Teacher's Guide

A Curriculum for Grade Levels 9-12

The Estuaries 101 Curriculum was produced for the National Oceanic & Atmospheric Administration (NOAA) and the National Estuarine Research Reserve System (NERR) by TERC.

To download the Estuaries 101 Curriculum and access other supporting materials, visit http://www.estuaries.gov

Teacher's Guide

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Foreword

Everyone loves the ocean, and most people know the ocean through their experiences at the shore, often in an estuary. A sunbather on a barrier beach, the captain of a cargo vessel maneuvering to offload freight in a seaport harbor, an artist painting a scenic salt marsh, shellfishers probing a mud flat, a family in a coastal city strolling along the waterfront, and a couple of kids out for a day sail in a protected coastal bay all depend on estuaries for their activities, yet few can even define the word if asked. Furthermore, human activities such as filling wetlands, armoring the shoreline, and discharging wastewater have seriously impacted the integrity of coastal ecosystems. When asked in a survey about the health of coastal waters, over a quarter of the public reported that they do not know enough about these areas to give an opinion (Belden et al., 1999). Though the public is aware of ocean and coastal resources, detailed knowledge of environmental science, ocean and coastal science, and the ocean's connection to humans' well-being is lacking (NEETF, 2005 and Belden et al., 1999). People need to know what estuaries are, how they are related to terrestrial and ocean systems, what important services they provide for humans, and how to restore and protect them.

In response to this challenge, we, in NOAA's National Estuarine Research Reserve System (NERRS), recognized an opportunity to build a national program that would help advance ocean and estuarine literacy, building on and integrating educational and scientific resources across the full NERRS system. Instead of a collection of locally-developed activities, we have worked to create a comprehensive national program, for use by all the NERRS education coordinators, as well as, students and teachers throughout the US. This integrated program was conceived and planned by all NERRS educators and built to meet the best pedagogical designs. Envisioned ultimately as a full K–12 set of activities, development begun with a high school set of modules that we called "Estuaries 101".

It is thus our pleasure to introduce the Estuaries 101 Curriculum. Focusing on estuaries, the curriculum modules feature hands-on learning, experiments, field work and data explorations. The curriculum consists of four modules, Life Science, Earth Science & Physical Science each using estuaries as the context for developing content knowledge and skills relevant to that domain, and a Chesapeake Bay Module which integrates and deepens the focus on estuarine concepts in a local context.

The Estuaries 101 Curriculum is comprised of four two-three week modules on estuaries. Designed for 9th–12th grade classrooms – with the flexibility to adapt to higher or lower grades – it covers key National Science Education Standards for Physical Science (Transfer of Energy and Properties, Changes in Matter), Earth Science (Structure of the Earth System), and Life Science (Interdependence of Organisms, Matter, Energy, and Organization in Living Systems).

While this version of the Estuaries 101 Curriculum, for grade level 9-12, is now available for distribution, we wish to remind all educators that curriculum design and review is a continuous, cyclic process. We wish to have a product that is truly effective for educators to implement in their classrooms. But to do so, we will evaluate it's effectiveness and continue to invite educators to provide us with feedback.

Many thanks go to all who have contributed to the development of the Estuaries 101 Curriculum: teachers, principals, parents, employer representatives, TERC staff, and to a very talented group of NERRS education coordinators. TERC, an educational non-profit with over 40 years of experience in science, math, technology, and engineering education, was the main partner in drafting and developing all the activities that form part of the Estuaries 101 Curriculum.

Our next steps? Building on this framework to offer our young people the most effective and meaningful teaching possible that will enable them in the future to make sound informed decisions about our estuaries and coasts.

Purpose & Goal

With the many threats that our nation's oceans face, it is time for a new era of ocean literacy and enhanced efforts to prepare today's children to be tomorrow's ocean stewards. Estuaries are an ideal topic to excite students about studying the ocean because of the strong personal connections people have with estuaries—from treasured recreation experiences, scenic views during transits, to making a living on the water. Advancing estuarine, coastal, and ocean literacy is a priority of NOAA's National Estuarine Research Reserve System (NERRS). It is our expectation that, through the Estuaries 101 Curriculum, students and teachers will gain an understanding of the great importance of estuaries and the intricate connections it has with the ocean and climate systems.

The goal of Estuaries 101 is for students and teachers throughout the nation to become more ocean literate through increasing their knowledge of coastal and estuarine science and how estuaries affect their daily lives. To achieve this increased literacy, teachers will use this estuaries.gov site to access the modules and activities for grades 9-12 and an online interface to real-time and archived estuarine monitoring data (from NERRS' System Wide Monitoring Program). Use of the Estuaries 101 Curriculum will be encouraged and supported through professional development trainings hosted at 27 Reserves and at professional meetings across the nation.

Using the Estuaries 101 curriculum, teachers will be able to teach their students about Earth System Science using coastal and ocean data. Through this curriculum—which includes interactive investigations, field studies, and data analysis—teachers and students will learn that estuaries provide shelter, spawning grounds, and food for many species, that they act as buffers to improve water quality, reduce the effects of floodwaters, and prevent erosion, and that coastal areas provide value to humans in the form of recreation, scientific knowledge, aesthetics, commercial and recreational fishing, and transportation (Thayer et al., 2003).

Why teach about estuaries?

Estuaries offer a wonderfully rich context for science education and inter-disciplinary learning. Estuaries are dynamic environments with a daily flux of ocean flows mingling with river water, creating a remarkably diverse range of life and ecosystems. As a result, they offer learners a convergence of such fields as Earth systems science, biology, chemistry, geography, geology and marine science. For example, students develop math skills through detailed measurements, modeling phenomena such as growth and cyclical variation, and analyzing data to make comparisons across multiple estuaries. They develop language skills as they read and write about estuary-related topics and communicate their explorations and findings with other students and scientists. Since estuaries have also played a significant role in human settlement, exploration and development, students gain new eyes on human history, geography and culture.

Most estuarine concepts and skills are part of the national and state science standards. Although "estuaries" per se may not appear prominently in many state standards, the underlying science concepts embodied in estuaries have broad connections throughout the standards. For example, most state science education standards refer to understanding "Earth as a system", with interwoven cycles and processes relating to land, air and water. Estuaries provide engaging and accessible examples of these processes at work. Estuaries also integrate key concepts in biology (e.g. habitat adaptations), chemistry (e.g. salinity analysis) and physics (e.g. wave motions). Furthermore, most state standards call for inquiry-based learning through hands-on experiments, direct observations and active use of data - all of which occur as students engage with estuaries.

In addition, while learning interdisciplinary skills using estuaries, students gain an appreciation for the importance of estuaries in their lives and learn how their behavior impacts coastal ecosystems. We believe that it is of utmost importance to prepare tomorrow's leaders to make sound decisions about the environment and the nation's oceans and coasts. Students must understand the crucial connection between estuaries, coastal, and upland areas, and the effects of a growing population.

Components of the Curriculum

About Estuaries 101

Recognizing the incredible power of estuaries to provide a rich environment for learning, exploration, and discovery, NOAA and TERC developed *Estuaries 101*—a series of three Modules: Life Science, Earth Science, and Physical Science—addressing different aspects of the estuary environment. You can do any or all of the Modules, which consist of a series of activities and a final assessment.

* The activities in the Estuaries 101 Modules have been field tested and found to be very engaging and popular with both teachers and students.

* They are inquiry-based, conveying both content knowledge and scientific thinking and problem solving skills.

* They are aligned with the National Science Education Standards and to some State Standards. Please check the estuaries.gov site to find new alignments to other State Standards.

* They are also based upon core principles and concepts identified by the National Estuarine Research Reserve System (NERRS) educators—key principles and concepts about estuaries that students need to master in order to become estuarine literate.

* They are grounded in specific estuaries within the NERR system, though you should feel free to adapt the activities for an estuary near your school or ones in parts of the world appropriate to your classroom and curriculum. (See the *About the Modules* section of this guide and each activity for specifics.)

* A number of the activities make use of Google Earth as a means of providing context to the students' investigations and offering virtual field experiences. A support guide on using Google Earth as part of the Estuaries 101 curriculum is available online and details related to exploring specific estuaries are included in the activities that use Google Earth. (See *Using Google Earth to Explore Estuaries*, available on the estuaries.gov site, and each activity.)

* And the activities all follow the same basic structure:
    - Teacher Guide, including an introduction and overview, learning goals and standards-matching, background information, materials and preparations, procedures, assessments, and extensions
    - Teacher Answer Key
    - Student Reading(s)
    - Student Sheet(s)
    - Student Data Sheet(s)

Finally, each Module concludes with an assessment piece, designed for use after completion of all the activities within that Module. These assessments, which overarch all the activities within a Module, provide a means for both grading, as appropriate, and checking in with student advances in understanding. Also, within each activity, there are opportunities for formative assessment.

About the Modules

Each Module tells the estuary story through one of three perspectives—through Earth, life, or physical science. With theses emphases on specific domains, each Module will appeal to different teachers, to be used together or separately.

Earth Science Module

Students investigate landforms and features associated with estuaries, tides and salinity in estuaries, watersheds and their relationship to the dynamic changes that occur in estuaries due to drainage and runoff, and how hurricanes can affect estuaries.

- Activity 1: Observing Estuaries: A Landform and Feature Scavenger Hunt
- Activity 2: Salinity and Tides in York River
- Activity 3: Estuary and Watershed
- Activity 4: Extreme Weather and Estuaries
- Final Earth Science Module Assessment

Life Science Module

Students investigate the range of conditions that selected animal and plant species need to survive in an estuary, model estuaries, consider algae blooms in estuaries, study how nutrients cycle through an estuary, suggest recommendations for reducing nutrient inputs to estuary waters, and investigate the incredible biodiversity that exists in estuarine environments.

- Activity 1: Survival in the Estuary
- Activity 2: Nutrients in an Estuary
- Activity 3: Biodiversity in an Estuary
- Final Life Science Module Assessment

Physical Science

Students investigate water quality parameters to study the nature of, and the cyclical changes inherent in, the chemistry of estuarine water, learn about dissolved oxygen and its effects on life, with a focus on the chemistry, model a pollution spill that occurred at Bangs Lake (a tidal lake within the Grand Bay NERR), and study the actual spill and how it changed water quality parameters in the estuary.

- Activity 1: Chemistry in an Estuary
- Activity 2: Dissolved Oxygen in the Estuary
- Activity 3: Human Impacts on Estuaries: A Terrible Spill in Grand Bay
- Final Physical Science Assessment

Curriculum Map—Earth Science Module

Enduring Understanding	Activities	Learning Objectives
Estuaries are unique, dynamic transition zones, between the watershed and the world ocean system. Earth processes create and determine the physical features of estuaries.	**Activity 1 — Observing Estuaries** Students investigate landforms and features associated with estuaries. They begin by taking a journey down a river to an estuary system where the river empties into the Gulf of Mexico near Weeks Bay NERR to investigate how landforms differ between uplands and riverine/ estuarine environments. Student teams then use Google Earth and other resources to engage in a scavenger hunt to locate and identify landforms and features of estuaries.	**Students will be able to:** • Describe differences between upland non-estuarine and estuarine landforms and features. • Visually identify and describe various landforms and features associated with estuarine environments, including salt marshes, barrier beaches, peninsulas, headlands, spits, mud flats, fjords, deltas, coves, harbors, sounds, and others.
Earth processes, characteristics of the watershed, and the physical features of the estuary affect patterns of mixing of fresh and salt water in an estuary.	**Activity 2 — Salinity and Tides in York River** Students observe time-lapse models of tides and salinity distribution in the York River, part of the Chesapeake Bay, VA NERR. They learn how salinity changes with an incoming and outgoing tide, observing the dynamics of the salt wedge at various sites along the river. They 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 they describe the patterns of each salinity graph and compare the graphs.	**Students will be able to:** • Analyze different forms of data and synthesize information to develop a hypothesis. • Explain how tides and the geology of the estuary affect water circulation in an estuary. • Describe daily patterns of salinity changes in the estuary.
Estuaries are part of watershed systems. The characteristics of the watershed determine some of the characteristics of the estuary.	**Activity 3 — Estuary and Watershed** Students investigate the nature of watersheds and their relationship to the dynamic changes that occur in estuaries due to drainage and runoff. They begin by examining the San Francisco Bay Estuarine Research Reserve and tracing the extent of its watershed using Google Earth. Then they identify possible sources of pollution and contamination along the major rivers that feed into the bay. Students also examine water quality data in the San Pablo region of the estuary and identify changes that occur due to a storm event.	**Students will be able to:** • Identify the processes in the watershed that affect conditions in the estuary and explain some specific examples. • Apply their understanding of changes in the watershed and the resulting effects on the estuary to explain real-life situations regarding land use and weather in watersheds. • Understand how water quality factors are affected by natural and man-made sources of pollution and contamination.
Coastal processes and interactions within the ocean system play an important role in estuarine dynamics.	**Activity 4 — Extreme Weather and Estuaries** Students investigate how hurricanes can affect NERRS estuaries. Students begin by studying the North Carolina NERR in the Cape Fear area with Google Earth and predict which areas of the reserve might be more vulnerable to the onslaught of high winds, heavy rain and storm surge than others. Then students monitor and interpret the changes in water quality factors day by day as a severe storm approaches, strikes the estuary, and then dissipates.	**Students will be able to:** • Describe the features and landforms associated with a coastal estuary. • Predict how major storm events affect NERRS reserves in the United States. • Investigate and interpret changes in water quality in an estuary due to a severe weather event. • Determine the relationship between the characteristics of an extreme weather event (heavy wind, torrential rains and storm surge) and the subsequent change in water quality over time.

Parts of the Activity	Estuary	Science Concepts	Assessment
• What is an Estuary? • A trip down the Alabama River • Estuary Landforms and Features—Scavanger Hunt	Weeks Bay NERR, Alabama	Watersheds, coastal geography, coastal circulation, coastal processes, tides	Discuss the following: • How do the terrain and types of landforms change as you travel down a river toward a source of salt water? • Which of the landforms and features on your scavenger hunt list were fairly common? • Which landforms were not present at all? Have students sketch an imaginary estuary system on a piece of paper. Direct them to draw and label as many landforms and features on their diagram as possible. Collect and evaluate them for accuracy, clarity, and the number of landforms correctly identified.
• Tides in Chesapeake Bay • Salinity as York River Flows into the Bay • Interaction of Tides and River Flow	Chesapeake Bay, VA NERR	The water cycle, salinity and density, tides, ocean currents and circulation, coastal processes	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.*
• Exploring the San Francisco Watershed • What's Upstream Comes Downstream • Water Quality at the Mouth of the Watershed • *Optional*: Mapping Your Local Watershed	San Francisco Bay NERR, California	Watersheds, water cycle, runoff, biogeochemical cycles, water pollution	1. Discuss the following: • How do agricultural areas, industrial sites, landfills, and sewage treatment plants affect water quality in a watershed? • Explain how an estuary can act as a filtration system for runoff in a watershed. 2. Supply students with a road map of the eastern U.S. and project a satellite image of the Chesapeake Bay watershed. Ask students to identify major urban areas around Chesapeake Bay and major rivers that drain the watershed. Ask students to predict where they would expect areas in the most danger of contamination and pollution if a major storm event such as a hurricane struck the region.
• Investigating an Estuary • Which NERRS are Affected by Hurricanes? • Impact of Extreme Weather on an Estuary	North Carolina NERR	Water cycle, climate change, sea level rise, ocean currents, coastal processes, food webs	Discuss the following with students: • What were the effects of a major storm event in the North Carolina NERR? • What caused the change in each of the four abiotic parameters studied in this activity? • Why is there a difference in the time it takes for the different parameters to return to normal? • What effects do you think the storm might have had on different plants and animals in the estuary?

Curriculum Map—Life Science Module

<table>
<tr><th>Enduring Understanding</th><th>Activities</th><th>Learning Objectives</th></tr>
<tr><td>Estuaries have unique communities that are adapted to variable, dynamic environment in these transition zones between watersheds and the ocean.</td><td>Activity 1 — Survival in an Estuary

Students investigate the range of conditions that selected animal and plant species need to survive in an estuary. They examine data for abiotic factors that affect life in estuaries—salinity, dissolved oxygen, temperature, and pH. Students use archived data (trend analysis graphs) and real-time conditions at Elkhorn Slough to predict whether a particular animal or plant species could survive in an estuary.</td><td>Students will be able to:
Describe three types of estuarine environments.
Describe the particular environmental conditions necessary for organisms to survive in an estuary.
List four principal abiotic factors that influence the survival of aquatic life in estuaries.
Determine the range of pH, temperature, salinity, and dissolved oxygen tolerated by some common estuarine species.</td></tr>
<tr><td>The flow of matter and energy in the estuarine ecosystem reflects the flow, mixing, and circulation of estuary waters.</td><td>Activity 2 — Nutrients in an Estuary

Students model estuaries, artificially enriching both fresh and salt water samples with different amounts of nutrients and observing the growth of algae over a several weeks. They relate their results to the phenomenon of algae blooms in estuaries. They then analyze data for different sites in a NERRS Reserve in Florida to discover the relationships between nitrogen, chlorophyll, and dissolved oxygen. Finally, they study how nutrients cycle through an estuary and suggest recommendations for reducing nutrient inputs to estuary waters.</td><td>Students will be able to:
Understand how water quality and nutrient parameters in an estuary can indicate disruptions to ecological processes in estuaries.
Interpret data from an experiment to explain the effects of over-enrichment on water quality and living things; and relate this lab experience to the phenomenon of algae blooms and eutrophication in an estuary.
Explain the phenomena of algae blooms and eutrophication in terms of total nitrogen, chlorophyll-a, and dissolved oxygen.
Describe the effects of eutrophication on the nitrogen cycle.
Explain how nutrients cycle in an estuary and how natural processes and human impacts affect this cycle.
Identify sources of nitrogen inputs to estuaries and identify some ways to limit them.</td></tr>
<tr><td>The biology of estuary species reveals their adaptations to the unique and variable estuarine habitats.</td><td>Activity 3 — Biodiversity in an Estuary

Students investigate the incredible biodiversity that exists in estuarine environments. They begin by exploring the Rookery Bay National Estuarine Research Reserve using Google Earth. Students then produce an estuary biodiversity concept map and individual organism profile that becomes part of an estuary wildlife exhibit.</td><td>Students will be able to:
Describe the physical and biological components of habitats that exist as part of an estuary.
Explain the relationships between primary producers, consumers, and secondary consumers.
Describe some adaptations of living organisms to the changing conditions within an estuary.
Explain why biodiversity is important and worth preserving in an estuary.</td></tr>
</table>

Parts of the Activity	Estuary	Science Concepts	Assessment
• The Estuarine Environment • Surviving Changes: Abiotic Factors that Affect Life • Surviving in an Estuary: Extreme Conditions • *Optional*: Investigating Other NERRS sites	Elkhorn Slough NERR, California	Adaptation, habitats, communities, abiotic vs. biotic environment, biodiversity, zonation, water cycle, coastal processes, communities, adaptation	• Direct your students to the Central Data Management Office Web site: <cdmo.baruch.sc.edu/>. Help students navigate through the site until they can successfully download trend analysis data for 2005 from one monitoring station at four other NERR sites. Encourage them to choose sites both in your region and in other parts of U.S. coastal areas. OR, download sample data from four sites and hand them out to students. • Direct students to fill out an Extreme Conditions table for each site. • Have students create graphs comparing parameter ranges and time between extremes for new sites with South Marsh data. • Discuss with students the patterns they see and ask them to explain why the ranges and rates of change for each factor vary at different estuary sites. Or ask them to write their answers down and collect student work to serve as a summative
• Nutrients in an Estuary • Using Data to Study Eutrophication and Conditions in an Estuary • Eutrophication and the Nitrogen Cycle	Guana Tolomato Matanzas NERR	Food webs, trophic interactions, biogeochemical cycles, coastal circulation, life cycles, migration	Students write a short letter to the town council of this region outlining your recommendations about steps to take to reduce the amount of nutrient flow into the estuary.
• Investigating Habitats in an Estuary • Biodiversity in an Estuary • Portrait of Life in an Estuary	Rookery Bay NERR, Florida	Adaptation, habitats, trophic interactions, cell biology concepts, physiology concepts	• Use the concept maps from Part 2 as an assessment of student understanding of the relationships between habitats, characteristics of the habitats, and the species that inhabit the estuary. • A simple way to do this is to give 1 point for each link on the concept map between two of the three variables. Then, award 2 points for each double link (two lines that reveal a relationship). Add 3 points for complex interrelationships in the concept map (3 or more lines coming from one box). Establish a class scale based on the total points given for each poster. • Evaluate the Wildlife Exhibit posters as a summative performance assessment for this activity. • Have a discussion with students after the Wildlife Exhibit viewing has ended. Ask students: a. Which animals or plants in Rookery Bay are endangered? b. What conditions in the estuary have caused populations of each of the endangered species to decline? Are any actions being taken or projects underway to protect the remaining population

Curriculum Map—Physical Science Module

Enduring Understanding	Activities	Learning Objectives
Estuaries are unique, dynamic transition zones, between the watershed and the world ocean system. Earth processes create and determine the physical features of estuaries.	**Activity 1 — Chemistry in an Estuary** Students investigate water quality parameters to study the nature of, and the cyclical changes inherent in, the chemistry of estuarine water. They study key water quality factors at several stations in a single reserve over time—current, daily, and yearly time scales—and compare water quality values over a yearly time scale in three different estuaries. Then students take water quality measurements at a site near them and compare it to the water in the three geographically diverse NERR estuarine environ-	**Students will be able to:** • Describe how different chemical and physical properties affect and interact within an estuarine environment. • Explain how analyzing chemical and physical water quality data can lead to an understanding of estuary dynamics. • Name and describe four basic water quality monitoring parameters—pH, dissolved oxygen, salinity (conductivity) and temperature. • Explain how change in chemical water quality is evidence for change in the estuary system.
The mixing of water in estuaries creates unique habitats for estuarine organisms. The water chemistry of an estuary affects the health of the estuarine ecosystem.	**Activity 2 — Dissolved Oxygen in an Estuary** Students learn about dissolved oxygen (DO) and its effects on life, with a focus on the chemistry. First, they are introduced to, and analyze data gathered from, water quality sensors in Narragansett Bay NERR, observing how DO and chlorophyll-a change from the surface to the bottom and considering the relationships between DO and temperature. Then, in the unique environment of Azevedo Pond in the Elkhorn Slough NERR, CA, they analyze DO data and speculate about how hydrodynamics, abiotic factors, and biological processes cause extreme fluctuations in DO in the pond.	**Students will be able to:** • Explain the relationships between dissolved oxygen and water depth, chlorophyll-a and water depth, and dissolved oxygen and temperature. • Explain how these parameters interact during estuarine processes and in such phenomena as eutrophication, algal blooms, and supersaturation-hypoxia fluctuations. • Understand how photosynthesis, respiration, and decomposition affect dissolved oxygen. • Explain the role of these processes in daily or seasonal dissolved oxygen fluctuations in some estuaries. • Explain how hypoxia and anoxia occur, using data as evidence, and explain the affect on estuarine animals.
Human activities affect the chemistry of estuary waters and the estuarine ecosystem.	**Activity 3 — Human Impact on Estuaries: A Terrible Spill in Grand Bay** Students make a model of a pollution spill that occurred at Bangs Lake, a tidal lake within the Grand Bay NERR in Mississippi, in April 2005, and measure water quality parameters in their model. They then study the actual spill, analyzing various forms of data to determine the date of the spill and identify how the spill changed water quality parameters in the estuary during and after the spill. They speculate on how various life forms in the estuary were affected. Finally, students produce a timeline of the spill event with recommendations to the state Department of Environmental Quality about how to prevent large-scale pollution spills like this in the future.	**Students will be able to:** • Describe how a chemical reaction affects water quality parameters of a sample of estuary water. • Use their lab results to predict the effects of an actual pollution event on water quality and life forms in an estuary. • Revise predictions based on new evidence. • Analyze water quality and nutrient data to identify variables that are out of a typical range and that may be indicators of a disturbance to the estuary, such as a pollution event. • Explain how estuarine species are threatened by drastic changes in water quality and nutrients. • Explain how the water chemistry of an estuary affects the health of the estuarine ecosystem and how monitoring estuary water chemistry can account for and predict changes to the health of the ecosystem. • Summarize data and develop a hypothesis to make a timeline that describes the spill and explains how it affected the chemistry of and life in an estuary. • Suggest ways to prevent adverse human impacts on estuaries.

Parts of the Activity	Estuary	Science Concepts	Assessment
• What is an Estuary? • Investigating Water Quality in an Estuary • Investigating Water Quality Over a Day • Investigating Water Quality Over a Year • Comparing Water Quality Data Between Two Different Estuarine Environments	South Slough NERR, Oregon Delaware NERR Old Woman Creek NERR, Ohio	Physical properties of water, water circulation, solubility, physical properties of water, watersheds, tides	• Ask students to summarize the factors that make estuaries such dynamic sites of transition and change for all the organisms that live within their boundaries. • If at all possible, take students to one or more sites on or near your school grounds to measure water quality. Have students measure each of the four water quality factors if possible at each site and record their results. Then have students compare their values for water quality with values taken from each NERR water quality graph on the date of students' observations. How do the parameters differ between your local site (s) and NERR sites? Explain the cause of differences you find.
• Dissolved Oxygen in Narragansett Bay • What's Happening in Azevedo Pond?	Narragansett Bay NERR, Rhode Island Elkhorn Slough NERR, CA	Physical properties of water, light, tides, water chemistry monitoring	• Discuss the following: a. In general, what is the pattern of DO levels in a pond over the period of a single day? b. In general, what is the pattern of chlorophyll-a in the same pond over the period of a single day? c. What causes hypoxic conditions in an estuary? • Have students compare DO levels at various sites within NERRS. Download or let students download graphs using SWMP data to compare DO stability between an area where eutrophication is common (e.g. Childs River, Waquoit Bay NERR) and a well-flushed area (e.g. Menauhant). How are the DO levels different? Explain why differences occur.
• Modeling a Chemical Spill • Learning More about the Spill • Analyzing Data Before and After the Spill	Grand Bay NERR, Mississippi	Water pollution, chemistry of specific pollutants, biochemistry of specific pollutants, nutrient cycles, dissolved oxygen, turbidity, land use, watersheds, erosion and sedimentation	• Discuss the following: a. What caused the massive spill in Grand Bay? What could have been done to prevent it? b. What were the immediate effects on organisms living in the bay? c. What are the reasons that water quality returned to normal after a brief span of weeks?

Curriculum Design

Modular Approach

Estuaries 101 was developed as a series of Modules for very specific educational reasons. *AAAS Benchmarks* (1993) notes that an overstuffed curriculum overemphasizes short-term memorization and impedes “the acquisition of understanding." A modular approach can help combat the difficulty of "a mile wide and an inch deep". Modules that focus on select concepts can facilitate deeper interaction with content and allow for project-based work.

Modules also offer usability advantages. Modules allow teachers to diversify their curricula by selecting standards-relevant content from various sources. The *NSES Standards* recognizes that integrated and thematic approaches can be powerful. Indeed, it is rare for high school science teachers to have the opportunity to dedicate a full-year or semester-long curriculum to the study of estuaries exclusively. However, it is quite common for high school teachers to incorporate several plug-in modules that allow them to cover standards and meet curriculum objectives in novel ways, through different perspectives, or with a particular focus in a topic such as estuaries.

The concepts within a study of estuaries can be woven into existing Earth, life, or physical science courses via plug-in modules by meeting standards and without contributing to an "overstuffed" curriculum.

Types of Experiences

Students learn best when they are immersed in topics they care about and are pursuing questions of personal relevance. The Estuaries 101 Modules take advantage of this, embedding the learning in investigations of dynamic estuaries.

Specifically, there are three different types of experiences in the activities:

* Data analysis,
* Field experiences, and
* Classroom experiments.

In the data analysis experiences, students work with actual data collected at the estuary upon which an activity focuses. They analyze graphs, data tables, and maps for the purpose of understanding a broader concept, relationship, or system, just as the scientists who study the estuaries do. For example, in Earth Science Activity 4: Extreme Weather and Estuaries, students monitor and interpret the changes in water quality factors, such as salinity and turbidity, day by day as a severe storm approaches, strikes the estuary, and then dissipates.

In the field experiences, students explore actual estuary locations virtual and in person. The activities do not assume that teachers and students will be able to get outdoors and to an actual estuary for hands-on experiences, so virtual field trips are included, using Google Earth and other online systems. For example, in Physical Science Activity 2: Dissolved Oxygen in an Estuary, students use the Web to take a virtual field trip to two sites in Narragansett Bay, Rhode Island, where an interactive tool allows them to access various water quality sensors at different depths for the purpose of considering the relationships between dissolved oxygen and water temperature. In addition, the NERR system provides a range of award winning education programs, including hands-on field experiences for students, and the Estuaries 101 Modules are designed to complement and relate to such experiences if you are able to actually visit one of the 27 reserves around the country. (See the Web site for additional information.)

Finally, in the classroom experiments, students get hands-on with some of the various factors and conditions important to estuaries and to the data they are studying from those estuaries. Aspects of the estuaries are brought into the classroom, where variables can be controlled and changed, models can be made and manipulated, and experiments can be conducted. For example, in Life Science Activity 2: Nutrients in an Estuary, students create estuary models in which they artificially enrich both fresh and salt water samples with different amounts of nutrients, observe the growth of algae over time, and relate their results to the phenomenon of algae blooms in estuaries.

Scaffolding and Supports

In the activities, these experiences are scaffolded and supported by background information for both the teachers and students, since there is a role for reading and direct delivery of content in learning, as part of the overall process; by student sheets, which provide guidance through the experiences and ask both specific response and reflection questions to ensure that students are on track and are thinking about what they are doing and why; by assessment pieces for individual activities and for entire Modules, providing a means for both grading, as appropriate, and checking in with student advances in understanding; and finally by optional extension inquiries, which provide suggestions on how the concepts, skills, data, and questions addressed in the activities can be pursued in more depth by classes or individuals interested in taking their explorations to the next level.

Estuaries 101 takes a rich educational approach, with opportunities to engage a wide-variety of school and classroom situations and all types of learners in exploring the science and excitement of estuaries.

Design, Review, and Testing of the Materials

A great deal of thought and energy went into the initial design and development of the Estuaries 101 Modules. This involved extensive work on defining a scope, conceptual sequence, and detailed rationale for all of the activities; standards matching; the development of and alignment with core principles and concepts; and the identification of activity-specific learning objects. (See the Core Principles section of this guide, the Standards Matching materials available on the Web, and the individual activities for more details.)

In addition, the Modules were reviewed by NERRS educators and scientists at numerous stages during their design, development, and revision to ensure that the final activities are scientifically rigorous and meet the educational needs of the NERRS and the teachers and students with whom they work.

Finally, all of the Estuaries 101 activities were pilot tested by teachers and students. Feedback was gathered from this testing, and revisions and additions were then made to the activities and assessments to specifically address the needs, desires, and realities of implementing the Modules within real classroom settings.

How Learning about Estuaries meets State and National Science Education

When NOAA/NERRS launched Estuaries 101, it also decided to conduct a national study to see how estuaries can meet state and national standards. TERC, an educational non-profit, was contracted to conduct this study, the results of which are published in this site. This study relates broadly to the concepts and skills that can be embedded in estuaries learning activities, and specifically to Estuaries 101, NOAA's newly released high school curriculum materials. This study and the curriculum were developed in collaboration with NOAA's National Estuarine Research Reserve System.

For this study, we compared the Estuaries learning goals with the National Science Education Standards as a common framework, and sample state standards to illustrate the diversity among states. While the National Science Education Standards (NRC, 1996) provides a common framework on which many states base their standards, each state defines and vets its own standards. In some cases, differences among states reflect issues of local relevance (e.g. coastal states might have a greater emphasis on oceans and coastal processes), or policy priorities (e.g. the balance between content and process standards). For the sample states, TERC selected California, Illinois, Massachusetts, Virginia and Washington, as (relatively populous) representatives of the nation, including coastal and inland states. TERC looked at high school standards in biology, Earth science, chemistry and physics (combined into Physical sciences, below), as the context in which these modules will be used. While Estuaries ultimately will become a full K-12 program, the first released modules are for high school. They are designed as supplemental modules, for inclusion in Earth science, biology and physical science courses, although they may also be used by other educators.

TERC conducted the analysis at four levels of concepts and skills:

- *estuaries* – TERC began with a narrow focus, searching for the term "estuaries" and directly related terms in these standards. This is often the first level that people consider when deciding to use curriculum materials – if their state standards include "estuaries" per se.
- *big ideas in science* – TERC next broadened the scope, to explore how the estuaries activities support the learning goals of the three major subject domains of the modules: Earth science, biology and physical science – looking especially at the "big ideas" in each field.
- *developing science thinking skills* – TERC focused on how estuaries modules meet standards for science thinking skills, such as inquiry, experimental design and data analysis. These fundamental skills permeate science, and are well supported by the Estuaries 101 activities.
- *ocean and climate essential principles* – As an effort to develop a common framework for ocean and climate literacy, NOAA and other agencies have developed a set of essential principles for each of these fields. TERC cross-referenced the estuaries modules with these important documents.

The full report, "How Learning about Estuaries meets State and National Science Education Standards", details the findings in each of these levels. In brief, the study found that estuaries per se are inadequately represented in the state standards. Remarkably, only four states refer to estuaries by name. While other states used comparable terms like marine and salt water environments, freshwater habitats, tidal environments, wetlands, brackish, bay, salt marsh, coastal swamp, etc., the study concluded that there is not a strong enough explicit need for covering estuaries per se to drive large scale use. On the other hand, estuaries can be an exceptional vehicle for conveying the "big ideas" of science – such as "habitat adaptation" in biology, and "water as solvent" in chemistry and "interacting systems" in Earth science. These concepts are included in ALL state standards we reviewed, in one form or another. The study also found strong correlations between the inquiry-based approaches used in the modules and the scientific thinking skills, such as experimental design and data analysis, called for in all state science standards. Finally, the study found a strong alignment between the proposed modules and the essential principles of ocean and climate literacy.

Summary - Conclusions of the Study

Conclusion #1 – The specific word "estuaries" does not have a prominent role in most state standards, but estuaries-related terms do. If we use related terms, like tidal environments and fresh and saltwater habitats, the concept of estuaries is included in the standards of nearly a quarter of the states, Hence, we should use such terms in describing the learning goals and activities.

Conclusion #2 – To make a more compelling case for the estuary curricula, we should emphasize the big ideas that are covered in each module. Most of the topics in the modules align well with the big ideas in life, physical and Earth science, as well as the over-arching "unifying concepts and processes". This is true at the national level and in the individual state standards.

Conclusion #3 – The estuaries modules align well with standards for science process and thinking skills. This is true in the national standards, and in our five representative states. Estuaries are an especially good domain for developing and applying these skills. We recommend making this point clearly when trying to establish the value of the estuaries modules.

Conclusion #4 – The estuaries modules strongly support ocean and climate literacy. The appeal and value of the estuaries models to help students learn about and apply these principles will increase as the Ocean Literacy and Climate Literacy documents become more visible and increase their impact on state and national standards.

The full report, "How Learning about Estuaries meets State and National Science Education Standards", can be found at::

http://www.estuaries.gov/estuaries101/Resources/Default.aspx?ID=151

Monitoring and Evaluation

All the Estuaries 101 activities are scaffolded and supported by:

- background information for both the teachers and students, since there is a role for reading and direct delivery of content in learning, as part of the overall process;
- by student sheets, which provide guidance through the experiences and ask both specific response and reflection questions to ensure that students are on track and are thinking about what they are doing and why;
- by assessment pieces for individual activities and for entire Modules, providing a means for both grading, as appropriate, and checking in with student advances in understanding; and
- finally by optional extension inquiries, which provide suggestions on how the concepts, skills, data, and questions addressed in the activities can be pursued in more depth by classes or individuals interested in taking their explorations to the next level.

Each Module concludes with an assessment piece, designed for use after completion of all the activities within that Module. These assessments, which overarch all the activities within a Module, provide a means for both grading, as appropriate, and checking in with student advances in understanding.

NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

NOAA National Estuarine Research Reserve System

NOAA's National Estuarine Research Reserve System (NERRS) strives "to enhance public awareness and understanding of estuarine areas, and provide suitable opportunities for public education and interpretation." The NERRS comprises 27 reserves, and is a great resource for all things related to estuarine ecology. The reserve system provides a range of award winning education programs ranging from hands-on field experiences for students to professional development opportunities for teachers. Reserve educators provide regularly scheduled public programs and special events and partner with local schools, community-based organizations and volunteers.

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Teacher Guide—Physical Science Module
Activity 1 — Chemistry in an Estuary

Featured NERRS activity:

Delaware NERR
http://www.nerrs.noaa.gov/Delaware/welcome.html

Activity Summary

In this activity, students investigate water quality parameters to study the nature of, and the cyclical changes inherent in, the chemistry of estuarine water. Students study key water quality factors at several stations in a single reserve over time—current, daily, and yearly time scales. Students also compare water quality values over a yearly time scale in three different estuaries within NOAA's National Estuarine Research Reserve System (NERR) —South Slough NERR, Oregon; Delaware NERR; and Old Woman Creek NERR, Ohio. Then students take water quality measurements at a site near them and compare their data to the water in the three geographically diverse NERR estuarine environments.

Learning Objectives

Students will be able to:

1. Describe how different chemical and physical properties affect and interact within an estuarine environment.
2. Explain how analyzing chemical and physical water quality data can lead to an understanding of estuary dynamics.
3. Name and describe four basic water quality monitoring parameters—pH, dissolved oxygen, salinity (conductivity) and temperature.
4. Explain how change in chemical water quality is evidence for change in the estuary system.

Grade Levels

9-12

Teaching Time

5 class sessions (55 minutes) + homework

Organization of the Activity

This activity consists of 5 parts which help deepen understanding of estuarine systems:

1. What is an Estuary?
2. Investigating Water Quality in an Estuary
3. Investigating Water Quality Over a Day
4. Investigating Water Quality Over a Year
5. Comparing Water Quality Data Between Two Different Estuarine Environments

Featured NERR Estuaries

- South Slough National Estuarine Research Reserve, Oregon
  http://www.nerrs.noaa.gov/SouthSlough/welcome.html
- Delaware National Estuarine Research Reserve, Delaware
  http://www.nerrs.noaa.gov/Delaware/welcome.html
- Old Woman Creek National Estuarine Research Reserve, Ohio
  http://www.nerrs.noaa.gov/OldWomanCreek

Background

This activity introduces students to the complex chemistry of estuarine water. Students investigate how chemical and physical (temperature is not chemical but physical) water quality factors—pH, temperature, dissolved oxygen, and salinity—change and interact over varying time scales in three estuaries—one on the west coast (South Slough NERR), one on the east coast (Delaware NERR), and one in the Great Lakes region (Old Woman Creek NERR). The three estuaries have very different physical and chemical characteristics, primarily because of their respective proximity to the ocean. Two of the estuaries are near oceans and one is a freshwater estuary. Students analyze data from the System-Wide Monitoring Program data website in several parts of the activity. You may wish to add to the discussion and definition of these following chemical factors when students view the gauge data.

pH

pH is a measure of how acidic or basic a solution is. The pH scale ranges from 0 to 14. Solutions with a pH of less than 7 are acidic, and those with a pH greater than 7 are basic (or alkaline).

Knowledge of pH is important because most aquatic organisms are adapted to live in solutions with a pH between 5.0 and 9.0. The pH in an estuary tends to remain relatively constant because the chemical components in seawater resist large changes to pH. Biological activity, however, may significantly alter pH in the freshwater portions of the estuary.

pH is actually a measure of the amount of hydrogen ions in solution. In fact, some people think of pH as being the "power of hydrogen." A lower pH indicates that there are more free hydrogen ions in the water, which creates acidic conditions, and a higher pH indicates there are less free hydrogen ions, which creates basic conditions. pH is equal to the negative logarithm of the hydrogen ion activity, meaning that the hydrogen ion concentration changes tenfold for each number change in pH unit.

Through a process called photosynthesis, plants remove carbon dioxide (CO_2) from the water and emit oxygen (O_2). Since CO_2 becomes carbonic acid when it dissolves in water, the removal of CO_2 results in a higher pH, and the water becomes more alkaline, or basic. When algae naturally begin to increase in estuaries, as they may do when days lengthen and the water temperature rises in spring, pH levels tend to rise. Respiration, on the other hand, releases CO_2 into the water, resulting in a lower pH, so pH levels may drop during the summer nights when the algae aren't photosynthesizing, but their respiration continues.

All aquatic organisms have a pH range to which they are adapted. Outside of this range, critical biological processes may be disrupted, leading to stress and death. Most organisms cannot live below a pH of 5 or above a pH of 9. pH is also used to monitor safe water conditions. Once the background range of pH has been established, a rise or fall in pH may indicate the release of a chemical pollutant, or an increase in acid rain. Additionally, pH affects the solubility, biological availability, and toxicity of many substances. For example, most metals are more soluble, and often more toxic, at lower pH values.

Temperature

Just knowing the temperature of the water in an estuary can give us a pretty good idea of how healthy it is. One important thing we can tell from water temperature is how much oxygen can be dissolved into the water.

Dissolved oxygen is critical for the survival of animals and plants that live in the water. As the water temperature increases, the amount of oxygen that can dissolve in the water decreases. For example, 100% saturated fresh water at 0°C contains 14.6 mg of oxygen per liter of water, but at 20°C, it can only hold 9.2 mg of oxygen per liter. Because dissolved oxygen is critical for survival, seasonal water temperature (and dissolved oxygen) is an important indicator of habitat quality for many estuarine species.

The temperature of the water also tells us what types of plants and animals are able to live in the estuary. All plants and animals have a range of temperatures in which they thrive and reproduce. For instance, salmon will only breed at temperatures below 18°F. If the water in the estuary is outside the normal seasonal temperature range in which most estuarine organisms can comfortably live, it is probably an indication that something is adversely affecting the health of the estuary. Differences in water temperature cause the formation of distinct, non-mixing layers in water, otherwise known as stratification because the density of water changes with temperature. This stratification leads to chemically and biologically different regions in water.

Dissolved Oxygen

To survive, fish, crabs, oysters and other aquatic animals must have sufficient levels of dissolved oxygen (DO) in the water. The amount of dissolved oxygen in an estuary's water is the major factor that determines the type and abundance of organisms that can live there.

Oxygen enters the water through two natural processes:
(1) diffusion from the atmosphere and
(2) photosynthesis by aquatic plants. The mixing of surface waters by wind and waves increases the rate at which oxygen from the air can be dissolved or absorbed into the water.

DO levels are influenced by temperature and salinity. The solubility of oxygen, or its ability to dissolve in water, decreases as the water's temperature and salinity increase. Therefore, DO levels in an estuary can also vary seasonally, with the lowest levels occurring during the late summer months when temperatures are highest.

Bacteria, fungi, and other decomposer organisms can reduce DO levels in estuaries because they consume oxygen while breaking down organic matter. Oxygen depletion may occur in estuaries when many plants die and decompose, or when wastewater with large amounts of organic material enters the estuary. In some estuaries, large nutrient inputs, typically from wastewater, stimulate algal blooms. When the algae die, they begin to decompose. The process of decomposition depletes the surrounding water of oxygen and, in severe cases, leads to hypoxic (very low oxygen) conditions that can kill aquatic animals. Shallow, well-mixed estuaries are less susceptible to this phenomenon because wave action and circulation patterns supply the waters with plentiful oxygen.

Salinity and Conductivity

Under laboratory conditions, pure water contains only oxygen and hydrogen atoms, but in the real world, many substances, like salt, are dissolved in water. Salinity is the

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

B2. Structure and properties of matter
B3. Chemical reactions

Content Standard F: Science in Personal and Social Perspectives

F4. Environmental quality

F5. Natural and human-induced hazards

concentration of salt in water, usually measured in parts per thousand (ppt). The salinity of seawater in the open ocean is remarkably constant between 30 and 35 ppt. Salinity in an estuary varies according to one's location in the estuary, daily and storm-driven tides, and the volume of fresh water flowing into the estuary.

Salinity and conductivity are closely related. Both measure the water's ability to conduct electricity, which is a surrogate measure estimating the quantity of salts dissolved in the water. Conductivity is a more sensitive measure (parts per million or less) than salinity (parts per thousand or greater). Pure water is a very poor conductor of electrical current, but salts, such as sodium, calcium, magnesium, and chloride, dissolved in the water are in ionic (charged) form and conduct electrical current. Conductivity, which is the opposite of resistance, measures the ability of water to conduct current. A higher conductivity indicates less resistance, and means that electrical current can flow more easily through the solution.

In saltwater estuaries, salinity and conductivity levels are generally highest near the mouth of a river where ocean water enters, and lowest upstream where freshwater flows in. Actual salinities vary throughout the tidal cycle, however, because as the tide rises more ocean water enters the estuary. In saltwater estuaries, salinity and conductivity typically decline in the spring when snowmelt and rain increase the freshwater flow from streams and groundwater. In freshwater estuaries, the salinity and conductivity are much lower than levels found in saltwater estuaries. The pattern of salinity (or conductivity) is normally the reverse of that found in saltwater estuaries. The waters of the Great Lakes have a lower salinity than the streams and rivers flowing into them. Lake water intrusion due to storm surges or seiches results in lower salinity near the mouth of the estuary. During storms and the resulting runoff, both salinity and conductivity levels usually fall as rainwater and the resulting surface runoff are very low in salts. Although this decrease is measurable in freshwater estuaries, it does not have the same ecological impact that it would in a marine estuary. Salinity and conductivity are frequently higher during the summer when higher temperatures increase levels of evaporation in the estuary.

Conductivity and salinity are dependent on many

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of Student Reading 1: A Tale of Three Estuaries
- ❑ Copy of Student Reading 2: Chemistry in an Estuary
- ❑ Copy of Student Worksheet 1: Chemistry in an Estuary
- ❑ Copy of Student Data Sheet 1: Chemistry in an Estuary

Teachers

- ❑ Download Google Earth <*http://earth.google.com/*>.
- ❑ Bookmark the *Monitoring Tutorial* presentation found in the estuaries.gov site, select the Teachers tab, Classroom Activities and then choose "Monitoring Tutorial". For quick access go to: http://www.estuaries.gov/estuaries101/ScienceData/Default.aspx?ID=156

  Please read the instructions to download this presentation. It is a large size, please be patient downloading it. Fast internet connections are prefer able.

- ❑ Water source (preferably from an estuary) with algae Digital camera

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

factors, including geology, precipitation, surface runoff, and evaporation. Conductivity, because it is a much more sensitive measurement, is also very temperature dependent. It increases as water temperature increases because water becomes less viscous and ions can move more easily at higher temperatures. Because of this, most reports of conductivity reference specific conductivity. Specific conductivity adjusts the conductivity reading to what it would be if the water were 25°C. This is important for comparing conductivities from waters with different temperatures.

Environmental factors that increase conductivity and salinity include: increased temperature, fertilizers from agriculture, sewage, road runoff containing automobile fluids and de-icing salts, and a local geology high in soluble minerals, such as carbonates. Conductivity and salinity also increase due to evaporation. On warm days, the evaporation of water concentrates the ions that remain behind, resulting in water with higher conductivity and salinity. Often, small diurnal fluctuations in conductivity and salinity are seen as a result of evaporation during the day and condensation and groundwater recharge at night. In saltwater estuaries, the influx of ocean water due to rising tides increases salinity and conductivity within the estuary.

Estuarine organisms have different tolerances and responses to salinity changes. Many bottom-dwelling animals, like oysters and crabs, can tolerate some change in salinity, but salinities outside an acceptable range will negatively affect their growth, reproduction, and ultimately, their survival.

Salinity also affects chemical conditions within the estuary, particularly levels of dissolved oxygen in the water. The amount of oxygen that can dissolve in water, or solubility, decreases as salinity increases. The solubility of oxygen in seawater is about 20 percent less than it is in fresh water at the same temperature.

(Text adapted from the *Estuaries Tutorial*, NOAA Ocean Service Education. URL:http://oceanservice.noaa.gov/education/kits/estuaries/estuaries10_monitoring.html. Accessed: 2008-08-05. (Archived by WebCite® at http://www.webcitation.org/5ZrNiZ0UA))

Google Earth

This activity *requires* the use of Google Earth. If students have computer access, the use of Google Earth (http://earth.google.com/) can help them develop spatial skills.

Find Tutorial "*Using Google Earth to Explore Estuaries*" in estuaries.gov, click under Teachers, Tips/Tutorials.

Google Earth

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Find Tutorial "*Using Google Earth to Explore Estuaries*" in estuaries.gov, click under Teachers, Classroom Activities and find the tutorial.

Preparation

- Download the *Monitoring Tutorial* presentation, and preview all parts of that presentation. Notice that the word "queues" in orange are valuable extensions of basic concepts. Find instructions on how to access this presentation in the "Materials" section of this Teacher Guide.

- Download Google Earth, if you haven't already done so, and install it on your classroom computer (s) or computer lab machines <*http://earth.google.com/*>. (To find a Find Tutorial "*Using Google Earth to Explore Estuaries*", please visit the estuaries.gov site, click under Teachers, Classroom Activities and find the tutorial.

- In Google Earth, locate the South Slough NERR, Old Woman Creek NERR, and the Delaware NERR in case you want to project maps of these sites for students.

- Find a local site (pond, lake, stream, river, or estuary) that you can use for students to obtain their own water quality data for DO (if possible), temperature, pH, and salinity or conductivity.

- Make copies of the *Student Reading—Tale of Three Estuaries*, *Student Reading—Chemistry in an Estuary, Student Worksheet—Chemistry in an Estuary*, and *Student Data Sheet—Chemistry in an Estuary*. The *Student Data Sheet* can also be projected in front of the class.

Procedure

Part 1 — What is an Estuary?

1. Ask students if they know what an estuary is. What makes an estuary different than a lake or the ocean? Accept all answers and begin the Old Woman Creek slide show on your classroom computer projector system.

2. Review the explanation about the NERRS System-wide Monitoring Program (SMWP) and Water Quality sections of the presentation. You may fast forward through water qualities not addressed in this activity, or you may choose to have students view all the parameters. Allow students a little time to take notes on what they observe.

3. Have students complete Part 1 of the *Student Worksheet—Chemistry in an Estuary*.

4. Discuss what would cause the water in an estuary to change over a period of a day, a season, or a year. (*Changes in stream flow, tides, weather events such as heavy rains and storms, seasonal temperature changes, etc.*). List the factors on the board.

5. Ask students to think about the nature of water in an estuary. What things could they measure about the estuary water to quantify the changes in the estuarine system? In this activity, we have chosen to study pH, dissolved oxygen, salinity, and temperature. Students may also mention other parameters such as nutrients (nitrates, nitrites, phosphates) or turbidity/water clarity.

6. Note: Consider having students read the *Student Reading—A Tale of Three Estuaries* and *Student Reading—Chemistry of an Estuary* as homework in preparation for Part 2 and beyond.

Part 2 — Investigating Water Quality in an Estuary

7. Have students read the *Student Reading—A Tale of Three Estuaries* and *Student Reading—Chemistry of an Estuary*.

8. Project an image of the South Slough NERR and point out the monitoring station—Charleston Bridge. This image also appears on the *Student Worksheet*.

9. If possible, use Google Earth or allow students to use Google Earth to explore the region around the Slough NERR.

10. Have students complete Part 2 of the *Student Worksheet—Chemistry in an Estuary*, using the data from the *Student Data Sheet* or online.

11. Discuss the tasks and questions from this Part.

Part 3 — Investigating Water Quality Over a Day

12. Have students complete Part 3 of the *Student Worksheet—Chemistry in an Estuary*. You may need to help students grapple with the unequal axes that result from downloading SWMP data. Go over an example of how to find a range if necessary. An example of range: the high water temperature is 20° C and the low water temperature is 12° C the range would be 20°-12° = 8° C.

13. Discuss the questions from Part 3.

Part 4 — Investigating Water Quality Over a Year

14. Have students complete Part 4 of the *Student Worksheet—Chemistry in an Estuary*.

15. Discuss the questions from Part 4.

Part 5 — Comparing Water Quality Data Between Three Different Estuarine Environments

16. If possible, use Google Earth or allow students to use Google Earth to explore the area around Blackbird Landing in the Delaware NERR and the area around the State Route 2 site in the Old Woman Creek NERR. Make sure students recognize the location of Blackbird Landing in relation to the ocean and the coast. Also, point out the key features of the Old Woman Creek site where water from the creek mixes with water from Lake Erie.

17. Have students complete Part 5 of the *Student Worksheet—Chemistry in an Estuary*.

Check for Understanding

1. Ask students to summarize the factors that make estuaries such dynamic sites of transition and change for all the organisms that live within their boundaries.

2. If at all possible, take students to one or more sites on or near your school grounds to measure water quality. Have students measure each of the four water quality factors if possible at each site and record their results. Then have students compare their values for water quality with values taken from each NERR water quality graph on the date of students' observations. How do the parameters differ between your loca l site(s) and NERR sites? Explain the cause of differences you find.

Optional Extension Inquiries

1. Have students compare two other sites in Narragansett Bay using an interactiver viewer at http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm.

- The Pomham Rocks site is: http://omp.gso.uri.edu/ompweb/doee/virtual/viewpr1.htm.

- The South Prudence site is: http://omp.gso.uri.edu/ompweb/doee/virtual/viewsp1.htm.

This interactive viewer allow students to compare the abiotic factors at two sites (Pomham Rocks and South Prudence) as the depth of water is varied. Have students explain what causes the differences in the factors at two sites within the same estuary. This extension would also make a good final assessment activity.

2. Expand the study of factors to other estuary reserves. Use the NERRS tour and let students choose reserves in proximity to their state. Have students graph the highs, lows, and ranges of each factor from each site and then compare and discuss what factors are most important in explaining sudden changes in water quality in estuarine environments.

Teacher Worksheet with Answers
Activity 1: Chemistry in an Estuary

1a. What is an estuary?

Answer: An estuary is a partially enclosed body of water where two different bodies of water meet and mix e.g. fresh water from rivers or streams meets and mixes withsalt water from the ocean or fresh water from rivers or streams meets and mixes with chemically distinct water of a large lake. In estuaries, water levels are affected by lunar or storm-driven tides. A freshwater estuary such as Old Woman Creek occurs when water from an inland source (stream or river) mixes with a much larger body of water such as one of the Great Lakes.

1b. List the types of habitats shown in the "Monitoring Tutorial" (http://www.estuaries.gov/estuaries101/ScienceData/Default.aspx?ID=156) .

Answer: Many kinds of habitat are shown—wetlands, mudflats, coastal beaches, river basins, forested areas, and grasslands.

1c. What features do estuaries have in common?

Answer: Most estuaries have cyclic changes in salinity, tidal fluctuations, and have regions of sand or other mud-like sediments. Many have a transition area or brackish water between salt and fresh water sources.

1d. List some of the water quality factors that are important in determining the suitability of the water for different species of plants and animals.

Answer: Changing salinity caused by incoming and outgoing tides would change water quality during the day. Increasing and then decreasing temperature during the day affects DO, temperature, pH, and salinity of the estuarine system. Over the year, seasonal temperatures, periods of increased precipitation, and increased runoff could cause changes to water quality factors. Others are mentioned in the "Monitoring Tutorial" .

2a. Write down the difference between the maximum and minimum value for each water quality parameter (this number is called the range of values).

Answer: Student answers will vary.

2b. What do you think causes the changes in each parameter over the course of one day?

Answer: Students may see that temperature changes and tides are probable causal agents in changing water quality factors.

3a. Describe the pattern of change for each parameter

Answer: Student answers will vary.

3b. Give a reason to explain what is causing the variation of each parameter over a 24-hour period.

Answer: Daily temperature changes, tidal flow, and weather events are all possible agents of change.

3c. Use the graphs to complete the following sentences:

i. When the temperature of the water in an estuary increases, the *pH, DO, and salinity* decreases.

ii. The water in the South Slough estuary is slightly *basic* on average during this 24-hr period.

4a. Describe the pattern of change of each water quality parameter over the course of a year.

Answer: Each factor goes through a cycle of seasonal changes.

4b. Explain what you believe is causing the variation of each parameter over the course of a year.

Answer: Seasonal changes, weather events, increased precipitation, and others may be mentioned by students.

5a. Compare the ranges of the water quality parameters at South Slough and Blackbird Landing? Which ranges are about the same? Which ones are different?

Answer: The pH at Blackbird landing is more acidic on average. Also, since Blackbird Landing is more inland, the salinity of its water is much lower than Charleston Bridge. Water temperature between the two sites is markedly different and the rise and fall of DO at Blackbird Landing is more pronounced than Charleston.

5b. Compare the time of year for the maximum and minimum pH, dissolved oxygen, salinity and water temperatures at each of the sites. Are they the same or different? Give one reason for any differences between them.

Answer: The maximum and minimum values of these three sites are different because of climatic variation between the moderate climate of Oregon (mild winters and summers) and the more extreme climate on the east coast (colder winters and warmer summer temperatures). The OWC NERR is freshwater only. The water parameters at OWC are markedly different than either of the other two saltwater estuaries.

5c. Does the pattern of change for any of the four water quality parameters vary appreciably between sites? If so, explain why the patterns are different.

Answer: See answer 5b.

6a. How are the values for your local water parameters different or the same as those from the three NERR estuaries?

Answer: Student answers will vary.

Student Reading—1
Activity 1: A Tale of Three Estuaries

An estuary is a partially enclosed body of water where two different bodies of water meet and mix e.g. fresh water from rivers or streams meets and mixes with salt water from the ocean or fresh water from rivers or streams meets and mixes with chemically distinct water of a large lake. In estuaries, water levels are affected by lunar or storm-driven tides.

Each estuarine environment is unique and is characterized by a set of biotic and abiotic factors determined by the nature of the physical setting. You will be comparing the water quality factors from estuaries separated by 3,000 miles. One, the South Slough NERR, is in Oregon on the west coast. Second is the Delaware NERR is located on the east coast. The third is the Old Woman Creek NERR, a freshwater estuary located on Lake Erie in Ohio. (A freshwater estuary such as Old Woman Creek occurs when water from an inland source [stream or river] mixes with a much larger body of water such as one of the Great Lakes.) As you investigate the water chemistry of these estuaries, note the difference in their proximity to the ocean, their physical make-up, and other characteristics that make them dynamic transition zones for life.

South Slough National Estuarine Research Reserve

The South Slough NERR contains upland forests, freshwater wetlands and ponds, salt marshes, mud flats, eelgrass meadows and open water habitats. The reserve is located five miles south of Charleston, OR, on the South Slough of the Coos Bay estuary.

The Coos estuary is an example of a drowned river mouth estuary. The formation of such estuaries along

Figure 1. Mudflats in the South Slough NERR

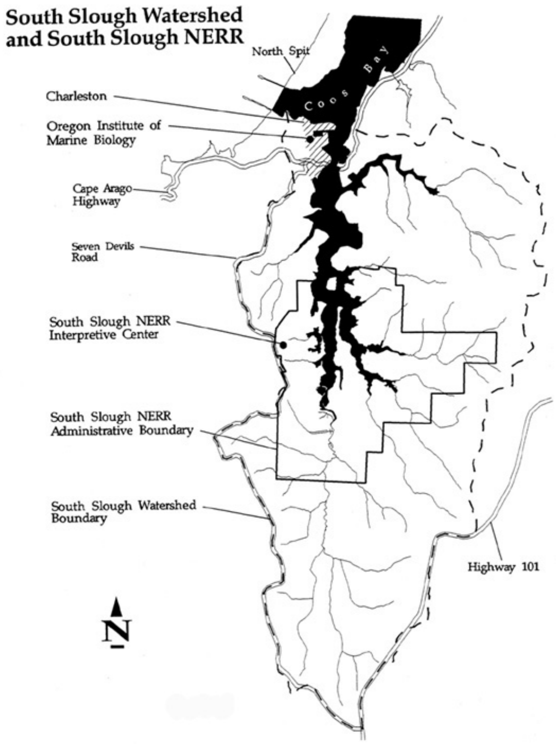


Figure 2. South Slough Watershed and South Slough NERR

the Oregon coast began 20,000 years ago as glaciers melted and sea level began to rise, flooding river valleys.

South Slough is important habitat for many animals, including several that are rare, threatened, or endangered, like the Coho salmon and the western snowy plover. The bald eagle and peregrine falcon, both of which were endangered but are making a comeback, also use the estuary. These species survive at South Slough because of the diverse habitats and plentiful food resources that the estuary provides.

Delaware National Estuarine Research Reserve

The Delaware NERR consists of two unique components, one on Blackbird Creek and the other on the St. Jones River. The St. Jones Reserve component is located six miles southeast of Dover. The Blackbird Creek component is located in southern New Castle County.

The Blackbird Creek component consists of non-tidal wetlands, tidal freshwater marshes, and tidal brackishwater marshes. Saltmarsh cordgrass and common reed are among the most common wetland plants. The uplands surrounding the marshes are a mixture of shrub and tree species, including both hardwoods and softwoods.

The Blackbird Creek watershed drains a portion of southern New Castle County, Delaware. This is a predominantly rural area, consisting of wetlands, forests and agricultural lands. Blackbird Creek flows into the Delaware River just upstream from Delaware Bay.

The St. Jones River component features tidal brackishwater and saltwater marshes dominated by saltmarsh cordgrass and salt hay. The marshes are bordered by open water habitats of the river and bay and upland habitats like meadows, woodlands, and farmlands.

The St. Jones River watershed drains a portion of the coastal plain in central Kent County, Delaware, including the city of Dover, the surrounding suburbs, industrial areas, agricultural areas and Dover Air Force Base. A dam impounds the upper St. Jones 10.5 miles upstream from the bay to form Silver Lake, a municipal recreation area. Some other headwater streams are also impounded. Much of the eastern portion (bayward) of the watershed consists of wetlands and forests, including lands and waters managed for waterfowl, wild turkey, deer and other wildlife.

Blackbird Core and Buffer Boundaries

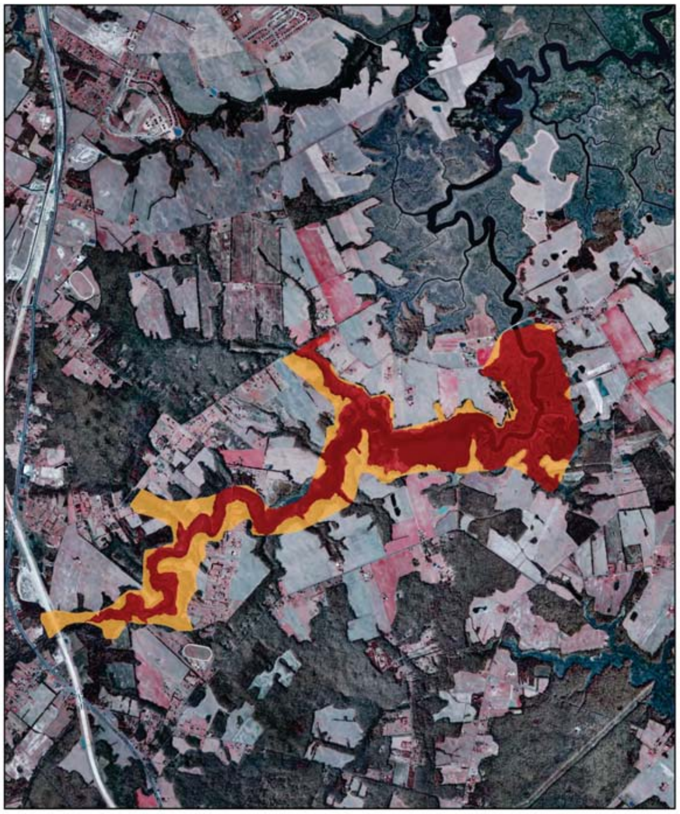


Figure 3. Delaware NERR, Blackbird Creek Component.

St. Jones Core and Buffer Boundaries

Figure 4. Delaware NERR, St. Jones Component

Old Woman Creek National Estuarine Research Reserve

Located near Huron, Ohio on the south-central shore of Lake Erie, the Old Woman Creek estuary is the drowned mouth of a small Lake Erie tributary. Since the retreat of mile-thick glaciers from the eastern United States and Canada, the land around the Great Lakes gradually rebounded, causing water levels to rise and flood the mouths of the rivers and streams flowing into them and creating the conditions for freshwater estuaries to develop. Today these estuaries are characterized by:

- drowned river mouths
- areas where stream and lake water meet and mix
- water levels that are regulated by changing lake levels (including wind-driven storm surges and resulting seiche events).

Figure 5. Barrier beach closed

Figure 6. Barrier beach open

Like water sloshing in a bathtub, seiches are tide-like rises and drops in Great Lakes coastal water levels caused by prolonged strong winds that push water toward one side of the lake, causing the water level to rise on the downwind side of the lake and to drop on the upwind side. When the wind stops, the water sloshes back and forth, with the near-shore water level rising and falling in decreasingly small amounts on both sides of the lake until it reaches equilibrium. In large bodies of water such as Lake Erie, the magnitude and timing of the seiches cause them to affect the coast much like lunar tides.

A barrier beach formed by waves and other forces within the lake isolates the estuary from the Lake Erie proper for extended periods. The barrier is normally opened by storm runoff from the watershed, but occasionally Lake Erie storm surges spill over the bar and into the estuary.

Like salt marshes, the emergent wetland plant communities of freshwater estuaries are among the most biologically productive areas on earth. Old Woman Creek NERR contains a variety of habitats including marshes and swamps, upland forests, open waters, bays and mudflats, tributary streams, a barrier beach and near shore Lake Erie. The estuary and surrounding environment support over 40 species of fish at some time during their life cycles, serve as a way station for over 300 species of migratory birds, and provide habitat for many species of mammals, reptiles, and amphibians.

Old Woman Creek flows 15 miles through portions of Huron and Erie counties including Townsend, Berlin and neighboring townships and the Village of Berlin Heights before entering Lake Erie 3 miles east of the city of Huron. Over 67% of the land within the creek's 27 square mile watershed is used for agriculture and the population is approximately 3,200. Although the estuary has remained relatively undisturbed, water quality is still negatively impacted by siltation, habitat alteration, and organic and nutrient enrichment stemming from agriculture and other land uses.

Figure 7. Old Woman Creek estuary photo (Credit: Gene Wright)

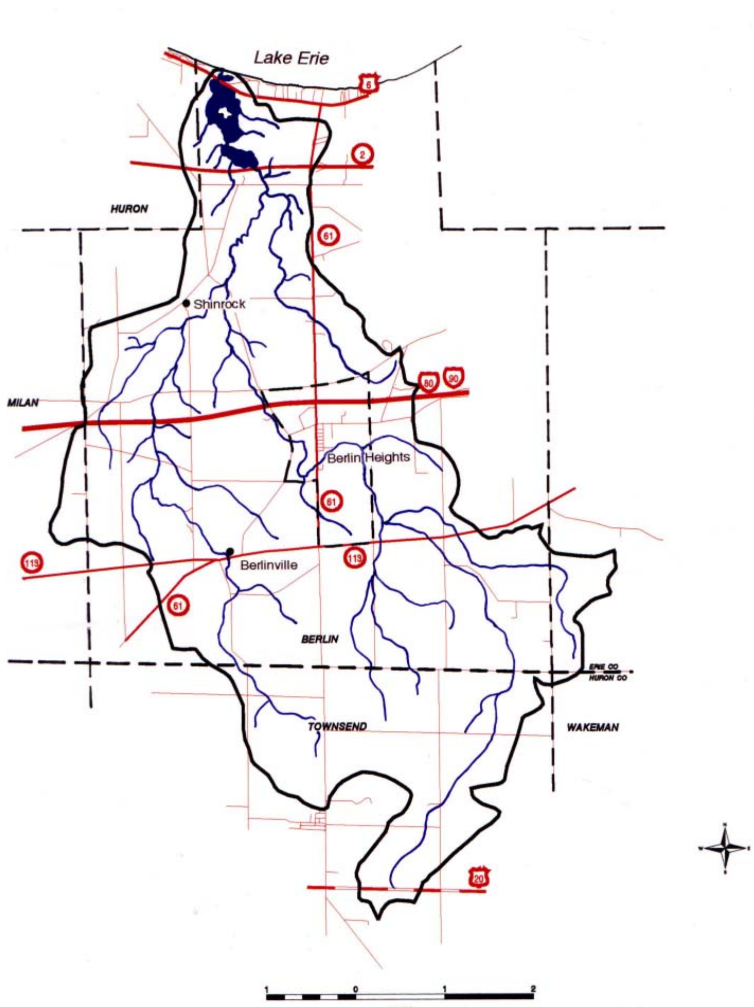


Figure 8. Old Woman Creek NERR, Ohio

Student Reading – 2
Activity 1: Chemistry in an Estuary

Estuaries are partially enclosed body of water and surrounding coastal habitats, where saltwater from the ocean mixes with fresh water from rivers, streams, or groundwater and where water levels are affected by lunar tides. In Great Lakes estuaries, fresh water from rivers or streams mixes with the chemically-distinct fresh water of the Great Lakes and water levels are influenced by wind-driven rather than lunar tides.

In fresh water, the concentration of salts, or salinity, is nearly zero. The salinity of water in the ocean averages about 35 parts per thousand (ppt). The mixture of seawater and fresh water in estuaries is called brackish water.

Estuaries are transitional areas that connect the land and the sea, or areas in which a source of fresh water such as a stream or river flows into a much larger body of water like one of the Great Lakes. The daily tides (the regular rise and fall of the sea's surface) are a major influence on many of these dynamic environments. Most areas of the Earth experience two high and two low tides each day. Some areas, like the Gulf of Mexico, have only one high and one low tide each day. In enclosed, non-marine location such as Lake Superior, the change in water levels due to lunar tides is measured in centimeters instead of meters. Although the lunar-driven tide is small on the Great Lakes, estuaries there are influenced by changes in water level resulting from wind-driven storm surges and resulting seiches.

Like water sloshing in a bathtub, seiches are tide-like rises and drops in Great Lakes coastal water levels caused by prolonged strong winds that push water toward one side of the lake, causing the water level to rise on the downwind side of the lake and to drop on the upwind side. When the wind stops, the water sloshes back and forth, with the near shore water level rising and falling in decreasingly small amounts on both sides of the lake until it reaches equilibrium.

The tidal pattern in an estuary depends on its geographic location, the shape of the coastline and ocean floor, the depth of the water, local winds, and any restrictions to water flow. For example, the Bay of Fundy, which is located off the northern coast of Maine extending up to Canada, can be found at the end of a long, narrow inlet. In this Bay, tides are heightened because a large volume of water is being forced into a very small space. The tide there is in excess of 40 feet!

While strongly affected by tides and tidal cycles, many estuaries are protected from the full force of ocean waves, winds, and storms by reefs, barrier islands, or fingers of land, mud, or sand that surround them. The characteristics of each estuary depend upon the local climate, freshwater input, tidal patterns, and currents. Truly, no two estuaries are the same.

Monitoring the environment of an estuary by measuring critical factors such as pH, dissolved oxygen, salinity, and temperature is vital to ensure that animals and plants thrive. It is important to know what these parameters are measuring.

pH

Scientists use pH as an indicator of whether water is acidic or basic. pH is measured on a scale of 1 to 14, where numbers less than 7 are increasingly acidic and numbers greater than 7 are increasingly basic. Distilled water has a pH of 7 and is said to be neutral. Water on the surface of Earth is usually a little acidic or basic due to both geological and biological influences.

pH is actually a measure of the amount of hydrogen ions in solution. In fact, some people think of pH as being the "power of hydrogen". A lower pH indicates that there are more free hydrogen ions, which creates acidic conditions, and a higher pH indicates there are fewer free hydrogen ions, which creates basic conditions. pH is equal to the negative logarithm of the hydrogen ion activity, meaning that the hydrogen ion concentration changes tenfold for each number change in pH unit.

All aquatic organisms have a pH range to which they are adapted. Outside of this range, critical biological processes may be disrupted, leading to stress and death. Most organisms cannot live below a pH of 5 or above a pH of 9. Additionally, pH is used to monitor safe water conditions. Once the background range of pH has been established, a rise or fall in pH may indicate the release of a chemical pollutant or an increase in acid rain. Additionally, pH affects the solubility, biological availability, and toxicity of many substances. For example, most metals are more soluble, and often more toxic, at lower pH values.

Temperature

Temperature is a measure of kinetic energy, or energy of motion. Increasing water temperature indicates increasing energy, or motion of water molecules and substances dissolved in the water. Temperature is a critical factor for survival in any environment. Organisms that live in water are particularly sensitive to sudden changes in temperature.

The Celsius temperature scale is used worldwide to measure temperature. Temperature has a significant impact on water density. Water density is greatest at 4 degrees Celsius, meaning that water at higher or lower temperatures will float on top of water at or near 4 º C. This is why ice floats on water, and warm water floats over cooler water. Differences in water temperature can cause the formation of distinct, non-mixing layers in water, otherwise known as stratification. This stratification leads to chemically and biologically different regions in water.

Salinity and Conductivity

Salinity and conductivity are measures of the dissolved salts in water. Salinity is usually described using units of parts per thousand or ppt. A salinity of 20 ppt means that there are 20 grams of salt in each 1000 grams of water. Because it is impractical to routinely determine the total amount of salts dissolved in water, a surrogate measure—the ability of the water to conduct electricity—is made for determining both conductivity and salinity.

Salinity and conductivity are closely related. Pure water is a very poor conductor of electrical current, but salts dissolved in the water are in ionic (charged) form and conduct electrical current. Conductivity, which is the opposite of resistance, measures the ability of water to conduct current. A higher conductivity indicates less resistance, and means that electrical current can flow more easily through the solution. Because dissolved salts conduct current, conductivity increases as salinity increases. Common salts in water that conduct electrical current include sodium, chloride, calcium, and magnesium.

All aquatic life in an estuary must be able to survive changes in salinity. All plants and animals have a range of salinity to which they are adapted. Outside of this range, they will be unable to function and may die. Salinity affects the ability of water to hold oxygen, and seawater holds approximately 20% less oxygen than freshwater. Many chemical reactions that determine the concentration of nutrients and metals in the water are influenced by salinity. The conductivity and salinity of seawater is very high while these parameters are comparatively low in tributaries and rivers. Freshwater lakes typically have conductivities and salinities even lower than those of inland streams. This is because inland streams pick up salts from rocks, soils, and roads as they flow over the landscape.

Many chemical reactions that determine the concentration of nutrients and metals in the water are influenced by salinity. For instance, salinity and conductivity affect the ability of particles to flocculate, or stick together, which is important in determining turbidity levels and sedimentation rates. Salinity also increases the density of water, with seawater being heavier than freshwater. This density difference inhibits mixing. In fact, conductivity and salinity serve as excellent indicators of mixing between inland water and sea or lake water, and they are particularly useful in indicating pollution events or trends in freshwater. For example, an overdose of fertilizers or the application of road salt will cause spikes in conductivity and salinity.

Conductivity and salinity are dependent on many factors, including geology, precipitation, surface runoff and evaporation. Since conductivity is a much more sensitive measurement than salinity, it is more impacted by changes in temperature. Conductivity increases as water temperature increases because water becomes less viscous and ions can move more easily at higher temperatures. Because of this, most reports of conductivity reference specific conductivity. Specific conductivity adjusts the conductivity reading to what it would be if the water was 25°C. This is important for comparing conductivities from waters with different temperatures.

Dissolved Oxygen

Dissolved oxygen (DO) is the amount of oxygen gas that is dissolved in a sample of water. DO is usually measured in units of milligrams per liter (mg/L). Just as we need air to breathe, aquatic plants and animals need dissolved oxygen to live. Dissolved oxygen is used for respiration, which is the process by which organisms gain energy by breaking down carbon compounds, such as sugars. Dissolved oxygen is also essential for decomposition, which is a type of respiration in which bacteria break down organic materials for energy. Decomposition is an important process that recycles nutrients and removes organic materials such as dead vegetation from our waterways. Because dissolved oxygen is required for aquatic life, balancing the sources and sinks of dissolved oxygen is essential in maintaining a healthy ecosystem.

The concentration of dissolved oxygen in water depends on a number of interrelated factors, including biological factors, such as the rates of photosynthesis and respiration, and physical and chemical factors, such as temperature, salinity, and air pressure.

Dissolved oxygen enters the water by diffusion from the air and as a byproduct of photosynthesis. Diffusion from the air occurs very quickly in turbulent, shallow water or under windy conditions.

The amount of oxygen that can dissolve in water depends on water temperature, salinity, and air pressure. As temperature and salinity increase, and pressure decreases, the amount of oxygen that can be dissolved in water decreases. Cold water holds more dissolved oxygen than warm water, and water at sea level holds more dissolved oxygen than water at high altitudes. Seawater holds approximately 20% less oxygen than freshwater at the same temperature and altitude.

Student Worksheet
Activity 1: Chemistry in an Estuary

Student Name:____

Part 1 — What is an Estuary?

As you are shown various images in the *Monitoring Tutorial*, take notes on the nature of estuaries and record any ideas you have about what factors would cause changes in water quality in an estuary over the course of a day, a season or a year.

1a. What is an estuary?

1b. List the types of habitats shown in the *Monitoring Tutorial*.

1c. What features do estuaries have in common?

1d. List some of the water quality parameters that are important in determining the suitability of the water for different species of plants and animals.

Part 2 — Investigating Water Quality in an Estuary

You will study four of the water quality parameters in the South Slough NERR in Oregon. You will look at how pH, dissolved oxygen, salinity, and water temperature are measured by one of the four monitoring stations comprising the estuary reserve—Charleston Bridge.

Look at the satellite image below to see the location of the site and its general position with respect to the ocean. If time permits, investigate this area more fully by using Google Earth.

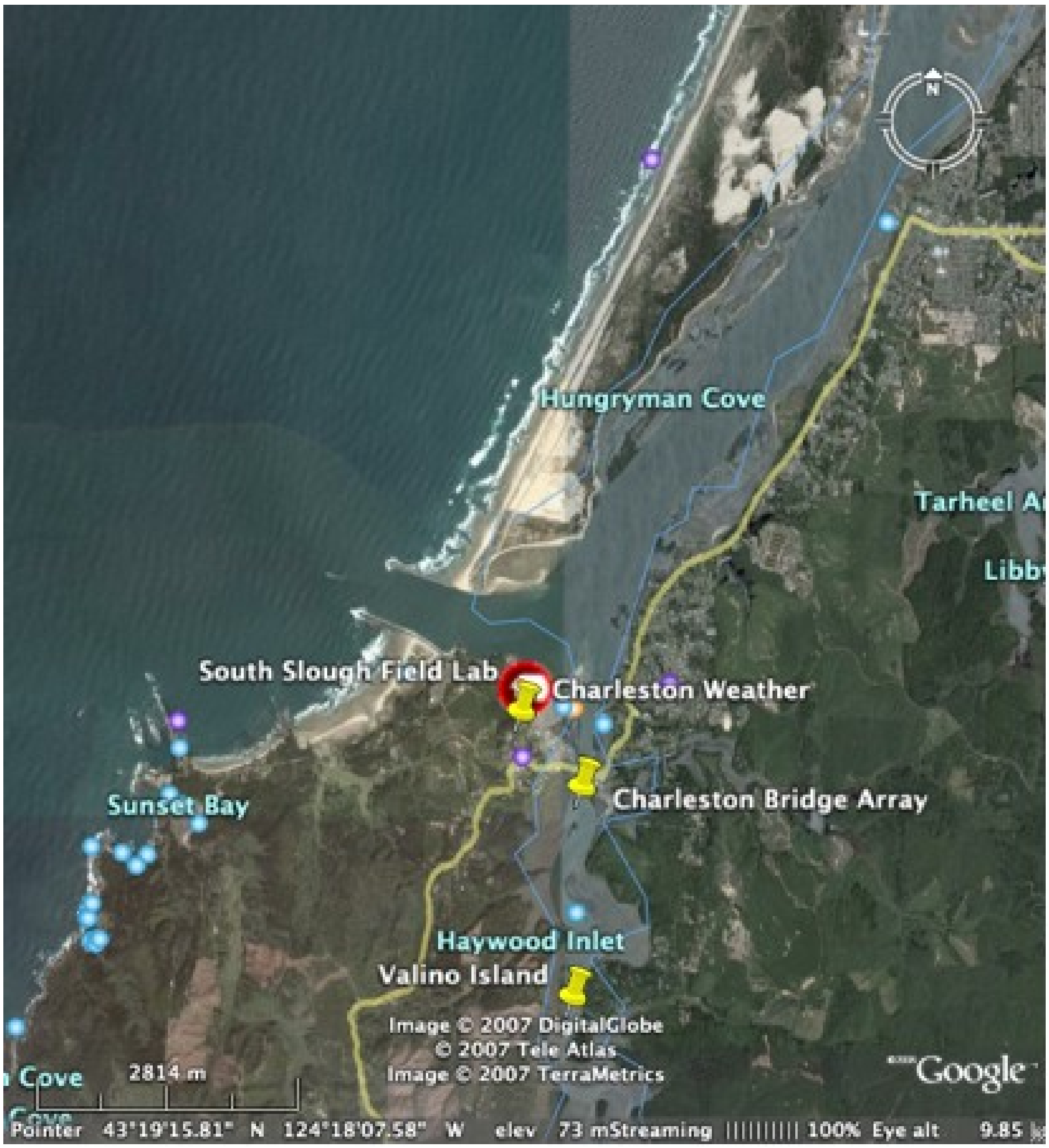


Figure 9. South Slough NERR with monitoring stations.

Study the sets of gauge data (Gauge Data for 9/5/07 at 11 AM EDT—Charleston Bridge) from the *Student Data Sheet—Chemistry in an Estuary*.

2a. Write down the difference between the maximum and minimum value for each water quality parameter (this number is called the range of values).

2b. What do you think causes the changes in each parameter over the course of one day?

Part 3 — Investigating Water Quality Over a Day

You will now study the same water quality parameters over a 24-hour period using a graphical display. Each graph (Graphical Data: Midnight 9/4 to 11 AM 9/5/07—South Slough, OR—Charleston Bridge) from the *Student Data Sheet* begins at midnight on Sept. 4 and ends at 11 AM on Sept. 5.

3a. Describe the pattern of change for each parameter.

3b. Give a reason to explain what is causing the variation of each parameter over a 24-hour period.

3c. Use the graphs to complete the following sentences:

i. When the temperature of the water in an estuary increases, the ________________________ decreases.

ii. The water in the South Slough estuary is slightly ______________________ (acidic or basic) on average during this 24-hour period.

Part 4 — Investigating Water Quality Over a Year

Now you will study the same four parameters as they vary over an entire calendar year, using the graphs (Graphical Data for the year 2006—South Slough, OR—Charleston Bridge) from the *Student Data Sheet*.

Compute the range for each water quality parameter for each site over the course of a year (high value - low value).

4a. Describe the pattern of change of each water quality factor over the course of a year.

4b. Explain what you believe is causing the variation of each factor over the course of a year.

Part 5 — Comparing Water Quality Data Between Three Different Estuarine Environments

You will now compare the ranges of water quality factors for South Slough, OR with two very different estuaries—Blackbird Landing, a monitoring station in the Delaware NERR, and Lower Estuary, a monitoring station in Old Woman Creek, Ohio, the only freshwater estuary in the National Estuarine Research Reserve System.

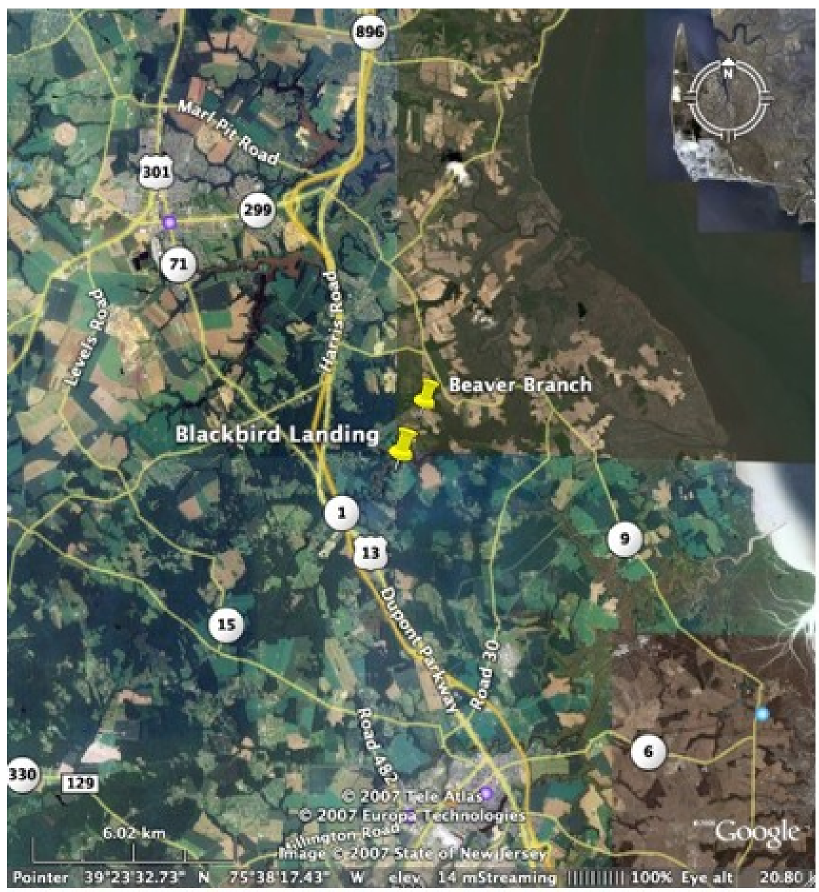


Figure 10. The Delaware NERR showing the location of Blackbird Landing

Figure 11. Aerial image of Old Woman Creek NERR showing the location of the Lower Estuary monitoring station

Study the 2006 data graphs (Graphical Data for the year 2006—Old Woman Creek, OH) from the *Student Data Sheet* and compute the yearly ranges for each of the four parameters.

Then study the 2006 data graphs for the Lower Estuary monitoring station in the Old Woman Creek NERR and compute the yearly ranges for each of the four parameters.

5a. Compare the ranges of the water quality parameters between the three sites: South Slough, Blackbird Landing, and Old Woman Creek Lower Estuary. Which parameter ranges are about the same? Which ones are different?

5b. Compare the time of year for the maximum and minimum pH, dissolved oxygen, salinity and water temperatures at each of the sites. Are they the same or different? Give one reason for any differences between them.

5c. Does the pattern of change for any of the four water quality factors vary appreciably between sites? If so, explain why the patterns are different.

Student Data Sheet
Activity 1: Chemistry in an Estuary

Part 2 — Investigating Water Quality in an Estuary

Gauge Data for 9/5/07 at 11 AM EDT — Charleston Bridge

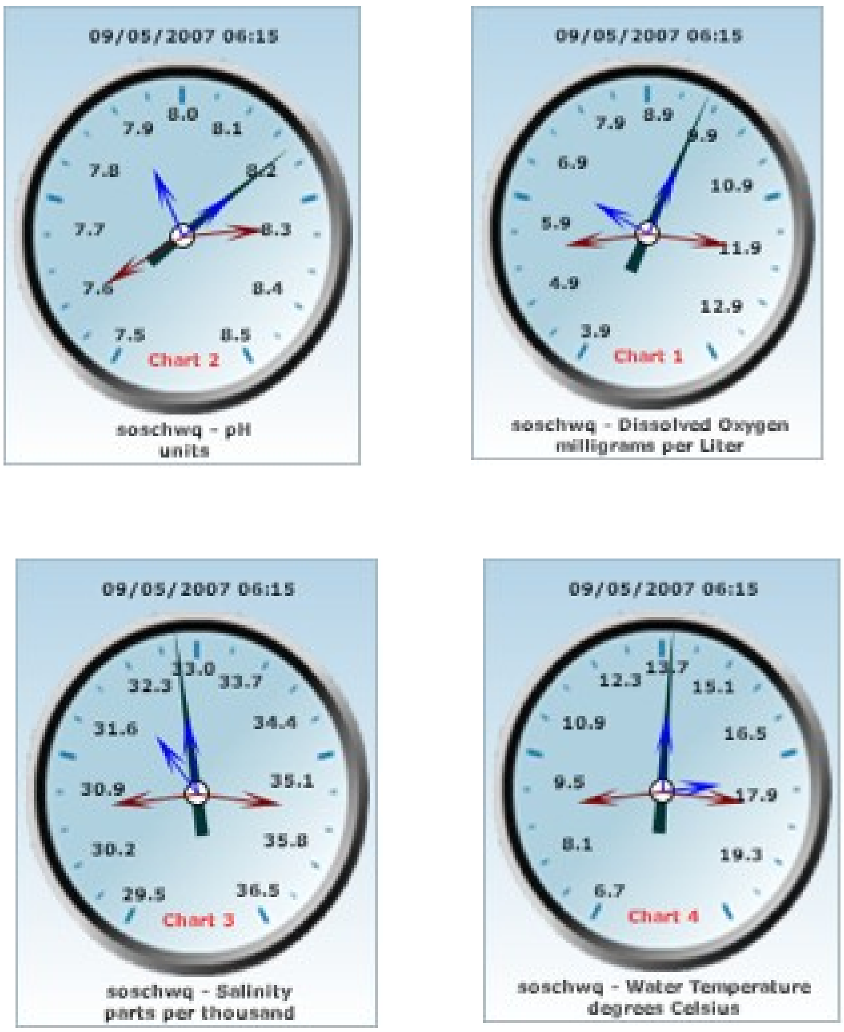


Figure 12. Gauge Data for 9/05/07 at 11 AM EDT—Charleston, Bridge

Part 3 — Investigating Water Quality Over a Day

Graphical Data: Midnight 9/4 to 11 AM 9/5/07—South Slough, OR—Charleston Bridge

NOTE: The vertical and horizontal scales differ somewhat from graph to graph.

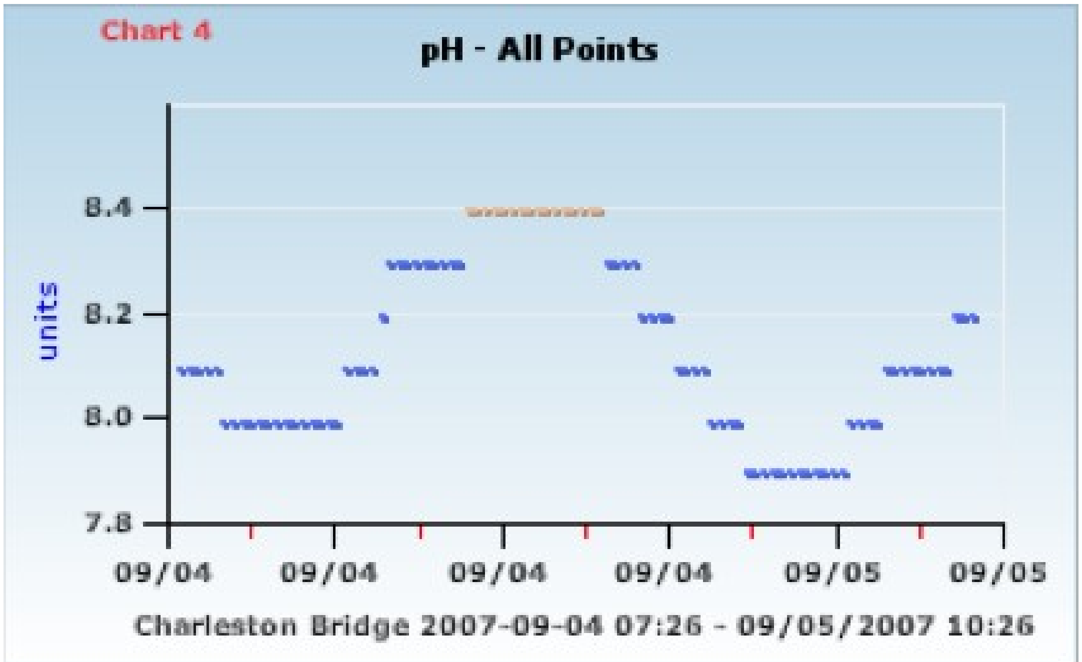


Figure 13. Daily pH: South Slough, OR—Charleston Bridge

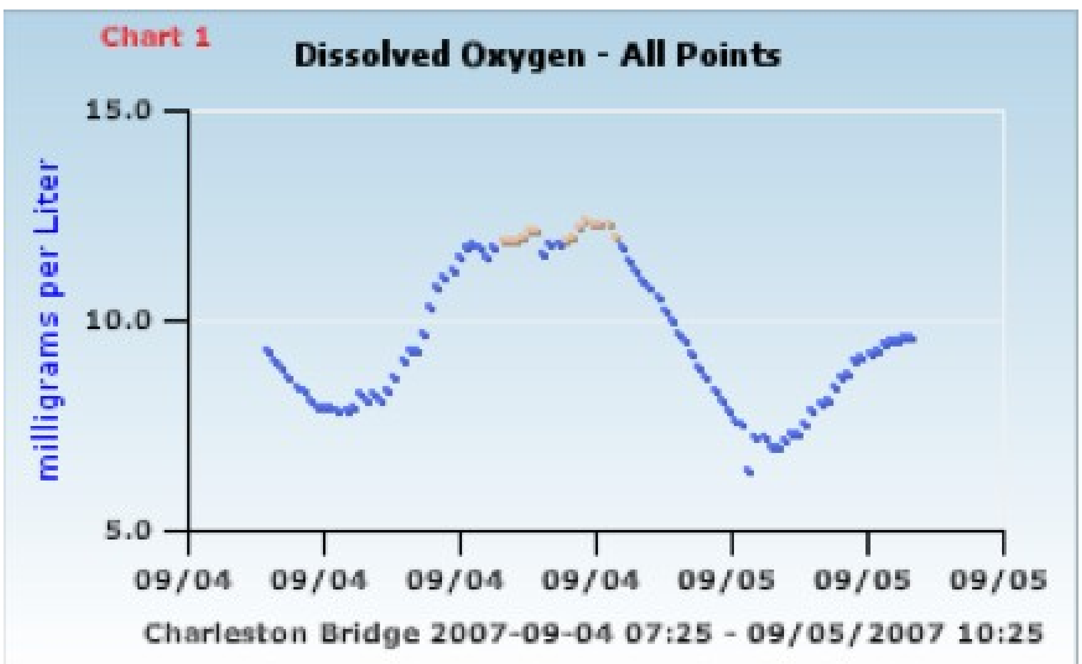


Figure 14. Daily DO: South Slough, OR—Charleston Bridge

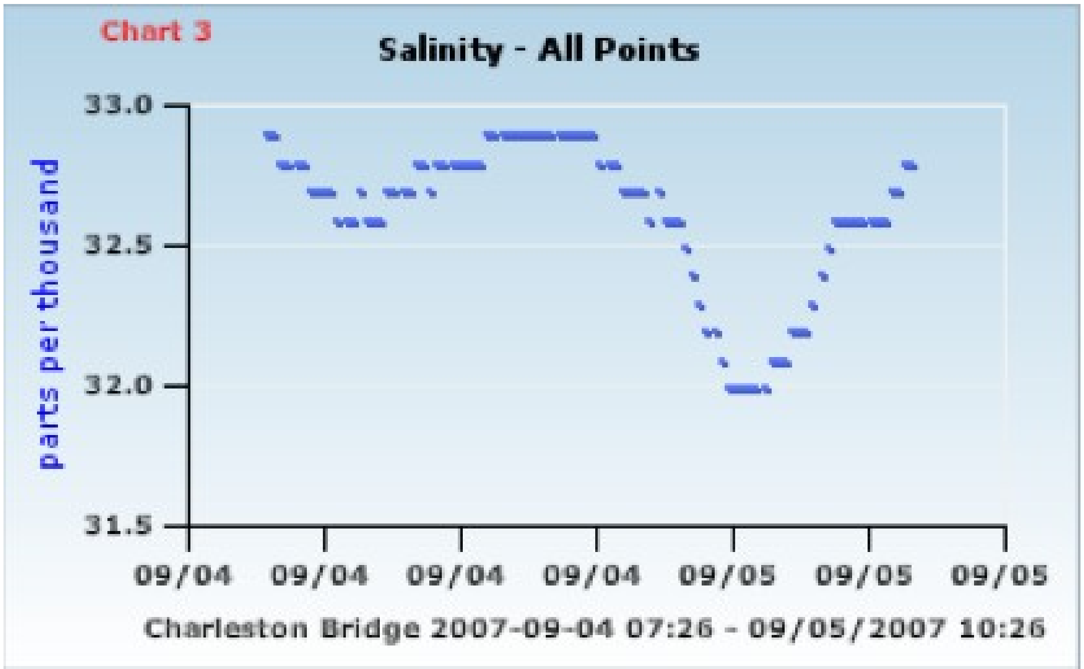


Figure 15. Daily Salinity: South Slough, OR—Charleston Bridge

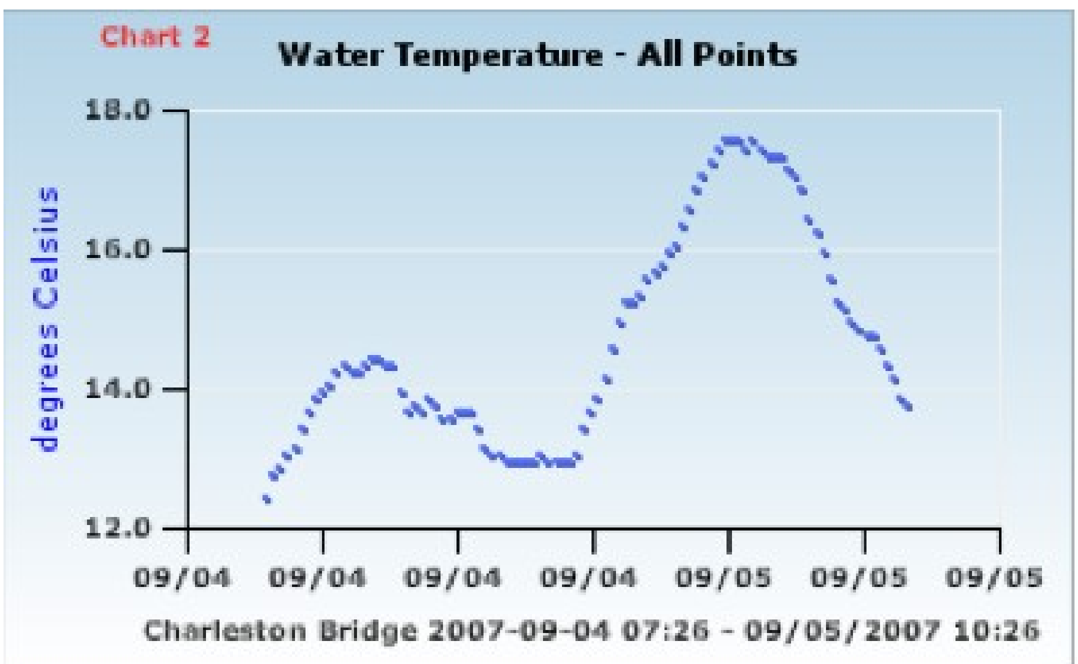


Figure 16. Daily Water Temperature: South Slough, OR—Charleston Bridge

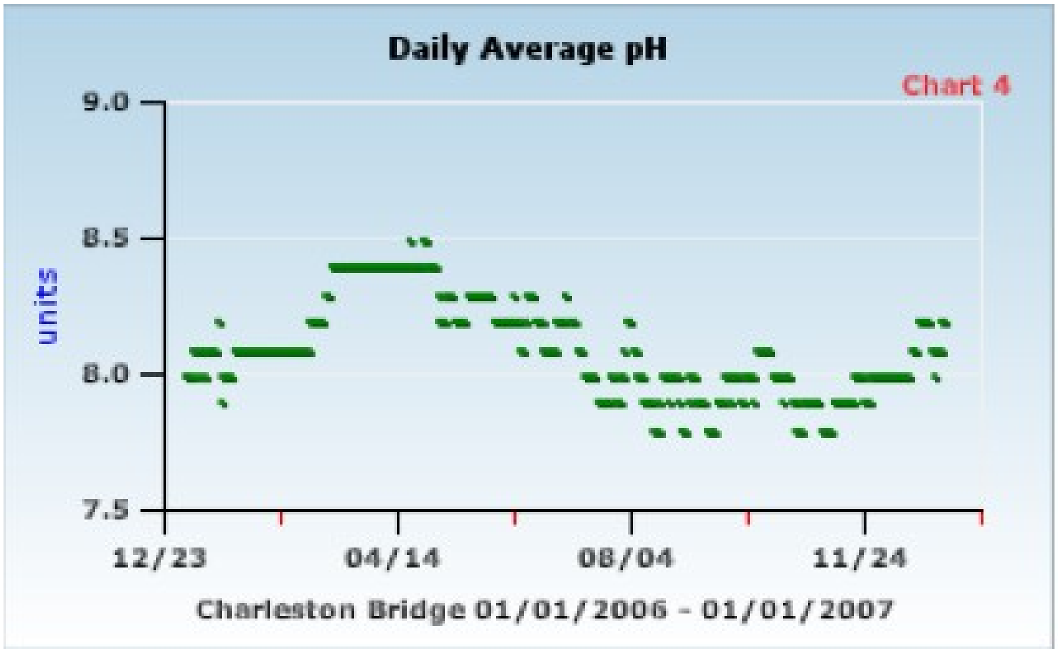


Figure 17. Annual pH: South Slough, OR—Charleston Bridge

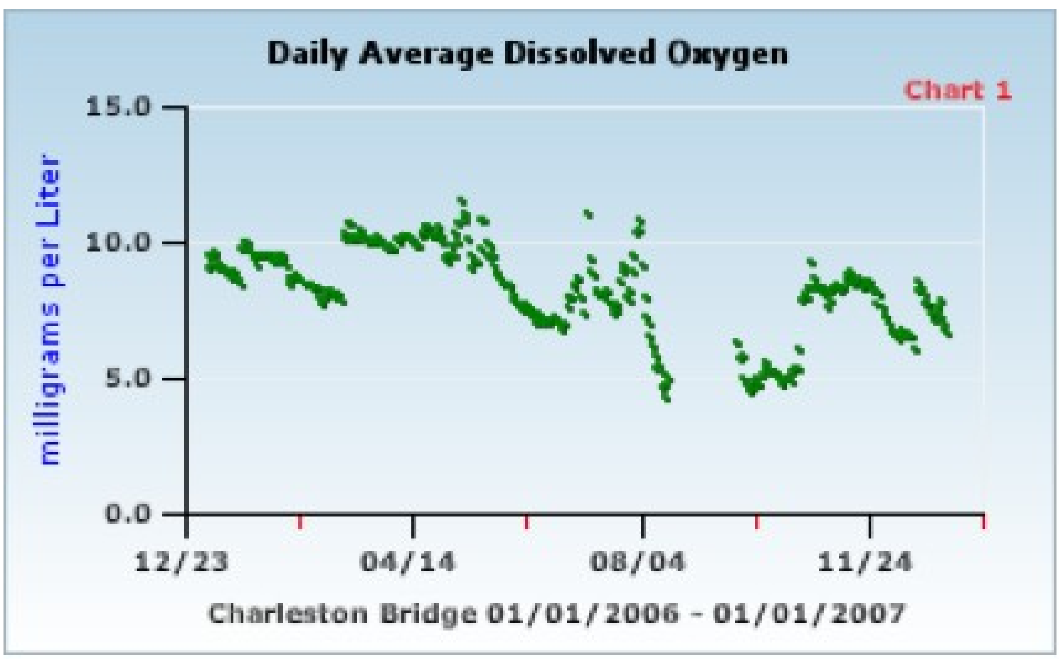


Figure 18. Annual DO: South Slough, OR—Charleston Bridge

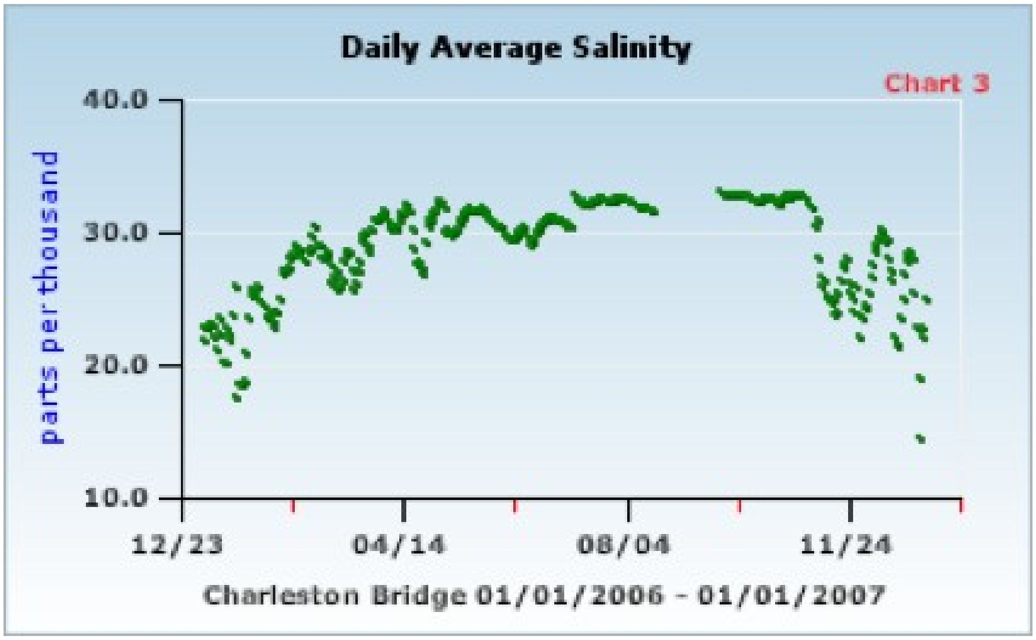


Figure 19. Annual Salinity: South Slough, OR—Charleston Bridge

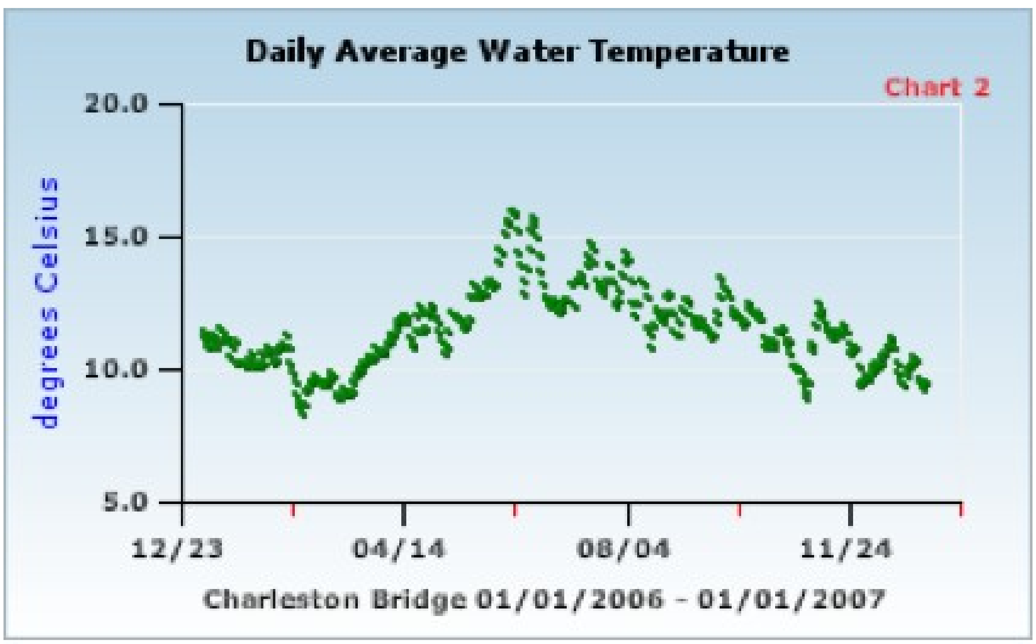


Figure 20. Annual Water Temperature: South Slough, OR—Charleston Bridge

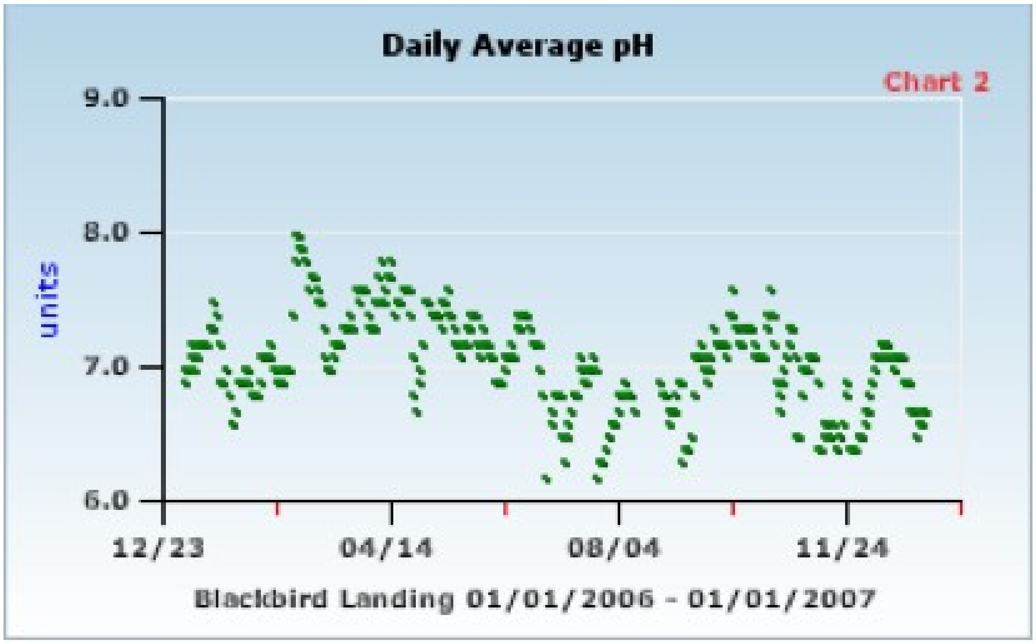


Figure 21. Annual pH: Blackbird Landing, DE

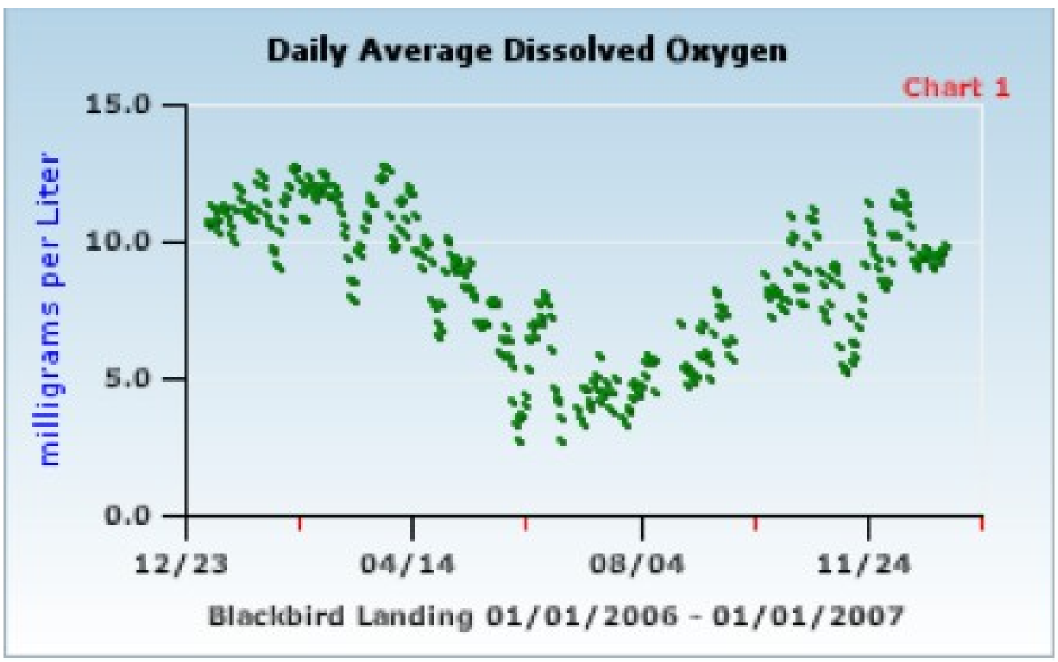


Figure 22 Annual DO: Blackbird Landing, DE

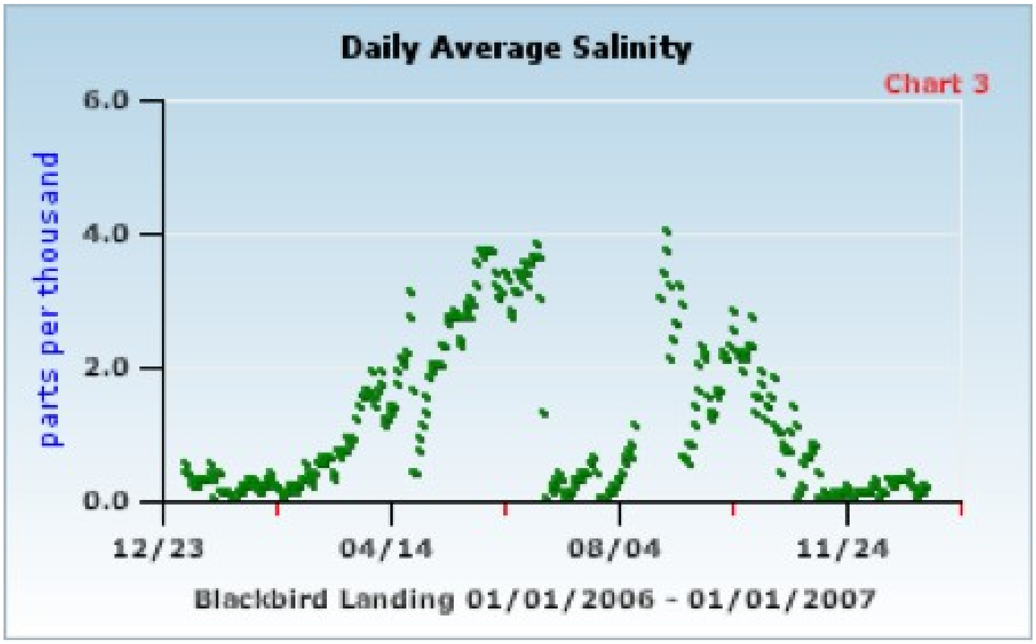


Figure 23. Annual Salinity: Blackbird Landing, DE

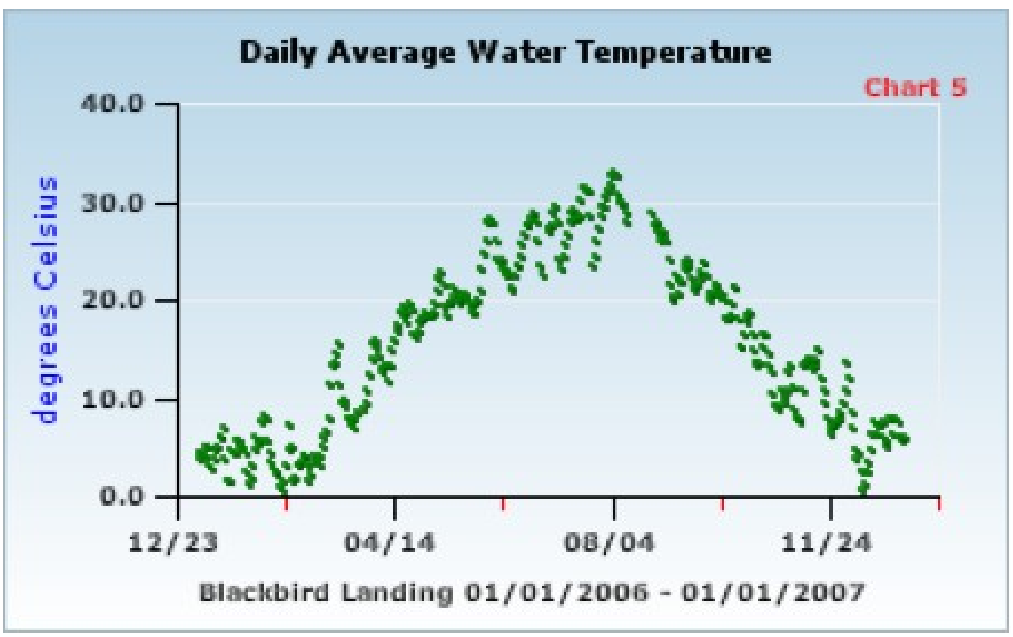


Figure 24. Annual Water Temperature: Blackbird Landing, DE

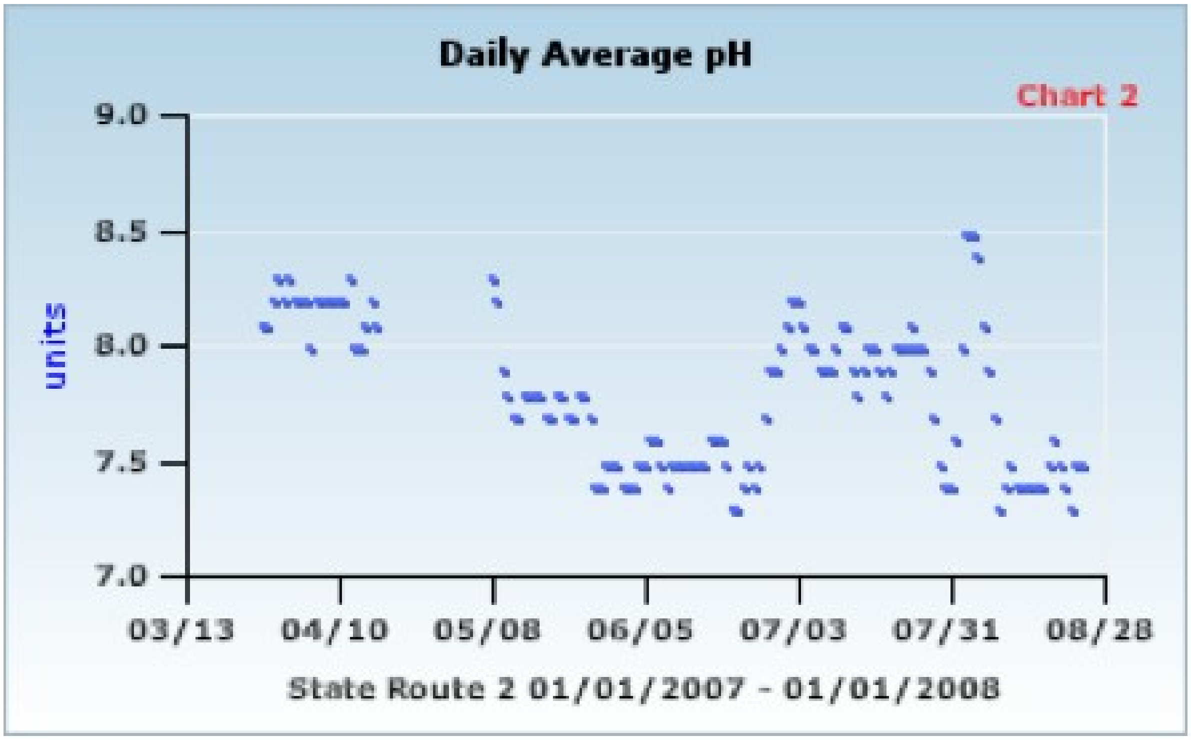


Figure 25. Annual pH: Old Woman Creek, OH—Lower Estuary

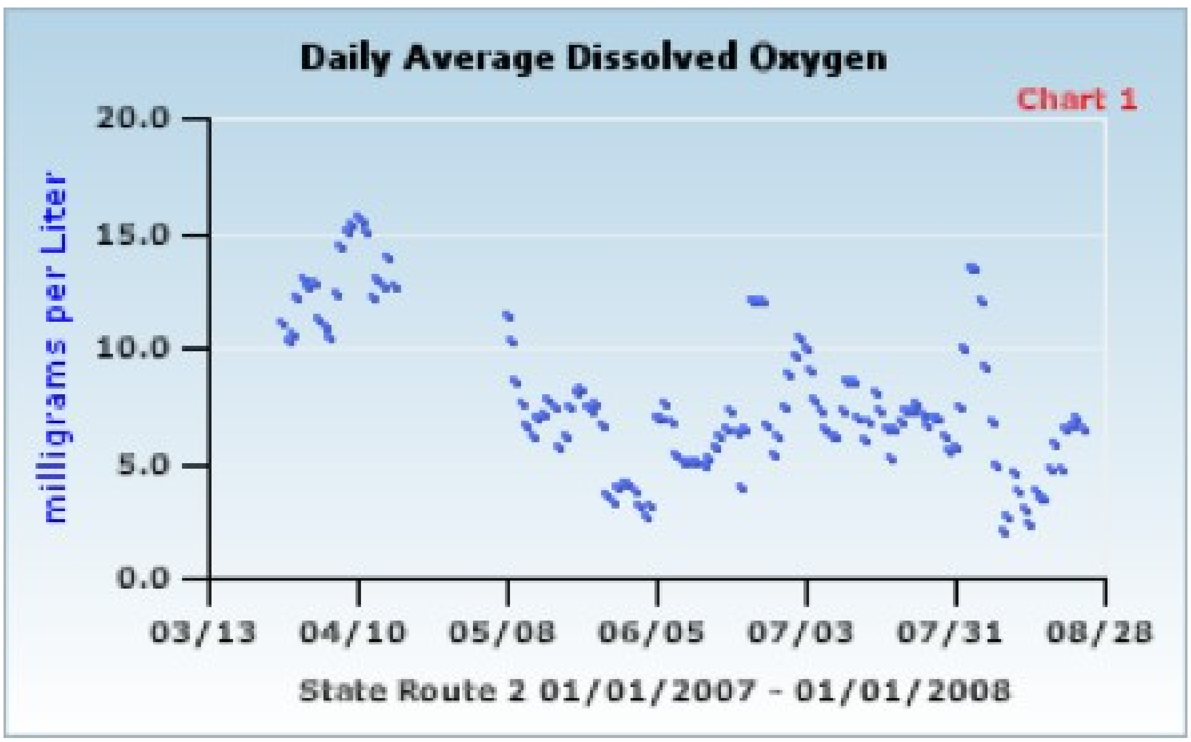


Figure 26. Annual DO: Old Woman Creek, OH—Lower Estuary

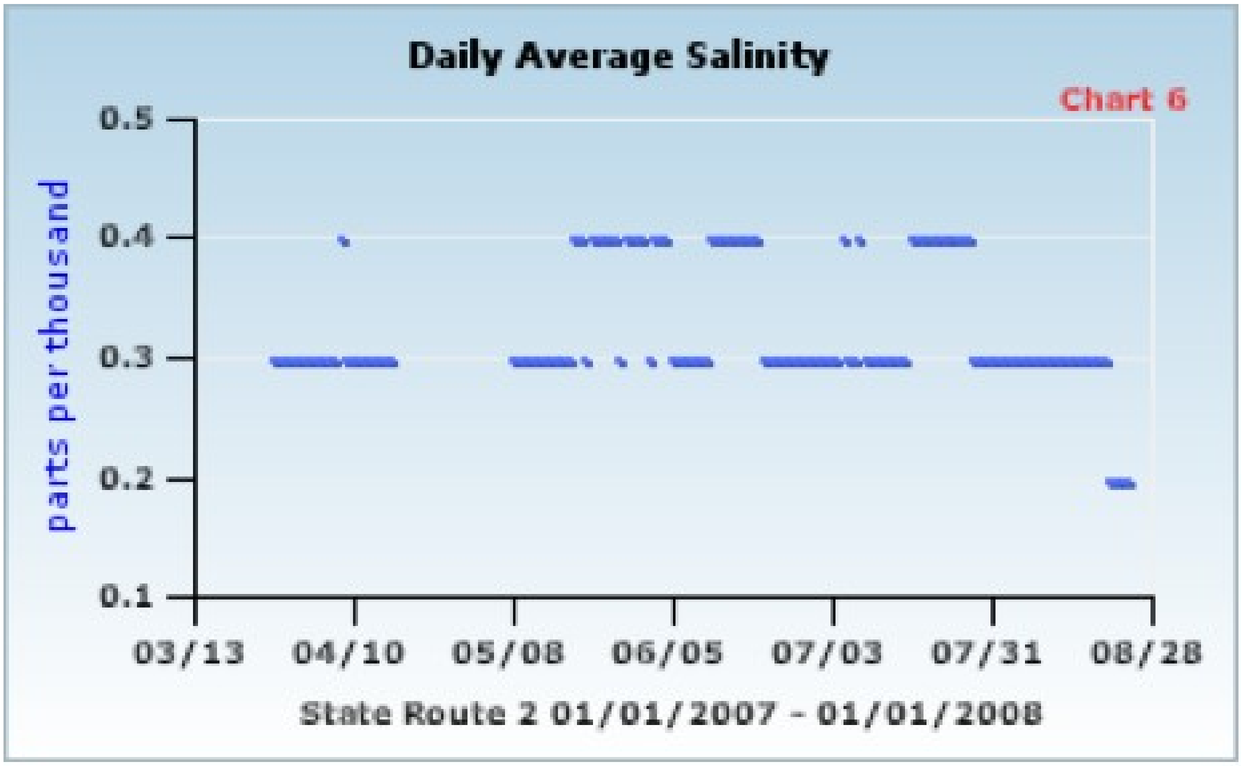


Figure 27. Annual Salinity: Old Woman Creek, OH—Lower Estuary

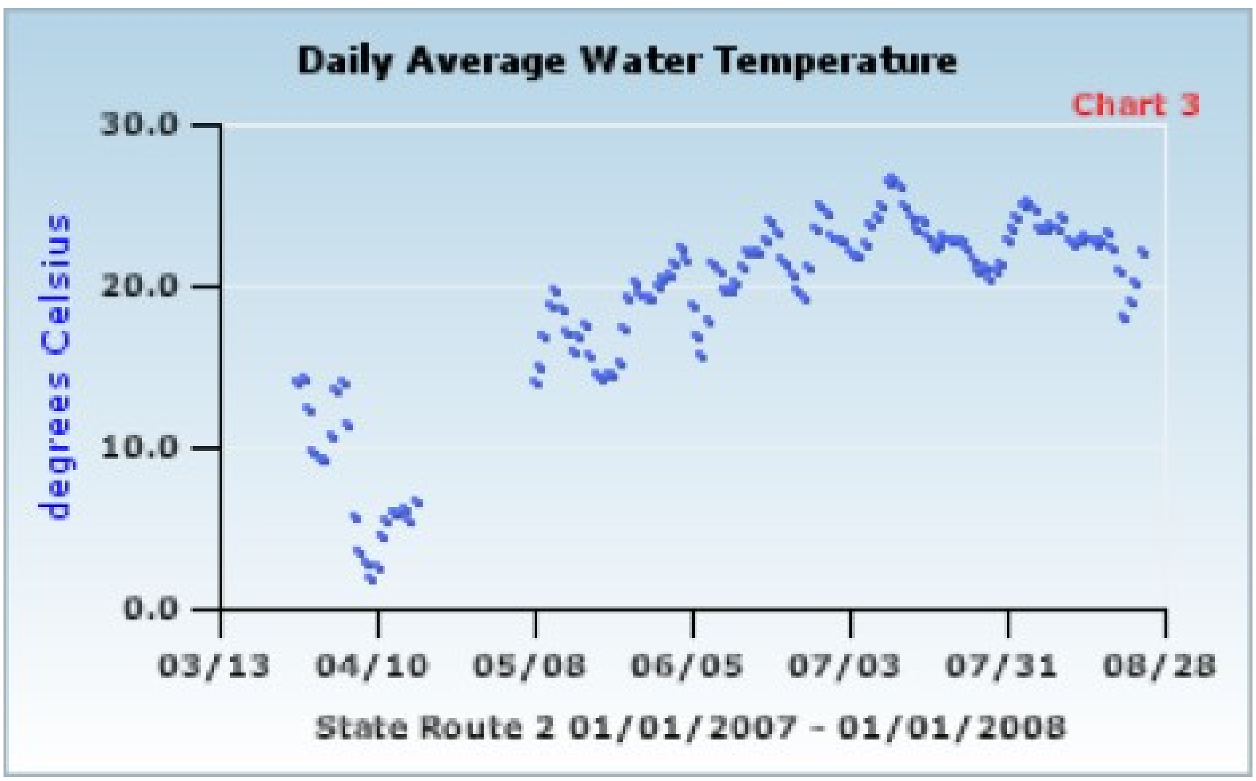


Figure 28. Annual Water Temperature: Old Woman Creek, OH—Lower Estuary

Teacher Guide—Physical Science Module
Activity 2 — Dissolved Oxygen in an Estuary

Featured NERRS activity:

Narragansett Bay National Estuarine Research Reserve, Rhode Island
http://nerrs.noaa.gov/NarragansettBay/welcome.html

Activity Summary

In this activity, students learn about dissolved oxygen (DO) and its effects on life, with a focus on the chemistry. First, they are introduced to, and analyze data gathered from, water quality sensors in Narragansett Bay National Estuarine Research Reserve (NERR), observing how DO and chlorophyll-a change from the surface to the bottom and considering the relationships between DO and temperature. Then, in the unique environment of Azevedo Pond in the Elkhorn Slough NERR, CA, they analyze DO data and speculate about how hydrodynamics, abiotic factors, and biological processes cause extreme fluctuations in DO in the pond.

Learning Objectives

Students will be able to:

1. Explain the relationships between dissolved oxygen and water depth, chlorophyll-a and water depth, and dissolved oxygen and temperature.
2. Explain how these parameters interact during estuarine processes and in such phenomena as eutrophication, algal blooms, and supersaturation-hypoxia fluctuations.
3. Understand how photosynthesis, respiration, and decomposition affect dissolved oxygen.
4. Explain the role of these processes in daily or seasonal dissolved oxygen fluctuations in some estuaries.
5. Explain how hypoxia and anoxia occur, using data as evidence, and explain the affect on estuarine animals.

Grade Levels

9-12

Teaching Time

3 class sessions (55 minutes) + homework

Organization of the Activity

This activity consists of 2 parts which help deepen understanding of estuarine systems:

Dissolved Oxygen in Narragansett Bay

What's Happening in Azevedo Pond?

Featured NERR Estuaries

- Narragansett Bay National Estuarine Research Reserve, Rhode Island
  http://nerrs.noaa.gov/NarragansettBay/welcome.html

- Elkhorn Slough National Estuarine Research Reserve, California (Azevedo Pond)
  http://nerrs.noaa.gov/ElkhornSlough/welcome.html

Background

Students focus on the relationship between dissolved oxygen, plant growth, chlorophyll-a and temperature using SWMP data from monitoring stations in the Narragansett Bay Estuarine Research Reserve. If your students have not studied the processes of photosynthesis or respiration, go over the equations as part of your introduction to the activity. What follows is additional background information on the concepts contained in this activity.

Dissolved Oxygen

To survive, fish, crabs, oysters and other aquatic animals must have sufficient levels of dissolved oxygen (DO) in the water. The amount of dissolved oxygen in an estuary's water is a major factor that contributes to the type and abundance of organisms that can live there.

Oxygen enters the water through two natural processes: (1) diffusion from the atmosphere and (2) photosynthesis by aquatic plants. The mixing of surface waters by wind and waves increases the rate at which oxygen from the air can be dissolved or absorbed into the water.

DO levels are influenced by temperature and salinity. The solubility of oxygen, or its ability to dissolve in water, decreases as the water's temperature and salinity increase. DO levels in an estuary also vary seasonally, with the lowest levels occurring during the late summer months when temperatures are highest.

Bacteria, fungi, and other decomposer organisms reduce DO levels in estuaries because they consume oxygen while breaking down organic matter.

Oxygen depletion may occur in estuaries when many plants die and decompose, or when wastewater with large amounts of organic material enters the estuary. In some estuaries, large nutrient inputs, typically from wastewater, stimulate algal blooms. When the algae die, they begin to decompose. The process of decomposition depletes the surrounding water of oxygen and, in severe cases, leads to hypoxic (very low oxygen) conditions that kill aquatic animals. Shallow, well-mixed estuaries are less susceptible to this phenomenon because wave action and circulation patterns supply the waters with plentiful oxygen.

Dissolved oxygen is critical for the survival of animals and plants that live in the water. Higher oxygen levels are one indicator of a healthier ecosystem. The more oxygen there is in the water, the healthier the ecosystem is. As the water temperature increases, the amount of oxygen that can dissolve in the water decreases. For example, fresh water at 0°C can contain up to 14.6 mg of oxygen per liter of water, but at 20°C, it can only hold 9.2 mg of oxygen per liter. Thus, seasonal water temperature (and dissolved oxygen) is an important indicator of habitat quality for many estuarine species.

Through a process called photosynthesis, plants remove carbon dioxide (CO_2) from the water and emit oxygen (O_2). Since CO_2 becomes carbonic acid when it dissolves in water, the removal of CO_2 results in a higher pH and the water becomes more alkaline, or basic. When algae naturally begin to increase in estuaries during the spring, pH levels tend to rise. An overabundance of algae (called an algal bloom) may cause pH levels in an estuary to rise significantly, and this can be lethal to aquatic animals.

Excessive plant growth and decay can cause significant increases in nutrients such as nitrogen and phosphorous in the water, a condition known as eutrophication. Eutrophication is sometimes a result of pollution sources such as the release of sewage effluent and run-off from lawn fertilizers into streams or rivers leading to the estuary. Eutrophication generally promotes excessive plant growth and decay, favors certain weedy species over others, and is likely to cause severe reductions in water quality, particularly DO. In aquatic environments, eutrophication may cause algae blooms that disrupt normal functioning of the ecosystem, causing a severe drop in DO that needed for fish and shellfish to survive. The water then becomes cloudy, colored a shade of green, yellow, brown, or red.

DO is measured in milligrams per liter of water. DO percent saturation depends on temperature (and also elevation). Percent Saturation is the amount of oxygen dissolved in the water sample compared to the maximum amount that could be present at the same temperature.

Preparation

- Make copies of the *Student Readings* and *Student Worksheets*.
- Arrange for students to have access to online data either by obtaining a computer projector to present the data in front of the whole class or by arranging for student groups to view the data on individual computers. On the computer(s), bookmark the site: http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm.
- Download the PowerPoint—*Azevedo Pond* to a computer that can project in front of the class or onto computers the students can access directly.
- Assign *Student Reading—Introduction to Narragansett Bay* and *Student Reading—Dissolved Oxygen in an Estuary* for homework before beginning this activity, if possible.

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

B2. Structure and properties of matter
B3. Chemical reactions

Content Standard C: Life Science

C4. The interdependence of organisms

C5. Matter, energy, and organization in living systems

C6. The behavior of organisms

Content Standard F: Science in Personal and Social Perspectives

F3. Natural Resources

F4. Environmental quality

F5. Natural and human-induced hazards

F6. Science and technology in local, national, and global challenges

Procedure

Part 1 — Dissolved Oxygen in Narragansett Bay

1. Have students read *Student Reading—Introduction to Narragansett Bay* and *Student Reading—Dissolved Oxygen in an Estuary*.

2. Ask the students for their ideas about oxygen and life in estuaries. What conditions are necessary for organisms to survive in an estuary? You can list the responses on the board. How do organisms that live in the water extract oxygen for their use? How does oxygen enter estuary water? Prompt students to apply the concepts they have already studied, such as solubility of gasses, photosynthesis and respiration, and interactions between the atmosphere, hydrosphere, and biosphere.

3. Ask students to identify abiotic factors, such as Earth processes in an estuary, or biotic factors that could affect DO.

4. Introduce students to the Web site http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm. and the interactive tool that allows them to see various water quality sensors at different depths. Explain that they will observe how dissolved oxygen, temperature, and chlorophyll-a change with depth for two different locations in the bay. You can go through the site with students or let them work through the activity in small groups.

5. As a class or in groups, have students complete the *Student Worksheet—Dissolved Oxygen in Narragansett Bay*, collecting and analyzing data from two sites: Pomham Rocks, a shore-based site, and South Prudence, situated further out in the Bay.

6. Discuss results and students responses.

Note: Consider having students read the *Student Reading—Introduction to Azevedo Pond* for homework, as preparation for Part 2.

Materials

Students

- ❑ Need to work in a computer lab or with a computer and projector
- ❑ Copy of Student Reading 1: Introduction to Narragansett Bay
- ❑ Copy of Student Reading 2: Dissolved Oxygen in an Estuary
- ❑ Copy of Student Reading 3: Introduction to Azevedo Pond
- ❑ Copy of Student Worksheet 1: Dissolved Oxygen in Narragansett Bay
- ❑ Copy of Student Worksheet 2: Dissolved Oxygen in Azevedo Pond.

Teachers

- ❑ Bookmark the following site in all computers: http://omp.gso.uri.edu/ompweb/doee/virtual/sensors.htm.
- ❑ Download the power point presentation titled “Azevedo Pond” from the estuaries.gov site. Click on the tab titled Teachers, Physical Science and find the presentation under “Supporting Materials”.

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

Part 2 — What's Happening in Azevedo Pond?

1. Have students read the *Student Reading—Introduction to Azevedo Pond*, project the PowerPoint—*Azevedo Pond*, and go over the list of characteristics

2. Have students complete the *Student Worksheet—Dissolved Oxygen in Azevedo Pond*. Students may need help interpreting the graph, particularly if it is not in color.

3. Discuss results and students responses.

Check for Understanding

- Discuss the following:

  a. In general, what is the pattern of DO levels in a pond over the period of a single day?
  b. In general, what is the pattern of chlorophyll-a in the same pond over the period of a single day?
  c. What causes hypoxic conditions in an estuary?

- Have students compare DO levels at various sites within NERRS. Download or let students download graphs using the System-wide Monitoring Data (SWMP) data to compare DO stability between an area where eutrophication is common (e.g. Childs River, Waquoit Bay NERR) and a well-flushed area (e.g. Menauhant). How are the DO levels different? Explain why differences occur.

Optional Extension Inquiries

1. Use dissolved oxygen probes, if available, to measure DO and consider how it changes over time under various conditions. For example, (1) take measurements of DO from water samples that include algae, (2) expose the samples to direct light for about five days, and then (3) measure DO again. (Samples can be collected from an estuary or created using tap water and Elodea.) Or (1) take measurements of DO from a jar of just tap water and another jar with tap water and chopped green vegetables and (2) monitor the DO in the jars over five days.

2. Analyze dissolved oxygen and chlorophyll-a data from sampling sites on Chesapeake Bay to identify conditions that caused fish kills and crab jubilees in the Bay during the summer of 2003. http://www.cbf.org/site/PageServer?pagename=resources_facts_deadzone#cause

3. Track recent algal blooms in Chesapeake Bay from the Maryland Department of Natural Resources Eyes on the Bay Site: http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm

Teacher Worksheet with Answers
Activity 2: Dissolved Oxygen in Narragansett Bay National Estuarine Research Reserve

Part 1 — Dissolved Oxygen in Narragansett Bay

Pomham Rocks

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)
1	*165*	*12.5*	*22*	*25*
3	*120*	*9.2*	*21*	*34*
5	*110*	*8.4*	*20*	*22*
7	*80*	*6.2*	*19*	*10*
9	*40*	*3.1*	*19*	*5*
11	*20*	*1.6*	*19*	*No reading at this depth*

South Prudence

Depth (meters)	DO Saturation (%)	DO Concentration (mg/L)	Water Temperature (degrees C)	Chlorophyll (µg/L)
1	*160*	*11.6*	*23*	*12*
3	*125*	*9.1*	*23*	*22*
6	*100*	*7.3*	*22*	*15*
9	*80*	*6.2*	*19*	*11*
12	*80*	*6.2*	*19*	*9*
15	*75*	*5.8*	*19*	*No reading at this depth*

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

Answer: DO concentration can be influenced by factors, such as water temperature, turbulence caused by winds, waves, currents, and mixing, all factors that change from site to site.

1b. As depth increases, how does:

- DO concentration change? DO saturation?

  Answer: As you go deeper, DO concentration and DO saturation both decrease. (Teacher Note: Oxygen dissolves in estuary water partly by diffusion from the atmosphere. This occurs mainly near the surface, DO is higher there. DO is also generated by turbulence in the water caused by currents, winds and waves and by mixing, which is greater near the surface. DO also decreases with depth because of increasing water pressure. DO is also generated by the photosynthesis of plankton and macroalgae (Seaweed), and plants that grow on the bottom. At greater depths, sunlight for photosynthesis decreases.)

- The temperature of the water?

  Answer: As you go deeper, the temperature of the water decreases, though not smoothly. (Teacher Note: Students may become confused by the fact that although water gets colder with depth, DO does not increase with these colder temperature. In these cases of changing depth, other factors must also be considered. Water pressure, which increases with depth, and reduced sunlight, which limits photosynthesis, are much stronger influences on DO than colder water.)

- Chlorophyll amounts?

  Answer: As you go deeper, chlorophyll concentration decreases. (Teacher Note: Less sunlight can penetrate the water at those depths. Therefore, less sunlight is available for photosynthesis.)

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

Answer: July, August, September, October

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)**
January 20	*12.7*	*4*
March 15	*13.7*	*4*
March 30	*12.6*	*6*

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)**
August 1	*5.8*	*26.9*
August 30	*5.5*	*21.9*
October 1	*6.5*	*19*

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

Answer: Generally, there is an inverse relationship. As temperature increases, dissolved oxygen decreases and as temperature decreases, dissolved oxygen increases. Water at colder temperatures can hold more dissolved oxygen.

Teacher Worksheet with Answers
Activity 2: Dissolved Oxygen in Azevedo Pond

Part 2 — What's Happening in Azevedo Pond?

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	*Most of the water will be close to the surface where oxygen will diffuse into the water, and light can probably penetrate the entire water column allowing for photosynthesis and creation of DO. However, light can probably heat the water column thoroughly, and temperatures that are too high will decrease DO.*
Restricted water flow	*The lack of much water exchange limits DO, because it keeps water from mixing and becoming aerated.*
High productivity of plankton	*Lots of photosynthesis will produce lots of DO, but if there is an overabundance of plankton, it may produce algal mats, especially if there is an excess of nutrients. When the algal mats die, they will decompose and this will consume oxygen.*
Large changes in temperature	*Can cause either a large increase of plant growth that increases DO, or a drop in temperature can cause massive die off of plant matter, subsequent decay and lowering of DO.*
Bordered by strawberry farm	*May receive a high amount of nitrates and phosphates from the fertilizers during rain runoff. These nutrients could cause algae blooms that will produce lots of oxygen, but which will eventually decay, consuming DO.*
Lack of tidal flushing	*Will mean not much mixing. Also means that nutrients and the algae will remain in the pond for longer periods of time, allowing for photosynthesis of algae blooms and creation of DO, but also decomposition of algal mats and eventual hypoxia.* *Poor flushing causes thermal stratification, which further keeps water from mixing. Warmer waters closer to the surface may limit production of DO.*

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.

2a. What is the range of DO (orange curves) for this period?

Answer: From a high of about 275% sat to a low of 0% sat.

2b Describe the pattern you see from day to day.

Answer: It steadily rises during daylight hours and spikes at about mid-day. Then it declines from evening until midnight, getting down to zero during the middle of the night.

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

Answer: PAR changes in the same way as DO throughout the 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.

Answer: Because the pond is poorly flushed by the tide, plankton and nutrients remain in the pond for long periods of time. The shallow water gets ample sunlight for algae and plants to photosynthesize throughout the water column, generating an abundance of DO. As PAR increases throughout the day, photosynthesis increases. This generates levels of oxygen that cause the water to be supersaturated, but only during the daylight hours. At night, the abundance of algae and the plants continues to respire, but without photosynthesis to balance the respiration. In darkness, the chlorophyll undergo respiration to the point where most of the oxygen is consumed and the water is hypoxic (the percentage of DO saturation is zero).

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

Answer: Azevedo Pond is the only one of these sites that has had hypoxic conditions every year between 1996 and 2006. Each year, about 15-20% of the year or 1.8-2.4 months (54-72 days) have hypoxic conditions.

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.

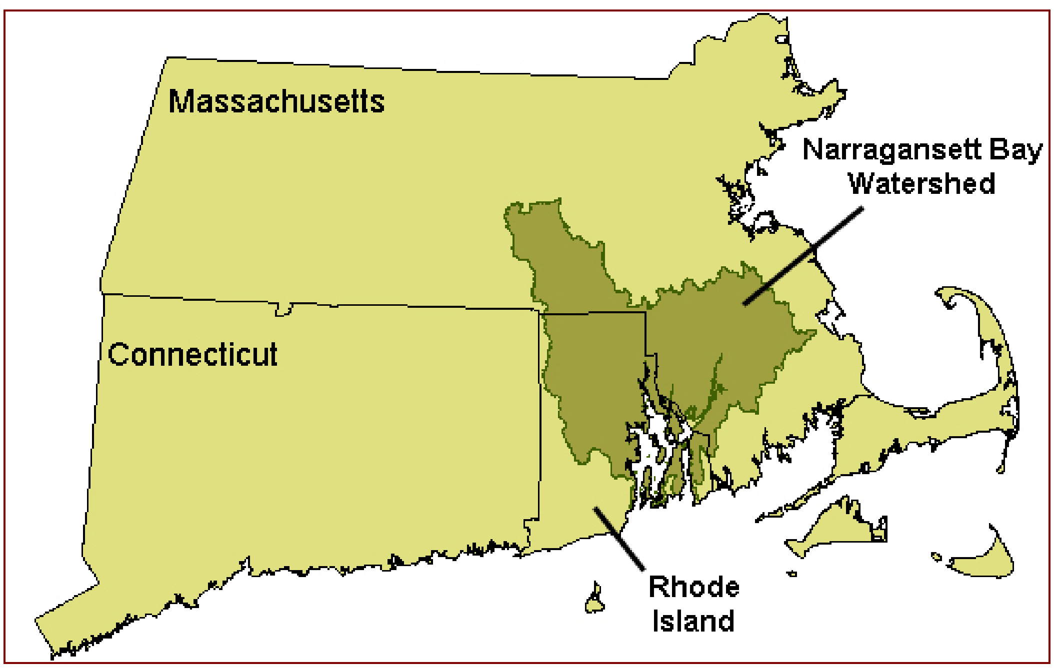


Figure 1 . The ~1600 square mile Narragansett Bay watershed extends up into the State of Massachusetts.

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.

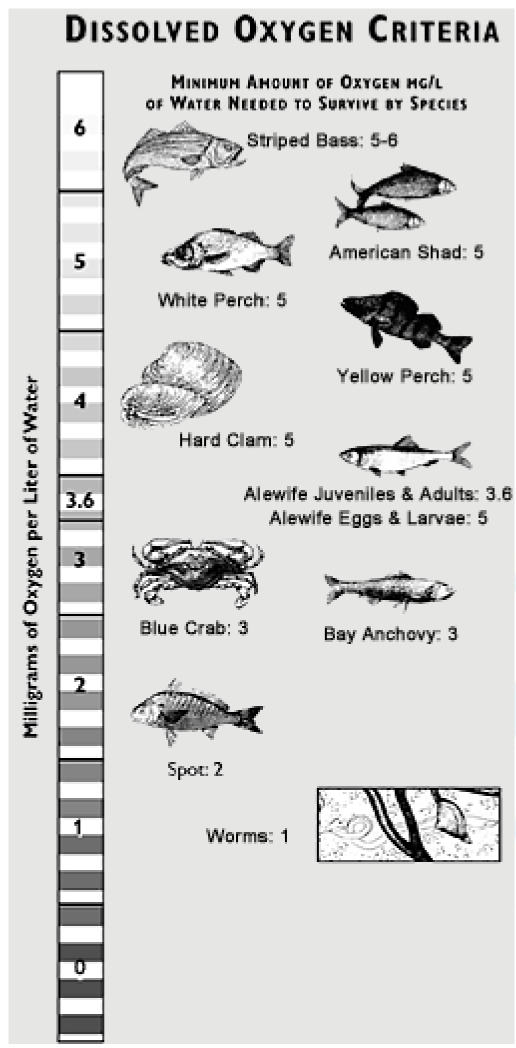


Figure 4. Minimum amount of DO needed for species to survive.

(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

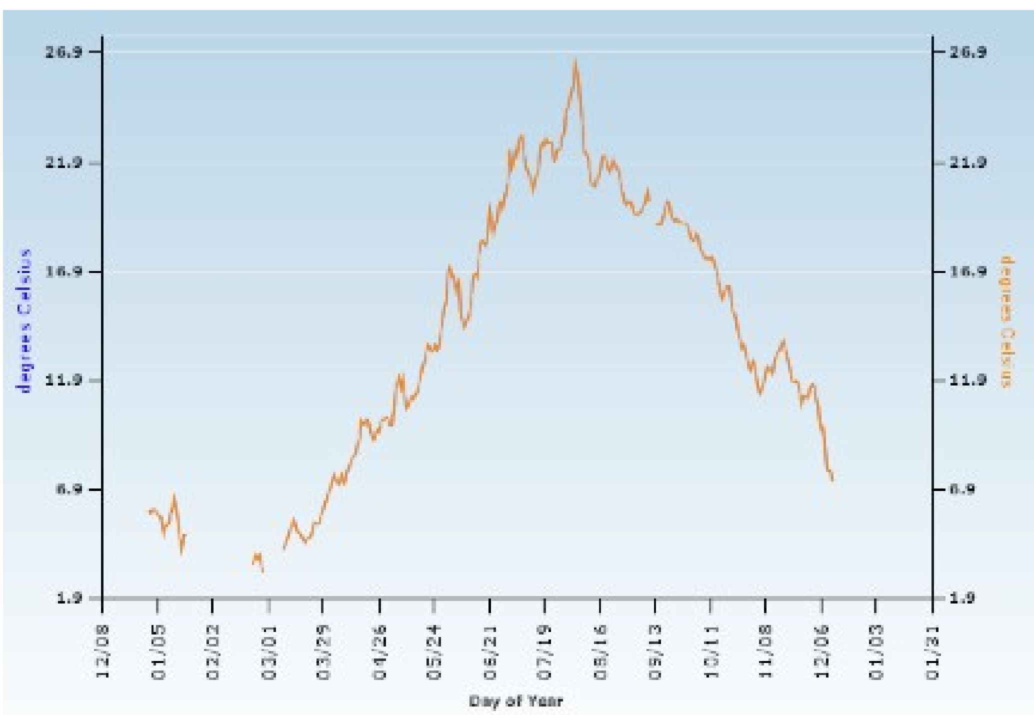


Figure 6. Daily Temperature: Narragansett Bay NERR

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.

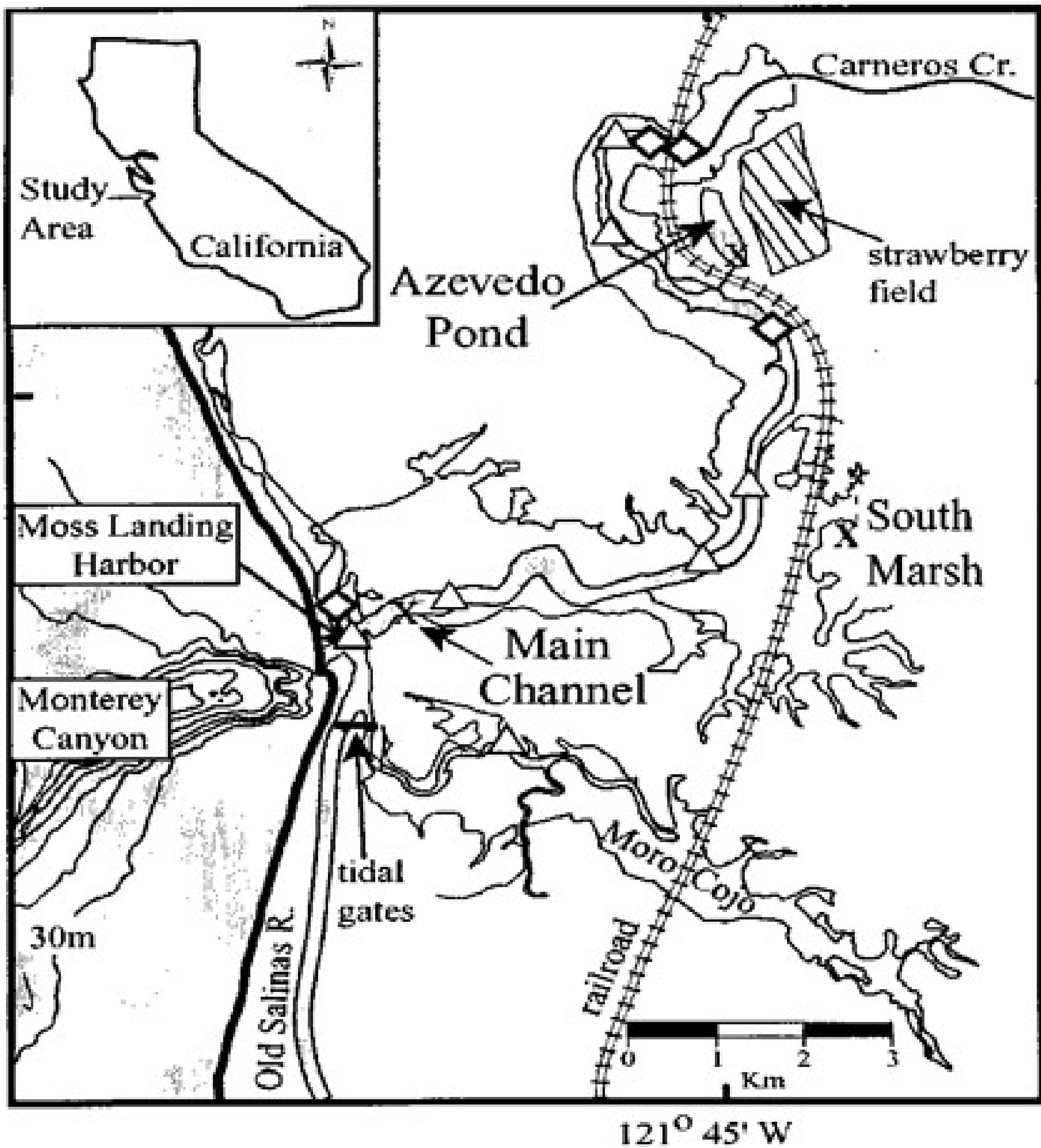


Figure 8. Map of Azevedo Pond and the Surrounding Area

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 tempera-ture	
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.

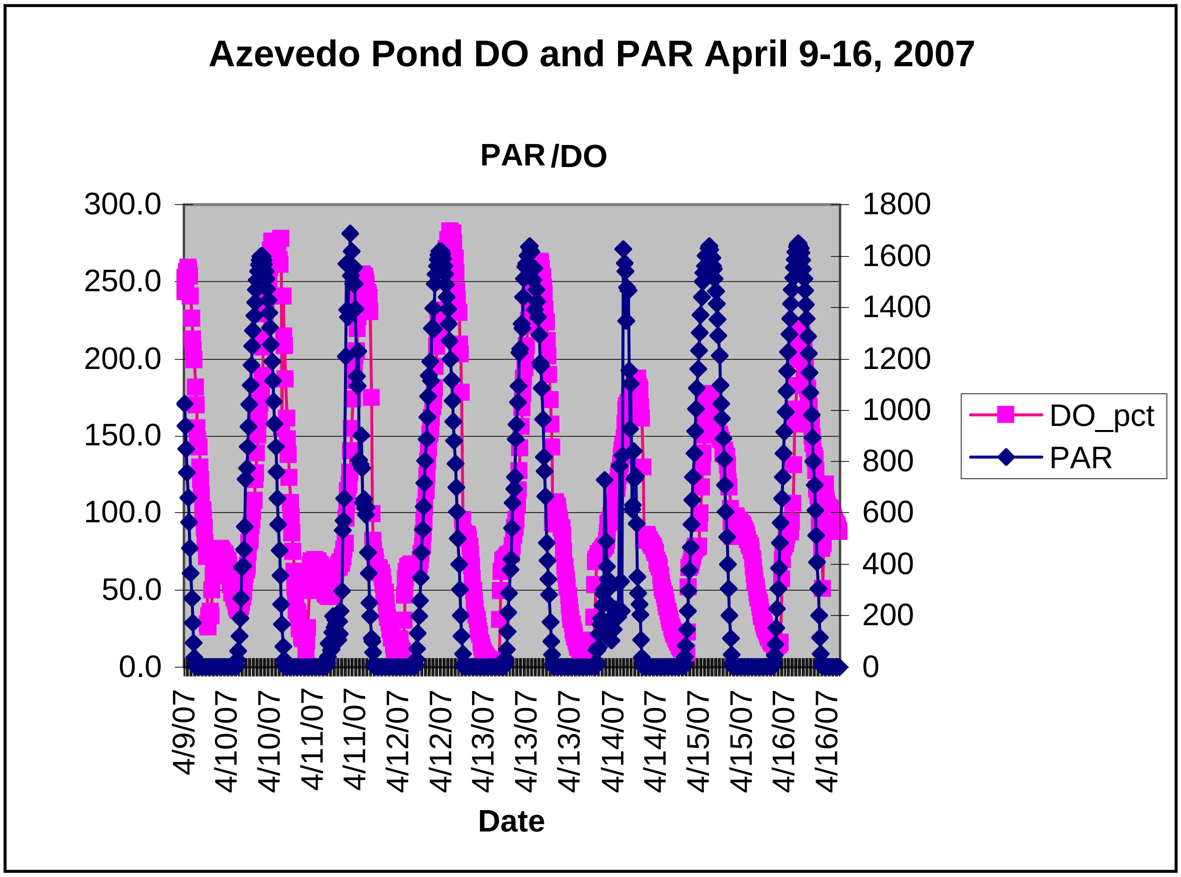


Figure 9. Azevedo Pond Dissolved Oxygen and Photosynthetically Available Radiation, April 9-16, 2007

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%.)

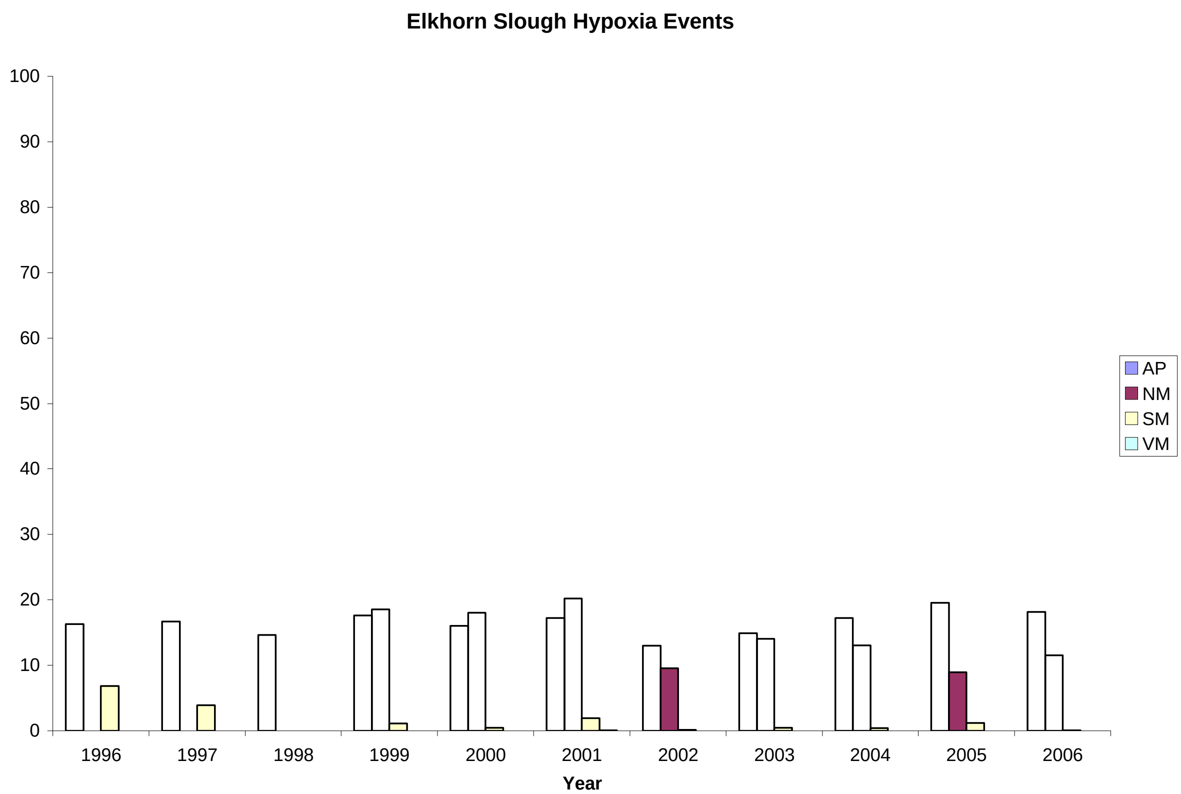


Figure 10 — Frequency of Anoxia in Azevedo Pond (first column in each series) compared to three other sites in Elkhorn Slough

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

Teacher Guide—Physical Science Module

Activity 3: Human Impact on Estuaries: A Terrible Spill in Grand Bay

Featured NERRS Estuary:
Grand Bay National Estuarine Research Reserve
http://www.nerrs.noaa.gov/GrandBay/welcome.html

Activity Summary

In this activity, students make a model of a pollution spill that occurred at Bangs Lake, a tidal lake within the Grand Bay NERR in Mississippi, in April 2005, and measure water quality parameters in their model. Students then study the actual spill, analyzing various forms of data to determine the date of the spill and identify how the spill changed water quality parameters in the estuary during and after the spill. They speculate on how various life forms in the estuary were affected. Finally, students produce a timeline of the spill event with recommendations to the state Department of Environmental Quality about how to prevent large-scale pollution spills like this in the future.

Learning Objectives

Students will be able to:

1. Describe how a chemical reaction affects water ... mple of estuary water.
2. ... edict the effects of an ... water quality and life forms
3. ... on new evidence.
4. Analyze water quality and nutrient data to identify variables that are out of a typical range and that may be indicators of a disturbance to the estuary, such as a pollution event.
5. Explain how estuarine species are threatened by drastic changes in water quality and nutrients.
6. Explain how the water chemistry of an estuary affects the health of the estuarine ecosystem and how monitoring estuary water chemistry can account for and predict changes to the health of the ecosystem.
7. Summarize data and develop a hypothesis to make a timeline that describes the spill and explains how it affected the chemistry of and life in an estuary.
8. Suggest ways to prevent adverse human impacts on estuaries.

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:

Modeling a Chemical Spill

Learning More about the Spill

Analyzing Data Before and After the Spill

Background

On the morning of April 14, 2005, a catastrophic pollution event occurred at Bangs Lake, a tidal lake within the Grand Bay National Estuarine Research Reserve (NERR) in Mississippi. The spill occurred when the walls of retaining ponds filled with wastewater collapsed at a fertilizer manufacturing company located 1.1 km (0.7 mi) from the lake. Approximately 17.5 million gallons of polluted water flowed out of the retaining ponds and into the lake. The released wastewater had a pH of 2.2 to 2.4 and contained elevated levels of phosphorus 4000-5000 ppm (parts per million). Mississippi Phosphates, the company that operates the fertilizer manufacturing plants, says that walls of the retaining ponds may have collapsed because of unusually high rainfall (over 43 cm) from March 31 to April 11.

Water quality data from the spill was captured at a monitoring station 1.9 km (1.2 mi) from where the spill entered the lake. The spill caused an immediate drop in pH. A water quality monitoring station maintained by Grand Bay NERR at the center of the lake showed that on April 15, the pH dropped three entire units in one hour. That day, the water registered a pH low of 3.7 units. Eleven days later, phosphorous levels in the lake were about 5000 times greater than levels before the spill. Chlorophyll-alpha (or chlorophyll-a), a measure of primary productivity was non-existent, suggesting that there was little or no phytoplankton or algae in the lake.

The contaminants of the spill were two sources of waste products that come from the creation of phosphates for fertilizer: calcium sulfate and wastewater (contaminated with phosphoric acid and other pollutants). In order to get useable phosphate for fertilizer, phosphate ore is reacted with sulfuric acid to produce phosphoric acid. The simplified equation of this reaction is:

$$Ca_3\,(PO_4)^2 + 3H_2SO_4 + 6H_2O \text{ --->} 2H_3PO_4 + 3CaSO_4{*}\,2H_20$$

A byproduct of the reaction is calcium sulfate ($CaSO_4{*}\,2H_20$), commonly called gypsum. For every ton of phosphoric acid that is produced, five tons of gypsum are also created. Gypsum can be made into sheet rock or plaster of paris, however, the gypsum created in the production of fertilizer contains small amounts of radioactivity so it cannot be used for these purposes. Instead, the gypsum created at the fertilizer plant is piled in mounds or "stacks" that surround and contain pools of wastewater. The wastewater contains a diluted mixture of residual phosphoric and sulfuric acids, so the pH of the water is generally close to 2.0. The water may also contain contaminants such as ammonia, fluoride, selenium, chromium, copper, cadmium, nickel, aluminum and even uranium, which can be toxic in sufficient doses.

Much of the damage was not immediate, but resulted from a chain of causes and effects. For example, several weeks after the spill, large algal mats covered the surface of some of the shallow, enclosed areas of the lake. Scientists believe that the algae populations exploded because there were so many nutrients in the water. Phosphates are some of the nutrients necessary for algae growth. In some estuaries, phosphates may be the growth-limiting nutrient.

The extensive algal blooms occurred in the shallow, enclosed waters near the point where the polluted water entered Bangs Lake. As these algal mats decayed, oxygen was removed from the water, eventually contributing to lower levels of dissolved oxygen (DO) in the lake. These hypoxic conditions contribute to the stress and death of various forms of life. Low dissolved oxygen levels continued into the fall.

Despite the extent of the damage, the estuary recovered relatively quickly. The algal blooms cleared up within a couple of months. Also within 4-8 weeks, fish and blue crabs had moved back into the area. The marsh vegetation began to recover during the summer and appeared to be "normal" by the time Hurricane Katrina hit the area in August of 2006. The upland vegetation has taken longer to recover; the grasses have come back but the shrubs and trees suffered high mortality.

The phosphate company where the gypsum stacks failed, Mississippi Phosphate, claims that the gypsum stack holding the wastewater failed because of heavy rainfall. Although the Mississippi Department of Environmental Quality (MDEQ) accepts this as a possibility, it also believes that the company tried to increase the capacity of the ponds and built the retaining walls too big and too fast. The gypsum stacks are ringed by a moat-like system, which environmental permits say should be designed to capture such spills. MDEQ believed that the levees around the gypsum stacks were not sufficient to catch the pond spill before it poured into the marsh.

The company's permits from MDEQ specify that the waste ponds must be designed to withstand a storm producing about 11 inches in a 24-hour period, according to the standard calculations produced by the National Oceanic and Atmospheric Administration for this part of the Gulf Coast.

Weather information from the Southern Climate Data Center indicates that there was no rainfall in Pascagoula on April 13 or 14, when the spill occurred. Weather service radar and Southern Climate Data Center reports indicate that on April 1, two weeks before the spill, an area along the Mississippi/Alabama border may have received about 8 inches of rain, the largest rainfall the Climate Data Center reported for that month.

Preparation

- Collect or make enough brackish water (with a salinity of about 8 ppt) for each team of students. Each team should have a sample of about one to two liters. To make a water sample of this salinity, mix 8 grams of salt or Instant Ocean per liter of tap water, or dilute a sea-water sample until it is 8 ppt —1.026 specific gravity on a hydrometer.
- Prepare one or multiple estuary models, such as in the following image. Add the brackish water to the basin. Set it up so that you can pour the simulated wastewater

Materials

Students

- ❑ Copy of Student Reading—A Terrible Spill in Grand Bay
- ❑ Copy of Student Worksheet—A Terrible Spill in Grand Bay
- ❑ Copy Student Data Sheet—Data on Conditions in Grand Bay.

Teachers

- ❑ Download the PowerPoint—*Terrible Spill in Grand Bay*.(To find the presentation go to the estuaries.gov site, choose the Teachers tab, click on the sub-tab titled Physical Science, and find it under "Supporting Materials".) For quick access go to:

http://www.estuaries.gov/estuaries101/Teachers/Default.aspx?ID=103

- ❑ Plastic shoeboxes or similar container(s)
- ❑ Clay, soil, cardboard, etc. for preparing estuary models
- ❑ Brackish water (salinity at about 8 ppt) — 1-2 liters per team
  - Prepare using, salt, seawater, or Instant Ocean
- ❑ Beakers or other containers for chemicals
- ❑ Graduated Cylinders
- ❑ Citric acid
- ❑ Gypsum—plaster of Paris OR sheet rock ground up into pow-der (with a mortar and pestle)
- ❑ pH papers (preferably from 2-14)
- ❑ Water test kits or probes for measuring water quality parame-ters
- ❑ Safety glasses
- ❑ Protective gloves
- ❑ Plastic bags for disposing of the simulated wastewater and any other gypsum, as gypsum may clog the sink
- ❑ Poster board for final assessment project

over a surface (of soil, clay, cardboard, etc.), allowing the wastewater to enter and mix with the water in the basin gradually.

- Review the first aid measures for gypsum at:

http://www.cameochemicals.noaa.gov/chemical/25028

Scroll down to Section 3 and read the "Response Recommendations". For another source of information, check out the following document:

http://www.allianceenergy.ca/downloads/MSDS/Alliance%20Gypsum.pdf.

- Measure out the materials for students to make the simulated wastewater. For each group:
  - 6 g of citric acid,
  - 20 g of plaster of Paris or ground up sheet rock*
  - 300 ml of tap water.

Instructions for making the simulated wastewater:

- Add 300ml of tap water to a 500 ml beaker.
- Measure 20 g of gypsum, add it to the tap water, and stir until all the plaster is well mixed with the water.
- Measure 6 g of citric acid and add it to the gypsum and water mixture.

*If you do not have plaster of Paris, you can grind up pieces of sheet rock with a mortar and pestle. The pH of the wastewater (citric acid plus gypsum in water) should be about 3 units.

IMPORTANT NOTE: Be careful while preparing these materials, particularly if grinding sheetrock. Wear goggles and gloves, and clean up thoroughly.

- Download the PS3 PowerPoint—*Terrible Spill in Grand Bay* onto a computer that can project in front of the class, or onto computers the students can access directly.
- Make copies of *Student Reading—A Terrible Spill in Grand Bay, Student Worksheet—A Terrible Spill in Grand Bay* , and *Student Data Sheet—Data on Conditions in Grand Bay*. Alternatively, the *Student Data Sheet* can be projected.

Procedure

Part 1 — Modeling a Chemical Spill

1. Write the following questions on the board and have students discuss answers in small groups.
   - What kinds of pollution can affect estuaries?
   - What are the effects of the pollution on water quality and on living things in the estuary?

2. Bring the groups back to share and discuss their ideas.

   Students may suggest natural sources of pollution, such as excess sedimentation and turbidity from heavy stream runoffs. But focus this discussion on pollution caused by human activity, such as heavy metals from industries, pathogens from sewage, and excess nutrients from farms and lawn fertilizers.

   Students may identify both point and non-point source pollution. If not, it is worth making the distinction. Non-point source pollution can introduce substances into the estuary that originate even far away from the estuary, including trash, waste, and chemicals that wash off of city streets, and sewage that overflows from storm drains after heavy rains.

3. Explain to students that they will model a chemical spill and use their observations and results to predict how an actual spill would affect life and water quality in an estuary. Students' work in Part 1 will relate to industrial chemical pollution disaster from a fertilizer manufacturing plant that occurred less than a mile away from the estuary.

4. Provide students with the necessary materials and have them complete Part 1 of the *Student Worksheet—A Terrible Spill in Grand Bay*. Tell students that the simulated wastewater is just an approximation of what actually went into Bangs Lake. The simulated wastewater contains most of the same components as

the actual wastewater, but in different forms and amounts so that it is safer for the students to handle. For example, the simulated wastewater includes citric acid in place of phosphoric acid. There is no radioactive waste in the wastewater.

IMPORTANT NOTE:

- Make sure that the students are careful with the simulated wastewater and its components. They should wear gloves and goggles at all times, carefully wash their hands afterward, and thoroughly clean up their supplies and work area.
- The water quality test your students conduct will depend on the materials available.
- Be aware that your students' results will differ from actual spill results.

5. Discuss the students' models, measurements, predictions, and answers.

NOTE: Consider having students read the *Student Reading—Introduction to Grand Bay* as homework in preparation for Parts 2 and 3.

Part 2 — Learning More about the Spill

6. Have students read the *Student Reading — Introduction to Grand Bay*.

7. Project or have students view the PowerPoint—*Terrible Spill in Grand Bay*, which addresses the conditions in Bangs Lake before and after the phosphate spill. Have students note the things that show the effects of the pollution or suggest damage to the estuary. Have them speculate on the cause(s) of the damage.

8. Have students complete Part 2 of the *Student Worksheet—A Terrible Spill in Grand Bay*, refining their predictions. Encourage them to think about the results from their experiment, the new information they have read, and the images of the estuary they observed.

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

B2. Structure and properties of matter
B3. Chemical reactions

B6. Interactions of energy and matter

Content Standard C: Life Science

C4. The interdependence of organisms

C5. Matter, energy, and organization in living systems

Content Standard D: Earth and Space Science

D1. Energy in the earth system
D2. Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives

F3. Natural Resources

F4. Environmental quality

F5. Natural and human-induced hazards

F6. Science and technology in local, national, and global challenges

Part 3 — Analyzing Data Before and After the Spill

9. Have students complete Part 3 of the *Student Worksheet—A Terrible Spill in Grand Bay*, using the data provided on the *Student Data Sheet—Data on Conditions in Grand Bay*.

   Consider giving the students the Month of Spill portion of the *Student Data Sheet* only after they have identified April as the month of the spill.

For students who do not identify April as the month of the spill, ask probing questions to get them to see the spikes in pH and phosphorous—the clearest indicators—during that month.

10. Discuss the data, answers, charts, and timelines.

11. Provide students with the complete story of the Bangs Lake spill and have them compare their hypotheses and analyses with actual effects.

Check for Understanding

Discuss the following:

- What caused the massive spill in Grand Bay? What could have been done to prevent it?
- What were the immediate effects on organisms living in the bay?
- What are the reasons that water quality returned to normal after a brief span of weeks?

Optional Extension Inquiries

- Have students complete the online activity, Affect of pH on Aquatic Organisms, available online at:

  http://waterontheweb.org/curricula/bs/teacher/ph/teaching.html

  If the activity can't be found its original site, please find it in the following site where it has been archived:
  Accessed: 2008-08-06. Archived by WebCite® at: http://www.webcitation.org/5Zs34rTm9

- Use a nearby body of water as a field study site to compare to the water and contaminants of Grand Bay with those at your local site. Check out monitoring equipment and test kits to different students each weekend and have them take measurements at the same location at your field site. After collecting data for nine consecutive weeks, have students plot rainfall amounts over the nine-week time period and compare their graphs against graphs of water quality and nutrient data at Grand Bay for the same time frame.

Teacher Worksheet with Answers
Activity 3: A Terrible Spill in Grand Bay

Part 1 — Modeling a Chemical Spill

1a. Measure and record the following water quality indicators in your 1 liter sample of brackish water:

Answer: Student answers will vary.

1b. Measure and record the following water quality indicators of the wastewater:

Answer: Student answers will vary.

1c. Predict how adding the mixture will affect the water quality variables.

Answer: Student answers will vary.

1d. Add the wastewater mixture to the sample of seawater, take measurements, and record your results in the chart above.

Answer: Student answers will vary.

1e. What do your new readings indicate about how the mixture might affect estuarine life?

Answer: Since it is acidic and contains other possibly toxic components, the mixture may be harmful to estuarine life.

1f. If a similar chemical mixture spilled into an estuary, how do you think the water quality would change over a week? Over a month?)

Answer: Short-term effects on plants and animals would be evident. Over the long term though, the tidal flushing and natural filtering process that takes place in estuarine environments would absorb most of the toxic components of the wastewater.

1g. How is this experiment different from an actual spill in an estuary? Explain why you may get different results in t his experiment than the results that would occur in an estuary.

Answer: The volume of the beaker compared to the wastewater introduced is miniscule compared to the spill into Grand Bay. Only a portion of the estuary would be affected by a spill.

Part 2 — Learning More about the Spill

2a. Think about what went into the estuary water. How could the different chemicals affect the water quality and plant and animal life in the estuary? Update your predictions of how the spill would affect the estuary in the short and the long-term. Explain in terms of specific water quality variables.

Answer: Student answers will vary.

Part 3 — Analyzing Data Before and After the Spill

3a. Determine the month in 2005 during which the spill occurred. Look for extremes that may suggest something out of the ordinary is happening.

Answer: Students will notice that many graphs spike during the month of April.

3b. Complete the following chart.

	Typical average values for	Average values for spill
Salinity	*5 ppt*	*20 ppt*
Temperature		
Dissolved oxygen	*5.0*	*5.0 (no sig. difference)*
pH	*7.5*	*6.5*
Chlorophyll-a	*No data*	*No data*
Total Dissolved phosphorous	*4.3*	*About 0.4*
Orthophosphates	*4.2*	*About .3*
Turbidity	*20*	*About 10*

3c. The spill occurred on which date?
Answer: Graphs indicate April 13th to 18th.

3d. Why do you think so? Which variables seem to suggest this?

Answer: Salinity drops precipitously on April 18th. DO drops on the 15th. There is a huge spike in turbidity on the 13th. The pH plunges on the 15th as well.

3e. Look at actual daily records of water quality and nutrient data for the month during which the spill occurred in 2005. Describe these values during that time. What were the most extreme values?

Answer:

- phosphorous peaked over 4.0 in April compared to levels normally about .2.
- dissolved phosphates peaked at 4.5, a 1000X higher than normal levels of about .1.
- pH plunged to less than 4.0 way below normal levels of 7.3.
- salinity dropped about 7 ppt during the event.
- DO dropped about 20% during the event to a seasonal tying low of 60 %.
- DO concentration showed a similar drop—from 7.0 to 5.0 mg/L, a yearly low.
- turbidity had a huge spike, moving from a modest value of 25 NTUs to a whopping 300 NTUs.

3f. When did the measures look "normal" again? What might be some reasons for the time it took to attain normalcy of water quality?

Answer: Phosphorous and phosphate remained at very high levels for month afterwards. Most of the other water quality factors rebounded in a matter of a few days to a week.

3g. Look at the charts on the following pages to determine what the effects would be on various life forms in the estuary.

Answer: Chart 1

- Oysters: Salinity levels would prevent oysters from surviving. pH levels too low as well.
- Clams: Same as oysters. The water would be toxic for them.
- Blue crab: pH is a little low for blue crabs so some will survive. Other will migrate to cleaner waters.
- Coho salmon: DO and salinity both too low for Coho salmon to exist.

Answer: Chart 2

With DO concentration at 5.0 mg/L, striped bass, shad and perch would not be able to survive in the spill area.

Student Reading
Activity 3: Introduction to the Grand Bay National Estuarine Research Reserve

About the Estuary

The Grand Bay National Estuarine Research Reserve (GNDNERR) is a protected marine area located in extreme southeastern Mississippi in Jackson County near the small community of Pecan (see map). The GNDNERR is comprised of approximately 18,000 acres, found chiefly within the Grand Bay National Wildlife Refuge and the Grand Bay Savanna Coastal Preserve. This reserve contains a variety of wetland habitats, both tidal and non-tidal, such as pine savannas, salt marshes, saltpans, bays and bayous as well as terrestrial habitats that are unique to the coastal zone like maritime forests.

Figure 1. Grand Bay NERR is composed of diverse habitats for estuarine plants and animals.

Healthy estuarine salt marshes and fire-maintained pine savannas are some of the most diverse habitats in North America, and the reserve is fortunate enough to contain considerable amounts of both. These habitats support many important species of fish and wildlife. Commercially and recreationally important species of finfish and shellfish, such as brown shrimp, speckled trout and oysters, abound here. Sea turtles, bottlenose dolphin and, on occasion, manatees can be found in the deeper waters of the reserve. Many species of carnivorous plants and orchids can be found in the higher savanna habitats.

The lands within the Grand Bay NERR are classified as either core areas or buffer areas. The core area (outlined by yellow on the above map) consists of approximately 12,800 acres of: estuarine tidal marsh, tidal creeks or bayous; shallow, open-water habitats; oyster reefs; seagrass beds; maritime forests; salt flats; sandy beaches; and shell middens. These habitats supply nutrients for many marine species. They also serve as buffer zones for hurricane protection and places of shelter for animals. Tidal marsh regions function as filters, removing pollutants such as sewage and surface run-off that otherwise would flow into the Mississippi Sound and degrade valuable marine aquatic resources.

The buffer area (outlined by blue above) consists of approximately 5,600 acres of tidal marsh, scrub shrub, pine flatwood and wet pine savanna habitats. Buffer areas are defined as "areas adjacent to the core areas that provide additional protection for estuarine-dependent species." Additionally, a small portion of intertidal marshes located adjacent to the boat ramp at Bayou Heron is also included in the buffer area. This disturbed area currently provides the only publicly-owned, waterway access point within the boundaries of the GNDNERR.

- Adapted from the Grand Bay NERR website.
URL:http://grandbaynerr.org/aboutus/. Accessed: 2008-07-19.
(Archived by WebCite® at
http://www.webcitation.org/5ZREBtbdl)

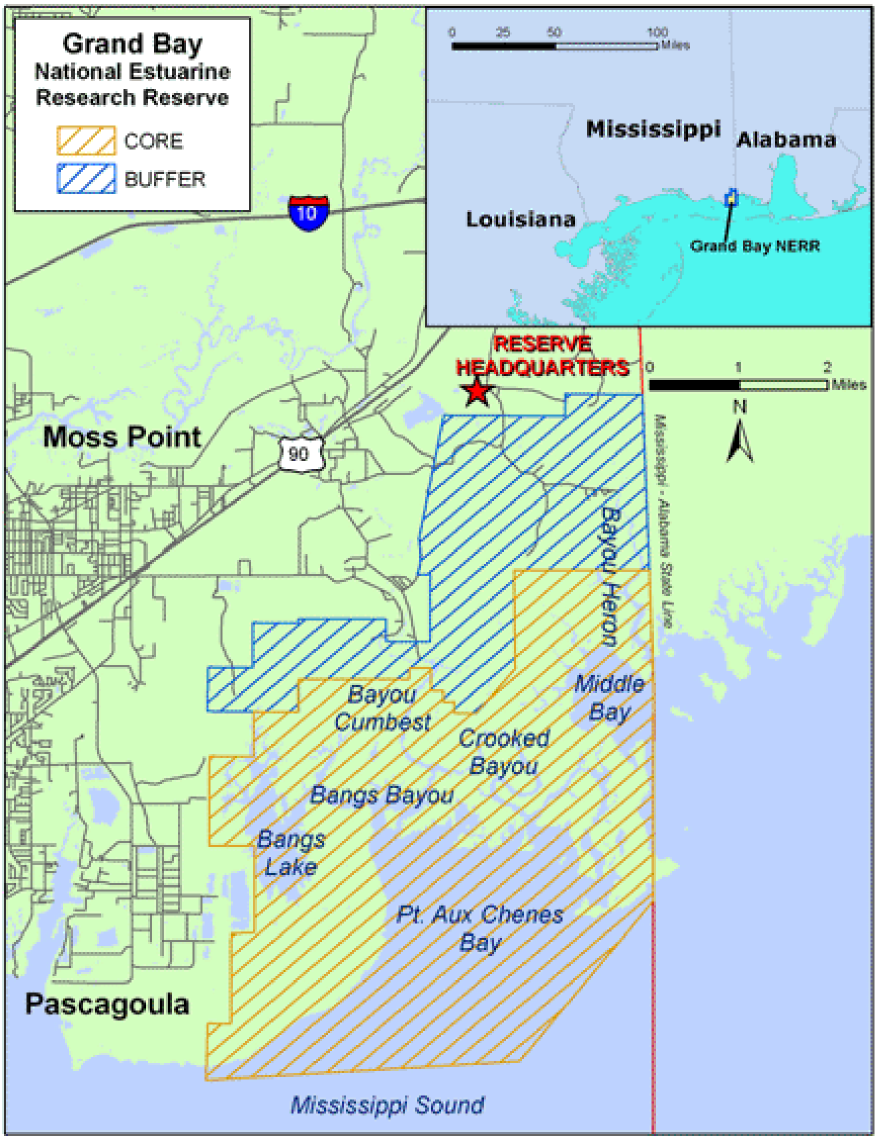


Figure 2. Your study will focus on Bangs Lake,
which is situated on the western edge of the reserve.

Student Reading
Activity 3: A Terrible Spill in Grand Bay: A Case Study of an Environmental Disaster

The Massive Spill

In 2005, a catastrophic pollution event occurred at Bangs Lake along the western border of Grand Bay NERR, MS. The spill occurred when the walls of retaining ponds filled with wastewater collapsed at a fertilizer manufacturing company located 1.1 km from the lake. Approximately *17.5 million gallons of polluted water* were released from the ponds and subsequently flowed into the estuary. The released wastewater had the following characteristics:

- a pH of 2.2–2.4
- elevated levels of phosphorus (4000-5000 ppm)
- high levels of aqueous ammonia (280-350 ppm).

The spill was sudden and organisms in the estuary felt the effects immediately.

Sources of the Pollution

The contaminants of the spill came from two sources that are produced in the creation of phosphates for fertilizer: calcium sulfate (or gypsum) and wastewater that was contaminated with phosphoric acid and other pollutants. In order to get useable phosphate for fertilizer, phosphate ore is reacted with sulfuric acid to produce phosphoric acid. A byproduct of the reaction is calcium sulfate ($CaSO_4.2H_20$), commonly called gypsum. The gypsum is piled in mounds or "stacks" which are used to create walls that surround and contain pools of wastewater. The wastewater contains a dilute mixture of residual phosphoric and sulfuric acids, so the pH of the water is close to 2.0. The water may also contain contaminants such as ammonia, fluoride, selenium, chromium, copper, cadmium, nickel, aluminum and even uranium, all of which can be toxic.

The Effect on the Estuary

Water quality data from the spill was captured at a monitoring station 3.0 km (1.9 mi) from where the spill entered the lake. The monitoring stations that measure the data are about 9 m from the bottom of the lake. When measured, chlorophyll-a, a measure of primary productivity, was non-existent. Two to three weeks later, large algal mats covered the surface of some shallow, enclosed areas of the lake.

The wastewater caused immediate damage to estuarine flora and fauna.

- 77 hectares of upland habitats were killed or seriously damaged from the chemicals in the polluted water.
- The value of the marsh grass killed was estimated to be $262,500.
- The average death rate for oysters in Bangs Lake was 74%.
- Fish and blue crab deaths (16 species) included over 100,000 individuals worth over $400,000.

Who is at Fault?

The phosphate company, Mississippi Phosphate, claims that the gypsum stack holding the wastewater failed because of heavy rainfall. It was also claimed that the company tried to increase the capacity of the ponds and built the retaining walls too large and put them up too fast. The gypsum stacks are ringed by a moat-like ditch-and-berm system, which environmental permits say should be designed to capture such spills. The Mississippi Department of Environmental Quality (MDEQ) believed that the levees around the gypsum stacks weren't sufficient to catch the pond spill before it poured into the lake.

The company's permits from MDEQ specify that the waste ponds must be designed to withstand a storm producing about 11 inches in a 24-hour period, according to the standard calculations produced by the National Oceanic and Atmospheric Administration for this part of the Gulf Coast. Weather information from the Southern Climate Data Center indicates that there was no rainfall in

Figure 3. The gypsum walls containing the wastewater are seen in this image taken before the collapse. (http://www.fluoridealert.org/phosphate/

Figure 4 . Phosphate processing facility adjacent to gypsum stacks in Polk County, FL.

(Image: Grand Bay National Estuarine Research Reserve)

Pascagoula on the two days before the spill occurred. Weather service radar and Southern Climate Data Center reports indicate that two weeks before the spill, an area along the Mississippi/Alabama border may have received about 8 inches of rain, the largest rainfall the Climate Data Center reported for that month. NOAA records indicate a storm of that intensity could be expected about once every five years along the Mississippi coast.

Figure 5. Algae bloom and dead marsh grass, Bangs Lake, Grand Bay National Estuarine Research Reserve

(Image: Grand Bay National Estuarine Research Reserve)

Student Worksheet
Activity 3: A Terrible Spill in Grand Bay

Part 1 — Modeling a Chemical Spill

To make a model that represents the spill in Grand Bay, you will pour a chemical mixture into a basin of brackish water representing the estuary. You will predict the effects of the chemical mix on the water quality of your sample. You will then consider the effects of the actual spill.

IMPORTANT NOTE: The chemicals in the wastewater you will make are much safer than those in the actual spill, but you must still use care and wear goggles and gloves because these chemicals can harm your eyes and may irritate your skin. Make sure you clean up and wash your hands carefully.

1a. Measure and record the following water quality indicators in your 1 liter sample of brackish water:

- salinity ______________________________________
- temperature ______________________________________
- . pH ______________________________________
- dissolved oxygen (if equipment is available)_______________________
- conductivity (if equipment is available) _________________________

Add 300ml of tap water to a 500 ml beaker.

Measure 20 g of gypsum, add it to the tap water, and stir until all the plaster is well mixed with the water.

Measure 6 g of citric acid and add it to the gypsum and water mixture. This will be your model of a wastewater or chemical spill.

1b. Measure and record the following water quality indicators of the wastewater:

- salinity ______________________________________
- temperature ______________________________________

• pH ______________________________________

• dissolved oxygen (if equipment is available)__________________________

• conductivity (if equipment is available) ____________________________

1c. Predict how adding the mixture will affect the water quality variables.

How will these	Prediction	Result after addition of
Temperature		
Salinity		
Conductivity		
pH		
Dissolved oxygen		

1d. Add the wastewater mixture to the sample of seawater, take measurements, and record your results in the chart above.

1e. What do your new readings indicate about how the mixture might affect estuarine life?

1f. If a similar chemical mixture spilled into an estuary, how do you think the water quality would change over a week? Over a month?

1g.. How is this experiment different from an actual spill in an estuary? Explain why you may get different results in this experiment than the results that would occur in an estuary.

Part 2 — Learning More about the Spill

Read the *Student Reading—Introduction to Grand Bay* and watch the PowerPoint presentation showing the Grand Bay NERR before and after the phosphate spill.

2a. Think about what went into the estuary water. How could the different chemicals affect the water quality and plant and animal life in the estuary? Update your predictions of how the spill would affect the estuary in the short and the long-term. Explain in terms of specific water quality variables.

	How would these indicators	Explain reason for change or no change
Temperature		
Salinity		
Conductivity		
pH		
Dissolved oxygen		
Phosphates		
Nitrates		

Part 3 — Analyzing Data Before and After the Spill

In this final part of the activity, you will analyze actual data related to the spill. The data are provided on the *Student Data Sheet—Data on Conditions in Grand Bay*.

3a. Determine the month in 2005 during which the spill occurred. Look for extremes that may suggest something out of the ordinary happened.

Note: Some extremes can be caused by natural conditions, but they are still worth looking into. Try to see if there are dates when several factors seem to be higher or lower than ordinary. Also, keep in mind that the quick charts and trend analysis graphs show **averages** for each day. On any one of those days, actual values at any given time could be much lower or much higher than those averages. You will not know until you look at the actual results for a particular day.

3b. Complete the following chart

	Typical average values for this month	**Average values for spill month 2005**
Salinity		
Temperature		
Dissolved oxygen		
pH		
Chlorophyll-a		
Total Dissolved phosphorous		
Orthophosphates		

3c. Determine exactly when during the month the spill occurred and identify the dates and effects of the spill on water quality.

The spill occurred on which date?____

3d. Why do you think so? Which variables seem to suggest this?

3e. Look at actual daily records of water quality and nutrient data for the month during which the spill occurred in 2005. Describe these values during that time. What were the most extreme values?

3f. When did the measures look “normal” again? What might be some reasons for the time it took to attain normalcy of water quality?

3g. Look at the charts on the following pages to determine what the effects would be on various fish in the estuary and the four life forms listed in the Chart 1.

Final Assessment

Create a timeline from the month of the spill to 6 months after the spill that explains the effects on the estuary that resulted from the spill. Include the following components:

- Dates that show extreme values of the water quality parameters you analyzed in the activity.

- The following terms: pH, phosphorous, phosphate, salinity, dissolved oxygen, rainfall, algae blooms, marsh grass, oysters, clams, crabs, and fish.

- Recommendations to the state Department of Environmental Quality for the future. Explain what should be done to prevent any future environmental impacts from the fertilizer plant. Place the recommendations in the form of a letter and attach it to your poster board presentation.

Chart 1

Limits of Tolerance to Environmental Factors for Selected Organisms

Oysters

- Grow best in water with a salinity of 12 ppt and above, perish if salinity is below 5 ppt or above 15 ppt
- Spawn only when the water temperature hits 18°C for four hours
- Spawn much more prevalent when salinity is over 20 ppt
- Need a DO level of around 4 mg/l
- Best growth when pH is between 7.5 and 8.5

Clams

- Grow best when the water salinity is above 15 ppt
- Spawn only when the water temperature hits 24°C for four hours
- Clam eggs die when the salinity is below 20 ppt
- Need a DO level of around 4 mg/l
- Optimal growth occurs between 10° and 25°C

Blue Crab

- Needs a DO level of 3 mg/l or more for survival, optimal at 5 mg/l
- Thrives if pH is between 6.8 and 8.2

Coho Salmon

- Like a DO level of 6 mg/l or higher
- Require a salinity of greater than 15 ppt
- Prefer temperatures between 4 and 20°C, do best at 13°C
- Spawn only when temperature is 18°C or higher
- Newly hatched salmon need a DO level of at least 5 mg/l to survive
- pH of 4.0 or lower or higher than 9 is lethal for salmon

Chart 2

Limits of Tolerance to Environmental Factors for Aquatic Animals

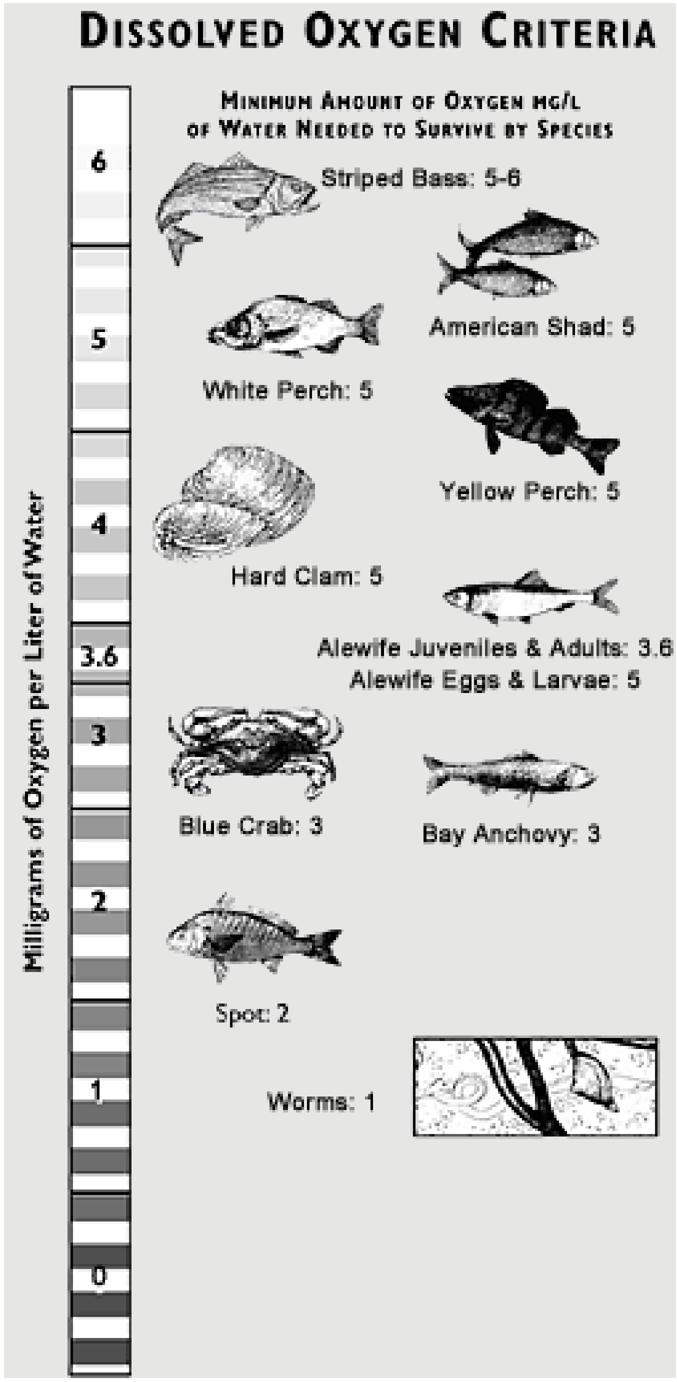


Figure 6. Minimum amount of DO needed for species to survive.

(Credit: Chesapeake Bay Program. URL:http://www.chesapeakebay.net/dissolvedoxygen.aspx?menuitem=14654. Accessed: 2008-08-06. [(Archived by WebCite® at http://www.webcitation.org/5Zs5lwMmM)](http://www.webcitation.org/5Zs5lwMmM)

Student Data Sheet
Activity 3: Data on Conditions on Grand Bay

Quick Charts of 2005 Water Quality Data from Bangs Lake, Grand Bay NERR, MS

Water Station: gndblwq Bangs Lake, MS 30° 21' 25.56 N, 88° 27' 46.44 W

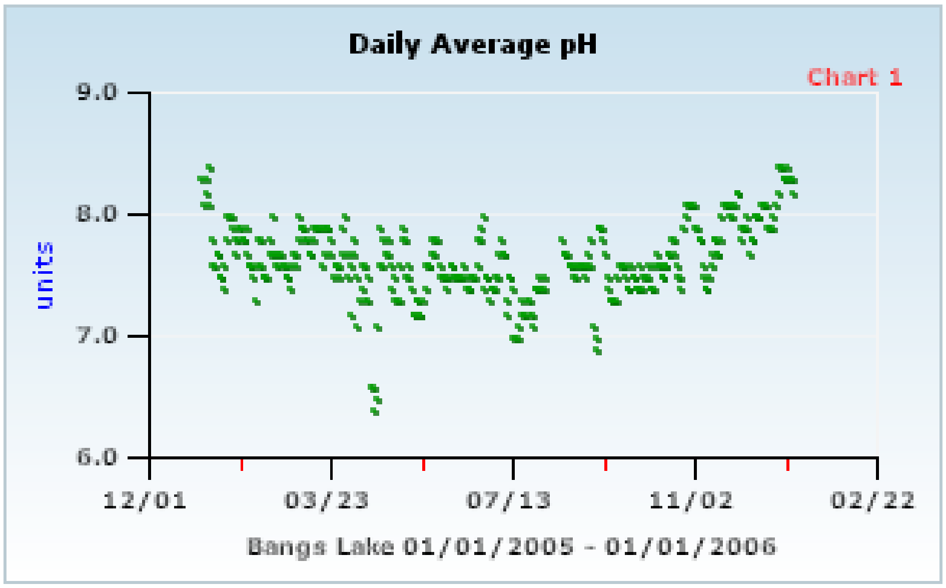


Figure 7. Daily pH:
Grand Bay NERR—Bangs Lake

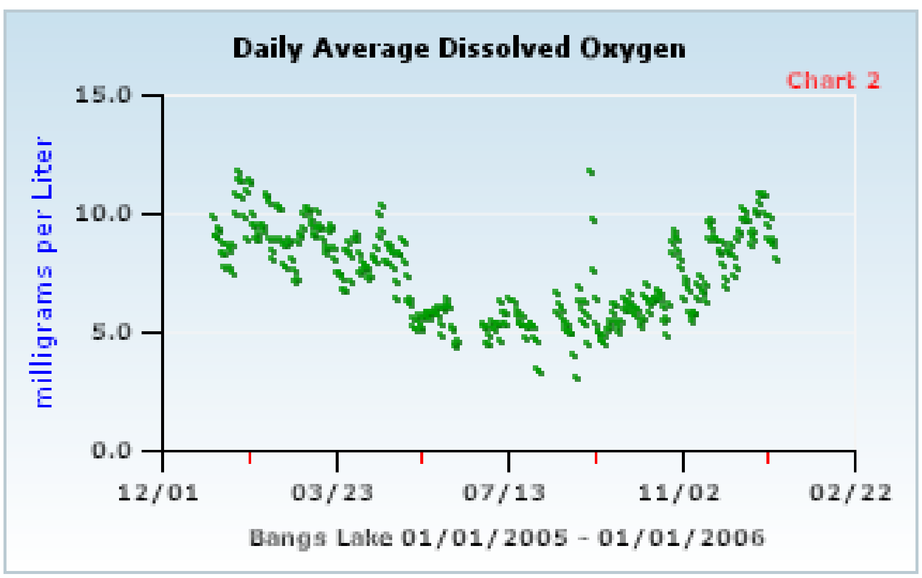


Figure 8. Daily DO:
Grand Bay NERR— Bangs Lake

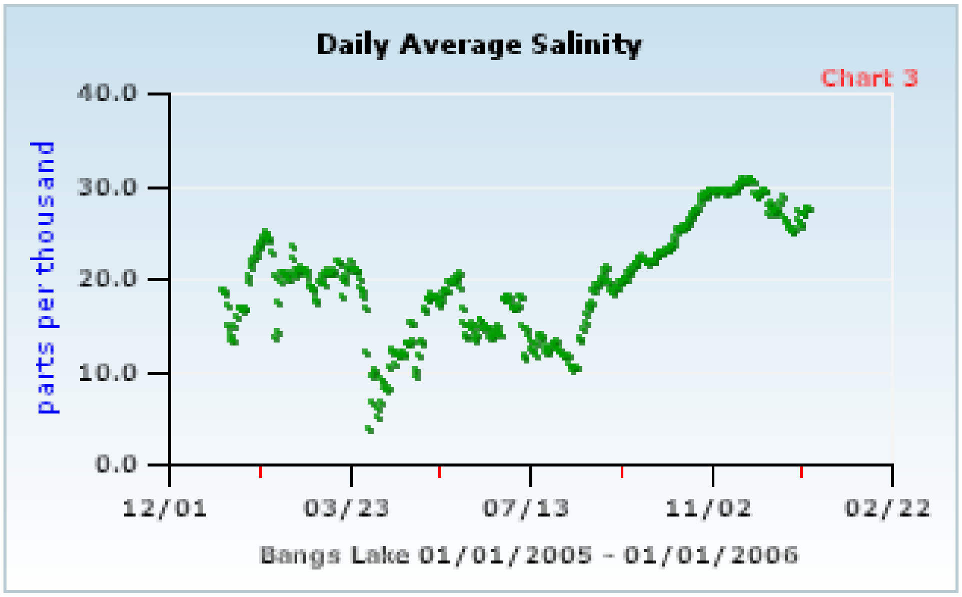


Figure 9. Daily Salinity:
Grand Bay NERR— Bang's Lake

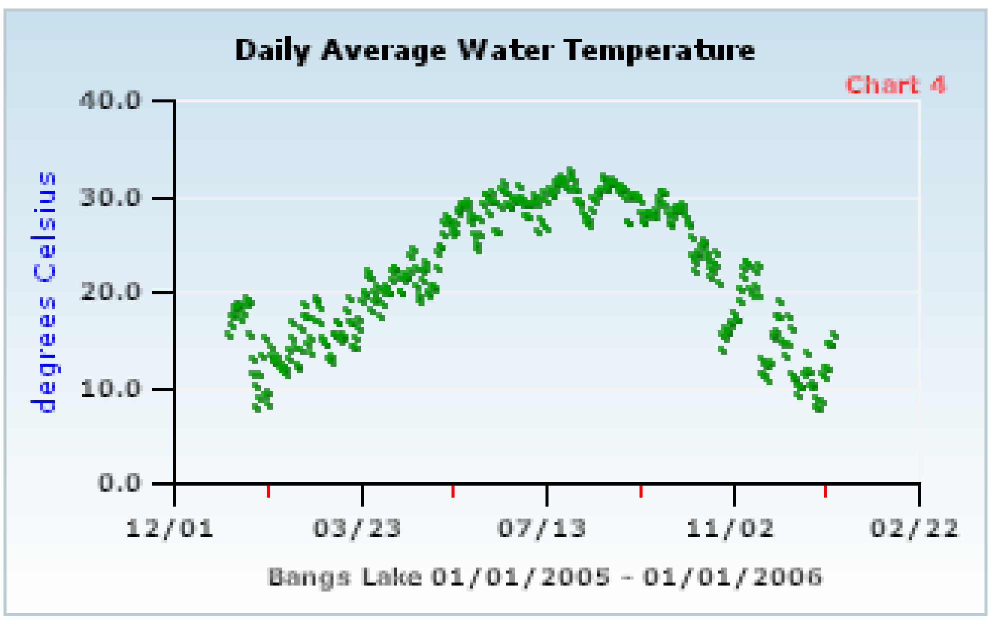


Figure 10. Daily Water Temperature:
Grand Bay NERR— Bangs Lake

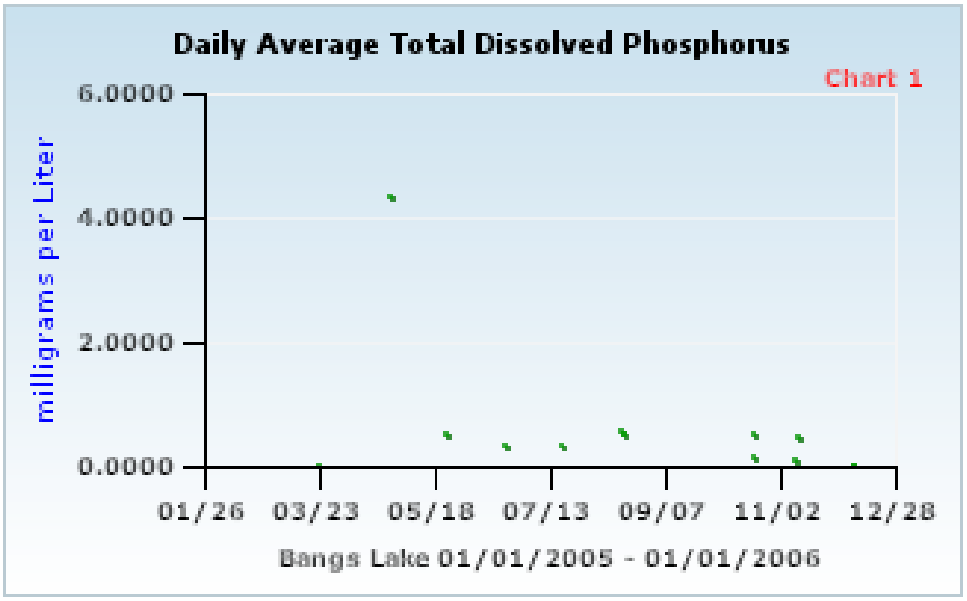


Figure 11. Daily Phosphorus:
Grand Bay NERR— Bangs Lake

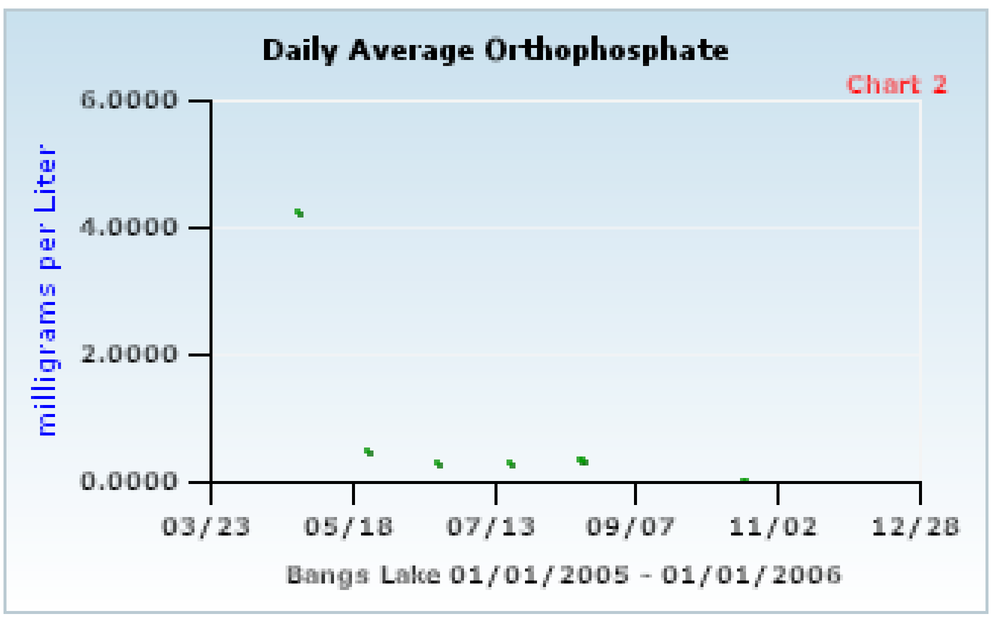


Figure 12. Daily Orthophosphate:
Grand Bay NERR— Bang's Lake

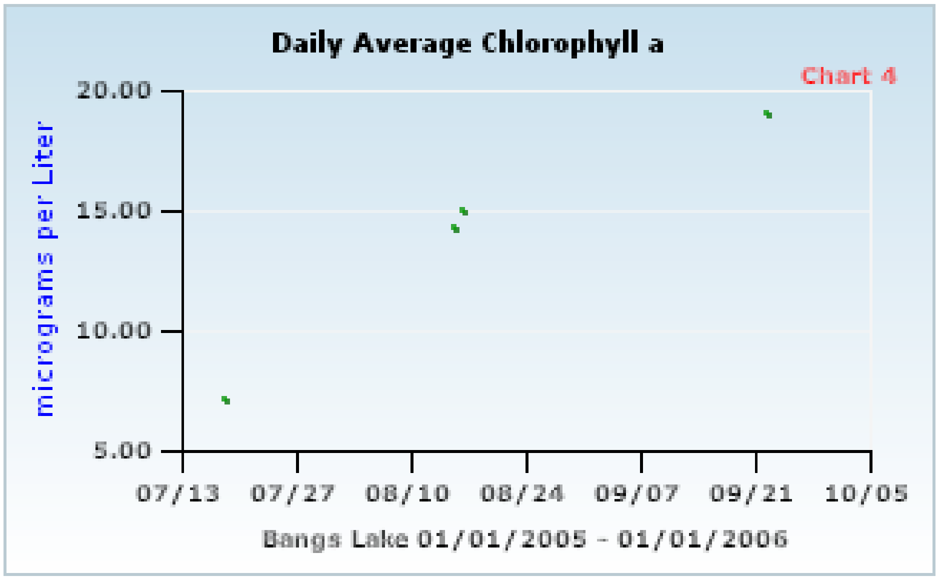


Figure 13. Daily Chlorophyll a:
Grand Bay NERR— Bangs Lake

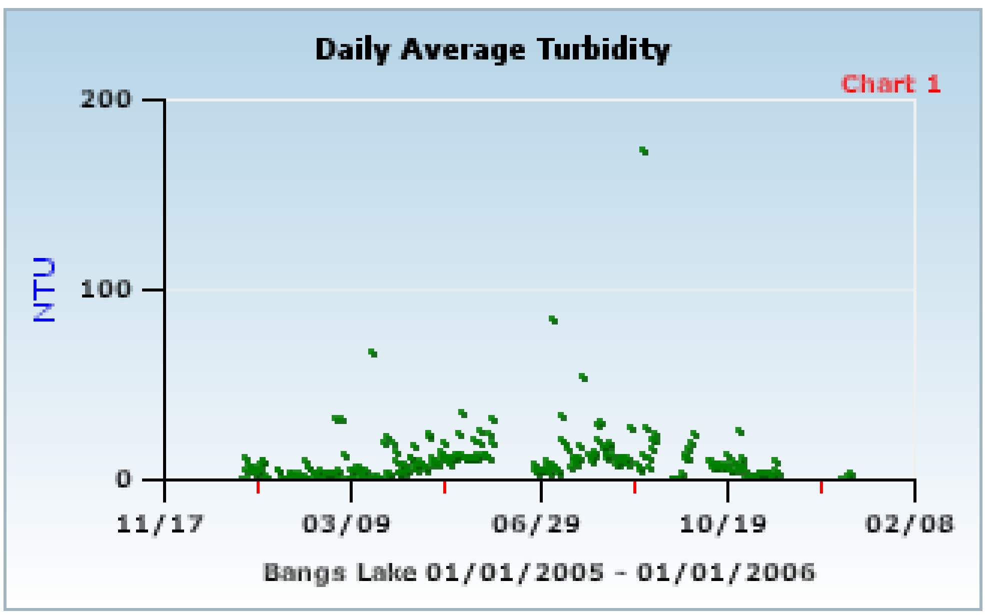
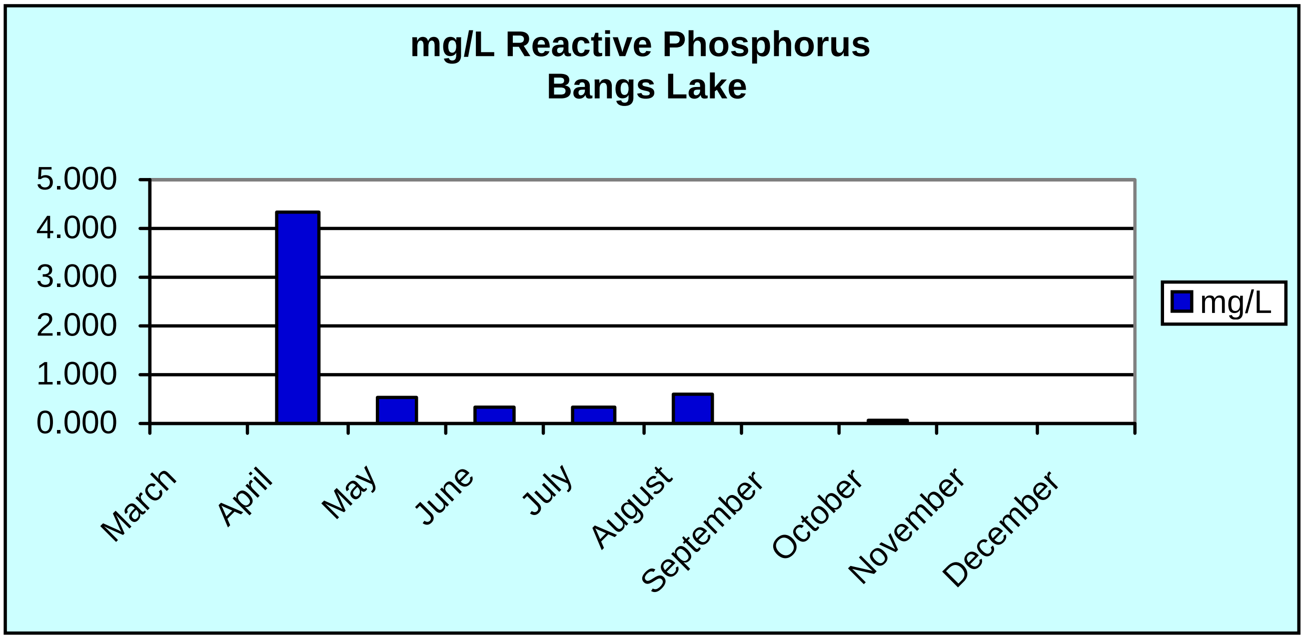


Figure 14. Daily Turbidity:
Grand Bay NERR— Bangs Lake

Month of Spill

Water Quality Readings, Bang's Lake, Great Bay NERR



NOTE: Even though the scale indicates a four-fold increase in phosphorous, the reading is actually 1,000X greater than normal. During May through August, phosphorous levels remained 100X normal.

Figure 15. Reactive Phosphorous (mg/L):
Grand Bay NERR—Bangs Lake

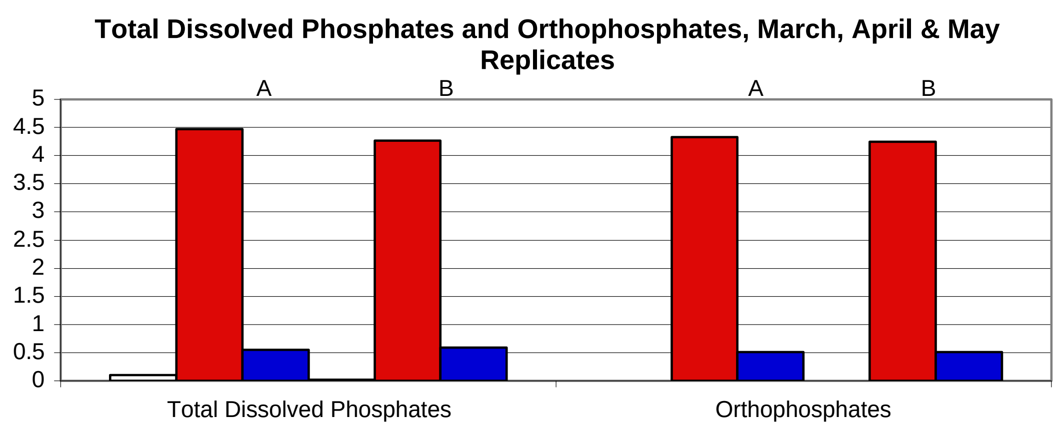


Figure 16. Total Dissolved Phosphates
and Orthophosphates: Grand Bay NERR—Bangs Lake

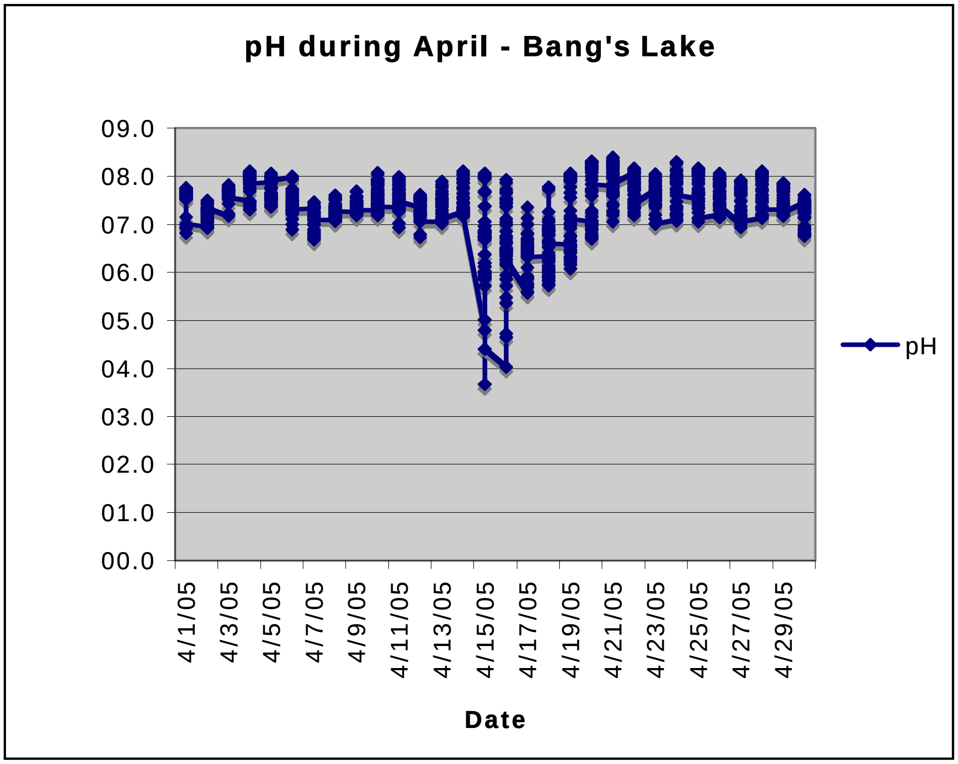


Figure 17. pH during April: Grand Bay NERR—Bangs Lake

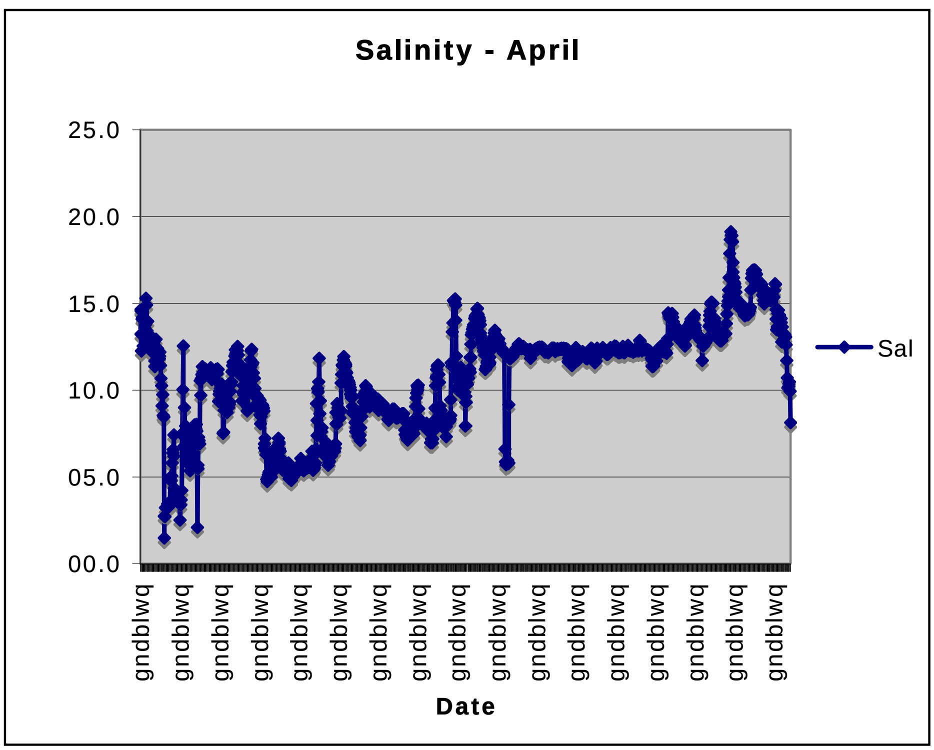


Figure 18. Salinity during April: Grand Bay NERR—Bangs Lake

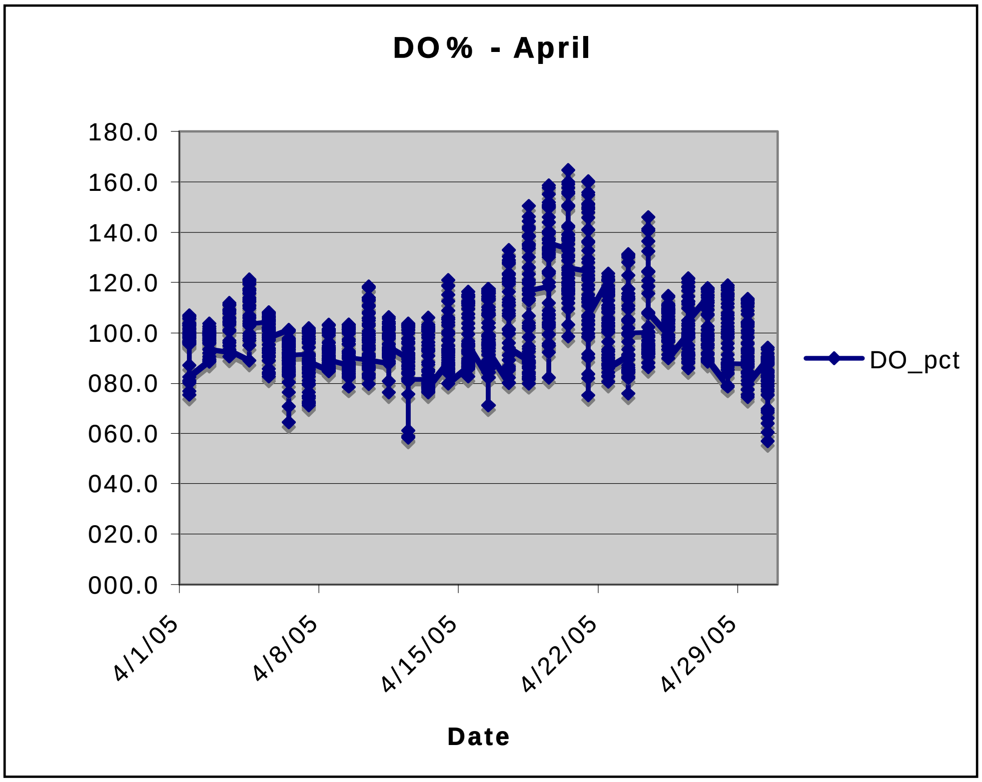


Figure 19. DO% during April: Grand Bay NERR—Bangs Lake

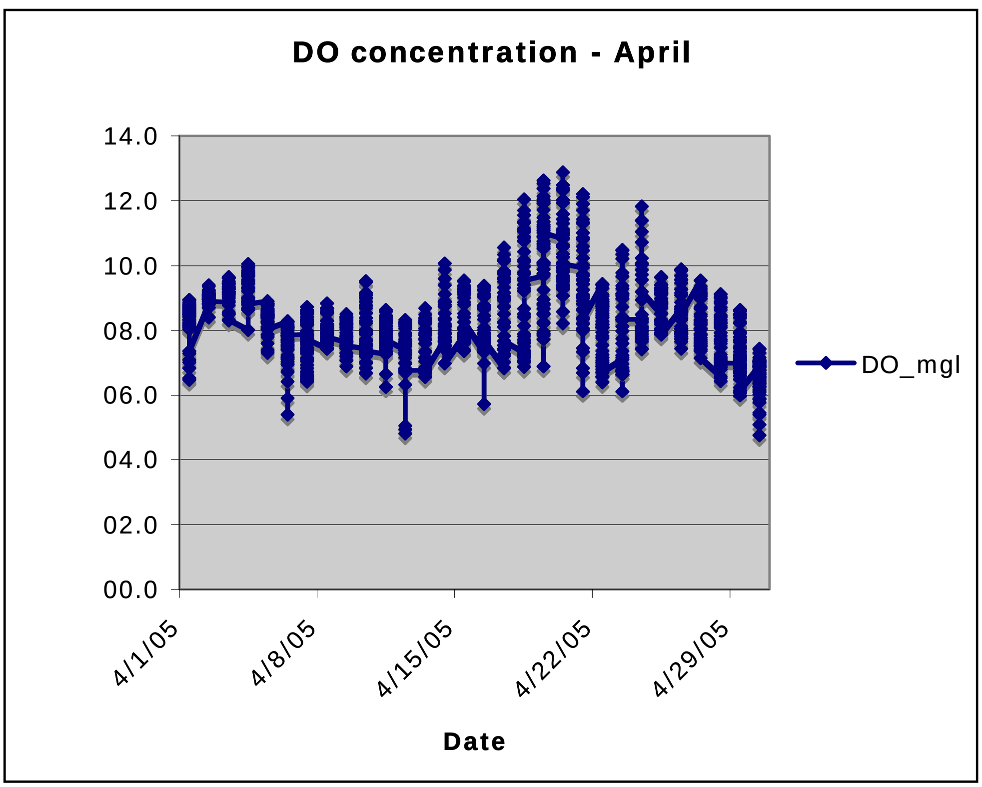


Figure 20. DO Concentration during April: Grand Bay NERR—Bangs Lake

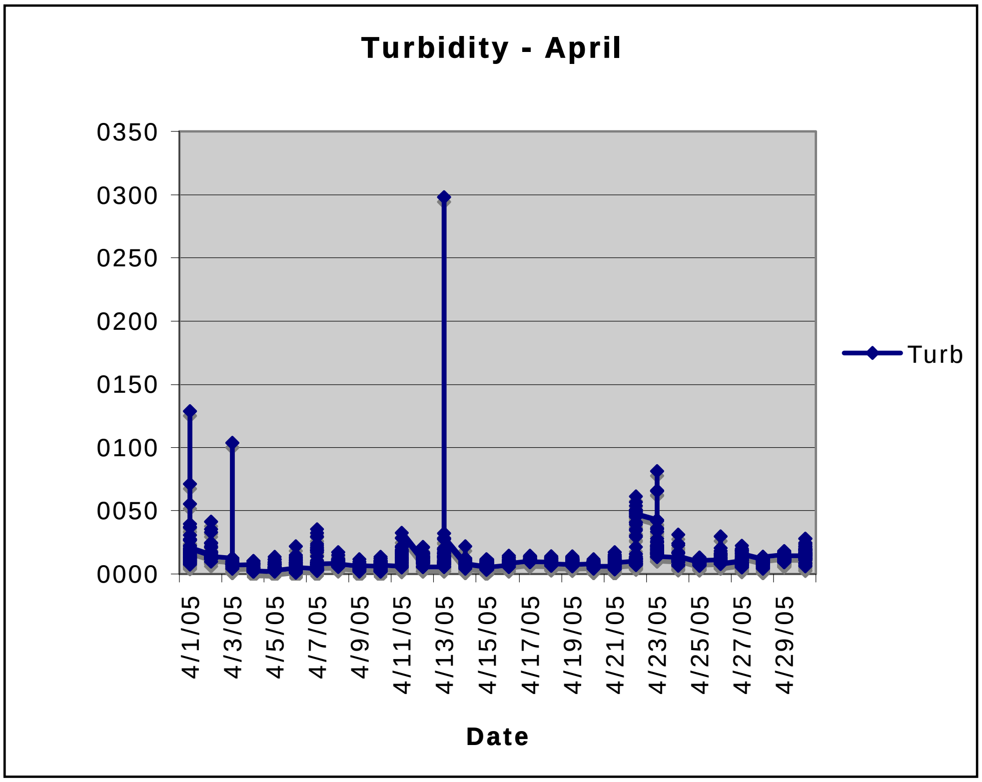


Figure 21.Turbidity during April: Grand Bay NERR—Bangs Lake

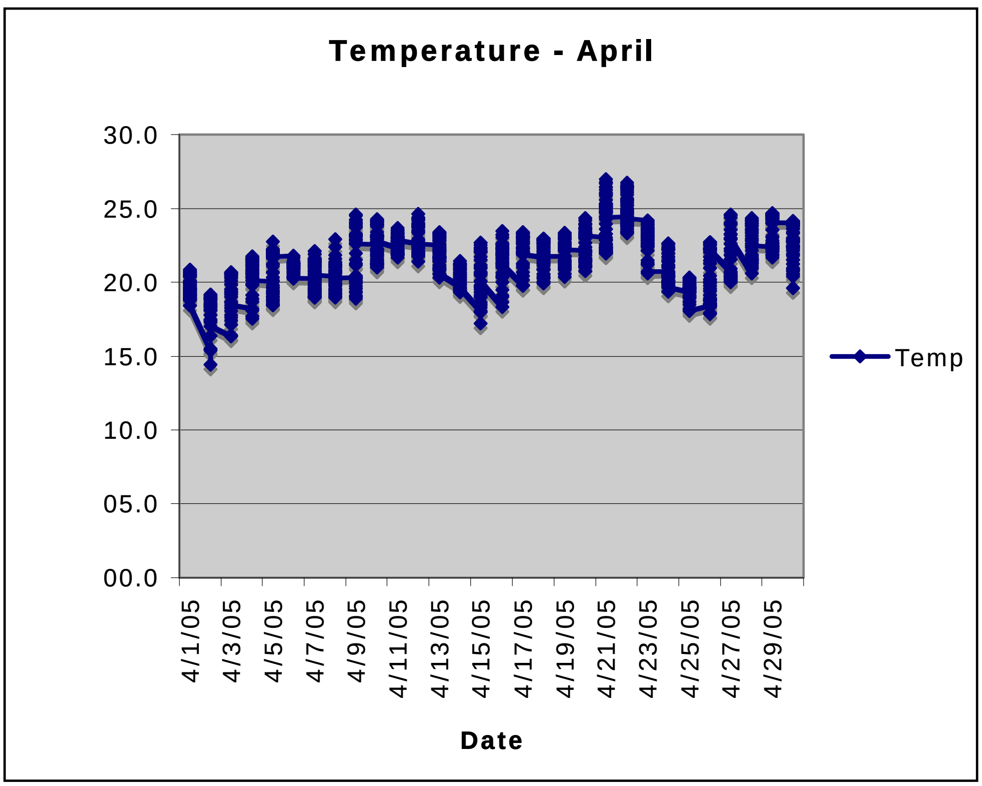


Figure 22. Temperature during April: Grand Bay NERR—Bangs Lake

Human Impact on Estuaries

Terrible Spill in Grand Bay, MS

Gypsum stack around a retaining pond holding wastewater

(Image: Grand Bay National Estuarine Research Reserve)

Fertilizer company is in the upper left corner. The spill crossed the road in the middle of the image and entered the lake. The faint green in the lower right corner are algal mats on the surface.

Photo: Grand Bay NERR

Area where the spill entered Bangs Lake. Note the algal mats on the left side of the image.

Photo: Grand Bay NERR

Marsh grass damaged by the spill.

Photo: Grand Bay NERR

Algal mats growing on the surface of the lake amid damaged marsh grass.

Photo: Grand Bay NERR

The fertilizer factory can be seen in the lower right corner. The red marker in the middle of the image shows the area of the lake where the spill entered. The other red marker shows the closest water quality monitoring station to the spill.

Photo: Grand Bay NERR

Teacher Guide—Physical Science Module
Final Assessment

1. Have students download 2005 CDMO abiotic data for Apalachicola NERR in Florida and examine the changes wrought by Hurricane Katrina in 2005. Have students download 2005 data from the CDMO site for three stations in the NERR: West Pass, Mid Bay, and Cat Point. Or download the data yourself, and print and copy it for students.

Figure 1. Apalachicola NERR region with monitoring stations.

2. Suggested guiding questions for students: Look at your graphs for the sites and use these questions as a guide to your analysis.
   a. Can you determine the dates that Katrina impacted the NERR?
   b. Describe the general pattern of values for each abiotic parameter over that time span.
   c. What is the range of values for each parameter in the NERR?
   d. Which parameter had the greatest change due the storm? Give a reason for why this parameter changed so much.
   e. What might cause the variations from station to station that you observed? Think about factors that influence this parameter, and how they might change.
   f. What questions do you have about this graph? For example, would data from another parameter help explain the variation in this graph?
   g. What additional information do you need to answer your questions?
   h. What impacts on organisms, habitats, or human life did the variation of this parameter cause?