

USE OF REMOTE SENSING ON THE PAMLICO SOUND
WITH IMPLICATIONS FOR NORTH CAROLINA
WATER QUALITY MANAGEMENT

Proposal

by
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Abstract

The Pamlico Sound serves a vital role in North Carolina's ecology and economy, but declining water quality threatens the health of this system. Currently, the state of North Carolina does no regular water quality monitoring of the Pamlico Sound so the true condition of the Sound remains unknown. Long-term monitoring is needed to track changes considering the nutrients that enter the Sound as a consequence of land-use change in the watershed. Use of remote sensing in the Pamlico Sound is an ideal way to track phytoplankton changes that occur over a broad range of time and space domains. Remotely sensed data would provide researchers with regular and long-term information that can be used to evaluate the impacts of existing land use and nutrient management programs. Improved information on the Pamlico Sound can help managers create standards aimed at altering human behavior and improving the condition of the Sound. This Masters Project investigates the feasibility of using remote sensing to track water quality in the Pamlico Sound. I conducted interviews with remote sensing experts and North Carolina water quality managers to determine whether remote sensing of the Pamlico Sound will be useful in future water quality monitoring programs. I determined that while water quality managers do not currently have the resources to incorporate remote sensing into existing programs, it is a tool that will be useful and cost effective in future monitoring plans.

Introduction

Coastal and estuarine waters are highly productive and valuable systems. Not only do people rely on coastal systems for food and recreation, but about 50 percent of the population of the United States lives within 50 miles of the coast (Environmental Health Center, 1998). Coastal waters may make up less than ten percent of oceanic systems, but the availability of nutrients make these waters far more productive than the open ocean. One of the many anthropogenic impacts in coastal areas is a decline in water quality. Clean water is necessary for both human and ecosystem health, but water quality has steadily declined due to land-use change in the watershed. Currently North Carolina environmental managers know little about water quality in the Pamlico Sound; studies have concentrated instead on the rivers that feed the Sound. The watershed loads excess nutrients, primarily nitrogen, and sediment from point and non-point sources. While nutrients may be filtered out by the time the water reaches the Sound, a baseline condition should still be developed and monitored over time to ensure that water quality is not declining. Use of remotely sensed data to monitor water quality indicators can provide information with high spatial and temporal range of the Pamlico Sound (Schultz and Engman, 2000).

Why is Clean Water Important?

Life on earth depends on water. Water supports and gives life to all species, plant and animal, and provides the basic framework that allows life to exist—including human life. The human body is over two-thirds water. Water helps supply our body with nutrients and is the most basic component of our cells and organs. Food availability also depends on water. We use water to irrigate crops, to give to livestock, and provide habitat for fish and shellfish (Adler, 1993). Water quality degradation can have negative affects on the functioning of these systems. In coastal systems, poor water quality can lead to fish kills or even changes in community structure (EPA, 2000). According to the North Carolina Division of Coastal Management, "without unpolluted water, the coastal area would no longer provide seafood, recreation activities, and lifestyles that people have increasingly come to enjoy" (Clark, 1990).

The term water quality describes the physical, chemical, thermal, and/or biological properties of water. Regulatory definitions of water quality are based on the intended human use of the water body—fishing, swimming, drinking, recreation. In the United States, the Clean Water Act regulates coastal water management through water quality standards—a combination

of chemical, physical, or biological limits and the intended use of the water body. Each state establishes these standards to ensure that humans can fish and swim in the waters (Adler, 1993; Grigg, 1996). To determine whether the standards are met, researchers must monitor the water bodies on a regular basis.

Government and private sources spend between \$63 and \$65 billion per year to improve and protect water quality (EPA, 2000). Monitoring and assessment are critical to ensure that managers spend this money wisely and that management efforts are improving the condition of our nations' waters. For scientists to determine long-term trends, monitoring efforts must be regular and consistent over long periods of time (Adler, 1993).

According to the 1999 National Estuarine Eutrophication Assessment, seventeen estuaries along the eastern seaboard lacked sufficient data to assess eutrophic conditions based on one of six indicators (chlorophyll *a*, epiphytes, macroalgae, low dissolved oxygen, submerged aquatic vegetation loss, and nuisance toxic blooms). Of these seventeen, the Pamlico and Albemarle Sounds were two of only five estuaries that had insufficient data across all six indicators—and these two estuaries were by far the largest. The Neuse and Pamlico Rivers were considered to have high eutrophic conditions (NOAA, 1999). Considering the interactions of these systems is not fully understood, monitoring is important to ensure that the Sound is not experiencing the same eutrophic conditions. The report also states that basic monitoring and assessment should be conducted for estuaries where there is not enough data.

Background: The Pamlico Sound Watershed

The Pamlico Sound is part of the second largest estuary system in the United States (after the Chesapeake Bay) with a surface area of 3,291 square miles (Paerl et al, 2001). Barrier islands separate the Sound from the Atlantic Ocean making the Sound the largest lagoonal estuary in the nation. Only four inlets allow water exchange with the coastal ocean resulting in a relatively long residence time of about one year. Also, the Sound is relatively shallow with a mean depth of 5 meters (Woodruff et al, 1999). The barrier islands protect the Sound and reduce the impact of tides in the region, resulting in wind driven circulation. The Neuse and Pamlico Rivers drain about a 12,000 square mile watershed and discharge directly into the Sound (U.S. Census, 2000).

The Pamlico Sound region remained relatively unpopulated until the late 1960's, but over the last 40 years, the population of the watershed has risen at a steady rate. In 2000, the

population of the Pamlico Sound watershed was about 2 million people—a 25 percent increase from 1990 (U.S. Census, 2000). This is a much faster than the national population increase of 13 percent and slightly higher than the North Carolina population increase of 21 percent (U.S. Census, 2000). While the watershed may have experienced rapid population growth, this growth has been concentrated in the metropolitan areas (e.g., Raleigh and Durham) (Table 1). The rural areas remain relatively unpopulated—by humans at least. While 10 year projections are not made on a county basis, we can assume that the population in Durham, Orange, and Wake counties will continue to increase steadily.

Table 1. County Population for the Pamlico Sound Watershed

County	2000 Population	1990 Population	% Change	Area (mi ²)	Population Density
Beaufort	44,958	42,283	6.3	828	53.4
Carteret	59,383	52,556	13.3	520	114.2
Craven	91,436	81,613	11.8	708	129.1
Durham	223,314	181,835	22.8	290	770.0
Edgecombe	55,606	56,558	-1.9	505	110.1
Franklin	47,260	36,414	29.8	492	96.1
Granville	48,498	38,345	26.5	531	91.3
Greene	18,974	15,384	23.3	265	71.6
Halifax	57,370	55,516	3.3	725	79.1
Hyde	5,826	5,411	7.7	613	9.5
Johnston	121,965	81,306	50.0	792	154.0
Jones	10,381	9,414	10.9	472	22.0
Lenoir	59,648	57,274	4.1	400	149.1
Nash	87,420	76,677	14.0	540	161.9
Orange	118,227	93,851	26.2	767	295.6
Pamlico	12,934	11,372	13.8	337	38.4
Person	35,623	30,180	18.0	392	90.9
Pitt	133,798	107,924	23.3	652	205.2
Vance	42,954	38,892	10.4	254	169.1
Wake	627,846	423,380	47.3	832	754.6
Warren	19,972	17,265	15.7	429	46.6
Wayne	113,329	104,666	8.3	553	204.9
Wilson	73,814	66,061	11.7	371	199.0
Total	2,110,536	1,686,167	25.2	12,268	

Source: U.S. Census, 2000

While population levels are increasing in the watershed, urban areas only encompass about 5 percent of the area. The primary land uses in the Pamlico Sound watershed are agriculture (~34 percent) and forestry (~32 percent). Water quality degradation in the watershed is caused primarily by these two land uses (NCSU, 2001; NC DEHNR, 1993). Agriculture practices result in nutrient runoff from fertilizers and sediment runoff, which increases water turbidity. Included in the agriculture land use characterization is industrial scale livestock operations. In recent years, the number of hog farms in the state has increased dramatically—from 2.6 million in 1987 to 9.5 million at the beginning of 2002 (NC Department of Agriculture, 2002).

The Pamlico Sound is an invaluable ecosystem rich in flora and fauna that provides essential habitat to young fish, oysters, crab, and clams. The Sound serves as a nursery for finfish and shellfish that grow to support over 90 percent of North Carolina's commercial and 60 percent of its recreational fisheries (Paerl, 2001), and all but one of the ten leading species in North Carolina's commercial fishery are dependent on the estuary for survival (Clark, 1990). It is important to monitor water quality in the region to ensure that it does not degrade to a point where the survival of young finfish and shellfish is threatened.

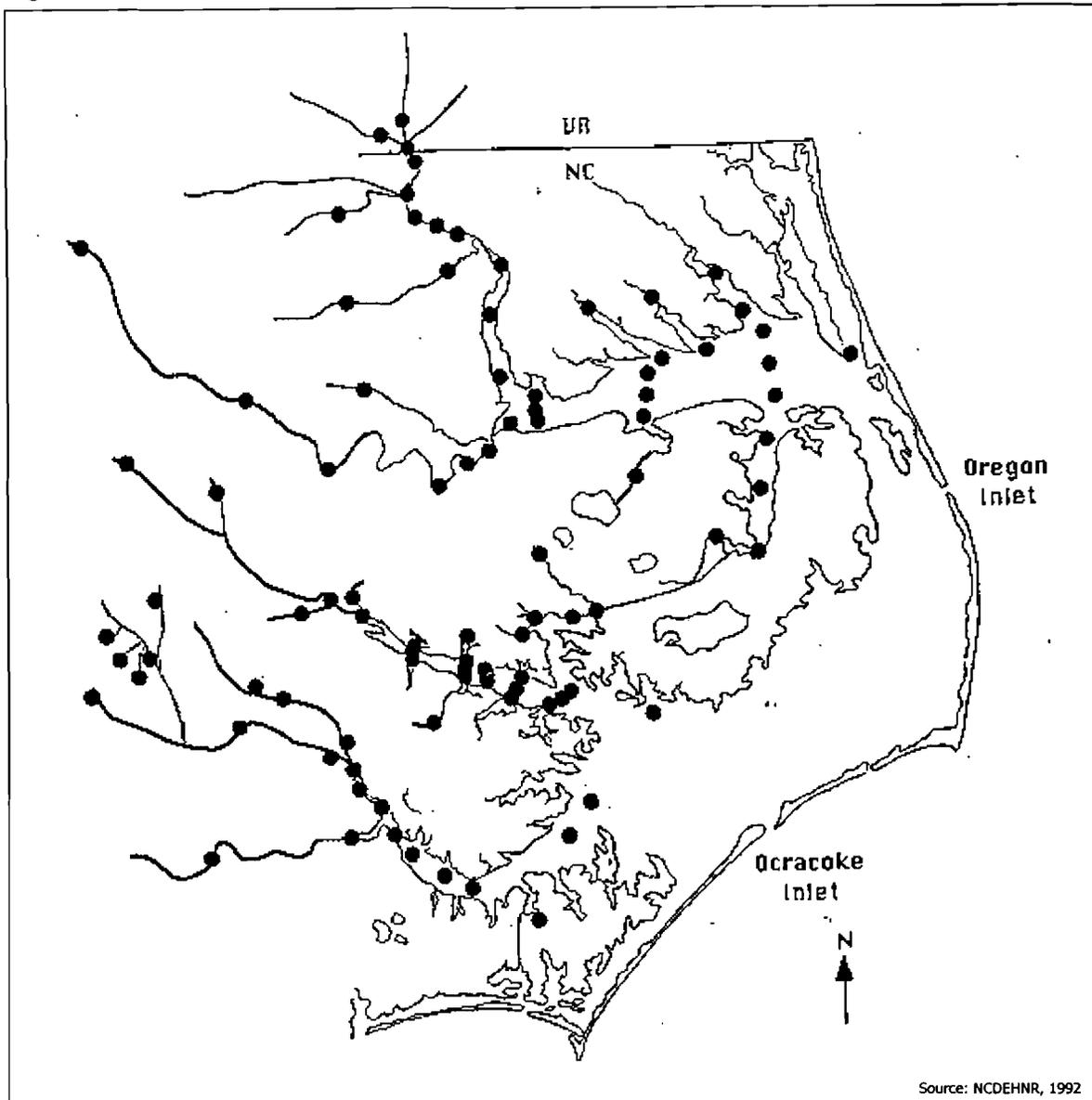
Current Water Quality Sampling

Most of the current sampling programs dealing with the Pamlico Sound region concentrate on the Neuse and Tar-Pamlico Rivers and very few programs have looked at the entire Sound. Many different institutions have sampling programs in the Neuse and Tar-Pamlico watersheds studying water quality, algal blooms, phytoplankton processes, and eutrophication. The state of North Carolina collects samples throughout the water column in the Neuse and Pamlico Rivers on a weekly basis (in conjunction with Eastern Carolina University), but this monitoring ends at the mouth of the rivers (Figure 1). No monitoring is performed on the body of the Sound (Ward, 2002; Roessler, 2002).

Only one program is collecting regular water quality data on the Pamlico Sound. In 2001, Hans Paerl of the UNC Institute of Marine Sciences and Joe Ramus of the Duke University Marine Lab started a project using ferries that regularly traverse the Pamlico Sound to collect water quality data. These ferries are operated by the North Carolina Department of Transportation along fixed routes (Swan Quarter – Ocracoke and Cedar Island – Ocracoke) that cross the entire Sound (Figure 2). Automated water quality monitors were produced and placed on these ferries to record temperature, salinity, pH, dissolved oxygen, and chlorophyll along with latitude and longitude points. Every three minutes this data is transmitted to computers located in the boats' pilot houses. Once a day a cell phone modem downloads this data to a computer at the Duke University Marine Lab in Beaufort. Another automated, refrigerated device collects water samples to be tested for nutrients, algal pigments, nutrients, colored dissolved organic matter (CDOM), and suspended solids. One ferry per route is equipped with monitors and the number of crossings depends on the route (Ramus, 2002).

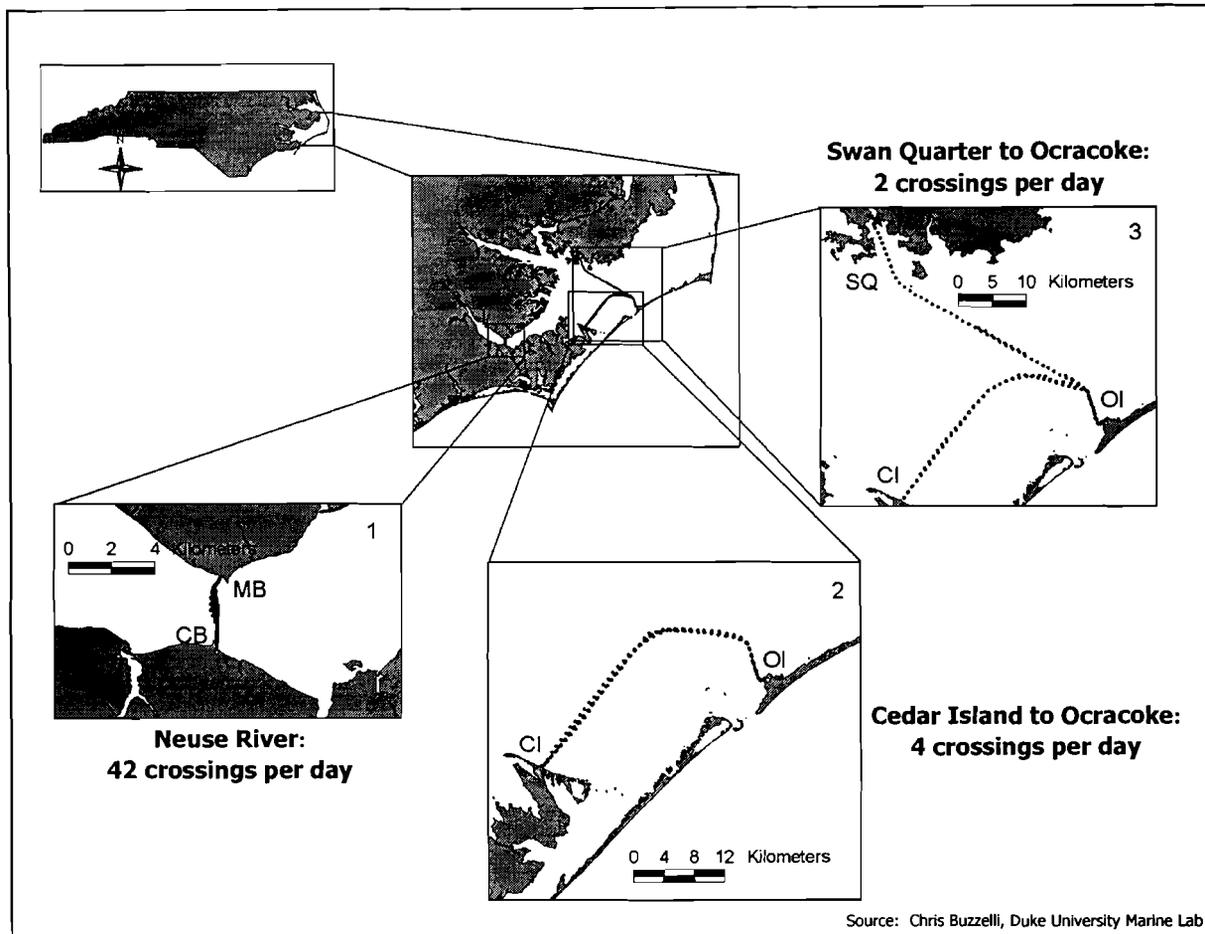
This monitoring program provides ample and continuous data that can be used to determine the status and trends of water quality in the Pamlico Sound. The monitors on the

Figure 1. Ambient Water Quality Stations in the Albemarle-Pamlico Study Area



ferries are relatively low cost and data is provided with relatively little human effort compared to conventional *in situ* monitoring. While this is an ideal means of collecting data on the Sound, this data is only applicable to a narrow band of water and more information is needed to track the condition of the entire Pamlico Sound. Use of remotely sensed data would enable researchers to determine trends over large scales and develop water quality parameters of the entire Sound rather than select areas (Woodruff, 1999).

Figure 2. FerryMon Routes



Water Quality Indicators

The materials affecting water quality in estuaries are suspended sediments, turbidity, chlorophyll concentration, chemicals, nutrients (primarily nitrogen and phosphorous), CDOM, and oils. These materials are traditionally monitored by *in situ* methods, but some can also be monitored by remote sensing, specifically chlorophyll, suspended sediment, CDOM, and oils. (Schultz and Engman, 2000)

Chlorophyll concentration is a proxy metric for phytoplankton biomass (Sathyendranath, 2000). In estuaries, the production of phytoplankton is controlled by a number of factors: availability of nitrogen, availability of light, water residence time, estuary depth and amount of water mixing, and the amount of grazing on phytoplankton by other organisms (Mann, 2000). In the Neuse River, nitrogen availability limits phytoplankton production during most of the year (Paerl et al, 1987). The addition of anthropogenic nitrogen to the system from agriculture and urbanization can lead to increases in phytoplankton production.

This increase in phytoplankton—leading to an increased supply of organic matter—can result in eutrophication of the system. A range of symptoms may be associated with eutrophication such as hypoxia, anoxia, fish kills, and species changes (Nixon, 1995). Remote sensing is one tool that researchers can use to monitor general trends in chlorophyll concentration, and therefore phytoplankton biomass, over a broader area to track changes in the system.

Addition of sediment to coastal water bodies can also be monitored by remote sensors. Sediment flux to the Pamlico Sound watershed has increased due to agricultural practices, forestry, and urban development. Greater amounts of suspended sediment increase the turbidity of coastal waters and reduce the depth of light penetration. This may inhibit growth of seagrasses and phytoplankton (Ongley, 1996).

Remote Sensing of Water Quality

Remote sensing is a group of techniques for getting information from a distance and then analyzing this data (Schultz and Engman, 2000). Remote sensing has many valuable environmental applications including monitoring natural events such as hurricanes and flooding and tracking oil spills and sea ice quantity. In the coastal environment, researchers can use remote sensing to track land use change, shoreline movement, soil erosion, and water quality parameters (Schultz and Engman, 2000). Suspended sediment, chlorophyll, CDOM, and oil produce visible changes in the optical properties of water. These visible changes are noticeable in the radiation reflected from the surface water. Remote sensing platforms record these changes in the spectral signature of the water-leaving radiation of the water body (Schultz and Engman, 2000). This type of remote sensing is called ocean color analysis—measuring the optical changes in the ocean to determine biological activity (Canadian Centre for Remote Sensing, 2002).

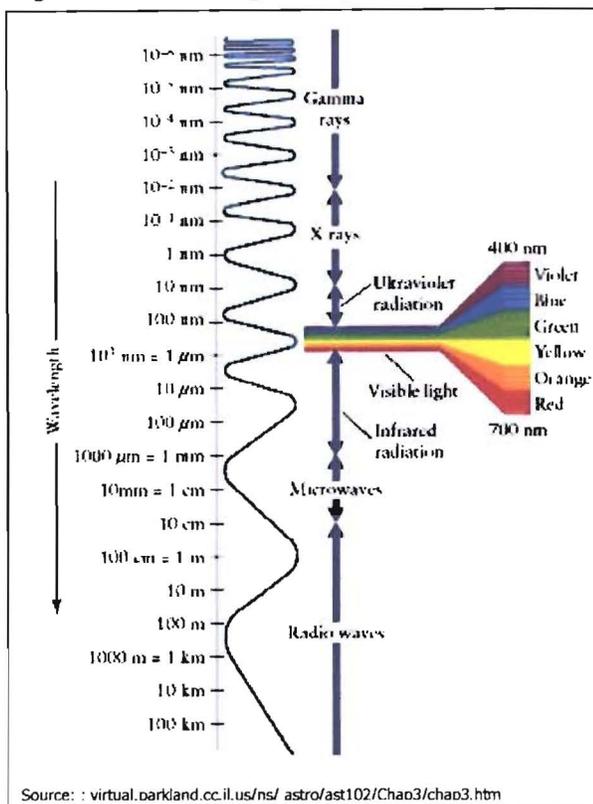
To collect data via remote sensing methods, an energy source is needed to illuminate the target in the form of electromagnetic radiation. When radiation is emitted from the energy source (the sun or a radar system) it must travel through the atmosphere. Some of the radiation will be absorbed, transmitted, or reflected by the atmosphere, but the rest will reach and interact with the earth's surface. The energy not absorbed will be reflected by the water depending on the materials in the water. The reflected radiation will travel back up through the atmosphere where

sensors in the satellite record the light flux. The data is then transmitted in a digital format to receiving stations on earth (Canadian Centre for Remote Sensing, 2002).

Ocean color remote sensing uses visible and infrared wavelengths. The visible spectrum—what our eyes detect—covers a very small portion of the entire electromagnetic spectrum (Figure 3). The longest wavelength is red (to 700 nm) and the shortest wavelength is violet (to 400 nm) (Canadian Centre for Remote Sensing, 2002).

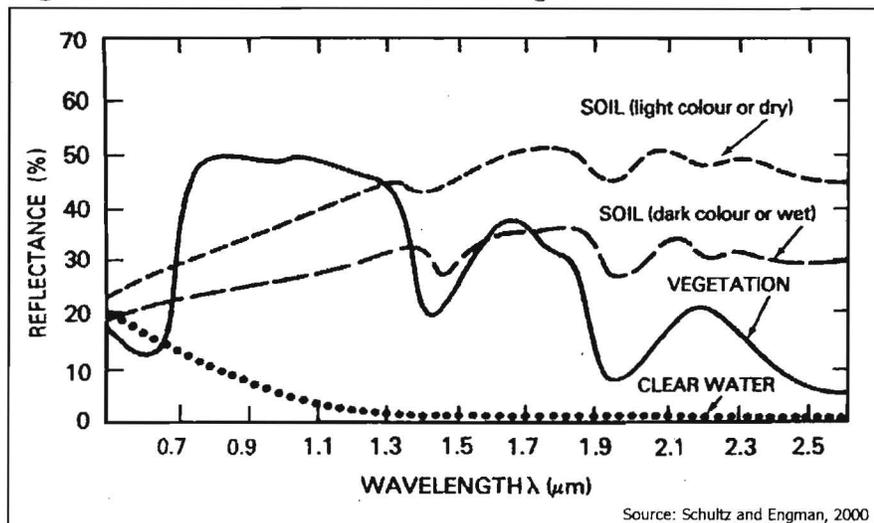
Different earth materials have their own unique reflectance value called a spectral signature. Figure 4 illustrates the spectral signatures for light and dark soil, vegetation, and clear water. At each wavelength, a land feature of interest can be distinguished from other land features (Schultz and Engman, 2000). If the substance is not reflecting the wavelength, then the wavelength is being absorbed. One example of this is chlorophyll in trees. Chlorophyll absorbs red and blue wavelengths but reflects green wavelengths. This is why leaves are green in

Figure 3. Electromagnetic Spectrum



Source: virtual.darkland.cc.il.us/ns/astro/ast102/Chap3/chap3.htm

Figure 4. Relative Reflectances of Earth Targets



Source: Schultz and Engman, 2000

summer when the chlorophyll content is highest. There is less chlorophyll in the leaves in autumn and more red wavelengths are reflected (Canadian Centre for Remote Sensing, 2002).

The same is true in the ocean where chlorophyll in phytoplankton absorbs

red light, resulting in the blue-green color of the ocean. Phytoplankton are abundant in coastal waters, along with suspended sediment and CDOM.

Remote sensing of coastal waters can be conducted using either passive or active sensing. Passive remote sensing uses energy from the sun that is reflected off the earth's surface. These sensors can only be used during daylight hours when the sun illuminates the earth. Passive sensors are housed in satellites orbiting the earth and data is made available to researchers. Several satellites carry sensors that monitor ocean color and more sensors are being launched that have the spectral bands to detect the wavelengths we are concerned with in coastal waters. Active remote sensing uses radiation emitted from an energy source to investigate a target. While active sensors can provide data at any time of the day or night and may provide better control in illuminating a target, these sensors are more expensive because they are housed in aircraft and overflights of the area of concern must be planned. (Canadian Centre for Remote Sensing, 2002)

Remote sensing of ocean areas is different from remote sensing of land areas. To analyze remotely sensed ocean color data, researchers must understand the optical properties of the water body being studied. Ocean and coastal waters contain varying amounts of dissolved and particulate matter that effect the optical properties and change in both space and time. Oceanic waters can be classified as case 1 or case 2 waters as defined by Morel and Prier (1977) and later refined by Gored and Morel (1983). The classification depends on whether the waters contain primarily phytoplankton, or a mix of phytoplankton, suspended sediment, and CDOM. Case 1 waters consist primarily of phytoplankton and while substances other than phytoplankton can be found in case 1 waters, they are not found at a high enough concentration to alter the optical properties significantly. Case 2 waters consist of other substances, predominantly inorganic suspended sediment and CDOM, that vary independent of the concentration of phytoplankton. These waters are more optically complex than case 1 waters, which has made interpretation of remote sensing data more difficult in coastal areas. These substances impact the amount of scattering, absorption, and refraction that occur and algorithms must be developed to take this into account. (IOCCG, 2000)

Historically, remote sensing of ocean color has concentrated on case 1 waters since it is not as difficult to develop an algorithm. Also, one algorithm can apply to all or most case 1 waters while algorithms for case 2 waters may need to be location specific. While case 1 waters make up 90 percent of the world water bodies, case 2 waters usually contain important breeding grounds and the health of these waters is vital. (IOCCG, 2000)

To analyze remotely sensed data, researchers must develop algorithms to account for both atmospheric correction and oceanic constituents. Algorithm development for case 1 waters is relatively simple. The algorithms can use chlorophyll-*a* concentrations alone to determine phytoplankton amount; atmospheric correction algorithms are simple since the water-leaving radiance of case 1 waters approaches zero in the near infrared wavelengths (IOCCG, 2000). In case 2 waters, the water-leaving radiance in the near infrared can be high due to the additional substances. Algorithms for case 2 waters must take into account several additional issues:

- Increased water-leaving radiance because of high scattering from suspended sediment.
- The possibility of bottom reflectance affecting the signal.
- The need for additional wavebands in the ocean-color satellite in order to distinguish between the substances of interest. (IOCCG, 2000)

Two basic methods are used to determine the relationship between radiance and the actual concentration of substances in the water: analytical and empirical. The empirical approach uses statistical relationships between the spectral properties (based on optical measurements) and measured water quality parameters (from *in situ* measurements). Empirical equations usually follow the form:

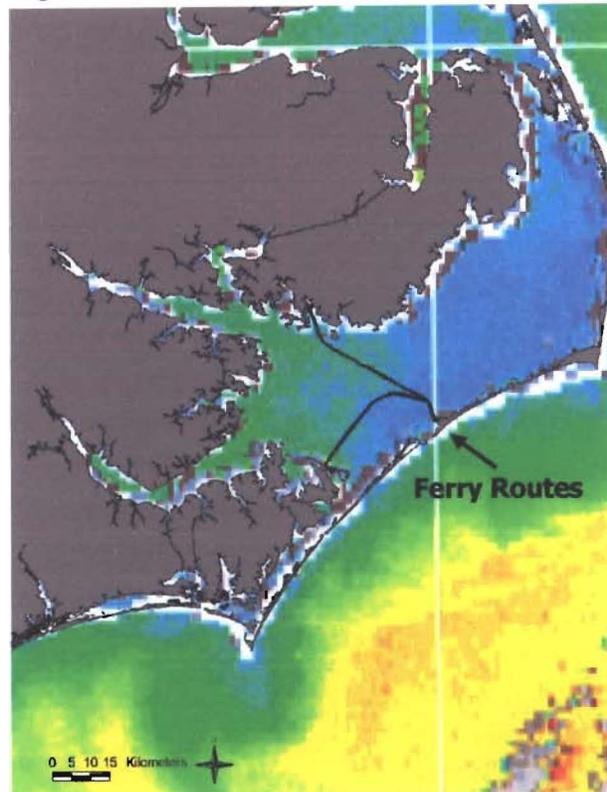
$$Y = A + BX \quad \text{or} \quad Y = AB^X$$

In this equation, Y is the measured radiance, X is the water quality parameter of interest (chlorophyll, suspended sediment, CDOM), and A and B are empirical factors that are modified based on the interactions between the water quality parameter and the optical properties. These algorithms are specific and must be altered to fit individual coastal water bodies (Schultz and Engman, 2000).

The analytical (or model-based) approach uses "bio-optical models to describe the relationship between water constituents and spectra of water-leaving radiance and reflectance, as well as radiative-transfer models to stimulate the light propagation through the water and the atmosphere" (IOCCG, 2000). Modeled information is used to develop the algorithm using a variety of mathematic principles.

Scientists need to measure the optical properties of the Pamlico Sound so that reflectance, downwelling irradiance, and upwelling radiance can be calculated. If these properties are not determined and accounted for when analyzing the remotely sensed data, the information obtained from the data can be incorrect (Woodruff et al, 1999). "Remote sensing studies of chlorophyll in water are based on empirical relationships between radiance/reflectance in narrow bands or band ratios and chlorophyll. Thus, field data must be collected to calibrate the statistical relationship or to validate models developed" (Schultz and Engman, 2000). Water samples must be collected at the same time as a satellite overpass to ground truth the satellite images and calibrate the algorithms. This is where a program like FerryMon becomes very useful. FerryMon already collects the water quality data necessary to calibrate the remote sensing data, specifically chlorophyll, suspended sediment, and CDOM. To obtain the water quality samples, researchers must time a sampling trip for the same time as a satellite fly-over and hope for a sunny day—images cannot be obtained on cloudy days. This makes FerryMon even more useful because the ferries are running every day and a global positioning system pinpoints where the water samples are collected along the ferry route.

Figure 4. Sample SeaWiFS Image



Source: SeaWiFS sensor, 10-29-99

Current Satellite Sensors

Many satellites carrying ocean color sensors orbit the earth. These sensors belong to different countries, but the data is available to anyone for research purposes. Remote sensing technology is constantly improving and the newer sensors have more spectral bands than those launched five years ago. The additional spectral bands, specifically for ocean color, makes it easier for researchers to differentiate between chlorophyll, suspended sediment, and CDOM (Canadian Centre for Remote Sensing, 2002). Table 2 details the satellites currently in orbit.

The sensors most useful for ocean color measurements have the finest spatial resolution (pixel size) and the highest number of bands in the visible and infrared wavelengths.

Table 2. Ocean Color Sensors

Sensor	Country	Satellite	Launch Date	Swath (km)	Resolution (m)	# of Bands	Spatial Coverage (nm)
MOS	Germany	IRS PS (India)	3/21/96	200	500	18	408-1600
SeaWiFS	USA	OrbView-2 (USA)	8/1/97	2806	1100	8	402-885
OCI	Japan	ROCSAT-1 (Taiwan)	1/99	690	825	6	433-12,500
OCM	India	IRS-P4 (India)	5/26/99	1420	350	8	402-885
MODIS	USA	Terra (USA)	12/18/99	2330	1000	36	405-14385
MISR	USA	Terra (USA)	12/18/99	360	250	4	446-867
OSMI	Korea	KOMPSAT (Korea)	12/20/99	800	850	6	400-900
MERIS	Europe	ENVISAT-1 (Europe)	3/1/02	1150	300/1200	15	412-1050

Source: www.ioccg.org

Ocean Color Sensor Acronyms	
MOS	Multispectral Ocean Color Scanner
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
OCI	Ocean Color Imager
OCM	Ocean Color Monitor
MODIS	Moderate Resolution Imaging Spectroradiometer
MISR	Multi-angle Imaging Spectroradiometer
OSMI	Ocean Scanning Multispectral Imager
MERIS	Medium Resolution Imaging Spectrometer

Water Quality Policy

Clean water legislation in the United States developed out of the historical context of using common law doctrine to solve water quality disputes (Norris, 1994). The institutional and legislative framework that developed out of this context did not place many restrictions on individual water users and disputes were handled in courts. This resulted in a very reactive rather than proactive process as disputes were handled after the pollution had already occurred. As a need was recognized for more structure to water quality management, Congress and states developed statutes to address water quality management (Norris, 1994).

In the past, water quality was considered the responsibility of states and there was no comprehensive federal legislation to address the issue until the Water Pollution Control Act of

1948. This law insured that states kept responsibility for water quality control, but that the federal government had authority to do research and conduct surveys (Norris, 1994). From 1945 to 1965 Congress enacted several laws to regulate water pollution including providing federal assistance to the construction of wastewater treatment plants. During this time there was a growing realization that the nations' waters were seriously polluted and that this degradation was harming both human and ecological health (Norris, 1994). In 1965, Congress enacted the Water Quality Act requiring states to develop pollution standards and creating the Federal Water Pollution Control Administration, which became part of the Environmental Protection Agency (EPA) when it was formed in 1969 (Grigg, 1996). The Water Quality Act preceded the Federal Water Pollution Control Act (the Clean Water Act) of 1972. The Clean Water Act is now the primary piece of federal legislation mandating the improvement of water quality in the United States. The objectives of the law are the "restoration and maintenance of (the) chemical, physical and biological integrity of (the) Nation's waters" (33 USC 26). The act also included specific goals:

- That the discharge of pollutants into the navigable waters be eliminated by 1985
- That wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983
- That the discharge of toxic pollutants in toxic amounts be prohibited
- That federal financial assistance be provided to construct publicly owned waste treatment works. (33 USC 26)

To achieve these goals, EPA has concentrated on reducing point source pollution using command and control regulations and water quality standards. EPA develops national water quality criteria that states must then use to establish standards for different water bodies while recognizing the unique characteristics of these water bodies (Grigg, 1996). The state sets standards to ensure that the existing use of these waters is maintained. The Clean Water Act uses a uniform system of technology-based effluent limits for point source polluters that relies on the National Pollutant Discharge Elimination System to impose controls and effluent limits (Healy, 1997). EPA gives point source polluters a permit that limits the amount of pollution that can be discharged based on the technological capability of the polluter. The law also required states to prepare water quality assessments every two years to track progress and trends in water quality (Grigg, 1996).

Congress amended the Clean Water Act in 1977, 1982, and 1987. The most important of these amendments, the Water Quality Act of 1987, required states to develop non-point source pollution management programs. While the Clean Water Act has been successful at reducing the amount of point source pollution, non-point source pollution has been harder to deal with and as a result, pollution reductions have not been as noticeable (Sohngen, 1998). Many bodies of water still do not meet water quality standards due primarily to non-point source pollutants. As a result, the original goals of the Clean Water Act have not been met (Healy, 1997). The Clean Water Act should be reauthorized every five years, but it currently has not been reauthorized since 1987. Congress has passed specific bills amending portions of the Act, but there has been no comprehensive reauthorization. This has been due to many disagreements on an effective and economical way of regulating water pollution in the United States.

Originally, North Carolina regulations emphasized building wastewater treatment plants to improve water quality and Bond Acts were used to raise money for the facilities. Now emphasis is expanding to reduce non-point source pollution since much of the water quality pollution is due to non-point sources, especially in the Pamlico Sound watershed (Gannon, 2001). One standard important for remote sensing uses is the state chlorophyll-*a* standard of 40 µg/l. This standard states that chlorophyll-*a* should "not (be) greater than 40 µg/l in sounds, estuaries, and other slow-moving waters" (NC Administrative Code Section 15A NCAC 2B.0212). Once a water body surpasses this point, regulators should consider developing a total maximum daily load for that water body. The North Carolina Environmental Management Commission adopted this standard on August 9, 1979 based on research done by scientists at the Water Resources-Research Institute. The proposed standard did not include directions on sampling method or the definition of what exactly constitutes a violation. The chlorophyll standard is used as an indicator of water quality problems rather than an inflexible threshold (WRRRI, 2001).

Water Quality Management Structure

In North Carolina, the Governor appoints the Secretaries of the State agencies and the General Assembly has the authority to make laws and policy. The General Assembly is strong compared to legislative bodies in some other states because the laws it enacts are final and are not subject to gubernatorial veto. The North Carolina General Assembly is a "citizen's legislature" (Fleer, 1994). This means that the members take time off from their professions to

serve as legislators. The General Assembly is only in session for part of the year, although there is not statutory requirement for when a session must end (NCGA, 2001). Due to the reduced period of time the Assembly is in session, Commissions are used to research public policy issues and frame legislative proposals (Fleer, 1994). The General Assembly delegated rulemaking authority to the Commissions to develop new regulations and standards. The most important Commissions with regards to water quality are the Environmental Management Commission, the Soil and Water Conservation Commission, and the Coastal Resources Commission. The Commissions work closely with state agencies to write legislation that the agencies will then administer (Norris, 1994).

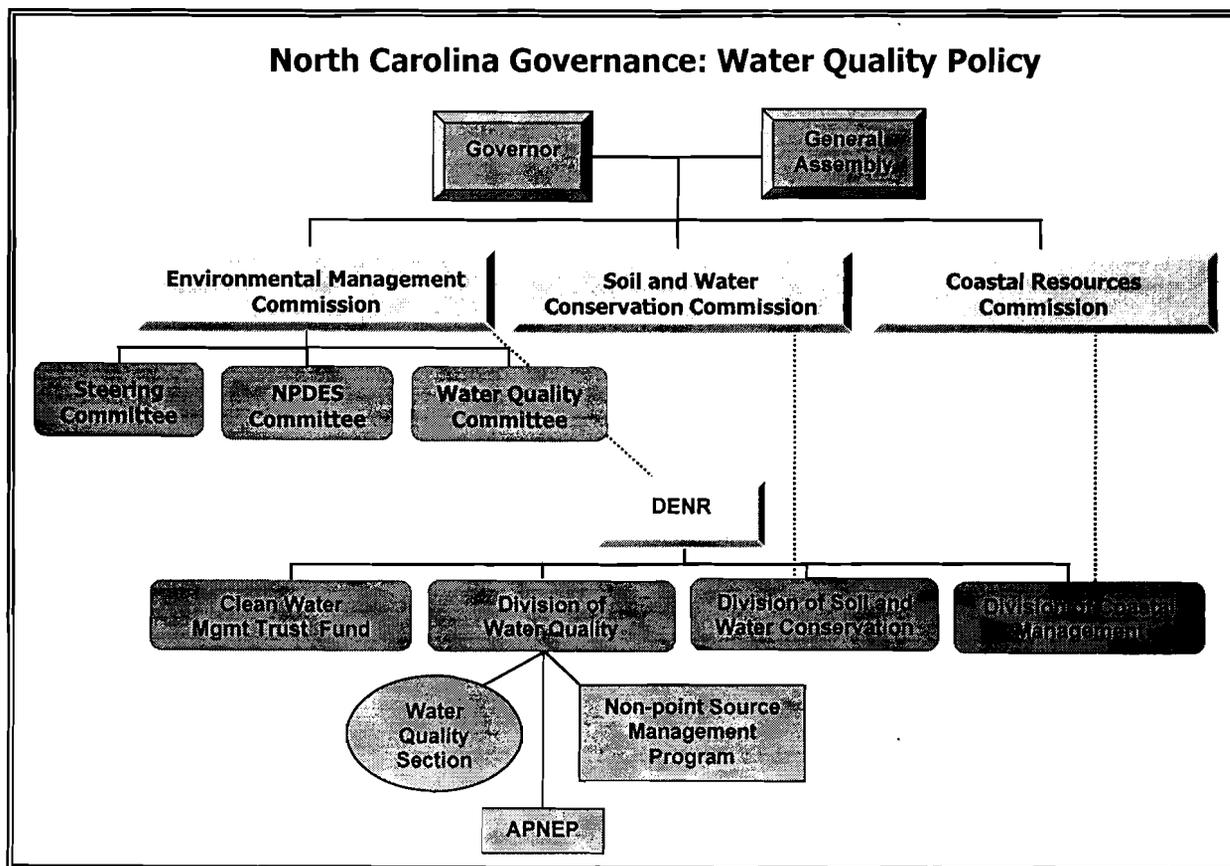
The Governor, the Senate Pro Tempore, and the Speaker of the House appoint the seventeen of the members Environmental Management Commission. The members represent various groups interested in environmental management, including a representative from the public. "The Commission is responsible for adopting rules for the protection, preservation, and enhancement of the State's air and water resources" (NC DENR, 2001). Within the Commission there are three Committees that are important, the Steering, Water Quality, and NPDES Committees. The most directly related is the Water Quality Committee that develops water quality classifications and standards. These classifications must be approved by EPA and must also be subject to a public hearing in order to be altered. The Soil and Water Commission writes regulations that will be implemented by the Division of Soil and Water Conservation and the Coastal Resources Commission writes regulations that will be implemented by the Division of Coastal Management (NC DENR, 2001).

State agencies implement the regulations that the Commissions have developed and in North Carolina, the Department of Environment and Natural Resources (DENR) is the lead stewardship agency responsible for preserving water quality. There are many Divisions within DENR, the most germane to this discussion are the Division of Water Quality (DWQ), the Division of Soil and Water Conservation, and the Division of Coastal Management. The DWQ is responsible for ground and surface water regulatory programs. The Water Quality Section within DWQ is responsible for developing water quality classifications and standards, issuing permits, and handling enforcement and compliance of those permits. This section deals primarily with point source polluters. Also within in the DWQ is the Non-Point Source Unit. This group is working to coalesce existing non-point source reduction efforts within both DENR and the entire state. This group is also involved in the preparation of the Non-Point Source

Management Plan that each state must prepare under the 1987 Clean Water Act Amendments (NC DWQ, 2001).

To provide funding for water quality improvement projects, the General Assembly established the Clean Water Management Trust Fund in 1996. This fund receives a minimum of \$30 million at the end of each fiscal year to be allocated as grants to help finance water quality improvement projects. A board of trustees has responsibility for allocating the funds with advice from an Advisory Council composed of the Commissioner of Agriculture, the Chair of the Wildlife Resources Commission, the Secretary of the Department of Environment and Natural Resources, and the Secretary of the Department of Commerce (CWMTF, 2001).

The Division of Soil and Water Conservation and the Division of Coastal Management deal with specific issues related to water quality. The Division of Soil and Water Conservation administers a program to protect and conserve soil and water including non-point source pollution management. The Division of Coastal Management supports the coastal non-point source pollution control program as required by the 1990 amendments to the Coastal Zone Management Act. The Governor designated certain non-point source management



responsibilities to specific agencies, with the DWQ serving as the facilitator. The responsibilities are as follows:

- The Environmental Management Commission for general water quality, urban runoff, wetlands and groundwater
- The Soil and Water Conservation Commission for agriculture
- The Sedimentation Commission for construction
- The Mining Commission for mining
- The Division of Environmental Health for on-site wastewater treatment and solid waste disposal
- The Division of Forest Resources for forestry
- The Department of Transportation for transportation
- The North Carolina Cooperative Extension Service for Education. (NC DWQ, 2001)

While the policies, plans, and programs are in place to deal with non-point source pollution, coordination among the different players is still not occurring and as a result money is not being spent on the most worthwhile projects. North Carolina developed a non-point source pollution plan, but the funding and the staff are not available to effectively implement the plan and manage the program (Gannon, 2001).

North Carolina is trying innovative water quality pollution programs and has implemented a nutrient trading program for nitrogen and phosphorous in the Tar-Pamlico River watershed. This program organizes point source polluters into a group called the Association. The amount of pollution allowed by the Association is determined by the state based on total maximum daily loads for the watershed (NC DWQ, 2001). Association members are free to allocate allowances amongst themselves in a way that is economically beneficial. If the Association is not able to achieve discharge levels amongst themselves, they can pay to implement Best Management Practices at agricultural enterprises in the watershed to offset their discharges (Gannon, 2001). Trades are arranged by the North Carolina Division of Soil and Water Conservation through an agricultural cost share program (Sohnngen, 1998). To date, the Association has not exceeded discharge caps even though the watershed has experienced economic growth and development (Stephenson, 2001). This program has helped reduce nitrogen and phosphorous in the watershed, yet these nutrients are not currently included in the permit program although they are often the cause of algal blooms and other water problems.

North Carolina is involved in another watershed management program. The Albemarle-Pamlico Estuary System is part of the National Estuary Program. This program examines a wide range of issues and attempts to bring many players into the problem solving and decision making process. Water quality management is one part of the problem for the system and is addressed in the management plan. The Albemarle-Pamlico National Estuary Program (APNEP) Baseline Water Quality Monitoring program has stations spread throughout the rivers, streams, and sounds of the Albemarle-Pamlico region (Figure 1). This is the North Carolina Division of Environmental Management's baseline water quality monitoring component of the Albemarle-Pamlico Estuary System water quality monitoring network. Data on ambient temperature, salinity, dissolved oxygen, pH, nutrients, coliform, and phytoplankton density are measured throughout the water column on a weekly basis (Ward, 2002). Water Quality Management Action 6 calls for continued, long-term monitoring (APNEP, 2001). The program monitors the rest of the watershed and monitoring of the Sound should be considered. By not monitoring the Sounds, the affects of nutrient loads from the tributaries remains unknown. This program has been a means of bringing experts from a wide range of fields to the table to discuss the status of the system and determine a management plan for the future. As with the non-point source pollution program, the program has not accomplished as much as managers desire due to insufficient funding and staffing (Gannon, 2001).

There have been mixed reviews on whether the Clean Water Act has been successful at improving the nations' water quality. Many critics claim that there is no uniform means of tracking improvement and data from state to state is inconsistent. Also, within a state there is not necessarily a sufficiently rigorous database to determine if water quality has really improved. In North Carolina, there is a different story depending on which organization or publication you consult. The EPA water quality inventory states that 94 percent of the estuaries and sounds in the state are fully supporting designated uses (EPA, 1998). A report prepared by the General Accounting Office states that the EPA inventory is unreliable due to poor and insufficient data acquisition and management so conditions may be much worse than the report cites (GAO, 2000).

Methods

To determine whether remote sensing of the Pamlico Sound is a practical means of tracking water quality, I conducted telephone interviews the following individuals:

- Tom Jones, Clean Water Management Trust Fund (February 19, 2002)
- Chris Roessler, NC Division of Water Quality, Planning Section (February 21, 2002)
- David Eslinger, NOAA Coastal Services Center (March 26, 2002)
- Garcy Ward, Tar-Pamlico Rapid Response Team (April 23, 2002)
- Darlene Kucken, NC Division of Water Quality, APNEP Contact (April 23, 2002)

I asked the respondents about current monitoring programs in the Sound or watershed and asked if the addition of remote sensing data would be useful to their management efforts. If the respondents were unfamiliar with the possibilities of remote sensing, I gave them some background on what data could be obtained. I also discussed the technical aspects of coastal remote sensing with Pat Tester of the National Oceanic and Atmospheric Administration and Dr. Larry Harding from the University of Maryland, Horn Point Laboratory. I communicated with these individuals over the course of the year in person or through email.

Results

Representatives from the Division of Water Quality stated that the resources are not available to track water quality in the main body of the Sound. They also commented that water quality is not an issue on the Sound, leaving little incentive to set aside funds for monitoring. The respondents claimed that water quality is not an issue because the nutrients are causing algal blooms in the tributaries to the Sound are filtered before reaching the Sound. As a result, they assume that water quality in the Sound has not been sufficiently altered. The respondents also questioned the accuracy of remotely sensed chlorophyll data and noted that, before it could be used for management purposes, the data would have to undergo intense quality control (Roessler, 2002).

The representative from the NOAA Coastal Service Center said that their office has been working with the New Jersey Department of Environmental Protection and the Bureau of Marine Water Monitoring on a similar project. New Jersey is interested in monitoring the health of its inland bays and this pilot study will help determine if remote sensing can be used to monitor water quality. Researchers are interested in tracking chlorophyll concentrations, salinity,

temperature, and nutrient concentrations—the same parameters that would be tracked in the Pamlico Sound. Due to issues of spatial and temporal scaling, airplane sensors are used more than satellite sensors, but this increases the cost of remote sensing (NOAA CSC, 2002). The representative from the Coastal Services Center noted that there have been many difficulties in convincing New Jersey water quality managers that remote sensing is a useful tool for tracking specific water quality parameters—hopefully successful water quality monitoring through remote sensing will silence the doubters (Eslinger, 2002). If the project is successful, it should help convince other states, such as North Carolina, that remote sensing can be a useful tool for water quality management.

University of Maryland researchers are working with NOAA, the National Science Foundation, the National Air and Space Administration, and the EPA to track chlorophyll through active remote sensing of the Chesapeake Bay. The program has been collecting data for ten years and produces a report every year on the phytoplankton conditions in the Bay. Researchers have been able to improve chlorophyll algorithms and have been successful in tracking phytoplankton concentrations and dynamics using remote sensing. (Chesapeake Bay Remote Sensing Program, 2002)

I also collected rough estimates on the costs of conventional monitoring of the Pamlico Sound and the FerryMon program (Table 2). The conventional monitoring costs are for biweekly monitoring cruises. The FerryMon costs take into account equipment and analysis costs. Satellite imagery is free for research purposes, for which water quality monitoring qualifies. Although the yearly costs of conventional monitoring and FerryMon are very close, Ferrymon is collecting data every day while conventional monitoring only collects data once every other week. This make FerryMon far more cost effective, and for remote sensing purposes, specific trips would not have to be planned to coincide with satellite fly-overs.

Table 2. Cost for Biweekly Sampling of the Pamlico Sound

	Cost/Year	Cost/Day*	Cost/Month
Lab Tech/ Data Analyzer	\$52,800.00	\$203.08	\$1,218.46
Boat Use	\$38,400.00	\$1,600.00	\$3,200.00
Equipment	\$1,000.00	\$3.85	\$15.38
Total Conventional Monitoring	\$92,200.00		\$4,433.85
FerryMon	\$100,000.00	\$384.62	\$8,333.33

*Based on a 260 day work year

Discussion

Remote sensing of the Pamlico Sound can be used to monitor water quality in the Pamlico Sound. For this tool to be used by water quality managers, the algorithms must be developed and remote sensing data must be regularly used by researchers to ensure that the data obtained is accurate. The state of North Carolina is not monitoring the Pamlico Sound primarily due to lack of funds. Since water quality is a more serious issue in other water bodies, that is where the money is spent. While this may be the case, because the Sound is such an important body of water, some kind of monitoring should be done to create a water quality baseline so that future changes can be noted. "Monitoring and assessing the quality of waters in stream, reservoirs, lakes, estuaries, and oceans are critical for managing and improving the quality of the environment" (Schultz and Engman, 2000). Remote sensing is also useful for studying the dynamics of the system on a large scale. Because current monitoring only has data for individual points, it is harder to understand system wide interactions.

Remote sensing technology is continually improving. Not only are the sensors improving, but the algorithms to analyze the data produced are constantly becoming more accurate. Pamlico Sound researchers can build upon lessons learned from remote sensing of the Chesapeake Bay watershed and the New Jersey bays to help develop accurate algorithms to track phytoplankton processes and improve current information about the Sound. The constant data from the FerryMon project makes development of remote sensing algorithms easier because researchers do not have to plan separate trips into the Sound at the same time as a satellite passover to obtain ground truthing data. The samples are already collected and researchers do not have to pay for the satellite images. The greatest cost for remote sensing would be personnel costs for algorithm development and data analysis.

Conclusions

While a direct link cannot be made to increases on chlorophyll content and changes in nutrient loadings, remote sensing is still a useful tool for water quality management of the Pamlico Sound. The greater spatial context of chlorophyll concentrations and suspended sediment amount can be useful to direct monitoring efforts. Remote sensing data may also be able to help in refining existing management plans. This data could also help determine TMDLs for Neuse and Pamlico Rivers. Chlorophyll concentrations from remotely sensed data could serve as a "heads up" for areas where the chlorophyll concentration reaches 40 µg/l.

Not considering other arguments, it is important to start monitoring the Sound so that in the future, managers and scientists can determine if the environmental condition of the Sound is improving or degrading. Monitoring is necessary to provide a baseline to compare future data to and to help in future decision making. Remote sensing is the most cost effective means of getting general data on the Sound to make these management decisions.

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