Report **89-07**

TAR-PAMLICO RIVER BASIN NUTRIENT SENSITIVE WATERS DESIGNATION AND NUTRIENT MANAGEMENT STRATEGY

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Department of Natural Resources and Community Development
Division of Environmental Management
Water Quality Section

Second Printing

This report has been approved for release by
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CORRECTIONS

Errors were detected in Figures 4, 5, and 6 and Table 1 in the first printing of this report. These figures and tables have been corrected for this printing. Pages 3, 4, and 18 have also been corrected due to the same errors.

RECOMMENDATIONS

1. Classify the Tar-Pamlico basin as Nutrient Sensitive Waters (NSW) to enable nutrient reduction programs for both point sources and nonpoint sources. The NSW classification should apply from the headwaters of the Tar River to a line in the Pamlico River connecting Roos Point and Persimmon Tree Point (Pamlico Point).

2. The initial overall nutrient goal shall be no increase in nitrogen or phosphorus inputs to the basin from point sources and a reduction in nitrogen and phosphorus inputs from nonpoint sources.

3. Pilot plant studies for nitrogen removal should be performed before effluent restrictions for new or expanded point sources are enforced. These pilot studies should have a target total nitrogen concentration of 6 mg/l and should be completed by 1992.

4. Nutrient reduction studies should be performed to better define what nutrient level reductions are required to alleviate nutrient-related water quality problems on a long-term basis.

5. The following actions are recommended to address nonpoint source impacts:

    a. The North Carolina Agricultural Cost Share Program should be expanded to provide funding for agricultural best management practices in the upper portion of the river basin.

    b. Nonpoint source strategies should emphasize problem animal feeding operations and other major contributors of nonpoint source nitrogen.

6. The following actions are recommended for point source dischargers:

    a. All new dischargers should evaluate non-discharge alternatives as their primary option and implement a non-discharge system unless they can demonstrate that non-discharge is technically or economically infeasible.

    b. All new dischargers larger than 0.1 MGD who cannot utilize a non-discharge alternative should meet effluent limits of 6 mg/l on total nitrogen and 2 mg/l on total phosphorus.

   c. Existing dischargers should not be required to meet effluent nutrient limits unless they expand to design flows greater than 0.5 MGD. However, all renewed NPDES permits in the basin should include a reopener clause to allow the inclusion of effluent nitrogen and phosphorus limits at any time in the future pending the outcome of nutrient reduction studies and pilot scale nitrogen removal tests.

   d. All expanded discharges that result in design flows larger than 0.5 MGD should meet effluent limits of 6 mg/l on total nitrogen and 2 mg/l on total phosphorus.

   e. Effluent phosphorus limits should become effective upon classification of the basin as NSW. Nitrogen limits should become effective in 1992 in order to allow affected dischargers adequate time to conduct pilot studies.

7. These actions should be reevaluated in 1992 and every five years thereafter to examine the system, progress toward goals, and modifications necessary to ensure protection of water quality in the Tar-Pamlico River Basin.

EXECUTIVE SUMMARY

BASIN OVERVIEW

The Tar-Pamlico River system contains one of the most productive estuaries in the Eastern United States. Its resources include an extremely valuable commercial and recreational fishery. As with most productive systems, the Pamlico has demonstrated the potential for over-enrichment which may become problematic. Changes in land use throughout the watershed in recent decades and problems with aquatic life measured instream have created concern for the health of the estuary.

Although the Tar-Pamlico River system has largely avoided the noxious algal blooms common to the Chowan and Neuse River basins, changes have occurred in the distribution and abundance of the dominant algal species. There has been increasing concern over outbreaks of unexplained fish diseases, high sediment loads, and locations of low dissolved oxygen which have been detected in the basin, particularly in the Pamlico River Estuary. High temperatures and large amounts of available detritus from winter/spring phytoplankton blooms and from organic material washed into the river exacerbate this condition. The natural variability inherent to all estuaries complicates indentifying man's effects on the estuary.

In the Pamlico River Estuary, phosphorus is always present in excess of amounts needed for plant growth, especially in the middle portion of the Pamlico River. Nitrogen is generally considered to be limiting phytoplankton growth in the Pamlico River, although the extreme upper portion of the Pamlico River and lower portion of the Tar River, near Washington, N.C., may be co-limited (i.e., limited by nitrogen during some parts of the year and by phosphorus during other parts of the year). High nutrient concentrations can lead to algal blooms which can cause significant oxygen depletion during decomposition. Although the relatively high salinities in the Pamlico River prevent severe outbreaks of noxious blue-green species, blooms of dinoflagellates are common in winter and late summer. These blooms do not usually result in summer chlorophyll a standard violations. Elevated growth of phytoplankton and chlorophyll a standard violations are most common in the upper portion of the estuary (19% of observations in 1986). An intensive survey in July 1987 found that chlorophyll a levels exceeded the 40 ug/l standard throughout the upper portion of the estuary. Chlorophyll a values as high as 380 ug/l were recorded during this intensive survey.

NUTRIENT MANAGEMENT STRATEGY

The 1988 nutrient budget indicates that nitrogen in the basin comes mostly from nonpoint sources. On an annual basis, about 30% of the nitrogen comes from cropland runoff, 21% from forest land runoff, 18% from atmospheric deposition, and 15% from wastewater treatment plants (WWTPs). In contrast, the phosphorus budget is point source dominated. About 65% of the phosphorus is from Texasgulf, 8% from cropland runoff, and 10% from WWTPs. Nutrient concentrations in the Pamlico River are similar to those of the Chowan and Neuse Rivers which have already been classified as Nutrient Sensitive Waters (NSW).

Two recent events alter the point source loading of phosphorus into the basin. These events are the enactment of a statewide ban on the use of phosphate detergents and a new NPDES permit and Special Order by Consent (SOC) for Texasgulf Industries. The phosphate detergent ban reduced the phosphorus budget by about 8%. The new permit issued by the Division of Environmental Management (DEM) will reduce Texasgulf's phosphorus loading by about 90%. The projected phosphorus budget after July 1, 1992, when Texasgulf is expected to fully comply with its new permit, is expected to show a decline in Texasgulf's percentage contribution from 65% to 15%.

Several treatment plant designs are capable of removing nitrogen and/or phosphorus from point source discharges. Most of these designs can be implemented relatively easily at existing biological treatment plants. Designs are currently available to meet nutrient limits in biological nutrient removal plants at about 6 mg/l for total nitrogen and 2 mg/l total phosphorus, but these processes have not yet been proven in North Carolina. The cost for implementing biological nutrient removal is very site-and process-specific and ranges from 5 to 50 % more than conventional secondary treatment alone.

Target nutrient reduction levels need to be determined before a final comprehensive management strategy can be selected. Uncertainty about the effects of the new Texasgulf permit and phosphate detergent ban further complicate the selection of a final strategy. Unfortunately, we cannot afford to wait for this information to be obtained before action is taken to control increased nutrient loading into the basin. The Division of Environmental Management believes that the appropriate nutrient management policy would be to strive to not allow additional nitrogen or phosphorus inputs into the basin while this necessary additional information is being gathered.

The Division of Environmental Management recommends that the Tar-Pamlico River Basin be classified as Nutrient Sensitive Waters from the headwaters of the Tar River to a line in the Pamlico River connecting Roos Point and Persimmon Tree Point (Pamlico Point) and that nutrient control strategies be applied to nonpoint sources and also to expanded point sources resulting in discharges larger than 0.5 MGD. It is recommended that these affected point source dischargers be required to meet phosphorus limits of 2 mg/l (quarterly average of weekly samples) and nitrogen limits of 6 mg/l. Effluent phosphorus limits should be enforced upon NSW classification, but nitrogen limits should not be enforced until 1992 to allow affected dischargers time to conduct pilot studies. Stricter limits may be necessary on a case-by-case basis for nutrient-related impacts on small or severely impacted waterbodies. All new point sources should be required to evaluate non-discharge alternatives (such as land application) as a first option. If these new dischargers can show that non-discharge alternatives are infeasible, then those larger than 0.1 MGD should be required to remove nitrogen and phosphorus with the limits outlined above.

It is also recommended that nutrient reduction studies be undertaken through the Albemarle-Pamlico Estuarine Study (APES) to further define target nutrient levels in the Tar-Pamlico River Basin. DEM also strongly encourages the wastewater treatment plants (WWTPs) in the basin to engage in pilot plant studies for nitrogen removal, similar to the phosphorus removal pilot plant work completed in the Haw River basin for Jordan Lake. These pilot tests should target nitrogen limits of 6 mg/l. Possible funding sources include local municipalities, Albemarle-Pamlico Estuarine Study, Water Resources Research Institute, EPA, and/or legislative appropriations. New and expanded treatment plant designs should not preclude the possibility of lower nutrient limits which may be necessary in the future. All renewed NPDES permits in the basin should include a reopener clause to allow the insertion of effluent nitrogen and phosphorus limits if the nutrient reduction studies demonstrate that they are needed and if the pilot plant studies show that they are technically and economically feasible. This nutrient control strategy should be reconsidered every five years beginning in 1992 when the APES project is scheduled for completion. Reconsideration should evaluate any changes in the system, progress toward goals, and modifications necessary to ensure protection of this valuable resource.

INTRODUCTION

Within the last decade, there has been an increasing public awareness of the value of maintaining good water quality in North Carolina's lakes, streams, rivers, and estuaries. Much attention has focused on the Tar-Pamlico River system as it represents one of the largest estuarine systems on North Carolina's coast and supports the most important commercial fishery in the state.

The Pamlico River Estuary has been extensively studied since the mid-1960's by several researchers. Funding for these projects has been provided by both government agencies and industries to study the area and the impacts of mining, development, and land clearing. The purpose of this report is to summarize major concerns of the State and researchers who have studied this basin and to propose a nutrient management strategy to address present and future water quality in the larger Tar-Pamlico Basin. A more detailed analysis of the basin is available in the 1987 Division of Environmental Management's report "Surface Water Quality Concerns in the Tar-Pamlico River Basin" (NCNRCD, DEM 1987).

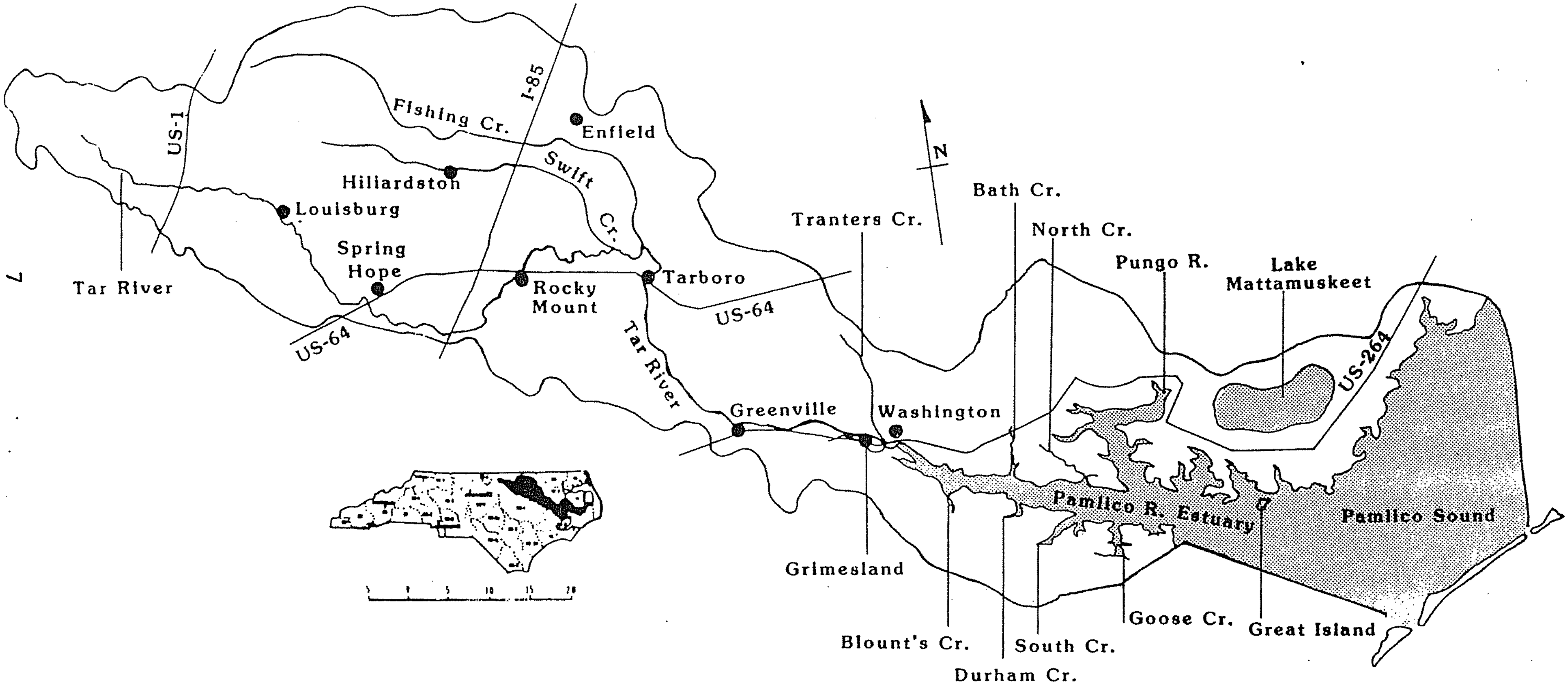
The Tar-Pamlico Basin has a drainage area of 4498 square miles and includes portions of 17 counties (Fig. 1). The population of the basin was 319,769 in 1980. The Tar River comprises the upper portion of the drainage system, flowing from the piedmont of North Carolina across the coastal plain, gradually widening to form the Pamlico River just east of Washington, North Carolina. The Tar River drains 77% of the basin and is roughly 140 miles in length, with a vertical drop of 590 feet.

Near the mouth of the Tar River, a number of tributaries drain marshes and swamps, providing freshwater flow to the Pamlico River Estuary. These include Blount, Tranters and Broad Creeks. Other major downstream tributaries include Pungo River, Durham, Goose, South, Bath, and North Creeks (Fig. 1). The Pamlico River Estuary flows approximately 35 miles before it enters Pamlico Sound near Pamlico Point. The river is about eight miles across at its widest point and has an average depth of six to fifteen feet.

Pamlico Sound is located behind the extensive barrier island system of the North Carolina coast. A limited number of relatively small inlets connect the sound to the Atlantic Ocean. As a result of the limited water exchange through these inlets and the large size and the shallow depths of the sound, wind tides can be substantial. Residence times for water in the sound can be long during low flow periods (Giese et al., 1979).

Salinities of nearly 20 parts per thousand (ppt) have been recorded at the Pamlico Sound end of the estuary and have been noted to range down to zero ppt at the upper end near Washington during high river flows (Hobbie, 1970a; Davis et al., 1978; Kuenzler et al., 1979; Copeland et al., 1984). Such salinity

Figure 1. Tar-Pamlico Drainage Basin



variation is typical of estuarine systems. Partly in response to this, a rich variety of estuarine organisms occurs in the system including floating and rooted plants, planktonic algae and invertebrates, benthic invertebrates, and numerous fishes.

The variety of invertebrates and anadromous and nonanadromous fish has encouraged extensive commercial fishing in the estuary. Important commercial species are southern flounder, blue crab, weakfish, eel, Atlantic croaker, striped mullet, and American shad. The estuary also supports a good recreational fishery. Other important recreational uses provided by the Pamlico's waters include boating, swimming, and other water sports.

Two-thirds of the land surrounding the estuary is forested, with a small amount of land (2%) occupied by cities, roads, and urban development (Copeland et al., 1984). The use of the land is changing, however, as forested land has been converted for agricultural activities (Heath, 1975; Copeland et al., 1984). Because of the low elevation and high water table of the land surrounding the Pamlico River, farming can be effective only if canals and ditches are maintained for drainage (Kirby-Smith and Barber, 1979; Skaggs et al., 1980; Copeland, et al., 1984). This alters the estuary's hydrology by increasing peak freshwater runoff from these drained soils. The Swampbuster provision in the recent Food Security Act may remove some of the incentive for draining additional land for agricultural purposes. Under Swampbuster, farmers who grow crops on wetlands converted since 1985 will lose eligibility for federal assistance such as price supports, crop insurance, and low-interest loans.

Other land-use patterns in the basin potentially conflict with maintaining habitat for estuarine biota. For example, during the last 20 years the number of farm animals being raised in the watershed has grown dramatically, with an estimated 86% increase in the number of hogs and a 241% increase in the number of chickens (United States Department of Commerce, 1983). In addition, low-lying land around the estuary coupled with high water tables make contamination from failing septic tanks a possibility. Development of the watershed adjacent to the estuary also threatens commercially valuable shellfish beds (Copeland et al, 1984). The phosphate mining industry also contributes large volumes of industrial effluent to the system.

Of special concern to the benthos and larval fish is alteration of the normal hydrology within primary nursery areas. Delivery of fresh water, sediment, and nutrients without natural wetland buffers is detrimental to these areas. Sedimentation has been implicated in impacts to benthic organisms and in loss of broadleaf submerged aquatic vegetation. Organic matter deposited in the estuary may further reduce dissolved oxygen concentrations in the bottom waters which experience natural oxygen depletion during some parts of the year. This organic matter either enters the estuary through tributary inflow or is produced within the system by phytoplankton.

Excessive growth of phytoplankton is a major concern in the estuary. Existing nutrient concentrations are capable of supporting bloom levels of phytoplankton during all seasons. Load reductions of major nutrients is the most appropriate management strategy available for reducing bloom potential.

Impacts noted in the Pamlico Estuary include a marked decrease in submerged aquatic vegetation, sporadic fish kills, periodic algal blooms, and periods of deoxygenation. Epperly and Ross (1986), believe that development has negatively impacted the Pamlico-Albemarle watershed and that this stress is likely to increase unless management actions are taken.

NUTRIENTS AND PHYTOPLANKTON

Nitrogen and phosphorus are critical nutrients for algal growth. Elevated nutrient levels often lead to noxious algal blooms in aquatic systems. Within the Chowan River system, elevated nutrient levels in combination with a long retention period have lead to problematic blue-green algal blooms which prompted designation of the system as Nutrient Sensitive Waters by the Environmental Management Commission in 1979. Nitrogen and phosphorus concentrations in the Pamlico are comparable to those of the Chowan. For instance, average total phosphorous levels from 1977 to 1981 in the Chowan River at Colerain were 0.12 mg/l while at Tarboro in the Tar-Pamlico basin they averaged 0.15 mg/l. Total nitrogen levels were 0.96 mg/l in the Chowan and 0.85 mg/l in the Tar River (data from NCNRCD-DEM, 1989).

The Tar-Pamlico River basin contains 634,400 acres of salt (class SA, SB, or SC) water. Water quality in the Tar-Pamlico basin has been assessed by DEM (NCNRCD, DEM 1988) in its 1986-87 305B report. About 89% of the acres support their designated uses (such as shellfishing or fish reproduction) while 11% partially support their uses. Most of this supporting acreage is in Pamlico Sound. The partially supporting areas are primarily in the Pamlico River from Washington to the Pungo River. In this area, extensive fish kills and high chlorophyll a levels are noted. The Tar-Pamlico basin had the highest reported incidence of fish kills and algal blooms of any North Carolina river basin in 1986-1987.

Environmental concerns related to increased phosphorus concentrations and subsequent eutrophication in the Pamlico were raised in 1965 with the establishment of Texasgulf Sulfur, now Texasgulf Chemicals Company - a phosphate mining, fertilizer and acid producing operation located along the south shore of the estuary. In 1966 funding was provided from various state agencies, as well as from Texasgulf, to begin monitoring phosphorus levels in the Pamlico. This monitoring has continued until the present resulting in a large data base for nutrients in the Pamlico River. An analysis of these data concluded that there is significant seasonal and annual variability in the system, and that this variability was equally important to long-term trends in nutrient loading (Stanley, 1988).

Within the Tar-Pamlico system, phytoplankton and chlorophyll a data have been collected at numerous stations by various agencies and researchers since 1970. These studies indicate that there are generally two periods of phytoplankton blooms each year (Hobbie, 1971, 1974; Hobbie, et al., 1972; Kuenzler, et al., 1979). The first - a winter bloom - is dominated by the dinoflagellate Heterocapsa triquetrum (formerly Peridinium triquetrum) and usually occurs in the middle parts of the estuary between January and April (Hobbie, 1970a, 1971, 1974; Hobbie, et al., 1972). The second bloom occurs in late summer and is smaller than the winter bloom. This summertime bloom is composed of dinoflagellates in the upper reaches of the estuary and diatoms in the lower portions (Hobbie, 1971; Kuenzler, et al., 1979). The dinoflagellate blooms that have been documented in the Tar-Pamlico River Basin have not been proven to be toxic to other aquatic organisms. They do, however, produce large amounts of organic carbon which can lead to oxygen depletion in the estuary (Davis, et al., 1978).

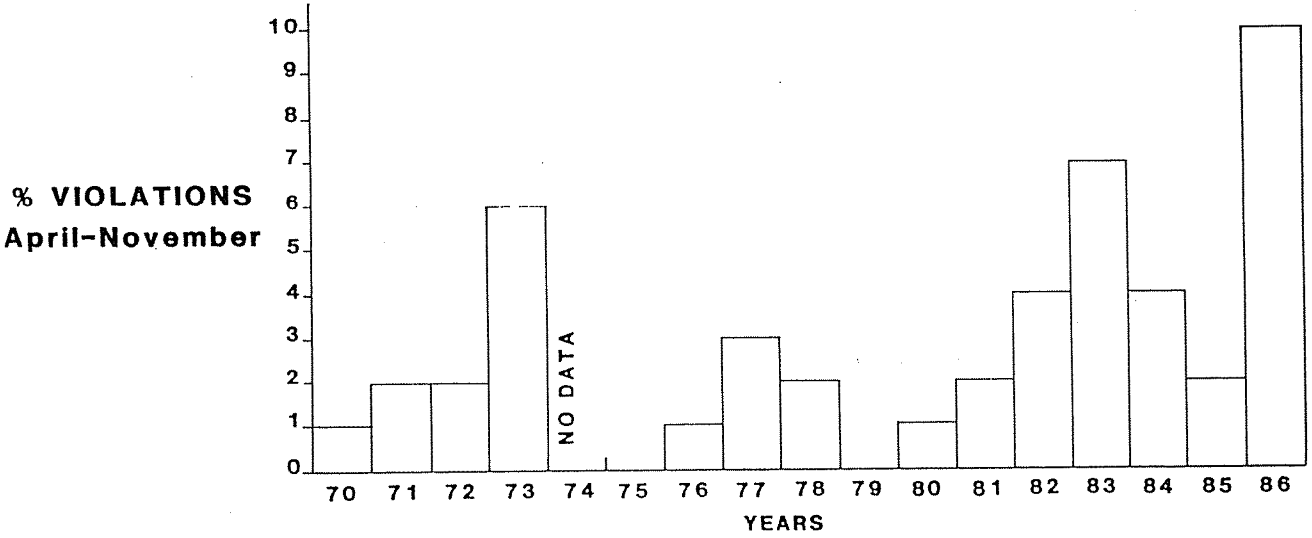
Both Hobbie (1971) and Kuenzler, et al. (1979) have studied the composition of dominant phytoplankton species in the Pamlico River. A comparison of these data indicates that there has been no change in species composition between these studies (Kuenzler, et al., 1979; Copeland, et al., 1984). The data also suggest that phytoplankton abundance and primary productivity increased between the 1966-1967 Hobbie study and studies conducted during 1975-77 (Davis, et al., 1978; Kuenzler, et al., 1979). However, since these were short-term studies and there is considerable yearly variation, it is unclear whether these changes are real.

Most researchers agree that nitrogen is the limiting factor in phytoplankton abundance in the estuarine portion of the Tar-Pamlico system (Hobbie 1971, 1974; Hobbie, et al., 1972; Harrison and Hobbie, 1974). Hobbie (1971) has suggested that turbid waters of the upper reaches limit the growth of algae (even though nitrogen and phosphorus are plentiful) and it is only in the clearer middle reaches that phytoplankton blooms can develop.

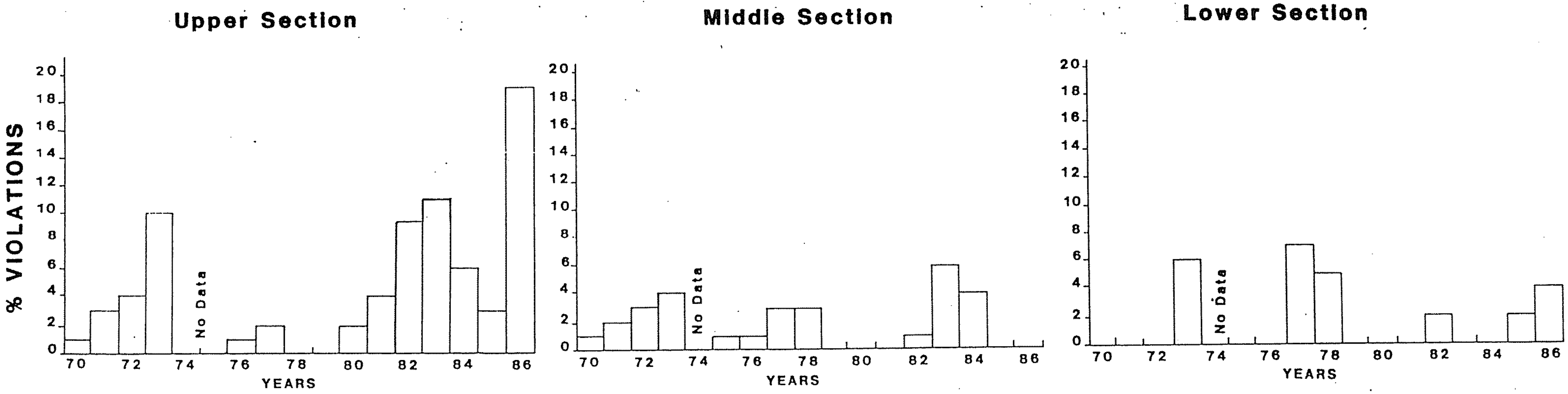
In 1979, the North Carolina Environmental Management Commission adopted a chlorophyll a water quality standard of 40 ug/l for all lakes, sounds, estuaries, reservoirs and other slow-moving waters not designated as trout waters. This standard applies during the summer months of April through November. A review of chlorophyll a data from 1970-1986 is shown in Figure 2 (Hobbie, et al., 1972; Hobbie, 1974; data from Stanley, 1975-1984; data from NCDNRCD DEM). A line from Durham to Bath Creeks separated section 1 (upper) from section 2 (middle). A line from the western edge of the mouth of the Pungo River to Goose Creek separated section 2 (upper) from section 3(lower).

The highest number of samples exceeding the 40 ug/l limit occurs in the winter months of January through March, when the standard is not applicable. From 1970 to 1986, 4% of the

FIGURE 2: % CHLOROPHYLL a VIOLATIONS VS TIME



% CHLOROPHYLL a VIOLATIONS VS TIME FOR EACH RIVER SECTION



chlorophyll a values were greater than 40 ug/l. The highest violation rate occurred in 1986 when 10% of the measurements exceeded 40 ug/l (19% in the upper river section). From 1979 to 1983, rates of violation increased annually. Violations decreased in 1984 and 1985 but then increased in 1986. Highest rates of violation generally occurred in the upper section of the river. Violations in the lower section of the river were always less than or equal to 7%. Violations appear to be cyclic (Fig. 2) but data are too sparse to confirm this conclusion. Subsequent decomposition of these wintertime blooms contribute to the organic carbon pool and to oxygen depletion during the summer months.

On July 21 and 22, 1987, DEM staff conducted an intensive survey of the Pamlico River for nutrients and chlorophyll a at 25 stations (Fig. 3). Chlorophyll a levels were greater than 40 ug/l from the Chocowinity Bay-Pamlico River junction to the Durham-Bath Creek line. The highest values recorded (230 and 380 ug/l) were found in Blounts Bay and near Goose Creek State Park, respectively. How often these extremely high chlorophyll a values are present is unknown but these results reinforce the need for a better understanding of temporal and spatial variation in chlorophyll a values in the Pamlico River and Sound.

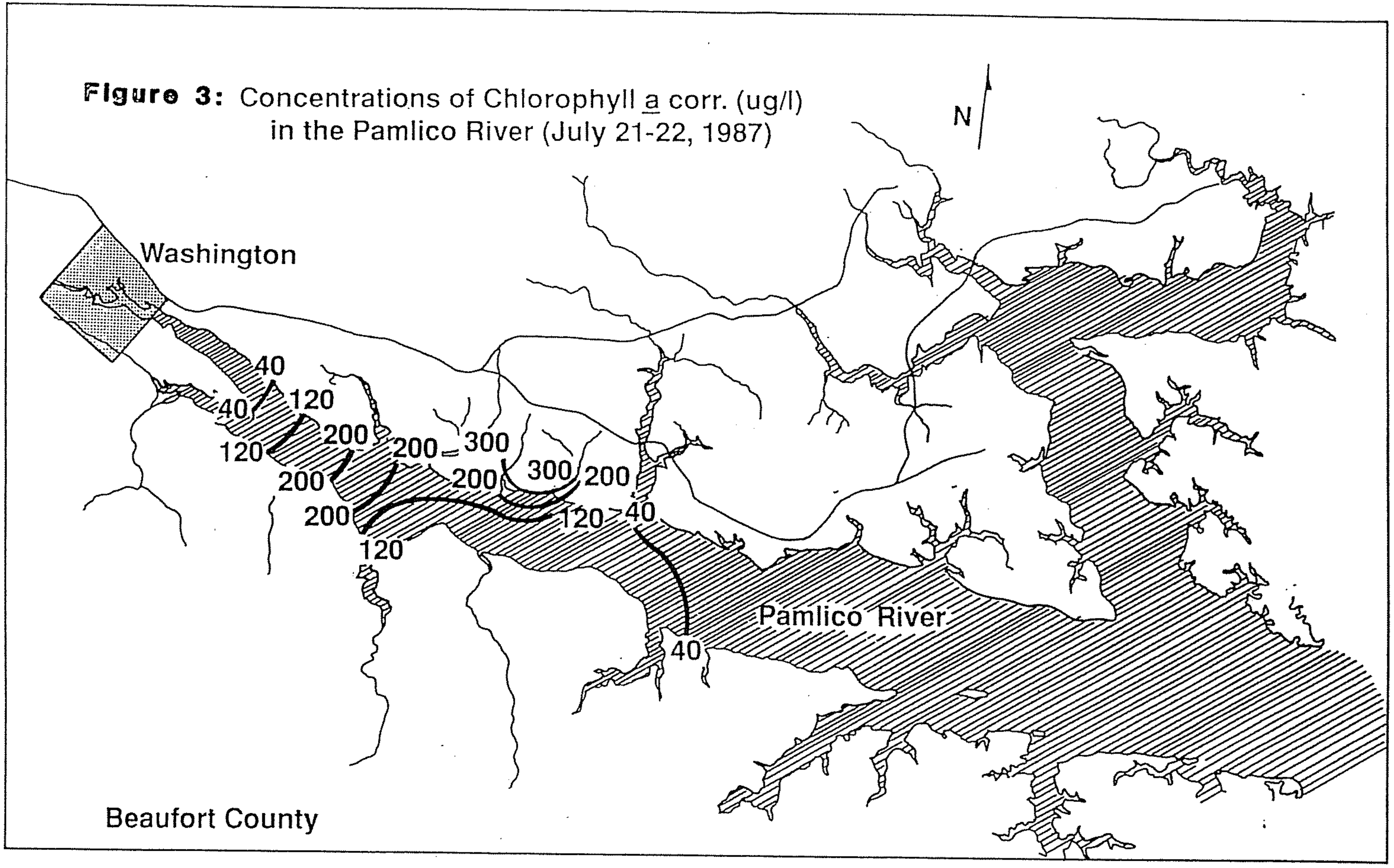
Data collected by DEM during the summer of 1988 on the Pamlico River from Washington to the Pungo River indicate that the upper portion of the Pamlico continues to experience excessive growth of phytoplankton during the winter and summer months. Highest summer chlorophyll a and phytoplankton populations were seen at the Highway 17 bridge where chlorophyll a ranged from 69 to 170 ug/l.

Even though the algal blooms of the Tar-Pamlico River system are not comprised of the same species as the blooms of the Neuse and Chowan Rivers, there is still reason for concern. Many of the same dinoflagellates noted in the Pamlico River blooms are common in tributaries to the Chesapeake Bay and other polluted or nutrient enriched systems (Hobbie, 1971). These phytoplankton and filamentous algal blooms play a significant role in eutrophication and contribute to the severity of low oxygen conditions and frequency of citizen complaints concerning odors, fishing disruptions and blockage of boat landing access by increased macrophyte populations.

NUTRIENT LIMITATIONS ON PHYTOPLANKTON GROWTH

The magnitude of Texasgulf's phosphorus load has caused local residents, fishermen, scientists, organized citizen groups (e.g. The Pamlico-Tar River Foundation, The National Wildlife Association, and the Sierra Club), and state and Federal regulatory agencies to question Texasgulf's effects on the river's ecosystem and water quality. Unfortunately, most past research efforts have not been directed toward establishing clear relationships between nutrient loading and water quality variables of concern (e.g., chlorophyll a or algal

Figure 3: Concentrations of Chlorophyll a corr. (ug/l) in the Pamlico River (July 21-22, 1987)



species/biomass). A large amount of water quality data has been collected for the estuary (Hobbie 1970b, 1972, 1974; Stanley 1975-1985). However, the task remains to develop descriptive and predictive tools to relate system inputs and estuary responses. In situ dilution bioassays (nutrient reduction studies) may be required to determine actual nutrient reductions necessary to limit phytoplankton growth in the lower estuary.

Kuenzler et al., (1979) have provided some important preliminary information which could be used to develop mechanistic models for relating rates of nutrient uptake to those for primary productivity. A modeling framework should incorporate this information so that chlorophyll a and/or other productivity responses (and their response to nutrient management) can be quantitatively predicted. Lauria and O'Melia (1980) developed a nutrient model for the Pamlico River, but its link to chlorophyll a was not clear and did not incorporate Kuenzler's nutrient kinetics information. Once a modeling framework is established, nutrient loading estimates and ambient water quality data can be used to calibrate and verify the model.

Some researchers have concluded that the Tar-Pamlico River system is naturally rich in phosphorus, though predevelopment baseline data are lacking. As of 1970, the estuary contained more than sufficient phosphorus year-round to support abundant algal growth (Hobbie, 1970b; Hobbie et al., 1972; Hobbie, 1974; Harrison and Hobbie, 1974; Kuenzler et al., 1979). Hobbie et al. (1972) noted that the estuary could be divided into three segments, based on differing concentrations of phosphorus. In 1974, Hobbie reported this zonation as follows: (1) an upper zone with moderate phosphorus concentrations due to inputs from rivers and streams; (2) a middle zone with high concentrations resulting from inputs from Texasgulf; and (3) a lower zone (mouth of the estuary) with lower phosphorus concentrations as estuarine waters are mixed with those from Pamlico Sound.

In 1969, after three years of intensive phosphorus monitoring with poor correlation between phosphorus concentrations and algal blooms, researchers began to focus their attention on nitrogen as the element whose concentration might be controlling algal growth (Hobbie et al., 1972). Nitrogen appears to be the major factor limiting production in the estuary (Harrison and Hobbie, 1974; Hobbie, 1974). It is least available during the summer and appears to trigger winter dinoflagellate blooms (Kuenzler et al., 1979). Ammonium-nitrogen has been reported at moderately high levels throughout the estuary on a year-round basis (Hobbie et al., 1972; Kuenzler et al., 1979). Hobbie (1974) has suggested that ammonium may be recycling in the Pamlico. Nitrate-nitrogen is present in the lowest quantities relative to plant needs (Hobbie, 1974), fluctuating between summer low and winter high concentrations (Hobbie et al., 1972). Hobbie et al., (1972) suggested that inorganic nitrogen concentrations are affected by Tar River flow. During times of highest flow (winter), there is a build up of nitrate at the upper end of the estuary. This build up appears to trigger winter dinoflagellate blooms in the middle of the estuary (Hobbie et al., 1972; Hobbie, 1974; Kuenzler et al., 1979).

On June 25, 1987, the EPA Region IV staff conducted an Algal Growth Potential Test using water samples from the Pamlico River. The EPA used a marine algae (Dunalicella tertiolecta) on samples at the Highway 17 bridge (station 1), Texasgulf on the south shore (station 2) and across from Texasgulf on the north shore (station 3). They added either 1 mg/l N or 0.05 mg/l P. The nitrogen additions substantially increased growth at all three stations (53% at station 1, 660% at station 2 and 139% at station 3). Phosphorus additions had no significant effect at any station. The test confirms earler work which concluded that nitrogen limited algal growth in the Pamlico River. However, it is possible that the phosphate detergent ban and new Texasgulf permit could eventually reduce phosphorus inputs into the basin enough to shift the system towards phosphorus limitation during some parts of the year.

Lauria and O'Melia (1980) suggested that:

(1) During winter high-flow periods, nitrate enters the estuary from upstream sources via the Tar River. This available nitrate, in conjunction with abundant phosphorus in the system, results in the winter dinoflagellate blooms that occur in the middle of the estuary.

(2) During summer low-flow periods, the estuary is very nitrogen-limited as upstream inputs are decreased by lower runoff and perhaps by nitrogen-retaining processes on land.

(3) During summer, higher saline bottom waters from Pamlico Sound move up the estuary, transporting phosphorus from the Texasgulf area. Summer stratification commonly occurs and bottom waters may become phosphorus enriched as phosphorus is released from the sediment under anoxic conditions.

(4) Summer blooms result at the upper end of the estuary where nitrogen is more abundant, relative to the remaining areas of the estuary.

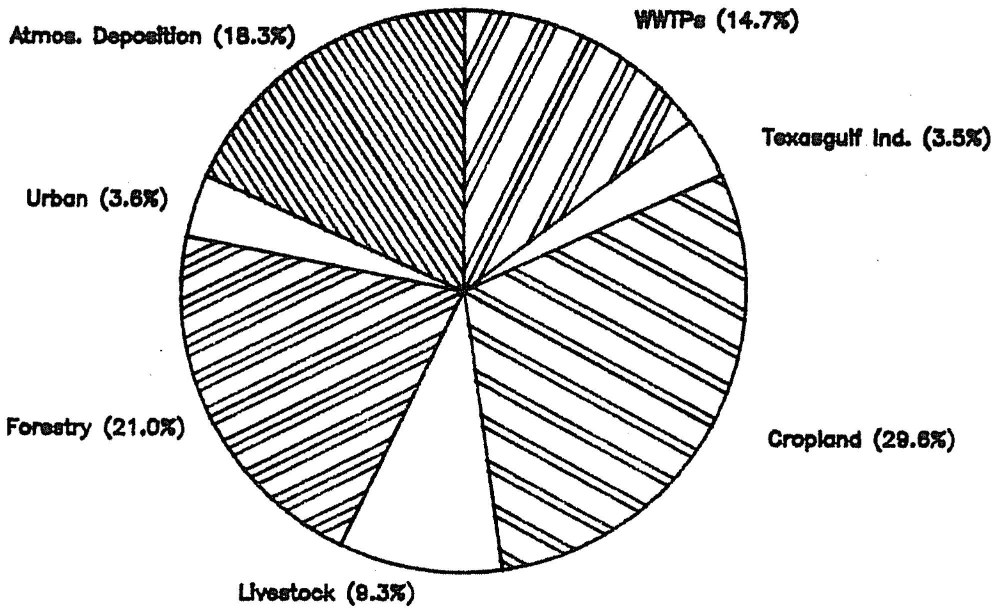
Lauria and O'Melia (1980) based their hypotheses on mathematical models from 1970-1973 Pamlico data collected by Hobbie. They concluded that from 1970-1973 nitrogen was the major limiting nutrient in the summer. During the winter, phosphorus was limiting only in the upper end of the estuary.

TAR-PAMLICO RIVER BASIN NUTRIENT BUDGETS

Nutrient budgets for the Tar-Pamlico Basin were revised to include effluent data from 1986-88. In addition, nonpoint source nutrient loading was separated into contributions from cropland, forestry, animal operations, urban runoff, and atmospheric deposition based on new information. These revised budgets are shown in Figure 4 and Table 1.

FIGURE 4

1988 TAR-PAMILICO NITROGEN BUDGET



1988 TAR-PAMILICO PHOSPHORUS BUDGET

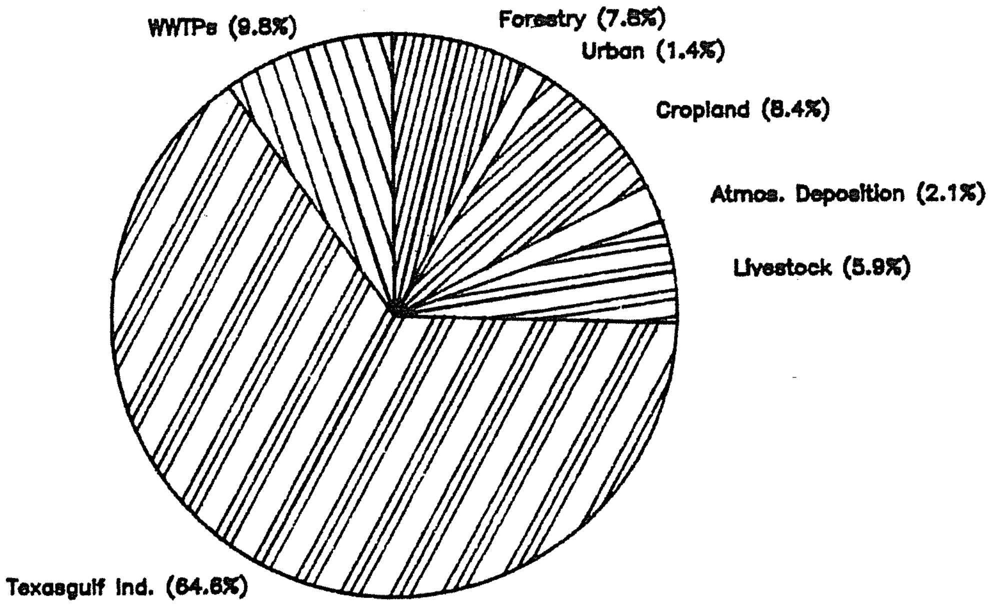


TABLE 1: TAR-PAMLICO RIVER BASIN NUTRIENT BUDGET

	1988 TOTAL NITROGEN		1988 TOTAL PHOSPHORUS (a)		1988 TOTAL PHOSPHORUS (b)	
	LOADING (kg)	% OF TOTAL	LOADING (kg)	% OF TOTAL	LOADING (kg)	% OF TOTAL
POINT SOURCE						
WWTPs	545496	14.7	95598	9.8	95598	23.4
Texasgulf Ind.	127940	3.5	630299	64.6	63030	15.4
Subtotal	673436	18.2	725897	74.4	158628	38.9
NON-POINT SOURCE						
Cropland	1096498	29.6	82397	8.4	82397	20.2
Livestock	346263	9.3	57259	5.9	57259	14.0
Forestry	780008	21.0	75647	7.8	75647	18.5
Urban	132550	3.6	13301	1.4	13301	3.3
Atmos. Deposition	678046	18.3	20782	2.1	20782	5.1
Subtotal	3033366	81.8	249386	25.6	249386	61.1
TOTAL	3706802	100.0	975284	100.0	408015	100.0

(a) After P ban, before Texasgulf renovations
(b) After P ban, after Texasgulf renovations

Since nutrient budgets were last calculated for the basin in 1986, two major events have occurred which have a significant influence on the present and future phosphorus budgets. First, the North Carolina General Assembly passed a ban on the sale of phosphate detergents which became effective on January 1, 1988. This action resulted in a 40% reduction in point source phosphorus loading to the basin. Overall, this legislation reduced the total phosphorus loading by 8% within the basin. Average effluent total phosphorus levels ranged from 1.56 to 6.98 mg/l before the phosphate detergent ban and from 0.70 to 3.35 mg/l after the ban. The basinwide average phosphorus concentrations before and after the P ban were 3.75 mg/l and 2.25 mg/l respectively. Phosphorus concentrations at Rocky Mount, Tarboro, Greenville, and Washington (after the phosphate ban) were 2.43, 2.36, 3.31, and 0.70 mg/l, respectively.

The second action that will affect future phosphorus budgets is the new NPDES permit for Texasgulf Industries, Inc. When it becomes fully effective, this new permit will result in a 90% decrease in Texasgulf's phosphorus loading. This reduction will translate to an overall phosphorus reduction of 58%. Figure 5 demonstrates the anticipated effects of these two actions on present and future phosphorus budgets. Figure 6 and Table 1 show the expected phosphorus budget after Texasgulf's permit becomes effective. Neither the phosphate detergent ban nor the new Texasgulf permit will significantly affect nitrogen loading into the basin.

Table 2 shows a list of all NPDES permitted dischargers in the basin and their design and average daily permitted flows. At present, there are at least four wastewater treatment plants in the Tar-Pamlico basin under consent orders to expand their design flow, while two other treatment plants are scheduled to cease operations in the near future. In addition, several other facilities are nearing their treatment capacities as shown by the percent of permitted flow column in Table 2. These facilities are likely to request permission to expand within the next few years. These actions will most likely result in increased nitrogen and phosphorus loading to the system.

Average point source total nitrogen concentrations ranged from 5.40 to 22.95 mg/l. The basinwide average effluent total nitrogen concentration was 14.38 mg/l. Nitrogen levels at Rocky Mount, Tarboro, Greenville, and Washington were 11.80, 18.23, 14.47, and 19.22 mg/l, respectively.

Several nutrient management alternatives were reviewed to determine their effectiveness in reducing nutrient inputs to the basin. Nitrogen limits of 3, 6, 8, and 10 mg/l and phosphorus limits of 1 and 2 mg/l were applied to facilities with design flows of 0.1, 0.5 and 1.0 MGD to determine the approximate percentage reduction in nutrient loading for each alternative. Reductions in phosphorus inputs ranged from 5 to 15 % and

FIGURE 5

TAR–PAMLICO PHOSPHORUS LOADING TRENDS

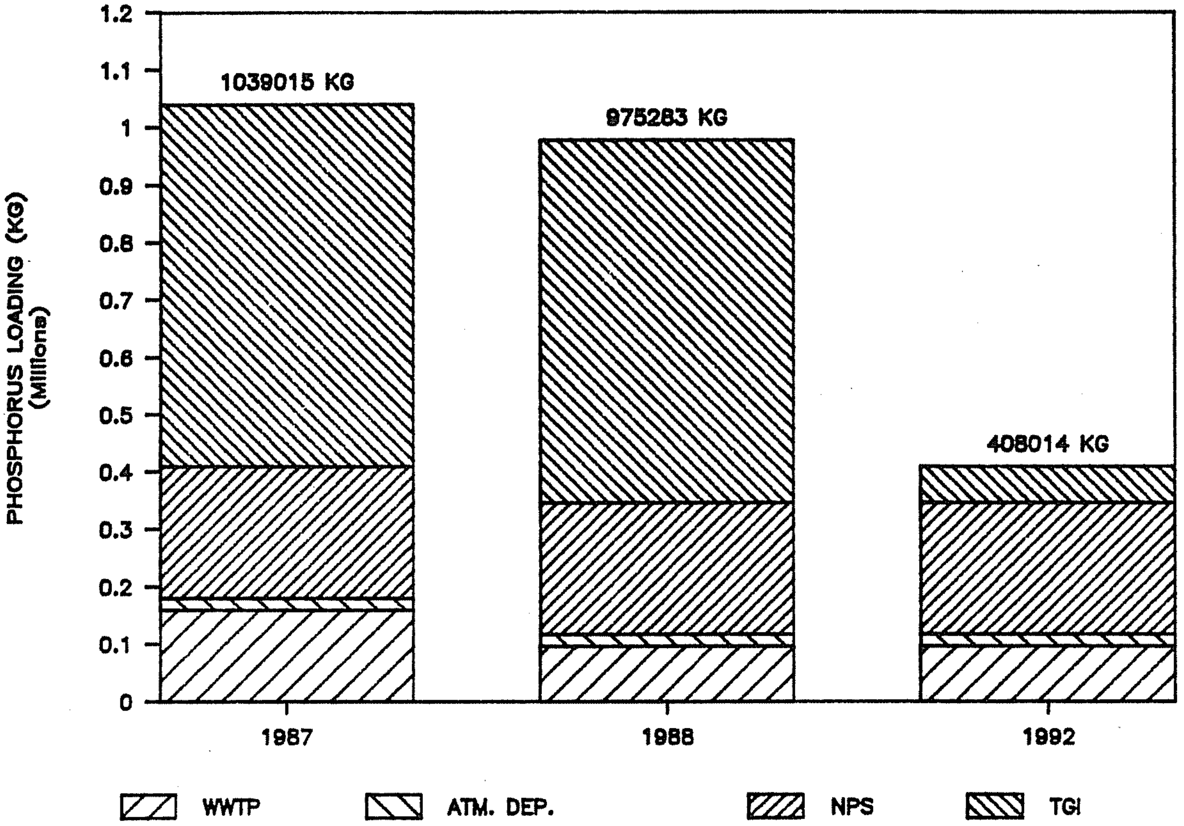


FIGURE 6

1988 REVISED PHOSPHORUS BUDGET

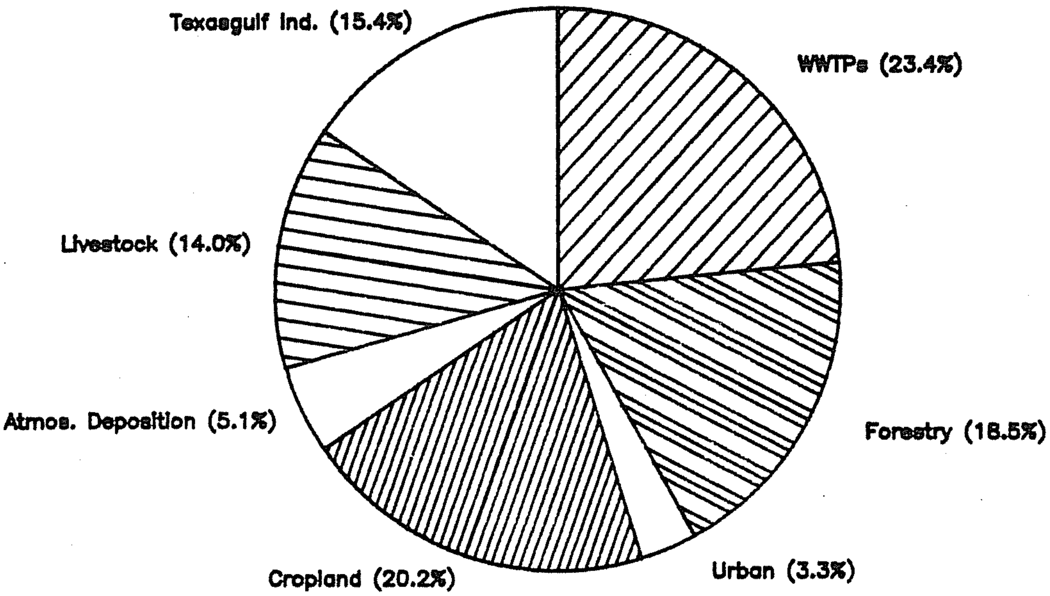


Table 2: NPDES permitted facilities in the Tar-Pamlico Basin with design flows larger than 0.1 MGD. *

FACILITY	NOTES	PERMIT	CURRENT DES. FLOW	AVERAGE FLOW	PERCENT OF DESIGN
Aurora WWTP		NC0021521	0.120	0.075	63
Belhaven WWTP	#	NC0026492	0.500	0.382	76
Bethel	(a)	NC0025615	0.225	0.197	87
Enfield		NC0025402	0.500	0.296	59
Franklin W&SA		NC0069311	0.500	0.279	56
Franklinton WWTP		NC0020672	0.300	0.186	62
Greenville		NC0023931	10.500	6.539	62
Littleton WWTP		NC0025691	0.280	0.168	60
Louisburg WWTP		NC0020231	0.800	0.473	59
Macclesfield		NC0050661	0.175	0.034	19
Nat. Spinning Co.		NC0001627	1.750	1.124	64
Oxford (Northside)	(b)	NC0025062	0.630	0.292	46
Oxford (Renovated)	(c)	NC0025054	1.250	0.325	26
Oxford (Southside)	(b)	NC0021415	0.750	0.790	105
Pinetops WWTP	#	NC0020435	0.300	0.277	92
Robersonville	(d)	NC0026042	1.200	0.961	80
Rocky Mount	#	NC0030317	14.000	10.384	74
Scotland Neck	(e)	NC0023337	0.675	0.287	43
Seaboard RR		NC0001503	0.100	0.039	39
Spring Hope WWTP		NC0020061	0.400	0.129	32
Tarboro WWTP		NC0020605	3.000	2.013	67
Warren County WWTP		NC0020834	2.000	0.321	16
Washington WWTP		NC0020648	2.250	1.444	64

Notes:
(a) - expanding to 0.75 MGD
(b) - to be abandoned
(c) - expanding to 2.17 MGD
(d) - expanding to 1.8 MGD
(e) - expanding to 0.9 MGD
- may soon need to expand

* - From Division of Environmental Management's Files

reductions in nitrogen inputs ranged from 4 to 12 % depending on facility size and nutrient limit. Results of these analyses are included in Appendix A.

NUTRIENT REMOVAL TECHNOLOGY

A major consideration when developing a strategy to control point source inputs of nutrients is the availability of economical and reliable treatment methods capable of removing nitrogen and phosphorus from point sources. A recent review (Appendix B) revealed several wastewater treatment alternatives which could be employed to reduce point source nutrient loadings to the estuary. Since nitrogen has been hypothesized as the major limiting nutrient for controlling algal blooms in the Pamlico River estuary, this review highlighted methods which could reduce nitrogen loadings to the basin. Methods which could reduce both nitrogen and phosphorus were also emphasized. To our knowledge, nitrogen removal processes have not been pilot tested in North Carolina, although they have been tested in other states (e.g. Virginia, Maryland, and Florida). In contrast, phosphorus removal processes have been extensively pilot-scale tested in facilities upstream of Jordan Lake.

This evaluation revealed that technology is available to limit total nitrogen concentrations to 6 mg/l throughout the year through biological treatment methods. These same biological processes are capable of achieving nitrogen concentrations of 2 mg/l during summer months, but biological activity slows during the colder winter months resulting in lower nitrogen removal rates. One must note that these limits are only achieveable if sufficent organic carbon is available to allow complete denitrification. Treatment plants with low BOD influents may have to add an external carbon source such as methanol to ensure denitrification, thereby increasing operating costs. Chemical nitrogen removal has been demonstrated to be reliable for removing nitrogen to 2 mg/l year-round. Chemical removal, however, is significantly more expensive than biological removal. Appendix B discusses these nitrogen removal processes in detail.

Biological phosphorus removal processes can consistently meet total phosphorus limits of 2 mg/l. Effluent total phosphorus concentrations well below 1 mg/l can be achieved using chemical phosphorus removal. Because the addition of chemicals to precipitate excess phosphorus results in increased sludge volume and sludge handling costs, larger wastewater treatment plants usually elect to utilize biological phosphorus removal to meet phosphorus limits of 2 mg/l. Many small treatment plants, however, have found chemical removal to be more cost-effective because of the larger capital investment required for biological phosphorus removal. The phosphate detergent ban may make chemical phosphorus removal more cost effective for all treatment plant sizes since lower influent phosphorus concentrations will require less chemical addition to achieve desired limits, thereby minimizing chemical costs and additional sludge handling costs. Appendix B also discusses phosphorus removal processes.

The estimated cost for a new treatment plant including biological nitrogen and phosphorus removal ranges from approximately $1.5 million for a 1 MGD plant to approximately $6 million for a 10 MGD facility. Plants constructed to remove only nitrogen cost about 10% less than if both nutrients are removed. Depending on which biological nutrient removal process is selected, significant patent fees may be required.

Existing wastewater treatment plants can often be adapted to biological nutrient removal. Anaerobic, anoxic, and aerobic zones are created within the plant to make conditions favorable for appropriate microorganisms to promote nitrification and denitrification as well as excess phosphorus release and subsequent luxury uptake of phosphorus. Retrofitting existing treatment works to biological nitrogen and phosphorus removal can be accomplished at a cost of approximately $900,000 for a 1 MGD facility and approximately $3.5 million for a 10 MGD facility.

Sequencing batch reactors may prove to be more cost-effective than continuous flow systems for facilities smaller than 0.5 MGD. In addition, sequencing batch reactors have been shown to be more reliable for removing nutrients because they are more easily regulated than continuous flow systems.

Pilot-scale testing will be necessary before a particular nutrient removal design can be selected at a given treatment plant due to the site- and influent-specific nature of biological nutrient removal processes. A cooperative regional effort would probably prove most useful for gathering these critical data.

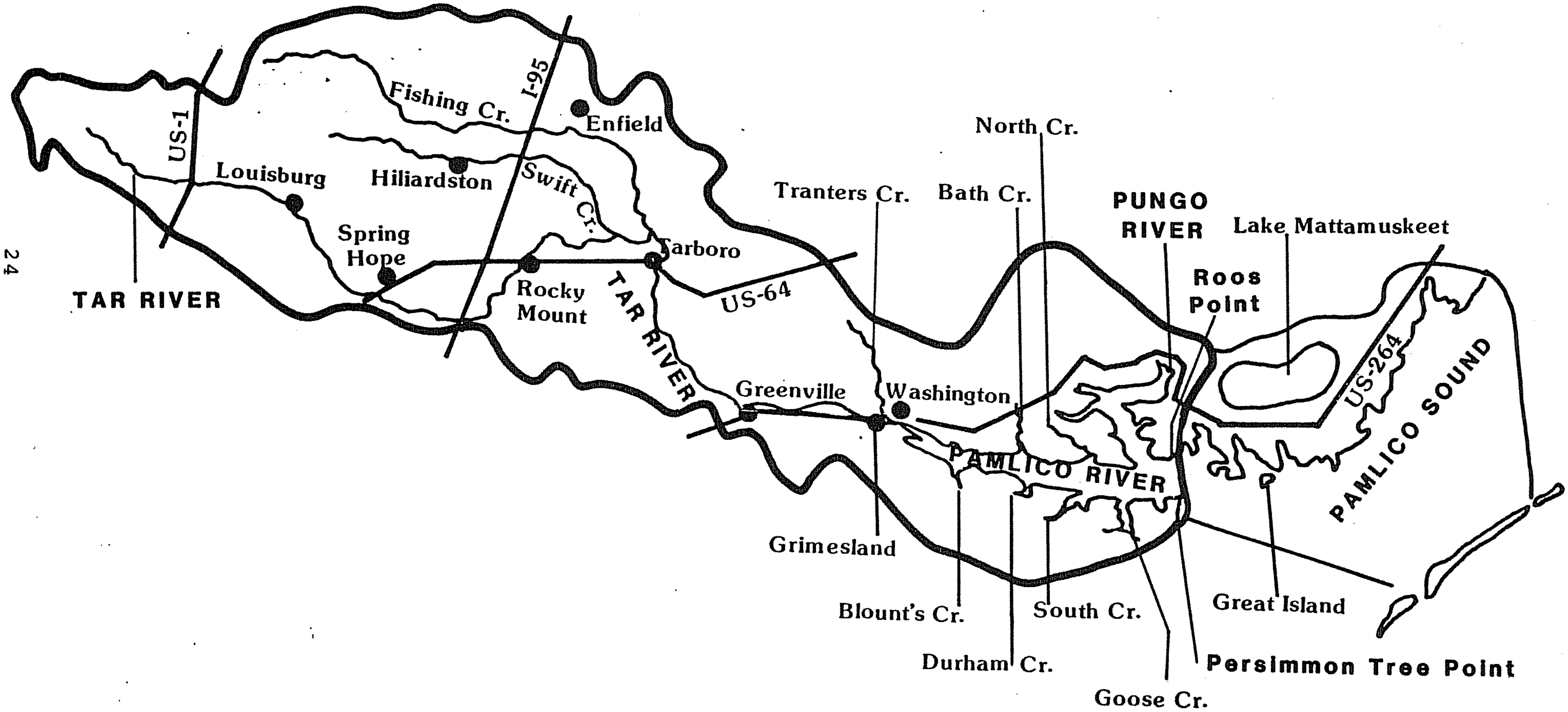
NUTRIENT MANAGEMENT STRATEGY

Given the complex nature of the Tar-Pamlico River Basin, it is difficult to recommend a plan of action that would best serve the needs of the basin and the citizens who live there. The major uncertainties that preclude complete nutrient limitations on dischargers at this time are: 1) the future effect of Texasgulf's removal of the vast majority of their phosphorus inputs to the river, 2) the lack of specific nutrient reduction targets, 3) uncertainty about the technical and economic feasibility of nitrogen removal processes, and 4) the relatively small effect of point source N or P removal on the overall budget (see Appendix A). Therefore, selecting an alternative that strikes the proper balance between cost and effectiveness is difficult. Unfortunately, we cannot afford to wait until all the necessary information is obtained through research because the problems are growing along with continued development in the basin. Due to these major uncertainties and in light of the continuing problem, we believe that an appropriate policy would be to strive to not allow additional nitrogen or phosphorus into the basin.

It is recommended that the basin be classified as Nutrient Sensitive Waters from the headwaters of the Tar River to a line in the Pamlico River connecting Roos Point and Persimmon Tree Point (Pamlico Point) (see Figure 7) and that nutrient control

FIGURE 7
TAR-PAMLICO RIVER BASIN

PROPOSED NSW BOUNDARY



strategies be developed for nonpoint sources and also for new and expanded point source dischargers. We recommend that no nutrient controls be imposed on existing point sources unless they expand to result in a design flow greater than 0.5 MGD. This action will essentially keep nutrient loadings at their current levels. Any new or expanded point source dischargers would be required to meet effluent limits for nitrogen and phosphorus. In addition, renewed NPDES permits should include a reopener clause which would allow effluent limits on nitrogen and phosphorus to be included at any time in the future depending on the results of pilot scale testing and nutrient reduction studies. Effluent total phosphorus limits should become effective on the date the basin is classified NSW. Total nitrogen limits should become effective in 1992 to allow the dischargers ample time to conduct necessary pilot nitrogen removal studies.

The NSW designation will provide agricultural cost-share funds to allow farmers to implement best management practices thereby reducing nonpoint source nutrient loadings. Locating problem animal operations should be a priority for the nonpoint source strategy.

DEM believes that total phosphorus limits of 2 mg/l and total nitrogen limits of 6 mg/l (quarterly average of weekly samples) can be met at a reasonable cost to large new or expanded dischargers. Most dischargers already have effluent phosphorus levels near 2 mg/l since the phosphorus detergent ban. This fact makes chemical phosphosus removal more cost-effective than before the ban to meet a 2 mg/l limit. Stricter limits, or a moratorium on increased pollutant loading, may be necessary on a case-by-case basis for waterbodies severely impacted by eutrophication or oxygen depletion. Wastewater treatment plants should not preclude the possibility of lower nutrient limits which may be necesary in the future depending on additional nutrient studies in the basin.

DEM suggests that the above limits be required of all expanded dischargers that result in a design flow greater than 0.5 MGD unless the discharger can prove that meeting these limits would be technically or economically infeasible. All new dischargers should be required to implement a non-discharge system (for instance, land-based disposal) unless the discharger can prove that this option is technically or economically infeasible. If non-discharge is infeasible, then all new dischargers larger than 0.1 MGD should be required to remove phosphorus similar to the expanded plants mentioned earlier. The 0.5 MGD cutoff for expanded dischargers was selected because facilities larger than 0.5 MGD represent 94 % of the point source total nutrient loading. Therefore, nutrient controls for smaller facilities would not result in a significant reduction in nutrient loadings. In addition, this size cutoff is consistent with DEM's policy in the Neuse River Basin where discharges larger than 0.5 MGD are required to meet total phosphorus limits. The 0.1 MGD cutoff was selected for new dischargers because we anticipate that growth in the basin will result in permit requests from several medium sized (0.1 MGD - 0.5 MGD) communities and sub-divisions. In addition, facilities larger than 0.1 MGD will generally require an experienced full-time attendant with or without nutrient removal.

We suggest that the wastewater treatment plants in the basin engage in pilot studies to evaluate biological nitrogen removal processes. These pilot studies should target an effluent nitrogen concentration of 6 mg/l and should be completed by 1992 at which time effluent nitrogen limits will become effective.

This recommendation should not be viewed as the long term solution to the water quality problems in the Tar-Pamlico River Basin but rather as an interim measure until actual target reductions can be determined and the effects on the river of Texasgulf's new permit requirements are evident. Furthermore, we believe that a nutrient reduction study should be a top priority for APES funding. This study would determine what reduction in nutrient loadings is necessary to alleviate the water quality problems in the Pamlico River Estuary. Once this information is known and the effects of the Phosphate Detergent Ban and new Texasgulf permit are considered, then a long-range plan of action can be selected. Reconsideration of this nutrient management strategy should be undertaken by DEM and APES at the completion of the APES effort in 1992 and every five years thereafter.

APPENDICES

APPENDIX A

EFFECT OF POINT SOURCE LIMITATIONS ON NUTRIENT BUDGET

Outlined below are alternative point source management strategies for the Tar-Pamlico basin with respect to the NSW designation. The strategies below are in addition to the NSW nonpoint source (NPS) option discussed in the Tar-Pamlico report. Some reductions (8%) in phosphorus loading have already occurred from the phosphate detergent ban and further reductions (45%) will result from Texasgulf's new permit. All options considered below assume that the P ban and Texasgulf reductions are already in effect.

A. Phosphorus control at existing point sources

These could vary by limit (1 or 2 ppm P) and facility size (>1 MGD, >500,000 GPD and >100,000 GPD). In addition, it may be possible to consider P limits geographically (piedmont vs coastal plain) but this is not analyzed in detail below. The approximate effect of these options on the overall revised P budget (taking Texasgulf and the detergent ban into account) is listed in the table below.

Approximate percent reduction in overall, revised P budget.

	Size		
Limit	>1 MGD	>500,000 GPD	>100,000 GPD
1 mg/l	12.7%	14.5%	14.8%
2 mg/l	5.2%	5.4%	6.0%

B. Nitrogen control at existing point sources.

These could (as with P) vary by limit (10, 8, 6 or 3 mg/l), facility size (> 1 MGD, >500,000 GPD or >100,000 GPD) or geography (coastal plain or entire basin). Geographical options are not analyzed in detail. These options are analyzed below to describe their overall effect on the basin's N budget.

Approximate percent reduction in overall, revised N budget

	Size		
Limit (mg/l)	>1 MGD	>500,000 GPD	>100,000 GPD
10	3.9%	4.4%	4.6%
8	5.5%	6.3%	6.5%
6	7.3%	8.2%	8.5%
3	9.9%	11.2%	11.6%

C. Nutrient controls for new point sources

The effect of these options on the nutrient budget cannot be (easily) predicted. Therefore, no budgetary calculations are presented.

APPENDIX B

NUTRIENT REMOVAL TECHNOLOGY

B.1 Nitrogen Removal

Adaptation of biological nitrogen removal (nitrification-denitrification) to conventional secondary treatment plants has been demonstrated for a wide variety of secondary biological treatment processes including activated sludge, rotating biological contactors (RBCs) and trickling filters. Nitrogen removal basically involves exposing ammonia-containing waste streams to oxygen in the presence of nitrifying bacteria to convert the ammonia to nitrate. The nitrate-containing waste stream is then exposed to anoxic conditions in the presence of denitrifying bacteria and a carbon source to convert the nitrate to nitrogen gas.

Treatment plants already designed to nitrify can realize a 40% reduction in oxygen requirements by denitrifying. This is due to the anoxic stages of a denitrifying plant in which nitrate-bound oxygen is used to satisfy part of the oxygen demand of the wastewater. Additionally, denitrification recovers approximately 50% of the alkalinity consumed during nitrification. These potential reductions in operational costs can help offset increased capital costs for a denitrifying plant.

Existing activated sludge plants can often be easily converted to nitrogen-removal plants simply by adding baffles to create oxic and anoxic zones within the treatment basin (Borberg, personal communication, December 1988). Appropriate recycle lines and pumps may also be required depending on the desired configuration of the zones. Some plants, however, will have to add treatment volume to allow adequate detention times for BOD_5 and nitrogen removal. Additionally, since organic carbon is required as an electron donor in denitrification, an external carbon source, such as methanol, may also be required to achieve complete denitrification.

B.1.a One-sludge Pre-denitrification

Several alternatives are available to eliminate or reduce the requirement for a costly external carbon source for denitrification. One alternative is to use the organic carbon in the influent wastewater as an electron donor. This is done by introducing the raw or settled wastewater into the anoxic zone of the process and recycling nitrate-rich wastewater from the aerobic zone and return sludge to the anoxic zone. This design is known as the one-sludge pre-denitrification process (Figure B-1a) and is the most commonly used design for activated sludge plants. When this process is used, a larger treatment volume is required to maintain adequate solids retention time with the additional recycle flow (Wilson et al., 1981). For wastewater streams with particularly low organic strengths (BOD_5), it may be necessary to bypass primary settling in order to avoid the

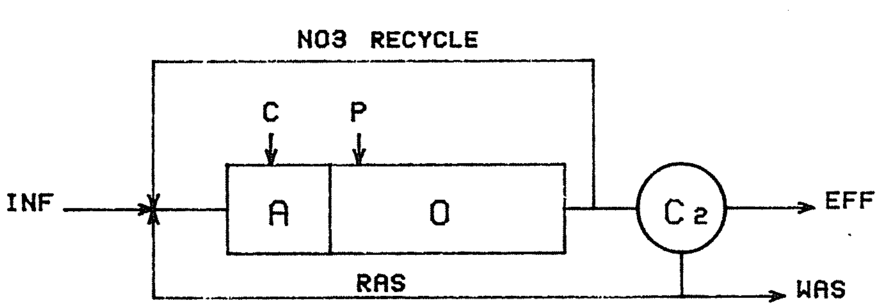


FIGURE B-1a: ONE-SLUDGE PRE-DENITRIFICATION

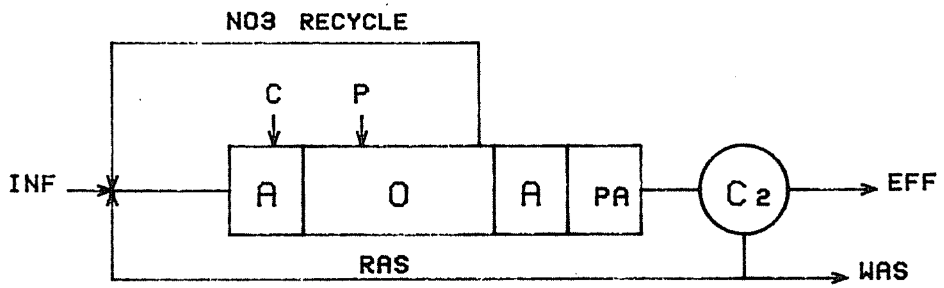


FIGURE B-1b: BARDENPHO

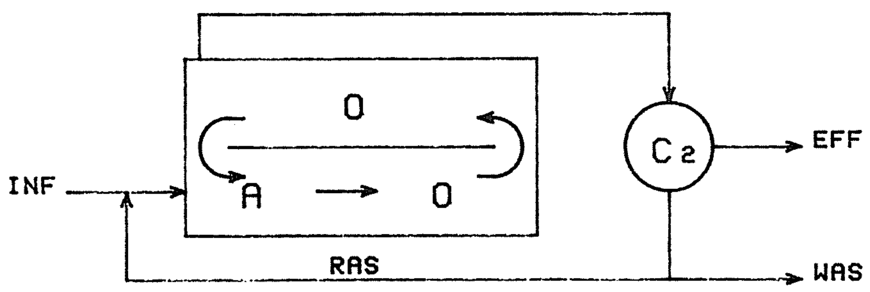


FIGURE B-1c: ROTANOX

LEGEND: INF = Degritted, screened wastewater
EFF = Final treated effluent
A = Anoxic
O = Oxic
WAS = Waste activated sludge
RAS = Return activated sludge
C2 = Secondary clarifier
C = External carbon addition (if necessary)
P = Chemical addition for phosphorus removal (if desired)
PA = Post-aeration

FIGURE B-1: NITROGEN REMOVAL PROCESSES

organic carbon loss that occurs in this process. Again, eliminating primary settling will increase the treatment volume required and oxygen requirements for BOD_5 removal (Ekama et al., 1983).

B.1.b Bardenpho

The Bardenpho process (Figure B-1b) is a variation of the one-sludge pre-denitrification process. Bardenpho incorporates a second anoxic zone after the aerobic zone to insure complete denitrification and better BOD_5 removal. Following the second anoxic zone, post-aeration raises the dissolved oxygen concentrations to 2-4 mg/l to prevent denitrification in the clarifier (Ekama et al., 1983).

B.I.c Rotanox

Rotanox, shown in Figure B-1c, is a modification of the activated sludge process developed in England which was designed for marginal improvement in effluent nutrient concentrations while keeping capital and operating costs at a minimum (Best et al., 1985). Rotanox, which stands for ROTary flow patterns with ANOXic zones, was tested at a full-scale diffused air activated sludge plant in London. A portion of the walls separating two parallel aeration basins were removed to encourage rotary action within the two basins. An anoxic zone was created by removing aerators from 25% of the basin and replacing them with mixers to promote circulation. Effluent nitrogen concentrations below 10 mg/l have been consistently achieved at this plant even at mixed liquor temperatures as low as 10°C.

A major limitation for biological nitrogen removal processes is wastewater temperature. As the temperature drops below 20°C, the rate of nitrification decreases. In many operating biological nutrient removal plants, nitrification has been lost during cold winter months in plants that do not have adequate hydraulic retention time to account for the reduced rates of nitrification (Borberg, 1988; Ekama et al., 1983). One solution to this potential problem may be to have different seasonal total nitrogen standards because biological nitrogen removal normally only experiences failure in winter months.

Under normal conditions, one-sludge pre-denitrification and Bardenpho can produce average effluent total nitrogen concentrations better than 6 mg/l and 4 mg/l respectively while maintaining good sludge settleability and BOD_5 removal. Summer operation of these processes has shown effluent nitrogen concentrations consistently below 2 mg/l (Wilson et al., 1981; Ekama et al., 1983). The experimental Rotanox process has demonstrated nitrogen removal to below 10 mg/l year-round.

Clearly, an effluent TN limit of 10, 8, or 6 mg/l could be met consistently with biological nitrogen removal. To achieve lower effluent concentrations year-round would probably require polishing with more expensive chemical processes such as breakpoint chlorination, ammonia stripping, or ion exchange, especially during winter months.

Existing plants that use rotating biological contactors can also be converted to nitrogen removal by operating some RBCs as aerobic units and others as anoxic units similar to the zones in activated sludge nitrogen removal plants. Anoxic operation could be performed by raising the wastewater level in the RBC, thereby eliminating air space (WPCF, 1983). It may be necessary to add more RBCs to the existing configuration to allow for an adequate solids retention time. Also, flowsheet alterations similar to those for activated sludge may be performed to allow nitrified wastewater to contact the organic-rich influent in the anoxic portion of the plant. Similarly, trickling filter plants can be adapted to biological nitrogen removal by adding nitrification/denitrification facilities.

B.2 Phosphorus Removal

Several processes show promise for removing both phosphorus and nitrogen from wastewater. Typically, for these processes nitrogen is removed in the same way discussed earlier. Phosphorus can then be removed by chemical or by biological means.

B.2.a Chemical Phosphorus Removal

Chemical phosphorus removal can be performed by metal salt addition or by lime precipitation. Metal salt addition for P removal involves adding iron or aluminum salts at any point within the treatment process. A chemical reaction occurs resulting in the precipitation of metal phosphates and subsequent accumulation in sludge. Lime precipitation involves raising the wastewater pH to approximately 9.5. Phosphorus will precipitate and accumulate in sludge. Both of these methods have been shown to produce effluent phosphorus concentrations of 1 mg/l or better. Both methods also result in the generation of significant amounts of chemical sludge which increases sludge handling and land application costs. For small treatment plants or plants with low influent total phosphorus concentrations, chemical phosphorus removal may be the least costly alternative.

B.2.b Biological Phosphorus Removal

Biological phosphorus removal (BPR) consists of anaerobic release of phosphorus followed by aerobic "luxury uptake" of phosphorus by selected microorganisms (Weston, 1985). Phosphorus-rich microorganisms will then be accumulated in waste sludge and removed from the system.

B.3 Simultaneous Biological Nitrogen and Phosphorus Removal

Nutrient removal processes that employ biological phosphorus removal as well as nitrogen removal include Phoredox (Modified Bardenpho), VIP (Virginia Initiative Process), UNC (University of

North Carolina), A^2/O (anaerobic/anoxic/oxic), and Sequencing Batch Reactors (SBRs). Phostrip uses biological and chemical phosphorus removal processes and can incorporate biological nitrogen removal. Figures B-2a - B-2e demonstrate these processes.

B.3.a Phoredox (Modified Bardenpho)

Phoredox is a modification of the Bardenpho process mentioned earlier. The difference between the two processes is that an anaerobic zone is added ahead of the first anoxic zone to promote phosphorus release, and the sludge recycle comes into the anaerobic zone rather than into the first anoxic zone. Phoredox is designed to maximize nitrogen removal. Under situations where denitrification is not complete due to low temperatures, low strength wastewater, or extremely high flows, biological phosphorus removal will suffer because nitrates will be introduced to the anaerobic zone (Ekama et al., 1983). Phoredox has been demonstrated to remove phosphorus to an effluent concentration of 2 mg/l and nitrogen to 4 mg/l (WPCF, 1983), but some doubt has been placed on its ability to consistently remove phosphorus in influent with a low organic strength (Ekama et al., 1983; Francisco, 1989). Phoredox has been modified to operate successfully in cold climates and low organic strength wastewater at Kelowna, British Columbia, Canada (Barnard et al., 1985).

B.3.b. Modified UNC (University of North Carolina) Process

Francisco (1988) has found that a modification of the UNC process is best suited for nitrogen and phosphorus removal in plants with low BOD_5 influent (< 250 mg/l). The modification involves switching the first aerobic basin to anoxic and recycling effluent from the last aerobic basin to the first anoxic basin to improve denitrification. The primary difference between this process and Phoredox is that effluent from a primary clarifier enters the first anoxic basin and that fermented primary sludge, containing an abundance of volatile acids, enters the anaerobic basin along with the return activated sludge. Of all biological phosphorus removal flowsheets tested, this flowsheet appeared to be least sensitive to influent BOD_5.

B.3.c. VIP (Virginia Initiative Process)

Unlike Phoredox and Modified UNC, the VIP process, also known as the UCT (University of Capetown) Process does not have a recycle of sludge to the anaerobic zone. The only recycle to the anaerobic zone comes from the anoxic zone which is free of nitrate. This design protects biological phosphorus removal during periods when denitrification is incomplete (Daigger et al., 1988). Pilot and full scale studies at York River WWTP in Norfolk, Virginia have consistently demonstrated total phosphorus residuals below 2 mg/l. Nitrogen removal, however, has been erratic during winter months (Borberg, 1988). Sludge settleability has also been a slight problem (Daigger et al., 1988).

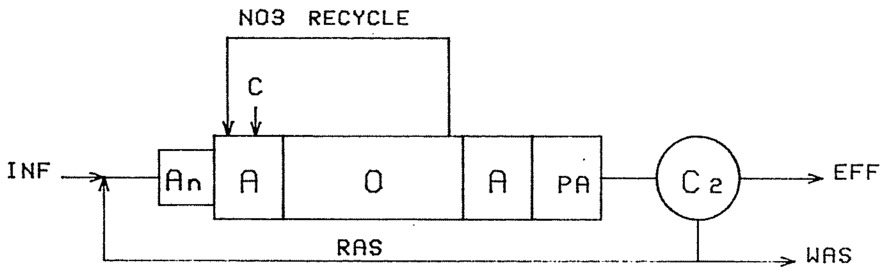


FIGURE B-2a: PHOREDOX (MODIFIED BARDENPHO)

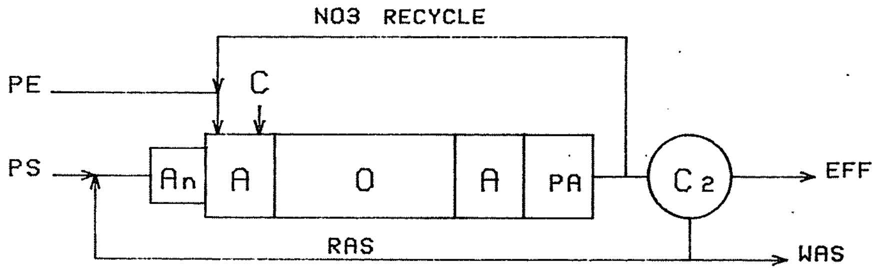


FIGURE B-2b: MODIFIED UNC

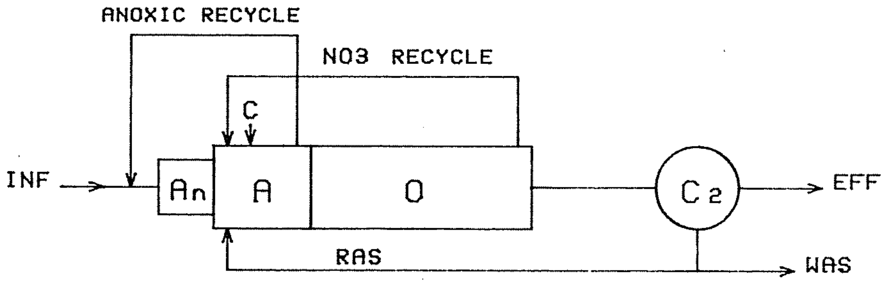


FIGURE B-2c: VIP (VIRGINIA INITIATIVE PROCESS)

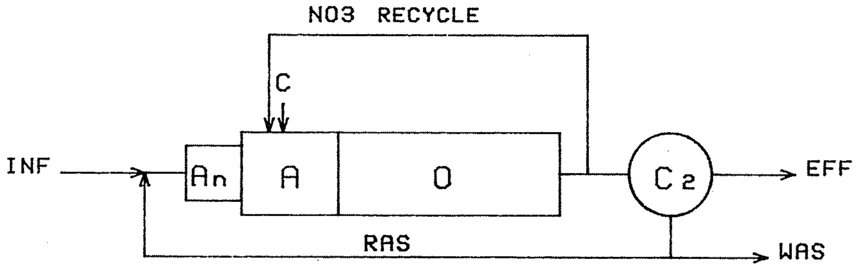


FIGURE B-2d: A2/0

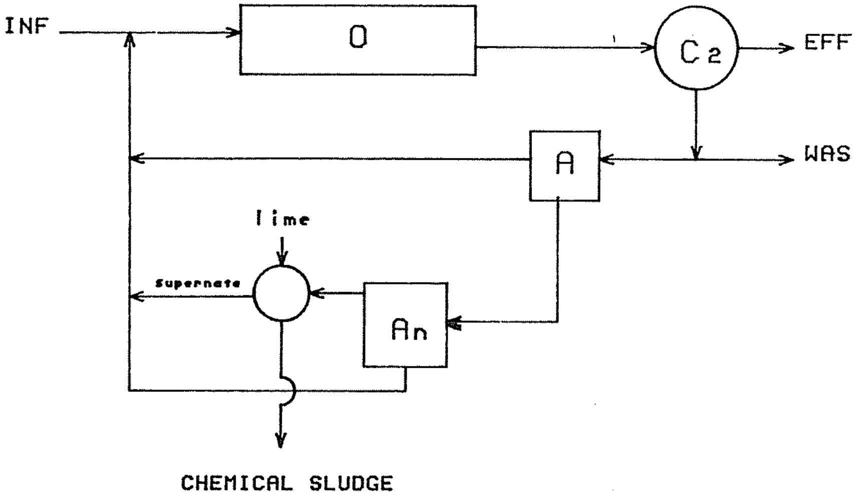


FIGURE B-2e: PHOSTRIP WITH NITROGEN REMOVAL

LEGEND: INF = Degritted, screened wastewater
EFF = Final treated effluent
An = Anaerobic
A = Anoxic
O = Oxic
WAS = Waste Activated Sludge
RAS = Return activated sludge
C2 = Secondary clarifier
C = External carbon addition (if necessary)
PA = Post-aeration
PE = Primary effluent
PS = Primary sludge

FIGURE B-2: PHOSPHORUS AND NITROGEN REMOVAL PROCESSES

B.3.d. The A^2/O (anaerobic/anoxic/oxic) Process

The A^2/O process, which similar to the Phoredox process without the second anoxic basin and post aeration, has been demonstrated to control phosphorus to below 2 mg/l and nitrogen to below 6 mg/l with a very good settling sludge (Daigger et al., 1988; Borberg, 1988).

B.3.e Phostrip

The Phostrip process has been demonstrated to remove phosphorus to below 1 mg/l through a combined biological treatment and lime precipitation process. This process can also include a denitrification basin to allow biological nitrogen removal. Because the Phostrip process incorporates chemical addition to remove phosphorus, sludge production is slightly increased. The increase is not as great, however, as for chemical addition without biological treatment. This is because the stream to which lime is added is only a small sidestream containing a high concentration of phosphorus.

B.3.f Sequencing Batch Reactors (SBRs)

Another process which has shown great potential for plants smaller than 0.5 MGD is called sequencing batch reaction (SBR). SBR involves batch treatment of wastewater in a single basin by cycling the operation of the aerators. It may be necessary to have several reactors in parallel depending on the regularity and magnitude of the plant flow. It is a very simple process and is primarily regulated by monitoring dissolved oxygen in the reactor. Because of their simplicity, SBRs are easily automated. Effluent concentrations for nitrogen and phosphorus of 3.5 mg/l and 1 mg/l have been reported for a 0.37 MGD sequencing batch reactor serving Culver, Indiana (STAC, 1986). Francisco (1988) also expressed optimism for the potential of SBRs for smaller plants based on laboratory studies conducted at the University of North Carolina on primary effluent from the Orange Water and Sewer Authority (OWASA).

Table B-1 summarizes the information presented in this section for each nutrient removal process.

Table B-2 shows the estimated cost of construction for a biological nutrient removal plant according to facility design flow. The costs for new plants are for the biological portion only (carbon and nutrient removal), and the costs for retrofit are for adding biological nutrient removal to an existing secondary plant. For many of the biological nutrient removal processes, significant patent fees will be required. For example, Air Products and Chemicals, Inc. has sued OWASA charging that OWASA should be required to pay a $300,000 liscensing fee.

Table B-1: Summary of nutrient removal technology

PROCESS	NUTRIENT REMOVED	EFFLUENT CONC. N	EFFLUENT CONC. P	COMMENTS
One-sludge pre-den	N	6 mg/l	N/A	
Bardenpho	N	4 mg/l	N/A	
Rotanox	N	10 mg/l	N/A	
Phoredox	N&P	4 mg/l	2 mg/l	
Modified UNC	N&P	unknown	unknown	No data found
VIP	N&P	unknown	2 mg/l	N-removal erratic
A^2/O	N&P	6 mg/l	2 mg/l	Best sett. sludge
Phostrip	P	N/A	1 mg/l	More sludge
SBR	N&P	5 mg/l	1 mg/l	For small plants

Table B-2: Cost of construction for a BOD_5 and nutrient removal plant

	Cost of New Plant ($\$x10^6$)		Cost of Adding N-Removal ($\$x10^6$)	
Facility Size	N[a]	N&P[b]	N[a]	N&P[b]
1 MGD	1.1-2.2	1.2-2.4	0.5-1.1	0.6-1.2
2.5 MGD	1.6-3.2	1.8-3.5	0.7-1.6	0.8-1.8
5 MGD	2.6-4.8	2.9-5.3	1.1-2.6	1.2-2.9
10 MGD	4.2-8.5	4.7-9.4	1.6-4.8	1.8-5.3
12 MGD	4.8-9.5	5.3-10.6	2.3-5.6	2.6-6.2

(a) Cost of N&P removal less 10% (Vogt, 1989).

(b) WPCF, 1983 [projected from 1983 to 1988 by best judgement (17.8% increase)].

Process design for plants performing nutrient removal is very site-specific. Influent wastewater characteristics are important when designing a plant for biological processes. Wastewater characteristics which should be considered include: temperature, TKN:COD ratio, TP:COD ratio, and the nutrient of primary concern. Sludge bulking and development of filamentous organisms in wastewater have also been a problem at some biological nutrient removal plants. For these reasons, bench and pilot-scale testing, similar to what was done in a study conducted by the University of North Carolina Water Resources Research Institute may be necessary to determine the configuration which would best meet the needs of wastewater treatment plants in the Tar-Pamlico River Basin. In these pilot studies, a mobile wastewater treatment plant was operated at several municipal plants to determine the potential applicability of various phosphorus removal processes to plants in the Jordan Lake watershed.

Conclusions

1. Technology is available in many cases to cost-effectively limit effluent total nitrogen concentrations to 6 mg/l.

2. Chemical nitrogen removal, although more expensive than biological treatment, can achieve nitrogen residuals below 2 mg/l.

3. Biological phosphorus removal can achieve effluent concentrations below 2 mg/l consistently.

4. Chemical phosphorus removal can remove total phosphorus to below 1 mg/l. Sludge handling costs will increase with chemical treatment due to the larger volumes of sludge produced, but these costs may be justified for small plants or plants with low phosphorus influent, especially since the phosphate detergent ban.

5. Retrofit of existing treatment plants to biological nutrient removal has been successfully demonstrated for a variety of common treatment plant configurations.

6. Sequencing Batch Reactors show promise for small treatment works due to the reduced treatment volume and ease of operation.

7. The estimated cost for building a new treatment plant including biological nitrogen and phosphorus removal ranges from approximately $1.5 million for a 1 MGD plant to approximately $6 million for a 10 MGD facility.

8. Retrofitting existing treatment works to biological nitrogen and phosphorus removal can be accomplished at a cost of approximately $900,000 for a 1 MGD facility and approximately $3.5 million for a 10 MGD facility.

9. Pilot-scale testing will probably be necessary before deciding on a particular nutrient removal configuration due to the site specific nature of biological nutrient removal.

REFERENCES

Barnard, J.L., G.M. Stevens, and P.J. Leslie. 1985. "Design Strategies for Nutrient Removal Plant". Water Science and Technology, Vol. 17, No. 11, p. 233-242.

Best, A.G., C.J. Hatton, A.J. Rachwal, and B. Hurley. 1985. "Biological Phosphorus and Nitrogen Removal at Experimental Full Scale Plant in the U.K." Water Science and Technology, Vol. 17, No. 11, p. 213-232.

Borberg, James, General Manager of the Hampton-Roads Sanitation District. 9 December 1988. Personal Communication.

Copeland, B. J., R. G. Hodson, and S. R. Riggs. 1984. The ecology of the Pamlico River, North Carolina: an estuarine profile. FWS/OBS-82/06. 83pp.

Daigger, G.T., G.D. Waltrip, E.D. Romm, and L.M. Morales. 1988. "Enhanced Secondary Treatment Incorporating Biological Nutrient Removal." Journal of the Water Pollution Control Federation, Vol. 60, No. 10, p. 1833-1842.

Davis, G. J., M. M. Brinson, and W. Burke. 1978. Organic carbon and deoxygenation in the Pamlico River Estuary. UNC WRRI #131. Raleigh, N.C. 123 pp.

Ekama, G.A., I. P. Siebritz, and G.V.R. Marais. 1983. "Considerations in the Process Design of Nutrient Removal Activated Sludge Processes," Water Science and Technology, Vol. 15, No. 3/4, p. 283-318.

Epperly, S.P. and S.W. Ross. 1986. Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex. NOAA Technical Memorandum NMFS - SEFC - 175. U.S. Dept. of Commerce. NOAA, National Marine Fisheries Service, SE Fisheries Center. Beaufort, N.C.

Francisco, Donald E., Department of Environmental Sciences and Engineering, University of North Carolina. 12 December 1988. Personal Communication.

Francisco, Donald E., Department of Environmental Sciences and Engineering, University of North Carolina. 16 February 1989. Personal Communication.

Giese, G. L., M. Wilder, and G. Parker, Jr. 1979. Hydrology of major estuaries and sounds of North Carolina. USGS Water Resources Investigation 79-46. Washington, D.C. 175 pp.

Harrison, W. G. and J. E. Hobbie. 1974. Nitrogen budget of a North Carolina estuary. UNC WRRI #86. Raleigh, N.C. 72 pp.

Heath, R. C. 1975. Hydrology of the Albemarle-Pamlico region, North Carolina: a preliminary report on the impact of agricultural development. USGS Water Resources Investigations 9-75. 98 pp.

Hobbie, J. E. 1970a. Hydrography of the Pamlico River Estuary, N.C. UNC WRRI #39. Raleigh, N.C. 69 pp.

Hobbie, J. E. 1970b. Phosphorus concentrations in the Pamlico River Estuary of N.C. UNC WRRI #33. Raleigh, N.C. 47 pp.

Hobbie, J. E. 1971. Phytoplankton species and populations of the Pamlico River Estuary of North Carolina. UNC WRRI #56. Raleigh, N.C. 147 pp.

Hobbie, J. E., B. J. Copeland, and W.G. Harrison. 1972. Nutrients in the Pamlico River Estuary, N.C. 1969-1971. UNC WRRI #76. Raleigh, N.C. 242 pp.

Hobbie, J. E. 1974. Nutrients and eutrophication in the Pamlico River Estuary, N.C. 1971-1973. UNC WRRI #100. Raleigh, N.C. 239 pp.

Kirby-Smith, W. W. and R. T. Barber. 1979. The water quality ramifications in estuaries of converting forest to intensive agriculture. UNC WRRI #148. Raleigh, N.C. 70 pp.

Kuenzler, E. J., D. W. Stanley, and J.P. Koenings. 1979. Nutrient kinetics of phytoplankton in the Pamlico River, N.C. UNC WRRI #139. Raleigh, N.C. 163 pp.

Lauria, D., and C. O'Melia. 1980. Nutrient models for engineering management of Pamlico River, N.C. UNC WRRI #146. Raleigh, N.C. 120 pp.

North Carolina Department of Agriculture. 1971 through 1985. North Carolina Agricultural Statistics. North Carolina Crop and Livestock Reporting Service. Raleigh, N.C.

N.C. Dept. of Natural Resources and Community Development -Division of Environmental Management. 1987. Surface Water Quality Concerns in the Tar-Pamlico River Basin. Report 87-04. Raleigh, N.C.

North Carolina Department of Natural Resources and Community Development, Division of Environmental Management. 1988. Water Quality Progress in North Carolina 1986-1987. 305b Report. Report No. 88-02. Raleigh, N.C. 196 pp.

North Carolina Department of Natural Resources and Community Development, Division of Environmental Management. 1989. The Chowan River Water Quality Management Plan 1989 Update. Final draft report. Raleigh, N.C. 39 pp.

Scientific and Technical Advisory Committe (STAC) Chesapeak Program. 1986. Nutrient Control in the Chesapeake Bay.

Skaggs, R. W., J. W. Gilliam, T. J. Sheets, and J. S. Barnes. 1980. Effect of agricultural land development on drainage waters in the North Carolina tidewater region, UNC WRRI #159. 164 pp.

Stanley, D.W., 1988. Water Quality in the Pamlico River Estuary 1967-1986. Institute for Coastal and Marine Resources. East Carolina University.

Stanley, D.W. 1975-1984. Unpublished raw data and summaries of water quality of the Pamlico Estuary, 1975-1985, submitted to NC NRCD-DEM.

United States Department of Commerce, Bureau of the Census. 1968-1983. Census of Agriculture, Vol 1, Area Reports, Part 33, North Carolina State and County Data.

Vogt, Donald R., Regional Environmental Manager. Post, Buckley, Schuh, and Jernigan, Inc., Bowie, Md. 7 February 1989. Personal Communication.

Water Pollution Control Federation. 1983. Nutrient Control: Manual of Practice FD-7, Facilities Design. Washington, D.C.: WPCF.

Weston, Inc. 1985. Emerging Technology Assessment of Phostrip, A/O, and Bardenpho Processes for Biological Phosphorus Removal, U.S. EPA report No. EPA/600/2-85/008.

Wilson, R.W., K.L. Murphy, P.M. Sutton, and S.L. Lackey. 1981. "Design and Cost Comparison of Biological Nitrogen Removal Processes," Journal of the Water Pollution Control Federation, Vol. 53, No. 8, p. 1294-1302.