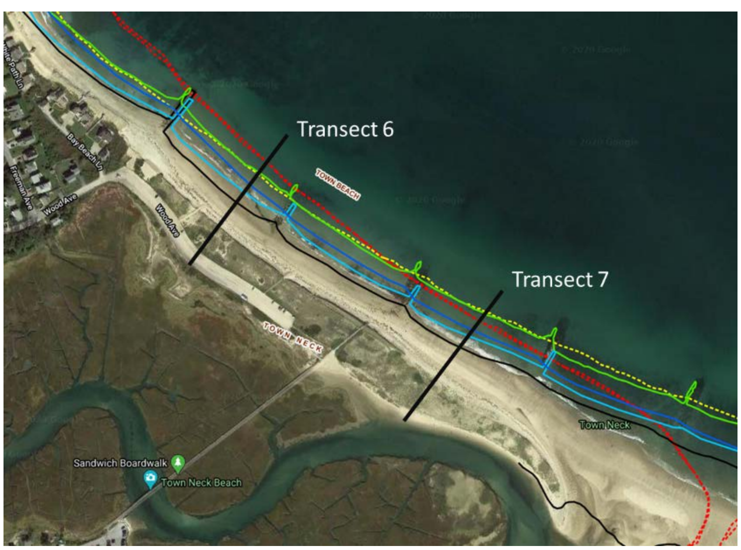
Below is a list of URLs associated with the various resources found in this lesson plan.

1. Massachusetts Shoreline Change Browser
   - https://www.capecod.com/newscenter/army-corps-report-confirms-canal-jetty-woes-for-sandwich-beaches/

2. Kids's Zone- Create a Graph
   -https://nces.ed.gov/nceskids/createagraph/default.aspx

Resource A: Teachers guide to Transects





Resource B: Example results for rate of change calculations for each transect

	Transect 1				Transect 2			
Year of High Water Line	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion
1870 (1844-1897)	--	--	--	--	--	--	--	--
1924 (1909-1939)	54	-257.95	-4.78	Erosion	No Data	No Data	No Data	No Data
1955 (1943-1969)	31	126.75	4.09	Accretion	85	963.26	11.33	Accretion
1976 (1970-1982)	21	28.85	1.37	Accretion	21	328.59	15.65	Accretion
1994	18	-3.65	-0.20	Erosion	18	-23.94	-1.33	Accretion
2000	6	77.74	12.96	Accretion	6	143.41	23.90	Accretion
2001	1	-16.8	-16.80	Erosion	1	-20.46	-20.46	Erosion
2008 (2007-2009)	7	90.09	12.87	Accretion	7	28.27	4.04	Accretion
What is the Minimum Shoreline Rate Change			-16.8	Erosion			-20.5	Erosion
What is the Maximum Shoreline Rate Change			12.95	Accretion			23.9	Accretion
Average Shoreline Rate Change			1.36	Accretion			5.5	Accretion

	Transect 3				Transect 4			
Year of High Water Line	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion
1870 (1844-1897)	--	--	--	--	--	--	--	--
1924 (1909-1939)	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
1955 (1943-1969)	85	-95.54	-1.12	Erosion	85	-230.33	-2.71	Erosion
1976 (1970-1982)	21	-92.94	-4.43	Erosion	21	-19.27	-0.92	Erosion
1994	18	-6.74	-0.37	Erosion	18	-49.59	-2.76	Erosion
2000	6	37.37	6.23	Accretion	6	55.12	9.19	Accretion
2001	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
2008 (2007-2009)	8	-11.69	-1.46	Erosion	8	-46.5	-5.81	Erosion
What is the Minimum Shoreline Rate Change			-4.42	Erosion			-5.81	Erosion
What is the Maximum Shoreline Rate Change			6.22	Accretion			9.18	Accretion
Average Shoreline Rate Change			-1.85	Erosion			-0.60	Erosion

	Transect5				Transect 6			
Year of High Water Line	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion
1870 (1844-1897)	--	--	--	--	--	--	--	--
1924 (1909-1939)	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
1955 (1943-1969)	85	-169.68	-2.00	Erosion	85	-68.98	-0.81	Erosion
1976 (1970-1982)	21	-14.4	-0.69	Erosion	21	14.46	0.69	Accretion
1994	18	-62.35	-3.46	Erosion	18	-98.78	-5.49	Erosion
2000	6	49.27	8.21	Accretion	6	36.28	6.05	Accretion
2001	No Data	No Data	No Data	No Data	No Data	No Data	No Data	No Data
2008 (2007-2009)	8	-77.33	-9.67	Erosion	8	-87.75	-10.97	Erosion
What is the Minimum Shoreline Rate Change			-9.67	Erosion			-10.97	Erosion
What is the Maximum Shoreline Rate Change			8.21	Accretion			6.05	Accretion
Average Shoreline Rate Change			-1.52	Erosion			-2.11	Erosion

	Transect 7			
Year of High Water Line	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion
1870 (1844-1897)	--	--	--	--
1924 (1909-1939)	No Data	No Data	No Data	No Data
1955 (1943-1969)	85	45.86	0.54	Erosion
1976 (1970-1982)	21	-12.02	-0.57	Accretion
1994	18	-107.8	-5.99	Erosion
2000	6	28.71	4.79	Accretion
2001	No Data	No Data	No Data	No Data
2008 (2007-2009)	8	-84.9	-10.61	Erosion
What is the Minimum Shoreline Rate Change			-10.61	Erosion
What is the Maximum Shoreline Rate Change			4.79	Accretion
Average Shoreline Rate Change			-2.37	Erosion

Resource C. Example Worksheet for students.

Names: _______________________________

1. Today you will be conducting a shoreline analysis along the beaches in Sandwich. What transect number was assigned to your group? _________________

You will be using *historical shorelines* to understand whether the beaches along Sandwich's coastline. *Historical shorelines* are lines representing the high-water line for a given year in time that were created from historical maps, on-foot surveys, or digitization of aerial photographs.

After accessing the CZM shoreline change viewer, navigate to the area of your transect.

2. Is your transect **North** or **South** of the Jetties? (circle one)

3. How many high-water lines are located at your transect?

4. List the dates of the available shorelines that are located at your transect.

5. Which high-water shoreline is from the earliest point in time? Which is the most recent high-water shoreline?

6. Calculate the span of time between the earliest and most recent high-water lines. Show your work.

7. You will now use the CZM shoreline change viewer to calculate the shoreline change rate of the beach located at your transect. The shoreline change rate provides information about whether the beach at your transect is eroding or accreting sand. An eroding beach is one that experiences a loss of sand, whereas an accreting beach is one that receives sand and grows in size. Use the following table to complete the analysis.
   - Cross out the year of high-water line that is not found at your transect, if any. Use question 4 to help you.
   - Calculate the years between shorelines.
   - In the CZM Shoreline change viewer, measure the distance between two consecutive shorelines. For example, the distance between 1924 and 1870.

     Note: if the more recent year is seaward of the earlier year, this is a *positive* distance. If the recent year is landward than the earlier year, this is a *negative* distance. Make sure to use a positive or negative sign in your answer.

   - Calculate the rate of change by dividing the distance between shorelines by the number of years between the two shorelines.
   - Make a note about whether this time interval is experiencing erosion or accretion.
     - A *positive* rate of change means the beach is accreting sand.
     - A *negative* rate of change means the beach is eroding sand.
   - Identify the min, max, and calculate the average of the rate of change and comment if each of these are considered erosion or accretion.

Year of High-Water Line	Number of years between shorelines	Distance from earliest shoreline (feet)	Rate of Change (ft/year)	Erosion or Accretion
1870 (1844-1897)	--	--	--	--
1924 (1909-1939)				
1955 (1943-1969)				
1976 (1970-1982)				
1994				
2000				
2001				
2008 (2007-2009)				
What is the Minimum Shoreline Rate Change				
What is the Maximum Shoreline Rate Change				
Average Shoreline Rate Change				

You will not answer the following questions after you have completed your graph of the data you collected in the table.

8. What is the general trend of change along your transect? Is it eroding or generally accreting sand?

9. What period shows the fastest rate of erosion? The Slowest?

10. What period shows the fastest rate of accretion? The slowest?

7th Grade Project Based Learning Capstone Projects

These lesson plans were developed to support other curriculum standards and result in creative student projects using available school technology to communicate the covered scientific information. Some examples of project-based learning capstone projects include:

1. Design, model, or build solutions and/or adaptations with emphasis on "Green Infrastructure" to protect the Town of Sandwich.

2. Use media room to record a commercial, report the news, or make a PSA covering the coastal changes along Sandwich's coastline.

3. Write a news article that details the severe erosion that Sandwich is facing.

4. Conduct a class debate or town hall meeting to discuss the pros and cons of coastal infrastructure.

5. Create a tri-fold brochure discussing the possible solutions to Sandwich's eroded coastline.

6. Contact and interview an expert/scientist about coastal processes.

8TH GRADE LESSON PLANS

Sea Level Rise in the Town of Sandwich

Time: 1.25 hours

Standards: 8.MS-ESS1-1. Explain the role of gravity in ocean tides, the orbital motions of planets, their moons, and asteroids in the solar system**.**

Question: What areas of Sandwich are most at risk as the sea level rises?

Objective: Students will assess the impacts of sea level rise to the Town of Sandwich using an online map viewer displaying Mean High-Water tide extents.

Background: Students should have a basic understanding of daily tidal cycles.

Materials: Personal student device with internet, Mean High Water map viewer

Vocabulary: Mean High Water, Sea level rise, tide, tidal cycle

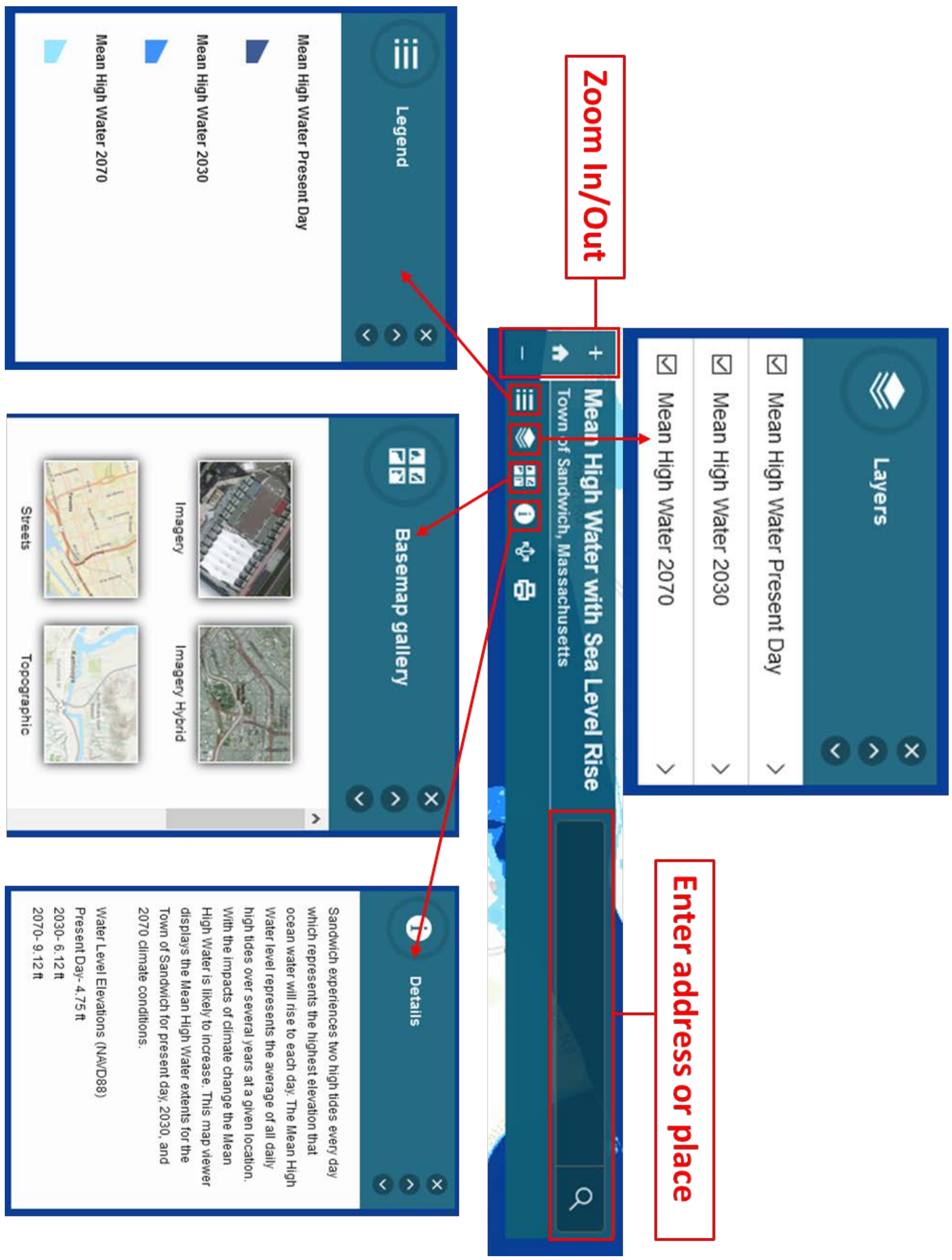
Introduction:

Mean high water (MHW) is the average of all daily high tide heights calculated from a long-term data set of daily high tides. Mean High Water is important in providing information on the long-term trend of how high water gets along a beach, within a marsh ecosystem or any coastal environment. In science, the mean high-water level can be used to help inform coastal zone management decisions and provide information on vegetation growth thresholds and/or patterns. For this part of lesson, students will view Present Day mean high water of a Sandwich salt marsh ecosystem.

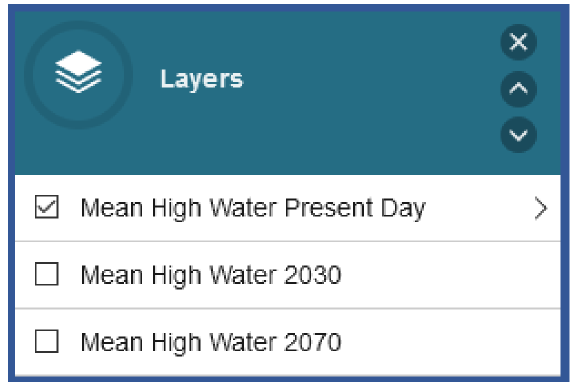
At the link below is a Mean High Water with Sea Level Rise viewer for the Town of Sandwich:

Mean High Water with Sea Level Rise Viewer[1]

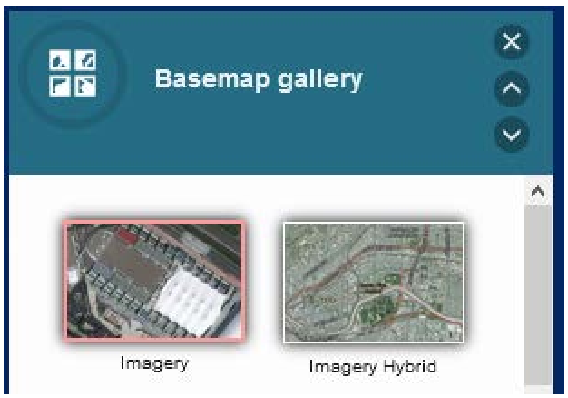
The viewer includes a variety of features that that will help guide the students. Refer to the figure below to become oriented with these features. There is a *Zoom in/out* button, a *Legend* to help distinguish between the three Mean High-Water layers and a *Layers* box where each layer in the viewer can be selected/unselected. There is also an option to change the basemap from the *Basemap Gallery*. It might be useful in this lesson to look at the imagery option. The information button provides *Details* about the viewer itself and lastly, there is a box where students can enter an address and/or specific location which will help navigate around the Town of Sandwich. To view all these options, you must push the button which will insert a pop-up box in the upper right corner of the viewer.



Project the Mean High-Water viewer onto the white screen to show the students how to navigate the viewer. For this part, only have the Mean High-Water Present-Day Layer selected from the *Layers* pop-up box.



After unselecting 2030 and 2070, you should change the base map to the aerial imagery that can be found in the *Basemap gallery***.**



The viewer should look like this. The Mean High-Water extent for Present Day has a water surface elevation of 4.75 ft (NAVD88). Any land that is below 4.75 ft (NAVD88) will become inundated with water at high tide.

From this view, you can click on and off the layer so the students can see the area of Sandwich that is under the Present Day Mean High Water extent. From here lead a discussion on whether Present Day Mean High Water is a problem for the Town of Sandwich. Some probing questions could be:

1. What part of Sandwich is inundated from Present Day Mean High Water? Is it normal?

    Ex. The Present Day Mean High Water is inundating the marsh ecosystem. Yes, it is normal. The data is showing Mean High Water, so it is likely that every day this marsh will become inundated during a high tide.

2. How is water entering this marsh environment?

    Ex. The water is entering from the tidal creek inlet along Town Neck Beach.

3. Does it seem that Present Day Mean High Water is flooding any other part of Sandwich that is not a marsh environment?

    Ex. Currently there is no flooding of non-marsh areas in the Town of Sandwich by Present Day Mean High Water.

4. With climate change, the Sea Level along the coastlines will rise, how do you think this will affect Mean High Water that is seen in the Sandwich Marsh system.

    Ex. If sea level rises, the elevation at which mean high water is found will also increase and move further up the beach face, or higher in the marsh.

5. What consequences are possible to the Town if MHW increases with Sea level Rise?

    Ex. A possible consequence of higher Mean High Water could be an increase in flooding of low-lying areas of the Town that are not considered marsh systems. Areas that were once dry every day during high tide will become flooded daily in the future. Another consequence to the Town is that a lot of development has occurred on the more inland edges of the Marsh. Naturally, Marshes can migrate landward overtime to keep up with changes in the sea level. For Sandwich, the development and infrastructure along the marsh edge act like barriers preventing the potential for future marsh migration.

Main Lesson

Students will now explore the Mean High Water with Sea Level Rise viewer to see how an increase in sea level impacts Mean High Water in the future. They will explore MHW in the years 2030 and 2070. The table below provides the water elevation for MHW for Present Day, 2030, and 2070 which are represented by the extents of the MHW levels in the online viewer. These MHW elevations correspond to 1.37 ft in Sea Level rise in 2030 and then another 3.0 ft of Sea Level Rise by 2070.

	Present Day	**2030**	**2070**
Mean High Water elevation (ft NAVD88)	**4.75 ft**	**6.12 ft**	**9.12 ft**
Sea Level Rise		**+1.37 ft**	**+3.0 ft**

Here is an example of a worksheet that students can work through as they learn how Mean High Water changes with Sea Level Rise.

With only the Present Day Mean High Water selected in the *Layers* pop-up answer the following questions:

1. Describe what you see when you look at the extent of Present Day MHW.
2. What type of environment is under water in Present Day?
3. Are there roads, houses, or other infrastructure that are under water in Present Day?

Now select the Mean High Water 2030 layer in the *Layers* pop-up.

4. Describe what happens when you selected the Mean High Water 2030 Layer.
5. Are there any roads, houses or other infrastructure that are under water in 2030?

Now select Mean High Water 2070 layer in the *Layers* pop-up.

6. Describe what happens when you selected the Mean High Water 2070 Layer.
7. Are there any roads, houses or other infrastructure that are under water in 2070?

In the table below are a few addresses and specific places from the town of Sandwich. Use the *Search Box* in the viewer to look up these locations and make some observations about how these areas are impacted by Present Day, 2030, and 2070 Mean High Water. Observations for these areas can include at what year this area becomes flooded and describe the type of infrastructure, if any, is flooded. Use the streets or topographic basemap from the *Basemap Gallery* in order help identify specific roads that may become impacted.

Location Area	Description of Impact
Sandwich Marina 25 Ed Moffitt Dr. Sandwich, MA	
Sandwich Town Hall 130 Main St, Sandwich, MA	
Sandwich Fire Station 115 Route 6A, Sandwich, MA	
10 Boardwalk Rd Sandwich, MA	

Now choose 2 locations in Sandwich of your choice and describe the impacts from Mean High Water in Present Day, 2030, or 2070.

Location	Description of Impact
1.	
2.	

Conclusion:

After the students are finished exploring the viewer and understanding how future Mean High Water affects the town of Sandwich have a few volunteers share some of the places they chose to explore.

End the lesson by asking a couple of critical thinking questions.

1. What areas of town are ok to flood?

    Ex. The salt marsh in Sandwich is ok to flood.

2. What areas of the Town cannot withstand substantial flooding?

    Ex. Buildings, houses, roads

3. Why is future MHW a concern for the Town of Sandwich?

Ex. A lot of infrastructure has been built-in low-lying areas where flooding is expected in the future. These areas cannot transition into marsh because the land as been significantly altered.

4. What are some ways to reduce the impact of flooding to the Town of Sandwich?

Ex. Let natural areas transition into marsh, retreat from buildings that are vulnerable, raise road elevations, etc.

Resources

1. Mean High Water with Sea Level Viewer

    -https://www.capecodcommission.org/our-work/cape-cod-chronology-viewer/

Examining Local Climate Change Data

Time: 3 hours
Standards: 8. MS-Esse-6. Describe how interactions involving the ocean affect weather and climate on a regional scale, including the influence of the ocean temperature as mediated by energy input from the Sun and energy loss due to evaporation or redistribution via ocean currents.

8.MS-ESS3-5. Examine and interpret data to describe the role that human activities have played in causing the rise in global temperatures over the past century.

Question: What is the difference between weather and climate? How is the climate changing on the local and regional scale?

Objective: Students will use an online data clearing house (Resilientma.org) to analyze and interpret climate change data on the state and local Level.

Background: The students should have a basic background on global weather and climate change data, and have the ability read and interpret scientific data from charts and graphs.

Materials: Personal student device with internet

Vocabulary: weather, climate, climate change, climate change projections

Introduction:

The difference between weather and climate is dependent on the scale of time being considered. *Weather* describes the short-term day to day changes in the atmosphere, whereas *climate* describes the long-term trends in the weather for a given location. Now, have the students demonstrate the difference between weather and climate.

Have the students fill out a 7-day forecast chart for the Town of Sandwich using any online weather platform (Ex. Weather.com).

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday

After they have completed this table, have the students describe what the weather is like during a whole year in Sandwich. The months of Winter (January-March), could be described as cold and snowy. For April through June, they may describe it as breezy, rainy, but warmer than the previous months. In the end they are describing the seasons of the year where Sandwich typically sees a cold and snowy winter, a warmer but rainy spring, a sunny, warm summer with temps in the 70's and 80's and a cool crisp fall. The students can fill out the monthly chart to help guide their responses.

January	February	March	April
May	June	July	August
September	October	November	December

After they complete these two exercises, ask some probing questions to complete the discussion.

1. Describe the difference between the 7-day forecast weather and the year-long description of the weather in Sandwich.

    Ex. The students should gather that the 7-day forecast is the weather changing day to day, but the yearlong description represents the climate of the Town.

2. Do you think the climate has changed from the past? If so, why and in what ways?

    Ex. Mostly an opinion piece.

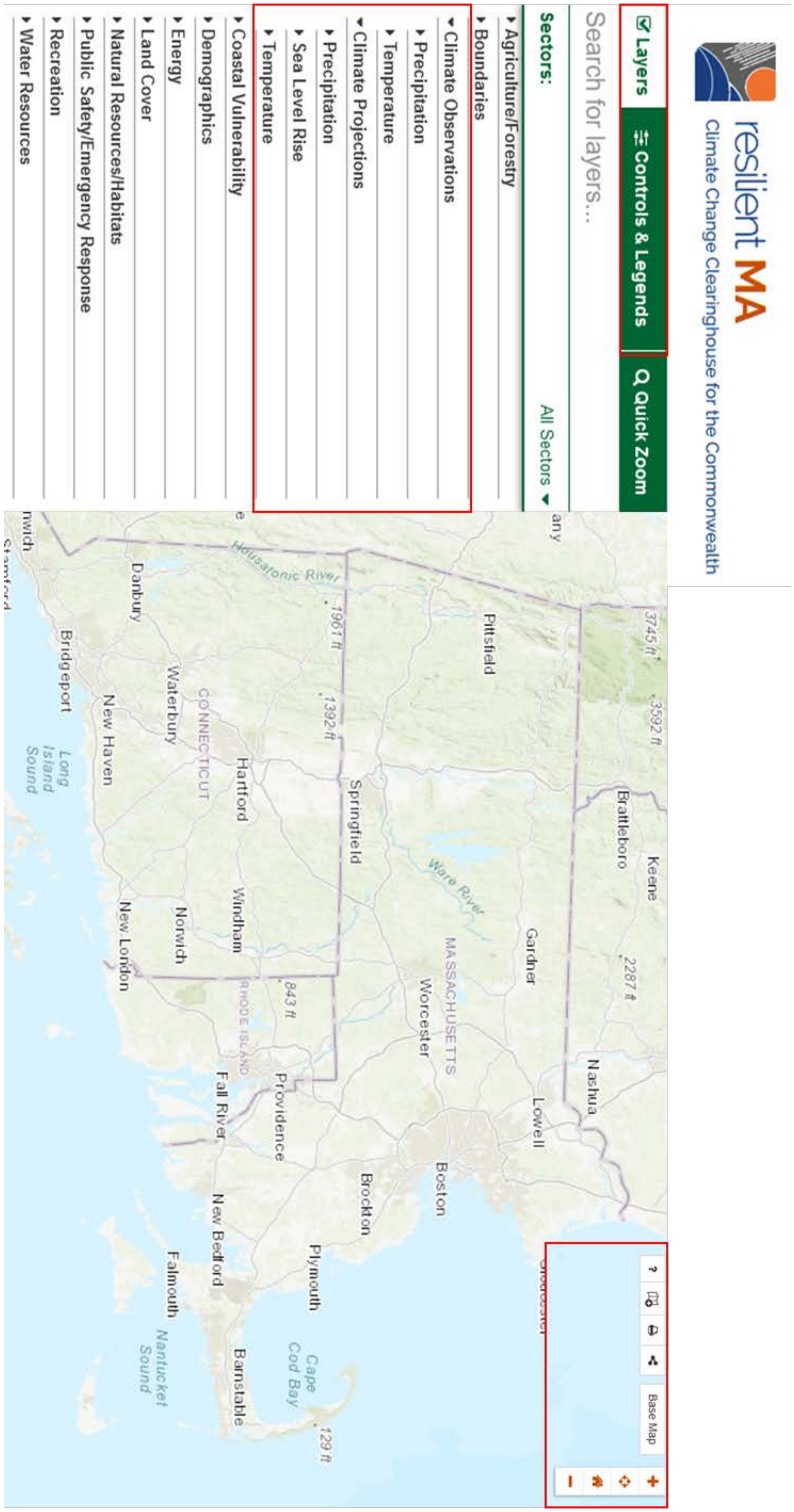
3. Do you think the climate is going to change in the future? If so why, and in what ways?

    Ex. Mostly an opinion piece.

Main Lesson:

The students are going to look at climate in a bit more detail. Students will use an online climate data clearing house to explore historical and future climate data on the state and local level. Here is the link to the Resilient MA Climate Clearinghouse Map[1].

This data clearinghouse was developed by the State of Massachusetts in 2017, for communities to have access to the best climate change science and data. Access to this information is provided in the hopes of creating more resilient communities to the impacts of climate change. The climate change data is specific to Massachusetts and was developed by the Northeast climate Adaptation Science Center at UMass-Amherst.

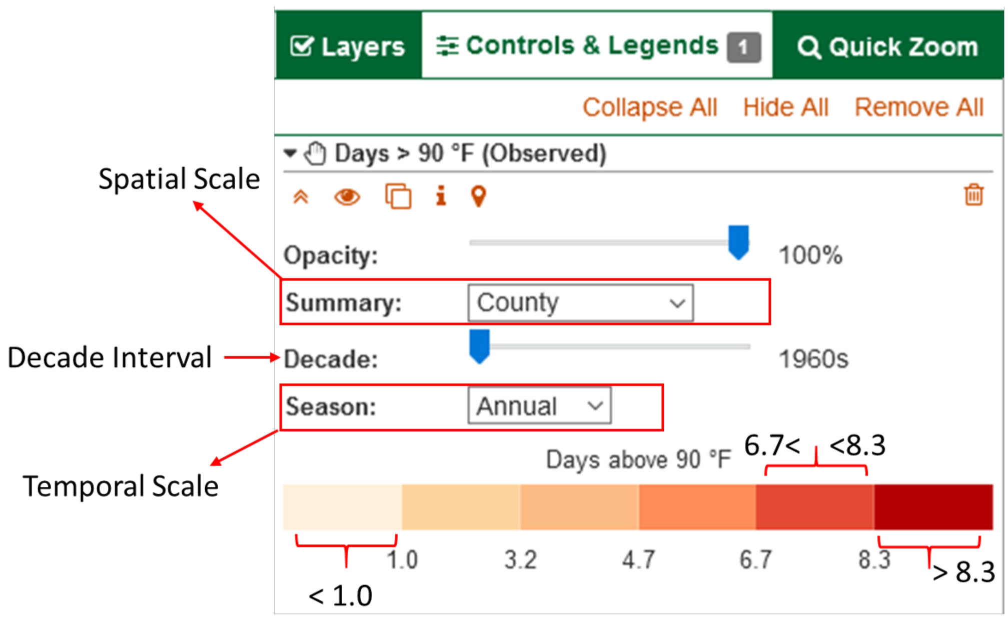

resilient MA
Climate Change Clearinghouse for the Commonwealth
Layers
Controls & Legends
Quick Zoom
Search for layers...
Sectors:
All Sectors
Agriculture/Forestry
Boundaries
Climate Observations
Precipitation
Temperature
Climate Projections
Precipitation
Sea Level Rise
Temperature
Coastal Vulnerability
Demographics
Energy
Land Cover
Natural Resources/Habitats
Public Safety/Emergency Response
Recreation
Water Resources
Base Map
Pittsfield
Springfield
Hartford
Worcester
Boston
Providence
Brockton
Plymouth
New Bedford
Falmouth
Barnstable
Cape Cod Bay
Nantucket Sound
Long Island Sound
MASSACHUSETTS
CONNECTICUT
RHODE ISLAND

Above is a screen shot of the clearing house map to help become familiar with the mapping platform. Orienting the students with the online platform will also be important before they complete the lesson.

The data clearinghouse includes numerous types of data including climate observations and projections, coastal vulnerabilities, demographics, energy, natural resources, etc. In this lesson, climate observations and projections will be explored. Under the *Layers* tab of the viewer, you can see all the available data sets.

Historical Observed Data

To analyze the climate observations from the past, select data sets from either Precipitation or Temperature within the Climate Observations grouping in the *Layers* tab. Once you have selected a data set, click on the *Controls and Legends* tab of the viewer. This tab allows the settings of the spatial (i.e. state, county, drainage basin) and temporal (i.e. annual or specific season) scales to be selected. The data can then be shown on a decades time interval to observe the historical trends of each type of data. The color ramp gives you the data point associated with each color tone. See the figure below for reference.



The students will now take time to interact with the Climate Observations (historical data). Below, there is an example of a data sheet the students can use to record and analysis the data. Feel free to make changes and/or select data types that are the most appropriate for the classroom. The students should record data on the state level and county level (Barnstable) to observe if there are differences between the state and local level. You can decide whether you want the students to record the range of data represented by color tones or report the upper end data point for each tone (for the 5th color in the image above the range would be 6.7-8.3 vs recording the high point of 8.3).

After the table is completed, you could have the students graph a few of the metrics to also show the data in a visual. The online graphing platform at NCES- Kids Zone[2] is a great platform for easy digital graphing. The table is also followed by probing questions revolving around the historical observed data.

Historical Climate Impacts	Percipitation					Temperatures				
	Consecutive Dry Days (Vulnerability to Drought)	**Summer Annual Percipitation** (inches)	**Winter Annaul Percipitation** (inches)	**Total Annual Percilpitation** (inches)	**Extreme Percipitation >2"** (Indicator of intense storms)	**Average Observed Temperatures**	**Days above 90 °F**	**Days Below 32°F**	**Maximum Temperature**	**Minimum Temperature**
1960's										
State										
County										
1970's										
State										
County										
1980's										
State										
County										
1990's										
State										
County										
2000's										
State										
County										
Conclusion *										
State										
County										

*Increasing, Variable, OR Decreasing

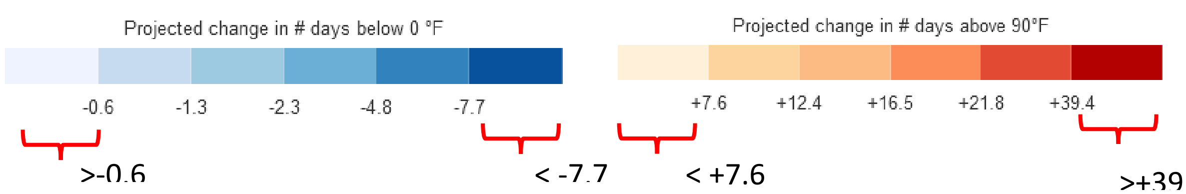
1. What are the overall trends of the precipitation and temperature data?

2. Are there differences between the state and local level? If so, what might be the reason for these differences?

3. Based on the trends you see from the historical observed data, what are your predictions for precipitation and temperature in the future? Will they increase, decrease or be variable? Why?

Future Climate Projections Data

The students will now look at data for climate conditions in the future. Again, data compiled for the clearing house was developed by the Northeast Climate Adaptation Science Center at UMass Amherst. For future climate projections, the *Controls and Legends Tab* on the viewer will now have a Scenario option. This option should remain at the High RCP8.5 designation. This correlates to the high greenhouse gas emission scenario from the model the was used to develop this data. The data for future temperature and precipitation is recorded with a **+** or **–** to signify the additional or a smaller number of units (e.g. days, degrees, etc.) from current conditions.



As a class, select Total Precipitation under the Climate Projections group in the *Layers* tab. Then designate Drainage Basin for the Summary setting and Annual for the Season factor under the *Controls and Legends* tab. The data shown in the future climate projections spans to four future time horizons: 2030, 2050, 2070, 2090. Step through these four-time horizons and answer the following questions:

1. Overall, will Massachusetts experience an increase in precipitation or a decrease?
2. What region of Massachusetts will most likely experience the highest increase in total precipitation throughout time? How do you know this?
3. What are possible explanations for this conclusion?

4. What region of Massachusetts will experience the lowest increase in total precipitation? How do you know this?

5. What are possible explanations for this conclusion?

Now select Average Temperatures under the Climate Projections group in the *Layers* tab. Then designate Drainage Basin for the Summary setting and Annual for the Season factor under the *Controls and Legends* tab. Once again step through these four-time horizons and answer the following questions:

1. Overall, will Massachusetts experience an increase or decrease in average yearly temperature?

2. What region of Massachusetts will most likely experience the highest increase in average yearly temperature throughout time? How do you know this?

3. What are possible explanations for this conclusion?

4. What region of Massachusetts will experience the lowest increase in total average yearly temperature? How do you know this?

5. What are possible explanations for this conclusion?

From this exercise, the students should begin to understand that climate change is going to affect the State of Massachusetts in different ways. Living on Cape Cod and surrounded by water will likely help lessen the severity of increased temperature impacts that are predicted in the Future.

The students will now take time to interact with the Climate Projections in more detail. Below, there is an example of a data sheet the students can use to record and analyze the data. Feel free to make changes and/or select data types that are the most appropriate for the classroom. The students should record data on the state level and county level (Barnstable) to observe if there are differences between the state and local level. You can decide whether you want the students to record the range of data represented by color tones or report the upper end data point for each color tone. After the table is completed, you could have the students graph a few of the metrics to also show the data in a visual. The online graphing platform at NCES- Kids Zone[2] is a great platform for easy digital graphing. Once the table is complete and a graph was made, the students can answer the following questions:

1. What are the overall trends of the precipitation and temperature data?

2. Are there differences between the state and local level? If so, what might be the reason for these differences?

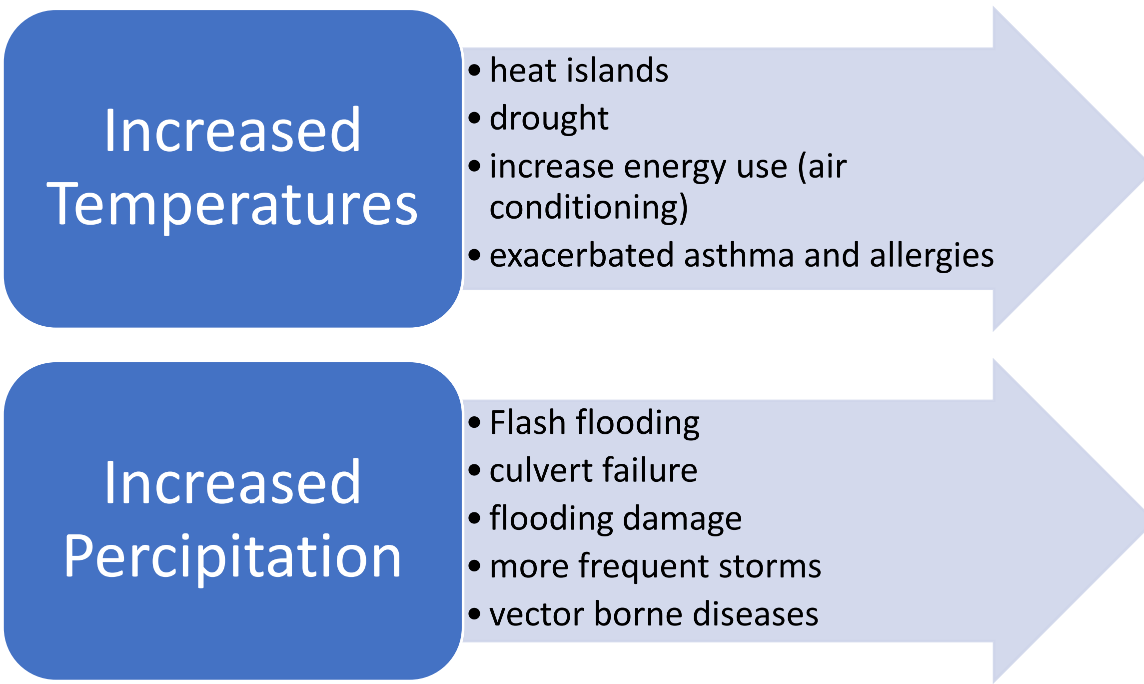
3. Is there a critical time horizon (2030, 2050, 2070) where the data drastically changes?

Future Climate Projections	Precipitation					Temperatures				
	Consecutive Dry Days (Vulnerability to Drought)	**Summer Annual Percipitation** (inches)	**Winter Annaul Percipitation** (inches)	**Total Annual Perciipitation** (inches)	**Extreme Percipitation >2"** (Indicator of intense storms)	**Average Observed Temperatures**	**Days above 90 °F**	**Days Below 32°F**	**Maximum Temperature**	**Minimum Temperature**
2030										
County										
State										
2050										
County										
State										
2070										
County										
State										
2090										
County										
State										
Conclusion										
County										
State										

*Increasing, Variable, OR Decreasing

Conclusion:

Now that students have looked the data, the students should think about the tangible impacts that increased temperatures and increased precipitation can have. Have the students create a list of the possible consequences of these changes. Create a class list after the students have developed their own. If the students need help, they can do some online research to help them determine the impacts of climate change.



Resources:

Below is a list of URLs associated with the various resources found in this lesson plan.

1. ReslientMA Climate Change Clearinghouse Map
   -http://resilientma.org/map/

2. Kids'z Zone- Create a Graph
   -https://nces.ed.gov/nceskids/createagraph/

Sandwich Coastal Vulnerability Assessment

Time: 3 hours

Standards: 8. MS-ESS2-6. Describe how interactions involving the ocean affect weather and climate on a regional scale, including the influence of the ocean temperature as mediated by energy input from the Sun and energy loss due to evaporation or redistribution via ocean currents.

8.MS-ESS3-5. Examine and interpret data to describe the role that human activities have played in causing the rise in global temperatures over the past century.

Question: How will climate change, specifically storm surge and sea level rise, impact infrastructure and natural resources of the Town of Sandwich.

Objective: Students will utilize flood model results to understand the impacts of storm surge and sea level rise to the Town of Sandwich and will conduct a coastal vulnerability assessment to identify town infrastructure at the highest risk of flooding.

Background: Students should understand the implications of flooding, and general knowledge of sea level rise, storm surge, and other coastal storm impacts

Materials: Personal student device with internet, drawing paper

Vocabulary: storm surge, sea level rise, vulnerability assessment, coastal vulnerability assessment, adaptation, coastal resiliency

Introduction:

In 2018, the Town of Sandwich completed a coastal vulnerability assessment (CVA) to identify areas of The Town that are vulnerable to the combined effects of sea level rise and storm surge from extreme storm events, assess the vulnerability of municipally owned public infrastructure and natural resources, and identify adaptation strategies that will help to mitigate the near-and long-term effects of sea level rise and storm surge. The goal of this lesson plan is to introduce the students to the process of conducting a coastal vulnerability assessment and have them conduct a simplified version of one for the Town of Sandwich. The three main steps of a CVA include:

1. Inventory and scoring of critical Town infrastructure/assets - These are municipally owned assets and other critical infrastructure that are important to the town and if damaged by storm surge and sea level will have consequences to Town function. Assets that are at risk of flooding will be scored using a suite of consequence criteria to understand the consequence of failure of each asset.

2. Assign probability of flooding value to each Critical Asset- Using the Massachusetts Coast Flood Risk Model developed by Woods Hole Group, the risk of failure from flooding will be assessed for each asset. This data provides the probability that an asset will become inundated with water at some point in any given year.

3. Calculate total risk score and prioritize assets for adaptation development- The multiplication of the consequence of failure score by the probability of inundation of each

asset creates the total risk score for each asset. Once the total risk score is calculated for each asset this list of assets can be ranked to identify specific assets or areas of town that are most at risk from storm surge and other impacts of extreme coastal storms.

Below is a link to the completed CVA for the Town of Sandwich and Town of Sandwich Story Map that can serve as a guide for the CVA process.

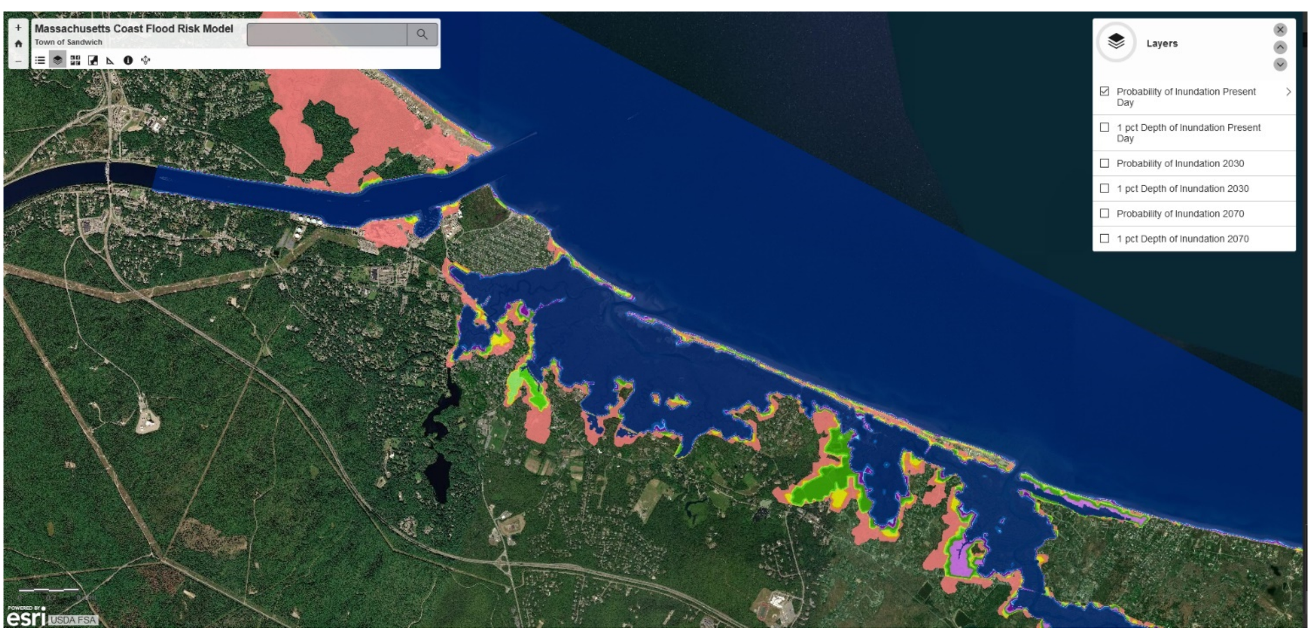
Town of Sandwich Coastal Vulnerability Assessment[1]

Town of Sandwich Climate Change Resilience Program StoryMap[2]

Before starting the CVA, the students should become familiar with the Massachusetts Coast Flood Risk Model, which will serve as the risk data that will provide the probability of inundation for each assessed asset in this lesson plan. The Massachusetts Coastal Flood Risk Model (MC-FRM) developed by the Woods Hole Group is the most comprehensive and sophisticated model available for anticipating how climate-related hazards (sea level rise and coastal storm events) will influence future coastal flood risks in the Commonwealth (MassDOT, 2019 in publication). MC-FRM was developed for the Massachusetts Department of Transportation (MassDOT) to assess potential flooding vulnerabilities to highways and other transportation infrastructure throughout the coastline of Massachusetts. The model is based on mathematical representations of the hydrodynamic processes that affect water levels along the coast – including tides, waves, winds, storm surge, sea level rise, wave set-up, wave run-up and overtopping. These processes were modeled at a high enough resolution to identify site-specific locations in Sandwich that are vulnerable and may require adaptation responses.

Below is the link to online MCFRM data viewer the students should explore.

MCFRM Online Data Viewer[3]



There are two sets of data in the viewer: probability of inundation and inundation depth for the 1% annual chance storm event for present day, 2030 and 2070 climate conditions. Probability of inundation is the probability that a locale will become inundated with storm flood water any given year. The 1% inundation depth data provides the depth of water at that locale during a storm that has a 1% chance of occurring that year.

While exploring the data viewer using the tools in the graphic above, have the students answer the following questions:

1. What kind of data is the data viewer showing for the Town of Sandwich?

   Ex. The data viewer is showing the probability of inundation and 1% depth of inundation.

2. What years of MCFRM results are available in the data viewer?

   Ex. Present Day, 2030, and 2070.

3. What color of probability flooding is the farthest inland? What is the chance (%) associated with that color?

   Ex. The pink color is the furthest inland and represents 0.1%.

4. What color of probability of flooding is the closest to the ocean? What is the chance associate with that color?

   Ex. Dark blue color is closest to the ocean and represents 100%

5. What is the significance of the last two questions?

   Ex. The chance of flooding from a storm that has a 0.1% chance of occurring is rare in any given year. The type of storm associated with 0.1% chance of occurring would be rare but could potentially be a large and devastating storm (i.e., 1 in 1000-year storm event. On the other hand, a storm occurring once a year 100% of the time could be a common coastal storm like a winter Nor’easter and causes a more short-term risk to the area.

6. While selecting/deselecting layers within the layers window, what is the general trend of the storm surge and coastal flooding impacts to the town?

Ex. Students should see that the extent and depth of water should be increasing further inland and getting deeper through time.

Main Lesson:

Step 1: The students will now perform a Coastal Vulnerability Assessment to assess the impacts of storm surge and sea level rise to Town Infrastructure. A few assets have been pre-selected for this lesson plan, but feel free to select alternative options. There is room in the lesson plan for students to identify assets that they are interested in assessing. This could be a local park, a coastal dock they visit frequently, their house, etc. The criteria on which the students will score their assets is also open for changes but provided below are the more common criteria used in CVAs.

The Table sets up the table in which the CVA will take place. The first part of the CVA is scoring the assets and calculate the total consequence score.

Critical Asset and Consequence of Failure Score	Area of Service Loss	Damage Cost	Importance to Town Safety	Importance for Town Economy	Impact to Environment	Total Consequence Score
Sandwich Fire Station #1 115 Route 6A	4	3	4	1	2	70
Boardwalk Parking Lot 8 Boardwalk Road						
Sandwich Town Hall 130 Main St	4	2	2	3	0	55
Entrance Booth at Town Neck Beach Bay Beach Lane	2	0	1	4	1	40
Student Example #1						
Student Example #2						
Student Example #3						

The scores given to the asset should fall between a scale between 0 and 4 from lowest to highest. Remember, the consequence of failure score is assessing the consequence to the town if this particular asset is damaged or ceases to function normally. The following definitions will help the students determine the scores of consequences.

1. **Area of Service Loss-** Assess the scale of the impact whether it affects a specific locale, several neighborhoods, or the entire town. For example, if this asset fails does it affect a specific location, or does it cause disruption for the entire town?

2. **Damage Cost-** The cost of damage to a particular asset can vary based on a variety of things like construction and construction materials, and how vulnerable a structure is to damage. Assess this criterion considering how much it would cost for repairs and/or level of damage.

3. **Importance to Town Safety**- This criterion allows the assessment of the value of safety a particular asset provides to the Town. Some assets provide emergency response and can be vulnerable during storm conditions.

4. **Importance to Town Economy**- Some assets provide economic value to the town and this criterion allows the assessment of the potential loss to the economy if it were to cease functioning from a storm event.

5. **Impact to the environment**- Some assets in dry conditions do not pose a risk to the environment but in the event of storm inundation an asset can be compromised and potentially pose a risk. For example, there could be negative environmental impacts if a structure that serves as storage for chemical is damaged during a flooding event.

The following graphic will provide some insight on how to score the assets based on these categories. The scores below are on a 0-4 scale and contain more categories than the students will be using but it will help frame the conversation.

Rating	Area of Service Loss	Duration of Service Loss	Cost of Damage	Impact on Public Safety & Emergency Services	Impact on Important Economic Activity	Impact on Public Health & Environment
4	Whole town/city	>30 days	>$10m	Very high	Very high	Very high
3	Multiple Neighborhoods	14-30 days	$1m-$10m	High	High	High
2	Neighborhood	7-14 days	$100k-$1m	Moderate	Moderate	Moderate
1	Locality	1-7 days	$10k-$100k	Low	Low	Low
0	Property	<1 day	<$10k	None	None	None

Once the students are done scoring their assets, they should calculate the total consequence score by summing up the consequence scores for the 5 criterion and dividing by the total possible score (20) and multiplying by 100. This will give the asset a total consequence score as a value out of 100. Higher consequence of failure scores signify assets that have the highest impact to the town if damaged.

Step 2: Next the students will assign a probability of inundation value from the MCFRM results. The students should use the MCFRM data viewer[3] to look at their assets in more detail. They can place the address of the assets into the search bar of the viewer to zoom to the location in question. They should record the value as a percent for Present Day, 2030, and 2070. While the Depth of Inundation for the 1% chance event is included in the data viewer, the students will only be recording the values for the Probability of Inundation data.

Students should look at the location in question and record the value associated with the color from the legend.

For example, the Town Neck Beach Entrance Booth is 30% in present day conditions.

Below is the table showing an example of the probability of inundation data recorded for each of the assets.

Critical Asset Total Consequence Score and Probability of Inundation	Total Consequence Score	Probability of Inundation Present Day (%)	Probability of Inundation 2030 (%)	Probability of Inundation 2070 (%)
Sandwich Fire Station #1 115 Route 6A	70	0.2	5	100
Boardwalk Parking Lot 8 Boardwalk Road				
Sandwich Town Hall 130 Main St	55	0.1	0.1	10
Entrance Booth at Town Neck Beach Bay Beach Lane	40	30	100	100
Student Example #1				
Student Example #2				
Student Example #3				

Step 3: The last step in the CVA process is calculating the total risk score by combining the total consequence of failure score and the probability of inundation. This calculation should

be completed for present day, 2030 and 2070. The results using the examples previously shown should look like the results in the Table below.

Critical Asset Total Risk Score	Total Consequence Score	Probability of Inundation Present Day (%)	Probability of Inundation 2030 (%)	Probability of Inundation 2070 (%)	Total Risk Present Day	Total Risk 2030	Total Risk 2070
Sandwich Fire Station #1 115 Route 6A	70	0.2	5	100	14	350	7000
Boardwalk Parking Lot 8 Boardwalk Road							
Sandwich Town Hall 130 Main St	55	0.1	0.1	10	5.5	5.5	550
Entrance Booth at Town Neck Beach Bay Beach Lane	40	30	100	100	1200	4000	4000
Student Example #1							
Student Example #2							
Student Example #3							

Lastly, once the Total Risk scores are calculated, the values for each time horizon can be ranked to create a list of assets that are most at risk from storm surge. The assets at the top of the list are those that have highest risk of flooding during storms but also would have significant impacts on municipal function if they are damaged or cease to function during a storm.

Once the students have ranked their assets here are some examples of questions the students can answer.

1. What assets did you chose to include in your CVA and why?

2. Are your assets vulnerable to the impacts of climate change and storm surge from coastal storms? (i.e. are they close to the ocean; are they close to a marsh?)

3. What asset received the high Total Consequence Score? The Lowest? What factors contributed to these scores.

4. What assets had the highest probability of inundation in present day? In 2030? In 2070?

5. Summarize the overall results of your CVA. What asset is most at risk for Present Day? For 2030? For 2070?

6. Were there any differences in the ranking between time horizons? Was one asset highest in 2030 and a different one that ranked higher by 2070? If so, what does this mean?

7. Were the results surprising? Why or why not?

8. What can be done to reduce the vulnerability of these assets?

At the end of this lesson plan is an example of an empty data sheet that students can use to record their data.

Conclusion:

The final goal of a CVA is the development of adaptation strategies to protect specific assets or regional adaptation strategies serving to protect multiple assets that are in the same vicinity. The students should now explore adaptation strategies. A major theme in coastal resilience planning is making the best strategic choice. Community resilience planning often explores the Protect, Accommodate, Retreat philosophy. Have the students do a little research to create definitions for these three coastal resiliency strategies. Here is a link to a great resource: ACAP[4]. This source provides quick definitions of these strategies.

Define:

Protect-

Accommodate-

Retreat-

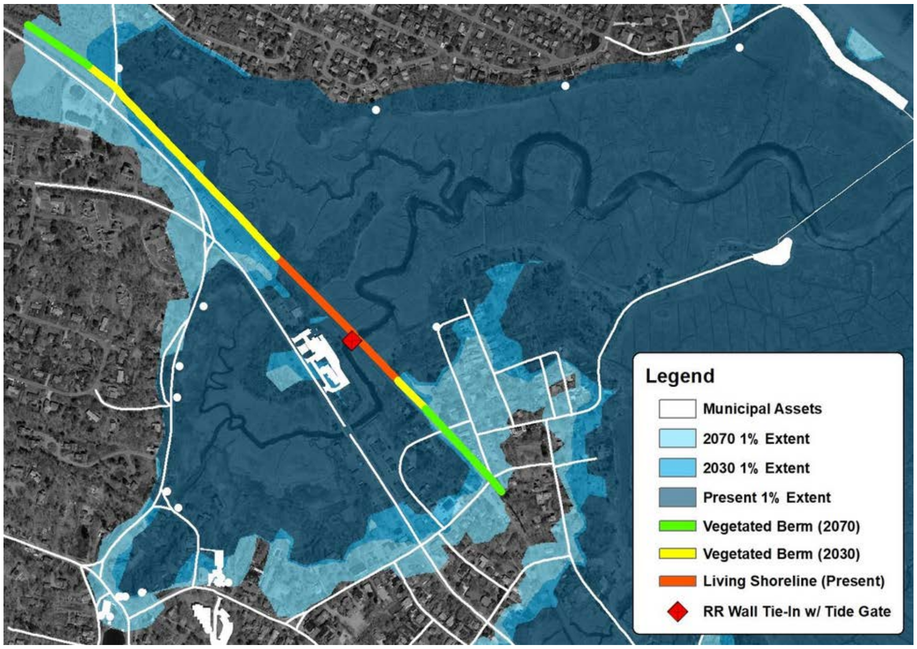
The students should now be creative and design some adaptations strategies for the assets from their CVA. The Cape Cod Commission has a webpage containing info sheets for a variety of coastal adaptation strategies. Cape Cod Commission Adaptation Fact Sheets[5]. The students should explore these strategies and decide which one they think would be helpful to protect their asset/s from the impacts of climate change.

Here are a few questions to ask regarding their selection.

1. What adaptation strategy did you select and why?

2. What are the benefits of this strategy? What are the disadvantages?

On a blank piece of paper have the students design their adaptation strategy as if they were creating a blueprint. It could look like this but much simpler. This diagram is a potential regional strategy to protect the Sandwich Fires Station using living shoreline and vegetated berm strategies.



Resources:

Below is a list of URLs associated with the various resources found in this lesson plan.

1. Town of Sandwich Coastal Vulnerability Assessment
   https://www.mass.gov/doc/final-report-17/download
2. Town of Sandwich Coastal Resilience Program Story Map
   https://storymaps.arcgis.com/stories/0cc1b190abbc40058219d66b2f355eaa
3. MCFRM Data Viewer
   https://whg.maps.arcgis.com/apps/View/index.html?appid=5a7288f3db0e438898332d275a4963e7
4. Atlantic Coastal Action Program Resiliency Definitions
   http://www.acapsj.org/staff-blog/2019/5/13/protect-accommodate-retreat
5. Cape Cod Commission Adaptation Strategies
   https://ww2.capecodcommission.org/coastal/#fact-sheets

Example of Datasheet for recording CVA data.

Coastal Vulnerability Assessment	Area of Service Loss	Damage Cost	Importance to Town Safety	Importance for Town Economy	Impact to Environment	Total Consequence Score	Probability of Inundation Present Day (%)	Probability of Inundation 2030 (%)	Probability of Inundation 2070 (%)	Total Risk Present Day	Total Risk 2030	Total Risk 2070
Sandwich Fire Station #1 115 Route 6A												
Boardwalk Parking Lot 8 Boardwalk Road												
Sandwich Town Hall 130 Main St												
Entrance Booth at Town Neck Beach Bay Beach Lane												
Student Example #1												
Student Example #2												
Student Example #3												

8th Grade Project Based Learning Capstone Projects

These lesson plans were developed to support other curriculum standards and result in creative student projects using available school technology to communicate the covered scientific information. Some examples of project-based learning capstone projects include:

1. Create a State of Coast Report covering Sandwich climate change data with a PSA, or news report (print or video).

2. Create a commercial that advertises various adaptation strategies for coastal resilience with associated cost for implementation.

3. Create a brochure discussing coastal resiliency and different types of adaptations.

4. Write a future news article based on the future climate change projections.

5. Conduct interviews with pairs of students that can be recorded. One student can be the interviewer and the other a scientist that can speak to how the climate is change in Sandwich.

6. Develop a school wide education platform (flyers, posters, etc.) to educate other students about local climate change impacts.