Teacher Guide—Earth Science Module
Activity 2: Salinity & Tides

Featured NERRS Estuary:
Chesapeake Bay Virginia National Estuarine Research Reserve
http://nerrs.noaa.gov/ChesapeakeBayVA/welcome.html

Activity Summary

In this activity, students learn about tides and salinity in estuaries. They observe time-lapse models of tides and salinity distribution in the York River, part of the Chesapeake Bay, VA NERR. Learn how salinity changes with an incoming and outgoing tide, observing the dynamics of the salt wedge at various sites along the river. Students also make predictions about the salinity changes at each site based upon their observations of the animation. They then use salinity data from monitoring stations along the river to see changes during a typical day. And, then describe the patterns of each salinity graph and compare the graphs.

Learning Objectives

Students will be able to:

1. Analyze different forms of data and synthesize information to develop a hypothesis.
2. Explain how tides and the geology of the estuary affect water circulation in an estuary.
3. Describe daily patterns of salinity changes in the estuary.

Grade Levels

9-12

Teaching Time

3 (55 minute) class sessions + homework

Organization of the Activity

This activity consists of 3 parts which help deepen understanding of estuarine systems:

Tides in Chesapeake Bay

Salinity as York River Flows into the Bay

Interaction of Tides and River Flow

Background

York River is one of several rivers flowing into Chesapeake Bay. As the nation's largest estuary, Chesapeake Bay contains a diverse collection of habitats including oyster reefs, seagrass beds, tidal wetlands, sandy shoals and mudflats. Chesapeake Bay and York River illustrate the complexities of tidal variation that respond not just to the gravitational pull of the sun and the moon, but also to the underlying topography of the bay and the dynamics of the estuarine river systems.

Chesapeake Bay Virginia National Estuarine Research Reserve has four sites on the York River, enabling research and education about the estuary, including extensive data from water quality stations and other observations by reserve scientists. In this learning activity, students use this multi-site system to explore tides and salinity from tidal freshwater to high salinity conditions along the York River estuary. Reserve components include Sweet Hall Marsh, Taskinas Creek, Catlett Island and Goodwin Islands.Rivers. Both rivers discharge into Chesapeake Bay.

Additional Resources

- For background on tides and estuaries, refer to *Student Reading — Estuarine Tides.*
- For a more thorough background on tides, see the NOS Tutorial on Tides and Water Levels: *oceanservice.noaa.gov/education/kits/tides/welcome.html*

Preparation

Make copies of *Student Reading — Estuarine Tides*, *Student Worksheet — Salinity and Tides*, and if you will not be providing computer-access to the data, *Student Data Sheet — Salinity and Tide Data for York River.* (Note that the data on the *Student Data Sheet* are for a specific date: March 21, 2007.)

Arrange for students to work with the animation and data, either in a computer lab or with a computer and projector. Bookmark the following sites:

- *nerrs.noaa.gov/ChesapeakeBayVA/welcome.html*
- *tidesandcurrents.noaa.gov/ofs/cbofs/wl_nowcast.shtml*
- *www.vims.edu/physical/web/presnt/qtime/Kimplot3.mov*
- *www2.vims.edu/vecos/SegmentChoice.aspx?param=MOBPH*

Figure 1.

The location of York River with respect to Chesapeake Bay

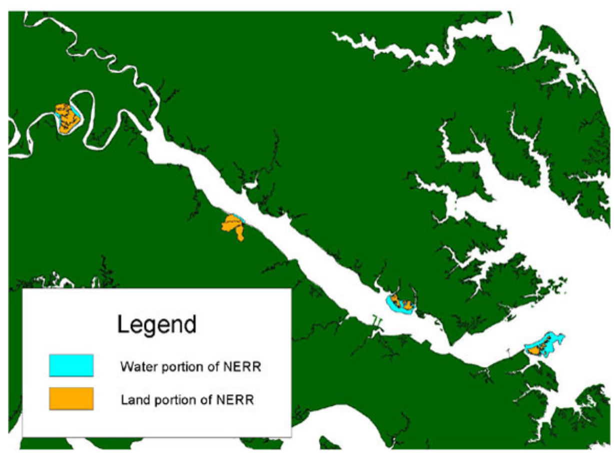

Figure 2.

Close-up Map of York River with NERR sites

Procedure

Part 1 — Tides in Chesapeake Bay

1. Introduce students to the Chesapeake Bay. If need be, use a U.S. Map to show students the location of Chesapeake Bay. Students can also learn more about the bay using Google Earth (refer to the *Student Reading — Using Google Earth to Explore Estuaries* for a brief how-to guide) or they can read more on the Chesapeake Bay Virginia NERR web site:

   nerrs.noaa.gov/ChesapeakeBayVA/welcome.html
2. Using a computer projector for the whole class or letting students work individually or in teams in the computer lab, demonstrate the Tides in Chesapeake Bay web site:

   tidesandcurrents.noaa.gov/ofs/cbofs/wl_nowcast.shtml
3. Have students complete Part 1 of the *Student Worksheet — Salinity and Tides.*

National Science Education Standards

Content Standard A: Science as Inquiry

A3. Use technology and mathematics to improve investigations and communications.

A4. Formulate and revise scientific explanations using logic and evidence.

A6. Communicate and defend a scientific argument.

Content Standard B: Physical Science

B4. Motions and forces
B5. Conservation of energy and the increase in disorder

B6. Interactions of energy and matter

Content Standard D - Earth and Space Science

D1. Energy in the earth system 189
D2. Geochemical cycles 189

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of the Student Reading — Estuarine Tides
- ❑ Copy of the Student Worksheet — Salinity and Tides
- ❑ Copy of the Student Data Sheet — Salinity and Tide Data for York River (if there is no computer-access to the data)
- ❑ U.S. Map and/or Google Earth
- ❑ Copy of Student Reading — Using Google Earth to Explore Estuaries (assuming you have computer access) - Find the tutorial in estuaries.gov, click under Teachers, Classroom Activities and find the tutorial.

Teachers

Bookmark the following sites:
nerrs.noaa.gov/ChesapeakeBayVA/welcome.html

tidesandcurrents.noaa.gov/ofs/cbofs/wl_nowcast.shtml

www.vims.edu/physical/web/presnt/qtime/Kimplot3.mov

www2.vims.edu/vecos/SegmentChoice.aspx?param=MOBPH

Equipment:
- ❑ Computer lab or
- ❑ Computer and Projector

Part 2 — Salinity as York River Flows into the Bay

Here, you focus on salinity, helping students think, in a general way, about the salinity gradient in the York River as the fresh water flows into the salty bay.

4. Make sure the students understand the location of York River in Chesapeake Bay.
5. Have students complete Part 2 of the *Student Worksheet — Salinity and Tides*, labeling the York River map with "fresh," "nearly fresh," "fairly salty," "close to seawater," or "seawater."

   If students have hands-on experiences in mixing fresh and seawater and/or have measured samples of fresh, brackish, and seawater, they can label the map with their best guesses about salinity, which will range from 0 (fresh) to about 35 parts per thousand (ocean).
6. Have students compare maps in small groups and explain why they marked them as they did.
7. Discuss daily and seasonal factors and Earth processes that affect salinity in an estuary.
8. Have students read *Student Reading — Estuarine Tides*. (This can be assigned as homework.)

Part 3 — Interaction of Tides and River Flow

With this part, students deepen their understanding of estuarine systems, focusing on the interaction of tides and rivers and how this affects salinity in the estuary.

9. Using a computer projector for the whole class or letting students work individually or in teams in the computer lab, demonstrate the animation of tides and salinity in York River at this web site: <*www.vims.edu/physical/web/presnt/qtime/Kimplot3.mov*>.

   Make sure students are aware that the animation shows the change in salinity over a tidal cycle of 24 hours. Explain that the animation is not a representation of salinity changes for a specific date, but rather a model of what salinity distribution might be like in the river on any given day.

   Provide a general orientation about the animation for students:

   - The bottom and larger part of the animation shows horizontal distribution—salinity changing from upstream to downstream.
   - There are four reference points on the animation. Three are sites for which students will analyze salinity graphs in Part 2. (GLPT is Gloucester Point, #1 is Yorktown, and #3 is Clay Bank.)
   - The three images to the right show transverse slices of each of the three points—cut-away views of those locations—and show how saltier and fresher water is mixing from the surface of the water to the bottom.
   - The scale on the left shows the amount of salinity in parts per thousand (ppt). Students should generally know that moving from blue to red on the scale represents fresh to increasingly saltier water.
   - Students should also be aware that arrows on the image indicate the direction of water flow.
   - The hour on the animation indicates the time of day on the 24-hour clock.
   - The isohalines (lines on a chart connecting all points of equal salinity) help students determine levels of salinity.

10. Encourage students to play this animation several times, looking for general patterns first, then at specific phenomena and distribution at specific places.
11. Have students answer the first set of questions in Part 3 of the *Student Worksheet — Salinity and Tides*.
12. Have students look at the cross-section views in the upper right of the animation, showing salinity with depth in the river, at the lines marked 1, 2 & 3, and answer the remaining questions.

Part 4 — Salinity as Measured by Water Quality Stations in York River

Having seen what a theoretical salinity distribution can look like in the river, students now observe actual salinity data for a specific day at five different sites along the river. You can do this activity either using computer access to near-current data or using the prepared data graphs in the *Student Data Sheet — Salinity and Tide Data for York River*.

13. If you use the computer access to data, follow the instructions in the *Student Worksheet — Salinity and Tides*. If you use the prepared graphs, hand them out to students.

Students will:

- Read information about the station including Salinity regime, Mean tidal range, Mean water depth, and Adjacent water.
- Make predictions about how fresher and saltier water will mix, and how salinity changes throughout the day will differ from site to site.
- Select data for the same date at each station. Students may select a date of their own choosing, but for the purposes of this initial activity, it will be best for the whole class to choose the same date for the sake of consistency when they are discussing results.
- Observe graphs of salinity data for that day at each site. It will be helpful for students to print out graphs for each site so they can compare changes from site to site, over time.

14. Encourage students to correlate the salinity graphs at the five sites with the generalized distribution shown in the animation. Students should pay particular attention to the graphs of Gloucester Point, Yorktown, and Clay Bank because this is the area marked by the three reference points in the animation.
15. Have students answer the questions in Part 4 of the *Student Worksheet — Salinity and Tides*.

Check for Understanding

1. Discuss the following:
   - How do the changes at each monitoring station compare with changes at those same areas in the animation?
   - Name several factors that determine why salinity changes are different depending on your location within the estuary.
2. Ask small groups to use their handouts to answer this question. Collect this assignment and use it as a final assessment.

   Imagine that an intense rainstorm dumps 3 inches of rain over the entire Chesapeake Bay region. Predict how the salinity would change at all four stations in the bay for a period of 24 hours after the storm ends. Supply a graph and an explanation of what you might expect to see at each station.

Optional Extension Inquiries

1. Have students access other data from the VIMS site to see how factors such as precipitation and temperature might have affected salinity on that date.
2. Have students investigate tides and salinity from other NERRS estuaries, using the NERRS data system: cdmo.baruch.sc.edu/QueryPages/googlemap.cfm
3. Other related activities include:
   - NOS Tides Lesson Plans oceanservice.noaa.gov/education/kits/tides/supp_tides_lessons.html
   - Waquoit Bay on Estuaries.gov, Time, Tides, and Quahogs www.estuaries.gov/pdf/timeandtide.pdf

Teacher Worksheet with Answers
Activity 2: Salinity & Tides

Part 1 — Tides in Chesapeake Bay

1a. At what time is the tide highest at the mouth of the bay near Norfolk? How high is the tide?

Answer: *Student answers will vary since this model is constantly updated to show near real-time. To determine the answer, work through the animation to find when the color at the mouth is deepest orange (or even red). Then read the time. For height, read the height (2-3 feet is a likely answer).*

1b. At what time did this tidal rise reach the northern tip of the bay near Baltimore? How high is the tide?

Answer: *Student answers will vary since this model is constantly updated to show near-real-time. To determine the answer, work through the animation to find when the color at the tip of the bay is towards the blue end of the scale. Then read the time. For height, read the height (.5 feet is a likely answer).*

1c. How long did it take the tide to move this distance?

Answer: *Student answers will vary. A typical answer is 12 hours.*

1d. Which location has higher tides? Why?

Answer: *Mouth of the bay because it is closer to the ocean where the tidal water enters the bay.*

1e. Which location do you think has saltier water? Why?

Answer: *Mouth of the bay because it is closer to the ocean where the salty ocean water enters the bay.*

Part 2 — Salinity as York River Flows into the Bay

2a. The map below shows the York River where it empties into Chesapeake Bay. On the map, indicate how you think the salinity might differ throughout the river and into Chesapeake Bay. Label parts of the map "fresh," "nearly fresh," "fairly salty," "close to seawater," or "seawater."

Answer: *Student areas will vary. However, students should show some gradation of salinity, moving from less salty water upriver (upper left of the map) to more salty as they approach the ocean. The actual mean salinity of Taskinas Creek (upriver) ranges from about 3-5 ppt in winter to about 14-16 ppt in summer. The actual mean salinity of Goodwin Islands (in Chesapeake Bay) ranges from about 13-15 ppt in winter/spring to about 23-25 ppt in summer/fall.*

Part 3 — Interaction of Tides and River Flow

3a. At the mouth of the river (lower right), what are the highest and lowest salinity levels, in ppt, during this time frame?

Answer: *High 22, low 20 ppt (approximately)*

3b. Now look up river at the upper left of the animation. What are the highest and lowest salinity levels there?

Answer: *High 13, low 6 ppt (approximately)*

3c. Why is there such a difference between these two locations?

Answer: *Fresh water enters up river, salt water enters from Chesapeake Bay.*

3d. Play the animation and study the full extent of the river. How often do the arrows change direction? How does that affect salinity throughout the river?

Answer: *The arrows flow up (as the tide rises) for about 6 hours, then down (as the tide falls) for 6 hours. As tide rises, salinity increases and works it way up river, then vice-versa as tide falls.*

3e. At what point are there greatest changes in salinity throughout the day? Why do you think so?

Answer: *Saltier water moves up the river at high tide and fresher water moves seaward at low tide. Water with salinity of about 22 ppt moves from the mouth of the river to beyond Point 1 when the tide comes in. The area from Point 1 to Point 3 ranges from about 22 to 12 ppt. The area from Point 3 upriver ranges from about 16 to below 5 ppt.*

3f. Does the freshest water (the darkest blue) ever appear on the image? Where and for how long? Does the saltiest water (red) ever appear on the image? Where and for how long?

Answer: *The freshest water (less than 5 ppt) appears in the upper-most part of the river about every six hours when the arrows are moving seaward. Water of 25 ppt does not seem to appear on the map. The saltiest water is about 22 ppt and appears in the lower right-hand corner of the map. It does not go upriver much past station 1.*

3g. How does the water get mixed from top to bottom as the salinity changes from upstream to downstream?

Answer: *The water seems to get most thoroughly mixed from top to bottom in the area that is farthest upstream and especially where the river is shallow. The salinity in the areas most seaward, and especially the deeper parts of the river, does not change much at all.*

Part 4 — Salinity as Measured by Water Quality Stations in York River

4a. Describe the general pattern of salinity data for each site: Goodwin Island, Gloucester Point, Yorktown (this station is not included in the data sheets provided for March 21-22, 2007), Clay Bank, and Taskinas Creek.

***Answer**: Student answers for all the sites will vary depending on the dates they select.*

4b. Describe changes in salinity from site to site.

***Answer**: Generally, salinity decreases as you go from the coastal areas up the York River. Generally the lowest salinity values for a day occur during low tide (when water depth is low). Students will find that stations further upriver have salinity patterns that more closely resemble patterns of water depth or tide height. This is clearly seen in the graphs for Taskinas Creek. Stations closer to the ocean have more irregular patterns that may not resemble patterns in graphs of water depth. Salinity graphs at these sites show more frequent peaks and valleys.*

4c. What do you think explains the differences in salinity from site to site?

***Answer**: Sites further upriver are influenced not only by the brackish water of the York River, but also by fresh water entering from creeks and groundwater. High tides bring saltier water and salinity goes up. During low tides, fresher water predominates and salinity goes down. Salinity for sites closer to the coast may seem more erratic throughout the day. These sites are subject to more thorough mixing of fresher and saltier water because of waves, winds, and currents.*

Student Reading
Activity 2: Estuarine Tides — It's Not Just the Sun and Moon

What Affects Tides in Addition to the Sun and Moon?

The relative distances and positions of the sun, moon and Earth all affect the size and magnitude of the Earth's two tidal bulges. At a smaller scale, the magnitude of tides can be strongly influenced by the shape of the shoreline. When oceanic tidal bulges hit wide continental margins, the height of the tides can be magnified. Conversely, mid-oceanic islands not near continental margins typically experience very small tides of 1 meter or less. The shape of bays and estuaries also can magnify the intensity of tides. Funnel-shaped bays in particular can dramatically alter tidal magnitude. The Bay of Fundy in Nova Scotia is the classic example of this effect, and has the highest tides in the world—over 15 meters. Narrow inlets and shallow water also tend to dissipate incoming tides. Inland bays such as Laguna Madre, Texas, and Pamlico Sound, North Carolina, have areas classified as non-tidal even though they have ocean inlets. In estuaries with strong tidal rivers, such as the Delaware River and Columbia River, powerful seasonal river flows in the spring can severely alter or mask the incoming tide. Local wind and weather patterns also can affect tides. Strong offshore winds can move water away from coastlines, exaggerating low tide exposures. Onshore winds may act to pile up water onto the shoreline, virtually eliminating low tide exposures. High-pressure systems can depress sea levels, leading to clear sunny days with exceptionally low tides. Conversely, low-pressure systems that contribute to cloudy, rainy conditions typically are associated with tides that are much higher than predicted.

— Adapted from NOAA's National Ocean Service website, section on Tides &Water Levels.
URL:http://oceanservice.noaa.gov/education/kits/tides/tides08_othereffects.html.
Accessed: 2008-07-20. (Archived by WebCite® at http://www.webcitation.org/5ZS2dFx8h)

For a more thorough background on tides, see the NOS Tutorial on Tides and Water Levels:

Student Worksheet
Activity 2: Salinity & Tides

Part 1 — Tides in Chesapeake Bay

You might think of tides as the simple rising and lowering of the sea level based on the gravitational pull of the sun and moon. However, tides are much more dynamic and interesting, especially in estuaries. In Chesapeake Bay, it can take several hours for the high tide to move from the mouth of the bay to the northern tip. The rivers feeding into the bay add their own dynamics to the tidal variations. Here, you will study animations of tides in the Chesapeake Bay and York Rivers to understand these tidal dynamics and their effect on salinity.

Tides in Chesapeake Bay

Go to the following web site, which has an animation that shows tides throughout the bay for the past 3 days: <*tidesandcurrents.noaa.gov/ofs/cbofs/wl_nowcast.shtml*>.

Watch the animation and look for patterns in the tidal pulse as it works its way up the bay. Notice the scale on the right, with yellows and reds as high tide, greens and blues as low tides. Step through the animation, pressing the “Prev” and “Next” buttons, to watch the tide move up the bay.

1a. At what time is the tide highest at the mouth of the bay near Norfolk? How high is the tide?

1b. At what time did this tidal rise reach the northern tip of the bay near Baltimore? How high is the tide?

1c. How long did it take the tide to move this distance?

1d. Which location has higher tides? Why?

1e. Which location do you think has saltier water? Why?

Part 2 — Salinity as York River Flows into the Bay

Next, you take a closer look at York River to see how tides and the flowing river interact and affect salinity of the water.

The map below shows the York River where it empties into Chesapeake Bay. On the map, indicate how you think the salinity might differ throughout the river and into Chesapeake Bay. Label parts of the map "fresh," "nearly fresh," "fairly salty," "close to seawater," or "seawater."

Figure 1.

The location of York River with respect to Chesapeake Bay

Figure 2.

Yorktown, Virginia is situated at the mouth of the York River.

Part 3 — Interaction of Tides and River Flow

Go to this web site: <*www.vims.edu/physical/web/presnt/qtime/Kimplot3.mov*>. The animation shows salinity in York River, and how it changes with the incoming and outgoing tide, over 24 hours.

Use the slide bar to control the animation at your own pace. Watch the animation several times, looking for patterns in the salinity. Notice the time counter at the top, marking half-hour increments, and the scale bar on the left showing salinity in parts-per-thousand (ppt).

3a. At the mouth of the river (lower right), what are the highest and lowest salinity levels, in ppt, during this time frame?

3b. Now look up river at the upper left of the animation. What are the highest and lowest salinity levels there?

3c. Why is there such a difference between these two locations?

3d. Play the animation and study the full extent of the river. How often do the arrows change direction? How does that affect salinity throughout the river?

3e. At what point are there greatest changes in salinity throughout the day? Why do you think so?

3f. Does the freshest water (the darkest blue) ever appear on the image? Where and for how long? Does the saltiest water (red) ever appear on the image? Where and for how long?

3g. Now look at the cross-section views in the upper right of the animation, showing salinity with depth in the river, at the lines marked 1, 2 & 3. How does the water get mixed from top to bottom as the salinity changes from upstream to downstream?

Part 4 — Salinity as Measured by Water Quality Stations in York River

The animations showed salinity distribution throughout a river based on a computer model. Now, you will observe actual salinity data for a specific day at five different sites along the York River. These sites use data buoys and other water quality stations to measure water depth, salinity, and other important data. These instruments support research at the Chesapeake Bay Virginia NERR and the affiliated Virginia Institute of Marine Science (VIMS).

You can do this activity in either of two ways: Use your computer to access real-time data and display your own graphs (see instructions below) or use the *Student Data Sheet* with its graphs for a sample date.

If you use your computer, follow these instructions:

- Open the Virginia Estuarine and Coastal Observing System site at: *www2.vims.edu/vecos/SegmentChoice.aspx?param=MOBPH*. This will bring up a page showing a regional view with some of the York River stations.
- Starting with Goodwin Island Continuous Monitoring Station (CHE019.38), click on each station, moving progressively up river (to Gloucester Point (YRK—5.40), Yorktown (YRK006.77), Clay Bank (YRKO15.09), and Taskinas Creek (TSK000.23).
- For each station, print the graphs of salinity and water depth.
- Read other information about the station including Salinity regime, Mean tidal range: 0.85 meters, and Mean water depth.

Figure 3. Location of selected monitoring stations in the Chesapeake Bay region.

Whether you use computer to access data or the pre-printed graphs, answer the following questions:

4a. Describe the general pattern of salinity data for each site:

Goodwin Island

Gloucester Point

Yorktown (this station is not included in the data sheets provided for March 21-22, 2007)

Clay Bank

Taskinas Creek.

4b. Describe changes in salinity from site to site.

Student Data Sheet
Activity 2: Salinity and Tide Data for York River

Salinity Data for March 21-22, 2007

Goodwin Islands Continuous Monitoring Station: CHE019.38

www2.vims.edu/vecos/StationDetail.aspx?param=CHE019.38&program=CMON

Location: N 37º 13' 01.2" W 76º 23' 19.2"

Tributary: York River

Salinity regime: Polyhaline

Mean tidal range: 0.79 meter

Mean water depth: 1.0 meter

Adjacent Water: located on the southern side of the York River, near the mouth of the River.

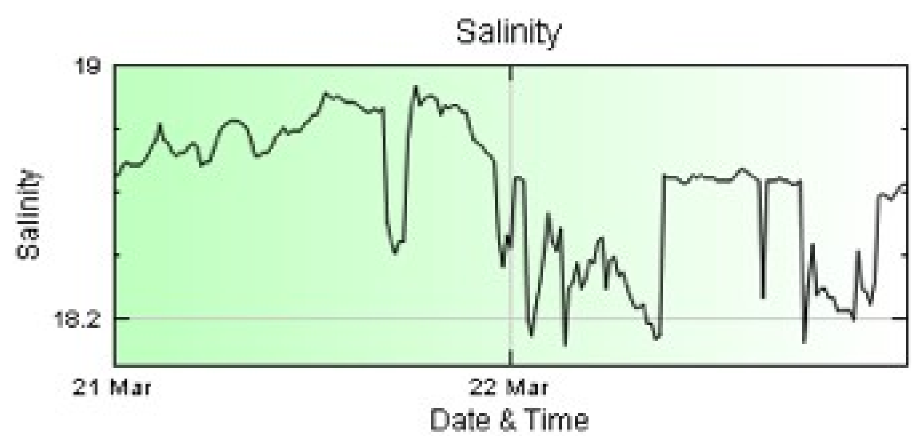

Figure 4. Salinity at Goodwin Islands Monitoring Station

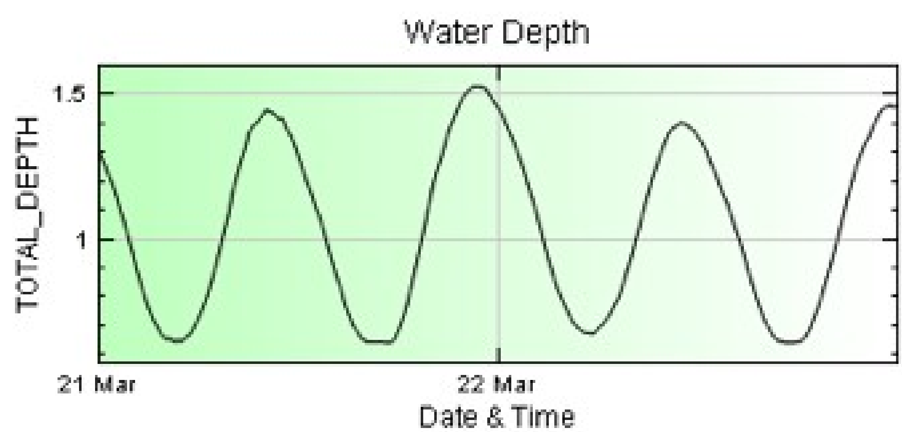

Figure 5. Water depth at Goodwin Islands Monitoring Station

Gloucester Point (GP) Continuous Monitoring Station: YRK005.40

Location: N 37º 14’ 53.82” W 76º 29’ 47.46” Tributary: York River

Salinity regime: Polyhaline

Mean tidal range: 0.73 meters

Mean water depth: 1.8 meters

Adjacent water: The Gloucester Point station is located north of the York River channel, approximately 5.4 nautical miles upstream from the River’s mouth.

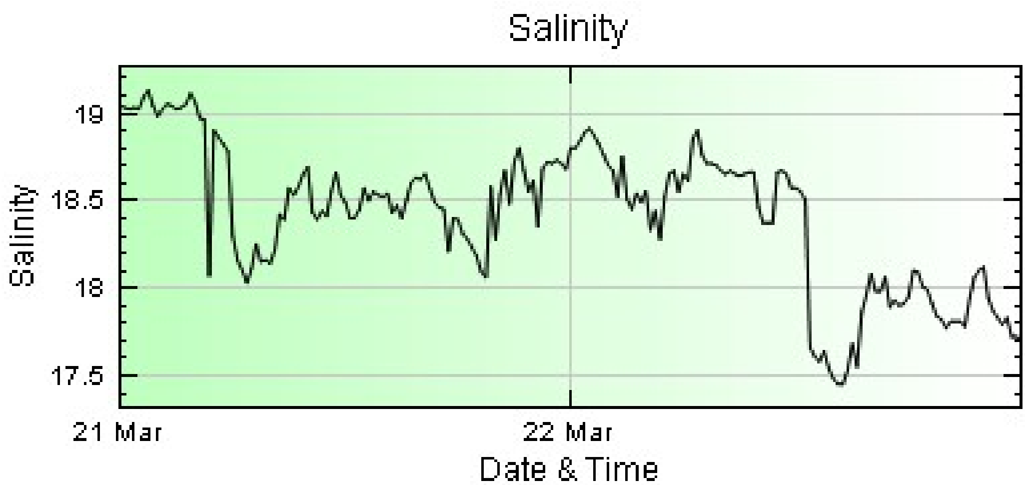

Figure 6. Salinity at Gloucester Point Monitoring Station

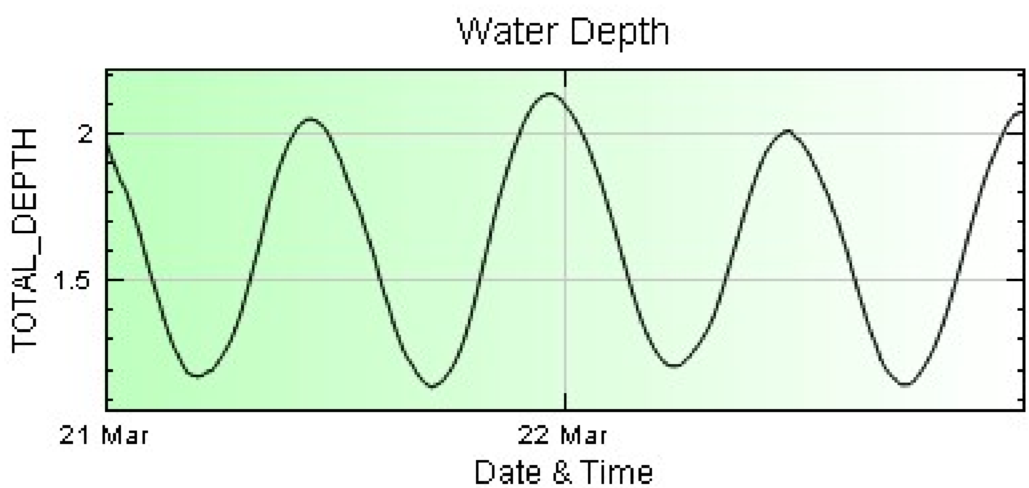

Figure 7. Water depth at Gloucester Point Monitoring Station

Claybank (CB) Continuous Monitoring Station: YRK015.09

Location: N 37º 20' 49.5" W76º 36' 41.94"

Tributary: York River

Salinity regime: Mesohaline

Mean tidal range: 0.85 meters

Mean water depth: 1.2 meters

Adjacent water: The Clay Bank station is located northeast of the York River channel, approximately 15.1 nautical miles upstream from the River's mouth.

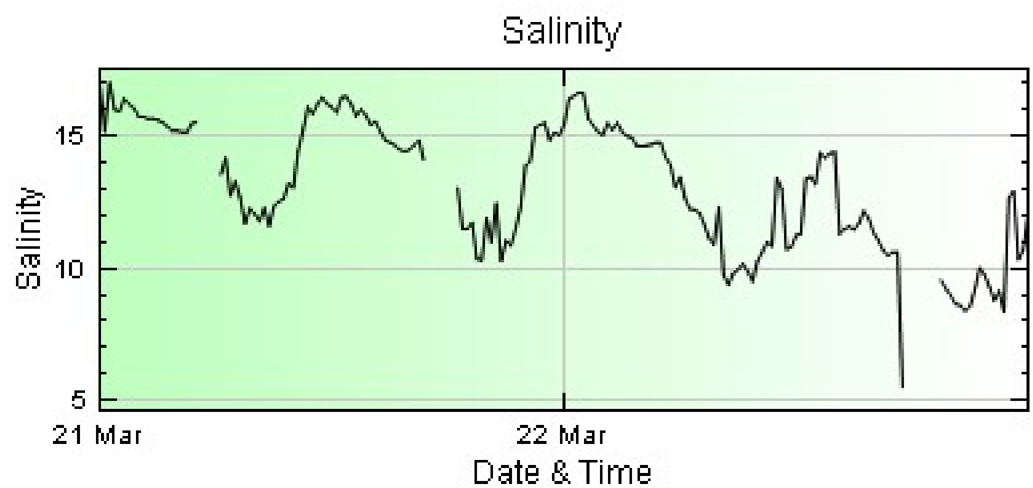

Figure 8. Salinity at Claybank Monitoring Station

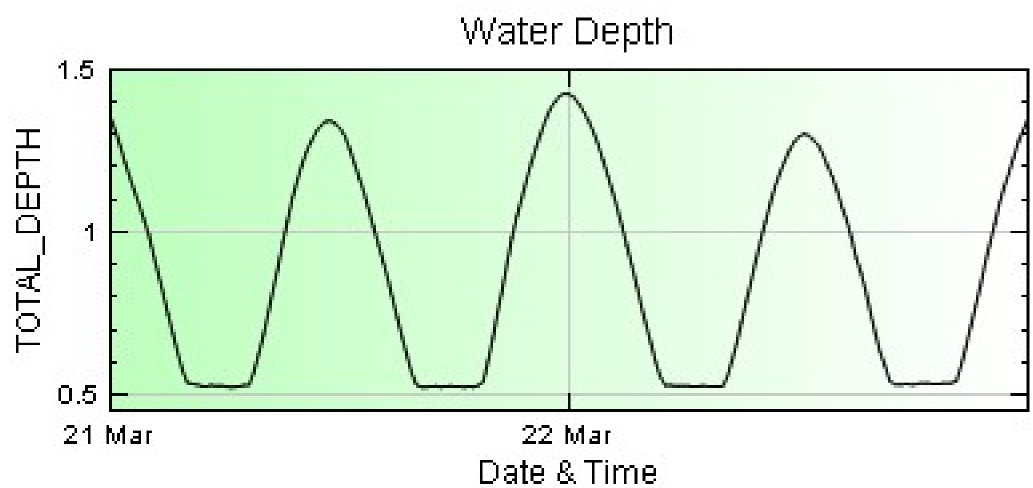

Figure 9. Water depth at Claybank Point Monitoring Station

Taskinas Creek (TC) Continuous Monitoring Station: TSK000.23

Location: N 37º 24' 54.79" W 76º 42' 52.74

Tributary: York River

Salinity regime: Mesohaline

Mean tidal range: 0.85 meters

Mean water depth: 1.5 meters

Adjacent water: The Taskinas Creek station is located southwest of the York River channel, approximately 23 miles upstream from the River's mouth.

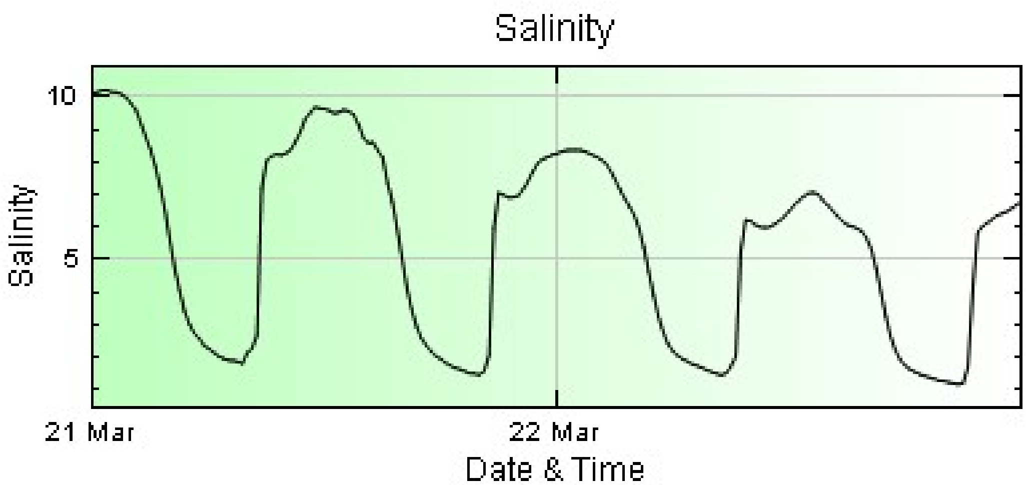

Figure 10. Salinity at Taskinas Creek Monitoring Station

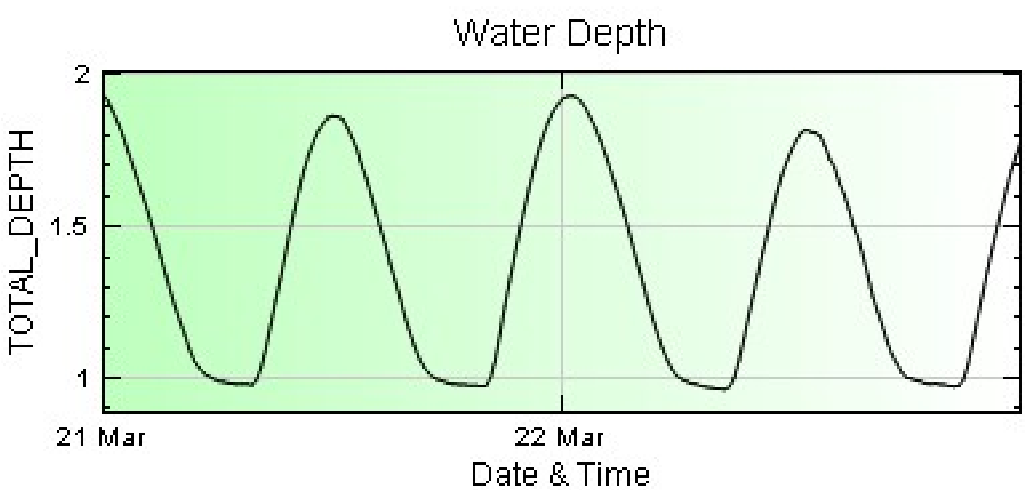

Figure 11. Water depth at Taskinas Creek Monitoring Station