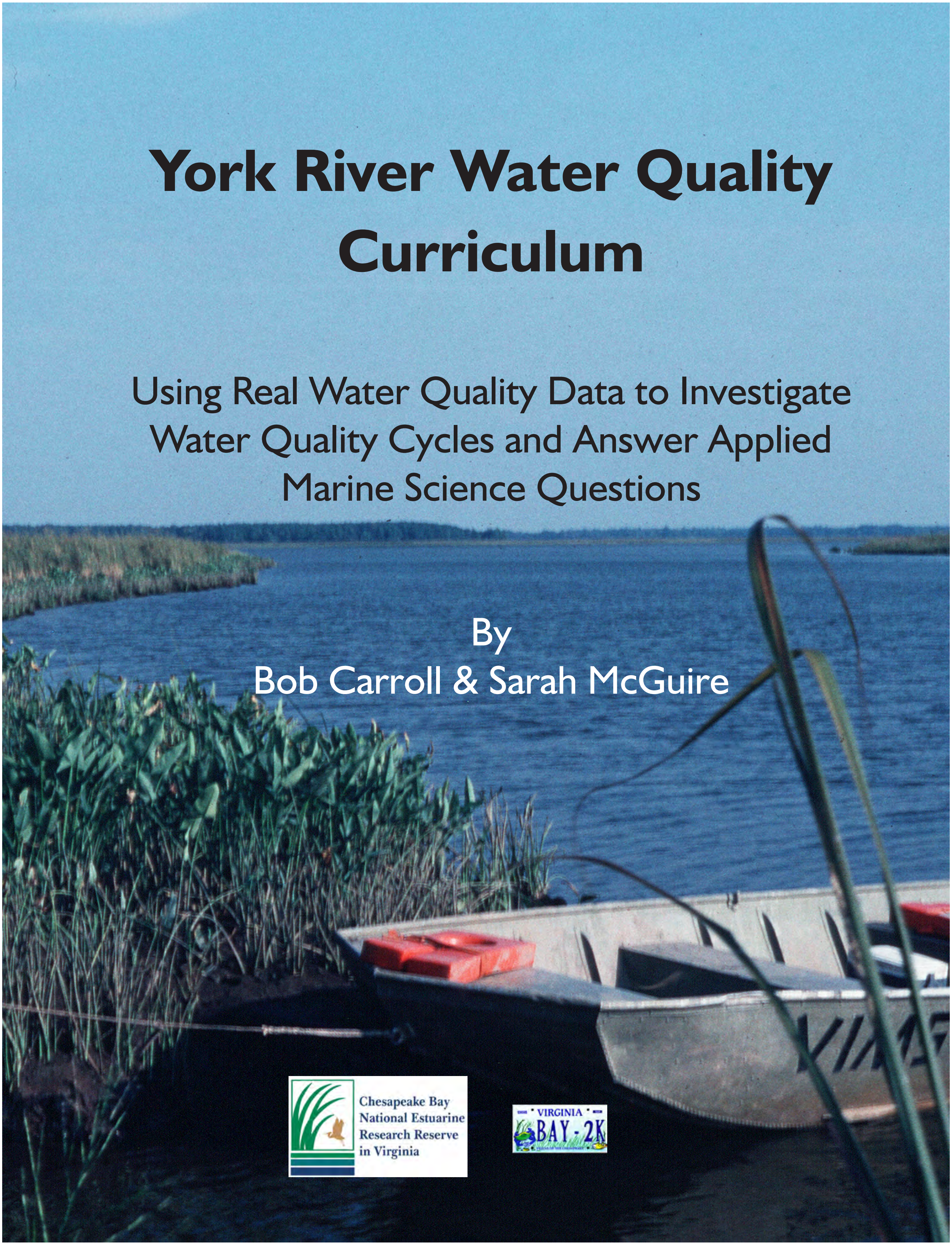

York River Water Quality Curriculum

Using Real Water Quality Data to Investigate Water Quality Cycles and Answer Applied Marine Science Questions

By
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Chesapeake Bay National Estuarine Research Reserve in Virginia

VIRGINIA BAY-2K

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Sincerely,

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Overview

Considering that Virginia has approximately 50,000 miles of rivers and streams, 2,500 square miles of estuarine water and 100 lakes greater than 100 acres, water quality monitoring with your students is a great hands-on activity that gets students thinking about the properties and processes occurring in classroom aquaria, lake, stream, river, estuarine and marine environments. It can be difficult to elucidate water quality patterns or trends with student generated data due to the low number of samples taken, the possibility of inaccurate results due to user error or expired test kit reagents as well as the innate lack of accuracy and precision associated with low-cost water quality test kits.

These activities were designed to enable teachers to expand upon their water quality and Chesapeake Bay curricula and incorporate real-world data collected in the Chesapeake Bay to address biology, earth science, computer mathematics, chemistry, and probability and statistics Standards of Learning for the Commonwealth of Virginia (specific SOL's are listed at the end of the *Teachers Pages*). The activities investigate applied marine science issues that deal with various living resources using water quality data gathered by the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) research and monitoring staff.

The activities in this curriculum cover the following topics:

- How water quality changes over time at each station (during tidal, daily, monthly, seasonal and yearly cycles; i.e. temporal variation on different time scales).
- How water quality is different at each station located along the York River (spatial variation of water quality parameters along the salinity gradient of the York River).
- Dissolved oxygen dynamics in different areas of the York River during different times of the day, season and year.
- Impacts of large storms and hurricanes on water quality in the Chesapeake Bay.
- Relationships between the water quality parameters, such as how the tide affects salinity, dissolved oxygen, turbidity, pH or water temperature at a water quality station.

We worked to include enough background information so that groups that are not familiar with water quality issues or have not performed water quality monitoring could also use these activities. Additional information on all the major water quality parameters, processes and relationship to the Chesapeake Bay can be found on the Internet links located in Appendix H. We tailored these activities to a high school audience, but the majority of the concepts could be used with middle school students who are skilled in the use of Microsoft Excel spreadsheets to sort data, calculate averages and create graphs.

Obtaining Water Quality Data from Estuaries Across the Nation

Water quality data for monitoring stations on the York River (Figure 1) and 25 other National Estuarine Research Reserve (NERRS) sites located in estuaries on the Atlantic, Gulf and Pacific coasts (Figure 2) can be found at the NERRS Central Data Management Office web page (http://cdmo.baruch.sc.edu/). The data is posted on the internet with a one-year lag time so that the data can be analyzed for errors and checked for accuracy.

The NERRS System Wide Water Quality Monitoring Program (SWMP) data *is not* stored in Excel on-line, but it is simple to save the data into Excel so you can work with it. Directions how to find this water quality data from across the nation on-line and save it in an Excel file are located in the *Accessing and Downloading NERRS Water Quality Monitoring Data from the Internet* section located after the *Introduction*.

Using the Activities

The intent of the activities is for the student to gain skills and confidence so they can work with NERRS water quality monitoring data to answer self formulated questions. The educational value of these activities is the *investigative process itself* (formulating questions and analyzing the data) instead of the actual answers to the questions posed in the activities. There are two ways that these questions can be answered.

1. Students can use the smaller data sets included on the CD to create graphs and calculate statistics with Microsoft Excel in order to answer the questions.
2. Students can query York River 2003 water quality data off the web at the NERRS Central Data Management Office web page (http://cdmo.baruch.sc.edu/) in order to

Figure 1. York River Water Quality Monitoring Stations.

answer the questions. Students can use the web site graphing and calculation tools to perform the work needed to answer the questions. Please note that the CDMO web page graphing tool graphs data using daily means, while the Excel data files on the included CD and data downloaded from the web use data collected every 15-minutes. USE of daily mean data will not be useful for many of the activities.

Encourage your students to dive into the data and try multiple ways to analyze the data to answer questions. There is no one right graph, average, chart or approach for any of these questions. There are many more relationships between the water quality parameters and uses of the data than covered in the activities. Possibly the best educational use of this data is to brainstorm your own water quality questions and work to answer them using the full 1-year data sets or the 1-week summer, 1-week winter data sets included on the CD or download water quality data from 25 different estuaries across the nation on the CDMO web page (http://cdmo.baruch.sc.edu/).

The activities are broken down into categories of complexity described below.

Level 1: Straightforward questions that use a small amount of data. *Level 1* activities can be used in somewhat of a 'cookbook' manner. Hourly data is used in some of these activities in order to simplify analysis.

Level 2: These activities use longer time periods, thus larger amounts of data, to answer questions that are not as straightforward as *Level 1*.

Level 3: Multifaceted questions that will take some planning in order to break down the components of the question, create a data investigation plan and formulate answers after considerable data manipulation. The large volume of data

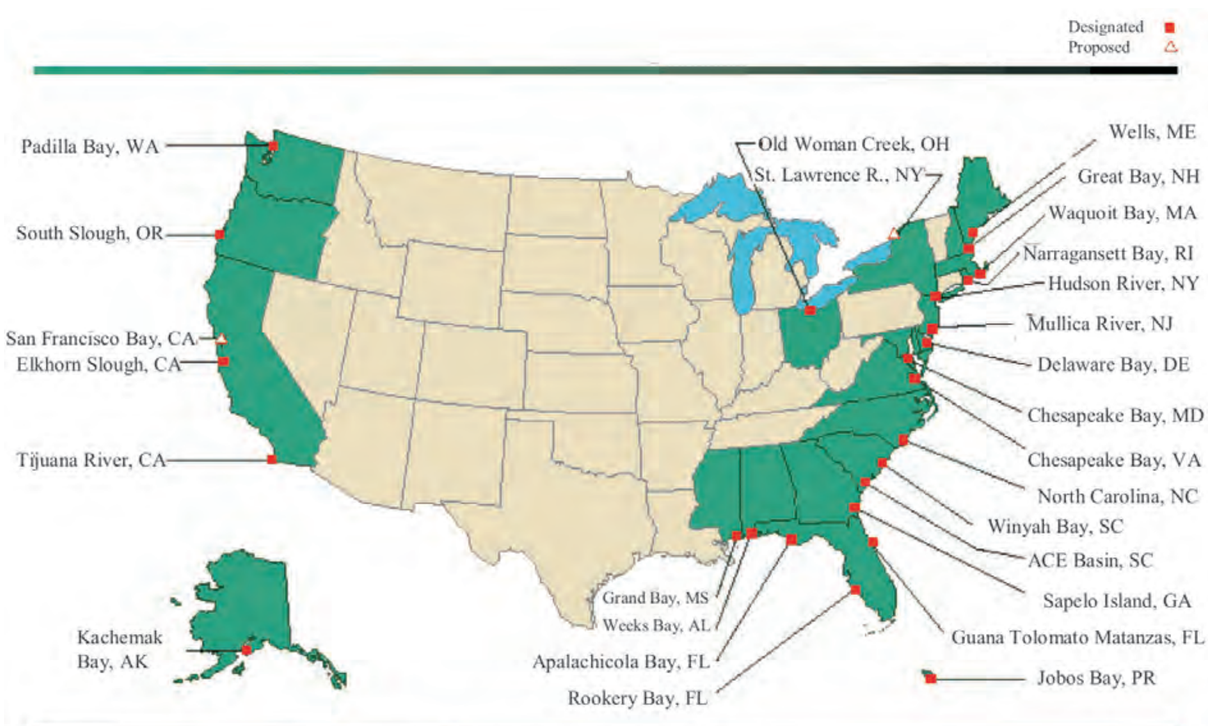


Figure 2. National Estuarine Research Reserve (NERRS) sites.

in the larger data sets can be daunting, but learning how to manage such large amounts of data is a useful exercise on its own.

Extension Activities: These questions often look for relationships between parameters (ie. tide and salinity). You may be able to answer the extension activities using the data sets you were using for the previous questions or you may have to use the full data sets. These questions are meant to help you explore the data and perform your own investigations to learn what is going on in the York River.

Geographic Extension Activities: These questions demonstrate some of the ways that the NERRS water quality data can be used to compare and contrast estuaries across the nation. Answers to these questions can only be found by downloading data from the NERRS CDMO web page and performing analysis.

Tips and Suggestions: We included suggestions on to how to approach several of the questions and manipulate the water quality data to formulate conclusions; *however these are by no means the best or only way to find the answers*. Please don't limit yourself to the approaches described.

Answers and Analysis: We included our attempts to answer Level 1, 2 and 3 questions at the back of the notebook. Our answers are by no means 100% accurate; so don't panic if you don't get the same answers. There are many ways to go about formulating answers to these questions and it's possible that you will do a better job than we did.

PowerPoint Presentation: A CD is included with this curriculum that has short pictorial description of the NERRS water quality monitoring program and demonstration graphs that display tidal, daily and seasonal cycles in the water quality data.

Activity Correlation to the Commonwealth of Virginia Standards of Learning

The CBNERRVA water quality monitoring data activities address the SOL's listed below. The extent to which the SOL's are addressed depends on the extent to which working with the water quality data is incorporated into the classroom curricula. A greater number of SOL's than listed are addressed if you actually perform water quality testing in the field with your students.

Physical Science

PS.1. The student will plan and conduct investigations in which:

a) independent and dependent variables, constants, controls, and repeated trials are identified;

b) data tables showing the independent and dependent variables, derived quantities, and the number of trials are constructed and interpreted;

c) data tables for descriptive statistics showing specific measures of central tendency, the range of the data set, and the number of repeated trials are constructed and interpreted;

d) frequency distributions, scattergrams, line plots, and histograms are constructed and interpreted;

e) valid conclusions are made after analyzing data;

f) research methods are used to investigate practical problems and questions; experimental results are presented in appropriate written form.

Earth Science

ES.1. The student will plan and conduct investigations in which:

b) technologies including computers, probeware, and global positioning systems (GPS), are used to collect, analyze, and report data and to demonstrate concepts and simulate experimental conditions;

c) scales, diagrams, maps, charts, graphs, tables, and profiles are constructed and interpreted.

ES.2. The student will demonstrate scientific reasoning and logic by:

a) analyzing how science explains and predicts the interactions and dynamics of complex Earth systems;

b) recognizing that evidence is required to evaluate hypotheses and explanations;

c) comparing different scientific explanations for a set of observations about the Earth;

d) explaining that observation and logic are essential for reaching a conclusion.

ES.3. The student will investigate and understand how to read and interpret maps, globes, models, charts and imagery. Key concepts include:

a) maps (bathymetric, geologic, topographic and weather) and star charts;

b) direction and measurement of distance on any map or globe;

c) location by latitude and longitude and topographic profiles.

ES.11. The student will investigate and understand that oceans are complex, interactive physical, chemical, and biological systems and are subject to long- and short-term variations. Key concepts include:

a) physical and chemical changes (tides, waves, currents, sea level and ice cap variations, upwelling, and salinity variations);

c) systems interactions (density differences, energy transfer, weather, and climate);

d) economic and public policy issues concerning the oceans and the coastal zone including the Chesapeake Bay.

ES.13. The student will investigate and understand that energy transfer between the sun and the Earth and its atmosphere drives weather and climate on Earth. Key concepts include:

a) observation and collection of weather data;

b) prediction of weather patterns;

c) severe weather occurrences, such as tornadoes, hurricanes, and major storms; and

d) weather phenomena and the factors that affect climate including radiation and convection.

Biology

BIO.1. The student will plan and conduct investigations in which:

b) hypotheses are formulated based on direct observations and information from scientific literature;

c) variables are defined and investigations are designed to test hypotheses;

d) graphing and arithmetic calculations are used as tools in data analysis;

e) conclusions are formed based on recorded quantitative and qualitative data;

f) sources of error inherent in experimental design are identified and discussed;

i) appropriate technology including computers, graphing calculators and probeware, is used for gathering and analyzing data and communicating results.

BIO.3. The student will investigate and understand the chemical and biochemical principles essential for life. Key concepts include:

a) water chemistry and its impact on life processes.

d) the capture, storage, transformation and flow of energy through the process of photosynthesis and respiration.

Computer Mathematics

COM.1. The student will apply programming techniques and skills to solve practical problems in mathematics arising from consumer, business, and other applications in mathematics. Problems will include opportunities for students to analyze data in charts, graphs and tables and to use their knowledge of equations, formulas, and functions to solve these problems.

Probability and Statistics

PS.16. The student will identify random variables as independent or dependent and find the distribution to determining probabilities, using a table or graphing calculator.

PS.1, 2, 3, 4, 5, 8, 18, 19, 20 and 21. The data sets used in these water quality activities are a natural fit to address many of the *Probability and Statistics* SOL's however the activities do not specifically demand the use of the techniques described in these SOL's. Please let us know if you or your students expand upon the data to address these, or other, SOL's because we would like to include such advanced use of the data in future editions.

Introduction and Background Information

York River

The Mattaponi and Pamunkey Rivers meet to form the York River at West Point, Virginia. The York is the Chesapeake Bay's fifth largest tributary in Virginia in terms of fresh water flow and watershed area. Approximately 4,280 square miles of land drain into the Mattaponi, Pamunkey and York Rivers. The headwaters of the York River begin in Orange County and flow approximately 220 miles to the Chesapeake Bay. The York River itself is only approximately 30 miles long from West Point to the Chesapeake Bay. The York River watershed is predominantly rural with forest accounting for 61% of the watershed's cover. Agricultural lands cover 19%; mixed open lands cover 14% and urban land use covers 4% of the watershed. Water bodies (streams, lakes and rivers) comprise the remaining 2% of the York River watershed. Tides reach as far 60 miles upriver from the mouth of the York River on the Mattaponi River and as far as 37 miles upriver on the Pamunkey River. Both the Mattaponi and Pamunkey rivers begin west of Interstate 95, and the Pamunkey River begins at the outflow of Lake Anna.

The York River is a sub estuary of the Chesapeake Bay, which is the largest estuary in the United States. An estuary is defined as a semi-enclosed body of water where fresh and salt water mix. Fresh water areas at the head of estuaries that experience tides are considered to be part of the estuary also. There is no real difference between the York River and the Chesapeake Bay; brackish water flows in and out through both with the tides. Estuaries typically experience a wide range of water quality conditions, both at any one location during tidal, daily, seasonal and inter-annual time periods and across the geographic range of the estuary.

Tidal salt marshes are found along the York River and extensive tidal fresh water marshes are found along the Mattaponi and Pamunkey Rivers. The Mattaponi and Pamunkey Indians both have reservations along the rivers named after them. The Pamunkey River has the largest population of American Shad of any river in Virginia. American Shad are an anadromous fish that spend their adult lives in the ocean and travel to the tidal fresh reaches of estuarine rivers to spawn. Striped bass and herring are two more anadromous fish species that spawn in the Pamunkey and Mattaponi Rivers. The York River provides habitat for blue crabs, croaker, spot, striped bass, seatrout and many other sportfish and aquatic animals. Diamondback terrapins live year round in the York, and protected species such as bottlenose dolphins, sea turtles and bald eagles frequent the York River at different times of the year.

Water Quality Cycles

Estuaries are very dynamic environments. Water quality parameters such as salinity, water temperature, turbidity (or water clarity), pH and dissolved oxygen can significantly change on a tidal, daily, weekly, seasonal or year-to-year basis as changes in tides, weather, rainfall, seasons and year-to-year meteorological trends occur. The changing water quality conditions common in many estuaries make estuaries a difficult place to live. Aquatic plants and animals that can deal with the changing conditions benefit from the high productivity (food source) and habitats that are found in estuaries such as oyster reefs, underwater grass, intertidal mudflats and intertidal marshes. These habitats offer protection from predators, food sources and the right environmental conditions (such as temperature, salinity, dissolved oxygen etc.) for a range of aquatic estuarine animals.

Some of the water quality parameters change on a daily basis during much of the year. These daily patterns are often due to changes in water temperature or the amount of sunlight during the day. Other water quality parameters change twice daily with the tides. The lower Chesapeake Bay experiences two high tides and two low tides a day. Such a tidal pattern is classified as 'semi-diurnal'. Tides also change on a monthly basis due to the lunar cycle. Seasonal cycles due to changing temperatures and solar radiation during the course of a year also have a large impact on many of the water quality parameters. Water quality parameters can also change from year to year as changing weather patterns (drought years vs. wet years) have large impacts on estuarine water quality. Familiarizing yourself with these patterns can help you understand much of the variability found in water quality data.

Many of the water quality parameters (such as tide and salinity, tide and water temperature, water temperature and dissolved oxygen etc.) influence each other. This added complexity is part of studying dynamic tidal waters.

Virginia Rainfall in 2003

The vast majority of the water quality data used in these activities is from 2003. 2003 was a very wet year in terms of precipitation in Virginia. Rainfall in the York River watershed was approximately 50% greater than the long-term average in 2003 and freshwater inflow into the Chesapeake on the whole was 53% greater in 2003 than the long-term average. Water budgets are measured in what is termed the water year. Water years span a time period of October 1 – September 30. 74.5 inches of rain fell in the time period between Oct 1, 2002 to Sept 30, 2003 in Williamsburg. This is approximately 58% greater than the 62-year average of 47.2 inches. This wet year came after a dry 2002 when only 30.4 inches of rain fell in the Williamsburg region. Stream flow in both the Mattaponi and Pamunkey reflected this higher than average amount of rainfall during the 2003 water year, with large fresh water flows depressing salinity levels in the York River. It is very important to know precipitation data for the activities dealing with salinity because salinity values in the York River change depending on rainfall amounts.

How This Data is Obtained

All of the data in these activities was generated by the water quality monitoring program at the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA). This program is funded by the National Oceanic and Atmospheric Administration (NOAA) and is based at the Virginia Institute of Marine Science (VIMS) in Gloucester Point, Virginia. CBNERRVA staff use state-of-the-art water quality monitoring instruments to gather water quality data in the York, Pamunkey, Mattaponi and other rivers and estuarine areas in Virginia. This data is used to track long-term changes and short-term variability in water quality in the York River.

The water quality monitoring stations on the York River are shown in Figure 1 and the stations distance from the mouth of the York River are listed in Table 1. The mouth of the York River is 40 km to the Atlantic Ocean.

Table 1. Location of York River Water Quality Stations.

Station Name	Location	Miles to Chesapeake Bay
Goodwin Island	Mouth of the York River; Southern side of the York River. York County	*Mouth of the York R. *40 km from Ocean*
Gloucester Point	North side of the Coleman Bridge. VIMS campus. North side of the York River in Gloucester County	12 km from the Bay
Clay Bank	North side of the York River in upper Gloucester County	27.2 km from the Bay
Taskinas Creek	Tidal Creek that feeds into the York; located in York River State Park in James City County	35.8 km from the Bay
Sweet Hall Marsh	Pamunkey River at river bend called Sweet Hall Marsh. King William County	70 km from the Bay

The water quality monitoring instruments are referred to as data sondes. Eight, size-C alkaline batteries power the data-sondes. The watertight data sondes are housed in water quality stations built in shallow water stations with water depths of approximately 1 meter at low tide. Probes attached to the data sondes measure specific conductivity (used to calculate salinity), water temperature, pH, water clarity (NTU), water depth, chlorophyll-a and dissolved oxygen (DO) every 15 minutes, 24 hours a day, 365 days a year. Each data sonde with the associated probes cost approximately $10,000.

Biofouling, or the growth of marine plants and animals such as diatoms, bacteria, algae, barnacles, encrusting bryozoans and even fish eggs that are deposited on the probes, can cause the data collected by the water quality probes to become inaccurate. Therefore the data sondes are switched in the field every week during the summer when biofouling is more active and every two weeks in the winter when cold water temperatures slow biofouling dramatically.

The water quality probes are located approximately 50 cm off the bottom, in water that is approximately 2 meters deep at high tide. The data sonde stations are located 1-meter from the shoreline at Sweet Hall Marsh and Taskinas Creek and 25 meters from the nearest shore at Goodwin Island and Clay Bank.

Data sondes are switched-out in the field so that there are no gaps in the data. A data sonde with probes that were calibrated in the laboratory are brought out to the water quality station and deployed. Calibration is the process where the probes are run in standard solutions of known value. This step is performed to make sure the probes are working right and will measure the water quality parameters accurately. The data sonde that was in the field is brought back to the lab for post-calibration and download. Post-calibration is the process where the probes are tested using solutions with known values (standard solutions) in order to tell how far off the water quality probe readings drifted while they were in the field. This information is used to adjust the data. The data sonde is hooked up to a computer and the water quality data is downloaded. The data is checked for errors in a process known as quality assurance and quality control or QA / QC. Erroneous readings are deleted or 'fixed' so the vast majority of the data you are looking at can be taken at face value.

Data Sets on the CD

Water quality data from 2003 was used for the majority of these activities. There are periods when sampling had not yet begun at that station or where the data had to be deleted for various reasons. You will also see that chlorophyll-a data was not measured at all stations, and the stations that did measure this parameter started doing so at different times of year. Table 2 shows the time coverage for data included at each station in 2003.

Table 2. Time Coverage of 2003 York River Water Quality Included on the CD.

Water Quality Station	Available Data Coverage in 2003
Sweet Hall Marsh	Full Year
Taskinas Creek	Jan 1 – Dec 17
Clay Bank	Full Year
Gloucester Point	June 1 – Dec 1
Goodwin Island	Jan 1 – Sept 17, Sept 30 – Dec 31
All 5 Sites	1 Week Summer and 1 Week Winter

Data Management

Several tips and suggestions on how to work with the data are provided below. All of these were learned the hard way, which means it is likely they won't make sense to you until after you have made all the same mistakes working with the data that I made.

- Make a list of exactly what you want to know or calculate in order to answer the questions before you begin working with the data, and make a plan of who will obtain each result and how to do it. Dividing the job among the group will often be a great way to get a tremendous amount done quickly, and a list of job responsibilities will help tremendously.
- Make a data management plan *before* you begin working with the data and creating Excel graphs. This includes making properly labeled folders on your computer.
- Make a copy of each data set before you begin working with it and work from that copy only. Label each data set as 'working' and 'original'.
- Use the same color on every graph for each water quality parameter (e.g. blue for water depth, red for water temperature etc.). This will make them much easier to understand as they get more complex or you combine work.

- Label each graph or spreadsheet with enough information so you will know exactly what each file or graph was at a later date. Never assume you will remember anything even 5-minutes later; label every spreadsheet and graph.
- Take time to delete spreadsheets and graphs that are not properly labeled, didn't work out or have problems. Deleting old and unused files can really help data organization.
- If you make a mistake with a spreadsheet that you do not have a backup copy for, you can always close that spreadsheet and reply NO when asked 'would you like to save changes to this file'. Excel will then save the spreadsheet that was last saved, hopefully reverting to a copy that does not have the mistake on it.
- A scientist is always responsible to know everything about the data that they are using. With this in mind, *look at all the data to get a feel for it.* An invaluable technique to get to know the data is to *v*isualize the data by making rough graphs with it. Invalid and questionable data points should be visible when you graph it as a data point, or a string of data points, that are wildly different from any others or undergo drastic changes with no apparent reason. These data points can be deleted from your Excel file (see 'massaging the data' below). Visualizing the data during this 'exploratory graphics stage' will help you *every single time* you are working with data for the rest of your life. Don't rely solely on averages calculated on the spreadsheet. Take time to graph the data as well.
- Graph as much as you can. You will see trends with greater resolution as you graph shorter time periods. You can also see relationships if you graph two water quality parameters (such as tide and salinity) on the same graph using a graph with two y-axes. Be sure that the time period that you graph for the two variables are the same.
- Save often. Save Often. SAVE OFTEN!

"Massaging the Data"

<u>Outliers</u>

Outliers are data points that far exceed the normal range of data (normally three standard deviations above or below the mean). After graphing some of this data myself I found that there were cases where data points seemed erroneous even though this data had already been inspected. These outliers were extremely high or low values that occurred for very brief periods of time and don't match any trend in that parameter before or after the outlier was observed. For instance, I would question a one-time dissolved oxygen data point of 1.2 mg/l if the dissolved oxygen readings before and after the 1.2 mg/l reading were steadily between 5 and 6 mg/l. I would similarly question a NTU (turbidity) reading of 550 NTU's surrounded by readings in the teens. If the extremely high or low readings are only found during one sampling interval it's a good chance the data sonde malfunctioned or that some unknown incident occurred such as a fish or crab was sitting on the probe when the reading was taken. These anomalous readings can't always be edited out of the data by professional NERRS staff because the instrument may not have reported being out of range or malfunctioning upon the QA/QC process and therefore the data cannot be deleted according to protocols.

After looking at the data, you may feel that more of the extremely high or low data points should be deleted. Feel free to edit the data as long as you have valid reasoning behind the data you cut. You are allowed to edit data in science as long as you record your methods for doing so and your reasoning for editing the data is logical.

Zero and Negative Data Points

The data sondes can become completely exposed during extreme low tides. These often occur during the winter months when strong Northwest winds push water out of the Bay. The water depth and other data values will often plummet to zero when this happens because the probes are out of the water and no longer function properly. Keep an eye out for this in the data and delete the data from these time periods.

Blank Data Points

You may find blank data points demarked by ‘ – ’ where there would normally be a data point. These were deleted from the data set due to errors. Feel free to delete these data points entirely if doing so helps create nicer graphs.

Red Data Points

Data in red font should not be used and should be deleted.

Your Answers Don’t Match Those in the “Answers and Analysis”

It is highly likely that your answers for the questions will be different than those listed in the *Answers and Analysis* section. It is easy to skip numbers here and there when making averages with such a large amount of data. It is also possible that we deleted certain data points from the data for our calculations that were included in the data sets that you are working with. Don’t worry about getting the exact number, as long as your answer is similar. For example, don’t worry if you calculated the average salinity value at Goodwin Island for the month of June to be 19.5 ppt and we calculated it to be 19.8 ppt. Such differences are likely due to differences in how we deleted outlier, out of range or ‘zero’ data points and interpreted graphs.

Accessing and Downloading NERRS Water Quality Monitoring Data from the Internet

** These instructions are valid as of Jan 24, 2006. They are likely to change as this internet page continues to improve.*

1. Go to http://cdmo.baruch.sc.edu/, the home page for NERRS Centralized Data Management Office. Information on the data and units for each parameter under "About Data".
2. In order to access data for making graphs with daily averages on the webpage itself, or to access data and download the data in order to make more detailed graphs or analysis, click on "Get Data", then "Query Data", then "Single Station".
3. Select the Chesapeake Bay, Virginia site on the map (purple dot in Virginia).
4. Select the Taskinas Creek site (#6) on the map of the York River that displays the Virginia water quality monitoring sites. Be sure to select Taskinas #6 because that is the station that has water quality data, and not just weather data.
5. Select "Water Quality Data" and then the year that you are interested in researching. Click "submit".
6. Next, select the water quality parameters that you are interested in. You can keep all parameters selected for now if you are not sure what you will need later on. Then, select the beginning and ending dates for the data. For example, you may want to get all of July's data, or all of 1995's data. Click "submit".
7. You will see part of the data displayed, with a tool bar across the top. You can have the webpage graph the data that you just queried, or calculate statistics for the time period you queried. The webpage graphing tool will only graph daily average values. The graphing and statistics tools are incredibly helpful, however there will be times when you want to export the queried or yearly data into Excel files so you can make graphs with two variables and look at the data more closely by analyzing the data that is collected every 15 minutes.
8. In order to export the queried data into an Excel file, select "Export Query Data" and then "Click Here to Export Data". Fill in the information asked for with your name, organization, and purpose for data and select "Submit".
9. Under "Name" select the link to the file with your data. Click "cancel" when it asks for a network password. If the data is already in neat columns, then click "File", "Save As", select where you are saving the data, and change file type to "Excel Workbook". If the data is not in neat columns already, highlight the first column (A), and go to "Data" on the toolbar, then "Text to Columns", "Delimited", Select ONLY the comma and unselect other terms, and then "Finish". Now you can save the file as described above.
10. Close the window you are working in, and open the Excel file you just created to work with the data.

Activities

Using the CDMO Web Page: Sample Activities

The following activities will help you become familiar with using the CDMO web site. This web site has water quality monitoring data for 26 estuaries around the United States. Instructions on how to use this website are located on the previous page at the end of the *Introduction* section.

Graphing Parameters

We will go to the NERRS CDMO web page (http://cdmo.baruch.sc.edu/) in order to download water quality data and use this data to make graphs and calculate statistics on the CDMO web page with their graphing and statistics tools. Directions on how to do this are on the previous page.

1. Go through steps 1, 2, 3 and 4 on the previous page (Accessing and Downloading NERRS Water Quality Monitoring Data from the Internet)
2. Select 1999 for the year (remembering that we are in Water Quality Data for Chesapeake Bay, Virginia, Taskinas Creek site).
3. Leave all parameters selected, and be sure that lower boundary date is 01/01/99 and upper boundary date is 12/31/99. Select "Get Data".
4. You will see some of the data displayed. Select "Graph Data" from the toolbar above the table. Temperature is already selected as the parameter. The graph displays the water quality data over the entire year. Try this for Salinity and other parameters to see how they change over an entire year.
5. Now, go back and change the boundary dates to 01/01/99 to 01/02/99 and see how the data changes over just one day. Notice that the web page calculates daily averages so this graph is not very useful.
6. Go back to the web page section where you choose the year that you are interested in and go to the next section below.

Graphing Parameters During A Storm Event

We will work with more data on the webpage with this activity and also save queried data (15-minute interval data) onto a file for later use.

1. Select 2003 (remembering that we are in Water Quality Data for Chesapeake Bay, Virginia, Taskinas Creek site).
2. Check off Salinity, Depth, and Turbidity as parameters and set lower boundary date to 09/01/03 and upper boundary date to 09/30/03. Select "Get Data".

3. You will see some of the data displayed. Select "Graph Data" from the toolbar above the table. Salinity will already be selected as the parameter. This graph shows the change in salinity during September 2003, when Hurricane Isabel hit the Virginia coast. Notice which dates were likely affected by the hurricane. Try this for Depth and Turbidity, as well as any other parameters that you think may be affected during a storm event.
4. * Save this data (the data, not the graphs) onto an Excel file on your computer hard drive or CD and label it '*Isabel*' for use during an upcoming activity. Directions on how to save this data into an Excel file are on the previous page (step 8, 9 and 10).
5. Go back to the web page section where you choose the year that you are interested in and go to the next section below.

Comparing Parameters

This activity again explores water quality data at Taskinas Creek using the CDMO web page tools.

1. Select 2000 for the year (we are still in Water Quality Data for Chesapeake Bay, Virginia, Taskinas Creek site).
2. Select Temperature and Dissolved Oxygen (mg/L). Set lower boundary date to 01/01/00 and upper boundary to 12/31/00. Select "Get Data".
3. You will see some data displayed. Select "Graph Data" from the toolbar above the table. Temperature will already be selected as the parameter in the graph. Notice the trend in temperature change over the course of the year. Now, graph the Dissolved Oxygen (mg/L) to see what the trend is for that parameter over the year. Do you notice any correlation between the two? You can go back and try other parameters that you think may be interconnected if there it time.

Graphing 15-minute data imported from the CDMO web page.

The CDMO web page only graphs and calculates statistics for daily average values. There are many times when you can learn a lot more by graphing or calculating statistics using the 15-minute interval data that you can import from the CDMO web page. You can also graph two dependent variables using Excel, which allows you to look for relationships between parameters (such as tide and salinity and many more) because both dependent variables are shown on the same graph.

The following activities are meant to make you comfortable making graphs from the 15-minute interval water quality data that we imported from the CDMO web page using Excel.

1. Minimize the CDMO web page and open the file you saved named 'Isabel'. This file should have the salinity, depth and turbidity for the month of September 2003 at Taskinas Creek. Hurricane Isabel hit on the 18th of this month.
2. Graph 1: We are going to work to make a single-dependent variable graph with water depth (the dependent variable) on the y-axis, and date (the independent variable) on the x-axis. Feel free to try this yourself if you are comfortable graphing in Excel, or look at the directions in Appendix C.

   a. What time had the highest tide in Taskinas Creek during the hurricane and how much higher was this tide than the next highest tide in September at this site?

3. Graph 2: Now make a two-dependent variable graph with salinity and turbidity (both dependent variables) on the y-axis, and date (the dependent variable) on the x-axis. Feel free to try this yourself on Excel or look at the directions in Appendix D.
   a. What happened with salinity and turbidity values in Taskinas Creek during Hurricane Isabel (Sept 18 – 19)?
4. We created a graph of the entire month of September. This large time scale may hide some interesting information. Please make another graph of water depth and salinity on the y-axis and time (not date this time) on the x-axis for the time period of midnight on September 17 to Midnight on September 19.
   a. Can you discern more information about the hurricanes effects on Taskinas Creek tides and water quality using this finer resolution?

Activities Using the Data on CD

Natural Cycles

Many of the water quality parameters measured by NERRS change on a regular basis over a tidal, daily (diel), monthly, seasonal or a year-to-year basis. You will begin to see these patterns when you graph some of the parameters for various lengths of time. We will investigate several of such natural temporal signals in the next several activities. Understanding how the water quality parameters change on a tidal, daily, monthly, seasonal and year-to-year basis will give you an advanced understanding estuarine science.

All of the questions from this point on can be answered using the data included on the CD and Microsoft Excel. You could also download the data from the CDMO web page to answer some of these questions if you want more experience using this resource.

Tides and Tidal Cycles

The questions below are based on water depth data. The CBNERRVA data sondes record water depth at each station every 15-minutes. Remember that the probes are 50 centimeters above the sediment when calculating total water depth.

Please note that there are times when the tide is so low that the probes are out of the water. These events appear in the data as zero or negative values in the tidal data points on the spreadsheet and you can feel free to delete them from the dataset. Negative water depth values will make any graphs look strange if you leave them in, but they won't ruin the overall information.

Level 1

Tide 1.1. What times were the two low tides and two high tides at the Goodwin Island Station on June 21, and were they equal in depth? How far apart in terms of time was each successive tide? Use Excel file *Tide 1* to answer this question.

Data Suggestion

I found it easiest to create a graph of tide level vs. time for this problem. Excel then told me the time of the lowest and highest tidal readings when I moved the cursor over the two lowest tides and then the two highest tides on the graph line.

Tide 1.2. What was the tidal range at the Goodwin Islands Station on June 21? Tidal range is the difference between the highest and lowest tidal reading during the time period of interest. Use Excel file *Tide 1* again for this exercise.

Data Suggestion

I found that the answer could be found by either moving the cursor on the highest and lowest tide level on the graph created in question *Tide 1* and reading the lowest and highest tidal heights in the text box *or* by sorting the data in Excel file *Tide 1* by water depth and subtracting the lowest tide height from the highest.

Level 2

* Excel file *Tide 2* has the tidal information that you will need to answer the next four questions.

Tide 2.1. What time are the two low tides at Goodwin Island, Gloucester Point, Clay Bank and Sweet Hall Marsh on June 21? How does the low tide move in the York River? Fill in Table 3 (next page) to make this answer easier.

Tide 2.2. What time are the two high tides at these same stations on June 21? How does the high tide move in the York River? Fill in Table 4 (next page) to make this answer easier.

Tide 2.3. What is the tidal range at each station? Tidal range is the difference in water height between low and high tides. Does the tidal range change as you move upriver? Complete Table 4 (next page) to answer this question.

Table 3. Low tide: York River Water Quality Stations, June 21, 2003.

Site	1st Low Tide	2nd Low Tide
Goodwin Island		
Gloucester Point		
Clay Bank		
Sweet Hall Marsh		

Table 4. High Tide and Tidal Range: York River Water Quality Monitoring Stations, June 21, 2003.

Site	1st High Tide	2nd High Tide	Tidal Range
Goodwin Island			
Gloucester Point			
Clay Bank			
Sweet Hall Marsh			

Level 3

Tide 3.1. What is the average tide level at the Goodwin Island monitoring station during the month of June. You want to know this because you know that underwater grass is growing all around the data sonde station, and you want to get an idea for the average tide level where underwater grass or submerged aquatic vegetation will grow. Remember that the probes are 50 centimeters, or 0.5 meters, off the bottom, so you have to add this amount to your average depth reading to calculate the average water depth at this station. Excel file *Tide 3* for this activity.

Data Suggestion

The best way to answer some of these questions is to perform calculations on the Excel spreadsheet instead of making graphs. In this case I had Excel calculate the average water depth values in file *Tide 3*.

Tide 3.2. What was the tidal range over the course of the month of June at Goodwin Island in 2003? The tidal range is the difference between the highest and the lowest tidal level during the month. Could you stand on the bottom at this station during the highest tide of the month? Use Excel file *Tide 3* for this activity.

Tide 3.3. Do all of the tides in June at Goodwin Island have the same tidal range or amplitude? The tidal range is the height difference between low tide and the next high tide, not the actual level of the low or high tide. Any guesses as to what makes the tides behave this way?

Data Suggestion

Graph the tide data from Goodwin Island for the entire month of June using Excel file *Tide 3* (you may have already done this for a previous question). Put the water depth data on the y-axis and time in hours on the x-axis.

The x-axis will not be pretty due to the large number of data points but you can adjust the x-axis by *right clicking on the x-axis* and going to *format axis* and then adjusting the *scale*. I have not found a way to get Excel to create the x-axis that simply places 1 date per 31 days of the month on the X axis, so don't worry so much about the x-axis for any graphs that show monthly, seasonal or yearly data. I often allow Excel to use the spreadsheet line numbers, instead of the dates for the x-axis to make a nicer graph

__Extension Questions__

1. During what phase of the moon would be the worst time for a coastal storm to send a storm surge into the Bay in terms of coastal flooding?
2. At what time and how high was the highest tide at Goodwin Island during 2003 other than Hurricane Isabel on Sept 17 and 18, 2003?
3. Is there a time of year when the tidal range, or variation, is much greater than other times of year? Tidal range is the difference between subsequent low and high tides.
4. Are there any instances other than Hurricane Isabel on Sept 17 and 18, 2003 when the tide stayed high or low for several days in a row? If so, when did it occur and what could cause this?

__Geographical Extension Questions__

1. Do other estuaries have the same tidal regime as the York River (ie. two low tides and two high tides each day)?
2. Do other estuaries in the United States have a greater tidal range (ie. the difference between low tide and high tide)?

Water Temperature: Diel and Seasonal Cycles

The Chesapeake Bay and its tributaries experience dramatic changes in water temperature during the course of the year. The temperature of shallow waters can range from freezing during the winter to 90° F during hot summer days. Deeper waters experience less temperature variation during the year. This great range of temperature during the year is another factor that makes the Chesapeake Bay a difficult place to live on a full time basis. We will look at seasonal changes in water temperature in later activities.

Water temperature is a water quality parameter that often exhibits a daily pattern, or daily cycle. The scientific word for a daily cycle is diel. Diel cycles normally have one high point and one low point during the 24-hour day, and these points typically occur at the same general time of day. Diel cycles are different than tidal cycles because tidal cycles have two high and two low points per day. The times of tidal cycles will also change from day to day as the time of high and low tide changes.

Water temperature may not display a diel cycle everyday. Cool cloudy weather during the day or an early afternoon high tide bringing in cooler water could keep water temperatures from warming during the day. The activities below will look for diel and seasonal trends in water temperature.

Level 1

Water Temperature 1.1. When is the lowest and highest water temperature for July 28, 2003 at Goodwin Island? Use date file *Water Temperature 1.1* for this activity.

Data Suggestion

You could either sort the data by the water temperature column in the Excel spreadsheet file Water Temp 1 or graph the water temperature on the y-axis with time of day (hh/mm) on the x-axis. I suggest you graph the data to observe the pattern of water temperature over the day.

Water Temperature 1.2. You are an avid fisherman and you know that rockfish and sea trout leave the flats (shallow water) when the water temperature is at its warmest during the day. Please investigate the water temperature data for the Goodwin Island monitoring station for the week of July 21-27, 2003 and report when the highest water temperatures occur during the day. When would you not want to be fishing for rockfish and sea trout at Goodwin Island? Use Excel file *Water Temperature 1.2* for this activity.

Data Suggestion

I made a graph of water temperature for this week on Excel with time on the x-axis and water temperature on the y-axis (Appendix C). I highlighted the matching time of day (column B) for the x-axis parameters and then adjusted the x-axis scale by the following steps in Excel (Right Click on the x-axis. Format Axis. Scale. # of categories between tick-mark labels = 24). I also adjusted the scale of the y-axis to better show the change in temperatures by changing the maximum and minimum unit on the y-axis to one degree above and below the actual high and low water temperature.

Level 2

Water Temperature 2.1. Now graph the water depth for July 21-27 at Goodwin Island on the same graph as the water temperature for this period. Does the tide appear to influence the water temperature? Use Excel file *Water Temperature 1.2* for this activity. This is the same data file that you used for the previous question.

Data Suggestion

You have to make a graph with two y-axes for this one. Directions for this are in the Appendix D. Remember to always use the same color for each different water quality parameter (blue for water depth). This will make it easier to read your graphs.

Water Temperature 2.2. Graph the water temperature for Feb 22 – 26, 2003 using the data in Excel file *Water Temperature 2.* Can you observe a diel cycle in water temperature during this winter week? What patterns do you see? Do they move on a daily basis?

Level 3

Water Temperature 3.1. What months are the warmest and coldest water temperatures observed at Sweet Hall Marsh? How warm and cool do the water temperatures get? Use data file *Water Temperature 3.1* for this activity.

Data Suggestion

Making a graph with this much data will test your skills in graphing with Microsoft Excel. Please read the graphing directions in the Appendix for help. You will have trouble with the X and Y-axis scale. The X-axis will be trouble because there are so many data points. The Y-axis will be trouble because the temperature probe was out of the water during low tides in the winter and registered negative readings. Both of these issues can be fixed by changing the scale of both of these axis.

Extension Questions

1. Given that shallow water heats up faster than deeper water, which tidal conditions (high tide or low tide) would you expect to find the warmest water in the early to mid-afternoon?
2. Do you think that changing tides would have some effect on changing water temperatures? Do you think a rising tide would bring in cooler or warmer water to a water quality monitoring station? Can you find evidence of this in the data?
3. The water temperature ranged from 0° C to 30° C at Sweet Hall Marsh during 2003. What are these readings in degrees Fahrenheit? This is a very large temperature range. Do you think such a wide range of temperatures during the year makes it hard for animals to live here? Search the Internet to find the temperature range over a year for an ocean location off Virginia. Does the water temperature range as much over the year in the ocean?

Geographical Extension Questions

1. How hot and how cold does the water get at the Rookery Bay Reserve in Florida? Is this range greater than we experience in the York River, Virginia?
2. How hot and how cold does the water get in Coos Bay located at the South Slough Reserve in Oregon? How does the temperature range compare with what we have in the York River, Virginia?
3. What is the warmest water temperatures recorded at the Wells Reserve in Maine? Would you swim in water at this temperature?

Salinity

Estuaries are semi-enclosed bodies of water where fresh and salt water mix. This mix of fresh and salt water is called brackish water. Salinity is the number of grams of salts dissolved into 1,000 grams of water. Ocean water is approximately 35 parts per thousand (ppt) salt. Another way of thinking about this is that 1,000 grams of seawater holds approximately 35 grams of salt.

Estuaries typically have a salinity gradient of nearly salt water (30 – 35 ppt) close to the ocean to fresh water at the head of streams, creeks and rivers. There are locations where fresh water parts of rivers, streams or bays are tidal, thus there can be tidal fresh water parts of estuaries. Tidal fresh water are between 0.0 and 0.5 ppt salt. Marine scientists classify estuarine areas by salinity regimes listed in the table below.

Salinity Regime	Salinity Values
Tidal Fresh Water	0.0 – 0.5 ppt
Oligohaline	0.5 – 5.0 ppt
Mesohaline	5.0 – 18.0 ppt
Polyhaline	18.0 – 35 ppt

Estuarine organisms not only encounter a salinity gradient, or changing salinities, as they move around the estuary, but they also can face changing salinities if they stay in the same place. Salinity often changes with the tides (*tidal cycle*), and can also change during the course of one year (*seasonal cycle*) as droughts or floods alter the amount of fresh water flowing into the estuary. Salinity can also change on a *yearly cycle* due to long term droughts or years with much greater than normal rainfall. This changing salinity is a difficult factor for aquatic organisms to deal with. The few species that can live in brackish water with these changing salinities are often found in huge numbers because estuaries are great habitats.

Looking at the salinity variation at a given site over the course of a day, week, month, season, year and between years can be very interesting. Here are some Level 1 and 2 questions to get you going.

Level 1

Salinity 1.1. Graph the salinity at Taskinas Creek for October 30, 2003. Use Excel file *Salinity 1* for this activity. What is the salinity difference between the highest and lowest salinity reading at this site?

Salinity 1.2. Now add the water depth to this graph. Is there a pattern between salinity and water depth? Use Excel file *Salinity 1* for this activity also. Use the help box in Excel or look at the Appendix for directions to create a graph with 2 y-axes.

__Level 2__

Salinity 2.1. What are the low and high salinity values for Sept 1, 2003 at the five CBNERRVA water quality stations? Use Excel file *Salinity 2* to fill in the data table below for this activity.

Is there a pattern to the salinity regimes at each station?

Is there a pattern of salinity as you move up the York River?

Table 5. High and Low Salinity: York River Water Quality Monitoring Stations, Sept 1, 2003.

Water Quality Station	Low Salinity Reading	High Salinity Reading
Goodwin Island		
Gloucester Point		
Clay Bank		
Taskinas Creek		
Sweet Hall Marsh		

Salinity 2.2. Graph the salinity data over the entire year of 2003 at the Clay Bank water quality monitoring station. What time of year are the highest and lowest salinity readings? Use the Excel file for Clay Bank from the *Full Data Sets* for this activity.

__Extension Questions__

1. Does the salinity at other water quality stations change as much as it does at Taskinas Creek during a 24-hour period?
2. Is the salinity pattern at Goodwin Island different in 2003 compared with 2002. You can use the data in the full data set for 2003. You will have to go to the CDMO web page to 'query' the data for 2002. What do you think is the reason any observed differences in salinity between the two years? Do you think the salinity pattern for 2002 at Goodwin is an example of a seasonal salinity cycle?

__Geographical Extension Questions__

1. Does the salinity change during the course of a year as much in the estuaries located in the Guano Tolomato Matanzas Reserve in Florida as it does in the York River? Why do you think this is?
2. What is the salinity in the Hudson River at the Hudson River Reserve? Is this still an estuary?
3. Is the salinity appropriate to grow oysters in other estuaries in the United States? Take your pick of which estuaries to study using NERRS sites across the nation on the CDMO web page.

Episodic Events

Hurricane Isabel

Hurricane Isabel Details

On September 18, 2003, Hurricane Isabel made landfall near Drum Inlet, North Carolina, approximately 150 miles south of the Chesapeake Bay mouth. Hurricane Isabel was a Category 2 storm with hurricane force winds (≥ 74 mph) extending up to 115 miles from the storm's center and tropical storm force winds (≥ 35 mph) extending up to 344 miles from the storm's center. Isabel moved in a northwest direction after landfall at a speed of approximately 19 miles per hour. The storm center passed just west of Richmond, Virginia at 11 pm on September 18. Tidewater Virginia was impacted by the northeast quadrant of the storm, which is typically the most damaging quadrant of tropical storms in terms of wind, storm surge and rain.

Minimum atmospheric pressure at along the York River during the passage of Hurricane Isabel was 990 millibars. Sustained winds of 45 miles per hour were recorded at Gloucester Point for six hours with winds gusts of up to 71 miles per hour recorded at this location. Large waves up to 6 foot high on top of the storm surge were measured off the Virginia Institute of Marine Science campus at Gloucester Point. The storm induced current moved up the York River at a speed of 2.2 miles per hour.

Total rainfall amounts ranged from 2.3 to 4.7 inches in the York River watershed during the passage of Isabel on September 18 and 19. Stream flow at gauging stations in the Mattaponi and Pamunkey Rivers increased by 20 – 30 times from pre-storm conditions shortly after the hurricanes moved through the area.

The CBNERRVA water quality monitoring stations at Gloucester Point, Clay Bank, Taskinas Creek and Sweet Hall Marsh made it through the storm and provide interesting information about how this major storm impacted the York River. The Goodwin Island data sonde was blown out of its fixed station housing during the storm and was found several weeks later half-buried in the sand approximately 30 feet from the station. Data from this data sonde is unusable from the point it was blown off the housing.

Your Job

You are a newspaper reporter for *Tidewater Virginian*, a newspaper covering Southeastern Virginia and the Peninsulas. Hurricane Isabel received tremendous news coverage as the storm approached and after the storm passed. The majority of the news coverage was on the damage to manmade structures and personal loss caused by the storm surge flooding, power outages and damage to homes and businesses. Several months after the storm, the *Tidewater Virginian* decided to run a cover story in their weekly *Outdoors* section about Hurricane Isabel's impact on the natural world including forests, streams, rivers and the Bay.

You are in charge of writing an article about Hurricane Isabel's impacts to water quality in the York River. After talking to several people at VIMS you were directed to the CBNERRVA water quality monitoring program and you obtained a copy of the water quality data for four stations along the length of the York River for the month of September 2003. Good investigative reporting entails that you do your own sleuthing through the data to find the facts, so have at it.

<u>Level 3</u>

Isabel 3.1. Write an article about Hurricane Isabel's impacts to water quality in the York River. Analyze the water quality data from the four water quality-monitoring stations and report interesting facts. As a news reporter, you have to make this article interesting as well as informative.

Complete data files for the month of September are in Excel file *Isabel Gloucester Point*, *Isabel Clay Bank*, *Isabel Taskinas Creek* and *Isabel Sweet Hall Marsh*. These four data files are in the Isabel folder located in the Data folder.

Tips and Suggestions

I went about this question by graphing all of the parameters for the month of September at each site and looked at the data visually. This doesn't take too long, especially if you are working in groups and divide the work. Several of the parameters have very obvious changes during the storm; others don't change at all during the storm, but change *after* the storm. It's important to look for changes on the day of the storm itself, and changes in the overall trends after the storm has passed. It is also interesting to report how the storm may have impacted areas of the River differently. Questions that may help you get started if you are having trouble are:

- What was the highest tidal level at each site and what time did that occur?
- How much higher was the storm surge than any other tide in September?
- Did the highest water of the storm surge stay around for an amount of time, or did it quickly drop?
- How did the tides behave during and soon after Isabel? Were there normal high and low tides on Sept 18 and 19?
- How did turbidity change at the stations during Isabel, and how long did the changes last?
- Were the turbidity increases due to phytoplankton (chlorophyll-a) or suspended sediment in the water?
- How did salinity values change at each station during the storm and was there a long-term change in salinity after the storm?
- Did the storm change DO levels and trends at the water quality monitoring stations?

Applied Marine Science Questions

Tidal Fresh Water Marsh Preservation

Tidal Fresh Water Marshes

Tidal marshes are low-lying areas with emergent vegetation that are flooded during high tides. Tidal marshes normally flood twice a day during the two high tides. Some tidal marshes are located at slightly higher land elevations and only flood during higher than average high tides.

Tidal marshes that occur in salty areas of the Bay are inundated by brackish water and are called salt marshes. Tidal marshes that occur in fresh water areas of the tributary rivers and tidal creeks are called fresh water marshes. Fresh water marshes are often found at the very top of tidal creeks and further up the tributaries where the tide moves freshwater back and forth during the normal tidal cycle. Tidal fresh water marshes are known to have much higher plant species diversity than salt marshes. Many species of migratory waterfowl eat the seeds, roots and rhizomes of fresh water marsh plants during their winter stopover in the Chesapeake Bay.

Tidal fresh water areas of creeks and rivers can become saltier through several mechanisms. Drought years and water diversion to other waterways, reservoirs, crop irrigation or industrial and municipal use all remove fresh water from rivers. These factors decrease the amount of fresh water coming down the river or creek to a point where brackish water moves further upstream.

Increasing salinity in historically tidal fresh areas can have a large impact on the plants and animals that live in these areas. Many species of fish such as striped bass, American shad, herring and white perch spawn in the tidal fresh water in rivers and streams. Tidal fresh water marsh plants do best in areas with zero salinity, but they can tolerate some salt for short periods of time. Tidal fresh water has a salinity of between 0.0 and 0.5 parts per thousand. Fresh water marsh plants begin to have difficulty growing as salinity increases and may stop growing areas with rising salinity. Migratory waterfowl feed in tidal fresh water marshes, especially during the winter. These waterfowl would be negatively impacted if areas of tidal fresh water marsh areas change over to a tidal salt water marsh because salt marsh plants are not as good of a food source for these birds as fresh water marsh plants.

Your Job

You work for *Save Duck Habitat*, a nonprofit organization that works to preserve migratory waterfowl habitat. You job with *Save Duck Habitat* is to locate marshes that are valuable habitat for waterfowl and purchase these lands so that the marshes will be preserved. You are particularly interested in preserving some of the tidal fresh water marshes on the Pamunkey River because these marshes provide winter habitat for a large diversity and abundance of waterfoul.

One of the tidal fresh water marshes that you are thinking about purchasing is Sweet Hall Marsh, however the salinity in the Pamunkey River may be increasing which could make the tidal fresh water marsh plants experience stress and possibly die out. Your job is analyze the salinity data recorded at the Sweet Hall Marsh water quality monitoring station in order to find out if the Pamunkey River that floods Sweet Hall Marsh is still fresh water. You do not want to purchase a tidal fresh water marsh that is experiencing increased salt water intrusion because the salt water will cause plant stress and could change the ecology of such areas.

Level 3

Tidal Fresh Water Marsh 3.1. Analyze the salinity data for the Sweet Hall Marsh water quality station for 2003 to see if this tidal fresh water marsh may be experiencing salinity stress due to salt water moving upriver. 2003 was a very wet year in terms of precipitation in this area of Virginia. Use Excel file *Salinity Sweet Hall Marsh 2003* for this exercise, and answer the following questions. *Compiling the data to fill in Table 6 may help to answer this question.

- Are there periods when brackish water (water above 0.5 ppt) is found at Sweet Hall Marsh in 2003?
- When are these periods (seasons or months)?
- Why do you think the river became saltier during these periods?
- Do you think that one year worth of data is enough to answer this question considering that precipitation was much greater than normal in 2003?

Table 6. Average Monthly Salinity: Sweet Hall Marsh, 2003.

Month	Average Monthly Salinity (ppt)
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	

Extension Question

1. Get on the CDMO web page and have the web page graphing tool graph the Sweet Hall Marsh salinity data for 2002 (instructions to do this are in the appendix). Can you tell if the salinity at Sweet Hall Marsh was greater during this year than in 2003? Remember that this graphing tool graphs daily averages, which could mask salt water coming in at high tide.

Bivalve Aquaculture in the York River

Bivalve Aquaculture

Oyster (*Crassostrea virginica*) and hard clam (*Mercenaria mercenaria*) harvesting used to be a large industry in Tidewater Virginia. Wild populations of oysters and hard clams have dwindled in the Chesapeake Bay, and the wild fishery can't support as many harvesters as in the past. Scientists at VIMS and industrious individuals have created ways to grow both oysters and hard clams (aka. Cherrystones, little necks, quahogs, chowder clams etc.) in dense numbers in a process known as mariculture. Aquaculture is similar to farming because the aquaculturalists (aka. growers) purchase oyster or clam seed, transplant them to good growing areas that they lease from the state through the Virginia Marine Resources Commission, use various means to protect them from predators and take care of them as they grow by cleaning the racks or trays, thinning them out as they grow larger etc. Oysters are harvested when they are 3 inches long, which takes between 18 to 28 months. Clams are harvested when they are in the smaller cherrystone to littleneck size, which can take between 2 and 4 years. Raising the animals entails much more cost and effort than harvesting from a natural population, but the oysters and clams can be grown in such high numbers that the growers can make a profit ***if*** everything works out.

Most oyster aquaculture operations grow their oysters in racks and cages that rest on the bottom or floats that are suspended off the bottom. Clam aquaculture operations grow the clams on the bottom in water shallow enough that they can work their clam beds at low tide. Fine mesh nets are placed over the clam beds in order to keep predators such as blue crabs and stingrays out. Clams do best in areas with mostly sandy bottoms.

Salinity is a critical factor when growing either clams or oysters. Oysters grow in water with salinities between 5 - 35 ppt, however they grow best in waters above 12 ppt. Oyster growth slows greatly as salinities drop near the 5 ppt mark. Oysters can survive for several days in salinities below 5 ppt. Oysters spawn in salinities from 12 – 35 ppt, and they reproduce more successfully in higher salinities. They begin spawning when the water temperature rises above 18° Celsius for four hours or more.

Hard clams prefer saltier water than oysters. Hard clam adults can live in water that is between 12 – 35 ppt (full ocean strength), but they grow better in water with salinity above 15 ppt. They are not abundant in the wild where the salinity is below 20 ppt, however they grow fine for aquaculture purposes in water that is greater than 15 ppt. Hard clam eggs cannot live in water below 20 ppt, which is one reason that there are few hard clams found in water with 12 – 20 ppt salinity even though adults can survive in these salinities. Hard clams spawn when the water temperature hits 23° Celsius for four hours or longer.

Oyster and clam aquaculture operations are too large to move if the salinity conditions become unfavorable at a given location. Entire crops can be lost if the salinity drops too low in a grow-out site.

Your Job

You have been saving your money and want to work for yourself as an oyster and clam grower in the York River. You have learned the 'ins and outs' of the business from your cousin Dell who is a successful aquaculturalist from the Eastern Shore of Virginia. You will learn some very important information about mariculture in the York River of Virginia in the questions below.

__Level 2__

Bivalve 2.1 and 2.2. Oysters expend a tremendous amount of energy during reproduction and become very 'skinny' after spawning. Oysters spawn several times during the summer, thus they are too skinny and 'watery' to be sold until they fatten back up sometime in the fall. The water temperature has to hit 18° C or greater for at least 4 hours to trigger the first oyster spawning event in late spring or early summer.

Bivalve 2.1. When would oysters begin spawning at the Goodwin Island station in 2003? Use Excel file *Bivalve Goodwin Island* for this exercise

Bivalve 2.2. Knowing the water temperature pattern for 2003, when would you plan to harvest the oysters you wish to sell before they spawned and became unmarketable? You would want to play it safe and harvest several weeks before spawning just to be sure you were shipping a good product. Use Excel file *Bivalve Goodwin Island* for this exercise.

Bivalve 2.3. Hard clams do not expend as much energy during spawning as oysters, and they are marketable all year round, or any time during the spawning cycle. VIMS scientists will pay you for clams that are several days away from spawning to use in various experiments. When did hard clams spawn at Goodwin Island in 2003? When would you start bringing in pre-spawn clams to VIMS? Hard clams spawn when the water temperature hits 23° Celsius for four hours. Use Excel file *Bivalve Goodwin Island* for this exercise.

__Level 3__

Before you spend $10,000 on spat (baby oysters) and $25,000 on baby clams and place them in the river on your grow out sites, you need to know where the salinity is high enough in the York River for your bivalves to thrive and grow quickly. Analyze the salinity data for Goodwin Island, Gloucester Point and Clay Bank so you could figure out where to lease river bottom in the York and plant your baby bivalves.

Bivalve 3.1. How far up the York River could you grow oysters considering the salinity regime oysters require as described in the introduction of this activity? Use Excel files *Bivalve Goodwin Island*, *Bivalve Gloucester Point* and *Bivalve Clay Bank* for this exercise and the next.

Bivalve 3.2. How far up the York River could you grow your clams considering the salinity regime hard clams require as described in the introduction of this activity?

Bivalve 3.3. Was 2003 a drought year or a wet year in Virginia? Could this information impact how you interpret the salinity data in terms of looking for sites to grow your bivalves?

Data Suggestion

Using Excel to create monthly salinity averages for each station is one way to start answering the two questions above. You can fill out the table on the next page if you decide to take this route. The other way to start in on this problem is to make a graph with Excel of the salinity at each site during the year and look at the salinity pattern for each site.

Table 7. Monthly Salinity Averages (ppt): GI, GP and CB for 2003.

Month	Goodwin Island	Gloucester Point	Clay Bank
January		No data	
February		No data	
March		No data	
April		No data	
May		No data	
June			
July			
August			
September			
October			
November			
December		No data	
Yearly Average			

Extension Question

1. Hard clams and oysters can 'close up' and live for several days if the dissolved oxygen becomes too low (further information about what dissolved oxygen can be found in a following section). Analyze the dissolved oxygen data in the *Bivalve Goodwin Island*, *Gloucester Point* and *Clay Bank* Excel files to see if these sites encountered significant low dissolved oxygen time periods in 2003. This could be important information when deciding where to put your oysters and clams.

Geographical Extension Question

1. Is the salinity high enough to grow oysters and clams in other estuaries in the United States? Query salinity data from the CDMO web page for other National Estuarine Research Reserve Sites to answer this question.

Submerged Aquatic Vegetation (SAV) Restoration

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) are aquatic plants that grow in the intertidal to shallow subtidal zone in the Chesapeake Bay. They are flowering, vascular, rooted plants that grow entirely underwater. There are twenty species of SAV that grow in the Chesapeake Bay, the majority of which grow in fresh water areas of the Bay. They differ from algae in the fact that they can transport material from one part of the plant to the other (ex. nutrients gathered by the roots can be transported to the leaves), they flower (angiosperms) and they produce seeds. Many algae species in the Chesapeake Bay such as sea lettuce and tapered red weed grow as large as SAV species but they do not have roots to gather materials they need from the sediment, and they can only take in nutrients and gasses necessary for photosynthesis through the surface of their leaves through osmosis. Algae also reproduce asexually and therefore do not have flowers.

Submerged aquatic vegetation differs from emergent aquatic vegetation, such as lily pads and cattails, because the entire life cycle of SAV species is completed underwater, while most of the leaves and the flowers of emergent vegetation are above the surface of the water, as is pollination of these species.

A habitat by definition is a place that provides animals a refuge from predation, adequate food to support growth and reproduction and the physical environment that is conducive to life (appropriate salinity, temperature, oxygen etc.). SAV is a very important habitat for many Chesapeake Bay animals including juvenile fish and blue crabs. The grass blades provide three-dimensional structure, which helps juvenile fish and crabs hide from predators. This structure attracts small animals such as skeleton shrimp, amphipods, isopods and other small crustaceans, which are an important component of the food chain. Juvenile blue crabs and small fish often graze on the bacteria, algae and animals such as barnacles, sponges and bryozoans that grow on the surface of the SAV blades. All sizes of blue crabs hide in SAV when they shed their shell during the growth process. SAV is also eaten by migratory waterfowl such as tundra swans, Canadian geese and ducks when they over-winter in the Bay.

SAV and Water Clarity

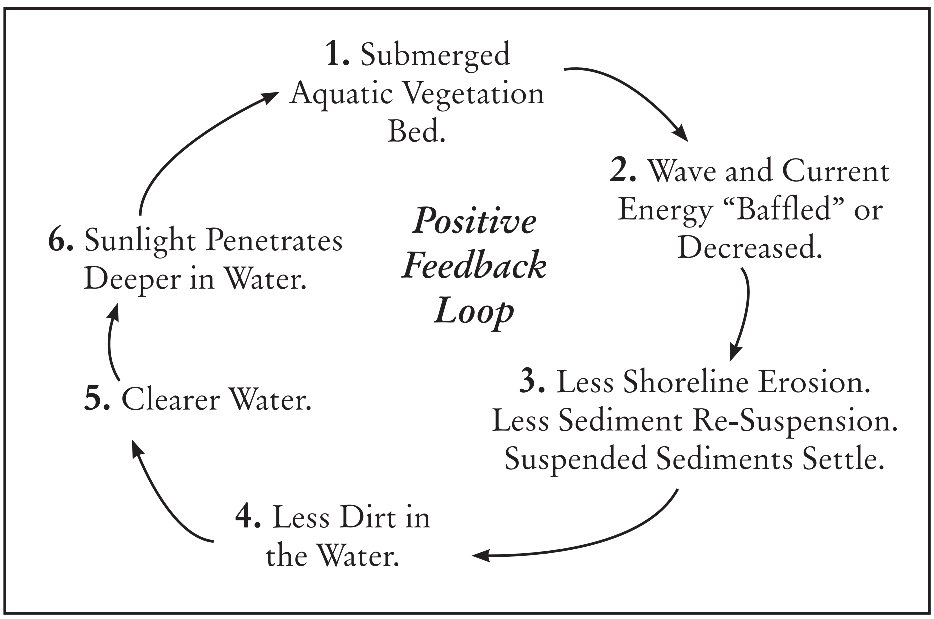
All plants need sufficient sunlight to power photosynthesis in order to make enough energy to live. SAV species require a relatively high level of light to travel through the water and reach their leaves compared to phytoplankton and macroalgae such as sea lettuce. SAV species that grow in lower salinity waters require approximately 13% of the sunlight that is found at the surface of the water. SAV species that grow in higher salinity water in the mid and lower Chesapeake Bay such as eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) require 22% of the sunlight that hits the waters surface in order to grow (Dr. Ken Moore, CBNERRVA). SAV species require such high levels of light to live because they have to expend extra energy pumping oxygen down to their roots and dealing with toxic hydrogen sulfide gas that is produced by anaerobic bacteria found in estuarine sediments.

Estuarine water is naturally more turbid, or murkier, than many areas of the ocean. However the Chesapeake Bay has become murkier and the amount of SAV found in the Bay has decreased over the years because the murky water blocks sunlight from reaching the underwater grass blades. Increased sediment pollution and greater microscopic phytoplankton growth fueled by nitrate and phosphate pollution flowing off the land have made the water murkier. Murky, or turbid, water blocks sunlight and decreases the depth where SAV can get enough sunlight to survive. The number of acres of SAV in the Chesapeake is approximately 10% of historic levels. SAV historically occurred to depths of approximately 2-meters at low tide in the Chesapeake Bay. SAV currently grows in areas where the Bay is approximately 1-meter deep or less at low tide, and SAV is absent from many areas where SAV historically grew due to poor water clarity.

Increasing nutrients in the water also increases the amount of algae growing *on* the SAV leaves. This epifaunal algae blocks even more sunlight from reaching the grass blade itself because the sunlight has to pass through the water *and* through the epifauna growing on the SAV leaves. It is reasonable to think that increasing nutrients in the water would serve as fertilizer and help increase SAV growth, but SAV have roots to extract nutrients from the sediment which gives them an edge over macroalgae in low nutrient waters. Increasing nutrient levels in the water actually benefits macroalgae and epifaunal species to a greater degree than SAV. These macroalgae, such as sea lettuce, can grow in dense patches which further block sunlight from reaching SAV.

Positive Feedback Loop

SAV helps keep the water clear and is considered to be one of the natural filters of the Bay along with forests, marshes and oysters. The roots and leaf blades serve to baffle, or decrease, wave and current energy, which allows suspended sediments to settle out of the water and keeps sediments from getting stirred up (re-suspension) due to wave and currents. Shoreline erosion is decreased along shorelines with healthy SAV beds offshore, thus keeping sediment from eroding into the Bay and clouding the water. SAV therefore helps increase water clarity, which creates better growing conditions for more SAV growth, which can lead to clearer water. This process is called a 'positive feedback loop' and is depicted at left.



Water Clarity Measurement

Water clarity or turbidity is measured several ways. The most well known method is by using a Secchi disk, which is nothing more than a weighted black and white disk. The disk is lowered into the water to the point where you can't see the difference between the black and white, then raised to a point where you can see the difference again. The depth that the disc was located in the water at these two points is averaged to get the Secchi depth of the water. *Deeper Secchi depths, and therefore greater Secchi readings, mean clearer water*.

The NERRS data sondes measure water clarity using a scale called NTU's, which stands for nephalometric turbidity units. The data sondes measure NTU's by measuring how much of a beam of light passes through a small amount of water. The data sonde then calculates the turbidity of the water using NTU's as the scale. *Greater NTU values mean murkier water*.

NTU values are correlated with Secchi depth readings because they both measure water clarity. To convert a Secchi disk reading to NTU's or vice versa, simply look at the graph below or use the equation below (equation thanks to Dr. Ken Moore, NERRS Research Coordinator).

Secchi Depth in meters = 1.45 / ((0.023 * NTU) + 1)

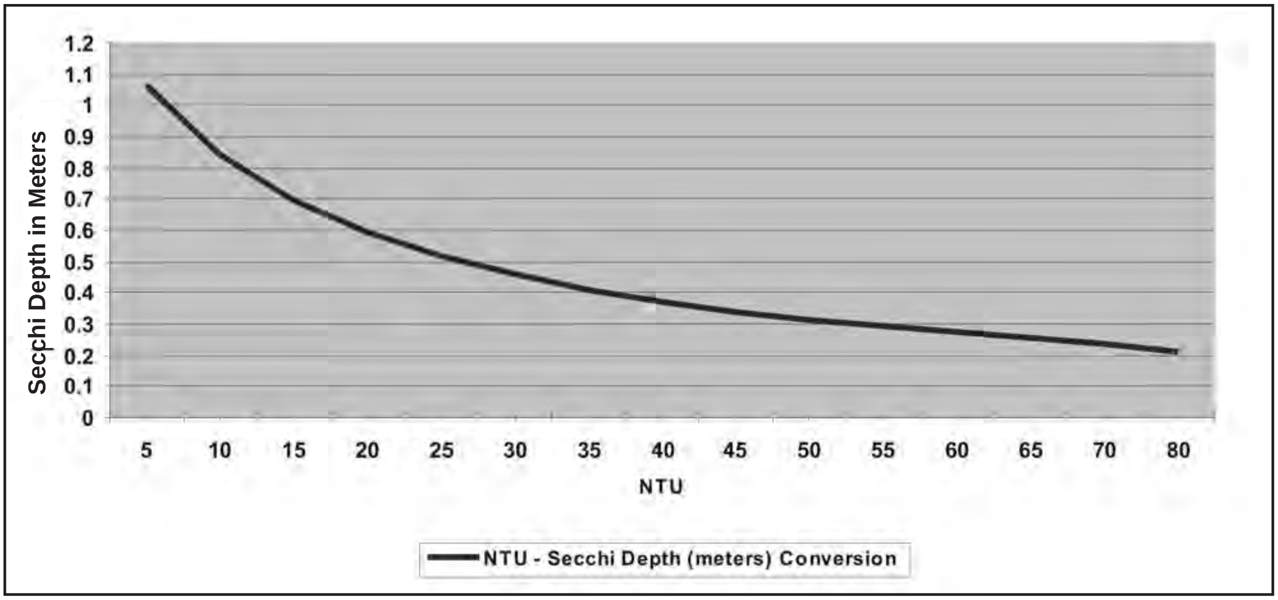


Figure 3. NTU – Secchi Depth Conversion.

There is an inverse relationship between the two water clarity parameters (Figure 3). This means that as the water gets clearer the NTU values decrease while the Secchi depth readings increase. Clearer water has lower NTU values. Think of an NTU as a dirt particle. Clearer water has less dirt particles, thus a lower number of NTU's. Clearer water has greater Secchi depth readings because you can see the Secchi disk deeper in the water. Take a minute to go over this point.

The Chesapeake Bay Program has set water clarity goals for the Chesapeake Bay with the intention of getting clearer water in the Bay. The logic is that clearer water allows more sunlight to penetrate through the shallow water, which will increase the amount of SAV growing in the Bay. The Bay Program goal for SAV growth in the middle and lower York River (including Goodwin Island, Gloucester Point and Clay Bank) is for SAV to be able to grow to a depth of 1-meter deep at low tide. The Secchi depth value necessary to achieve this 1-meter deep SAV growth is estimated to be roughly 1 meter*. (* The actual value is 1.1 meters but we are using 1 meter here for simplicity.)

In other words, the water clarity at Goodwin Island, Gloucester Point and Clay Bank has to be equal to or greater than 1-meter Secchi depths in order to meet the Bay Program water quality goals for these areas of the York River. A 1-meter Secchi depth equals approximately 7 NTU's (Figure 13). We can now analyze the CBNERRVA water quality NTU data to see if the water clarity goals are being met in the middle and lower York River.

Your Job

You are a SAV restoration scientist working for the Virginia Institute of Marine Science (VIMS). Your job is to restore eelgrass, one of the main SAV species in the lower Chesapeake Bay, to portions of the York River to a 1-meter depth using both eelgrass transplants and eelgrass seeding methods.

SAV transplants or sprouts will not survive if the water clarity is not clear enough to allow adequate amounts of sunlight through the water to reach the SAV leaves. Your job is to analyze the CBNERRVA water quality data to see if the water clarity at Clay Bank, Gloucester Point and Goodwin Island is clear enough to warrant performing SAV restoration projects using transplants and seeding at these three locations.

Eelgrass is a cold-water species. The Chesapeake Bay is the southern range of eelgrass along the East Coast and it grows best during the spring and fall in the Chesapeake Bay and often dies back during the summer when water temperatures get too warm. Water clarity is important during the entire eelgrass-growing season, which is approximately March 1 – November 30.

Level 3

Analyze the NTU data for Clay Bank, Gloucester Point and Goodwin Island to see if the water quality at each site averages 7 NTU's or less during the SAV growing season (March 1 – Nov 30). Average water clarity values greater than 7 NTU's during the SAV growing season are not clear enough to allow SAV to grow to a depth of 1-meter deep at low tide, and the water quality at such stations does not meet the Chesapeake Bay Program water clarity goals for SAV restoration. Please break the data down by month to figure out which months the water clarity is not clear enough for SAV to grow at low tide depths of 1 meter. We are only concerned with the water clarity values during the SAV growing season, although it wouldn't hurt to analyze the NTU data during the winter months as well.

Use Excel data files *Turbidity Clay Bank*, *Turbidity Gloucester Point* and *Turbidity Goodwin Island*, located in the Turbidity folder for these activities.

Note:

- Water quality monitoring at Gloucester Point did not begin until June 1, 2003.
- There is no data at Goodwin Island from Sept 17 – Oct 1, 2003 due to Hurricane Isabel damage.
- I decided to cut any NTU values about 500 NTU's in the files that are included in these activities. Feel free to cut any NTU data points that you feel are outliers as long as you can logically argue why you feel the data points you cut were erroneous.

The following questions are difficult due to the amount of data involved. Filling out the table on the next page may help. You may find it easier to have the CDMO web page calculate the average NTU readings for you to answer these questions instead of doing the work with Excel.

Table 8. Average Turbidity (NTU) Per Month at Clay Bank, Gloucester Point and Goodwin Island.

Month	Average Turbidity (NTU) by Site		
	Goodwin Island	**Gloucester Point**	**Clay Bank**
January		*No data*	
February		*No data*	
March		*No data*	
April		*No data*	
May		*No data*	
June			
July			
August			
September			
October			
November			
December		*No data*	
Growing Season Avg.			

Turbidity 3.1.

a. Which of the three sites meet the water clarity goals necessary for eelgrass to grow 1-meter deep?
b. Would you move forward with eelgrass restoration projects at these sites?
c. What months or seasons had the least turbid (clearest) and the most turbid (murkiest) at this site/s?

Turbidity 3.2. Is the trend in water clarity at all three sites similar during the year (ie. are the more turbid and less turbid months the same at the three stations)? Do you have any thoughts as to why these trends are so?

Turbidity 3.3. Was the reason that the NTU values were too high at failing sites during failing months due to chronic bad water clarity (ie. NTU values were high during the *entire* month) or were these months failing grades due to acute events (ie. NTU values were high only during *short* events)? Do you have any ideas what could cause such long-term trends and short-term spikes in the NTU data?

Data Suggestion

Graph NTU data in 1-week and 1-month during summer at Goodwin Island and Gloucester Point to investigate this question.

Extension Questions

1. Increased turbidity is predominantly due to both phytoplankton growth and suspended sediments in the water. Can you pick up any periods when chlorophyll-a values increase along with NTU values, indicating a phytoplankton bloom? Chlorophyll-a values are used to approximate the amount of phytoplankton in the water.
2. If the NTU increases don't occur during times of increasing chlorophyll-a, then you can assume that sediments are causing the increased turbidity. Can you find archived wind data on the Internet and check to see if turbidity increases occurred during periods of high onshore winds at the stations, which would make waves that stir up the bottom sediments?
3. What could be causing the turbid water, or where could the turbid water be coming from during times of high turbidity that can't be correlated with high onshore winds at the stations or increasing cholorophyll-a?

Dissolved Oxygen

What is Dissolved Oxygen?

Dissolved oxygen (DO) is molecular oxygen (O_2) that is dissolved in the water. Aquatic animals require dissolved oxygen just as humans need atmospheric oxygen. Living cells (at least the ones we are dealing with here) use oxygen to burn carbohydrates to make energy and to store this energy. The energy burned during cellular respiration powers the cell and ultimately allows animals to move, obtain and digest food, grow, reproduce, repair damage and maintain their internal environment. Aquatic species in the Chesapeake Bay generally obtain their oxygen from the water through their gills.

The oxygen molecules that are bound in water (H_2O) are tightly bound by hydrogen bonds and are not available for animal respiration. Dissolved oxygen is present at an extremely smaller concentration in water compared to the atmosphere. Oxygen comprises approximately 21% of the total gasses in our atmosphere, but water contains only a small fraction of one percent of dissolved oxygen (< 0.00002%). Dissolved oxygen is found at such small amounts in the aquatic environment that it is measured and reported in parts per million (ppm), or milligrams per liter (mg/l). These values are interchangeable.

Dissolved Oxygen Sources and Sinks in Shallow Water

Dissolved oxygen is introduced in the water (source) and depleted from the water (sink) by several mechanisms. DO naturally dissolves into the water from the air. Agitation of the water's surface through wind and wave action also increases the amount of dissolved oxygen in the water.

DO is also produced by aquatic plants. Aquatic plants include microscopic plants called phytoplankton, benthic algae, larger macro algae such as sea lettuce and rooted aquatic plants known as submerged aquatic vegetation. These aquatic plants produce oxygen as a byproduct of photosynthesis when sufficient sunlight is available thought the equation below.

$$106\ CO_2 + 122\ H_2O + 16HNO_3 + H_3PO_4 \rightarrow (CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\ O_2$$

Carbon Dioxide + Water + Nitrate + Phosphate → Carbohydrate + Oxygen

Plant cells use oxygen 24 hours a day for the storage of energy and the burning of carbohydrates to make energy just like animal cells. Aquatic plants create more oxygen through photosynthesis than they use for cellular respiration during bright and sunny days, making them a net source of oxygen in the water when sufficient sunlight is available. Aquatic plants are a dissolved oxygen sink during cloudy days and at night when photosynthesis slows or stops and the plant cells create less oxygen than the plant cells consume during regular cellular respiration. The respiration equation is the reverse of photosynthesis and is listed below.

Carbohydrate + Oxygen → Carbon Dioxide + Water + Ammonia Nitrogen + Phosphorus

Bacteria are also an oxygen sink in the aquatic environment. Aquatic bacteria consume ('eat') organic matter (things that were once alive) to get the energy they require. They use dissolved oxygen in this process, similar to how we need oxygen to digest food. These bacteria break down, or decompose, organic matter including organic matter washed in from the watershed (leaves, grass clippings, manure and broken down marsh grass), dead organisms in the water (phytoplankton, zooplankton, fish) and particulate organic matter that can be anything from leftovers from 'sloppy feeding' by zooplankton to fish excrement. These decomposing bacteria, which are found both in the water column and in the sediments, can be a large consumer of dissolved oxygen in the aquatic environment.

In summary, several components are responsible for the amount of dissolved oxygen in the water. They are listed in Table 9. All of the sources and sinks in Table 9 are part of the natural ecosystem; however human activities in the watershed can greatly alter the dynamics of phytoplankton and bacteria growth. Increased nutrient input from the watershed fuels phytoplankton growth, which can cause DO problems in the Bay through a process known as eutrophication. The amount of organic matter that washes into the Bay is also greatly increased due to human activities. This matter is consumed by bacteria, which use oxygen during the decomposition process.

Table 9. Sources and Sinks of Dissolved Oxygen.

Component	**Daytime (bright light)**	**Nighttime and low light**
Diffusion from Air	Source	Source
Wind and Waves (through diffusion)	Source	Source
Aquatic plants and phytoplankton	Source	Sink
Decomposing Bacteria	Sink	Sink
Aquatic Animals	Sink	Sink
Source = produces DO Sink = Uses DO		

Plant, animal and bacterial respiration can deplete dissolved oxygen faster than it is replenished under certain circumstances. As the amount of nutrients and organic matter increase in the water the frequency and duration of low oxygen events can increase. The combined effects of bacterial and plant respiration during cloudy days or nights can be such a major oxygen sink under certain conditions that the water becomes dangerously low in dissolved oxygen (hypoxic) or devoid of dissolved oxygen (anoxic, Table 10). This often occurs in shallow water between midnight to dawn on hot summer nights.

Table 10. Dissolved Oxygen Water Quality Terms.

Dissolved Oxygen Reading	**Water Quality Term**
≥ 6.0 mg/l	Healthy for Migratory Fish Spawning and Nursery Areas (SH)
≥ 5.0 mg/l	Healthy for Shallow Water Stations
2.0 – 5.0 mg/l	Hypoxic
0.2 – 2.0 mg/l	Severely Hypoxic
0.0 – 0.2 mg/l	Anoxic

Dissolved oxygen levels in shallow water can also be driven down when circulation patterns created by wind and tidal conditions bring up hypoxic water from deeper waters. Motile animals such as fish and crabs have the ability to move away from low oxygen waters in attempts to find more suitable water. There are times when the animals move to very shallow water or even beach themselves in attempts to escape the hypoxic waters. This is known as a 'crab jubilee' because you can walk the beach collecting blue crabs, flounder and other tasty animals. Sessile animals such as clams, oysters, sea squirts and benthic worms do not have the ability to get away from the hypoxic water and have to shut down in hopes that the low oxygen conditions don't last too long.

Aquatic Animal Dissolved Oxygen Requirements

Dissolved oxygen concentrations greater than 5 mg/l are suitable for most Chesapeake Bay species. Water is said to be hypoxic when DO levels are between 0.2 mg/l and 5.0 mg/l and anoxic when dissolved oxygen is virtually absent (0.0 – 0.2 mg/l, Table 10.). Severely hypoxic and anoxic conditions can cause fish kills, increased mortality of aquatic organisms, reduced growth rates, and altered behavior and distribution of aquatic animals. Motile aquatic animals will try to move away from hypoxic waters, but this often leads them to less-than-perfect habitats where there could be less prey, more predators or unfavorable physical conditions such as water temperatures. This is known as the 'habitat squeeze'. For instance, sturgeon prefer cooler waters that are found in the deep areas of the tributaries, but these deeper waters often suffer from low oxygen conditions. The sturgeon have to swim out of the cool deeper water when oxygen levels decrease and move into warmer water where their metabolism increases and they become stressed as their metabolism runs best at cooler temperatures. Less motile and sessile organisms can't move away from hypoxic water. Such animals are usually better able to slow down their body processes for a period of time in order to survive low oxygen events, however even the hardiest of animals will die if the low oxygen conditions last long enough, creating what are known as 'dead zones.'

Aquatic animals vary in their sensitivity to low oxygen (Table 11). Spot are one of the tougher fish in regards to low DO levels and can survive for a period of time in water with 2 mg/l dissolved oxygen. Benthic worms can handle even lower DO for short periods of time. Most species can survive short periods of hypoxic conditions, but suffer more deleterious effects if the low oxygen conditions last for longer periods of time.

Table 11. Minimum Dissolved Oxygen Requirements for Chesapeake Bay Species.

Species	**Dissolved Oxygen Requirement**
Striped Bass (Rockfish)	5 – 6 mg/l
Alewife Eggs and Larvae	5 mg/l
American Shad	5 mg/l
Yellow Perch	5 mg/l
Hard Clam	5 mg/l
Blue Crab	3 mg/l
Bay Anchovy	3 mg/l
Spot	2 mg/l
Benthic Worms	1 mg/l

Dissolved Oxygen Percent (%) Saturation

The amount of dissolved oxygen that water can hold varies depending on the water temperature and salinity. Higher salinity and higher temperature both reduce the ability of water to hold dissolved oxygen. Thus warmer, saltier water can hold less DO than cooler, fresher water. Cool mountain streams running over riffles and waterfalls would typically hold between 12- 15 mg/l dissolved oxygen. The amount of dissolved oxygen that water with a given salinity and temperature can hold can be seen on Table 12. Water can also be super-saturated with respect to DO during times of intense photosynthesis, displaying values above 120% saturation.

Percent saturation (% saturation) is used in order to obtain a better understanding of the *actual* DO value observed in the water with respect to the amount of DO the water *could* hold if was fully saturated. Use of percent saturation values eliminates the confounding effect of both temperature and salinity on DO readings, making this value a great parameter to use when trying to compare DO values at a site with changing temperature and salinity or between sites that have different temperature and salinity. The equation used to calculate % saturation is below.

% Saturation = Actual DO reading (mg/l) / 100% saturation DO value for water with that temperature and salinity (Table 12) x 100.

For example, in order to calculate a 6 mg/l DO reading from a site where the salinity was 18 ppt and the water temperature was 25°C, you would divide 6.0 by the 100% saturation value of 7.4 (value from Table 12.) for value of 81% saturation. This means this sample of water held 81% of the oxygen that it *could* hold given temperature and salinity conditions. This water is holding less oxygen then it potentially could based on the temperature and salinity of that water.

Table 12. 100% DO Saturation Based on Salinity and Temperature.

Temperature °Celsius	**Salinity (ppt)**				
	0	9	18	27	36
0	14.6	13.7	12.9	12.1	11.4
5	12.8	12.0	11.3	10.7	10.1
10	11.3	10.7	10.1	9.5	9.0
15	10.1	9.5	9.0	8.5	8.1
20	9.1	8.6	8.2	7.7	7.3
25	8.2	7.8	7.4	7.1	6.4
30	7.5	7.2	6.8	6.5	6.2
35	6.9	6.6	6.3	6.0	5.7

* source: The Monitors Handbook, Lamotte Company. 1992

Level 1 and 2 Activity: Diel Hypoxia in Shallow Waters

Your Job

You were fishing for spotted seatrout all night in the shallow water grass beds off Goodwin Island and you observed a small fish kill comprised mostly of menhaden, or bunker, at approximately 3 am on July 17, 2004. You also stopped catching any fish after midnight. You want to know what caused this fish kill because you are concerned about the Bays health and hope to learn a thing or two that will help you catch more fish. You contacted the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERRVA) and obtained water quality information for the Goodwin Island monitoring station for the 32-hour period surrounding when you observed the fish kill.

Level 1

Oxygen 1.1. When does hypoxia occur at Goodwin Island on July 17th, 2004? Use Excel File *Oxygen 1* to answer this question.

Oxygen 1.2. What is the trend in dissolved oxygen (mg/l) during the 32-hour period around this event? Use Excel File *Oxygen 1* to answer this question.

Data Suggestion

This problem will be much easier if you graph the parameters using Excel. A graph with time as the independent variable (x axis) vs. DO mg/l as the dependent variable (y axis) will help you answer this question.

Oxygen 1.3. Analyze Excel file *Oxygen 2* which has data from a similar 32-hour period for July 9-10, 2004 at Goodwin Island to see if a similar trend in oxygen levels as observed at Goodwin Island on July 16 - 17, 2003 occurs. Are the trends similar?

Oxygen 1.4. Why are these hypoxic events occurring? You may be able to answer this question by reviewing the oxygen sources and sinks table and thinking about the cumulative effect of these processes during the diel (day-night) cycle.

Level 2

Oxygen 2.1. Does the hypoxia appear to have any relationship with water depth (tide)? Use Excel File *Oxygen 1* and *Oxygen 2* to compare the DO vs. water depth (tide) information for the two days.

Data Suggestion

Make a graph with *two* dependent variables, or two y-axes, in order to answers questions that ask for relationships between two parameters such as this (DO and water depth in this case). Directions on how to make a double y-axis graph using Excel are in Appendix D. Once you have the two graphs with DO mg/l and water depth on the same graph for July 9-10 and July 16-17 you can look at the trends in DO values as the tide changes and answer the question.

Oxygen 2.2. Does the hypoxia appear to have any relationship with water temperature? Use Excel file *Oxygen 1* and *Oxygen 2* for this activity.

Data Suggestion

The easiest way to look for this relationship is to graph both water temperature and DO mg/l for the same 32-hour time period on the same graph with a two independent variable graph.

Oxygen 2.3. Do all of the water quality monitoring sites display the same diel (daily) pattern of high DO during the day and low DO values during the night as Goodwin Island during summer time?

* Use the *1 Week Summer 1 Week Winter Data Sets* to answer questions Oxygen 2.3 and 2.4. Note that the weeks included in the *1 Week Summer 1 Week Winter Data Sets* are not all the same to do gaps in the data.

Oxygen 2.4. Does this daily trend in dissolved oxygen values occur in the winter?

Level 3: Does the York River Pass the Dissolved Oxygen Criteria?

The Chesapeake Bay Program has created dissolved oxygen criteria with values that provide sufficient dissolved oxygen to support the survival, growth and reproduction of aquatic animals living in the Chesapeake Bay and the tidal tributaries. There are different DO criteria for different sections of the Bay and tributaries. The DO criteria for shallow water stations are listed in Table 13. These criteria apply to the Goodwin Island (GI), Gloucester Point (GP), Clay Bank (CB) and Taskinas Creek (TC) water quality monitoring stations in the activities to follow.

Table 13. Dissolved Oxygen Criteria: Shallow Water (Applies to stations GI, GP, CB, TC)

Duration	DO Concentration (standards apply all year)
30-day mean	5.0 mg/l
7-day mean	4.0 mg/l
Instantaneous minimum	3.2 mg/l

According to the criteria in Table 13, shallow waters at these four areas of the river meet the DO criteria if the average DO reading is ≥ 5.0 mg/l for the month. DO levels can drop below 5.0 mg/l for short durations of time as long as the average DO levels during these time periods are ≥ 4.0 mg/l during the 7-day period when the DO levels dropped below 5.0 mg/l. DO levels can also never go below 3.2 mg/l at any time (instantaneous minimum) during the month for the area in question to pass the DO criteria for shallow water. The instantaneous minimum DO level of 3.2 mg/l is in place in part to prevent lethal effects due to hypoxia to the shortnose sturgeon, which is an endangered species in the Chesapeake Bay. A site would not meet the DO criteria if the monthly average value was greater than 5.0 mg/l but DO levels dropped below 3.2 mg/l for a short time. Please don't blame the author on these complex rules, we didn't make them up.

The Sweet Hall Marsh water quality monitoring station (SH) is located on the Pamunkey River in waters that are important for migratory fish spawning and juvenile habitat. Striped bass (rockfish), American shad, alewife and herring use tidal fresh waters to lay their eggs, and the young of these species use these areas while they are in the larval and juvenile life stages. Fish eggs, larvae and juveniles are generally more sensitive to poor water quality; therefore the DO criteria are more stringent in these areas. You can see in Table 14 that the waters around Sweet Hall Marsh have more stringent DO criteria during spawning season (Feb 1 – May 31).

The river at Sweet Hall Marsh must average ≥ 6.0 mg/l dissolved oxygen during the February 1 – May 31 spawning season. The use of the 7-day mean confers that the DO levels can drop below 6.0 mg/l as long as they average 6.0 mg/l for any 7-day period you are analyzing. The instantaneous minimum of 5.0 mg/l means that DO levels can never dip below 5.0 mg/l and still meet the dissolved oxygen criteria for that body of water during the spawning time period. The criteria relax from June 1 – January 31 to the same levels used for shallow waters (Table 13.)

Table 14. Dissolved Oxygen Criteria: Migratory Fish Spawning and Nursery Use Areas (Sweet Hall Marsh - SH).

Time Period	Duration	DO Concentration
February 1 – May 31	7-day mean	6.0 mg/l
	Instantaneous Minimum	5.0 mg/l
June 1 – Jan 31	Same as Shallow Water Requirements Shown Above	

Your Job

You are the York River Tributaries Plan Manager working for the Virginia Department of Healthy Waters. Your boss wants to know if the York River is meeting the Chesapeake Bay Program criteria for dissolved oxygen.

> **Oxygen 3.1.** Analyze the dissolved oxygen mg/l data for Sweet Hall Marsh to see if the water quality at this station meets the Chesapeake Bay Program criteria for dissolved oxygen. Remember to use the migratory fish spawning and nursery use criteria (Table 14) during March, April and May and the shallow water criteria (Table 13) for June through April.

Your job is to be able to answer whether dissolved oxygen at Sweet Hall Marsh meets the Chesapeake Bay Program goals. If the DO mg/l fell below the criteria level, please provide summary information as to the time of year or time of day these hypoxic events occurred, how long the DO didn't meet the requirements, and how low the DO levels dropped.

Tips and Suggestions:

This job is very large, so I suggest breaking up into groups and dividing the job into smaller pieces.

We know from earlier DO questions that DO levels are very high during the winter so we don't have to spend time checking November, December, January and February. I tackled this question by calculating the average DO mg/l for each month and graphing the DO for March – October. Visualizing the data lets you quickly see which months pass the DO criteria or need further analysis. You can 'fail' a month quickly during the spawning season (March, April and May) if the lowest DO reading drops below the instantaneous minimum of 5.0 mg/l.

I used Excel to calculate average DO levels for time periods when the DO level looked close to averaging 6.0 or less during the spawning season to see if these low oxygen time periods lasted for more than 7 days. Remember to use the shallow water DO criteria for June through October (Table 13).

It would be of great value to calculate how many hypoxic events occurred, and how long each lasted during each month. This extra information will really make you look good in front of the boss.

> **Oxygen 3.2**. Answer the questions posed in **Oxygen 3.1** at Sweet Hall Marsh for the remaining four CBNERRVA water quality-monitoring stations. These stations all use the shallow water DO criteria listed in Table 13.

Suggestion

This is a large task, so division of labor is essential. Break into four groups so that each group can work on the water quality data from one station. Once in groups, divide the DO mg/l data into months so that group members can tackle different months. Graph the DO mg/l data (y axis) vs. time (x axis) for every month to look at trends and see if DO ever drops below the instantaneous minimum or appears to drop below the 30- and 7- day average criteria. If DO levels appear to drop below the criteria set by the Chesapeake Bay Program, further investigate by finding out what the lowest level was, how long the levels were low and the average DO for each 7-day time period around the hypoxic or anoxic events.

<u>Extension Question</u>

1. Considering what you learned about when the hypoxic conditions occurred from your work above, what can be done to increase DO levels in the water around these stations?

<u>Geographic Extension Questions</u>

1. Do other estuaries in the United States have hypoxic conditions during the summer time? Get on the NERRS CDMO web page and query data for several different NERRS sites across the nation. You may want to download the data because the graphing tool on this web page graphs daily average readings. Daily average values could 'hide' low oxygen conditions that occur for parts of the day.

Answers and Analysis

Tides

Tide 1.1. The tides (Figure 4) at Goodwin Island on June 21, 2003 were at high at 2:00 AM, low at 8:30 AM, high at 15:15 (3:15 pm) and low again at 21:30 (9:30 pm). The observed tides on June 21 were 6 hours and 30 minutes, 6 hours and 45 minutes and 6 hours and 15 minutes apart respectively.

There are two low tides and two high tides on our average day in the Chesapeake Bay. Two low and two high tides each day are referred to as semi-diurnal tides. The two high tides and two low tides are rarely of equal magnitude, and often one tide is much more exaggerated than the other. The 'exaggerated' tide often displays a much higher high tide and lower low tide of the day. This is not the case on June 21, 2003 at Goodwin Island.

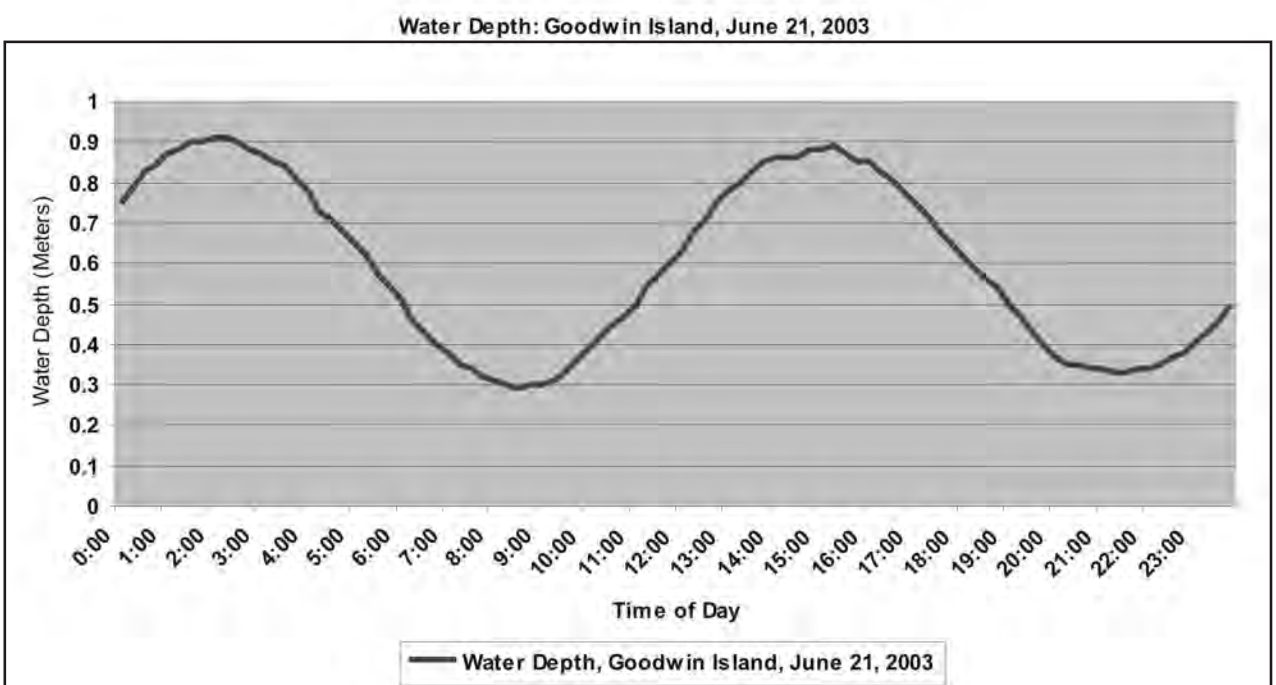


Figure 4. Water Depth: Goodwin Island, June 21, 2003.

Tide 1.2. The tidal range for Goodwin Island on June 21 was 0.62 meters (0.91 m – 0.29 m = 0.62 meters). What is this range in feet?

Tide 2.1. The tidal data for June 21, 2003 (Table 3) shows that low tide first occurs at the mouth of the York River and occurs later in the day as you move up river. Low tide occurs approximately 3 hours and 45 minutes later in Sweet Hall Marsh, the furthest upriver station, than Goodwin Island at the mouth of the York River.

Table 3. Low Tide: York River Water Quality Monitoring Stations, June 21, 2003.

Site	1st Low Tide	2nd Low Tide
Goodwin Island	8:30	21:30
Gloucester Point	8:45	21:45
Clay Bank	9:30	22:30
Sweet Hall Marsh	12:15	PM tide on the next day

Tide 2.2. The high tide data for June 21, 2003 (Table 4) shows that high tide first occurs at Goodwin Island, where the York meets the Chesapeake Bay, and moves upriver. The thought of the high 'tidal wave' moving upriver is easy to understand. High tide occurs approximately 3 hours and 45 minutes later in Sweet Hall Marsh, the furthest upriver station, than Goodwin Island. This is the same amount of time between the low tides at these stations. Goodwin Island and Gloucester Point are so close in proximity that the data probes recorded high tide to occur at the same time. Remember that the data probes record water quality measurements every 15-minutes.

Table 4. High Tide and Tidal Range: York River Water Quality Monitoring Stations, June 21, 2003.

Site	1st High Tide	2nd High Tide	Tidal Range
Goodwin Island	2:15	15:15	0.62 m
Gloucester Point	2:15	15:15	0.68 m
Clay Bank	3:00	15:45	0.72 m
Sweet Hall Marsh	6:00	19:00	0.67 m

Tide 2.3. The data for June 21, 2004 indicate that the tidal range at each site (water height difference between high and low tide) does not change significantly as you move upriver (Table 4). Another way to put this is that the tidal height does not appear to be greater, or amplified, as you move up river. Keep in mind that tidal amplification as you move further upriver could still occur. We don't have data for higher reaches of the Pamunkey River for 2003.

The average tidal range at the four sites on June 21 was 0.67 meters, or 2 feet and 2 inches.

Tide 3.1. This question contains more data to deal with which makes it more daunting. The easiest way to answer this question is have Excel calculate the average value for all of data points in column c, which are the water depth data points. The average tidal level recorded at Goodwin Island is 0.55 m. The sampling probes are suspended 0.5 meters off the bottom so the average water depth at the Goodwin Island water quality station is 1.05 meters. Using the conversion table (Appendix B) allows you to calculate that this is 3 feet, 5 inches deep. The fact that underwater grass is growing in this area which has an average tidal depth of 3 feet and 5 inches deep tells you that enough light passes through the water to this depth to allow underwater grass to grow to in water that is 3 feet 5 inches deep in this portion of the Chesapeake Bay.

Tide 3.2. The tidal range at Goodwin Island during June was at least 1.26 meters. You can find the answer quickly by sorting the entire June data set by column c, or tide height in meters, and recording the difference between the highest tide and the lowest tide. You could also find the answer by graphing the tidal data for the month and place the cursor over the highest reading and the value will be shown on the graph. The highest tidal reading is 1.26 meters. The lowest tidal readings are 0.00 which means the tide dropped below the height of the suspended probes. The tide may have dropped even more at this station but there is no way to know. 1.26 meters equals roughly 4 foot 1 inch.

Tides 3.3. Graphing this amount of data may be problematic, and it very well may be impossible to get the X-axis labels to show properly using Excel, but it is important that you can graph data for future Level 2 and 3 problems.

You can see in Figure 5 that the tidal amplitude does vary over the month. The tides become more exaggerated in the middle of the month, meaning the lows are lower and the highs are higher. Another way to think of this is that the difference in water depth between low and high tide is greater. This corresponds with a full moon on June 14. The new moon (meaning no moon) was on June 29. The tidal range did not increase later in the month during the new moon as is often the case.

Cycles of smaller tidal variation followed by larger tidal variation are due to the gravitational effects of the moon. Spring tides (higher highs and lower lows) typically occur during the full and new moon, which occur roughly two weeks apart. Smaller neap tides occurr in between the new and full moon times.

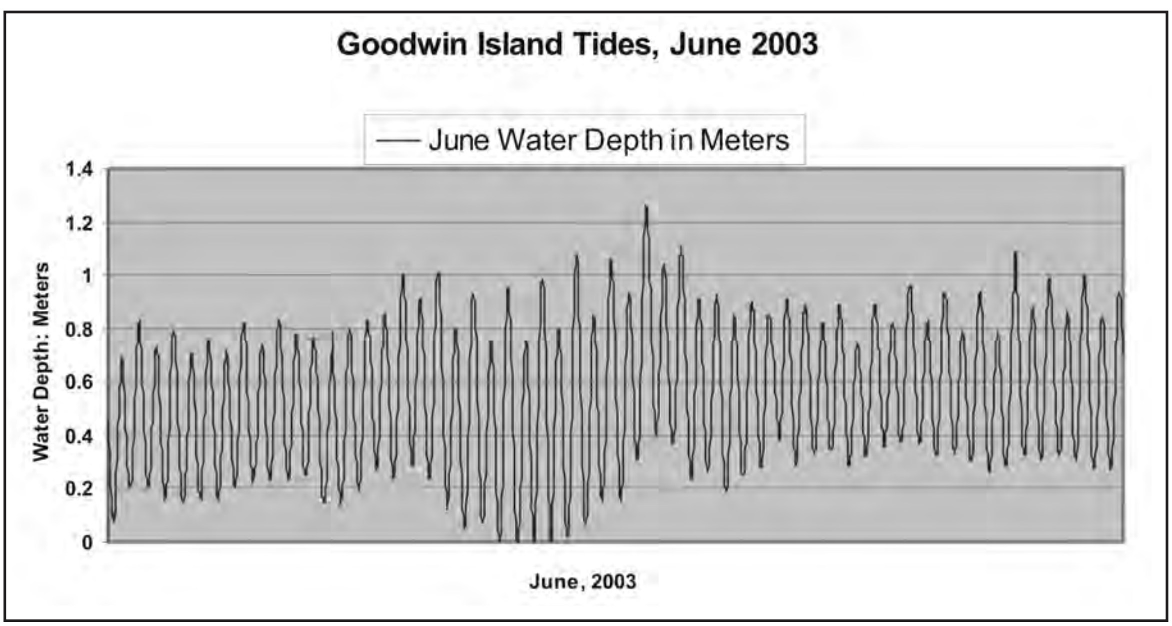


Figure 5. Water Depth: Goodwin Island, June 2003

Water Temperature

Water Temperature 1.1. The lowest water temperature recorded at Goodwin Island on June 28, 1003 was at 4:30 AM and was 26°C (Figure 6). The water temperature rises during the day to a max of 30.7°C at 14:00 hours (2:00 PM). Water quality parameters that have one high and one low during the day such as this are changing on a daily, or diel, cycle. In this case the summer sun and air warms the water during the day, and then the water cools during the afternoon and night. Such trends or patterns are not always so easily observed as tides and changing weather during the day could affect the water temperature.

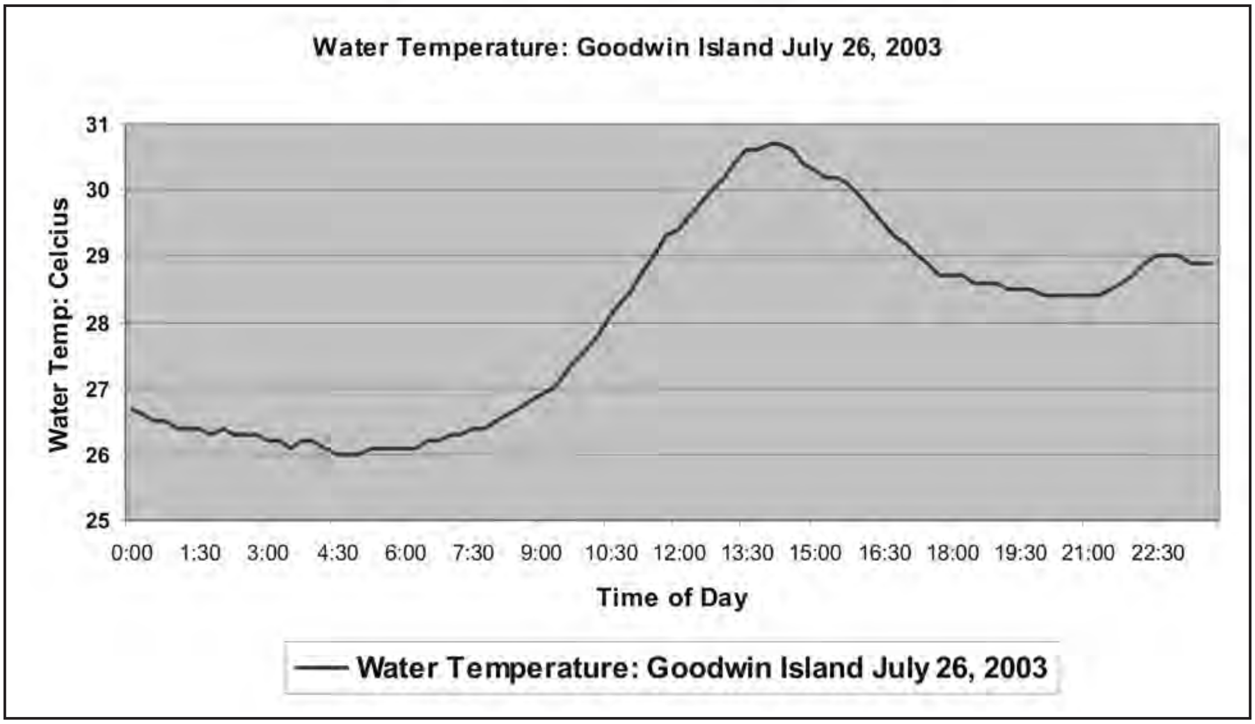


Figure 6. Water Temperature: Goodwin Island, July 26, 2003.

Water Temperature 1.2. Water temperature does not behave the same each day during the week of July 21 – 27 at Goodwin Island (Figure 7, next page). This makes sense because no two days have exactly the same weather or tides. Some days could have been cloudy and cooler while others could have been hot and sunny. There are seven somewhat distinct peaks in water temperature, which indicates that water temperature changes due on a daily basis. The warmest water occurs in the early afternoon (approximately 12:45, 12:15, 1:15, 2:00, 2:15, 2:30 and 1:30 during the week respectively) and not at high noon. Water temperature often occurs past noon because the hot sun has more time to heat the shallow water. The coolest water temperatures generally occur near dawn to the early morning hours during this week.

You would want to avoid fishing the Goodwin Island flats from approximately 10:00 am until early evening (7 pm) if you were looking to catch any rockfish or sea trout. Many sport fish feed during the dawn and dusk because their vision is best at these low-light times of day. Dawn and dusk feeding is referred to as crepuscular feeding.

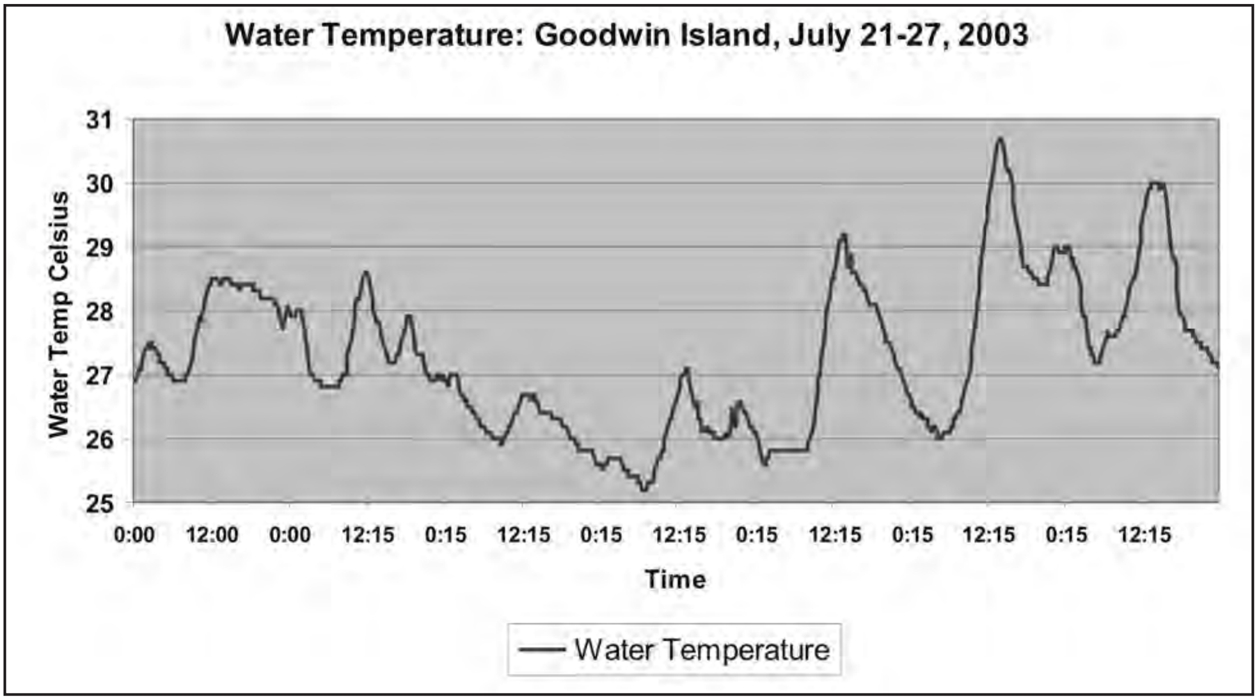


Figure 7. Water Temperature: Goodwin Island, July 21-27, 2003

Water Temperature 2.1. This is a complicated question because there is a lot of data involved in this two y-axis graph (Figure 8). In order to figure out patterns for such a graph it can help to focus on smaller parts of the graph. For instance, you could look at the water temperature and depth trends from 9 am to 3 pm each day and relate what they are doing in terms of one another.

The largest daily increases in water temperature occur on the last three days. You can see that the water temperature at this station rises during the morning and early afternoon. This rise in water temperature occurs over a time period when the tide is falling *and* then rising.

Thus the easiest answer to this question is that the tide did not appear to control the water temperature during this week and water temperature changed on a diel, or daily, pattern due to weather conditions.

Water Temperature 2.2. There is no daily trend for the first two days of this week, but there does appear to be a daily trend in water temperature for the 3rd, 4th, 5th and 6th days of this week (Figure 8, next page). The water temperature increases from the morning to the late afternoon or early evening during these four days of this week. Thus water temperatures can change on a daily, or diel, pattern in the winter as well when the weather is warmer during the day than at night.

The lack of any changes in water temperature during the first two days makes me think they were cloudy and cold days. These days were followed by a warming trend in the middle of the week and water temperatures rose during the day accordingly and decreased at night.

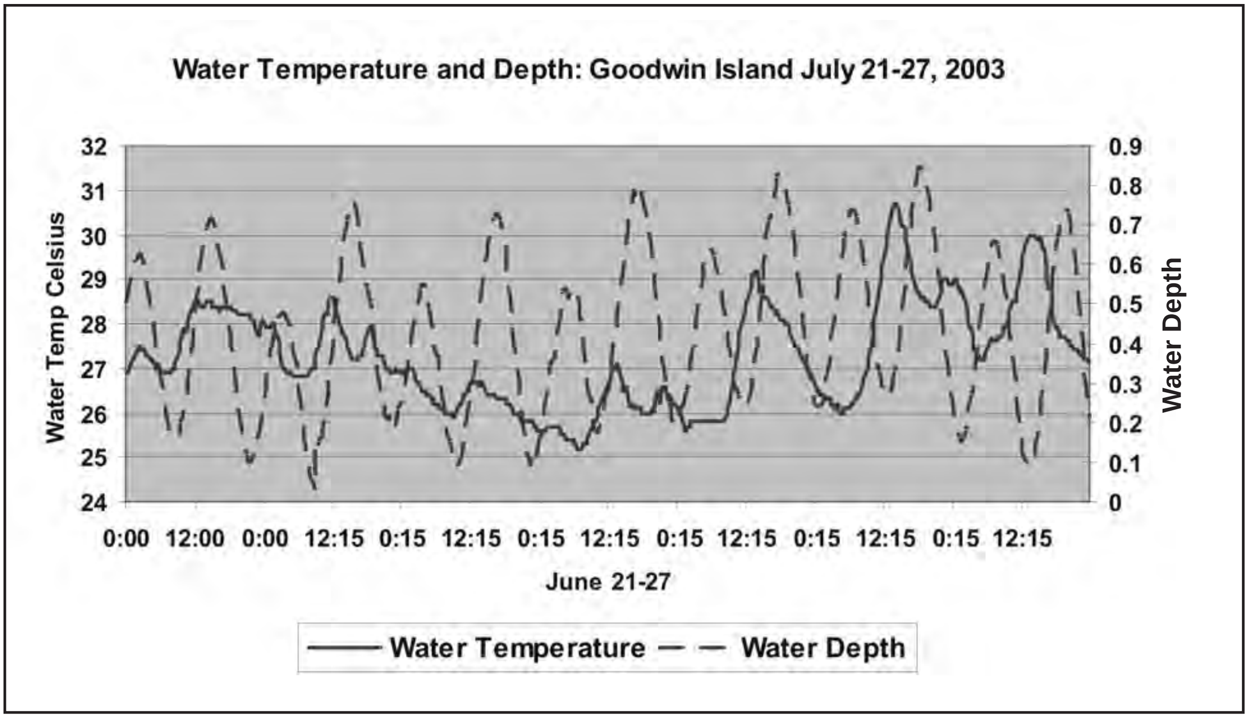


Figure 8. Water Temperature and Water Depth: Goodwin Island, July 21-27, 2003

Water Temperature 3.1. We learned in the previous activities that water temperature often changes on a daily pattern. Water temperature also changes on a seasonal cycle as well (Figure 9). The coldest water temperatures occur in late January and reach 0° C. The water warms during the spring and reaches 27° C on July 1. The water temperature stays warm throughout the summer, and drops below 27° C on September 5 when it begins to cool during fall. Notice that the water temperature curve is not smooth during the year. Warm and cold periods during the year can be observed in smaller rises or dips in the yearly water quality graph.

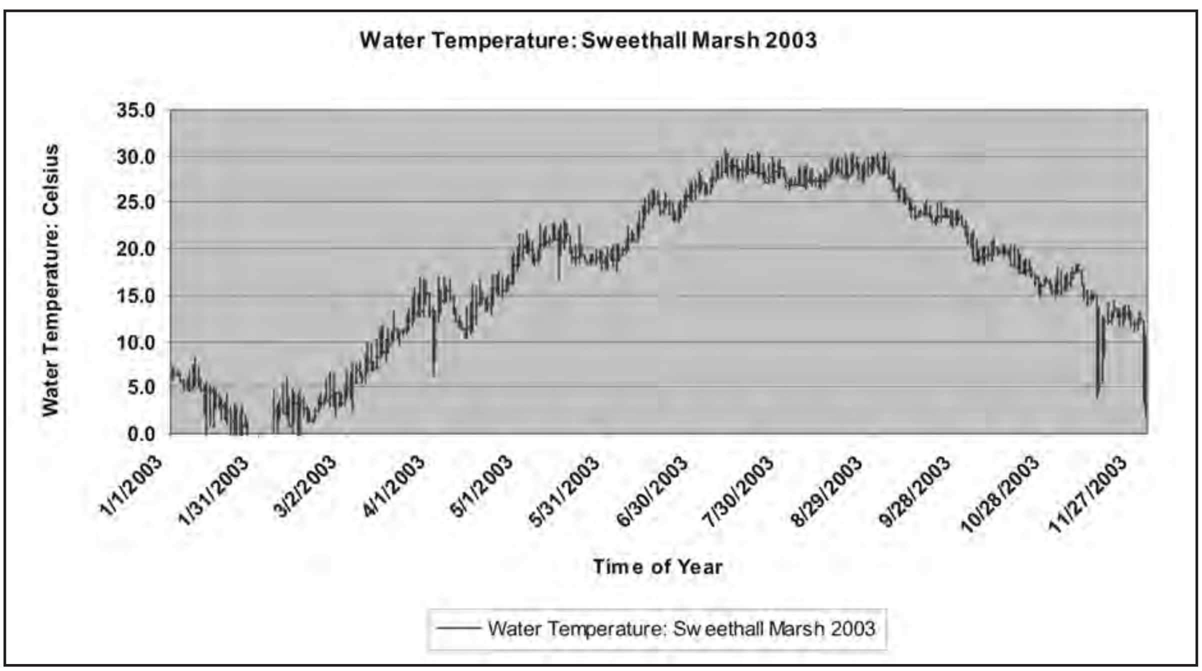


Figure 9. Water Temperature: Sweet Hall Marsh, 2003

Salinity

Salinity 1.1. There is a very large variation in salinity during the course of Oct 30, 2003 in Taskinas Creek (Figure 10). The highest salinity recorded is 11.72 and the lowest value recorded on Oct 30 is 1.36 for an overall difference of 10.36 ppt. This is a very large variation in salinity for one tidal cycle. Taskinas Creek is a small creek feeding into the York River at York River State Park. Such large salinity variations make Taskinas Creek one of the most interesting stations to analyze because both the brackish York River and the fresh water creek heavily influence it.

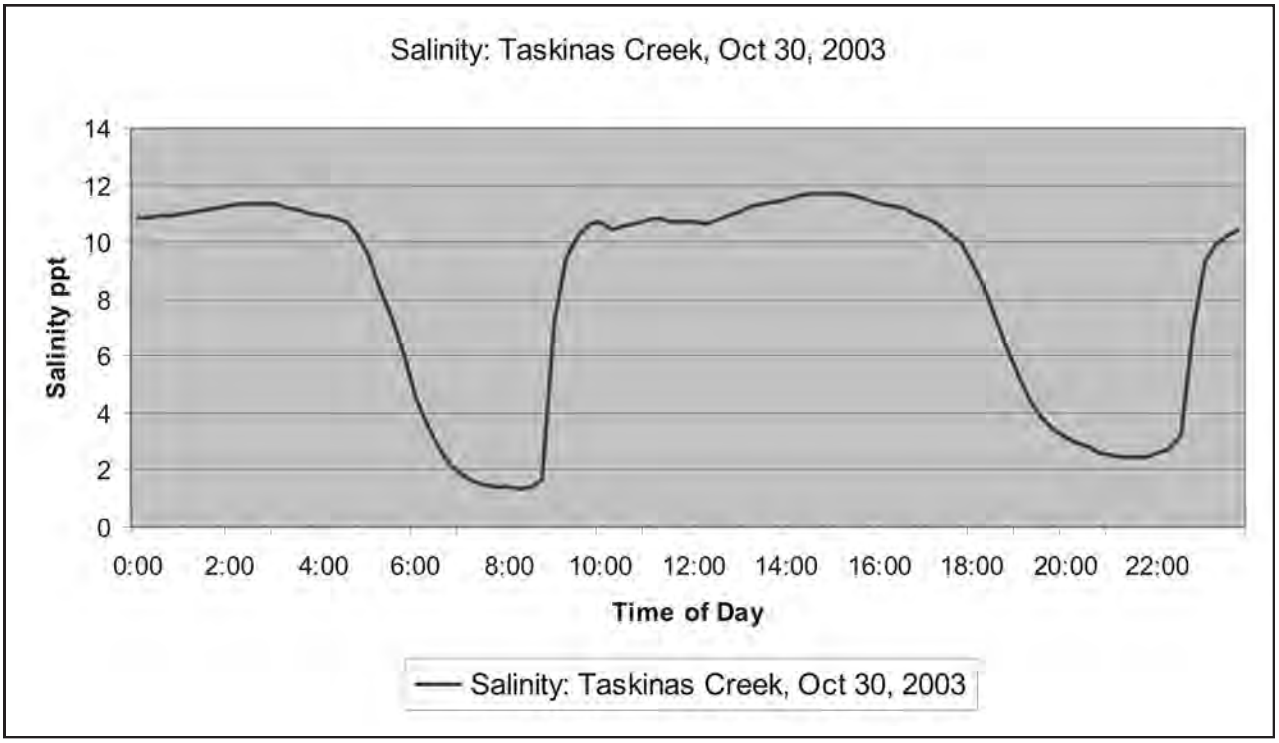


Figure 10. Salinity: Taskinas Creek, Oct 30, 2003

Salinity 1.2. Looking at the salinity and tide level on the same graph highlights the fact that the two are correlated at this site (Figure 11, next page). The lowest salinity occurs at low tide. Fresh water from the groundwater fed stream at the head of Taskinas Creek moves downstream as the tide falls and the salinity drops at the water quality monitoring station. The salinity jumps back up when the tide begins to rise and brackish York River water flows back into the creek.

Salinity 2.1. The overall trend is that salinity decreases as you move up the York River (Figure 1 and Table 5, next page). Salinity is also lower at each site during low tide than at high tide.

Surprisingly, the salinity at Gloucester Point is higher than the salinity at Goodwin Island. This could be due to the fact that salty Bay water tends to flow upriver on the north side (Gloucester Point side) of the York River, while fresher water flows down the south side of the York River (Goodwin Island side) due to the Coriolis force affecting water currents.

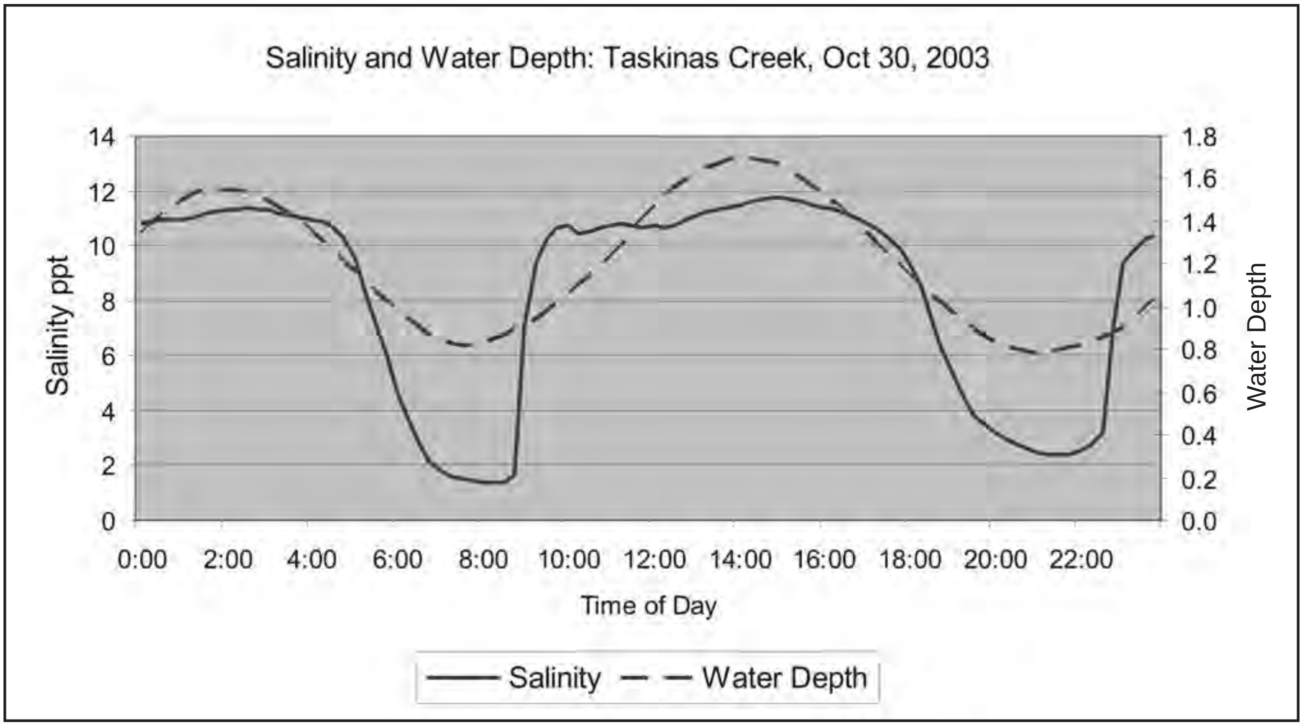


Figure 11. Salinity and Water Depth: Taskinas Creek, October 30, 2003

Table 5. High and Low Salinity: York River Water Quality Monitoring Stations, Sept 1, 2003.

Water Quality Station	Low Salinity Reading	High Salinity Reading
Goodwin Island	17.2	18.1
Gloucester Point	18.6	19.5
Clay Bank	15.0	18.1
Taskinas Creek	3.5	12.9
Sweet Hall Marsh	0.2	2.6

Salinity 2.2. The salinity does change during the 2003 at Clay Bank, there is no discernable pattern to the change during the course of the year (Figure 12). Salinity often has a seasonal pattern of being highest in the late summer and early fall and lowest during the late winter and early spring due to average rainfall, evaporation and evapotranspiration rates during the year. Rainfall patterns are different from year to year however, which is observed in salinity data. 2003 was a very wet year and a seasonal pattern in salinity at Clay Bank is not present.

Note that the graph below has tremendous dips in the salinity values where the data line drops to 0. These are times when the tide drops so low that the data sonde is out of the water and reads 0 ppt salinity. These data points should be deleted from the data file, or disregarded when interpreting the graph.

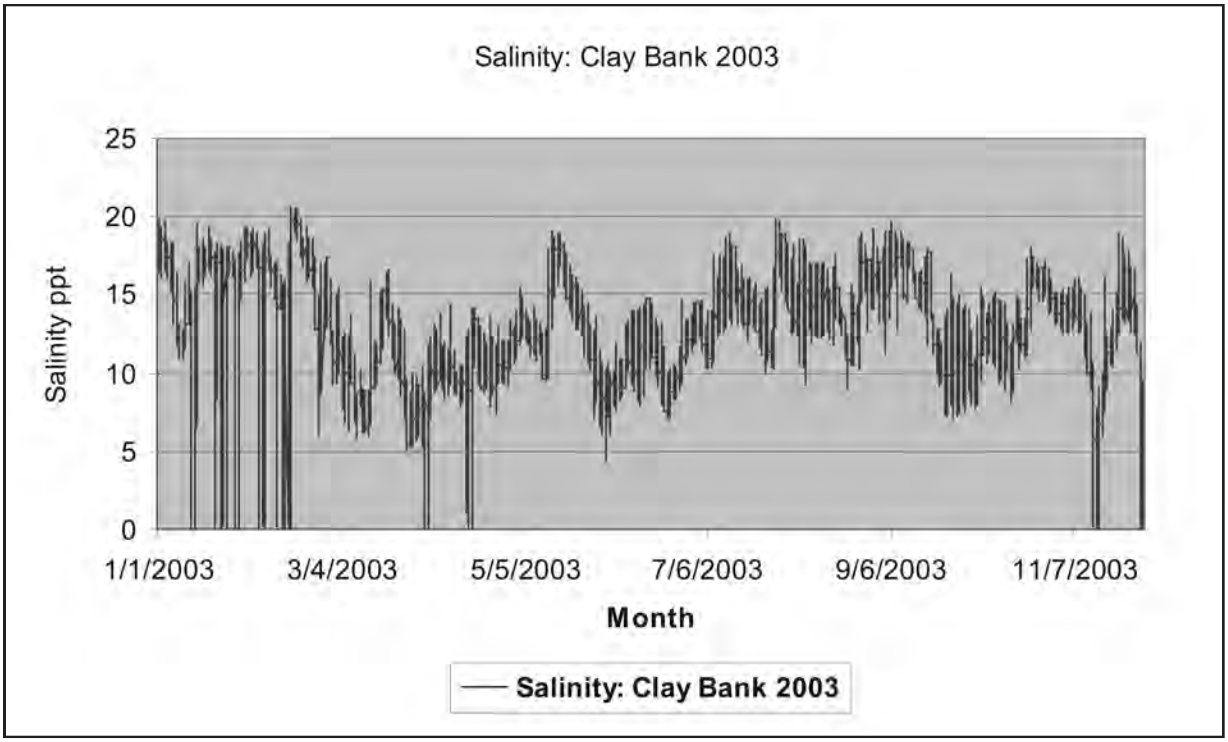


Figure 12. Salinity: Clay Bank, 2003

Hurricane Isabel

Isabel 3.1. There is no one answer to this question. There are several very interesting observations in the data that could add interesting pieces to newspaper story on water quality changes in the York River due to Hurricane Isabel. I took a shot at this question below.

Life in the York River During Hurricane Isabel

Most people didn't have time to think about how the wind, rain and storm surge of Hurricane Isabel affected the waters of the York River during Hurricane Isabel because most were preoccupied by riding out the storm safely. Now that all but a few storm damaged houses are back in shape, we took some time to learn how Hurricane Isabel impacted the waters of the York River by investigating water quality data from four sites along the York River provided by the Chesapeake Bay National Estuarine Research Reserve in Virginia which is located at Gloucester Point.

The water in the York River started rising due to the Hurricane Isabel storm surge on the morning of September 18. This damaging surge of water peaked at 2:45 pm at Gloucester Point with water that was 3.6 feet higher than the next highest tide at the Point during the month of September. This peak of high water moved up the York River and peaked at Clay Bank at 3:30 pm, Taskinas Creek (located in York River State Park) at 6 pm and at Sweet Hall Marsh on the Pamunkey River at 8:45 pm. The storm surge completely overpowered the tides during the afternoon and night of the 18th. Many locals knew they were in for trouble when the tide kept coming in when it was supposed to turn and begin falling with the low tide. Water levels dropped during the night of the 18th and morning of the 19th. The storm surge and then receding storm surge waters completely overpowered normal tides in the river.

The water level wasn't the only thing to rise during Isabel. Water clarity, which is vitally important to the health of the underwater grass beds and is measured in NTU's, decreased dramatically as the waves ate away at the shoreline and stirred up bottom sediments in the River. Taskinas Creek, located in a pristine watershed at York River State Park, had the dirtiest water with values of 2,103 NTU's during the storm. Gloucester Point had the second highest NTU readings at 760. These turbidity readings are incredibly high considering that the Gloucester Point average turbidity value in 2003 was 9.7 NTU's. Lucky for the underwater grass, NTU values dropped back down to pre-storm conditions just a day or so after Isabel, so the underwater grasses should not be impacted from to this cloudy water.

Salinity values took a roller coaster ride at upriver sites on the York River. The normally fresh water of the Pamunkey River near Sweet Hall Marsh rose to a salinity of 11.6 parts per thousand during the storm surge. Salinities like this are normally found near the middle stretches of the York River such as Clay Bank. The salinity at Sweet Hall Marsh decreased back to normal levels in two days as the storm surge receded. Salinity values declined along the entire York River in the days after the storm as fresh water from Isabel's heavy rains coursed down streams and rivers into the York.

Surprisingly, dissolved oxygen in the York River only increased slightly during the storm despite all of its winds, waves and turbulence, which normally provide oxygen to the water. Dissolved oxygen *decreased* in the weeks after Isabel at Sweet Hall Marsh in the Pamunkey River. Large amounts of organic matter washed into the Pamunkey River from the land during the flooding and heavy rains. Organic matter is comprised of things that were once alive and comes in all sizes from dead trees and fallen leaves to microscopic particles. Aquatic bacteria decompose this organic matter and use oxygen in the process. Average dissolved oxygen conditions at Sweet Hall Marsh dropped to hypoxic levels in the weeks after Isabel, likely causing some sensitive aquatic animals to move to areas of the river with more dissolved oxygen.

Overall, it appears that while Isabel had a large impact to residents in the watershed, the storm didn't hurt the waters of the York River all too badly. Sediments that were washed into the river or were stirred up off the bottom with the waves settled out quickly, and the high salinities in the Pamunkey fell almost as fast as the storm surge waters. Oxygen levels in the Pamunkey did drop after the storm, but migratory fish spawn in March, April and May in that stretch of river, so hopefully the juvenile striped bass, American shad and herring were old enough to be able to tolerate the lower dissolved oxygen conditions in the Pamunkey River in the weeks after Isabel. Chlorophyll-a and salinity values dropped along the river after Isabel passed indicating that the river got a good flushing out. The York should be able to digest any organic matter and nutrient inputs received during Isabel over the fall and winter seasons when algae blooms and hypoxic conditions do not typically occur.

Tidal Fresh Water Marsh

Fresh Water Tidal Marsh 3.1. I calculated the average salinity per month from the Sweet Hall Marsh 2003 data on the Excel spreadsheet (Table 6). September of 2003 is the only month that had an average salinity above the definition of fresh water (0.0 – 0.5 ppt). I then graphed the salinity data for the entire month of September to investigate the salinity trend (Figure 12). Pulses of 1-5 ppt brackish water were observed at Sweet Hall Marsh early in the month and a large pulse of brackish water (up to 11 ppt) was observed on September 19 due to the Hurricane Isabel storm surge. Looking at the water depth line on this same graph tells you that the brackish water moves in with high tide at this station. The pulses of brackish water were associated with normal high tides earlier in the month and with the Hurricane Isabel storm surge (Sept 17, 19, 19) in the second case.

One year of data is not enough to answer this question. 2003 was a very wet year in Virginia, which would send more fresh water down the rivers and depress salinity levels in the estuary. You would want to analyze the salinity data during a dry year as well before you purchased this fresh water marsh in order to be sure that it would stay a fresh water marsh.

Table 6. Average Monthly Salinity: Sweet Hall Marsh, 2003.

Month	Average Monthly Salinity (ppt)
January	0.42
February	0.38
March	0.08
April	0.07
May	0.17
June	0.05
July	0.08
August	0.14
September	0.84*
October	0.20
November	0.06
December	0.05

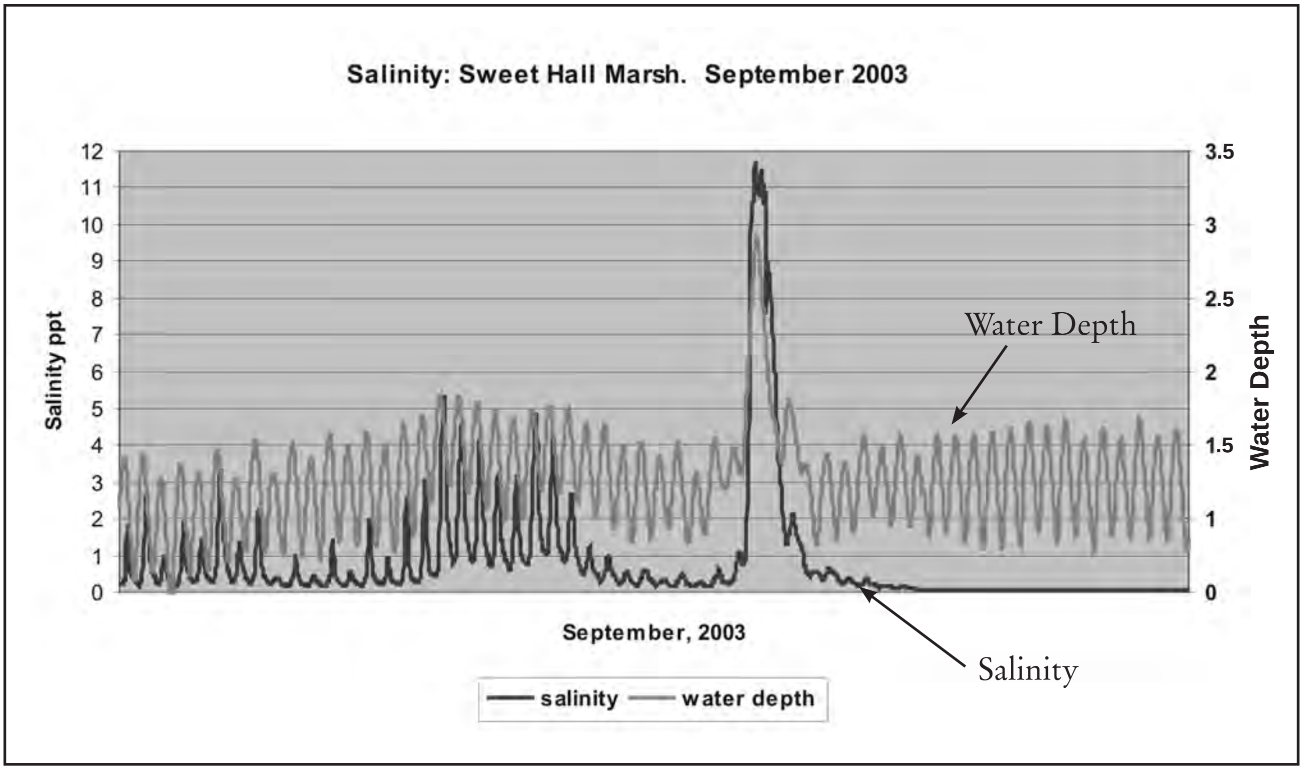


Figure 13. Salinity and Water Depth: Sweet Hall Marsh, September 2003

Bivalve Aquaculture in the York River

Bivalve 2.1 Oyster Spawning: Our analysis of the water temperature data from Goodwin Island indicates that the first spawning event for oysters could have occurred on April 27, 2003 as water temperatures rose to 18°C or greater for more than four hours at this time. Even though the temperature was right for spawning, April 27 may have been too early for oysters to spawn because their gonads may have still been developing. The only way to know if the oysters spawned on this date would be to collect some, open them up and inspect them.

Bivalve 2.2 Oyster Spawning: The oysters may have still been in the conditioning stage on April 27. 'Conditioning' means that their gonads are developing. You would not want to risk shipping oysters that have spawned because they will be incredibly 'skinny' and 'watery', making the buyer extremely unhappy. Therefore you would want to harvest your oysters from your oyster grounds near Goodwin Island some time in the middle of April in order to be sure that your oysters hadn't spawned yet.

Bivalve 2.3 Hard Clam Spawning: The data from Goodwin Island indicates that the hard clams would begin spawning in the afternoon of June 6, 2003 because this is the first time during the year that the water temperature hits 23° C or greater for more than four hours. Clams are external spawners which means they release their gametes into the water where the sperm meet the eggs and fertilization occurs. Clams spawn during slack low tide in order to increase the chance that eggs and sperm will meet in the water column. There is less water above them and little current during slack low tide.

Considering this information you plan to start bringing in adult clams to your contact at VIMS during the last week of May so you can be sure to bring them in just prior to spawning.

Bivalve 3.1 Oysters: Table 7 on the next page also indicates that you *could* grow oysters from the mouth of the York River (Goodwin Island) all the way upriver to Clay Bank. While oysters can live in salinities as low as 5 ppt, they grow best in water that is 12 ppt salinity and above. The average monthly salinity at Clay Bank dips below 12 ppt for 5 months during 2003. The oysters would survive this but would not grow much during this time. The key to successful aquaculture is to grow your animals fast. Therefore you would likely want your furthest *upriver* oyster grow-out site somewhere between Clay Bank and Gloucester Point because the salinity would be higher between these two points.

Bivalve 3.2 Hard Clams: The table below indicates that you could place your hard clam beds from the mouth of the York River (Goodwin Island) to Gloucester Point knowing that the water salinity is conducive to hard clam growth (above 15 ppt). You would not want to place your clam beds at Clay Bank because salinities drop below 12 ppt and there is a strong possibility that they would all die over the course of the year due during time periods of low salinity that occur that far upriver.

Bivalve 3.3 Oysters: 2003 was a wet year and it is a safe bet that the average monthly salinity values in 2003 for the York River are as low as they get barring any major tropical storms in the York River watershed. You could therefore feel confident that any oysters you place in the York

River from Clay Bank down to the mouth of the York would face saltier conditions during years with average precipitation or drought conditions.

Hard Clams: Even though 2003 was a wet year which means that the salinity in the York River were very low, you would not want to risk placing $25,000 worth of clam seed at locations near Clay Bank knowing that this area of the river can experience low salinity periods that could kill your clams. Considering how salinity increases as you move down the York River, you could begin to grow clams somewhere between Gloucester Point and Clay Bank, but it's impossible to know exactly where based on this data.

Table 7. Monthly Salinity Averages (ppt): GI, GP and CB, 2003.

Month	**Goodwin Island**	**Gloucester Point**	**Clay Bank**
January	19.9	No data	16.1
February	19.6	No data	16.3
March	15.8	No data	9.7
April	15.0	No data	9.8
May	16.0	No data	13.0
June	15.2	14.7	10.2
July	18.0	18.0	13.7
August	18.3	18.1	16.4
September	18.2	17.4	9.8
October	16.5	16.4	12.7
November	17.5	16.8	12.4
December	16.0	No data	10.6
Yearly Average*	17.2 ppt	16.9 ppt	12.6 ppt

*yearly averages calculated from the 12 monthly means.

Submerged Aquatic Vegetation (SAV) Restoration

SAV 3.1. Large beds of SAV used to grow around Goodwin Island and on the North side of the York River from the mouth of the York past Gloucester Point all the way upriver to Clay Bank. Currently, SAV can be found at Goodwin Island and along the North side of the York River from the mouth to Gloucester Point. SAV does not currently grow upriver from Gloucester Point.

Table 8. Average Turbidity (NTU) Per Month: Clay Bank, Gloucester Point and Goodwin Island, 2003.

Month	Average Turbidity (NTU) by Site		
	Goodwin Island	**Gloucester Point**	**Clay Bank**
January	3.2	***No data***	17.1
February	5.1	*No data*	16.6
March	5.6	*No data*	19.6
April	4.9	*No data*	25.5
May	5.5	*No data*	31.9
June	4.6	10.2	22.5
July	16.2	10.6	21.6
August	12.4	11.1	22.7
*September***	15.2	12.8	16.3
October	5.8	6.0	16.3
November	4.0	5.6	18.0
December	6.1	***No data***	12.8
Growing Season Avg.*	6.6 NTU*	9.4 NTU*	21.6 NTU*

Italics = Eelgrass growing season

* *Growing season* averages calculated from all the data points, not the monthly means.

** Goodwin Sept Data only until Sept 18. No data from Sept 19 – Oct 1 at Goodwin Island due to Hurricane Isabel damage to the data sonde station.

SAV 3.1 a. I calculated the average NTU values for each month and the entire year for each station using Microsoft Excel Table 8. The table shows that none of the three sites in the York River had clear enough water for eelgrass to grow to 1-meter deep in during the 2003 SAV growing season. This is strange considering that eelgrass was growing at both Goodwin Island and Gloucester Point in 2003. The SAV at these sites may have been in a 'stressed' condition where they are using energy reserves to get through poor water clarity time periods. Question 3.4 may be able to provide more insight into how SAV can grow at both Goodwin and Gloucester Point even though the average monthly NTU readings were greater than 7 NTU during several of the eelgrass growing season in 2003.

SAV 3.1 b. I would not move ahead with eelgrass restoration at any of these sites because you need clear water for the SAV to grow and survive. You may want to plant small plots for study purposes, but I would not move forward with large scale SAV restoration at these locations.

SAV 3.1 c. Goodwin Island had the highest average NTU readings in July, August and September. The average monthly water clarity was sufficient for SAV growth at Goodwin during the rest of the year.

Gloucester Point had the highest average NTU readings in the summertime also, with monthly average NTU values dropping below 7 NTU's in the fall.

Clay Bank had monthly average NTU readings above 7 NTU's during every month of 2003. The highest readings were in April and May with the lowest in December.

SAV 3.2. In general, the clearest water at all three sites occurred during the colder months when phytoplankton growth is minimal. The highest monthly average NTU readings occur in the summertime, when phytoplankton growth is high. The murkier water observed in the summertime coincides with the highest water temperatures of the year. High water temperatures (above 30° C) combined with murky water can stress SAV to the point where it dies.

SAV 3.3. The answer to this question depends on the site. Graphing the NTU data for several months at Clay Bank with Excel shows that the NTUs are chronically (i.e. generally) greater than 7 NTU at this site and that large acute (short term) spikes in the NTU readings also occur. Eelgrass does not grow at Clay Bank at 1-meter depths because the water is rarely below 7 NTU's.

Graphing monthly NTU data with Excel at Gloucester Point and Goodwin Island reveals that there are long periods when the turbidity is below 7 at each of these stations, and increases above 7 NTU's for short ¼ -day to 2-day time periods (Figure 14, next page). Remember that eelgrass grows at both of these stations to depths of 1-meter. While the average NTU data for several summer months is greater than 7 NTU's at Gloucester Point and Goodwin Island, the eelgrass may be getting enough sunlight during the times when turbidity is below 7 NTU's to make enough food reserves to sustain itself during periods when the turbidity is above 7 NTU's. This is similar to binge eating where you go for long periods without eating (SAV experiencing murky water) interspersed with large meals (water clear enough for SAV to make enough food to sustain itself).

A water quality value more precise than the average monthly NTU's is necessary to predict if SAV can grow at a site. Perhaps marine scientists will be able to calculate how much time during a month the turbidity has to be below 7 NTU for SAV to survive. Can you think of a more precise way to report water clarity data for the year that would help eelgrass scientists?

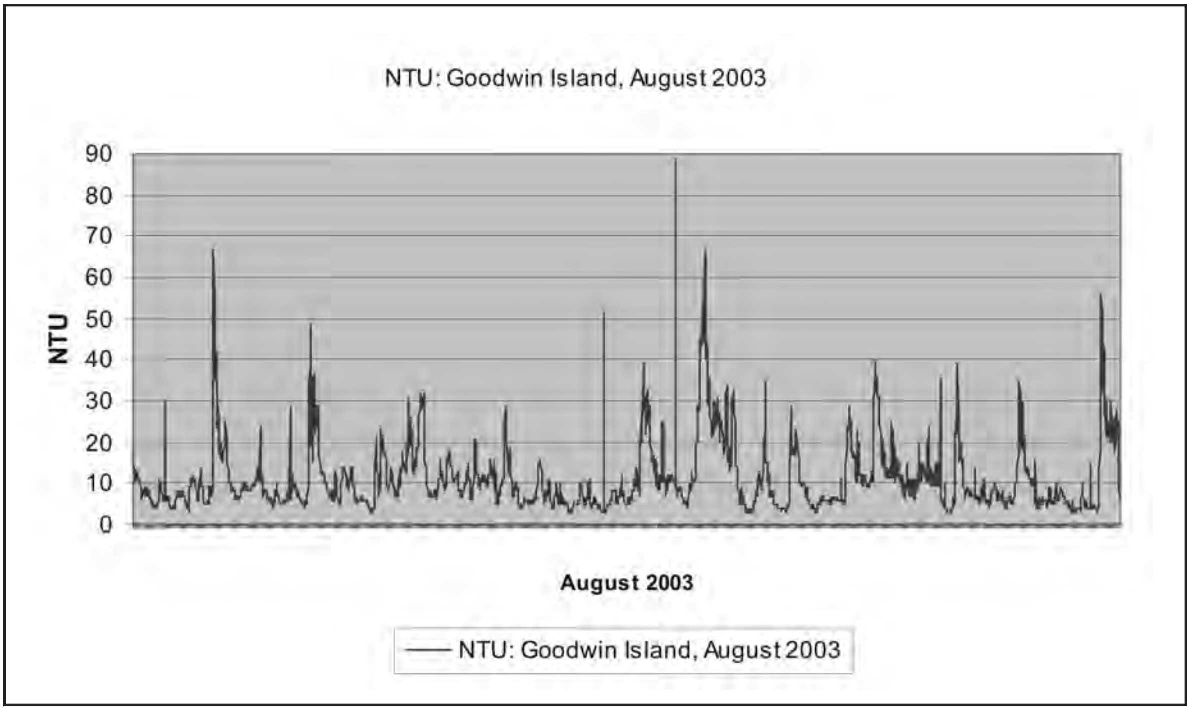


Figure 14. NTU: Goodwin Island, August 2003

Dissolved Oxygen

Oxygen 1.1. The dissolved oxygen values became hypoxic (dropped below 5 mg/l) sometime just before July 17, reading 4.5 mg/l at midnight, 0000 July 17 (Figure 15). DO continued to drop to a low of 2.6 mg/l at 3 AM on the morning of July 17 before beginning to rise. The hypoxic event lasted 5-hours. The fish you observed dying that night were juvenile menhaden, which are very sensitive to low oxygen conditions. The low dissolved oxygen could also explain why you stopped catching fish around midnight. Fish either became stressed and stopped eating, or moved away from this area when oxygen levels fell below 5 mg/l.

Oxygen 1.2. Dissolved oxygen values during this 32-hour period of July 16 – 17, 2004 peak at 9.7 mg/l at 15:00 (3 pm) in the afternoon on the 16th and declined until reaching the low of 2.6 mg/l at 0300 (3 am) on the morning of the 17th (Figure 15). DO values then begin to rise during the morning of July 17.

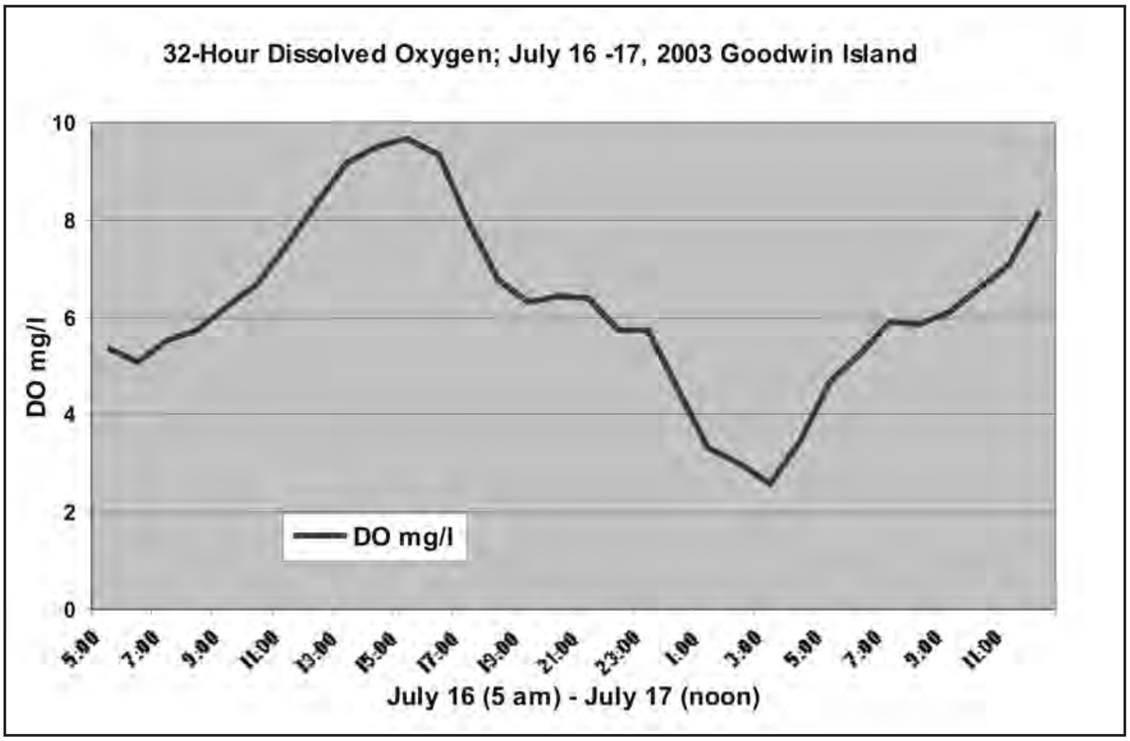


Figure 15. Dissolved Oxygen: Goodwin Island, July 16-17, 2003.

Oxygen 1.3. The trend in dissolved oxygen is similar between July 9-10 and July 16-17. DO values are high during the day, decline at night and bottom out in the early morning hours during both time periods. Trend means the overall pattern of the data. The dissolved oxygen graphs are different for the two time periods, but the general trends of highest DO in the daytime and lowest DO during the late night and pre-dawn hours are the same.

Oxygen 1.4. Hypoxic conditions (DO $\leq$ 5.0 mg/l) occur during the early morning hours due to the net effects of photosynthesis, cellular respiration (plant, animal and bacterial), oxygen diffusion across the air/water interface and water movement. Photosynthesis creates more oxygen during the day than is being used by the plant, animal and bacteria cells. DO values can increase during daylight hours to where the water is supersaturated with oxygen, meaning that it holds more oxygen than it can under normal conditions. Photosynthesis shuts down as the sun sets and community respiration (plant, animal and bacteria) consumes more oxygen than can diffuse from the air into the water and DO values drop, often reaching their lowest point in the predawn hours before the sun rises and photosynthesis starts back up.

Oxygen 2.1. *Low* tide occurs at approximately 3:30 AM on July 16-17 while *high* tide occurs at this time on July 9-10, so the tides are opposite on these two dates.

A relationship between water depth and DO exists in conjuncture with time of day and the rate of photosynthesis. Isolating relationships can be difficult in estuaries as factors change simultaneously.

The tide does have some influence on DO readings, but the *overall* DO trend during both time periods that DO levels increase during the day and decrease at night is the same (Figure 16). DO levels tend to decrease during an outgoing tide and rise with an incoming tide during the night at Goodwin Island for these two periods. The reason that DO levels decrease as the tide drops could be that bacterial respiration in the sediments consumes oxygen from overlying water. This process could decrease the DO to hypoxic conditions faster when the overlying water is shallower during lower tides. In any event, we see DO levels drop as the tide drops during the night and increase as the tide rises back over the shallows.

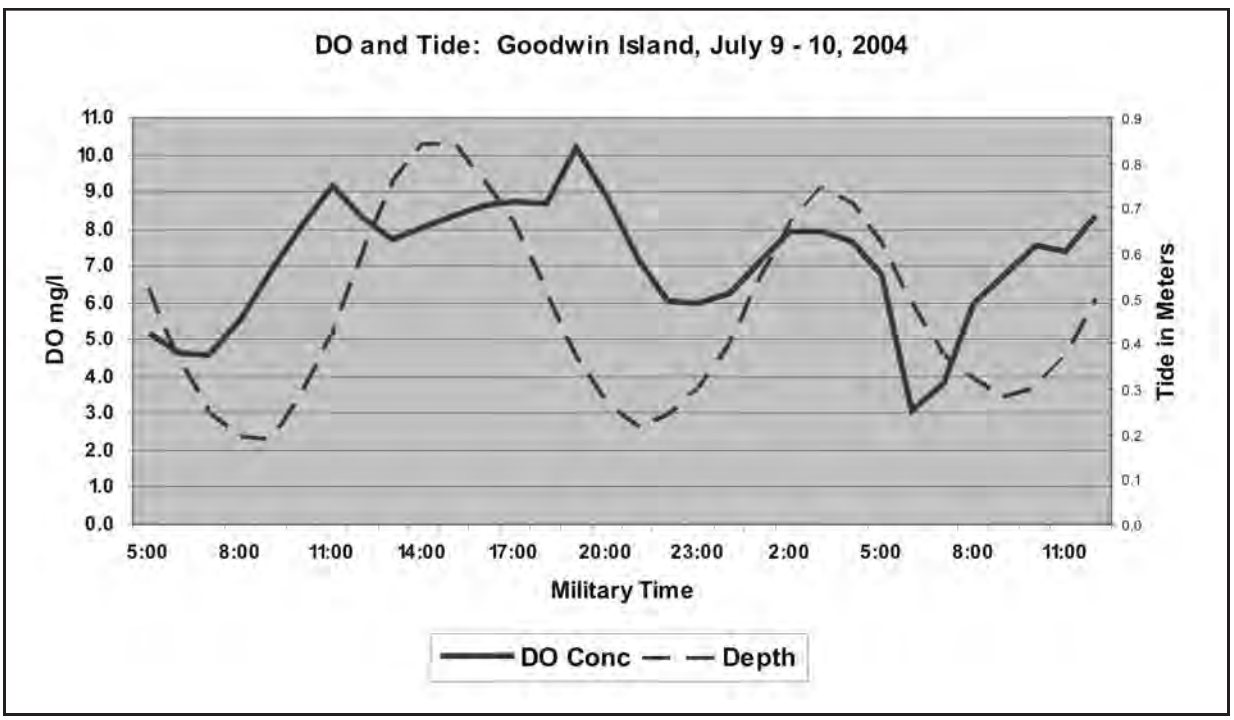


Figure 16. Dissolved Oxygen and Water Depth: Goodwin Island, July 9-10, 2004.

Oxygen 2.2. There does *appear* to be a relationship between DO and water temperature (Figure 17). Water temperature and DO values rise during the day and decrease during the night during the time periods in *Oxygen 1 and 2*. However these two parameters change due to different processes and are not due to one another. This observed correlation is *spurious*, meaning that it is not real. Warm water holds less oxygen and cool water holds more oxygen so the observed relationship does not make scientific sense. Dissolved oxygen values change during the day due to the net oxygen budget at this site and not due to water temperature. Water temperature changes during the day based on air temperature. You always have to think about what the data shows because it can trick you sometimes.

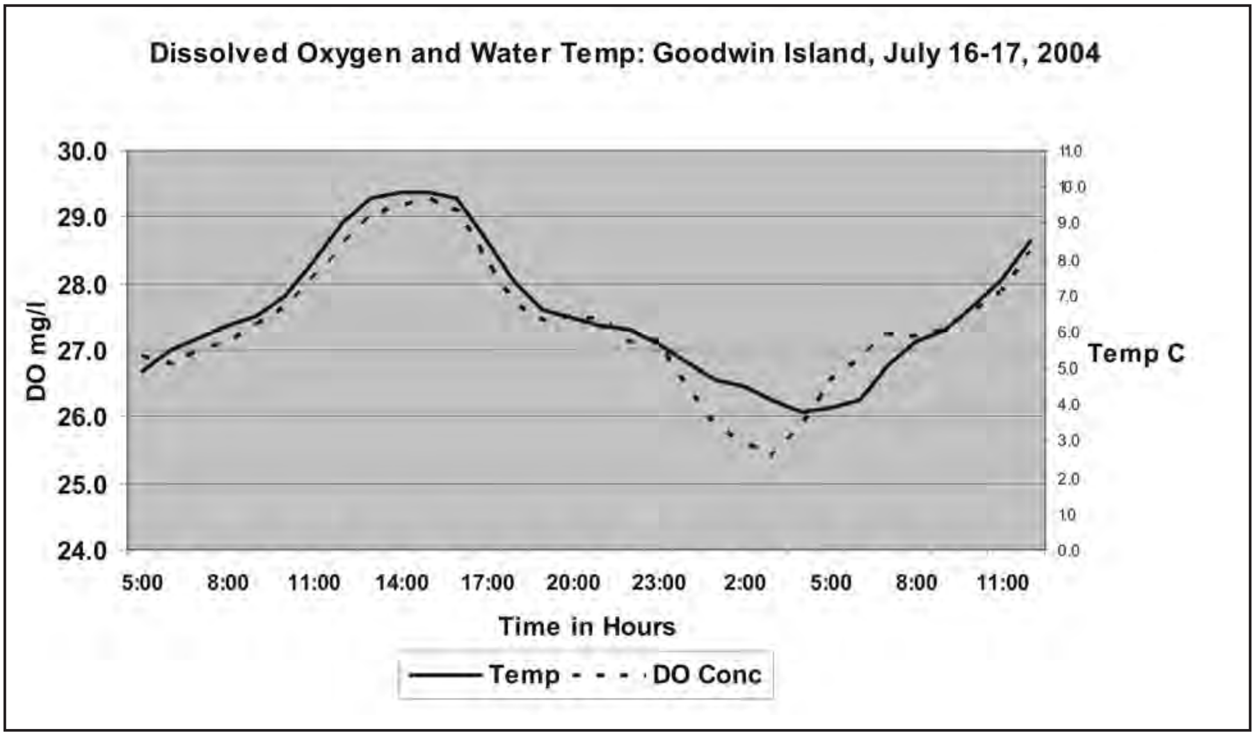


Figure 17. Dissolved Oxygen and Water Temperature: Goodwin Island, July 16-17, 2004

Oxygen 2.3. The water at all five water quality monitoring stations experience diel dissolved oxygen cycles in the summer similar to those that we investigated in previous questions. All five areas experienced hypoxic conditions to some degree. Sweet Hall Marsh and Clay Bank appear to have the least hypoxic conditions during the nightly DO decreases, with low values not dropping below 4 mg/l. Taskinas Creek has the lowest DO drops during the night, and Taskinas Creek came close to having anoxic conditions with the lowest value recorded of 0.9 mg/l.

Oxygen 2.4. Every site has much greater DO mg/l values in the winter. The average DO mg/l at several sites is between 12 and 14 mg/l for the winter week. This is due to the fact that cooler water can hold more oxygen and cellular respiration (plants, animals and bacteria) slows as the temperature drops thus less oxygen is consumed during in colder water. There are no hypoxic periods at any site during the winter week.

Taskinas Creek displays a tidal DO pattern. There are 14 peaks during the winter week, corresponding to the 14 high tides during the week.

Gloucester Point and Goodwin Island display diel oxygen cycles that can be observed by the seven DO peaks during the week (one for each day of the week). This is due to increased photosynthesis during the day, even during the winter.

Oxygen 3.1. Table 15 shows some important DO statistics for the water quality station at Sweet Hall Marsh. The Pamunkey River at Sweet Hall Marsh meets the dissolved oxygen criteria during the spawning season (March 1 – May 31). Sweet Hall Marsh also passes the DO criteria during June and July. This site fails the DO requirements in August because DO levels drop below the instantaneous minimum to 2.8 mg/l on August 17 from 7:15 – 8:45. Sweet Hall Marsh also fails for the month of September because the DO drops below the instantaneous minimum on four separate occasions (9/25 from 7:00 – 7:15 am, 9/26 at 7:30am, 9/27 from 3:15 am – 9:30 am and 9/28 from 4:00 – 9:15 am). Looking at the DO graph for September also gives an indication that this site fails the 4.0 mg/l seven-day average during the end of the month, which is the case. The DO average from Sept 23 – Sept 30 is 3.6 mg/l.

Table 15. Dissolved Oxygen: Sweet Hall Marsh, 2003

Month	Average DO (mg/l)	Minimum DO (mg/l)	Min 7-Day Average
*March	10.3	7.8	Satisfactory
*April	8.9	6.8	Satisfactory
*May	6.7	5.3	Satisfactory
June	5.7	4.3	Satisfactory
July	5.6	4.2	Satisfactory
**August	5.1	2.8**	Satisfactory
**September	5.0	2.7**	Sept 23rd – 30th = 2.7**
October	6.5	3.7	Satisfactory

* denotes spawning season
** denotes failing mark

The failing grade in August is an acute (short-lived) event that is likely due to the summertime diel DO drop occurring on a falling tide. It is my bet is that it was a very cloudy morning also which didn't allow photosynthesis to start until after sunrise.

The failing grade in September is a more chronic (long –lasting) event that is due to large amounts of organic matter washing into the Pamunkey during Hurricane Isabel. This input increased the biological oxygen demand in the river as bacteria decomposed the matter and used dissolved oxygen in the process. Oxygen levels began to drop on Sept 20, reaching as low as 2.7 mg/l before rebounding nine days later. Dissolved oxygen levels rebounded to pre-storm levels of 6.0 mg/l on Oct 5, 2003 and then continued to rise, which gave the month of October a passing grade with respect to the Chesapeake Bay Program DO criteria.

Oxygen 3.2. A results table for dissolved oxygen conditions at Gloucester Point are included in Table 16 on the next page. You can see that the York River at Gloucester Point does not meet the Chesapeake Bay Program dissolved oxygen criteria during July, August and September due to dropping below the instantaneous minimum on several occasions each month. Surprisingly, I could not find a 7-day period that averaged below 4 mg/l DO during July, so the station met the 30-day and 7-day average values for all of the months analyzed.

The authors did not work through this problem for Clay Bank, Taskinas Creek and Goodwin Island due to time constraints. You can work to keep it simple: if a month doesn't meet the 30-day minimum average of 5.0 mg/l, or DO drops below the instantaneous minimum, you don't have to look any further unless you are interested in learning more; you can simply fail that month and move on.

If you want to know more about the DO dynamics at each site, calculate how many hypoxic events occurred, and how long each lasted for each month. This extra information will be incredibly informative about the nature and extent of dissolved oxygen problems in the York River.

Table 16. Dissolved Oxygen: Gloucester Point, 2003.

Month	Average DO (mg/l)	Minimum DO (mg/l)	Min 7-Day Average
June	7.5	No events below 3.2	All above 4.0
July*	6.1	Multiple events below 3.2*	All above 4.0
August*	7.3	Two events below 3.2*	All above 4.0
September*	7.1	Three events below 3.2*	All above 4.0
October	7.6	No events below 3.2	All above 4.0
November	8.9	No events below 3.2	All above 4.0

* Denotes failing mark

__Extension Question__

Oxygen 1. The short and sweet answer to this monumental problem is that we need to decrease the amount of nutrients and organic matter washing into the Bay. Decreasing nutrients will decrease the amount of phytoplankton, which will lessen their oxygen demand during the night and help stop the process known as eutrophication where dead phytoplankton cells sink to the bottom and are decomposed by bacteria in a process that uses dissolved oxygen. Decreasing organic matter loading into the Bay will also decrease the amount of dissolved oxygen that the bacteria use decomposing this matter.

Pick up your pet waste, stop fertilizing your lawn, plant native bushes and trees and don't dump leaves or grass clippings into the creek.

Appendix

Appendix A: Military Time

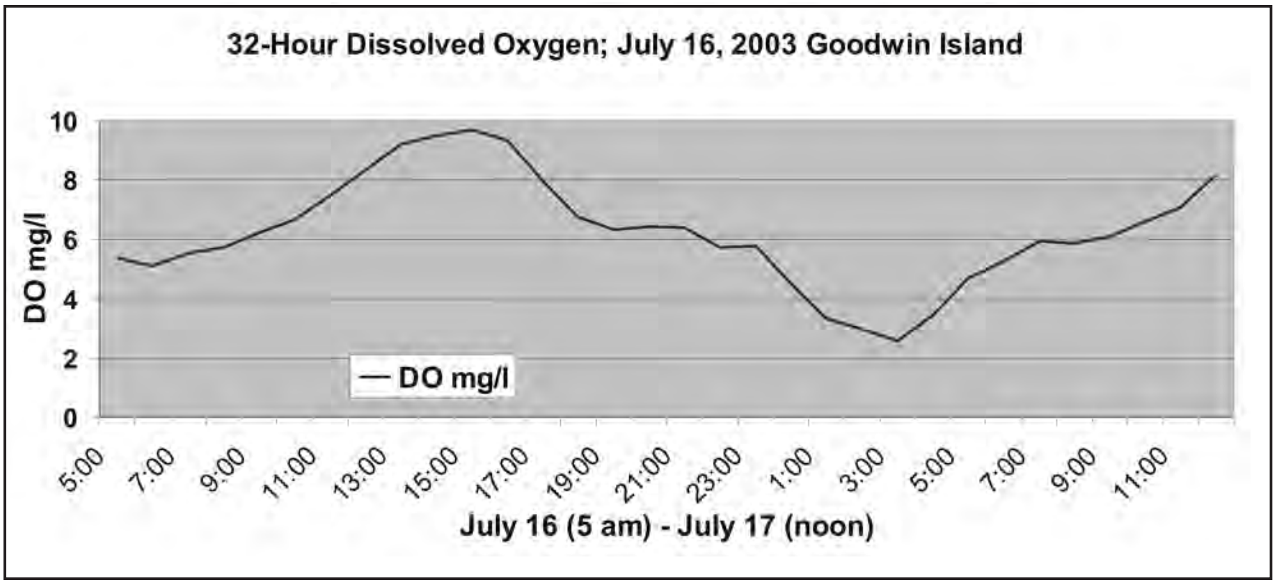
Local Time	Military Time
Midnight	0000 – 'Zero hundred hours'
1 am	0100 – 'Zero one hundred hours'
2 am	0200 – 'Zero two hundred hours'
3 am	0300 – you get the point
4 am	0400
5 am	0500
6 am	0600
7 am	0700
8 am	0800
9 am	0900
10 am	1000 – 'Ten hundred hours'
11 am	1100 – 'Eleven hundred hours'
Noon	1200 – 'Twelve hundred hours'
1 pm	1300 – you get the point
2 pm	1400
3 pm	1500
4 pm	1600
5 pm	1700
6 pm	1800
7 pm	1900
8 pm	2000 – Twenty hundred hours
9 pm	2100 – Twenty one hundred hours
10 pm	2200
11 pm	2300

Appendix B. Unit Conversions

1 km	=	0.62 miles
1 m	=	39.37 inches
1 cm	=	0.39 inches
1 mm	=	0.04 inches

Appendix C: Single Dependent Variable Graph on Microsoft Excel

A single dependent variable graph plots an independent variable (i.e. salinity) on the y-axis with the dependent variable (i.e. 24 hour time period on June 21) on the x-axis. The graph will allow you to see how the salinity changes over the course of the day and match points on the graph (i.e. salinity values with time of day). Such visual representation of data is incredibly valuable to understand what the data means.



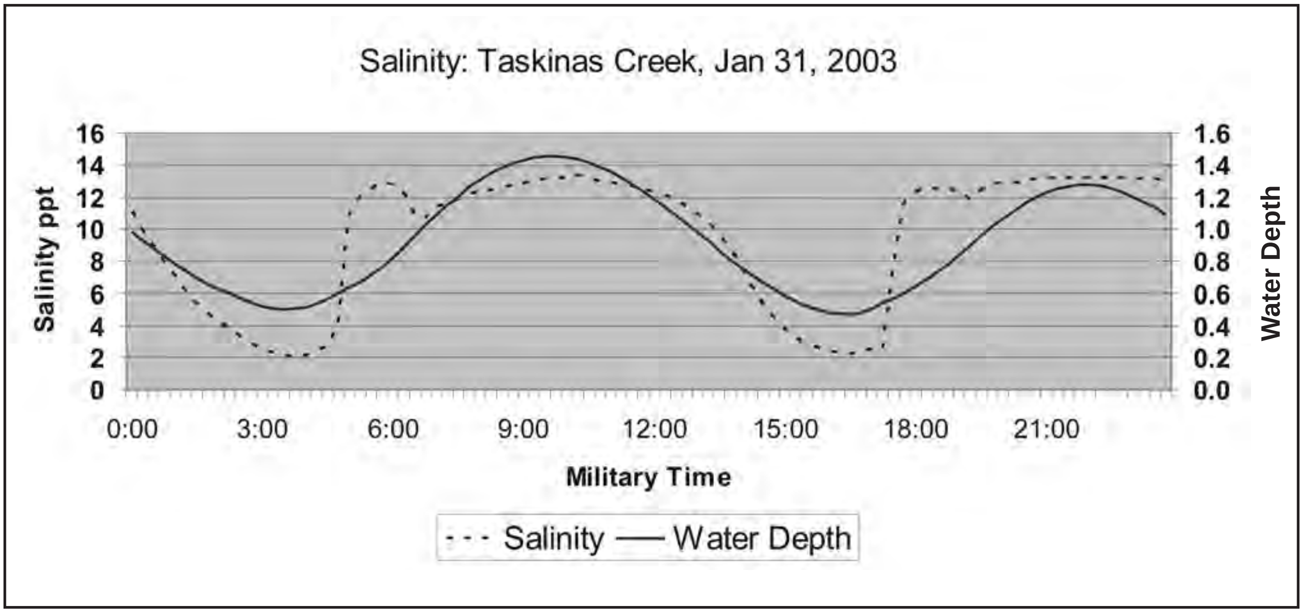
On Excel Spreadsheet:

1. Once the data is in the Excel spreadsheet, it will be in columns with the title of each column at the top.
2. Left click on the colored icon of the bar chart on the menu bar.
3. Left click on 'Standard Types'.
4. Left click on 'Line', and then left click on one of the line graphs to the right where you can see the individual data points as dots along the line.
5. Left click 'Next'. You may see a graph at this point. I recommend doing continuing with the steps below until you really get the hang of graphing.

6. Left click on ‘Series’.
7. If Excel has tried to do you a favor and made plots or series lines other than you specified on the graph you are creating you have to remove these unwanted series from the graph by highlighting ‘Series’ and left click ‘Remove’. I suggest removing all of the series so you know exactly what you have on your graph once you make it.
8. Now you will make the graph you want. Left click on ‘Add’.
9. Left click on the colored box next to ‘Values’, then highlight *all* of the values (drag click) in the column of dependent variables that you wish to graph on the y-axis and then left click on the colored box again. This is DO mg/l in the graph shown above.
10. ‘Category (x) axis labels’: click on the colored box next to these words, highlight the column of independent variables for the x-axis and click on the colored box again. The independent variables will often be time.
11. ‘Name’ in this dialogue box refers to naming the line you just graphed. So if the graphed line represents DO levels in mg/l, click on colored box next to ‘name’, then click on cell with ‘DO mg/l’ in it and then click the colored box again. The name is usually the title of the column that you graphed. In this case you want to name the dependant variable ‘DO mg/l’. Taking time to name and label all of your axes and graph lines properly will save you incredible confusion later on.
12. Label. Take the time to make very well labeled graphs or you will forget what they are.
13. Finish
14. To change the scale of the axes, right click on x-axis on finished graph and click ‘format axis’. Left click on scale and change # of categories between tick-mark labels. Changing the scale to one that works for your graph is a trial and error process in Excel so it may take several tries.

Appendix D: Two Dependent Variable Graph

Use: A two dependent variable graphs allows you to plot two parameters on the same graph. Both of these parameters must have the same independent variable on the x-axis. For instance you could plot the salinity and water depth on the two y-axes for June 21. Both of these independent variables share the same dependent variable of time that is on the x-axis. Plotting two parameters, or variables, allows you to look for trends and patterns between the two parameters.



On Excel Spreadsheet:

1. You will be plotting two dependent variables that have the same independent variable (time or date) in order to create this type of graph. Once the data is in the Excel spreadsheet, it will be in columns with the title of each column at the top.
2. Left click on the colored icon of the bar chart on the menu bar. This opens the graphing process.
3. Left click on 'Standard Types'.
4. Left click on 'Line Graph', and then left click on one of the line graphs where you can see the individual data points as dots along the line.
5. Left click 'Next'.
6. If Excel has tried to do you a favor and made plots or series lines from the spreadsheet you have to remove these unwanted series from the graph by highlighting the 'Series' you do not want in the 'Series' box and left click 'Remove'. I suggest removing all the series so you know exactly what you have on your graph once you make it.
7. Now you will make the graph you want. Left click on 'Add'.
8. Left click on the small colored box next to 'Values = (1)', then highlight all of the values (drag click) for the first column of dependent variables that you wish to graph on the y-axis. Then left click on the colored box again to graph it.

9. Name what data series this is by typing it in the 'Name' box or highlighting from the spreadsheet using the icon and the header of that column.
10. 'Category (x) axis labels': click on the colored box next to these words, highlight the column of independent variables for the x axis (time) and click on the colored box again to make these your x-axis values.
11. Left click on 'Add' to add the second trend line.
12. Left click on the small colored box next to 'Values', then highlight all of the variables for the second column of dependent variables that you wish to graph on the y-axis. Then left click on the colored box again to graph it.
13. Name this second trend line by typing what values it shows in the box or using the icon and the spreadsheet.

    **** The graph will not look correct at this point, as there are two trend lines in the graph but only one y-axis. Hang in there for now.
14. Add labels in the appropriate boxes. Take the time to label as much as you can so you will remember what the graph mean.
15. Finish
16. Now, on the finished graph, RIGHT click on the trend line of the *second* dependent variable that you graphed, or the second series line that you created. Right clicking on the trend line itself is tricky. You will know you have it right when you see the option 'Format Data Series' at the top of the pop-up options.
17. Left click on 'Format Data Series'.
18. Left click on 'Axis.'
19. Left Click on 'Secondary Axis.'
20. OK
21. Now your graph should have two y-axes, both with different scales. Take time to look at the graphs to see if they make sense and display what you wanted to graph.
22. Right click on each axis, then left click on 'format axis' to adjust the scale of the x and y axes.

Appendix E. How to Keep the Title Row Visible When Working in Excel

Being able to see the Excel row with the column titles will be very valuable as you scroll through these large Excel files. In order to always see the row with the column titles, follow these steps:

- Highlight the column below the headings and go to 'Window' on the menu bar.
- Select 'Freeze Panes'. This will keep the headings in view as you scroll down the Excel file.

Appendix F. Sorting Data in Microsoft Excel Spreadsheets

Don't forget that Excel has a help button that can be very useful. Below are brief directions to sort data.

- Know which column you will be sorting in advance.
- Highlight the entire data field for the time that you wish to sort. This means you have to highlight all of the rows and columns even though you will only be sorting one column.
- You can sort by more than one column. The program will sort first by the first column you list, and then the second column that you list. Excel does work to secondarily sort the data for you automatically (for instance if you sort by tide height, it will secondarily sort by date), but there may be instances where you want to override this and secondarily sort by another parameter.
- 'Data' – 'Sort' – pick column to 'sort by' and then choose either ascending or descending, then hit 'OK'.

Appendix G. Calculate Averages with Microsoft Excel Spreadsheets

Again, the help icon on the spreadsheet can be very handy. Below are very brief instructions on how to have Excel calculate an average value for you. The process is very similar for many of the Excel calculating functions.

- Click on the cell that you want the final answer to be located on the spreadsheet. Try to place this cell in a logical location and label it by writing what the value is in a cell next to, above or under the cell where the calculated value will be.
- Left click on the fx button in the toolbar.
- Left click on Average and left click again on OK.

- Left click on the box with blue and red color on it next to the box titled ‘Number 1’.
- Left click and drag on all the data values that you wish to create the average from.
- Left click on the colored box again. An average value and the cells used to calculate this average will appear in a text box. Check to see if the cells listed (ex. g3:g2888) are the ones that you wanted to average. If so, click OK.
- The average value calculated by Excel will now appear in the cell you started from.
- Don’t forget to label that cell by naming what that cell you just calculated is in a nearby cell. Excel will tell you what that number is if you click on it should you not put a label nearby.

Appendix H. Useful Water Quality Web Sites

NERRS CDMO
This web site has archived water quality data from 26 estuaries around the nation. http://cdmo.baruch.sc.edu/

Chesapeake Bay Program
Information about all aspects of the Chesapeake Bay, including Chesapeake Bay dissolved oxygen and salinity maps. http://www.chesapeakebay.net/wquality.htm

Sea Grants Ocean Science On-Line Education Center
Clearinghouse of classroom education activities including a variety of activities that use real data. http://www.vims.edu/bridge/

United States Geological Survey
Stream flow data in Virginia. http://waterdata.usgs.gov/va/nwis/rt

Eyes on the Bay
www.eyesonthebay.net
This web page has a tremendous amount of water quality data from Maryland tributaries and the upper Chesapeake Bay, background information and activities about salinity, dissolved oxygen and harmful algae blooms as well as Flash Media presentations about harmful algae blooms. Much of the data on this site is graphically represented for you based on the water quality data from monthly samples, 15-minute semi-continuous samples and water body water quality mapping data. Real time data is also available. Archive data is also available for several sites and can be copied and pasted directly into an Excel file.

Virginia Department of Environmental Quality water home page
http://www.deq.virginia.gov/water/homepage.html

Virginia Department of Environmental Quality water quality monitoring information. This web page includes a comprehensive guide to citizen water quality testing, what the parameters mean, testing methods etc. http://www.deq.virginia.gov/cmonitor/guidance.html

The GLOBE Program water quality testing instructions for teachers.
http://www.globe.gov/tctg/tgchapter.jsp?sectionId=143

United States Environmental Protection Agency water quality information.
http://www.epa.gov/owow/monitoring/

Information on dissolved oxygen in the Chesapeake Bay
http://www.chesapeakebay.net/pubs/doc-do_101_backgrounder.pdf

Appendix I. Definitions

- **Anadromous:** A life history pattern where adults live in the ocean and migrate to fresh water rivers to spawn their young.
- **Brackish water:** A mix of fresh and salt water.
- **Chlor-a:** Chlorophyll-a is a pigment found in the chloroplasts of plant and algae cells that is used to harness sunlight to make energy. Chlor-a data is one method used to figure out how much phytoplankton is in the water.
- **Data Sonde:** The instrument used to collect the water quality data.
- **Dependent Variable:** A mathematical variable whose value is determined by the value assumed by an independent variable; a variable affected by another variable.
- **Diel:** "daily" in the sense of a 24-hour period rather than the time between sunrise and sunset. Thus a "diel variation" is a variation that occurs regularly once per 24-hour period.
- **Dissolved Oxygen:** (DO) The amount of free dissolved oxygen (O_2) molecules in the water.
- **Estuary:** A semi-enclosed body of water where fresh and salt water mix.
- **Independent Variable:** A variable whose value determines the value of other variables
- **Metric:** System of measurement where the meter, kilogram, and second is the standard of measurement.
- **NTU:** A measure of water clarity that is measured by the CBNERRVA data sondes. Higher NTU readings indicate murkier water.
- **Parameter:** A distinguishing characteristic or feature; a set of measurable factors.

- **Percent Saturation or DO % Saturation:** The amount of dissolved oxygen in the water in relation to how much dissolved oxygen that water could hold (100% saturated) given temperature and salinity. 100% saturation means that the water is holding as much DO as it could. Supersaturation (>100%) and under saturation (<100%) values are common in the marine environment.
- **pH:** The hydrogen ion concentration of a liquid or substance used to measure the acidity or alkalinity of a solution. Numerically equal to 7 in neutral solutions, increasing with increasing alkalinity, and decreasing with increasing acidity. Fresh water is usually approximately a pH of 7 while seawater is closer to 8. pH plays an important role in the toxicity of elements that are naturally dissolved in estuarine water. pH values can change during tidal, diel and seasonal cycles in the Bay. Phytoplankton respiration at night releases CO_2, which has an acidifying effect on the water. Phytoplankton takes CO_2 out of the water during the day during photosynthesis, which has an alkalizing effect. This pattern can be observed even in well-buffered water when large populations of phytoplankton are present.
- **Piscivorous:** Habitually feeding on fish; fish-eating.
- **Probes:** The instruments plugged into the data sonde that measure individual water quality parameters.
- **Salinity:** The number of grams of dissolved salts in 1,000 grams of liquid. Measured in parts per thousand.
- **Secchi Depth:** Another measure of water clarity collected by the use of the Secchi Disk which measures how far down into the water you can see a black and white disk. Higher Secchi readings indicate clearer water.
- **Semi-diurnal:** Occurring or coming approximately once every 12 hours, as the tides.
- **Statistic:** A numerical value that characterizes the sample or population.
- **Temperature:** All temperatures in the data are water temperature measured by the Celsius scale. Celsius = (Fahrenheit – 32) * (5/9)
- **Turbidity:** A measure of water clarity. More turbid water is murkier water. Less turbid water is clearer water.
- **Variable:** A quantity that is capable of assuming any set of values.
- **Water depth:** The data sondes measure the water depth in meters above the probes. This is the same as measuring tidal height. 1 meter = 39.37 inches
- **Water Quality Monitoring Station:** The structure built in the sampling locations that house the data sonde. These are fixed locations.
- **Water Year:** The “Water Year” is defined as the period between October 1st of one year and September 30th of the next. Hydrologists often use this interval because hydrological systems are typically at their lowest levels near October 1.