I INTRODUCTION AND BACKGROUND

Written by

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A. THE STUDY

A. 1. Background

During the last decade, the U. S. Environmental Protection Agency has directed its attention to "management conferences" on estuaries of national concern. This concern became necessary in response to public perception that some of the nation's prominent estuaries were in stages of decline in spite of a plethora of laws and regulations enacted in the 1970's to protect them. Chesapeake Bay, Maryland and Virginia, was the first so designated. Later, Narragansett Bay, Rhode Island, Buzzards Bay, Massachusetts, Long Island Sound, New York, Puget Sound, Washington, and San Francisco Bay, California, were added to the list. The Albemarle-Pamlico Estuarine System of North Carolina was designated in 1987. A series of activities were initiated to culminate, in 1992, with a comprehensive management plan to more effectively manage the system to reverse the perceived trend of degradation. This technical report is a preliminary analysis of status and trends that will serve as the precursor for development of the comprehensive management plan.

Estuarine management is the responsibility of all, but the actual management requires good technical information and a public that understands the system, its problems and issues. Such understanding forms the basis for long-term commitment and development of support for specific management strategies. Considerable technical knowledge about estuaries exists in publications, reports and the scientific community of state, federal and private organizations. In addition, new information is being generated by studies supported by the Albemarle-Pamlico Estuarine Study. Only limited efforts have been undertaken to synthesize and integrate this knowledge into a comprehensive report.

The Albemarle-Pamlico Estuarine Study Policy Committee (on 15 August 1986) resolved that:

> The goal of the Albemarle-Pamlico project will be to provide the scientific knowledge and public awareness needed to make rational management decisions so that the Albemarle-Pamlico Estuarine System can continue to supply citizens with natural resources, recreational opportunities and aesthetic enjoyment.
>
> The objectives of the project will include, but are not limited to, generating understanding of what is needed to maintain, and where necessary restore, the chemical, physical and biological integrity of the estuary, the wildlife habitat of the estuary, and the production levels of recreational and commercial fisheries of the estuary.

This report is the starting point for achieving the goals and objectives of the Albemarle-Pamlico Estuarine Study.

A. 2. Purpose of the Study

This report is an attempt to synthesize the existing information about the Albemarle-Pamlico Estuarine System and to assess the status and trends of probable causes apparent in the system. This exercise will establish the precursor to the development of a comprehensive management plan for the Albemarle-Pamlico Estuarine System. Technical documents resulting from the analysis of each segment of this study will be summarized in a general interest document suitable for public use.

The overall goal of this project is to provide agencies, scientists and the public with an integrated packet of information describing the state of knowledge of the Albemarle-Pamlico Estuarine System. It is intended that a second publication will summarize this more technical version for general interests. Specific objectives, therefore, are:

1. To develop an outline for each of the key issues of Critical Areas (Chapter II), Water Quality (Chapter III), Fisheries Dynamics (Chapter IV) and Human Environment (Chapter V), and set up a mechanism for analysis and summarization;

2. To direct the attention of an organized group of the state's top experts in each area to develop a consensus of the status of each;

3. To generate a narrative of the status and trends, including an analysis of probable causes, of the four key areas and test the conclusions against technical experts, organizations and leaders of public opinion; and

4. To publish the current information in a technical document that can later be used to develop a final "Status and Trends Report" and to create a general interest summary for public use.

A. 3. Limitations of the Study

This exercise was approached through a series of work sessions in which the experts available provided their ideas about the status and trends of issues facing the estuary. Data files available to and utilized by these experts form the basis for the technical analyses. Technical quality was emphasized more than completeness–i.e., it was concluded that it is far better to relate an accurate picture than to include every shred of data that has ever been collected.

It should be emphasized that the content of this report is a "preliminary technical analysis" of the status and trends. It will serve as the base from which a concentrated and extensive analysis of status and trends will be developed during the fourth year of the study. Subsequently, a comprehensive management plan will be developed from the status and trends analysis.

A large limitation was the constraint of time compared to the magnitude of the task of analyzing status and trends. Besides, the analysis of status and trends should and will involve the input of all strata of interests in Albemarle-Pamlico Estuarine System.

B. THE SETTING

B. 1. Geography and Boundaries

The Albemarle-Pamlico Estuarine System (A/P System) is one of the largest and most important in the United States. With approximately 2,900 square miles of area (Table I-1), the complex is the second largest estuarine system on the East Coast of the United States, exceeded in area by only the Chesapeake Bay. Individual "estuarine profiles" have been completed for the Albemarle and Pamlico systems (Copeland et al. 1983; 1984).

Table I-1. Comparison of Albemarle and Pamlico Sounds (from the Albemarle-Pamlico Estuarine Study Work Plan).

Item		Albemarle	Pamlico
Area	(km^2)	2,330	5,200
	(mi^2)	900	2,000
Watershed	(km^2)	47,552	32,427
	(mi^2)	18,360	12,520
Percent area of state inshore total		26	56
Freshwater Inflow (ft^3/sec)		17,000	32,000
Volume of Sound	(billion ft^3)	23.1	91.5
	(million acre ft.)	5.3	21
Time for inflow to replace volume		6 weeks	14 weeks
Salinity		low	moderate to high
Fisheries		anadromous	marine and fresh
Percent catch of state total		14	78
Percent value of state total		5	73

The estuarine system comprises an extensive complex of creeks, rivers, swamps, marshes and open water sounds dominating northeastern North Carolina (Figure I-1). Tributaries originating in the Piedmont serve as conduits to a major geographic portion of North Carolina and southeastern Virginia. Albemarle Sound is the drowned portion of the Roanoke River and its extensive floodplain. Other major, lateral tributaries of Albemarle Sound include the Chowan, Perquimans, Little, Pasquotank and North Rivers on the north; and the Scuppernong and Alligator Rivers on the south. Pamlico Sound is the drowned portion of the Tar and Neuse Rivers and their extensive floodplain. Several small, lateral tributaries drain off the low, flat, swampy coastal area; with the largest one being the Pungo River on the north.

Both sounds are not directly connected to the Atlantic Ocean, but are behind extensive barrier islands referred to as the "Outer Banks". Albemarle Sound has three open-water estuaries at its eastern end that are parallel to the ocean and Outer Banks–the freshwater Currituck Sound to the north and brackish Croatan and Roanoke Sounds to the south. Albemarle Sound is connected to the ocean through Croatan and Roanoke Sounds via Pamlico Sound. As a result, Albemarle Sound is strongly influenced by freshwater and only marginally by the ocean. Pamlico Sound is connected to the ocean through several inlets including Oregon, Hatteras, Ocracoke, Drum, Bardon and Beaufort. These tidal connections exert considerable oceanic influence on Pamlico Sound.

Albemarle Sound and Pamlico Sound, as well as Core, Bogue and Currituck Sounds, are the focus of the Albemarle-Pamlico Estuarine Study and therefore this report. The study area (Figure I-1) extends upstream in tributary basins to the seaward-most impoundment, or if there is no impoundment, to the upstream boundary of the drainage basin, or if the basin extends into Virginia,

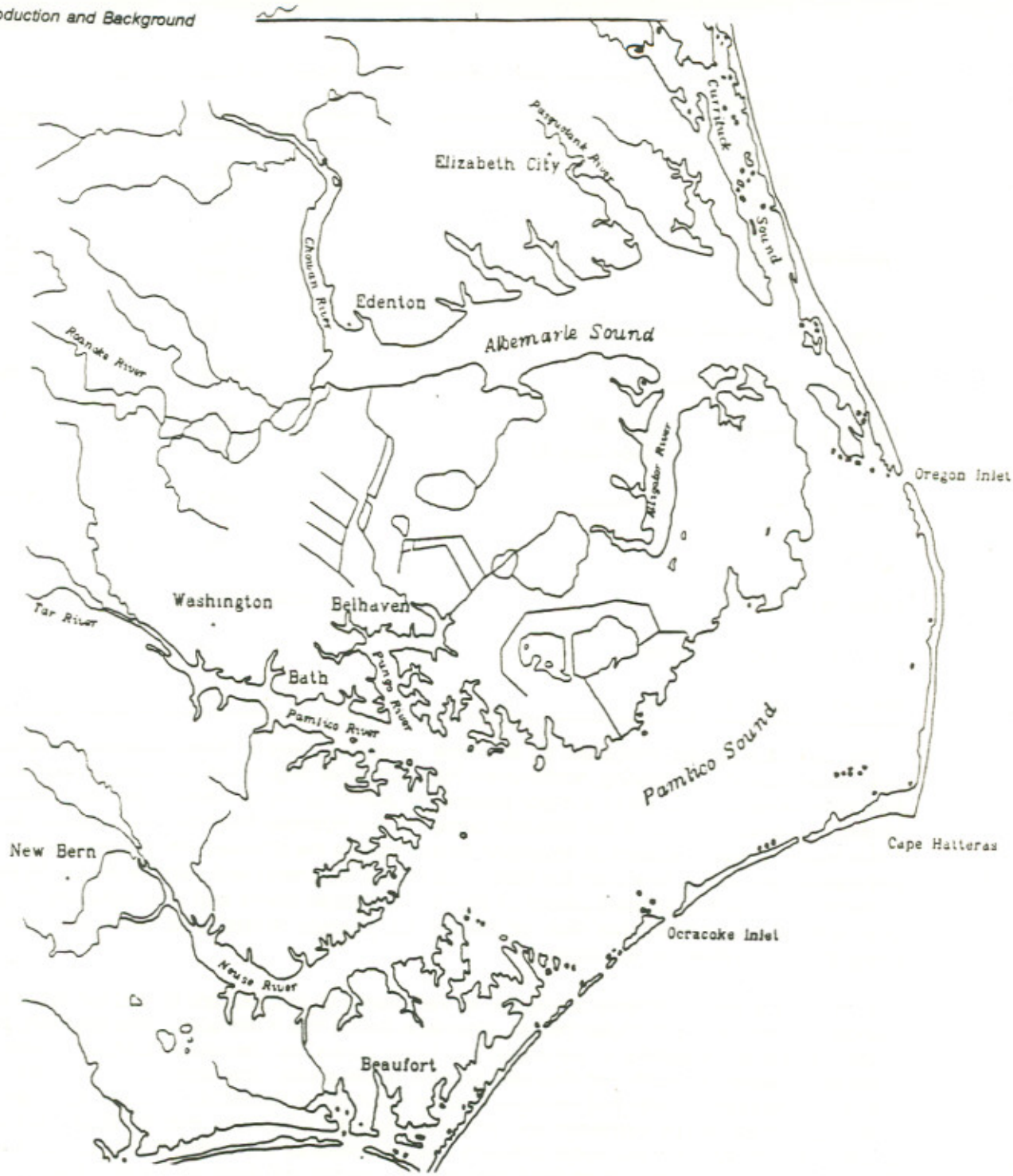

Fig. I-1. Albemarle-Pamlico Estuarine Study Area

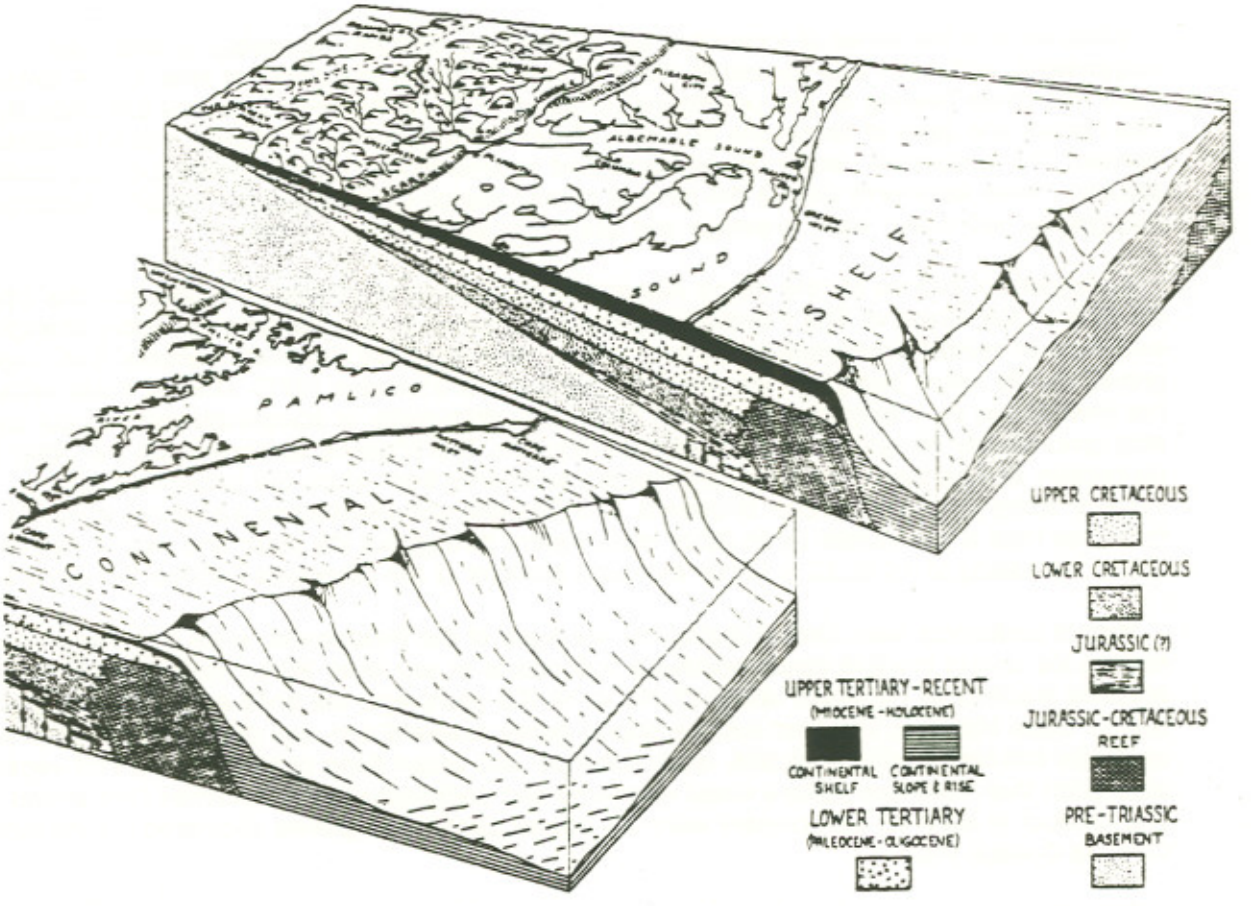

Fig. I-2. Cross-section of the Stratigraphy of Northeastern North Carolina. From Fairbridge 1960.

to the North Carolina-Virginia state line. The seaward limit of the study area is the Atlantic Ocean shoreline.

B. 2. Geological Origin

Sediments and sedimentary rocks of marine origin underlie the entire sound region (Brown et al. 1972). These sediments were deposited on top of the same type of crystalline rocks that occur in the Piedmont and were deposited when the ocean covered portions of the coastal plain. As the coastal system migrated back and forth across the coastal plain-continental shelf during geological times (for at least the last 100 million years) stratified rock layers were laid down. The marine sediments range from 600 m thick at Washington, North Carolina, to 1500 m near Swanquarter, to over 3 km at Cape Hatteras (Figure I-2).

While each in the series of formations has a distinctive textural, mineralogical and fossil composition, and each was deposited during a specific period of geological time, these formations have little direct bearing on the present-day functioning of the Albemarle-Pamlico Estuarine System. The names and ages of formations in Figure I-2 place the present-day estuary and its sediments in context. The uppermost veneer of unconsolidated sediments has a direct bearing on the modern estuary. These sediments dictate the general characteristics of the estuarine margins, bottoms, topography, soil types, water drainage and use of the adjacent land areas.

Sediments of interest for the recent Albemarle-Pamlico Estuarine System range from the Upper Miocene to the Pliocene. The Pliocene sediments deposited during this time of rapidly changing sequence in coastal environments (25 to 1 million years ago) are extremely complex and include gravel, sands, clays, peats and all possible combinations (Hartness 1977). Most of these units are not fossiliferous or, if they have been, the fossils are often partly or completely leached out by the acid groundwater moving through the surface aquifers. The Miocene sediments, on the other hand, do contain several fossil layers and provide the sediments from which the phosphate mining industry along the Pamlico River is derived. The Pliocene and Pleistocene sediments range in thickness from a few meters up to 20 or more meters throughout the inner and middle estuarine areas, increasing to 15 to 25 m under the outer portions of the Albemarle-Pamlico Estuarine System.

Recent sediments were formed during the Ice Ages of the Pleistocene, when the retreating and melting ice sheets brought about worldwide fluctuations in sea level. When the last major glacial ice advance reached its maximum about 17,000 to 18,000 years ago, the shelf edge was about 40 km east of Cape Hatteras. The land surface sloped gently seaward and was dissected by rivers and associate tributaries with moderately deep channels and broad flood plains. Climate and vegetation were such that maximum surface water discharge and sediment erosion occurred (Whitehead 1981). The product of such an environment were the coarse sands and gravels deposited on the North Carolina Coastal Plain.

The present rise of sea level began sometime after 17,000 years before the present (BP) when the climate began to warm and glacial ice masses receded. The sedimentary and physical character of the present sound system began to be defined at that time. As the climate continued to warm, the vegetation slowly evolved into the hardwood and pine forests that characterize the southeastern United States today. And, the estuarine system impinged landward across the continental shelf to its current position.

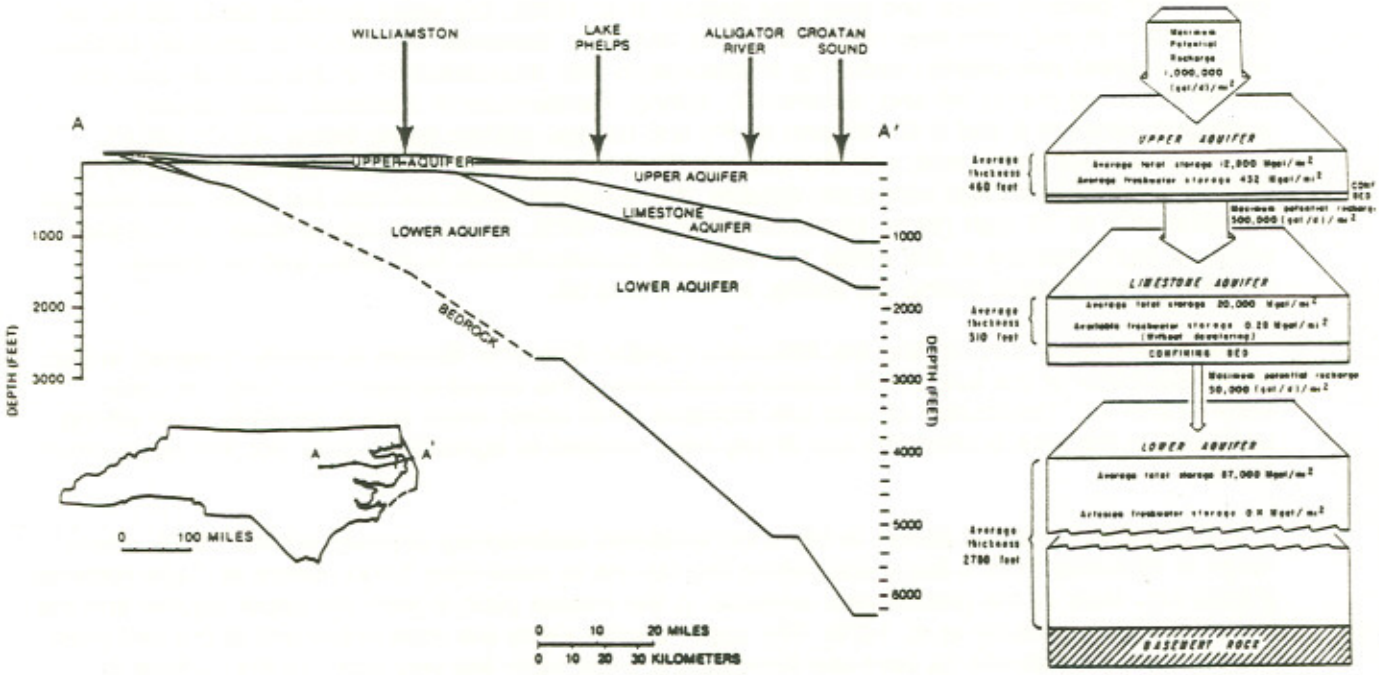

Fig. I-3. Cross-section of Aquifers (from Heath 1980) and Estimated Recharge and Storage of Aquifers (from Wilder et al. 1978) underlying the North Carolina Coastal Plain.

A major geomorphic feature known as the Suffolk Scarp, or the Arapahoe Ridge, trends north and south across the western portion of the A/P system and divides the area into two distinct geomorphic provinces. This prominent sand ridge rises to 6 to 9 m elevations and represents an old barrier island shoreline formed by the sea during a previous Pleistocene interglacial when sea level was higher than it is now. West of the Arapahoe Ridge, the terrain gently rises to the Piedmont. To the east lies the Pamlico Terrace, which has a low, flat surface sloping from 3 to 5 m elevations at the base of the scarp eastward to 0.3 to 0.6 m elevations at the end of the land peninsula. This geologic setting has resulted in low, poorly drained land with extensive swamps and pocosins composed of organic peat soils that generally thicken eastward.

B. 3. Climate and Land

The climate in the area of the Albemarle-Pamlico Estuarine System is moderately mild and moist, creating a good environment for agriculture, forestry and fisheries. Northeastern North Carolina generally receives between 47 and 56 inches (120 and 142 cm) of rain per year, which varies greatly from place to place and over time (Wilder et al. 1978). Dry years average about 35 inches (89 cm) and in wet years may reach 78 inches (200 cm). Seasonal distribution is relatively uniform, with the highest precipitation occurring in association with thunderstorms in the summer and the lowest occurring during fall and, secondarily, spring. Temperature is moderate, with January averaging between 6 and 8 C° (43 and 46 F°) and the low seldom falling below -12 C° (10 F°). Summers are hot and humid, with the average daytime temperature often above 32 C° (90 F°) in July and August. Although winds are variable, the prevailing winds are from the S-SW with average velocities of 9 to 10 mph (15 to 16 km/hr) (Clay et al. 1975). Special situations arise with northern winds of high velocities in the winter and localized thunderstorms, hurricanes and tornadoes creating major impacts during the spring, summer and fall.

The area directly surrounding the Albemarle-Pamlico Estuarine System is heavily forested; in fact, about two-thirds of the land in the counties surrounding the sound system is in forest or under water (Table I-2). Distribution of land use indicates small urban areas and a generally rural setting. Land use in the area is changing but largely from forested to agricultural uses, not into large urban areas.

Abundant groundwater occurs in the unconsolidated sedimentary deposits (Heath 1980), which range in thickness from a few meters along the fall line to more than 3,000 meters at Cape Hatteras (Figure I-2). Most of the groundwater available in the coastal plain is from the upper aquifer and the limestone aquifer (Wilder et al. 1978). The upper aquifer yields the most water and is the one most likely to be contaminated by land use activities–the water table lies very close to the surface in much of the low-lying areas around the sounds.

Table I-2. Land Area and Land Use (in acres) in the Counties Surrounding Albemarle-Pamlico Estuarine System (from the U. S. Soil Conservation Service National Resources Inventory of 1982).

County	Total Acres	Water	Urban Etc.	Crop Land	Forest (total)	Wet-lands
Beaufort	612,980	86,530	20,800	131,300	333,000	43,700
Bertie	471,379	22,784	2,100	95,600	331,800	93,300
Camden	203,770	49,857	300	40,400	93,900	69,100
Carteret	673,625	337,260	22,400	53,000	93,500	48,800
Chowan	154,784	38,622	3,300	49,100	55,800	11,900
Craven	487,213	38,272	21,900	76,400	250,500	69,800
Currituck	281,082	117,505	2,800	54,200	55,400	31,200
Dare	800,601	550,495	15,800	5,200	33,978	58,078
Hyde	871,136	471,635	800	117,000	170,800	121,600
Pamlico	368,186	150,119	2,900	36,700	138,700	50,900
Pasquotank	185,203	39,283	5,800	76,100	46,400	26,400
Perquimans	208,845	51,212	2,200	96,500	52,400	11,800
Tyrrell	383,143	122,778	200	61,900	187,000	187,000
Washington	264,486	52,243	2,000	81,400	115,800	47,200
Total	5,966,433	2,128,595	103,300	974,800	1,958,978	870,778
Percent		36	2	16	33	15

B. 4. Hydrography

The Roanoke and Chowan Rivers are the main sources of freshwater into Albemarle Sound (Giese et al. 1979). Of the approximately 17,000 cubic feet per second (cfs) net, annual average freshwater inflow to Albemarle Sound, over half (8,800 cfs) is from the Roanoke River (Table I-3). Major sources of freshwater into Pamlico Sound (Table I-4) are Albemarle Sound (17,000 cfs), Pamlico (Tar) River (5,400 cfs) and the Neuse River (6,100 cfs) for a major portion of the average annual inflow of 31,700 cfs (Giese et al. 1979). Freshwater input is not evenly distributed throughout the year, with the highest runoff during the late winter and early spring, and the lowest during the fall.

Wind is the most important factor influencing short-term circulation in the Albemarle-Pamlico Estuarine System, with tides and freshwater inflows from tributaries playing secondary roles (Giese et al. 1979; Pietrafesa et al. 1986) The embayed lateral tributaries are very responsive to wind tides, such that winds blowing downstream may often drive most of the water from the embayment (Overton et al. 1988). Because of the shallowness, long fetch of the waterbodies and essential separation from the ocean, wind and wave action usually eliminate vertical stratification (especially in Albemarle Sound) except under certain calm or high freshwater inflow conditions.

The total annual average outflow from Albemarle Sound (about 17,000 cfs) is larger relative to the sound's volume (about 5.3 million acre-feet) than the Pamlico Sound (32,000 cfs and 21 million acre-feet, respectively). This difference gives rise to an apparently much shorter "time for inflow to replace volume" for water in Albemarle Sound than in Pamlico Sound (Table I-1). Combined with the almost total isolation of Albemarle Sound from the ocean, the short time for inflow to replace volume results in very much lower salinity conditions than in the Pamlico.

Table I-3. Gross Water Budget (cfs) for Albemarle Sound, 1965-1975 (from Giese et al. 1979).

Month	Precipi-tation	Evapo-ration	Chowan Inflow	Roanoke Inflow	All Other Inflow	Total Output
January	2,800	1,000	6,500	10,000	4,200	23,000
February	3,400	1,700	9,100	12,000	5,900	28,000
March	2,900	2,200	8,600	10,000	5,600	25,000
April	2,500	3,400	6,600	11,000	4,300	21,000
May	2,800	3,900	3,700	10,000	2,400	16,000
June	3,600	4,200	2,600	8,500	1,700	12,000
July	5,400	4,100	3,000	8,000	1,900	14,000
August	5,000	3,500	3,500	7,500	2,200	15,000
September	4,300	2,800	3,000	6,500	2,000	13,000
October	2,500	1,800	2,200	6,500	1,400	11,000
November	3,000	1,400	2,500	7,500	1,600	13,000
December	2,600	900	4,400	8,300	1,300	16,000
Annual	3,400	2,600	4,600	8,800	2,900	17,000

Table I-4. Gross Water Budget (cfs) for Pamlico Sound (from Giese et al. 1979).

Month	Precipi-tation	Evapo-ration	Albemarle Inflow	Neuse Inflow	Tar Inflow	Total Output
January	6,800	2,300	22,800	8,700	7,600	44,200
February	7,900	3,300	28,300	11,000	9,700	54,500
March	6,600	4,900	25,000	9,700	8,600	45,800
April	5,400	7,500	21,300	6,700	5,900	32,400
May	6,600	8,600	15,500	5,800	5,100	24,800
June	9,300	9,300	12,200	3,200	2,800	18,400
July	12,600	10,000	14,200	4,600	4,000	25,700
August	12,100	7,700	14,700	5,600	4,900	30,000
September	10,800	6,100	13,100	4,300	3,800	25,300
October	6,700	4,100	10,700	4,000	3,600	21,200
November	7,100	3,000	13,300	4,200	3,700	26,600
December	7,000	2,000	15,600	5,700	5,000	31,800
Annual	8,300	5,700	17,200	6,100	5,400	31,700

B. 5. Groundwater Resources and Quality

Coble et al. (1985) have reviewed groundwater resources of North Carolina. Giese et al. (1987) and others have summarized information on groundwater quality for North Carolina. The following discussion was drawn almost exclusively from these two sources.

B. 5. a. Overview Groundwater supplies nearly 58% of the approximately 6.2 million people in North Carolina; about 435 million gallons per day of fresh groundwater is used in the State. The economic importance of groundwater is high in the Coastal Plain province, where high-yielding

aquifers supply most municipalities, industries, rural areas and livestock. The lack of reliable groundwater supplies has been a limiting factor in economic growth in the eastern area of the state, particularly in parts of northeast North Carolina and the Outer Banks.

The amount of precipitation that recharges the groundwater system averages about 20% of the annual precipitation (Winner and Simmons 1977), which ranges from about 44 to 56 inches (112 to 120 cm) in the Coastal Plain. Most of the water recharged to the groundwater system moves laterally through shallow aquifers and discharges to streams; thereby constituting a major part of surface water baseflow. Less than one inch per year of the recharge typically reaches the deep aquifers in the Coastal Plain.

In general, the quality of the groundwater in the Albemarle-Pamlico Estuarine region is good and most groundwater supplies meet drinking water standards (N. C. Department of Human Resources 1984). Treatment of ground water is required in some places, however, because of naturally-occurring or human-induced water quality problems. The presence of salt or brackish water in all aquifers in the eastern part of the State is the most widespread naturally-occurring groundwater quality problem in the Albemarle-Pamlico Estuarine region (Figure I-4). In locations where ground water is pumped near naturally-occurring saltwater, the saltwater may move upward and spread laterally toward pumped wells resulting in increased dissolved solids concentrations in parts of the aquifer.

Other naturally-occurring conditions which may render untreated ground water unsuitable for drinking water include excessive hardness, extremes in pH, and unacceptably high concentrations of dissolved solids, chloride, fluoride, iron, manganese and sodium. Radioactive radon gas may be dissolved in groundwater that occurs in rocks of higher-than-average uranium content and relatively low permeability. Rocks of this type include shale, clay, granite and phosphate ore.

Human-induced contamination of groundwater generally results from leachate from landfills, seepage from waste lagoons, seepage from underground storage tanks and accidental spills of chemical materials; as well as from pumping near naturally-occurring saltwater. Aquifer recharge areas are generally the most vulnerable to contamination and, because groundwater moves slowly, the contamination may go undetected for years. These contamination problems are serious where they occur, but the best information indicates that known problems are local in extent.

B. 5. b. Principal Aquifers in the Albemarle-Pamlico Region Four of the five major aquifers in North Carolina used for water supply are in the unconsolidated to partly consolidated sedimentary deposits of the Coastal Plain (Figure I-3). The four aquifers are the surficial, the Yorktown, the Castle Hayne and the Cretaceous aquifers. The areal extent and characteristics of the aquifers are given in Figure I-4 and Table I-5, respectively. The fifth aquifer, which lies in the Piedmont and Blue Ridge provinces of the State, is the crystalline-rock aquifer.

The **Surficial** aquifer, which is a near-surface deposit of either marine-terrace sand and clay or of sand dunes, is a principal aquifer in two parts of the Albemarle-Pamlico basin–on the Outer Banks and on the mainland north of Pamlico Sound (Figure I-4). Individual well yields from this aquifer typically range from 25 to 200 gpm (gallons per minute); but may exceed 500 gpm, particularly on the mainland.

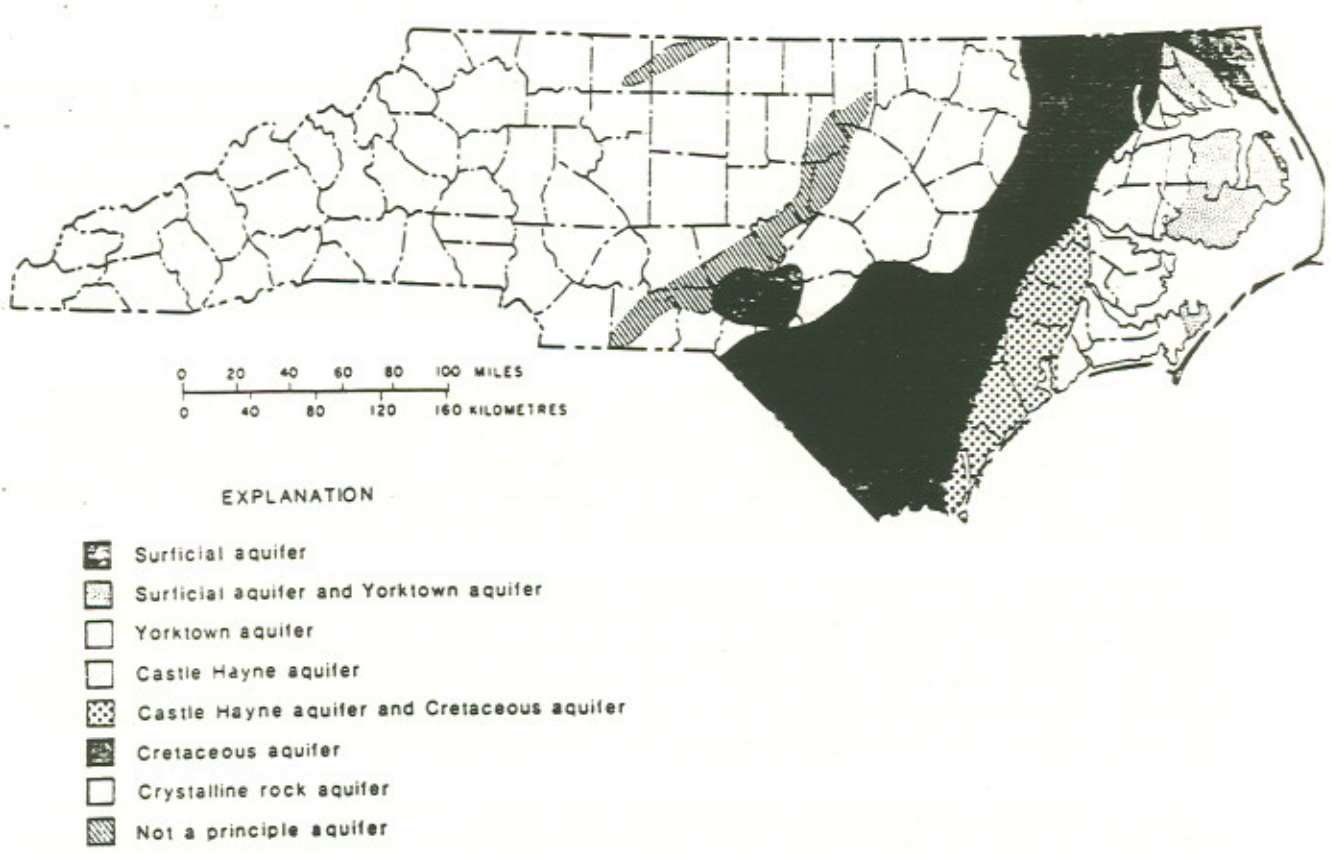

Fig. I-4. Principal Aquifers of North Carolina. From Coble et al. 1985.

Table I-5. Aquifer and Well Characteristics in the North Carolina Coastal Plain (from Coble et al. 1985).

Aquifer	Description	Depth (ft)	Yield (gpm)
Surficial	Sand, Silt, Clay & Gravel Unconfined or Partially Confined.	40 to 175	25 to 500
Yorktown	Sand & Clay. Partially Confined or Confined.	50 to 190	15 to 500
Castle Hayne	Limestone, Sandy Limestone & Sand. Confined.	70 to 400	200 to 2,000
Cretaceous	Sand, Clayey Sand & Clay. Confined.	100 to 800	200 to 1,400

The surficial aquifer is the only source of freshwater, other than precipitation, for much of the Outer Banks. Because freshwater is seldom found more than 100 ft below land surface on the Outer Banks, water supplies are usually obtained from a large number of shallow vertical wells or from shallow horizontal wells. Even so, as a result of pumping or of naturally-occurring conditions, the concentration of dissolved solids in water pumped from this area can exceed the 500 mg/l national secondary drinking-water standard (U. S. Environmental Protection Agency 1986).

On the mainland, the surficial aquifer is between 50 and 200 feet thick, and the aquifer may yield one million gpd (gallons per day) from small well fields. Dissolved solids concentrations, which are typically lower than on the Outer Banks, are generally less than 200 mg/l. The pH, on the other hand, may be as low as 5, which renders the water corrosive. Large amounts of humic material in some parts of the surficial aquifer may make the water unsuitable for chlorination and public supply (U. S. Environmental Protection Agency 1985). Upon chlorination, the humic material combines with chlorine to form trihalomethanes, which are thought to be carcinogenic.

Declines in water level in the surficial aquifer are not widespread. Pumping one million gpd from a well near Elizabeth City resulted in no measurable decline in an observation well 0.5 miles from the well field.

The Yorktown aquifer is typically present at depths of between 50 and 150 ft below land surface in the northern part of the Coastal Plain (Figure I-4). The Yorktown commonly yields 15-90 gpm to individual wells, although yields may occasionally exceed 500. Near Elizabeth City, the Yorktown supplies about 1.4 million gpd to a well field.

Background, or naturally-occurring, concentrations of sodium are higher in water from the Yorktown aquifer than from any of the other principal aquifers in North Carolina. The median concentration of sodium in samples from the aquifer was reported to be 38 mg/l and 25% of the samples had concentrations of sodium in excess of 130 mg/l (Giese et al. 1987). Although no state or national standards have been established for sodium in drinking water, the U.S. Environmental Protection Agency (1985) proposed a health advisory guidance level maximum of 20 mg/l for sodium in drinking water. It appears that ion exchange is responsible for the high levels of sodium

in the Yorktown aquifer (Wilder et al. 1978); calcium in the groundwater apparently exchanges for sodium in the aquifer materials, thereby increasing the concentration of sodium and decreasing the concentration of calcium in the groundwater.

Withdrawals from the Yorktown are generally minor and the aquifer is readily recharged. Consequently, widespread water-level declines have not occurred in this aquifer. Near Belhaven, withdrawals of about 1.2 million gpd over a period of about 10 years have resulted in a water-level decline of less than 10 feet.

The major source of freshwater in the southeastern coastal area, where nearly all aquifers contain some saltwater, is the **Castle Hayne** (Figure I-4). In some locations where aquifers above and below the Castle Hayne contain saltwater, the Castle Hayne can yield freshwater. The Castle Hayne is the most productive of the state's principal aquifers. Wells that yield more than 1,000 gpm can be readily developed in the aquifer, and yields in excess of 2,000 gpm have been possible.

Water from the Castle Hayne is generally hard (121 to 180 mg/l as calcium carbonate) to very hard (greater than 180 mg/l) and may require treatment for some uses. Hardness is lower near recharge zones, but increases with residence time in the aquifer. In contrast, iron concentrations are more likely to exceed the state drinking water standard of 0.3 mg/l in recharge areas, but iron precipitates out as water moves through the limestone formation. Silica concentrations in excess of 50 mg/l are common, and saltwater may be found in the deeper parts of the aquifer.

The largest groundwater withdrawals in the state are from the Castle Hayne aquifer to decrease artesian pressure and de-water overlying phosphate ore beds at a phosphate mine in Beaufort County. Over 60 million gpd are withdrawn from the aquifer near Aurora, and, as a consequence, water levels have declined 5 feet or more in the Castle Hayne over an area of 1,300 square miles. Near the mine, a water level decline of over 80 feet has been observed since 1965 (Coble et al. 1985).

The **Cretaceous** aquifer (Figure I-4) is the most widely used aquifer in the Coastal Plain, with much of the withdrawals coming from the central and southern parts of the province. The aquifer occurs at depths of between 100 and 600 feet below land surface (800 feet in some sites) and is very thick relative to the other principal aquifers in the state. Individual wells in the Cretaceous aquifer typically produce between 200 and 400 gpm; some well fields in the aquifer produce more than one million gpd.

Water from the Cretaceous aquifer is generally soft and alkaline and requires little or no treatment for must uses. Water from some parts of the aquifer may, however, contain fluoride concentrations in excess of 4 mg/l, which is the maximum allowable concentration under national drinking water standards (U.S. Environmental Protection Agency 1986). Hence, the presence of excessive fluoride may limit the use of water for drinking from some parts of the aquifer. Additionally, the Cretaceous aquifer generally contains brackish water in the deeper parts of the aquifer (Figure I-4).

Because the Cretaceous aquifer is heavily utilized throughout the Coastal Plain, declines in water level are widespread throughout the area. An observation well in the Cretaceous aquifer near Kinston has shown water level declines of 80 feet or more since 1968. Water levels have declined over an area of several thousand square miles in northeastern North Carolina because of withdrawals of 35 million gpd or more near Franklin, Virginia (about 10 miles north of the state line).

At the state line, water levels have declined abut 45 feet since 1966 and are estimated to have declined as much as 100 feet since the early 1940's when the extensive withdrawals began.

B. 5. c. Groundwater Management The N. C. Division of Environmental Management (DEM) has the major responsibility for groundwater management and regulatory programs in the state. DEM administers the point-source permit program, which primarily regulates facilities that discharge to surface waters, but also includes unlined basins and holding ponds that have the potential to contaminate groundwater. The nondischarge permit program, which is also administered by DEM, is, in essence, a groundwater permit program that regulates activities such as sewer extensions, sludge disposal, land-application systems and waste lagoons that do not discharge to surface waters. Monitoring to assure compliance with permits is conducted at over 750 wells, which are monitored by the owners in accordance with the conditions of the permits.

A well construction permit must be obtained from DEM for public supply, industrial and irrigation wells, wells with a designed capacity of 100,000 gpd or greater, wells to be used for injection, recharge or disposal purposes, and a non-domestic well located in a designated Capacity Use Area (North Carolina Well Construction Act of 1967, Article 7-87-88). A Capacity Use Area is an area in which the renewal and replenishment of the groundwater supplies are believed to be threatened, and is designated by the N. C. Environmental Management Commission. All well drillers must register annually with DEM, and are required to report all well completions and abandonments.

Landfills are regulated by the N. C. Division of Health Services (DHR). DHR is responsible for monitoring solid and hazardous waste disposal sites. DHR is also responsible for the human health aspects of public water supply systems, including approval of sources of raw water and establishment of state drinking water standards.

B. 6. The Estuary and Society

Native Indians called Albemarle Sound "Weapemeoc" and lived around the area prior to the coming of European settlers in the sixteenth century. Albemarle was first explored by Sir Walter Raleigh's colonists under the leadership of Ralph Lane during the spring of 1586. Not unlike today, Lane's Albemarle Sound expedition encountered natives fiercely proud and defensive of their territory, bad weather, and conflicts over presumed rights. While the details and characters have changed, people in the four centuries since are the product and continuation of historical Albemarle Sound (Stick 1982).

The size and isolation of the Pamlico Sound limited early settlement by colonists. Beginning with the settlement of Jamestown, Virginia, in 1607, early settlement began north of Albemarle Sound and later spread southward. Settlers built homesteads along the shores, produced crops for export and sailed their crafts from sound to sea through the inlets of Currituck and Roanoke in the 1600's. Throughout the seventeenth century, Albemarle Sound was the hub and heart of North Carolina and Edenton, one of the colonial capitals, was the center of trade (Stick 1982). Numerous communities and small towns were established near the water, and land was cleared in ever-increasing acreages for agriculture. Fishing thrived and timber provided raw materials for local use and export. Southern migration continued, leading to the establishment of Bath on the shore of Pamlico Sound in 1704. The sounds served as important highways for the transport of goods in colonial North Carolina. Even with the addition of a modern tourism economy, coastal North Carolina is still very dependent upon agriculture, forestry and fishing just as it was 400 years ago. It is important that policy and management decisions be made in the total context of settlement history. The Albemarle-Pamlico

Estuarine System has dominated eastern North Carolina for centuries and is bound to continue to do so.

C. ENVIRONMENTAL CONCERNS AND PROBABLE CAUSES

C. 1. Identification of Environmental Concerns

Definite changes have taken place in the Albemarle-Pamlico Estuarine System in recent years. The "Albemarle-Pamlico Estuarine Study Work Plan" identified a series of environmental conditions that concern scientists, management agencies and the public. There is a general impression that events of concern have become more frequent and conditions that cause definitive environmental problems are not well understood.

C. 1. a. Declines in Fisheries Productivity Major declines in commercial fisheries have occurred in the Albemarle-Pamlico region since the 1970's. Striped bass, shad and river herring landings from the Albemarle Sound are greatly depressed from historic levels. Commercial landings of croaker, catfish and flounder have declined since 1980. Blue crab landings have fluctuated, with a current lower-than-average catch. The shrimp catch, traditionally the most valuable of all North Carolina commercial fisheries, has declined over the last decade. Recreational fishermen often complain that "fishing is not what it used to be" and the catch per unit effort has declined over the past decade. The reasons for these declines remain equivocal, but undoubtedly include declining water quality, critical habitat loss or alteration, and over-fishing. Declines are expected to continue unless causes can be ascertained and corrective steps taken.

C. 1. b. Sores and Diseases Recent outbreaks of ulcerative mycosis in commercially important species in the Pamlico present a major challenge. A large percentage of menhaden sampled in the Pamlico River estuary during the past five years were affected, as well as other commercially important species (such as flounder and weakfish) to a lesser extent. Recent investigations suggest that stress related to water quality degradation is an important factor leading to disease outbreaks, but epidemiological relationships are poorly understood. A red sore disease reached epidemic proportions in some commercial species in Albemarle Sound during the 1970's, but the causes for the outbreaks and the potential for re-occurrence remain ambiguous.

More recently, blue crabs in the Pamlico River estuary have been reported with "holes" in their shells. Preliminary research indicates that the holes are the result of microbial invasion, possibly due to water quality degradation.

C. 1. c. Anoxia-Related Fish Kills Fish kills reported from the Pamlico River estuary have significantly increased in recent years. Variability in interannual conditions and the lack of reliable reporting make trend analysis difficult, but the available information suggests that fish kills are becoming more common. Most of the fish kills are seemingly related to oxygen depletion (probably because of eutrophication, increased organic oxygen demand and stratification), but the causal mechanisms are poorly understood. Regardless of the lack of specific documentation, fishermen complain that the intensity and extent of anoxic waters have recently increased.

C. 1. d. Changes in Distribution Patterns of Benthic Organisms Historic changes in distribution patterns of important benthic organisms have been dramatic. Surveys suggest that viable oyster beds, for example, have been displaced downstream roughly 10-15 miles in the Pungo, Pamlico and

Neuse Rivers since the 1940's. The causes of this displacement are uncertain, but changes in salinity, sedimentation patterns and harvesting have been implicated.

Extensive beds of brackish water submerged macrophytes that existed in the 1970's had almost disappeared by 1985. This decline parallels similar declines that have been documented in the Chesapeake Bay and elsewhere. Reduction in submerged aquatic vegetation is of crucial environmental concern because this decline represents a reduction in fisheries and waterfowl habitats. The causes for this observed decline have not been elucidated. Some recovery in several areas has been recently observed.

C. 1. e. Impairment of Nursery Area Function The fringe marshes and small embayments of the Albemarle and Pamlico sounds provide essential nursery functions for a majority of the commercial and recreational fish and shellfish in the North Carolina coastal area. Freshwater drainage, land-use changes and eutrophication have jeopardized the functional aspects of the primary nurseries in several locations. Although the exact extent of impairment may prove difficult to estimate where historical data are lacking, restoration/mitigation may be easily accomplished through proper and timely assessment programs.

C. 1. f. Eutrophication Blooms of noxious phytoplankton in response to cultural enrichment of estuarine waters with nutrients are well documented in the Albemarle-Pamlico Estuarine System. The most notable blooms have occurred in the Chowan River (Albemarle) and the Neuse River (Pamlico) during the last two decades. Many other tributaries display periodic blooms, depending on flow regimes, nutrient loading, hydrography and meteorologic conditions. While research has uncovered some of the environmental relationships between conditions and algae blooms, and management for minimizing their occurrence is slowly evolving. However, scientists have not yet integrated all the information needed to explain how, when and why blooms occur.

C. 1. g. Habitat Loss Human activities in the region of the Albemarle-Pamlico Estuarine System have greatly affected ecosystem functions of estuarine and closely-linked wetland habitats. Dredging, draining and filling of productive bottoms, marshes and pocosins have significantly reduced their areas and modified reproductive, migratory and feeding patterns for a wide variety of aquatic and terrestrial organisms. The relative value of such habitat is poorly known and restoration or mitigation potential for impacted areas has yet to be evaluated. Implementation of new programs like "Swampbuster" should reverse the trend in declining acreages of wetlands.

C. 1. h. Shellfish Closures Closure of shellfish waters due to pathogenic microbial contamination in North Carolina has remained relatively constant over the past few years. About 320,000 acres of estuarine waters in the state are closed to shellfishing on temporary or permanent basis (of this acreage, about 50,000 are thought to be productive shellfish areas). Often, after heavy rainfall, additional acreage is closed for several days to several weeks. Albemarle Sound is not a contributor of commercial shellfish, but Pamlico Sound has oysters, clams and bay scallops in several areas. Most of the closure is outside the study area, but Core and Bogue Sounds are affected in a major way. New techniques to more accurately measure contamination and potential human impact are needed so that management can more effectively allocate shellfish resources. Relationships between contamination and land-use characteristics are poorly understood.

C. 1. i. Toxicant Effects Very little is known about the effects of toxicants on estuarine organisms and/or the distribution of toxic substances in the Albemarle-Pamlico Estuarine System. Specific locations have been identified where toxicant problems are thought to exist, but large-scale problems have not been documented. Public concern has been voiced about the potential toxicity of

specific constituents of permitted and proposed discharges, but few known "hot spots" have been identified to date. A preliminary survey of toxic contaminants in the sediments is currently underway.

C. 2. Identification of Probable Causes

Human activities in the Albemarle-Pamlico Estuarine System include agriculture, forestry, residential and commercial development, mining, national defense, recreational and commercial fishing, tourism and recreational development, and wildlife hunting and preservation. All these activities generate waste to be disposed of and/or changes in the landscape and land-use. During the time-frame in which the environmental concerns outlined above have become more apparent, human activities have undergone major changes.

C. 2. a. Agriculture Agriculture is the largest industry in the 28 counties of the central and northern Coastal Plain surrounding the Albemarle-Pamlico Estuarine System. These counties generate an annual return of over $1.5 billion from agriculture. The highly productive soils represent 45% of the state's cropland and produce a large portion of the state's swine, chicken, corn, soybean, tobacco, potato, wheat and peanut crops.

In the lower areas east of the Suffolk Scarp, crops are dominated by corn, wheat and soybeans. Farming activities are highly mechanized, and each individual operation is much larger than the statewide average. Soils require extensive drainage for most agricultural operations; consequently, large acreages are drained into networks of canals eventually reaching an estuary.

Concerns about agricultural impacts include (1) nutrient loading of freshwater, particularly from animal wastes and fertilizers applied to the fields; (2) increased freshwater peak flows into saline primary nursery areas; (3) degradation of water bodies from sedimentation; and (4) pathogenic microbes in shellfish areas. The degree to which agriculture serves as a probable cause depends upon many factors, including the weather, specific crops grown and the application of Best Management Practices (BMP's). BMP's recommended for the Coastal Plain control soil erosion, sediment delivery, animal waste disposal, fertilizer runoff and drainage water management, and have all been demonstrated to reduce the impact of agriculture on water quality.

Agriculture acreage is expected to remain relatively constant in the region during the foreseeable future. Relative mixes of crops and agriculture activities will vary interannually depending upon economics and environmental conditions. Animal (particularly hogs and chickens) production is expected to continue to increase at a rate similar to that of recent years. But, the use of Best Management Practices should reduce the potential for nonpoint pollution, particularly with the impetus given BMP implementation by the N. C. Agriculture Cost Share Program in all counties of the area. Effective water management is proving to be very attractive to farmers and its use should increase.

C. 2. b. Commercial Forestry Forest land of the area produces raw materials for a diverse forest products industry. The forests also function as wildlife habitat, recreational areas, and as a filter and surge control mechanism for fresh waters entering the sounds.

Analysis of recent U. S. Forest Service woodland inventories and information from the N. C. Division of Forest Resources reveal the following trends in forestry activities:

1. Total forest area has declined at an average annual rate of about 20,000 acres per year during the past few years.

2. The areal extent of pond pine, oak-gum-cypress and natural pine stands decreased between 1964 and 1984. Other hardwood types and pine plantations have increased during the same period.

3. Land ownership patterns have shifted, with private-owned acres declining and corporate-owned acres increasing.

4. The annual rate at which pine plantations are established has decreased, and the degree of disturbance associated with plantation establishment has also declined.

5. The use of herbicides, prescribed burning and fertilizer application during the establishment of pine plantations have increased.

6. Installation rates of drainage systems in woodlands have declined. It is estimated that about 75 to 80% of the land owned by the forest industry for which drainage is feasible have drainage systems in place.

C. 2. c. Residential and Commercial Development Residential and commercial development varies greatly from one area to another in the Albemarle-Pamlico region. Residential uses, including trailer parks, condominiums and housing neighborhoods, are concentrated at the ocean end of the region and around the extensive shorelines of the sounds. Commercial uses, varying from marinas to central business districts and shopping centers, are concentrated near population centers and the Outer Banks. The initial push to develop was concentrated at the oceanfront, but has recently expanded to the sounds and rivers further inland. Activities seem to be most concentrated in Dare, Carteret, Craven and Beaufort Counties. These trends seem to be continuing.

C. 2. d. Mining and Industrial Development The Albemarle-Pamlico Estuarine area is not highly industrialized in comparison to other areas of the country. There are several, isolated large manufacturing and mining operations in proximity to the sounds that have potentially significant impacts on water quality. Notable examples include a phosphate mining and processing facility on the Pamlico River, pulp and paper mills on the Neuse, Chowan and Roanoke Rivers, a metal plating operation on the Neuse River, and textile/synthetic fibers manufacturing plants on the Pamlico, Chowan, Roanoke and Neuse Rivers.

Several smaller industrial operations, such as animal processing operations, fish houses, printing, chemical manufacturing and boat building/repair lie around the shores and tributaries of the sounds. Industrial operations upstream also affect the estuary. Large scale peat mining in the region is still a speculative venture.

C. 2. e. National Defense The U. S. Department of Defense operates 19 facilities occupying more than 97,000 acres in the Albemarle-Pamlico region. Included are:

1. Atlantic Intracoastal Waterway-Transportation activities have potential impacts from oil spills, petroleum by-products and wastes from vessels. Maintenance dredging generates intermittent impacts from turbidities and disposal of spoil. There is increasing use of the waterway by recreational crafts.

2. Military Bases–The Cherry Point Marine Air Station is the largest installation adjacent to the sounds. It is a potential source of hazardous wastes and point source waste disposal.

3. Bombing Ranges and Target Areas–Site-specific physical affects occur in the several such areas around and in the sounds. Broader and more significant impacts may be the use conflicts with commercial fishing, recreation users, wildlife, commercial and private aircraft, and travelers on the Intracoastal Waterway. Proposals have been recently offered to expand bombing ranges in the area.

C. 2. f. Waste Disposal A major use of the Albemarle-Pamlico Estuarine System and its tributaries is the disposal of wastes generated by domestic, industrial and defense facilities, and by other human activities on the watershed. Point source contributions come from identifiable facilities through discharges, which are regulated by the North Carolina Division of Environmental Management. A very large proportion of the inputs are non-point in origin, which comes from runoff from land-based activities and groundwater discharge.

Impacts of waste disposal are evident in the Albemarle-Pamlico system, but the exact causal relationships and magnitudes of effects are not well documented. Eutrophication, as expressed in algal blooms, is an obvious effect from anthropogenic augmentation of nutrient fluxes. Other effects, such as the occurrence of ulcerative sores in fish and major shifts in distribution and abundance patterns of estuarine organisms, have resulted from waste loadings, but the causative relationships are extremely unclear.

C. 2. g. Commercial Fisheries Commercial fishing is as old as colonial North Carolina and serves as a traditional coastal industry. The Albemarle-Pamlico Estuarine System is the ecological basis for most of our fishery. Its diversity and setting result in a complex of habitats supporting diverse exploitable fishery species. Gear and fishermen are equally diverse. The number of licensed vessels fishing in the area continues to increase. Most fishermen do not rely on single species, but pursue a variety of species over different seasons with different gear types.

Problems in commercial fisheries include over-fishing, conflicts in allocation of species and catch between commercial and recreational demands, by-catch from trawling and pound net fisheries and declining catches for several species. Other issues revolve around the impacts of mechanical harvesting of shellfish on the environment and habitat intervention by traditional harvesting techniques.

C. 2. h. Recreational Fishing and Boating Millions of man-days of recreational fishing occur in the Albemarle-Pamlico area on an annual basis. Therefore, a large proportion of boating activities support the recreational fishing effort. Boating also results from commercial fishing, sailing, skiing and other recreational activities. In 1986, over 49,000 boats were registered in the 25 counties in the study area, which was about 23% of the 218,000 boats registered in North Carolina (many inland boaters and fishermen also utilize the sounds). Boating access consists of 64 public launching ramps and 117 privately owned or commercial access areas. Specific estimates of fishing and boating effort and fish harvest are not available, but the activity is increasing at a rapid rate.

C. 2. i. Tourism and Recreation Tourism and recreation are significant economic and growing forces in the Albemarle-Pamlico area. Development of second homes and facilities to support this growing industry has accelerated. There is a general consensus that demand for recreational activities in the coastal area will continue to increase over the next few years. As recreation-related

activities increase, human impacts in terms of waste disposal, water supply requirements, destruction of wildlife habitat, stormwater runoff from developed areas, and pollution associated with pleasure boats and marinas will become increasingly significant sources of stress on the estuarine environment.

C. 2. j. Wildlife Resources The Albemarle-Pamlico Estuarine System area is an important component of wintering waterfowl habitat in eastern North Carolina. Surveys have consistently shown that the majority of wintering Canada geese, snow geese, tundra swans, brant, diving ducks and sea ducks utilize the estuary system. A variety of other wildlife also utilize the diverse habitat available in the area. Several threatened and endangered species are found around the sounds. Potential human impacts come from increasing hunting activities and development of private waterfowl impoundments.

The U. S. Fish and Wildlife Service owns and manages 9 wildlife refuges in the area, encompassing 254,226 acres. These are Mattamuskeet, Swanquarter, Pungo, Cedar Island, Alligator River, Pea Island, Currituck, Mackay Island and a portion of the Great Dismal Swamp (more recent proposals for sites on the Roanoke River and Dare/Tyrrell County peatlands will add to the total). Major management objectives include provision of optimal habitat for waterfowl and other migratory birds, preservation of threatened and endangered species, preservation of prime examples of habitats, and provision of opportunities for wildlife-oriented education, interpretation and recreation. Managing wildlife refuges to provide maximum habitat and species is difficult, and some off-site impacts can occur.

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