Teacher Guide—Earth Science Module
Estuary and the Watershed — San Francisco Bay

Featured NERRS Estuary:
San Francisco Bay
National Estuarine Research Reserve

Activity Summary

In this activity, students investigate a large watershed, look for sources of pollution in the watershed, and study the impacts of a rain storm on a watershed and estuary, without going on field trip. Students begin by examining the San Francisco Estuary using Google Maps (Part 1), identifying possible sources of pollution and contamination along the major rivers that feed into the estuary (Part 2). Students also examine graphs of water quality data from the estuary and identify changes that occur due to a storm event (Part 3).

Learning Objectives

Students will be able to:

1. Demonstrate a more complete understanding of watersheds.
2. Identify and articulate connections between land-use in the watershed and water quality in rivers and estuaries.
3. Analyze and interpret water quality graphs to understand how a storm impacted water quality in San Francisco Estuary.

Grade Levels

6-12

Teaching Time

4 (55 minute) class sessions + homework

Organization of the Activity

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

Part 1: Exploring the San Francisco Watershed

Part 2: What's Upstream Comes Downstream

Part 3: Water Quality at the Mouth of the Watershed

Background

San Francisco Bay is an extensive and shallow estuary that drains approximately 40% of the land in California. Ninety percent of the water flowing into the bay comes from the Sacramento and San Joaquin rivers, whose headwaters are in the Sierra Nevada Mountains. Both rivers flow into the Delta, a vast network of channels, agricultural lands and fresh water wet-

lands, and then into San Francisco Bay where they mix with salt water from the Pacific Ocean.

Northern California's climate has a distinct wet and dry season, with nearly all of the rain coming in the winter months, often during large storms. These distinct seasons makes it an ideal estuary and watershed for an introduction to how rainfall in a watershed changes water quality in an estuary.

San Francisco Bay National Estuarine Research Reserve includes China Camp State Park on the north-west shore of the estuary. China Camp State Park was the site of a Chinese shrimp-fishing village where some 500 people lived in the 1880s. The water quality data in this activity were collected from a monitoring station on this historic pier that was part of the village.

Preparation

Read the Student Reading for more background information.

Connect to the internet and find China Camp State Park in San Rafael, CA on Google Maps, satellite view.

Materials

Students

Need to work in pairs, small groups, or individually at computer with internet access

Copy of Student Reading Part 1: Exploring the San Francisco Watershed

Color Copy of Student Worksheet Part 1: Exploring the San Francisco Watershed

Copy of Student Worksheet Part 2: What's Upstrem Comes Downstream

Copy of Student Worksheet Part 3: Water Quality at the Mouth of a Watershed

Copy of Student Data Sheet 1 Part 1: Exploring the San Francisco Watershed

Copy of Student Data Sheet 2 Part 3: Water Quality at the Mouth of a Watershed

Dark colored markers

Teachers

Optional Resources:

- ❑ Part 1: Computer and Projector with Google Maps, satellite or "earth" view on and centered on Golden Gate Bridge in San Francisco, California
- ❑ Part 3: Descriptions of water quality parameters, available on the NERRS Estuary Education Science at Data page.

Procedure

Part 1 — Exploring the San Francisco Watershed

1. Ask students what, if anything, they know about watersheds. If possible, walk outside your classroom, observe and discuss your local watershed with students. Where does the water that passes through gutters, ditches, creeks, or steams near your school go? (Note: If your students need an introduction to watersheds, you may want to complete first exercise in Estuaries 101 Activity called "Oil Spill: The Rest of the Story".)
2. Hand out the Student sheets (*Reading, Worksheet and Data Sheet*) for Part 1: Exploring the San Francisco Watershed and markers.
3. Have the students read the *Student Reading, Part 1: Exploring the San Francisco Watershed.*
4. Have students (preferably in pairs) follow the directions for question #1 on the *Student Worksheet, Part 1: Exploring the San Francisco Watershed* to outline the general limits and confines of the watershed of San Francisco Estuary. Check that the students recognized that there are sub-watersheds within the huge area outlined on their image that makes up the entire estuary's watershed.
5. Have students move to computers with internet access, start Google Maps and select "Earth" (or satellite) view. Show students their starting point (Golden Gate Bridge) on Google Maps and have them finish the rest of the questions in Part 1 of the *Student Worksheet.*

   If students are new to using Google Maps, show them how to zoom in and out to change viewing altitude and move around the image. You may want to start with a view that is familiar (like your school) for the initial orientation.
6. Review and discuss the tasks and questions in Part 1 of the *Student Worksheet.*

Part 2 — What's Upstream Comes Downstream

1. Have students complete Part 2 of the *Student Worksheet — What's Upstream Comes Downstream* choosing one of the two rivers and taking a Google Map trip to identify areas and man-made features that may be potential sources of pollutants and contaminants.
2. Review and discuss the Part 2 tasks and questions. Have students report their findings to the class.

Part 3 — Water Quality at the Mouth of a Watershed

1. Ask students what might happen to the salinity and turbidity in the San Francisco Estuary after a rainstorm. Go over the other water quality factors students will be analyzing, too.
2. Have students complete Part 3 of the *Student Worksheet—Water Quality at the Mouth of a Watershed.*

   The data given in this section reveals a major rain event in the San Francisco watershed during January 2017. Several inches of rain fell over the area over the two-day span.
3. Review and discuss the Part 3 tasks and questions.

Next Generation Science Standards

This lesson uses the following Practices:

1. Asking questions (for science) and defining problems (for engineering)
2. Analyzing and interpreting data
3. Using mathematics and computational thinking
4. Constructing explanations (for science) and designing solutions (for engineering)
5. Engaging in argument from evidence

Extension ideas connect this lesson with HS—LS2, HS-ESS2, and HS-ESS3.

Check for Understanding

1. Discuss the following:
- ❑ What watershed do you live in? Is there more than one right answer to that question?
- ❑ Would an estuary with a small watershed that was en-tirely forested respond to a rain storm differently than the San Francisco Estuary did? How might graphs of water-quality after a storm in that type of watershed and estuary look different than the ones you exam-ined?

2. Project a satellite image of the Chesapeake Bay and its watershed (or your local watershed). Ask students to identi-fy major urban areas around Chesapeake Bay (or your lo-cal bay or water body) and major rivers that drain the wa-tershed. Ask students to identify areas of potential pollution.

Optional Extension Inquiries

1. Investigate your own watershed! Have students lo-cate possible sources of pollution and contamination in your local watershed (as in Parts 1 and 2).
2. Establish a water-monitoring program at a stream or river near your school to study how your watershed responds to rain storms.
3. Is there a National Estuarine Research Reserve close to you? Your students can create their own graphs of water quality data to look for storm impacts in "their" estuary. Graphs are easy to make at coast.noaa.gov/SWMP.
4. Connect to NGSS Standards HS-LS2 and HS-ESS3 by designing solutions to limit pollution running off into estuary during storms.
5. Connect to NGSS Standards HS-ESS2 by using stream tables before this lesson to explore the im-pacts of runoff.

Teacher Worksheet with Answers

Part 1 — Exploring the San Francisco Watershed

1. *Answer: Lines drawn on the image will vary, but should follow the peaks of the mountain ranges, including the Sierra Nevada Mountain in the far east of the image. There is a small watershed near the bottom of the image that flows into the Pacific Ocean, rather the Estuary. The key aspect of this section is that the students demonstrated an understanding of watersheds and sub-watersheds.*

2a. Fly around the bay in a clockwise direction, identify the rivers that empty into the bay, and list the name of the river (if you can find a label) or the closest labeled landmark to where the river meets the bay.

Answer: The Petaluma River (Black Point, Green Point, Sears Point are all near here), Napa River, Carquinez Straight (students may record this as San Joaquin River and Sacramento River, or Suisun Bay if they explored upstream), Alameda Creek (near Coyote Hills Regional Park), and Coyote Creek. Depending on their observation and attention, students may identify many smaller rivers.

2b. Describe what kinds of human activity or evidence of man-made changes you see along the shore of the estuary.

Answer: Variety of answers, including cities, bridges, ships, salt ponds (these are the brightly colored areas at the south end of the estuary), landfills, and sewage treatment plants.

2c. What is the most interesting thing you saw along the shoreline? What do you wonder about it?

Answer: Variety of answers.

2d. List at least five interesting features you noticed on the journey back to the estuary.

Answer: Variety of answers, including several large "lakes" or reservoirs, farmland, big curves in the river, natural (protected) areas, changes in color of the water (an artifact of piecing together satellite images taken on different day or at different times of day), and the City of Sacramento.

2e. How is the land that the San Joaquin River travels through different from that of the Sacramento River?

Answer: Variety of answers, including more snowy, more mountainous, more agriculture. It is harder to follow the San Joaquin River.

Part 2 — What's Upstream Comes Downstream

2a. List ten possible sources of pollutants or contaminants along the river. Record the source and a place name or latitude and longitude coordinates for each site.

Answer: Student responses will vary, and may include:

Napa River:

1. *Shipyards (Mare Island)*
2. *Salt ponds*
3. *Golf course*
4. *Urban streets*
5. *Agricultural fields (mostly growing wine grapes)*
6. *Wineries*
7. *Ponds of wastewater*
8. *Landfill (Clover Flat Landfill)*
9. *Sewer treatment ponds (just south of Calistoga)*
10. *Reservoir/lake at Kimball Canyon*

Coyote Creek

1. *Salt ponds*
2. *Wastewater treatment facility*
3. *High-tech industry plants (Cisco Systems, etc.)*
4. *Golf course*
5. *Urban streets*
6. *Zoo*
7. *Commercial businesses (malls, Costco, etc.)*
8. *Freeways/roads*
9. *PG and E facility*
10. *Agricultural fields*
11. *Reservoir/boating at Anderson Lake*

Answers may spark conversations about types of pollution and contaminates. For example, students may list wetlands, or tidal salt marshes, as sources of pollution because they are often muddy. If so, this can lead to discussion about role of marshes in filtering out sediments from the water. Could something be both a source and a sink for pollution?

2b. What do you think is the most likely source of pollution and contamination along the river you investigated?

Answer: Student answers may vary, but could reasonably include any of the answers they listed in 2a.

2c. Can you see any evidence that contaminants are being released into the river?

Answer: Students may be able to see sediment plumes at various places, notice differences in water color in treatment ponds, or may see (or infer) other evidence. Or they may not see any evidence. The important aspect of this question is to start looking for actual evidence, rather than making assumptions.

2d. How could you collect evidence of pollution or contaminants?

Answer: Students could collect water samples and test them for pollution. They could also look at data collected by professional scientists.

2e. Did you see any natural or manmade features that might clean the water before it enters the river or estuary?

Answer: Students should notice tidal wetlands where both rivers meet the estuary, and may notice other wetlands along the waterway. There are forested/natural/wild areas along both waterways. On the Napa River, there are riparian forests (trees) along the banks of the river in most places that keep it cleaner and create habitat.

Part 3 — Water Quality at the Mouth of a Watershed

3a. Predict how this event would affect these water quality factors in the estuary:

Answer: Student answers will vary.

3b. Consult the *Student Data Sheet 2 — Water Quality Data*, look for evidence of a major storm event that occurred in 2017. When did the storm occur? What evidence did you use to determine when it occurred?

Answer: A major rain and storm event appears to have begun on January 7th or 8th. The best evidence for this is a significant drop in salinity. If they students did not reach this answer, you may need to review estuaries being a mix and fresh and salt water, and how the salinity at any given location changes with the tide, season, and amount of rainfall. Students could use turbidity data as evidence and decide the storm started January 7th; this could be correct too. The factor to look for is that they interpreted the graphs correctly and used evidence from the graphs to make their determination.

3c. Look at the graphs and record what happened to each of the water quality parameters in response to the storm. Did the parameter increase, decrease or stay the same? Describe patterns or changes you notice.

Answer: Student answers may vary but most typical are listed below. These answers could lead to further investigations.

	Increase, Decrease, Same	Patterns/Changes
Water Temperature	Decreased, then increased	Temperature warmed up after storm
pH	Decreased after storm	Bigger spikes after storm
Dissolved Oxygen	Accept variety of answers; difficult to summarize	Spikes at start of storm, general increase after storm, more restricted daily range immediately after storm
Salinity	Decreased after storm	Changes daily, more restricted daily changes after storm, drops almost to 0.
Turbidity	Increased at start/before storm, Spikes	Very high spikes beginning with storm and continuing after

3d. How well did your predictions match what actually happened during the storm event? For any predictions that didn't match, explain why your original reasoning may or may not have been correct.

Answer: Answers will vary based on their original predictions, but should center around the idea that the storm meant lots of freshwater was flowing through the estuary. At China Camp, where the water is typically a mix of freshwater from the watershed and saltwater from the Pacific Ocean, the storm meant that there was proportionally more freshwater. More information about each of the water quality parameters can be found in the "Science and Data" section of the NERRS education website (coast.noaa.gov/estuaries). The intent of this question is to promote careful observation of graphs and practice arguing from evidence.

Temperature: This could be evidence of the storm bringing warmer weather or of freshwater coming down the estuary being warmer than saltwater from the Pacific Ocean.

pH: The pH of saltwater is higher than the pH of freshwater, so the decline in pH indicates that there is proportionally more freshwater at China Camp after the storm.

Dissolved oxygen: This graph is more difficult to interpret and explain. Perhaps the storm was preceded by wind that added oxygen into the water through waves? It might be interesting to discuss this graph further and to compare it with graphs from other storms to see if the pattern is consistent (other similar storm: December 25, 2005 through January 5, 2006;).

Salinity: This is the most clear of the graphs. Salinity drops because there is more freshwater flowing down the estuary. The up-down oscillation is caused by the tide.

Turbidity: Turbidity (or murkiness of the water) begins to spike as the storm starts. This is the strongest indicator of muddy flood waters coming down the estuary from its' watershed.

Student Reading
Part 1- Exploring the San Francisco Watershed

A watershed, also called a drainage basin, is the area in which all water, sediments, and dissolved materials drain from the land into a common body of water, such as a river, lake, estuary, or ocean. A watershed encompasses not only the water but also the surrounding land from which the water drains. Watersheds range in size from huge areas like the Mississippi River drainage basin to small areas like your backyard. A large watershed is made up of smaller ones, which may be made up even smaller ones. These watersheds within a watershed can be called sub-watersheds.

Whether large or small, a watershed's characteristics can greatly affect how water flows through it. For example, if the terrain in the watershed is steep (like in a canyon), rainfall can wash down into the river quickly, causing flash flooding. In general, in a watershed with steep terrain with little vegetation, heavy rain can cause rapid increase in stream flow. In other watersheds, heavy rains will cause a gradual increase in stream flow. For example, on heavily vegetated, relatively flat terrain, much of the rainfall is absorbed by the soil, and runoff is slowed by vegetation, so the water takes a longer time to reach the river. In these areas, stream flow will rise slowly even after heavy rains. These differences in the watershed change the quality of water in the rivers. For example, swiftly moving water, like that found in a steep watershed or after very heavy rains, are more likely to be muddy (have high turbidity).

Human-made features of the watershed, like dams or large paved areas, can also change stream flow and alter the watershed. Water flows off paved areas very quickly because it can't be absorbed by the soil and there is no vegetation to slow the flow.

Water quality of a body of water is impacted by everything that goes on within its watershed. Mining, forestry, agriculture, and construction practices, urban runoff from streets, parking lots, chemically-treated lawns and gardens, failing septic systems, and improperly treated municipal sewage discharges all affect water quality. Reducing pollution and protecting water quality requires identifying, regulating, monitoring, and controlling potential sources of pollution. Some examples of control practices include creating small wetlands or catchment basins in urban areas to trap sediment and pollutants flowing off paved areas before they reach the river. Creating and/or protecting wetlands throughout the watershed is beneficial because wetlands slow runoff, absorb floodwaters, and filter sediment and other pollutants from the water.

Estuaries are semi-enclosed bodies of water where freshwater meets the ocean (or Great Lake). As such, they lie at the mouth of watersheds. Large estuaries, like Chesapeake Bay, Mississippi River Delta, and San Francisco Bay are made up of many sub-watersheds and drain large portions of the United States.

San Francisco Estuary is a shallow, extremely large estuary and its' watershed drains about forty percent of the land in California. Nearly ninety percent of the fresh water flowing into the estuary comes from the Sacramento and San Joaquin Rivers. The saltwater comes from the Pacific Ocean.

In this activity, you will virtually explore the San Francisco Estuary and its' watershed. Later in the activity, you will analyze and interpret graphs of water-quality data collected at China Camp State Park in San Rafael, CA. China Camp is located on the northwest shore of the estuary and was the site of a Chinese shrimp-fishing village where some 500 people lived in the 1880s. The location is part of the San Francisco Bay National Estuarine Research Reserve (NERR). The water quality data you will examine in Part 3 of this activity were collected at this site.

Student Worksheet
Part 1 — Exploring the San Francisco Watershed

In this part of the activity, you will examine the San Francisco Bay's estuary and watershed, and then investigate the impact of the natural and man-made features that cause materials to be carried down river into parts of the estuary.

1. Look at your color copy of the "Oblique View" of the San Francisco Bay Area on *Student Data Sheet 1 — Exploring the San Francisco Watershed*. Locate the San Francisco Estuary in the middle of the image. Use a dark-colored marker and outline any high ridges or mountains you see surrounding low basin areas. Did you outline the San Francisco Estuary's watershed? Does your outline include smaller sub-watersheds that make up the larger Estuary's watershed? Adjust your outline, if necessary, so the entire San Francisco Estuary's watershed is outlined. Are there small watersheds that are not part of the San Francisco Estuary's watershed?

Part 1 — Exploring the San Francisco Watershed (continued)

Now you will take a closer look at both the estuary and the nature of the watershed using Google Maps with Earth view. If you are unfamiliar with Google Maps, your teacher will give you a short demonstration on how to navigate and change your viewing altitude. Enter 37° 48' 53.12 N, 122° 28' 38.26 W, the coordinates of the Golden Gate Bridge, into the Search box. After taking a look at the bridge, increase your viewing altitude (zoom out) so you can see the entire San Francisco Estuary. Zoom back in so you can see the Golden Gate National Recreation Area to the north and most of the city of San Francisco to the south, as well as some of the Pacific Ocean to the west and Treasure Island to the east. The scale bar in the bottom right of the screen should say "1 mile". This is a good viewing altitude to explore at.

2a. Fly around the bay in a clockwise direction, identify the rivers that empty into the bay, and list the name of the river (if you can find a label) or the closest labeled landmark to where the river meets the bay.

2b. Describe what kinds of human activity or evidence of man-made changes you see along the shore of the estuary.

2c. What is the most interesting thing you saw along the shoreline? What do you wonder about it?

Part 1 — Exploring the San Francisco Watershed (continued)

When you return to the Golden Gate Bridge, check your list of major rivers. Did you notice a huge channel entering the estuary called the "Carquinez Straight". Fly back to it and follow the channel east past Grizzly and Suisun Bay to Browns and Sherman Islands. Two major rivers intersect here—the Sacramento and San Joaquin Rivers. Follow the northern river (Sacramento) along its course. When it branches, keep taking the northern branch until you can no longer observe its course. At this point, search for "source of the Sacramento River" in the map's search bar. It should take you to a remote part of the Klamath Mountains. Try to loosely follow the path of the water as it travels from the source all the way to the San Francisco Estuary.

2d. List at least five interesting features you noticed on the journey back to the estuary.

1. _____

2. _____

3. _____

4. _____

5. _____

Travel back to the junction of the two rivers and trace the path of the San Joaquin River and locate its source (using search feature on the map). You should end up in a remote part of the Ansel Adams Wilderness called Thousand Island Lake. Try to follow the water as it travels from Thousand Island Lake all the way to the San Francisco Estuary.

2e. How is the land that the San Joaquin River travels through different from that of the Sacramento River?

Student Worksheet
Part 2 — What's Upstream Comes Downstream

You will now take a closer look at a sub-watershed within the San Francisco Estuary's watershed and try to determine the nature of the pollutants and contaminants that might be washed downstream into the estuary by heavy rain and floods. Choose a medium sized river flowing into San Francisco Estuary to follow upstream (good choices are Napa River or Coyote Creek). Napa River enters the estuary in the north, near the Mare Island Shipyards and the city of Vallejo. Coyote Creek enters the estuary at the South Bay Salt Ponds, near the San Jose-Santa Clara Wastewater Facility. Fly low—1,000 feet on the scale bar to start with —to see features that could be possible sources of contaminants.

Selected River (circle one): Napa River Coyote Creek

2a. List ten possible sources of pollutants or contaminants along the river. Record the source and an approximate place name or latitude and longitude coordinates for it.

Possible Source of Pollution/Contaminants	Name or Location
1. _____	_____
2. _____	_____
3. _____	_____
4. _____	_____
5. _____	_____
6. _____	_____
7. _____	_____
8. _____	_____
9. _____	_____
10. _____	_____

Part 2 — What's Upstream Comes Downstream (continued)

2b. What do you think is the most likely source of pollution and contamination along the river you investigated?

2c. Can you see any evidence that contaminants are being released into the river?

2d. How could you collect evidence of pollution or contaminants?

2e. Did you see any natural or manmade features that might clean the water before it enters the river or estuary?

Student Worksheet
Part 3 — Water Quality at the Mouth of a Watershed

In this activity, you will make predictions about how a major storm might affect water quality in San Francisco Estuary, specifically at China Camp State Park in San Rafael, CA. Imagine the following: A major storm dumps several inches of rain across the watershed of the San Francisco Estuary. Regional flooding occurs along rivers flowing into the estuary and the runoff increases the volume of fresh water running into the estuary.

3a. Predict how this major rainfall event would affect these water quality factors in the estuary (i.e. would they increase, decrease, or stay the same) and briefly explain your reasoning:

	Increase, Decrease, Same	Patterns/Changes
Water Temperature		
pH		
Dissolved Oxygen		
Salinity		
Turbidity		

3b. Consult the *Student Data Sheet 2, Part 3: Water Quality Data*. These are graphs of real data collected by automated instrument. Familiarize yourself with the graphs; they show water-quality data from before, during, and after a major rain storm. Can you determine from looking at the graphs when the storm started? What evidence did you use to determine when it occurred?

Part 3 — Water Quality at the Mouth of a Watershed (continued)

3c. Look at the graphs again and record what happened to each of the water quality parameters in response to the storm. Did the parameter increase, decrease or stay the same? Describe patterns or changes you notice.

	Increase, Decrease, Same	Patterns/Changes
Water Temperature		
pH		
Dissolved Oxygen		
Salinity		
Turbidity		

3d. How well did your predictions match what actually happened during the storm event? For any predictions that didn't match, explain why your original reasoning may or may not have been correct.

Student Data Sheet - 1
Part 1: Exploring the San Francisco Watershed

Student Data Sheet 1:
Oblique View

Figure 5. An oblique view of the San Francisco Bay area showing the outer margins of the large watershed drained by the San Joaquin and Sacramento Rivers. The Sierra Nevada Mountains are on the top right edge of the image. The vertical scale has been exaggerated by a factor of 5.

Student Data Sheet 1:
Optional Resource: Road Map

Figure 6. Road map of the San Francisco Bay area

Student Data Sheet 1:
Optional Resource: Satellite View

Figure 7. A satellite view of the San Francisco Estuary.

Student Data Sheet 1:
Optional Resource: San Francisco Estuary

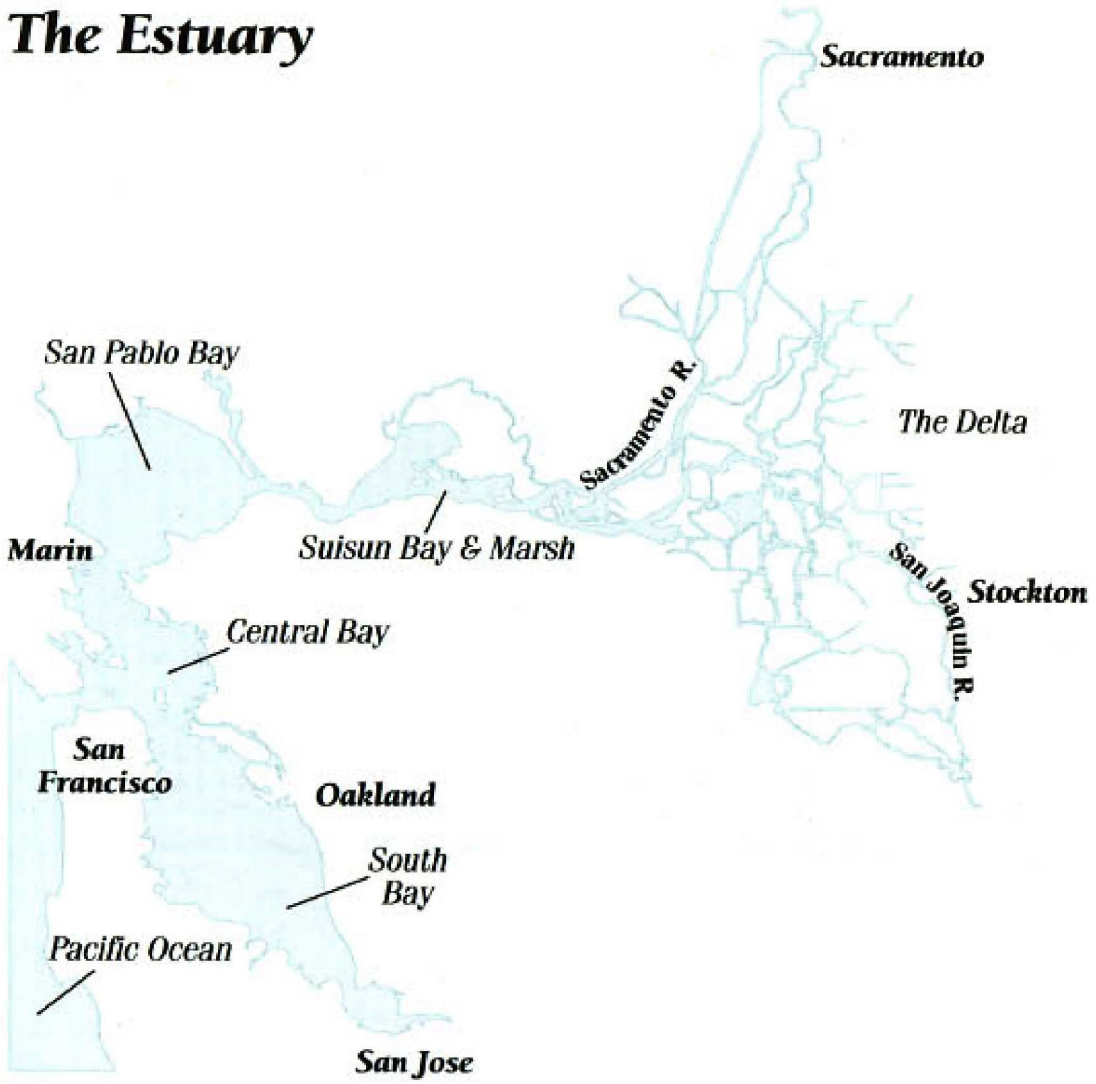
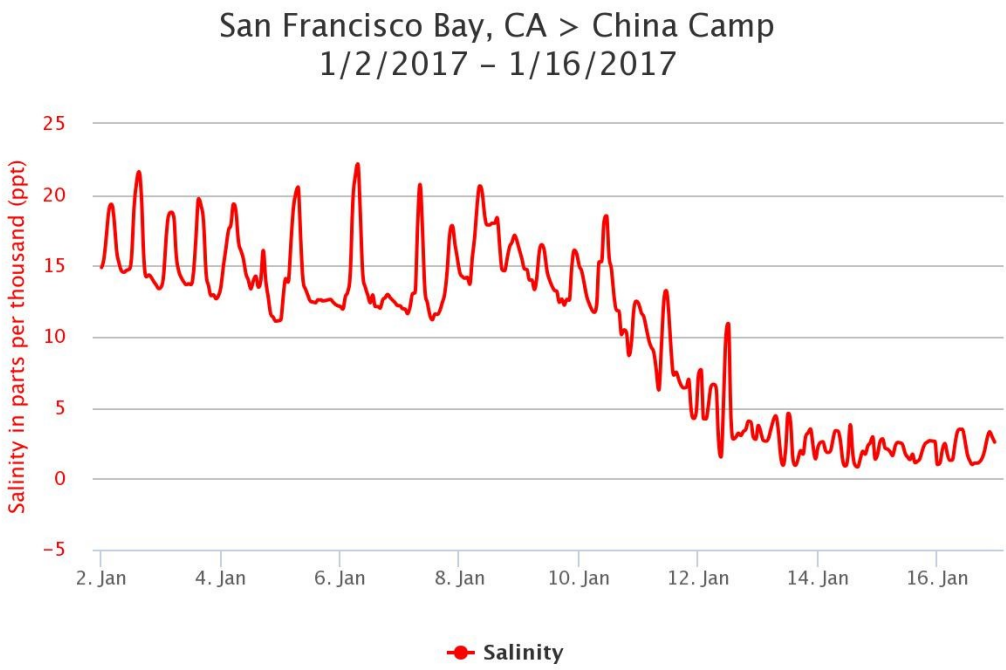


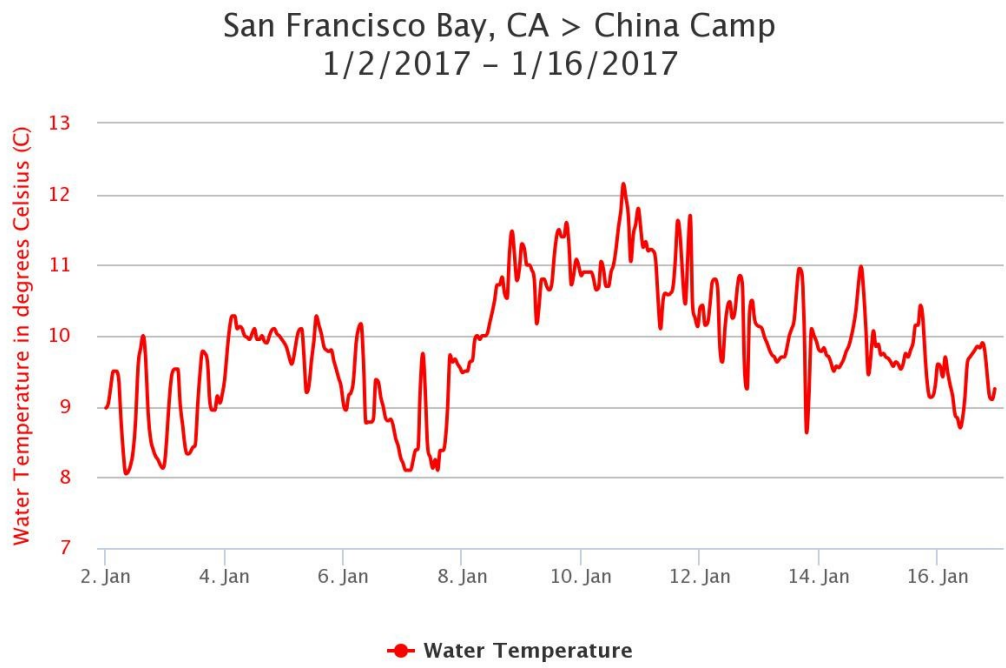
Figure 8. The San Francisco estuary has many parts.

Student Data Sheet - 2
Part 3: Water Quality at the Mouth of the Watershed

China Camp State Park, San Francisco Estuary

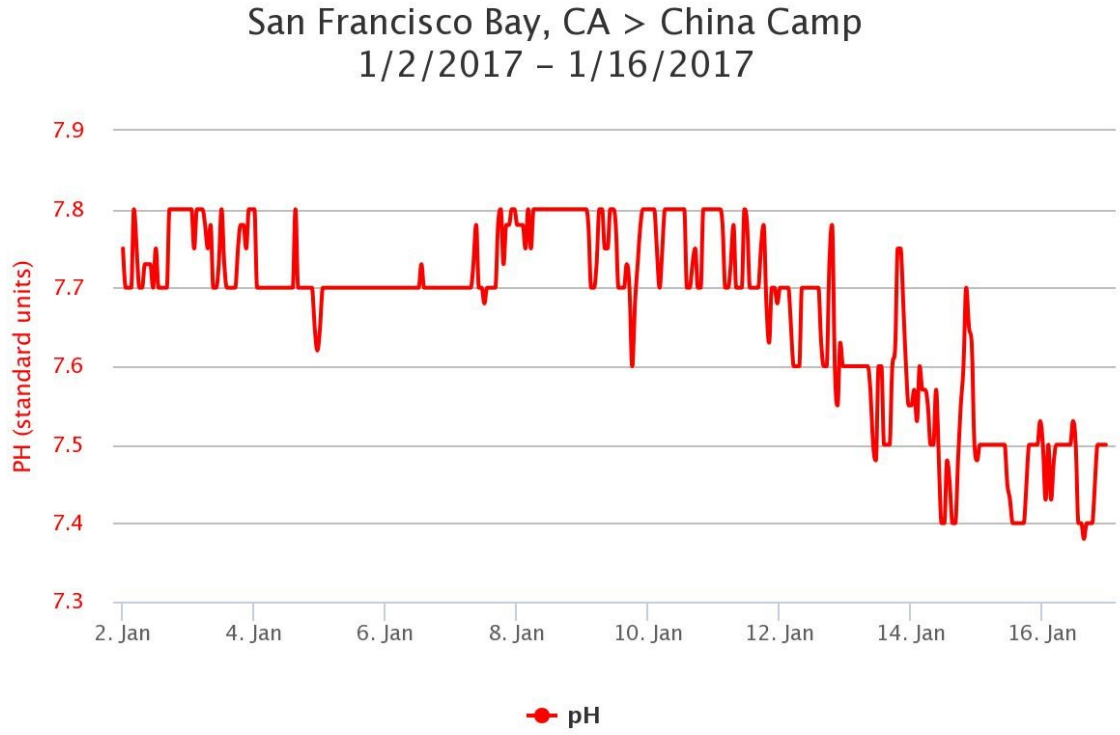
All data are from the NERRS System-wide Monitoring Program San Francisco Bay—China Camp water-quality station. Data available online at: https://coast.noaa.gov/estuaries/science-data/.

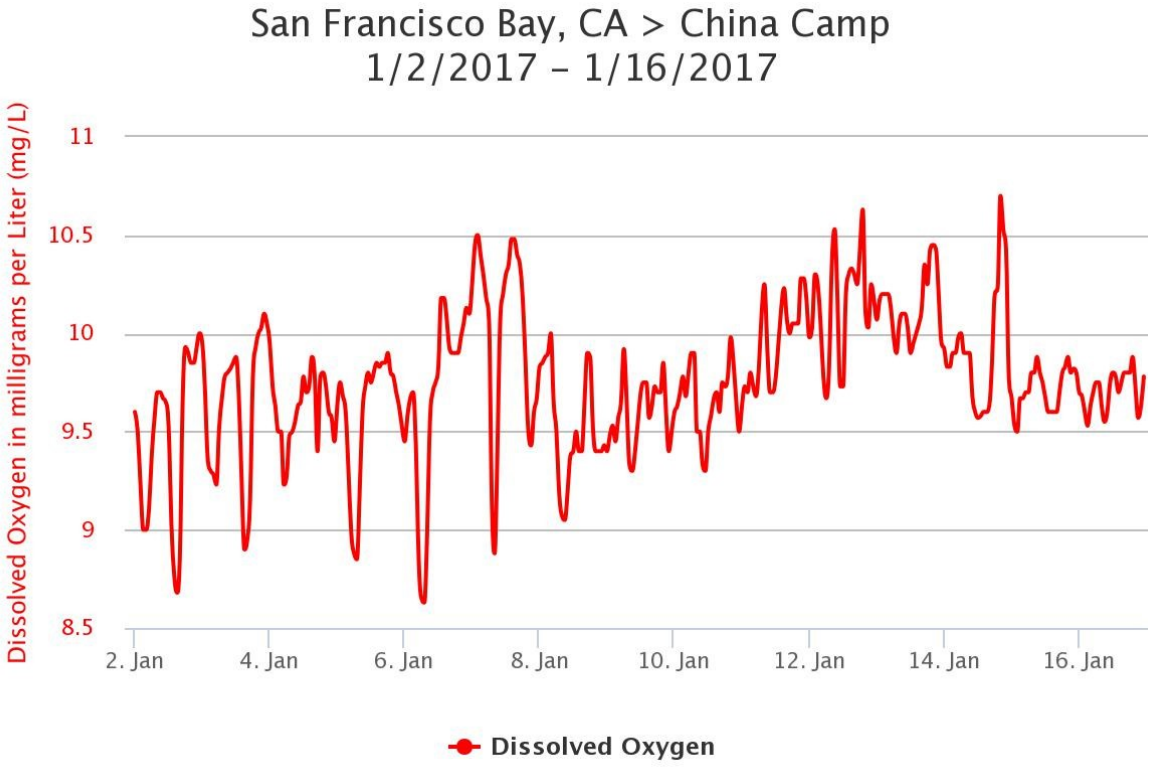




Student Data Sheet - 2

Part 3: Water Quality at the Mouth of the Watershed (continued)





Student Data Sheet - 2

Part 3: Water Quality at the Mouth of the Watershed (continued)