Student Reading—1
Activity 2: Introduction to the Narragansett Bay National Estuarine Research Reserve

The Narragansett Bay National Estuarine Research Reserve (NBNERR) is located in the geographic center of Narragansett Bay. The Narragansett Bay watershed drains over 1600 square miles of land and over 60% of the watershed is in Massachusetts. The Bay's watershed is heavily populated and urbanized. Rivers and streams in the watershed feed about 2 billion gallons of fresh water into Narragansett Bay every day. To get a sense of how much water that is think about this; two billion minutes is about 3,800 years!

The Narragansett Bay Research Reserve encompasses roughly 4,400 acres of land and water out to a depth of 18 feet on Prudence, Patience, Hope and Dyer Islands located in the center of Narragansett Bay. Prudence Island is the Reserve's biggest island and is home to the Reserve's headquarters. Approximately 80% of Prudence Island is held in conservation thanks to the Reserve and other local conservation groups. The only way to get out to Prudence Island is by boat, and a ferry runs back and forth to the island each day. Only about 150 people choose to live out on Prudence Island year round. They have to rely on the ferry for everything, even getting groceries and supplies back to their homes in the winter. It is a tough way of life, so not many people spend the whole year on the island. In the summer the island becomes a popular vacation destination and as many as 3000 people might be on Prudence during a weekend in the summer.

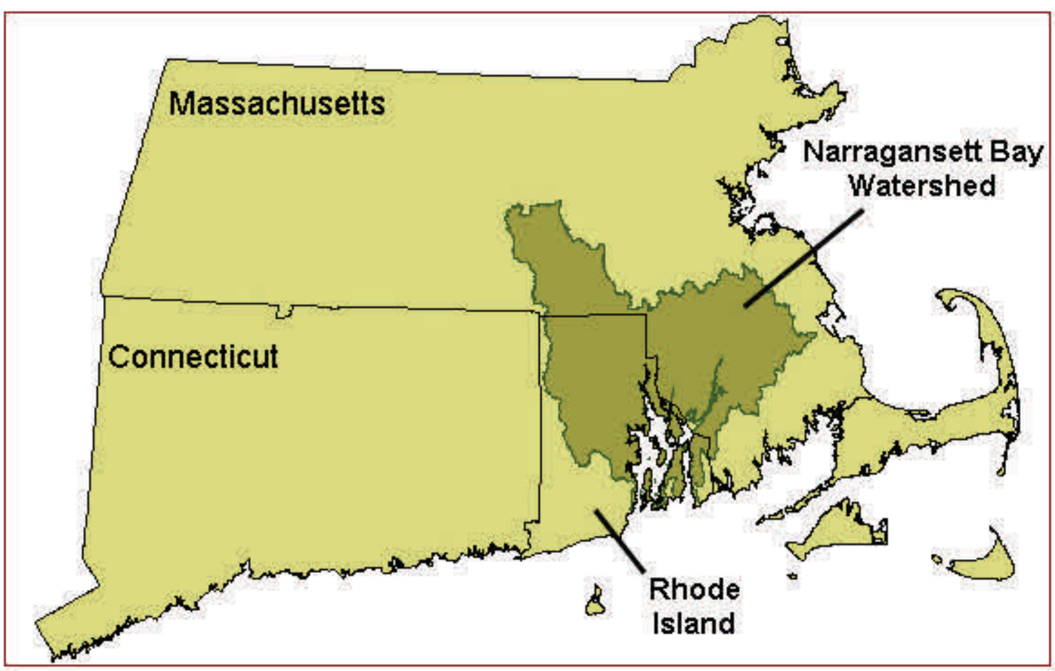

Figure 1 . The ~1600 square mile Narragansett Bay watershed extends up into the State of Massachusetts.

Figure 2 . Prudence, Patience, Hope, and Dyer Islands
make up the Narragansett Bay Research Reserve in the center of Narragansett Bay.

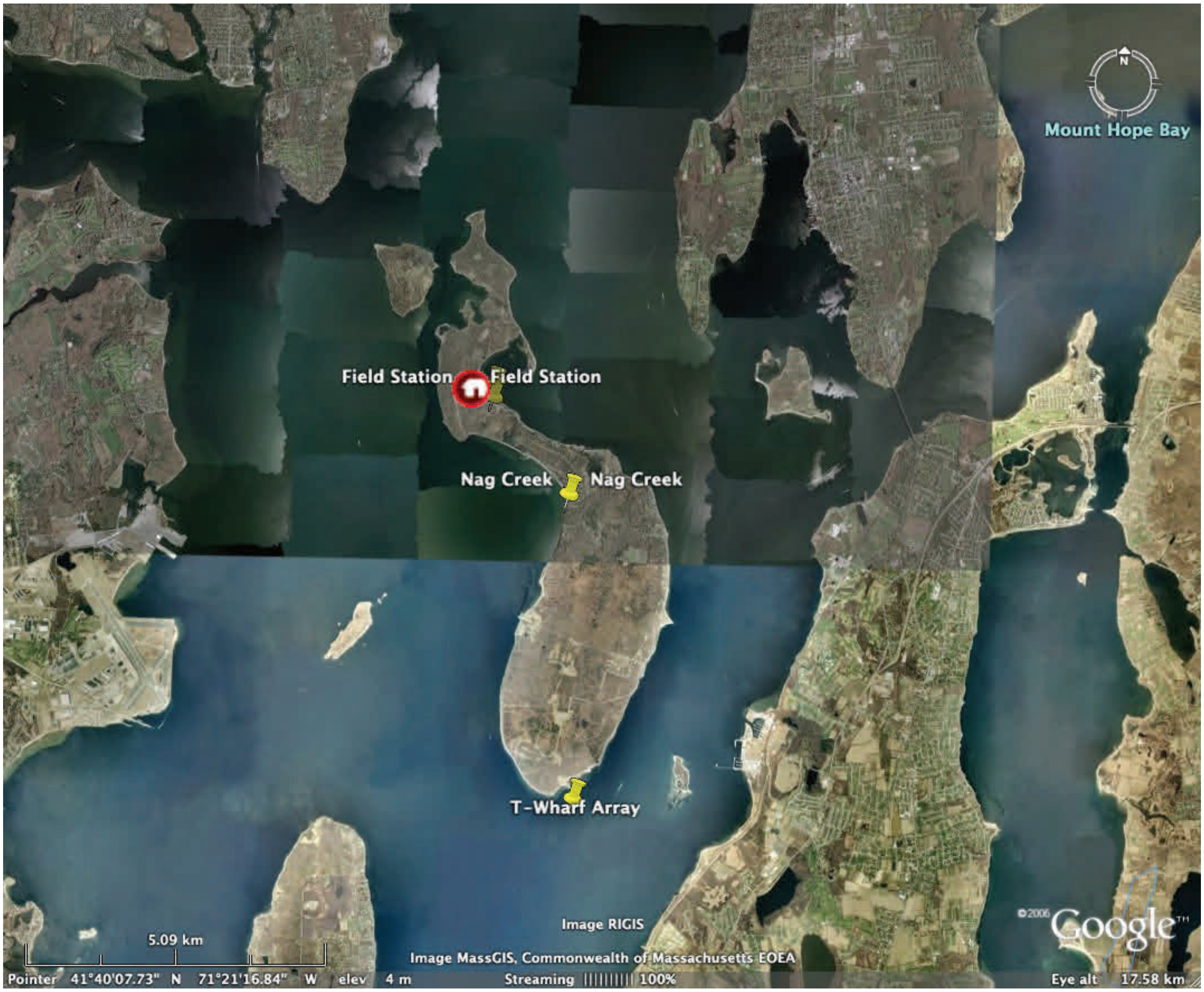

Figure 3 . You will use field and monitoring station data from the sites seen in this satellite view.

Student Reading – 2
Activity 2: Dissolved Oxygen in an Estuary

Dissolved Oxygen in an Estuary

Aerobic aquatic organisms such as zooplankton, invertebrates and fish require sufficient levels of dissolved oxygen (DO) to survive. The amount of DO in the water is a factor in determining the species and abundance of organisms that can live in an estuary.

Oxygen is supplied to estuarine waters through two natural processes: (a) diffusion of atmospheric oxygen into the water and (b) photosynthesis by phytoplankton, aquatic seaweeds and seagrasses. Mixing of surface waters by wind and waves also increases the rate of absorption of atmospheric oxygen into the water.

Levels of DO are influenced by temperature and salinity. The solubility of oxygen, or its ability to dissolve in water, decreases with increasing temperature and/or increasing salinity. DO levels in an estuary vary seasonally, with the lowest levels occurring during the late summer months when temperatures climb to their highest levels of the year.

Oxygen is removed from the water by aerobic respiration and bacterial decomposition. **Respiration** is a process in which animals and plants take up oxygen from the water and produce carbon dioxide.

Respiration is the release of energy from food in the presence of oxygen. Like photosynthesis, it is a sequence of chemical reactions that can be summarized in a shorthand chemical equation:

$$\underset{\text{sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{O_2} \longrightarrow \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \underset{\text{ATP and Heat}}{\text{Energy}}$$

Respiration occurs all the time, while photosynthetic production of oxygen by plants occurs only during daylight hours. As a result, dissolved oxygen levels in an estuary may vary widely because of differences in the amount of oxygen produced by plants. Bacteria, fungi, and other organisms affect DO levels in an estuary because they consume oxygen while breaking down organic matter produced in the estuary or delivered from the uplands by stream flow and runoff. These decomposers consume oxygen in the process of gaining energy through the breaking of chemical bonds in organic matter.

Oxygen depletion may occur in an estuary when many plants die and decompose, or when runoff or poorly treated wastewater containing large amounts of organic matter enters the estuary. In some estuaries, large nutrient inputs, normally from sewage inputs, stimulate phytoplankton blooms. When these organisms die, their bodies fall to the bottom of the estuary and begin to decompose. The decomposition process depletes the surrounding water of oxygen and, in severe cases, may lead to **anoxic** (very low oxygen) conditions that kill bottom-dwelling organisms. Shallow, well-mixed estuaries are less susceptible to this phenomenon because wave action and circulation patterns can easily supply the waters with oxygen.

Dissolved Oxygen and Life

All life in an estuary depends on oxygen in sufficient amounts. DO can increase and decrease suddenly, causing a struggle for survival for many animal and plant species.

Cold water can hold more dissolved oxygen than warm water and fresh water can hold more dissolved oxygen than salt water. So the warmer and saltier the water, the less dissolved oxygen there can be. The maximum amount of dissolved oxygen that the water can hold is called the saturation value. Dissolved oxygen measurements are given as a percent of saturation (%) or in units of milligrams per liter (mg/l).

If you consider the equation for **photosynthesis**, you can see why an explosion of plant growth (see algal blooms below) can cause water to become over saturated with oxygen. A huge amount of plant growth releases so much oxygen that the water becomes supersaturated (120%).

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} \xrightarrow{\text{sunlight}} \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

When the opposite is true, when water has very low levels of oxygen, the condition is called **hypoxia**. DO levels of less than 28% saturation or concentrations between .5 and 2 mg/L are considered lethal to most aquatic life. Hypoxia is often caused by excessive growth of algae, called "algal blooms." Although these blooms may result from natural conditions, they are also linked to excess nutrients that enter estuaries from human sources, such as: point source discharges from sewage and industry and septic tanks; wastewater treatment plants; exhaust from cars; emissions from industry; fertilizers from lawns, golf courses and farms, as well as from animal waste. These nutrients enter estuaries directly from point sources or they are transported to estuaries by stream flows, rain, leaching, groundwater, and storm water. The influx of high nutrient levels causes excessive growth of algae. When algae dies, it sinks to the bottom, where it is decomposed by bacteria in the sediments.

This process removes oxygen from the water. As bacteria decompose more algae, more oxygen is consumed. If too much oxygen is removed from deep waters, the small organisms that fish and crabs eat die off. Fish and other predators may die themselves or move to other areas in search of more oxygen. **Anoxia** refers to water that has been completely depleted of oxygen. Large areas of estuaries where organisms have died off or left for lack of sufficient oxygen are called **dead zones**. Some estuaries experience dead zones regularly. Weak tidal flushing, shallow water depth, and stratification between warmer surface water and colder bottom water may also lower DO concentrations. All of these conditions exist in Azevedo Pond.

Algal blooms can be detected by measurements of chlorophyll-a. Chlorophyll-a is a pigment in phytoplankton that is involved in photosynthesis. Concentrations of chlorophyll-a are measures of phytoplankton abundance. Concentrations measured are measured in units of μ/L. The presence of chlorophyll-a indicates an abundance of algae, which initially increases levels of DO. But eventually the algae decay, driving DO levels down again.

Some estuaries, like Azevedo Pond, have extreme fluctuations in dissolved oxygen from day to night regularly.

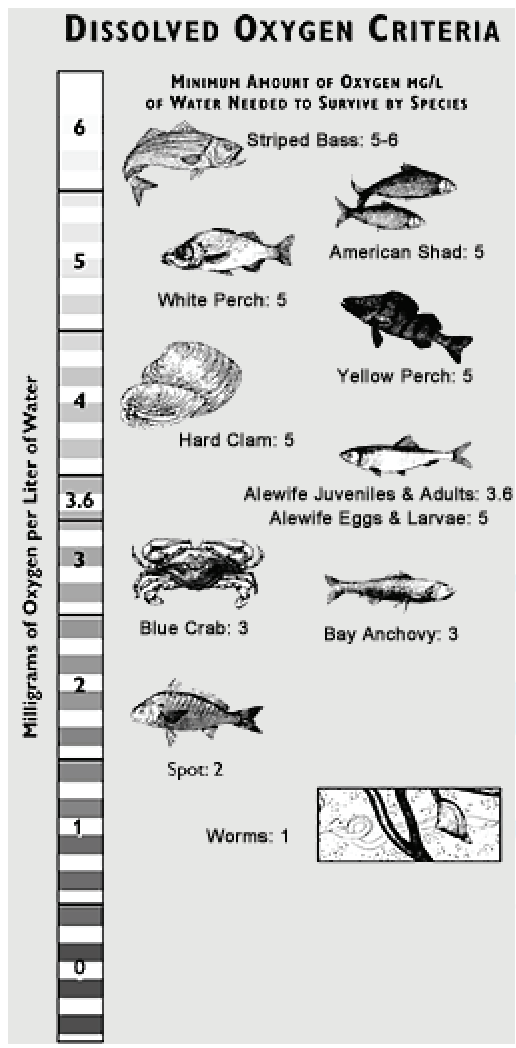

Figure 4. Minimum amount of DO needed for species to survive.
(Credit: Chesapeake Bay Program. URL:http://www.chesapeakebay.net/dissolvedoxygen.aspx?menuitem=14654. Accessed: 2008-08-06.

These estuaries may go through weeks of daily cycles that are marked by supersaturation in the day and hypoxia at night. Supersaturation can occur during the daytime when algae on the surface photosynthesizes, producing an over-abundance of oxygen. This supersaturation of DO during daylight can be followed by hypoxia during the night. In darkness, phytoplankton and plants no longer have the light they need to photosynthesize, but they do continue the process of respiration, which consumes oxygen.

- Adapted from the National Estuarine Research Reserve System website. URL:http://www.nerrs.noaa.gov/Monitoring/WaterOxygen.html. Accessed: 2008-08-08. (Archived by WebCite® at http://www.webcitation.org/5Zv9dN1Z6)

Student Worksheet—1

Activity 2: Dissolved Oxygen in Narragansett Bay

Student Name: ____

1. Open the Web site: <http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm>.

2. Read the description for Pomham Rocks.

3. Click on the star labeled Pomham Rocks and then click on "Go to Water Reading Sensors."

4. Record DO Saturation, DO Concentration, Water Temperature, and Chlorophyll at each depth for Pomham Rocks.

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)

5. Repeat these steps for the South Prudence site.

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)

6. Examine your data for patterns and relationships.

7. Compare the graphs of DO Concentration and Temperature in 2006 near South Prudence, RI.

8. Use your tables and these graphs to answer the Questions.

Figure 5. Daily DO: Narragansett Bay NERR

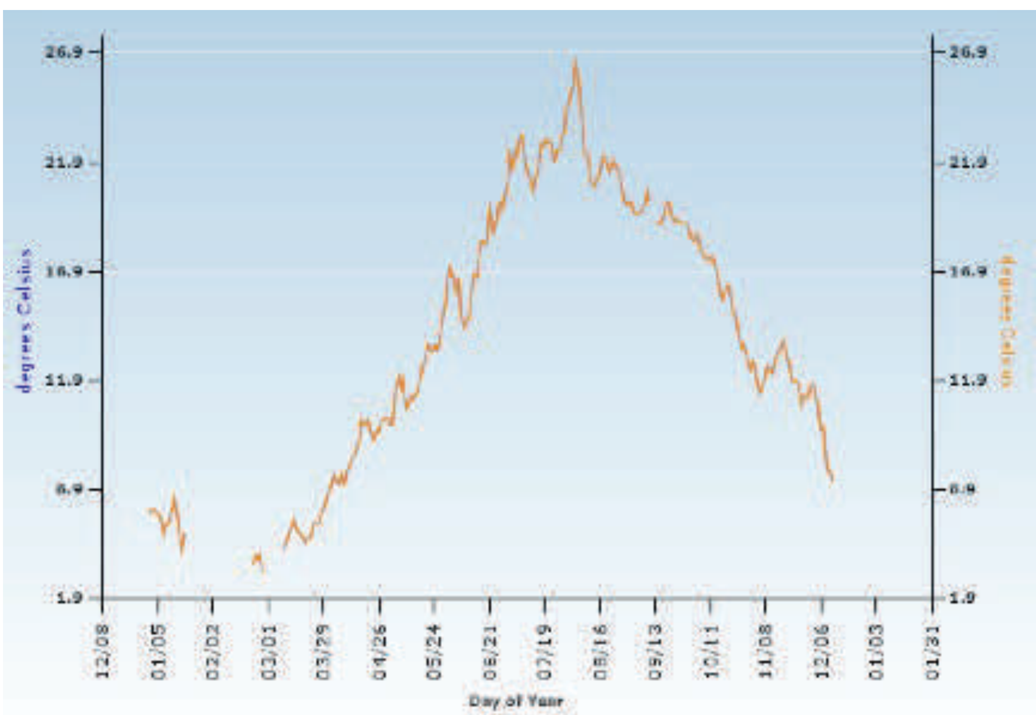

Figure 6. Daily Temperature: Narragansett Bay NERR

Questions

1a. Why might there be differences in DO concentration at two different locations, at the same depth, within the same estuary?

1b. As depth increases, how does

- DO concentration change?

- DO saturation?

- The temperature of the water?

- Chlorophyll amounts?

1c. During which months in 2006 does DO concentration reach its lowest extremes in this estuary?

1d. What are the approximate dates for the three highest recordings of DO concentration as presented on the graph? What is the water temperature on those dates? Record your data in the table below.

Date	**DO Concentration (mg/L)**	**Water Temperature (degrees C)**

1e. What are the approximate dates for the three lowest recordings of DO concentration as presented on the graph? What is the water temperature on those dates? Record your data in the table below.

Date	**DO concentration (mg/L)**	**Water Temperature (degrees C)**

1f. What is the relationship between DO concentration and temperature?

Student Reading – 3
Activity 2: Introduction to Azevedo Pond

Azevedo Pond is a small tidal pond located along the shore in the northern part of the Elkhorn Slough National Estuarine Research Reserve in California. Elkhorn Slough is one of the relatively few coastal wetlands remaining in California. The main channel of the slough, which winds inland nearly seven miles, is flanked by a broad salt marsh.

The reserve lands also include oak woodlands, grasslands and freshwater ponds that provide essential coastal habitats that support a great diversity of native organisms and migratory animals.

More than 400 species of invertebrates, 80 species of fish and 200 species of birds have been identified in Elkhorn Slough. The channels and tidal creeks of the slough are nurseries for many species of fish.

Figure 7. A satellite view of Elkhorn Slough NERR and Azevedo Pond

Azevedo Pond is characterized by:

- Restricted water flow: It has only a partial tidal connection to the estuary, so water in the pond does not get flushed out well and often remains in the pond for a long time.
- Azevedo Pond is only flushed with Upper Elkhorn Slough water when the tide height is greater than 1.2 m. The lack of tidal flushing means that the water can get separated into distinct warmer and cooler layers .
- The pond is surrounded by a strawberry farm. The only groundwater and surface runoff input the pond receives is from the strawberry farm during rainfall.
- Shallow depth: It is less than 1.5 m deep.
- High productivity by phytoplankton.
- Large daily temperature changes that occur periodically.
- The pond produces thick mats of algae during the summer and fall months.

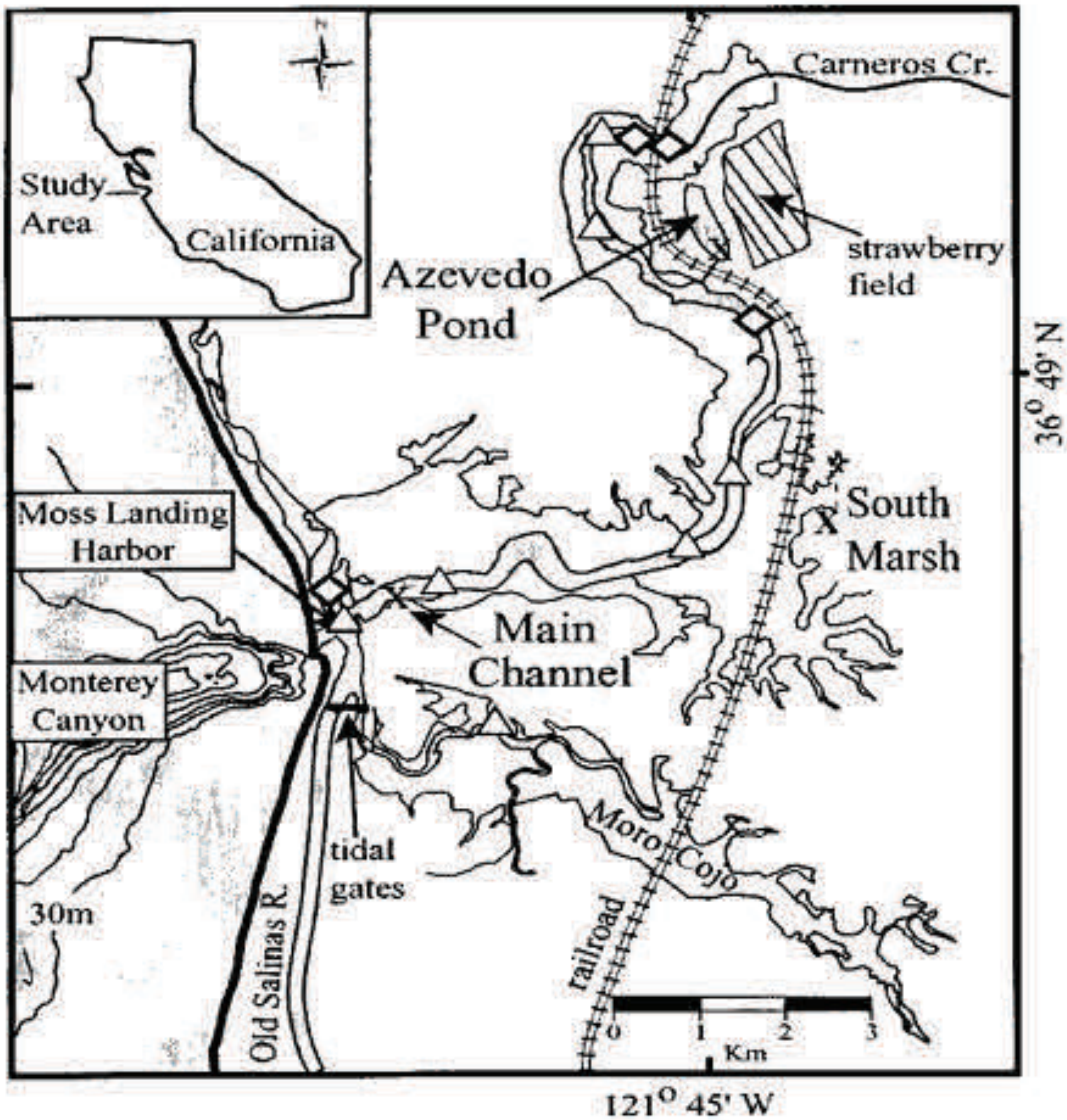

Figure 8. Map of Azevedo Pond and the Surrounding Area

Student Worksheet
Activity 2: Dissolved Oxygen in Azevedo Pond

Student Name: ____

1. What are the features of Azevedo Pond that could affect dissolved oxygen? List them in the chart below and explain how they could affect dissolved oxygen.

Feature	Affect on Dissolved Oxygen
Shallow	
Restricted water flow	
High productivity of plankton	
Large changes in temperature	
Bordered by strawberry farm	
Lack of tidal flushing	

2. Look at the graph of DO Saturation and PAR (photosynthetically available radiation—a synonym of visible light) for Azevedo Pond during the week of April 9-16, 2007.

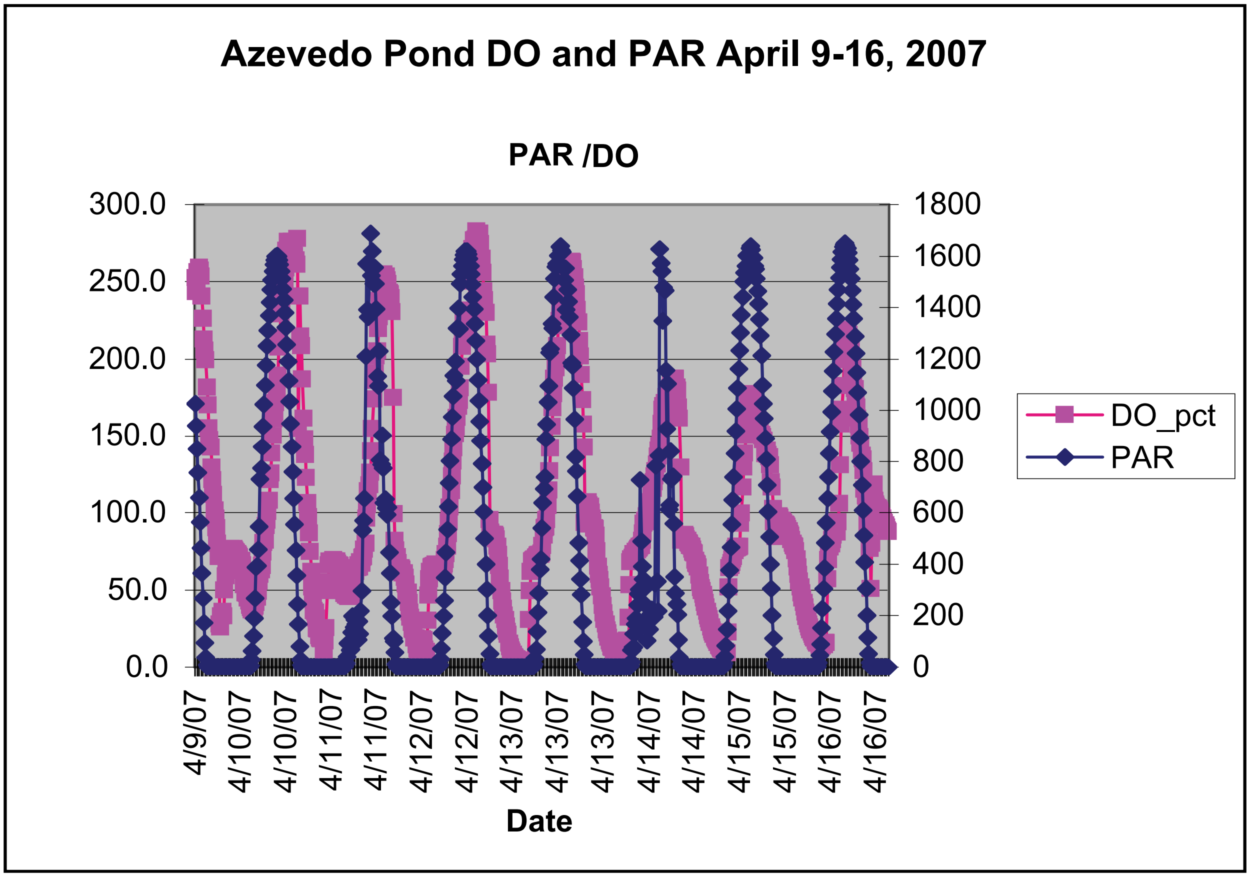

Figure 9. Azevedo Pond Dissolved Oxygen and Photosynthetically Available Radiation, April 9-16, 2007

2a. What is the range of DO (dotted-line) for this period?

2b. Describe the pattern you see from day to day between DO and PAR.

2c. How does PAR change in relation to DO percentage from day to day?

2d. Why do you think DO percentage and PAR vary like this in Azevedo Pond during April 2007. Try to explain in terms of photosynthesis, respiration and the features of the pond that affect dissolved oxygen.

Look at the graph of Elkhorn Slough that shows the frequency of hypoxic events (what percent of the year) in Azevedo Pond and three other sites within the Slough. (Note: Hypoxia is defined as a DO saturation level of less than 28%.)

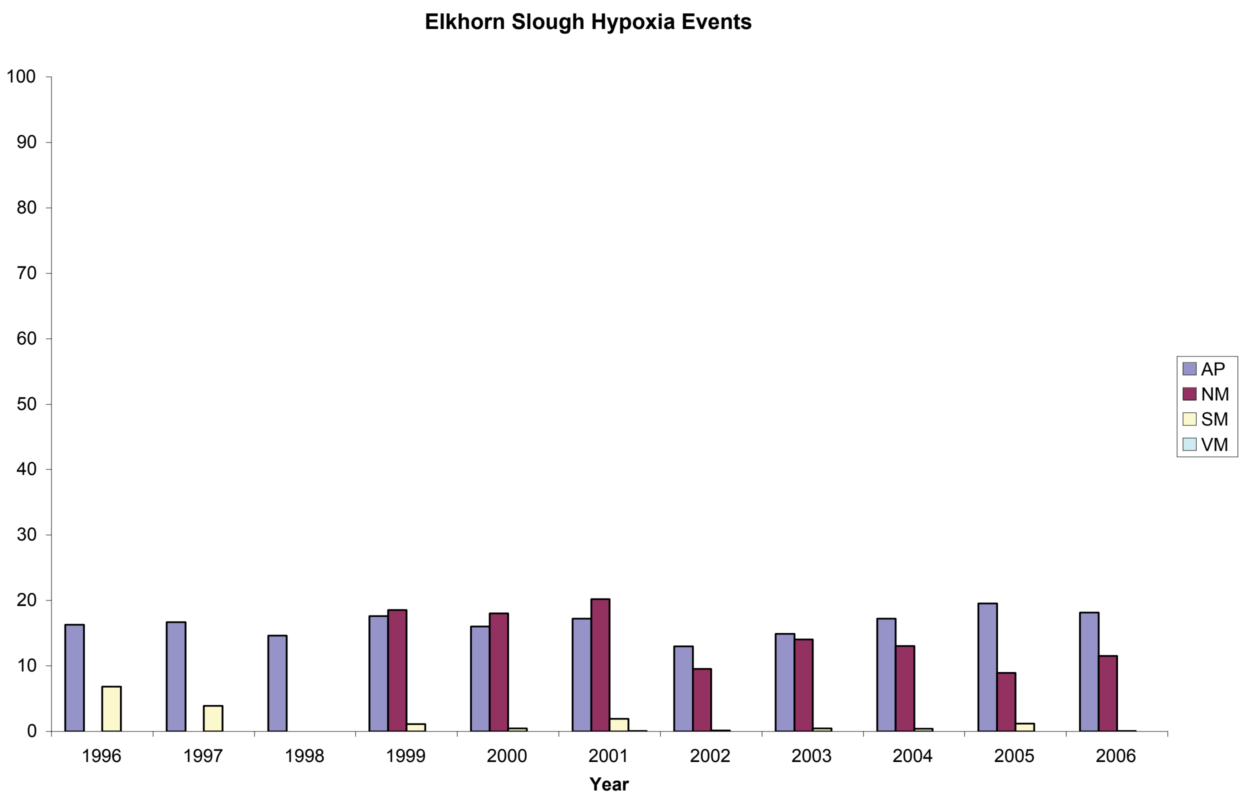

Figure 10 — Frequency of Anoxia in Azevedo Pond (first column in each series) compared to three other sites in Elkhorn Slough

3. What percent of each year has Azevedo Pond had hypoxic conditions? How does this compare with other sites?