ASSATEAGUE ISLAND NATIONAL SEASHORE WATER QUALITY MONITORING 1987-1990 DATA SUMMARY AND REPORT

Water Resources Division

and

Assateague Island National Seashore

Technical Report NPS/NRWRD/NRTR-91/06

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November 1991

United States Department of the Interior
National Park Service
Washington, D.C.

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UNIT ABBREVIATIONS

The following unit abbreviation conventions are utilized in this report:

Table 1. Unit Abbreviations.

Abbreviation	Complete Unit Name
m	meters
°C	degrees centigrade
ppt	parts per thousand
mg/l	milligrams per liter
mmhos/cm	millimhos per centimeter
μg/l	micrograms/liter
mpn/100ml	most probable number per 100 milliliters
μm[1]	micromoles

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[1] Nutrient concentrations were reported from the lab in micromoles (μm) of nitrogen or phosphorus. These units have been used in the report to maintain conformity with subsequent measurements. Often, however, other sources report nutrients in milligrams per liter (mg/l). To convert from μm to mg/l: (1) multiply the μm by the gram molecular weight (GMW) of nitrogen or phosphorus (found in the Periodic Table of Elements - thus one μm of nitrogen has a GMW of 14.007 micrograms and one μm of phosphorus has a GMW of 30.9738 micrograms) to compute micrograms/liter; (2) divide the micrograms/liter by 1,000 to arrive at milligrams/liter. This procedure simplifies to μm*GMW/1,000 = mg/l. A duplicate set of figures and tables which express nutrients in mg/l is included in the Appendix.

ACKNOWLEDGEMENTS

Many individuals have contributed both directly and indirectly to the water quality monitoring effort at Assateague Island National Seashore (ASIS). The original study was designed by Mark Flora of the National Park Service Water Resources Division (WRD) and Bruce Rodgers of ASIS. Gordon Olson and Jack Kumer, Natural Resource Management Specialists at ASIS, supervised the collection of water quality samples and ensured that rigorous quality assurance/quality control procedures were followed. John Karish, Mid-Atlantic Chief Scientist, provided invaluable conceptual support and review of documents. The Horn Point Environmental Laboratory at the University of Maryland and the Worcester County, Maryland Sanitary Commission Laboratory provided excellent laboratory analysis of each water quality sample.

EXECUTIVE SUMMARY

Assateague Island National Seashore (ASIS), part of a 37 mile long barrier island along the Atlantic Ocean in the states of Maryland and Virginia, was established by the Congress in 1965 to protect and develop the natural resources of the Seashore for public outdoor recreation and enjoyment. In 1976, the park's enabling legislation was amended by Congress. The new legislation called for increased measures to protect the natural resources and the ecosystem of the park. This new language clearly sets the framework for an aggressive resource preservation program at ASIS. One component of such a resource preservation program is water quality monitoring. Water-based recreation, such as swimming, fishing, and boating, and the health of the estuarine ecosystem are contingent upon good water quality in the Chincoteague-Sinepuxent Bay complex. With the exception of infrequent, localized events which have closed areas of the bay to shellfish harvesting, the overall historical water quality of the bay has been good.

The acceleration of development along the mainland in traditionally rural, undeveloped, sparsely populated Worcester and Accomack Counties has raised concern that present good water quality could deteriorate, jeopardizing the purposes for which ASIS was established. The potential cumulative impacts of increasing residential development, new and expanded marinas, failing septic systems, active poultry and agricultural operations, heavy recreational use, and the absence of any comprehensive baseline or ongoing monitoring program spurred the National Park Service (NPS) to initiate water quality monitoring in the Chincoteague-Sinepuxent Bay complex.

Water quality monitoring in the Chincoteague-Sinepuxent Bay complex was initiated by the NPS ASIS in 1987. Nine monitoring stations were established - five in the Chincoteague and four in the Sinepuxent. At each of these nine monitoring stations, data on 17 water quality parameters were generally collected monthly by park personnel from April through October (the primary visitor use season) over the last four years. Supporting environmental, physical, and temporal data were also recorded. In addition, two diel studies were conducted in 1989.

The results indicate that the overall water quality in the Chincoteague-Sinepuxent Bay complex is good. Except for localized, infrequent events in confined tidal areas, water quality is well within the acceptable ranges specified by Maryland water quality regulations and compare favorably with comparable areas in the Chesapeake Bay. The sample location with the "lowest" relative water quality on the Chincoteague-Sinepuxent Bay complex was CB1 in Newport Bay near the mouth of Trappe Creek.

The results provide an excellent baseline for subsequent monitoring. Recommendations for modifying the current monitoring program are presented. These include continued monitoring at the nine sample locations; expansion of monitoring to the southern Chincoteague Bay; dropping specific conductivity, total dissolved nitrogen, and total dissolved phosphorus; adding dissolved reactive silicate and enterococcus bacteria; and collecting more vertical profile samples with the HYDROLAB.

INTRODUCTION

Assateague Island is a 60 km. (37 mi.) long barrier island, comprising approximately 7,610 ha. (18,804 ac.) along the Atlantic Ocean in the states of Maryland and Virginia (Figure 1). The authorized boundary of Assateague Island National Seashore (ASIS) encompasses 20,848 ha. (51,515 ac.). This area includes approximately 13,238 ha. (32,711 ac.) of water (submerged lands under Chincoteague-Sinepuxent Bay complex and the Atlantic Ocean owned by the States) adjacent to the barrier island, as well as the 7,610 ha. (18,804 ac.) land area of the Island. The National Park Service (NPS) administers the northern and central portions of Assateague Island (3,209 ha., 7,928 ac.) as ASIS. The southernmost portion of Assateague Island is managed by the U.S. Fish and Wildlife Service as Chincoteague National Wildlife Refuge (3,994 ha., 9,868 ac.). Assateague State Park (282 ha., 696 ac.), managed by the Maryland Department of Natural Resources, splits ASIS into northern and central sections.

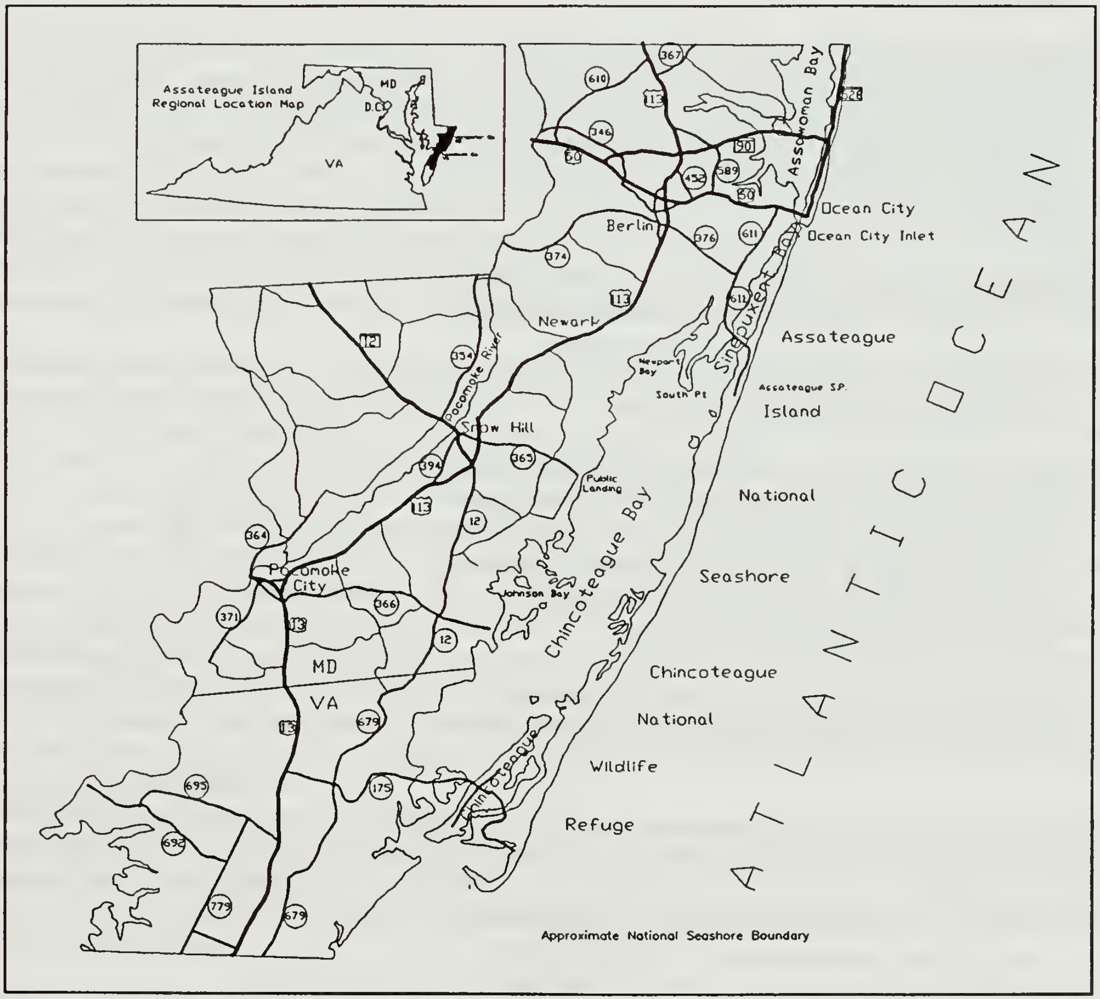

Figure 1. Assateague Island National Seashore (ASIS) Location Map.

ASIS was established by the Congress in September 1965, three years after a devastating storm leveled the island, in order to protect and develop the natural resources of the Seashore for public outdoor recreation and enjoyment (P.L. 89-195). The creation of ASIS addressed four mounting concerns: (1) increasing recreational demand for seashore activities by the 30 million people residing within a 200 mi. (322 km.) radius; (2) prevention of infeasible and unsuitable private development in an area prone to flooding and overwash; (3) preservation of dwindling, undeveloped barrier islands; and (4) generation of tourism revenue in Worcester County, Maryland and Accomack County, Virginia.

Much of the recreation at ASIS is water-based, focusing on the Atlantic Ocean to the east and the Chincoteague-Sinepuxent Bay complex to the west. Swimming, fishing, and boating are the primary recreational opportunities dependent on water quality in the bay. Water quality is also critical to the productivity and health of the estuarine ecosystem. With the exception of certain infrequent, localized events, the historical water quality in the bay has been generally good. Recent developments outside ASIS in traditionally rural, undeveloped, sparsely populated, Worcester and Accomack Counties have raised concerns about their potential impacts on water quality in the Chincoteague-Sinepuxent Bay complex. The activities causing concerns include:

- Present and proposed marina expansions which could add gasoline, oil, greywater and sewage, and heavy metals to the bay

- Non-point source pollution from poultry and agricultural operations in the bay's watershed on the Delmarva Peninsula which could introduce additional nitrogen, phosphorus, suspended sediment, and other agricultural non-point source pollutants into the system

- Increasing residential development along the mainland coast adjacent to the bay which could add suspended sediments, zinc, cadmium, lead, oil, pesticides, herb-icides, and other pollutants commonly associated with urban and residential runoff to the bay

- Failing septic systems and inadequate sewage treatment, identified in the Comprehensive Development Plan of Worcester County, Maryland as an Area of Critical State Concern (1989), at existing and proposed developments which could increase the level of fecal coliform bacteria and other pollutants in the bay

- Point and non-point source loading of tributaries which empty into the bay, especially Trappe Creek

Additionally, potential water quality impacts on the Chincoteague-Sinepuxent Bay complex could originate from the following activities/land uses within ASIS:

- Chemical and flushing toilets in camping units and waste disposal facilities which, if improperly used, could increase fecal coliform levels and add other chemicals to the bay

- Seasonal housing at Toms Cove and the northern end of ASIS which could increase fecal coliform levels and runoff-associated pollutants entering the bay

- Two visitor centers and associated housing, maintenance yards, sewage and water treatment plants, and parking lots which could introduce fecal coliform bacteria, gas, oil, suspended sediment, and other pollutants into the bay

As a result of these potential impacts and the importance of water-based recreation at ASIS, the National Park Service initiated a water quality monitoring program for the Chincoteague-Sinepuxent Bay complex (Flora and Rodgers 1986) beginning in 1987. The purpose of this report is to organize and analyze the four years of data which has been collected by NPS personnel in order to establish a baseline, report on any apparent initial trends and relationships, and to make recommendations concerning future conduct of water quality monitoring at ASIS.

ENVIRONMENTAL SETTING

Physiography:

The Chincoteague-Sinepuxent Bay area is characterized by relatively flat or gently undulating topography. The primary physiographic regions, stretching east to west, include: (1) Atlantic Ocean; (2) Assateague Island and other coastal islands; (3) Chincoteague-Sinepuxent Bay complex; (4) tidal marshes; and (5) mainland (USDI-NPS 1982). Most of Assateague Island is less than 3 m. (10 ft.) above sea level, with 6.4 m. (21 ft.) the maximum elevation attained. Although Assateague Island stretches north-south approximately 60 km. (37 mi.), its width is generally 4.8 km. (3 mi.) or less. As a consequence, the Island is subject to overwash during severe storms. In unstabilized, overwash areas, the physiography from ocean to bay encompasses beach, foredune, grassland and scattered shrubs, dense shrubs, high salt marsh, and low salt marsh. In stabilized areas, the physiography proceeds as beach, primary dunes, secondary dunes, high salt marsh, and low salt marsh (USDI-NPS 1982).

The Chincoteague-Sinepuxent Bay complex, sandwiched between the mainland and Assateague Island, has two outlets to the Atlantic Ocean: Ocean City Inlet to the north and Chincoteague Inlet to the south. The bay is very shallow with a mean depth of 1.22 m. (4 ft.). Depths range between 1.8 and 7.6 m. (6 and 25 ft.) near the Inlets to 0.3 and 0.9 m. (1 to 3 ft.) along Assateague Island (Boynton 1970). At mean low water (MLW), the water surface area is 32,851 ha. (81,175 ac.). The volume at MLW is 410 million cubic meters (14,494 million cubic ft.). At mean tide, the bay's water volume increases approximately 10.5% to 454 million cubic meters (16,025 million cubic ft.) (Pritchard 1960). The mean tidal range is 0.12 m. (0.4 ft.) in the middle of the bay, increasing to 1.07 m. (3.5 ft.) at the Inlets. The Chincoteague-Sinepuxent Bay complex has been characterized as relatively stagnant since only 7.5 percent of the water volume is replaced each day by inflow of fresh water or exchange through the Inlets. Thus, 63 days are required to replace 99 percent of the bay water with ocean and freshwater (Pritchard 1960). Moreover, currents in the bay are generally independent of nontidal ocean currents. Consequently, any pollutants discharged into the bay will likely remain for an extended period. Although the inflow of freshwater into the bay isn't that significant, the greatest influx occurs during spring from Trappe Creek into Newport Bay.

Approximately 9,308 ha (23,000 ac.) of irregularly flooded salt tidal marsh surround the Chincoteague-Sinepuxent Bay complex (Keefe and Boynton 1973). Generally, the tidal marsh is flooded only by spring tides, not daily lunar tides. The tidal marsh is dominated by Spartina alterniflora, with smaller amounts of Distichlis spicata and Salicornia ssp. also present.

The mainland, beyond the tidal marshes, is primarily upland with a maximum elevation of 13.7 m. (45 ft.). Slopes are generally smooth and less than 5 percent, except above breaks on drainage ways where the slope may approach 30 percent. Many freshwater swamps occur near the bay and tributaries. Oval swales or basins, known locally as "whale wallows" or "Maryland basins" make the mainland appear hummocky (USDOD-Army Corps of Engineers 1976).

Geology and Soils:

The geology of the Chincoteague-Sinepuxent Bay region is dominated by unconsolidated, subsurface sediments comprised of layers of gravel, sand, clay, loam, and shell marls. The gradual erosion of the Appalachian Mountains and Piedmont Plateau, 177 km. (110 mi.) to the west, and the slow ocean level rise over the last 20,000 years are the primary sources of this sediment. In certain areas, these sediments may have become compacted into irregularly shaped layers of rock. Erosional forces, such as wind, waves, currents, and runoff continue to influence the area's geology. Underlying the sediment is very old bedrock thought to be of igneous origin.

Three soils associations comprise the majority of the area: (1) Fallsington-Woodstown-Sassafras (FWS); (2) Othello-Fallsington-Other Soils (OFO); and (3) Tidal Marsh-Dune Sand-Coastal Beach (TDC). The FWS association, consisting of level or nearly level sandy clay loam, covers 42.8 percent of the region. Occupying 21.3 percent of the area, the OFO association is level or nearly level and poorly drained (USDA-Soil Conservation Service 1973, Accomack-Northampton Planning District Commission 1973, USDOD-Army Corps of Engineers 1976). Sandy clay loam and silty clay loam subsoils comprise most of the OFO association. The TDC association covers 19.3% of the region, including most of the shoreline surrounding the bay. The OFO association has severe limitations for development and agriculture. Soils in FWS are generally better suited for development than other soils in the region. The four other smaller associations which occur in the region are: (1) Mattapex-Matapeake-Othello; (2) Muck; (3) Woodstown-Dragston-Other Soils; and (4) Lakeland-Klej-Plummer.

Climate:

A northern temperate climate moderated by the Atlantic Ocean prevails in the Chincoteague-Sinepuxent Bay area (USDOD-Army Corps of Engineers 1976). The average annual temperature is 13.5° C (56.3° F), ranging from 2-4° C (36-39° F) during the winter to about 24-25° C (76° F) during the summer. A sea breeze during the summer helps keep the bay area slightly cooler than the mainland. In the winter, both the daily maximum and minimum temperatures are also moderated by the ocean. The 45-47" of annual precipitation is generally evenly distributed throughout the year, with March, July, and August being the wettest months. Prevailing winds during the winter are generally from the northwest; while during the rest of the year winds are typically from the southwest. Although there are very few calm days, wind velocities usually aren't excessive.

PREVIOUS AND ONGOING WATER QUALITY STUDIES/DATA SOURCES

Water quality data for the Chincoteague-Sinepuxent Bay complex dates back to at least 1943 when the Chesapeake Biological Laboratory took four years of temperature and salinity observations in the area. The Maryland Tidewater Fisheries Commission also collected four years of temperature and salinity data beginning in 1948. Although the raw temperature and salinity data from these two efforts are tabulated in McGary and Sieling (1953), there doesn't appear to have been any interpretation of these data. Visual inspection reveals a range of water temperatures from 0°C to 34°C and salinity from 13.2 ppt. to 35.4 ppt[2]. From 1951 to 1953, the Chesapeake Bay Institute (McGary and Sieling 1953) conducted a regular water quality monitoring program, compiling data on temperature, salinity, dissolved oxygen, turbidity, meteorologic conditions, and other parameters to determine possible causes of a decline in oyster production throughout the bay and recommend means and methods for restoring productivity. Unfortunately, although this document appears to contain the complete tabular data set, there is no summary, analysis, or interpretation of the data.

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[2] The range of these early salinity observations corresponds closely to what was measured in the Chincoteague-Sinepuxent Bay complex during NPS monitoring from 1987-1990. The maximum water temperature, 34°C, was 4°C warmer than the highest measurement made during NPS monitoring.

During the 1970s, the Virginia Institute of Marine Science (VIMS), under contract from the Water Resources Administration (WRA) of the Maryland Department of Natural Resources, conducted an intensive hydrographical and water quality survey of the Chincoteague-Sinepuxent Bay complex and Assawoman Bay (Cerco et. al. 1978). The purpose of the assessment was to quantify non-point source pollution in the bays in order to support the WRA's Basin Water Quality Management Plan for the area under the authority of Section 303(e) of the Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500). Utilizing the U.S. Army Corps of Engineers Storage, Treatment, Overflow, Runoff Model (STORM), VIMS concluded that point sources in the area contributed larger quantities of ammonia and phosphorous to the bays; while non-point sources were the primary origin of nitrate and coliform (Cerco et. al. 1978). The VIMS study also highlighted the increasing importance of non-point source pollution as existing point sources are controlled or eliminated by the National Point Discharge Elimination System. Additionally, the report indicated that after only a single half-inch storm, the marshes surrounding the Chincoteague-Sinepuxent Bay complex can contribute as much non-point pollution to the bay as all upland non-point sources within the Basin do in a month.

The most active, ongoing water quality monitoring on the Chincoteague-Sinepuxent Bay complex is performed by the Standards and Certification Division (contact Paul DiStefano, Certification Section Head, at (301) 631-3603) of the Water Management Administration in Maryland's Department of the Environment (MDDOE). MDDOE routinely monitors fecal coliform bacteria on a monthly basis (twice monthly if an area has been closed to shellfish harvesting) in support of the Shellfish Growing Water Certification Program at 43 stations across the Chincoteague-Sinepuxent Bay (Figure 2). The intent of this program is to prevent human consumption of unsafe shellstock. As a consequence, shellfish harvesting in Johnson Bay, on the western edge of Chincoteague Bay south of the Public Landing, has frequently been forbidden. Water temperature, salinity, dissolved oxygen, and pH are collected at 12 of the 43 stations. The MDDOE also investigates unusual water quality events, such as fish kills and algal blooms, when they are reported.

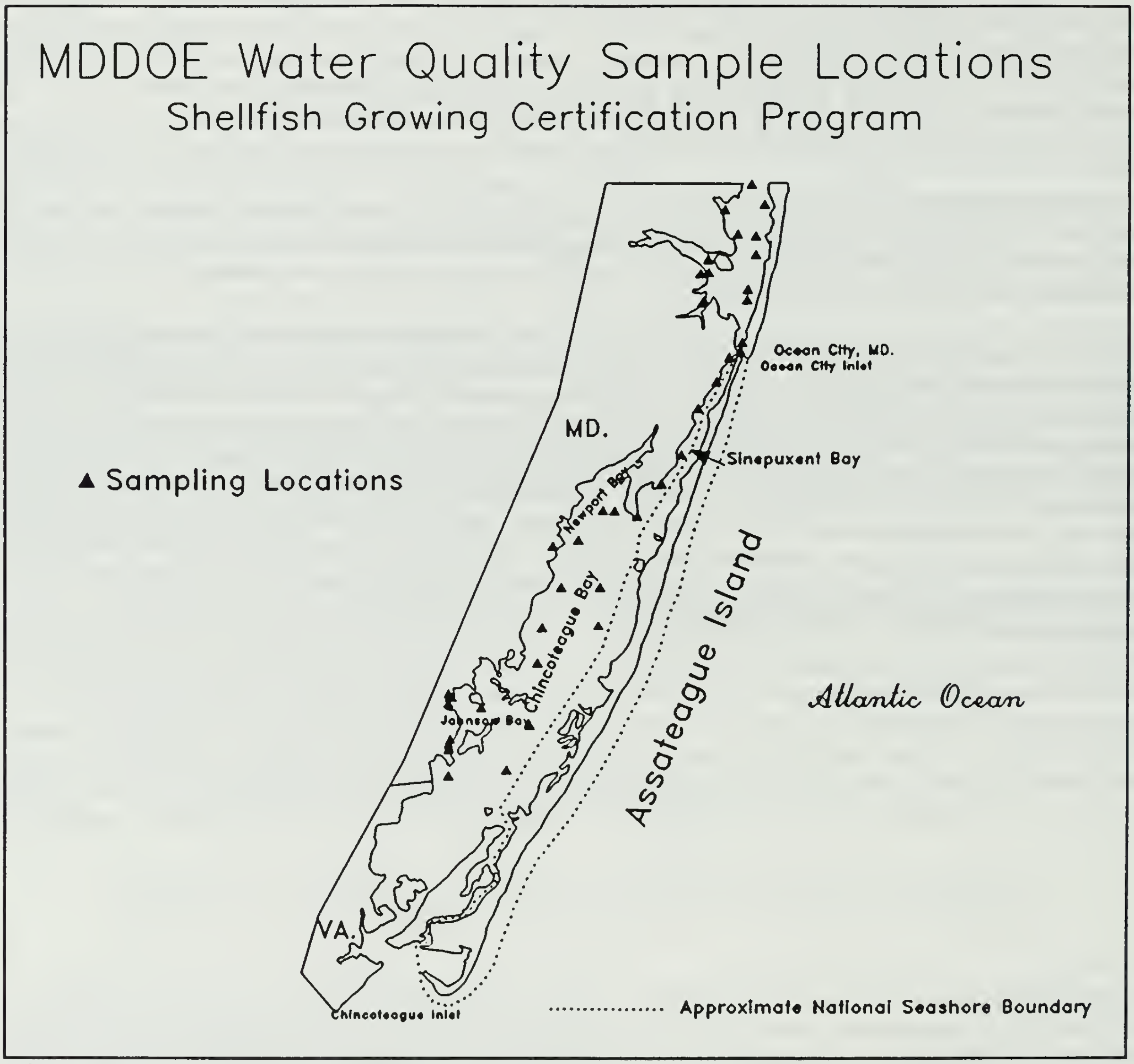

Figure 2. MDDOE Water Quality Monitoring Stations in Chincoteague-Sinepuxent Bay Complex Monitored Monthly for Fecal Coliform Bacteria.

Water quality monitoring at nine stations in the Chincoteague-Sinepuxent Bay complex was initiated by the staff of Assateague Island National Seashore in April 1987 to establish a baseline monitoring program and assess the impact of various land uses and land use change on water quality. The name, location, and purpose of each water quality monitoring station is provided in Table 2. Figure 3 displays the spatial distribution of these station locations.

Table 2. Purpose and Location of NPS Water Quality Monitoring Stations in the Chincoteague-Sinepuxent Bay (1987-1990).

Station	Location	Purpose
SB-1	Sinepuxent Bay at Outlet of Commercial Fish Harbor	Impact of Harbor/ Marina Expansion
SB-2	Sinepuxent Bay at Outlet of Snug Harbor	Impact of Harbor/ Septic Systems
SB-3	Sinepuxent Bay at Assateague Island Bridge	Middle Sinepuxent Bay Water Quality
SB-4	Sinepuxent Bay at Marker "28" North of South Point	Lower Sinepuxent Bay Water Quality
CB-1	Newport Bay West of Newport Neck	Influence of Trappe Creek on Bay
CB-2	Chincoteague Bay 1/3 Across Bay East of Public Landing	Northern Chincoteague Bay Water Quality (Landward)
CB-3	Chincoteague Bay 1/3 Across Bay West of Winter Quarter	Northern Chincoteague Bay Water Quality (Seaward)
CB-4	Johnson Bay at Marker "1" Southeast of Tizzard Island	Historical Water Quality Problems in Johnson Bay
CB-5	Chincoteague Bay 1/4 Across Bay West of Pope Island	Middle Chincoteague Bay Water Quality

At each of the nine monitoring stations, data on 17 water quality parameters were generally collected monthly from April through October. In addition, during 1989 two special 24 hour (diel) studies were undertaken. Table 3 displays the 17 parameters monitored monthly and the reason for their measurement. In addition to these 17 water quality parameters, the date, time, wind speed, wind direction, air temperature, and times of low and high tide at Ocean City and Public Landing were noted at each station. Daily logs of precipitation were also maintained at ASIS headquarters and the North Beach Ranger Station.

Figure 3. Location of ASIS Water Quality Monitoring Stations in the Chincoteague-Sinepuxent Bay Complex During 1987-1990.

Table 3. NPS Water Quality Parameters and Reasons for Measurement in the Chincoteague-Sinepuxent Bay (1987-1990).

Water Quality Parameter	**Reason for Measurement**
Water Depth (m)	Tidal Stage, Dilution
Water Temperature (°C)	Aquatic Life/Dissolved Oxygen Saturation Computation/Chemical Solubility
Salinity (ppt)	Aquatic Life
Dissolved Oxygen (mg/l)	Aquatic Life/Point-source Pollution
Secchi Disc Depth (m)	Aquatic Life/Light Transmittance
pH	Aquatic Life/Chemical Solubility
Conductivity (mmhos/cm)	Estimate Total Dissolved Solids/Index of Inorganic Pollutants
Chlorophyll a (μg/l)	Algal Biomass
Total Suspended Solids (mg/l)	Aquatic Life/Light Transmission
Fecal Coliform (mpn/100 ml)	Public Health/Non-point Source Pollution
Orthophosphate Dissolved (μm)	Nutrient Enrichment
Total Phosphorus Dissolved (μm)	Nutrient Enrichment
Total Phosphorus (μm)	Nutrient Enrichment
Ammonium Dissolved (μm)	Nutrient Enrichment
Nitrates & Nitrites Dissolved (μm)	Nutrient Enrichment
Total Nitrogen Dissolved (μm)	Nutrient Enrichment
Total Nitrogen (μm)	Nutrient Enrichment

Fecal Coliform test had a maximum value of 16 mpn/100 ml and 240 mpn/100 ml in 1988 and 1989, respectively.

Chlorophyll a was measured beginning in 1988.

Salinity was also measured at 0.5 m intervals in the water column during 1989.

ANALYTICAL TECHNIQUES AND METHODOLOGY

All water quality samples were collected by ASIS personnel and, unless noted otherwise, were collected at a depth of .5 meters in the water column. Chemical analysis of water quality samples was undertaken by the University of Maryland, Horn Point Environmental Laboratory and the Worcester County, Maryland Sanitation District Laboratory.

Physical parameter measurements were recorded by ASIS personnel with a HYDROLAB[3]. Water temperature, dissolved oxygen, specific conductance, pH, salinity, and depth were measured with the HYDROLAB. A Secchi disk was used to record Secchi disk depth.

Nutrient and chlorophyll a analyses were performed by the University of Maryland - Horn Point Lab[4]. Nutrients were determined at the Lab with a Technicon Auto Analyzer Model AA2 continuous flow colorimeter[5]. Chlorophyll a was measured using a fluorometer. Beginning in 1991, the Horn Point Lab will use a new gas chromatographic method to measure chlorophyll a and will assume the responsibility of analyzing ASIS water quality samples for total suspended solids.

Fecal coliform and total suspended solids were analyzed by the Worcester County Sanitation District[6]. Fecal coliform was determined using the fermentation tube method and reported as the most probable number per 100 milliliters. Total suspended solids were determined by filtering through a Whatman 934-AH 1.5 micron glass fiber filter and then dried at 103°C.

NPS CHINCOTEAGUE-SINEPUXENT BAY WATER QUALITY RESULTS

Water Temperature:

Temperature is a fundamentally important water quality parameter due to its direct influence on aquatic life and interaction with many other water quality parameters. Temperature directly affects the solubility of oxygen and other gases in water. Higher temperatures tend to make gases less soluble in water. Compounding this temperature/oxygen solubility problem, degradation of organic material is directly related to temperature. Thus, warm water temperatures and the presence of organic material in water usually result in depressed oxygen levels. Warm water temperatures also tend to accelerate the rate at which bacteria and algae reproduce; while cool water temperatures tend to decrease the metabolic rate of cold-blooded animals and plant life.

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[3] ASIS contact is Gordon Olson at (301) 641-1443.

[4] University of Maryland, Horn Point Lab contact is Lois Lane at (301) 228-8200.

[5] For a detailed, technical discussion of the relative merits and disadvantages of these and other analytical techniques, see Standard Methods For the Examination of Water and Wastewater (Clesceri et. al. 1989).

[6] Worcester County Sanitation District contact is Elizabeth Matthews at (301) 524-6760.

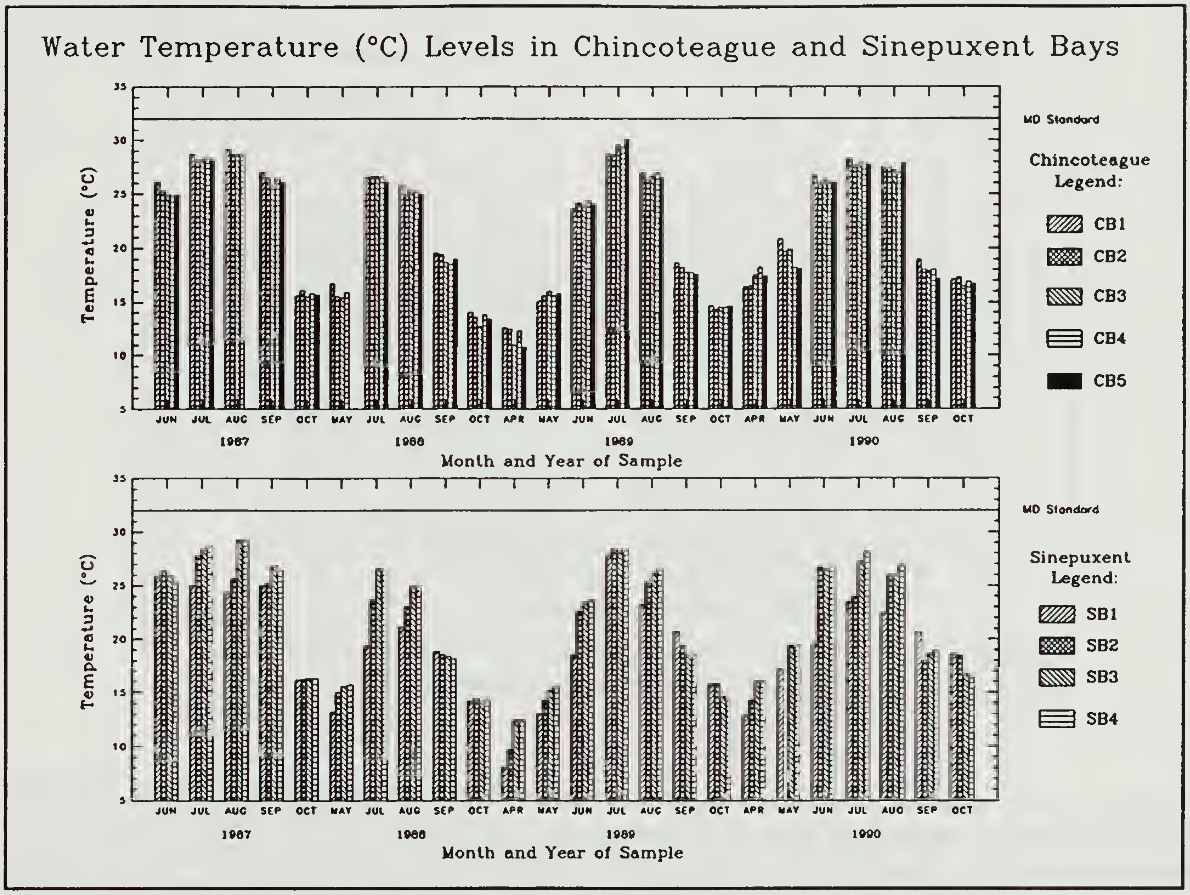

Figure 4. Seasonal Water Temperature Distribution in the Chincoteague-Sinepuxent Bay Complex.

Water temperatures in the Chincoteague-Sinepuxent Bay complex exhibited the expected seasonal trend (Figure 4). The coldest water temperature recorded during monitoring months was 8°C at SB1 during April 1989[7]; while the warmest was 30°C at CB5 during July 1989. In addition, SB1 experienced the lowest arithmetic mean temperature (19.34°C), lowest standard deviation (S.D. = 4.91), and lowest maximum temperature (27.8°C); most likely attributable to the location of SB1 near the Ocean City Inlet, the influence of greater water exchange with the Atlantic Ocean[8], and being the furthest north sampling station. CB1 experienced the highest mean temperature (21.87°C). Although not statistically significant ($\sigma = .05$), overall mean temperatures in the Chincoteague Bay area were slightly warmer (21.54°C, S.D. = 5.60) than the Sinepuxent Bay area (20.78°C, S.D. = 5.36), perhaps due to the north-south orientation of the Chincoteague-Sinepuxent Bay complex (Figure 5). No water temperature observations exceeded the Maryland state standard of 32°C (COMAR 26.08.02).

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[7] Water quality monitoring was done only during the following periods: June-October 1987; May-October 1988; April-October 1989, and April-October 1990. Extension of monitoring activities into the winter periods would have yielded lower water temperatures. The results reported here are only for the listed sampling periods.

[8] The influence of water exchange with the Atlantic Ocean through the Inlet occasioning lower temperatures was also noted by Boynton (1970) who took several water quality measurements in support of his phytoplanktonic primary production study.

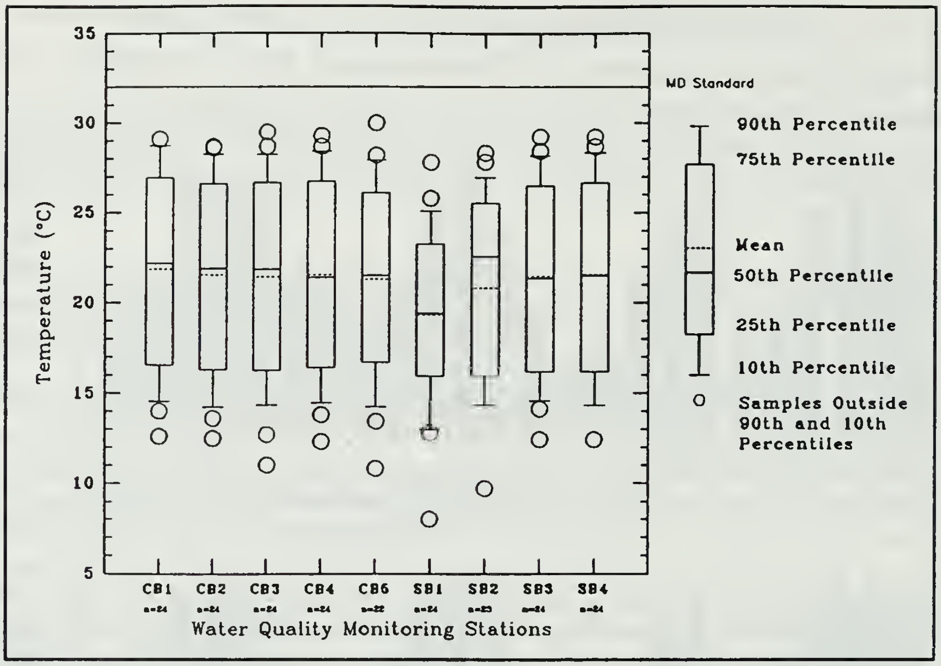

Figure 5. Water Temperature Distributions in Chincoteague-Sinepuxent Bay Complex.

To monitor the daily water temperature fluctuations, two special diel samples were taken during the day and into the night and following morning on June 19, 1989 and August 1, 1989 (Figure 6). The results indicate that water temperatures can vary as much as 5° or 6°C over the course of several hours at SB1 and SB2, the sample locations closest to the Ocean City Inlet, likely due to greater tidal fluctuations and the influence of the Atlantic Ocean. The rate of temperature change at stations further from an inlet (CB1 and SB3) is much more gradual in response to solar input. The shallow waters of the Chincoteague-Sinepuxent Bay complex, however, can warm very quickly.

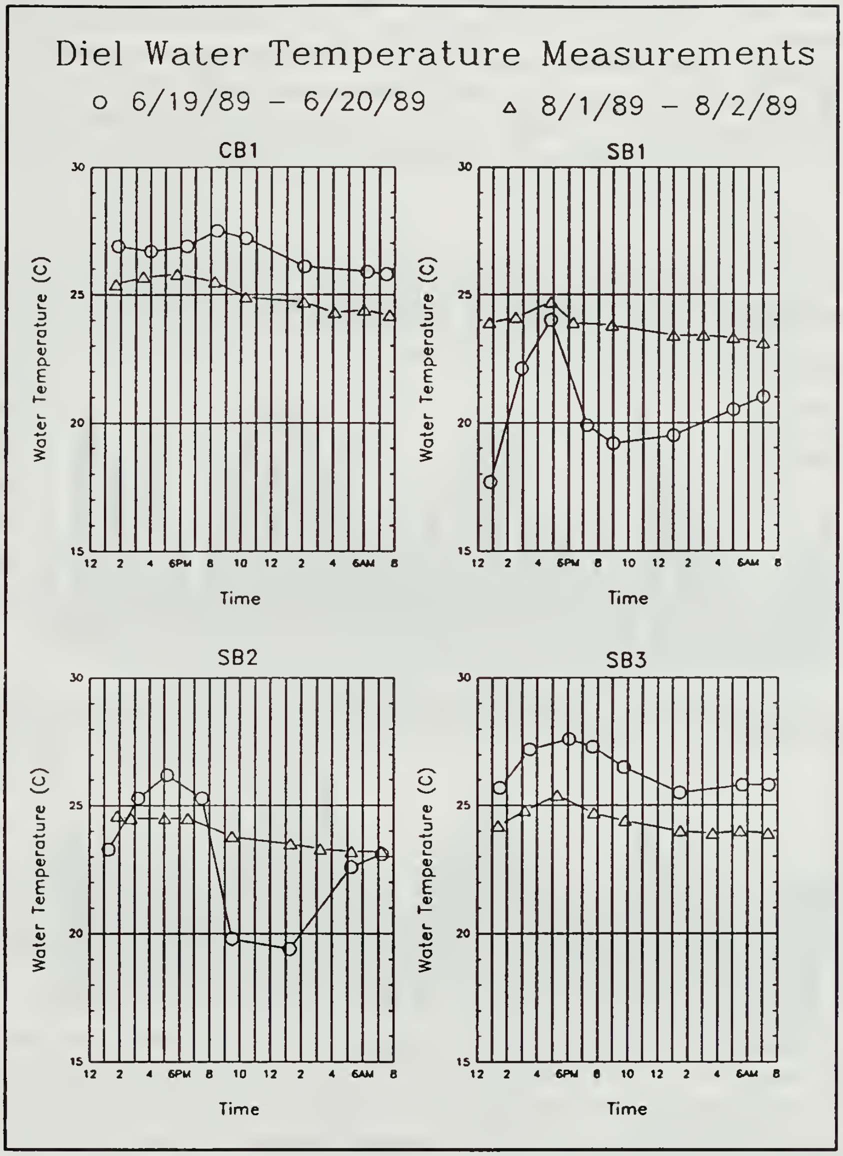

Figure 6. Diel Water Temperatures During 6/19/89 - 6/20/89 and 8/01/89 - 8/02/89 in the Chincoteague-Sinepuxent Bay Complex.

Dissolved Oxygen:

The concentration of dissolved oxygen (DO) in water is a good indicator of the balance between oxygen-depleting and oxygen-generating processes *when the sample was taken.* The timing of the DO measurement is critical, since, as discussed briefly above, the concentrations of oxygen and other gases are inversely related to temperature. Hence the concentration of DO fluctuates diurnally and seasonally, with greater concentrations typically measured just prior to dusk, as a consequence of day-time photosynthesis, and the lowest concentrations occurring around dawn. Additionally, dissolved oxygen is less soluble in saline than fresh waters. A lack of DO occasions anaerobic decomposition of organic materials in water - with the resultant production of hydrogen sulfide, methane, ammonia, and other toxic and noxious gases. DO is essential for the biochemical oxidation of ammonia to nitrate in natural waters and for the survival of fish and other aquatic organisms. Waters with DO concentrations from 0 to 0.2 mg/l are considered anoxic; while concentrations from 0.2 to 2.0 are considered hypoxic. A minimum concentration of 4-5 mg/l of DO is generally thought necessary to support a healthy, diverse fish population. According to the Code of Maryland Regulations (COMAR 26.08.02), DO should not drop below 5.0 mg/l.

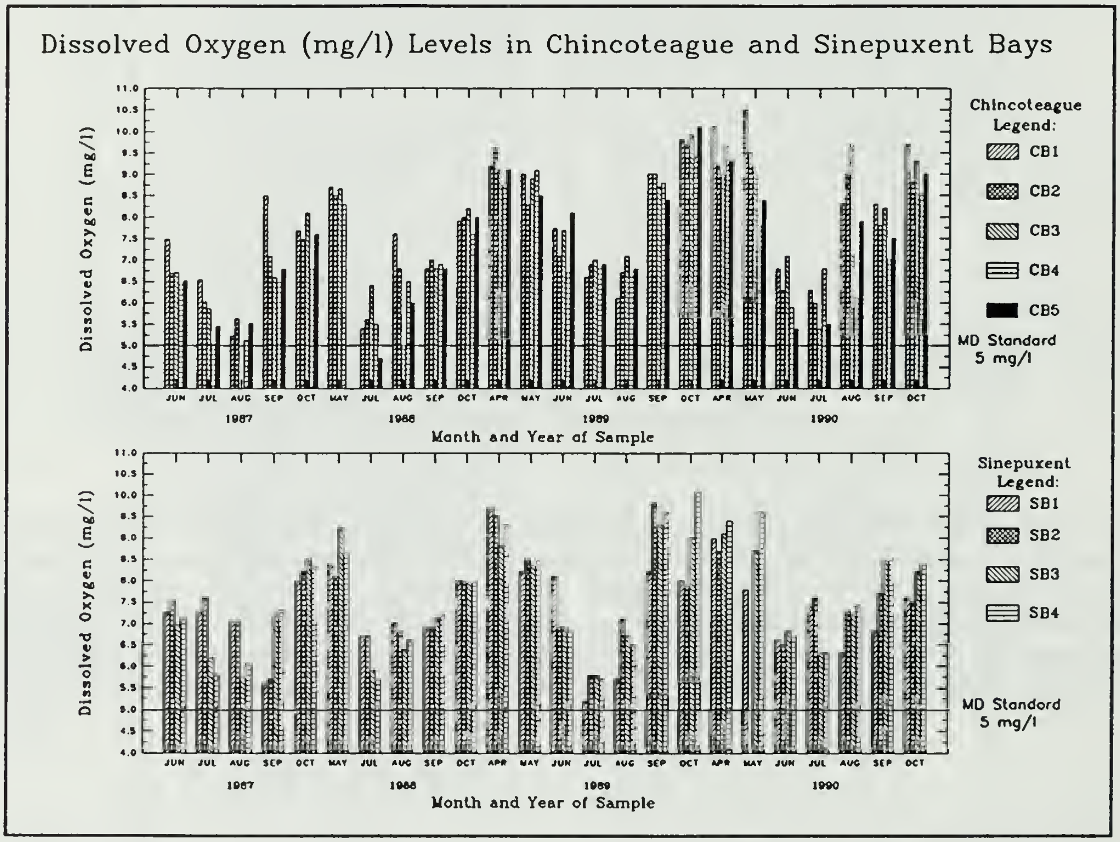

Figure 7. Seasonal Dissolved Oxygen Distribution in the Chincoteague-Sinepuxent Bay Complex.

As expected, DO levels in the Chincoteague-Sinepuxent Bay complex were strongly, inversely correlated (Chincoteague r=-.72, Sinepuxent r=-.80, combined r=-.75) with water temperatures. During the sampling periods, the highest levels of DO were obtained in April, September, and October - the coldest water temperature sampling months (Figure 7). DO levels were at their lowest during July and August when water temperatures are naturally their warmest. CB1 (7.89 mg/l, S.D.=1.46) exhibited the greatest arithmetic mean level of DO on the Chincoteague; CB4 (7.20 mg/l, S.D.=1.33) the least. SB2 (7.65 mg/l, S.D.=1.36) exhibited the greatest arithmetic mean level of DO on the Sinepuxent; SB1 (7.37 mg/l, S.D.=1.07) the least. Overall mean DO levels in the Chincoteague and Sinepuxent were very comparable (Chincoteague mean=7.56 mg/l, S.D.=1.40; Sinepuxent mean=7.52 mg/l, S.D.=1.15). DO levels at SB1 and SB2, the stations subject to the greatest influence of the Atlantic Ocean due to their proximity to the Ocean City Inlet, however, were the least variable across the entire bay system. The box plot in Figure 8 conveys the distribution of DO levels at each sample site. DO levels in the Sinepuxent never dropped below the Maryland Daily Average and Minimum Standards of 5.0 mg/l and 4.0 mg/l, respectively. In the Chincoteague, only one sample (at CB5 - 4.7 mg/l on 7/28/88) was below the

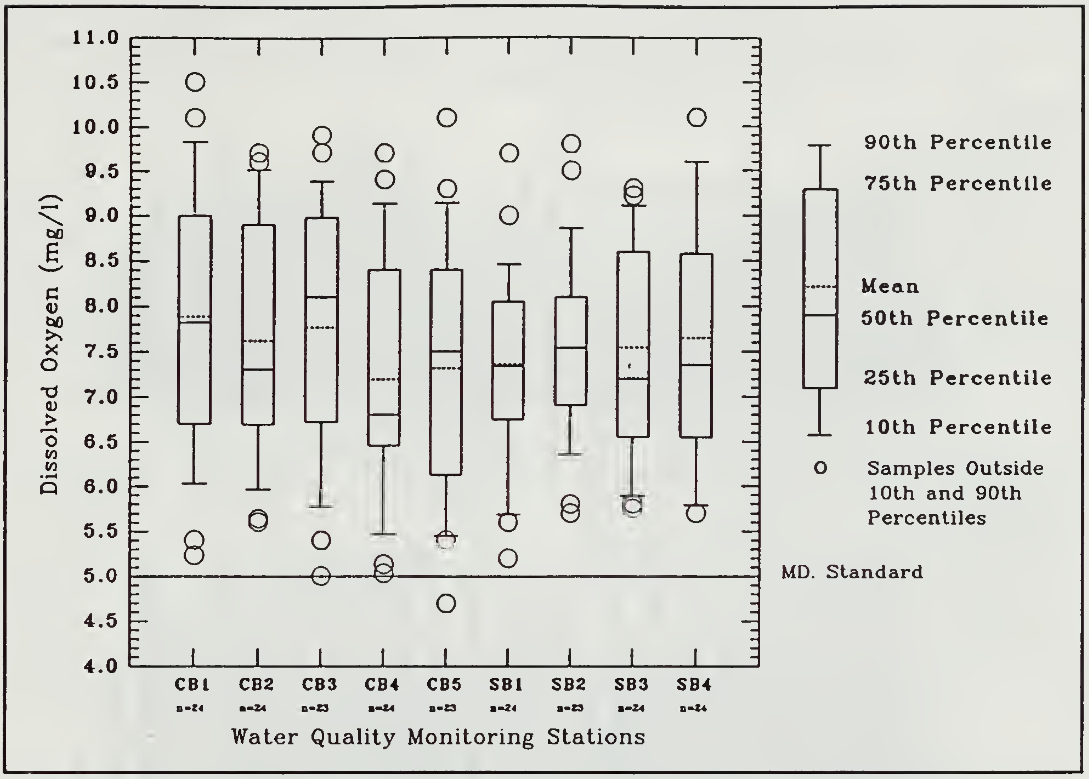

Figure 8. Dissolved Oxygen Distributions in Chincoteague-Sinepuxent Bay Complex.

Maryland Daily Average Standard, although one sample at CB3 (8/25/88) and another at CB4 (7/22/87) equalled the standard. As most of these samples were taken between 9:30 AM and 3:30 PM, they don't necessarily reflect the true levels of DO; which fluctuate diurnally, reaching highest levels just before sunset and lowest levels just prior to dawn.

The DO results of the special diel samples are displayed graphically in Figure 9. Based on this Figure, it is easy to ascertain that the concentration of DO in both the Chincoteague (CB1) and Sinepuxent (SB1, SB2, SB3) Bays varies diurnally and seasonally. DO concentrations were usually at their maximum daily values around 5 - 6pm. Minimum daily values were generally attained between 7 - 8am. The concentration of DO at each sample location for the diel samples was always greater in June than August - indicative of the inability of the late-summer warmer water to hold oxygen or other gases and possibly less photosynthesis due to lower nutrient availability.

Salinity:

In the common vernacular, salinity describes the degree of water saltiness. Salinity, however, is actually a measure of the concentration of dissolved solids in water or, more formally, the total quantity (grams) of solid material contained in one kilogram of seawater after oxidation of all organic matter, conversion of carbonate to oxide, and replacement of bromine and iodine by chlorine has occurred. The primary dissolved constituents of

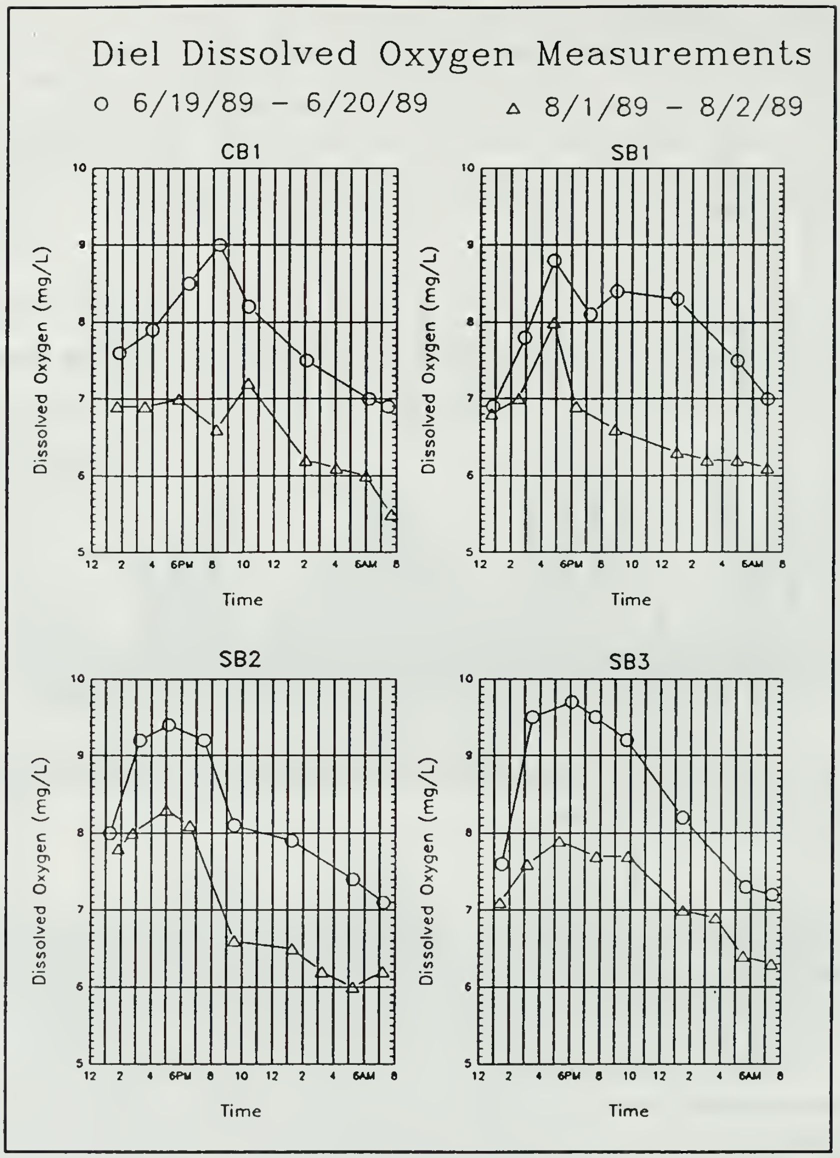

Figure 9. Diel Dissolved Oxygen During 6/19/20 - 6/20/89 and 8/01/89 - 8/02/89 in the Chincoteague-Sinepuxent Bay Complex

seawater (and their relative percent contribution) are chloride (55%), sodium (31%), sulfate (8%), magnesium (4%), calcium (1%), potassium (1%), and bicarbonate (.5%). Salinity is an important water quality parameter since the spatial and temporal distribution of salinity can profoundly affect the activities of aquatic organisms. Salinity perturbations usually occur as a result of freshwater input and basin geometry. Salinity concentration is also influenced by water circulation. Specific conductance, or the ability of water to convey electrical current, is directly proportional to the concentration of total dissolved solids in water. Consequently, salinity is often measured by the specific conductance of water, or vice-versa. Since the relationship of the major dissolved constituents in water is almost constant, simple math may be used to compute an estimate of the concentration of each major constituent.

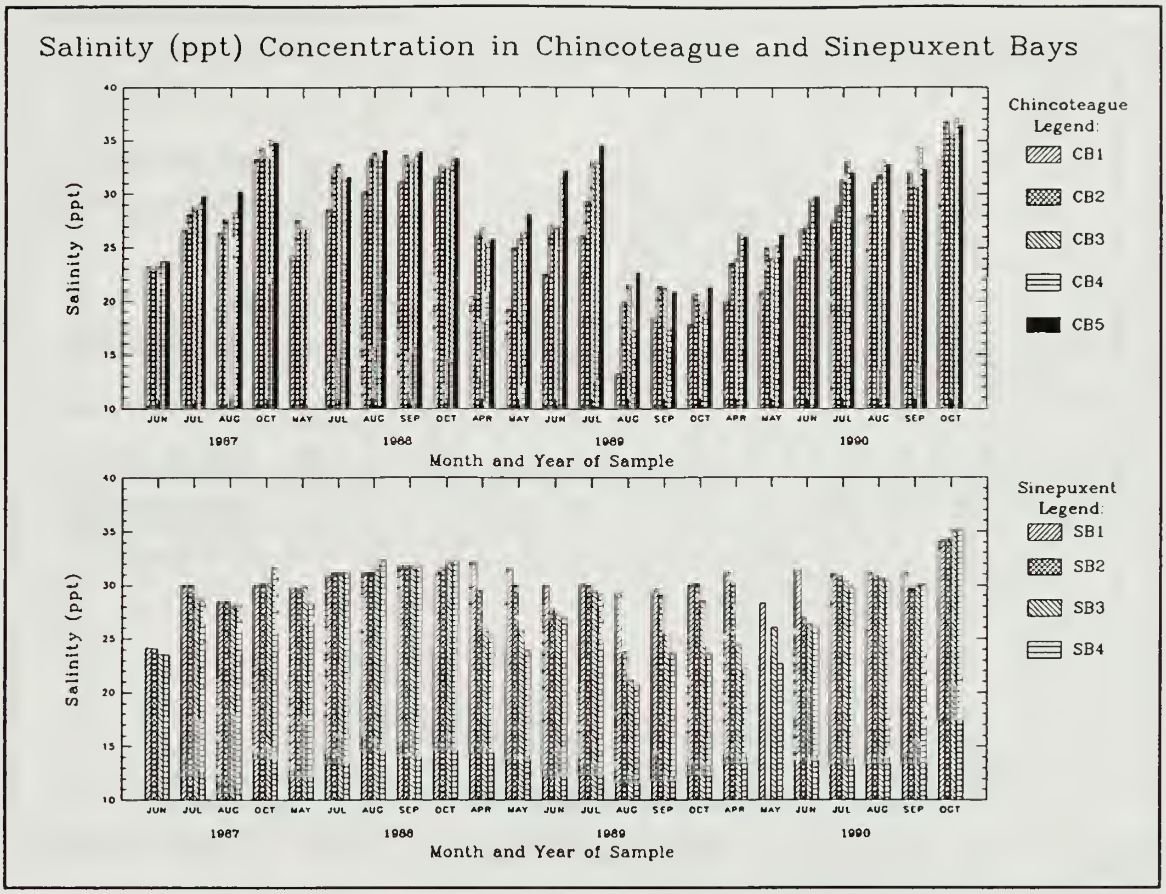

Figure 10. Seasonal Salinity Distribution in the Chincoteague-Sinepuxent Bay Complex.

Salinity levels in the Chincoteague-Sinepuxent Bay complex displayed some seasonality, particularly on the Chincoteague (Figure 10). Salinity levels on the Chincoteague increased slightly from spring into the summer and fall in 1987, 1988, and 1990; while 1989 salinity levels peaked in June and July and then diminished significantly in the fall. Salinity levels ranged from a low of 13.2 ppt at CB1 in August of 1989 to 37.2 ppt at CB4 in October of 1990. Arithmetic mean salinity levels ranged from 25.00 ppt (S.D. = 5.37) at CB1 to 29.64 ppt (S.D. = 4.64) at CB5. The location of sample point CB1 in Newport Bay at the mouth of Trappe Creek (freshwater input) likely contributed to its lower mean salinity concentration. The mean level of salinity at CB1 was significantly ($\sigma = .05$) lower than all other Chincoteague sample locations. Salinity levels were much less variable on the Sinepuxent (Figure 11).

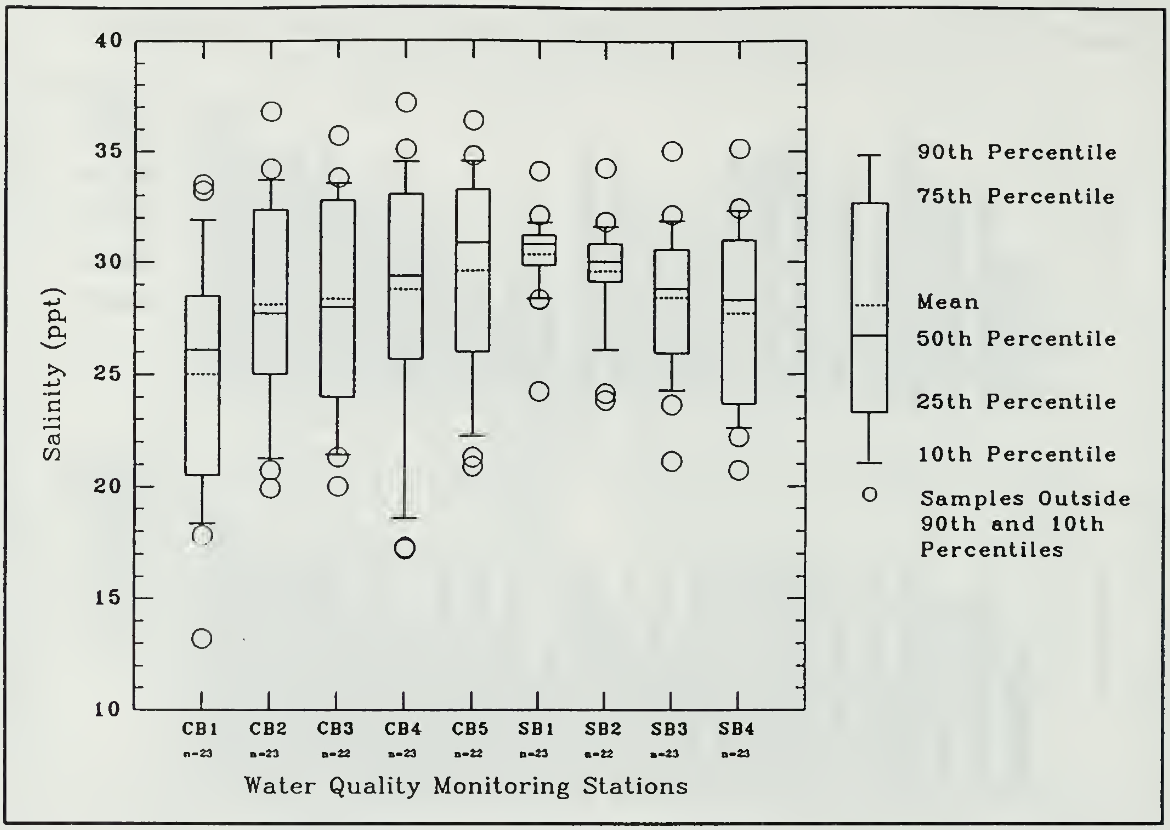

Figure 11. Salinity Distributions in the Chincoteague-Sinepuxent Bay Complex.

The minimum and maximum salinity values were 20.7 ppt in August of 1989 and 35.10 in October of 1990, both recorded at SB4. Mean salinity levels ranged from 27.70 ppt (S.D.=3.94) at SB4 to 30.36 ppt (S.D.=1.83) at SB1. The salinity level at SB1, near Ocean City Inlet, was significantly greater than SB4 ($\sigma=.05$). Overall, there was no significant difference in salinity concentrations in the Chincoteague (27.96 ppt, S.D.=5.18) and Sinepuxent (29.00 ppt, S.D.=3.09) Bays at $\sigma=.05$.

Salinity and conductivity were strongly positively correlated (Pearson's r=.989) in the Chincoteague-Sinepuxent Bay complex. Figure 12 displays the near perfect linear relationship between conductivity and salinity at each sample point. The only sample points that failed to achieve a correlation greater than r=.99 were CB2 and SB2. One outlier, possibly the result of measurement error or anomalous conditions, at each location mars the otherwise near-perfect linear relationship[9]. The diel salinity measurements, displayed in Figure 13, follow the same daily pattern as conductivity. Salinity values varied more during the June diel sample, particularly at CB1, SB1, and SB2. The daily variation ranged from 2-4 ppt. For the August diel sample, salinity was consistent throughout the day.

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[9] At CB2 on October 20, 1988, conductivity measured 58 mmhos, the maximum ever at any sample location, while salinity was 32.60 ppt. At SB2 on July 25, 1990, conductivity measured 37.40 mmhos while salinity was 30.80 ppt.

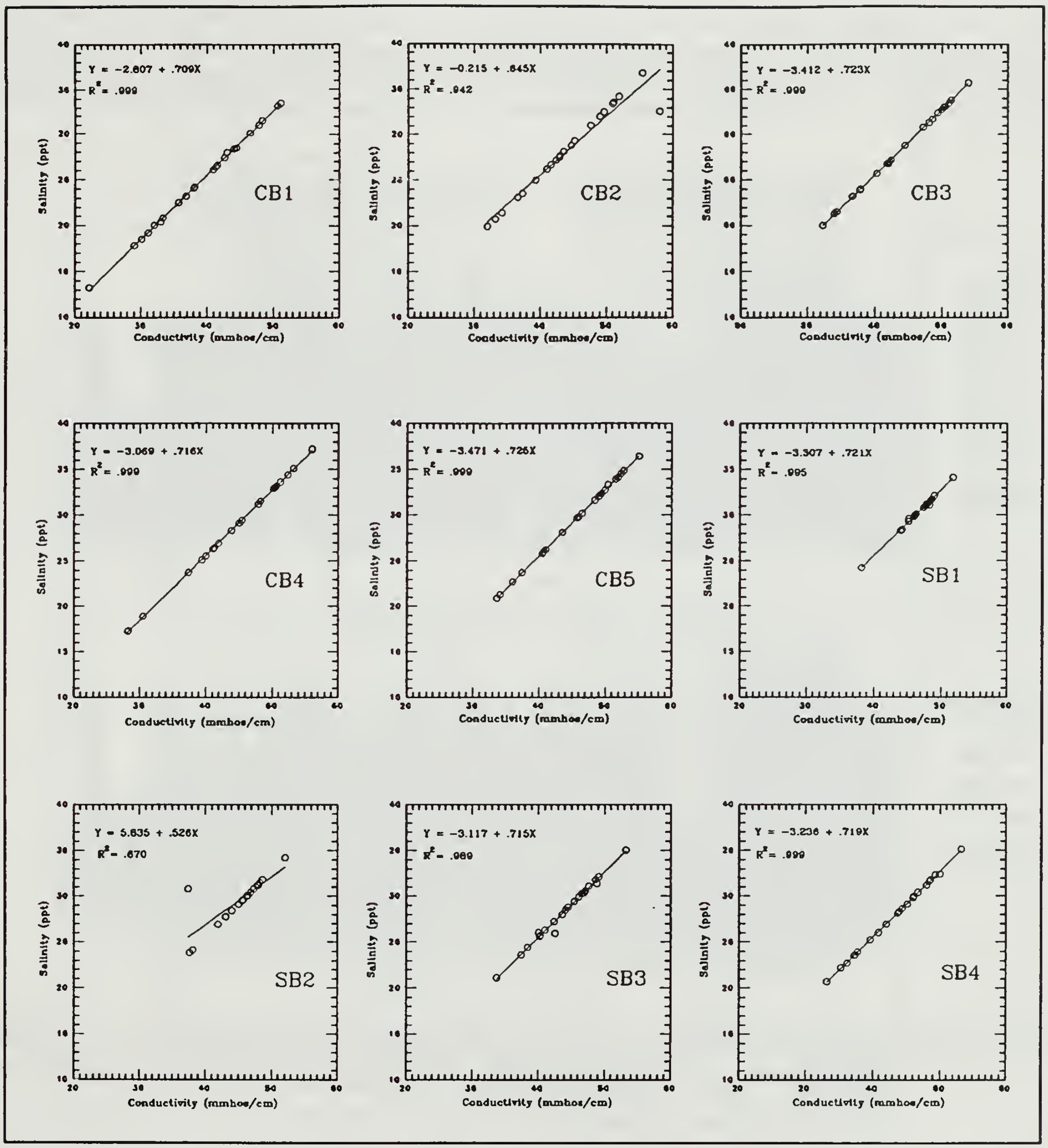

Figure 12. Expected Near Perfect Linear Relationship Between Specific Conductance and Salinity.

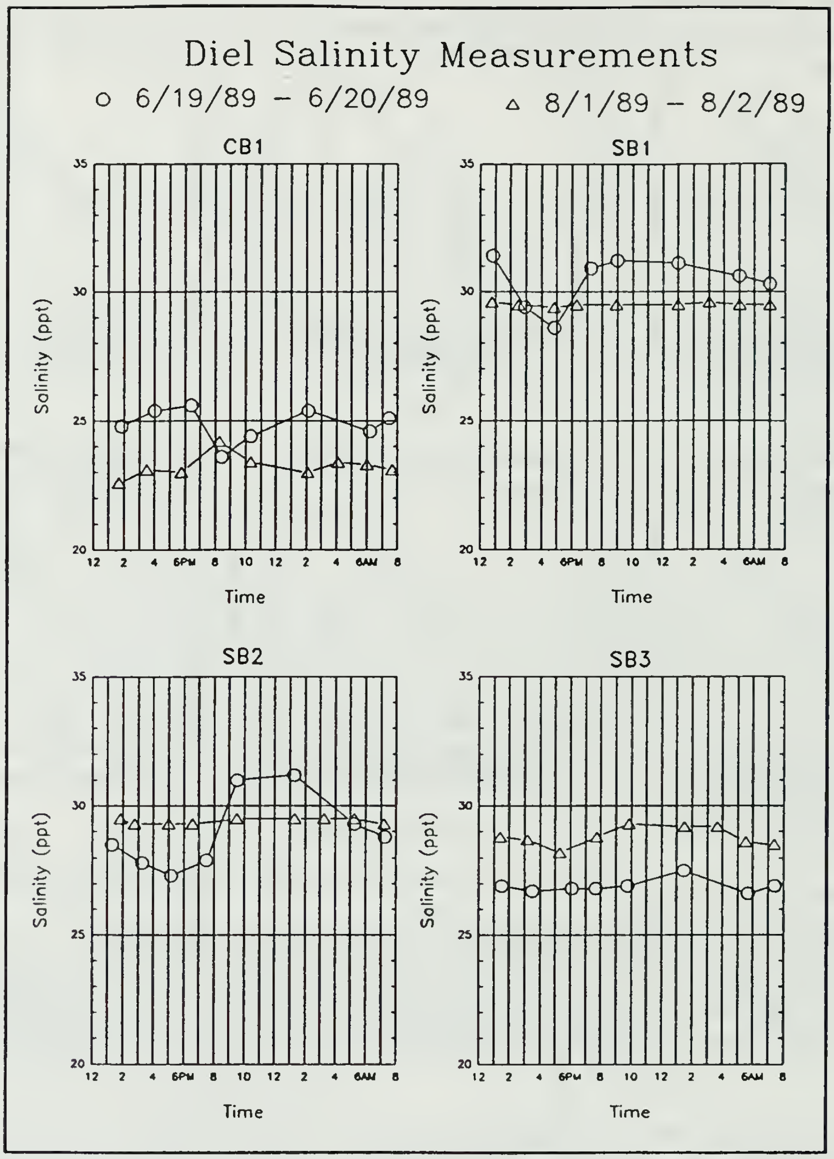

Figure 13. Diel Salinity During 6/19/89 - 6/20/89 and 8/01/89 and 8/02/89 in the Chincoteague-Sinepuxent Bay Complex.

pH:

The hydrogen ion concentration or pH is an indicator of the hydrogen ion activity in water. Mathematically, pH is the logarithm of the reciprocal of the hydrogen ion activity ($pH=-\log_{10}[H^+]$), where $[H^+]$ is the hydrogen ion activity. pH ranges from 0 (very acidic) to 14 (very basic)[10]. The level of pH in natural waters is usually a function of the carbonate system - carbon dioxide, carbonic acid, bicarbonate ions, and carbonate ions. pH is an important factor in all chemical and biological systems. A change in pH can indicate a breakdown in seawater's buffering system and that a carbon dioxide imbalance may exist - an imbalance that

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[10] As a means of comparison, human tears (lacrimal fluid) and blood have a pH of approximately 7.4.

could prove fatal to marine life. pH also plays a significant role in influencing the toxicity of other materials in the water. For example, the toxicity of ammonia and cyanide are greatly influenced by pH levels. A pH range of 6.7 to 8.5 is recommended to support marine and estuarine organisms (USDI-Federal Water Pollution Control Administration 1968) while the Maryland Code of Regulations (26.08.02) specify a range from 6.5 to 8.5.

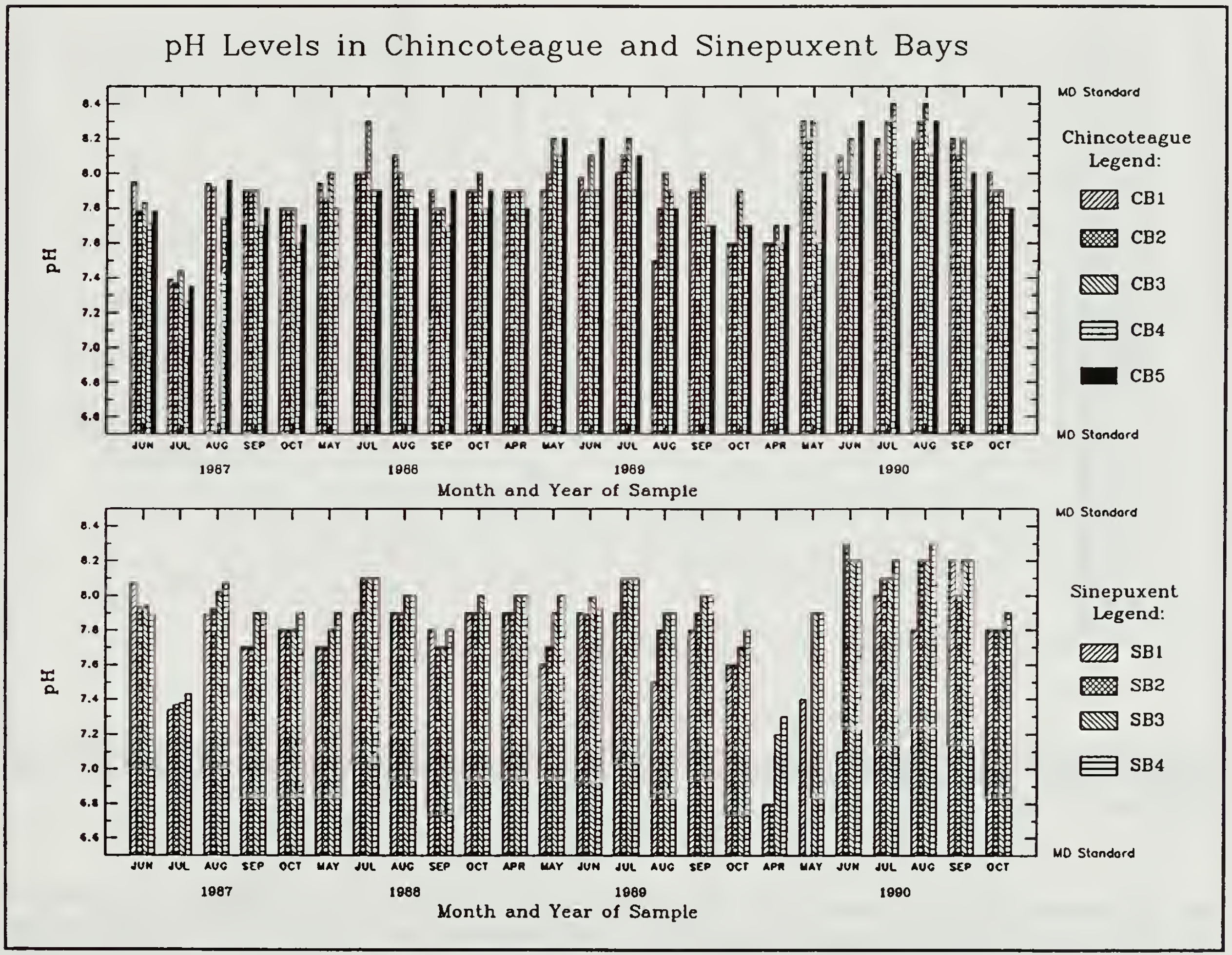

Figure 14. Seasonal pH Distribution in the Chincoteague-Sinepuxent Bay Complex.

The pH level in the Chincoteague-Sinepuxent Bay complex demonstrated little seasonality (Figure 14). The minimum and maximum pH values measured on the Chincoteague were 7.26 at CB4 and 8.4 at CB3 and CB4, respectively. CB3 and CB4 exhibited the lowest and highest mean[11] pH levels: 7.81 (S.D. = 1.028) at CB4 and 8.01 (S.D. = 1.029) at CB3 (Figure 15). The mean pH level at CB3 is statistically greater ($\sigma = .05$) than at CB4.

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[11] Mean pH values were calculated by computing the mean of the transformed pH logs and then reconverted to the standard log pH.

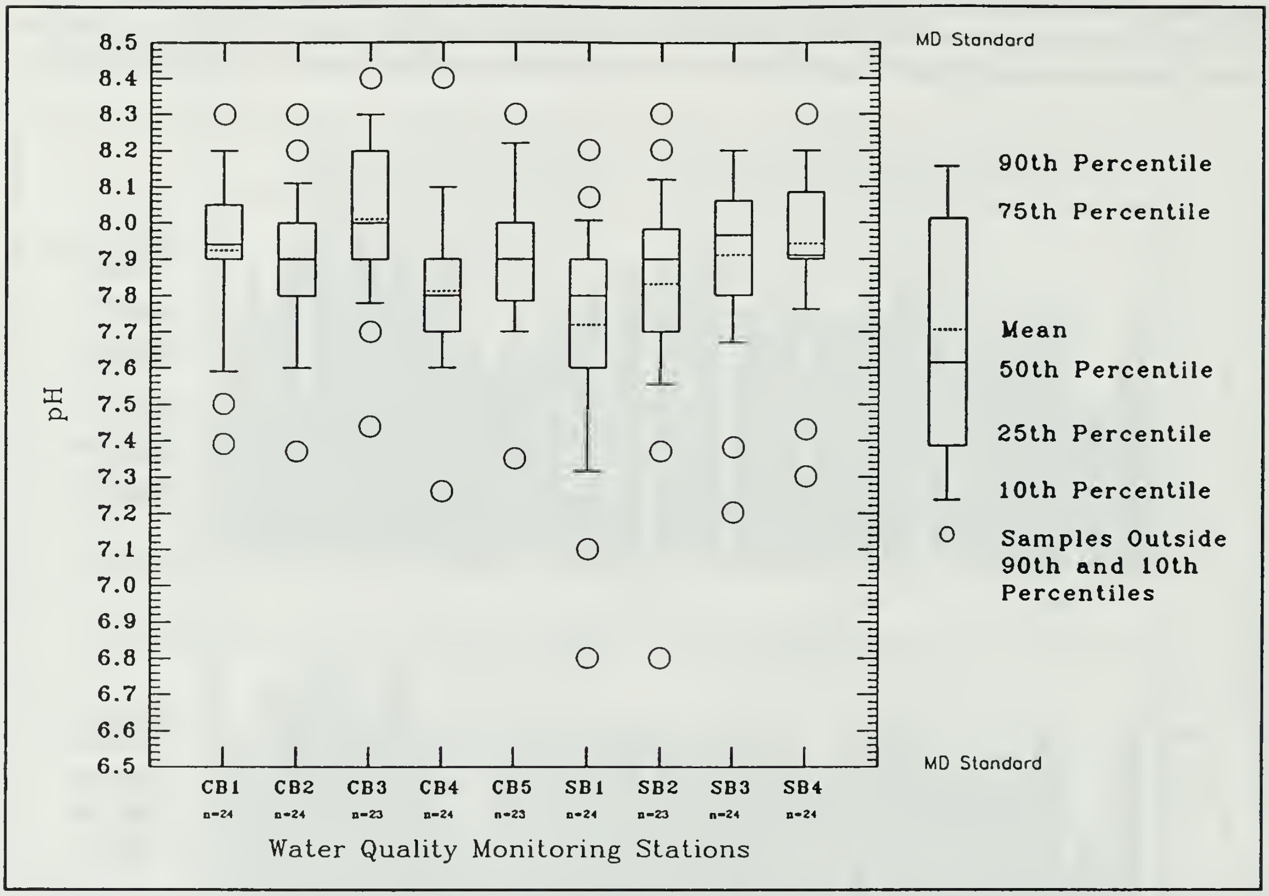

Figure 15. pH Distributions in the Chincoteague-Sinepuxent Bay Complex.

On the Sinepuxent, pH levels ranged from a maximum of 8.3 at SB2 and SB4 to a minimum of 6.80 at SB1 and SB2. The lowest and highest mean pH concentrations on the Sinepuxent were at SB1 (7.72, S.D.=1.043) and SB4 (7.94, S.D.=1.029). The mean pH level at SB1, the station closest to Ocean City Inlet, is statistically greater (σ=.05) than the mean pH levels at SB3 and SB4. One peculiarity illustrated by Figure 14 are the lower pH values for July 1987 and April 1990 in both the Chincoteague and Sinepuxent. Since the preceding and subsequent pH values were consistently higher, the lower values in July 1987 and April 1990 may reflect calibration or measurement error or, perhaps, an anomalous event. Overall, there was no statistically significant difference in pH levels between the Chincoteague (7.91, S.D.=1.029) and the Sinepuxent (7.85, S.D.=1.038) Bays at σ=.05.

The diel pH measurements (Figure 16) exhibit a weak diurnal pattern with pH increasing slightly through the day and dropping slightly at night. During the June diel measurements, however, SB2 and SB3 experienced significant pH increases (SB2 from 7.9 to 8.7 and SB3 from 8.1 to 8.5) between 5:00AM and 8:00AM. The pH increase between samples at SB2 and SB3 greatly exceeds the changes between any other two sequential samples and the pH measurement of 8.7 at SB2 exceeds the upper limit (8.5) of the pH range specified in the Maryland Code of Regulations (26.08.02) and recommended for marine and estuarine systems (USDI-Federal Water Pollution Control Administration 1968).

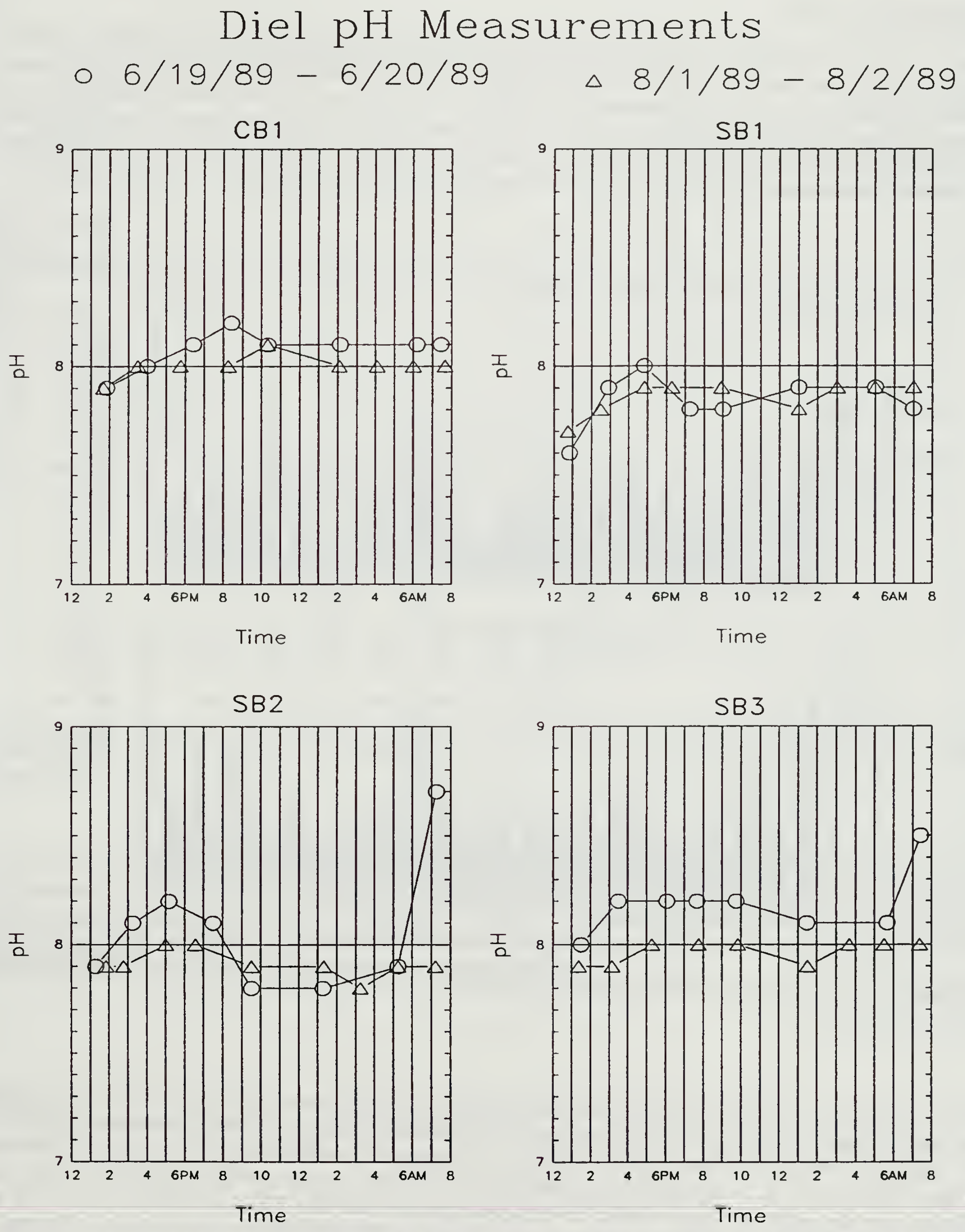

Figure 16. Diel pH During 6/19/89 - 6/20/89 and 8/01/89 - 8/02/89 in the Chincoteague-Sinepuxent Bay Complex.

Total Suspended Solids:

Total suspended solids (TSS), primarily silt, clay, organic detritus, and plankton, occur naturally in water. Erosion, runoff, and wind-blown dust and debris from forestry, agriculture, mining, construction, and other human endeavors can increase the concentration of TSS in water. TSS can have several deleterious effects on aquatic life: abrasive injuries, clogged gills, smothered eggs, and obliterated spawning areas. Depending on the source of TSS, toxicity problems may also arise. Additionally, TSS, by increasing turbidity (discussed below), can decrease light penetration which, in turn, suppresses photosynthesis and can result in oxygen depletion.

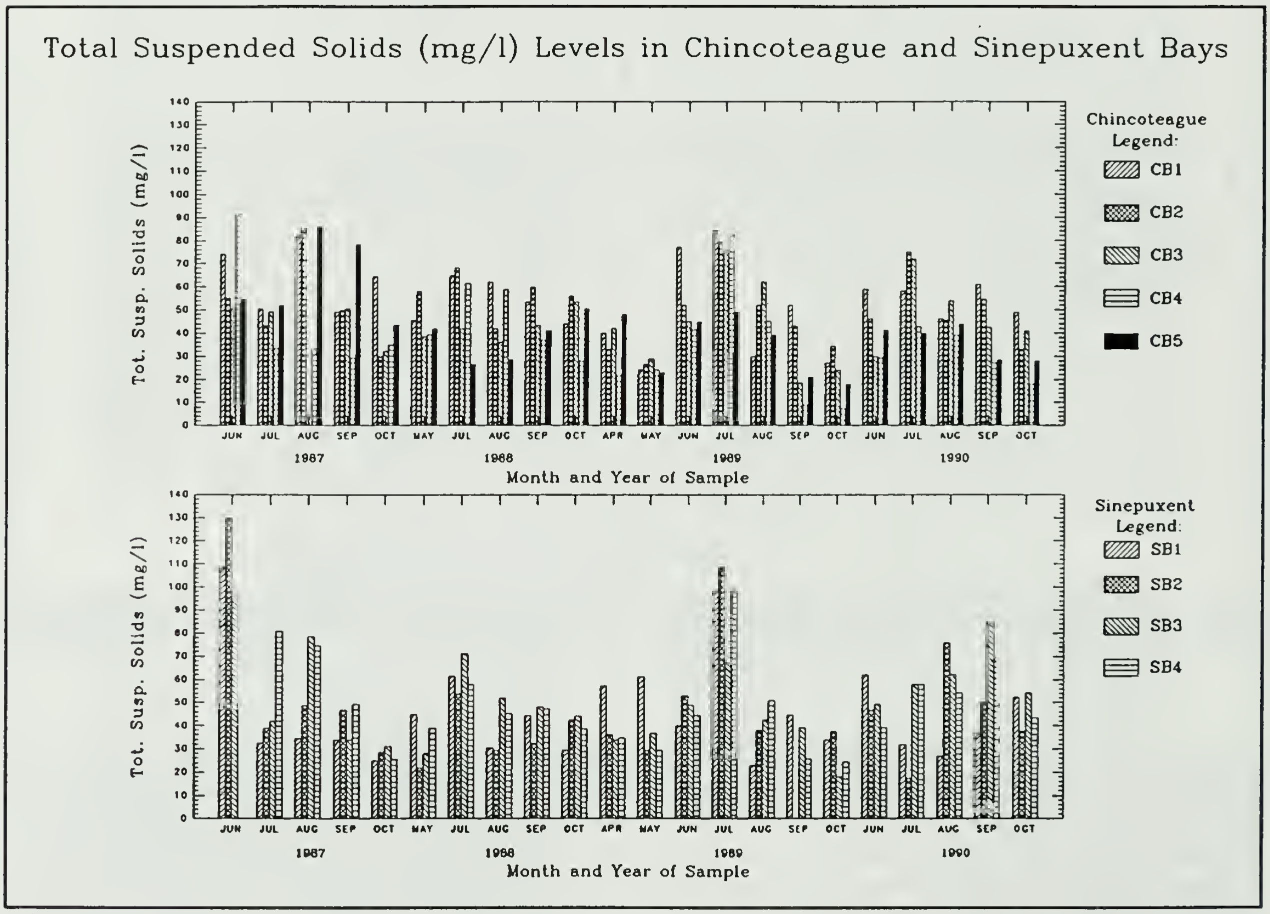

Figure 17. Seasonal TSS Distribution in the Chincoteague-Sinepuxent Bay Complex.

The concentration of TSS in the Chincoteague-Sinepuxent Bay complex during the sample periods was greatest during the summer periods, particularly June and July (Figure 17). TSS values in the Chincoteague ranged from 7.2 mg/l (10/25/89) to 91.2 mg/l at CB4 (6/30/87). The arithmetic mean level of TSS ranged from 37.85 mg/l (S.D.=20.58) at CB4 to 54.40 mg/l (S.D.=16.45) at CB1. The TSS concentration at CB1, located in Newport Harbor near the outlet of Trappe Creek, is significantly greater than CB3, CB4, and CB5 at $\sigma = .05$. On the Sinepuxent, TSS levels ranged from a minimum of 17.50 mg/l at SB3 (10/25/89) to a maximum of 129.6 mg/l at SB2 (6/30/87). The maximum and minimum TSS concentration's for each bay occurred during the same months. Arithmetic mean TSS levels were very consistent (Figure 18), ranging from 46.06 mg/l (S.D.=22.10) at SB1 to 50.94 mg/l (S.D.=19.47) at SB3. There was no significant difference among the mean concentrations of TSS on

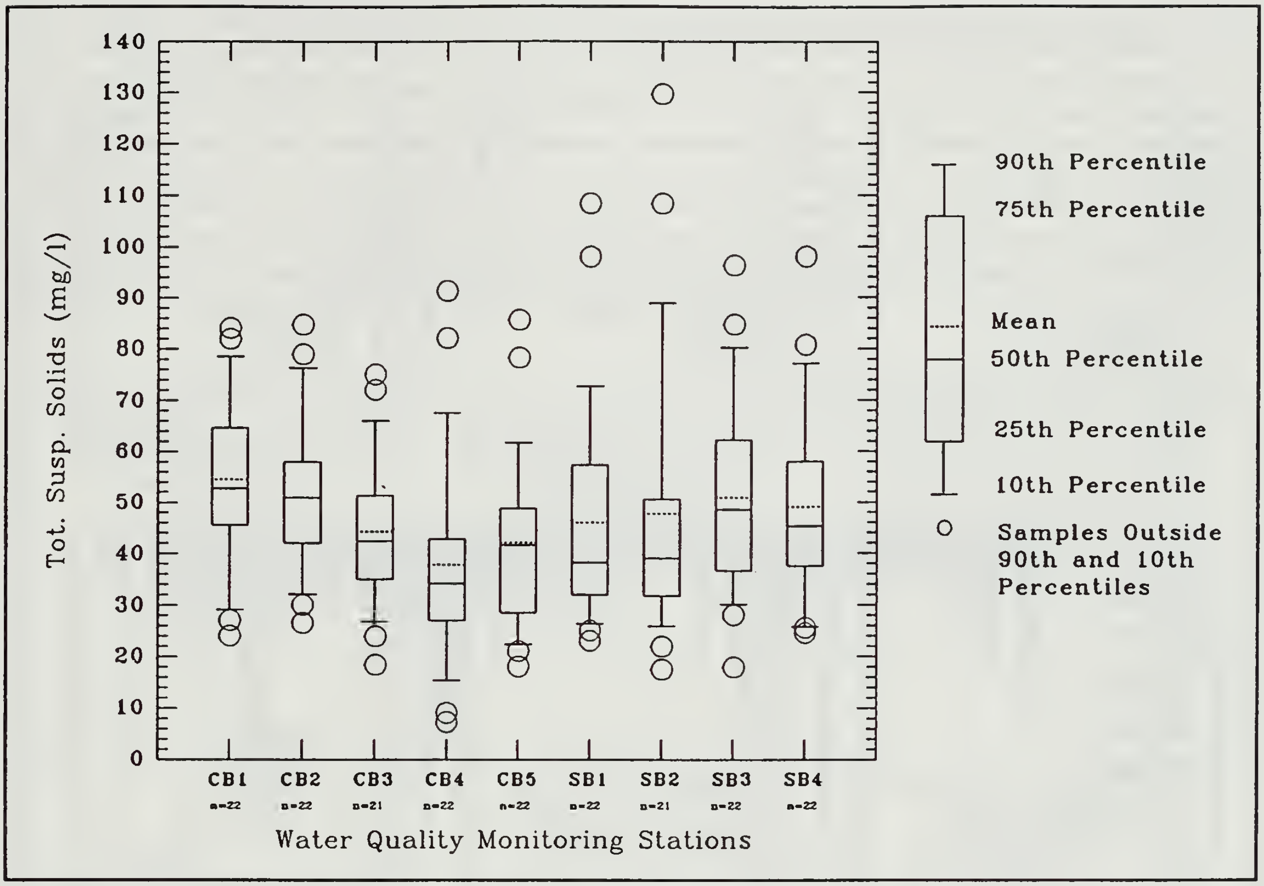

Figure 18. TSS Distributions in the Chincoteague-Sinepuxent Bay Complex.

the Sinepuxent (σ=.05). Overall mean TSS concentrations were not significantly different between the Chincoteague (45.94 mg/l, S.D.=17.66) and Sinepuxent (48.47 mg/l, S.D.=21.82), although the Sinepuxent exhibited greater variability (Figure 18). Figure 19 displays the expected inverse correlation (simple linear regressions and 95% confidence intervals) between water turbidity/clarity and TSS at each sample location. Only at CB5 was there no apparent relationship between TSS and turbidity.

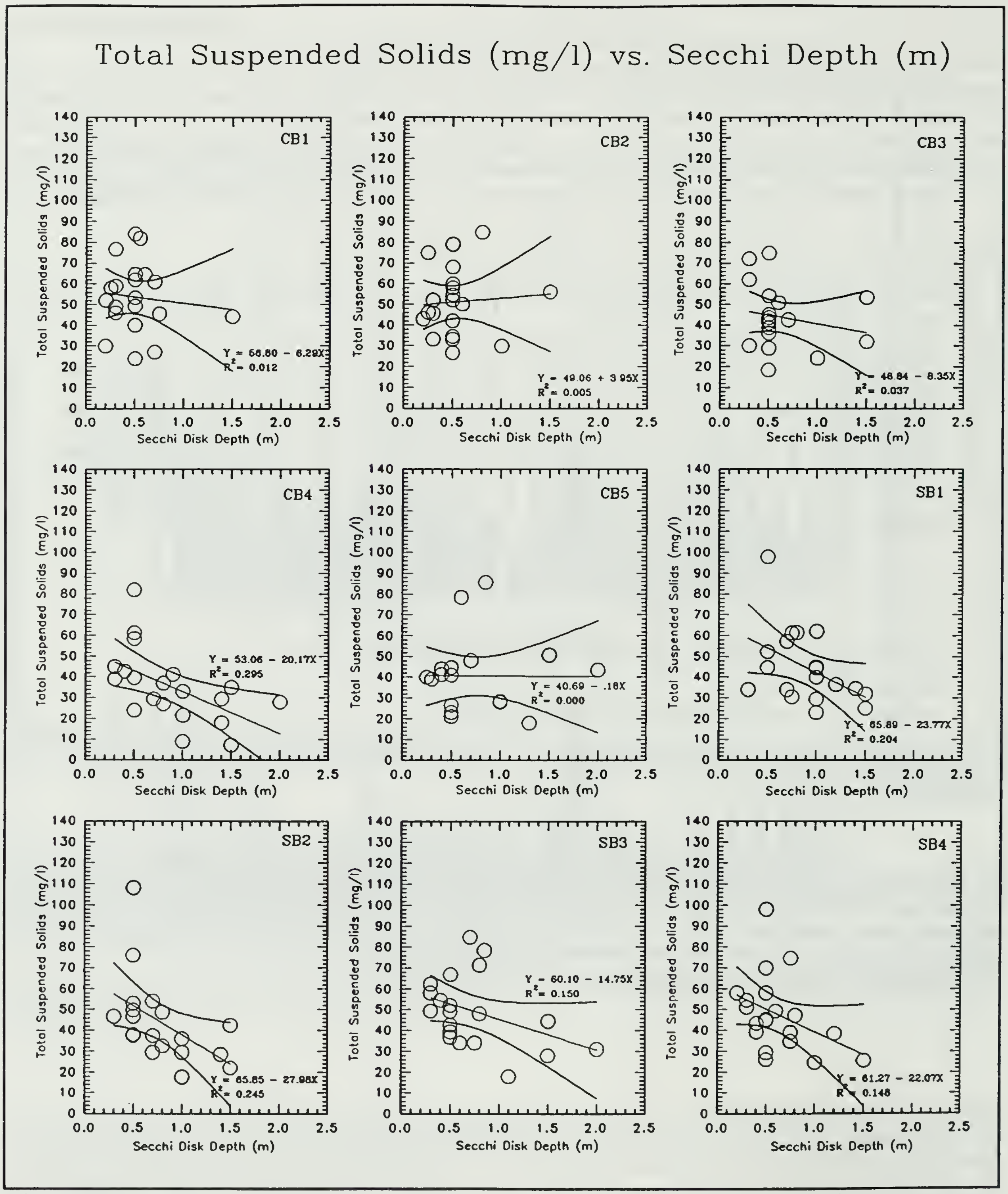

Figure 19. TSS and Water Clarity Relationship in the Chincoteague-Sinepuxent Bay Complex.

Turbidity/Water Clarity:

The turbidity or clarity of water is an important water quality parameter for both aquatic life and recreational use. Turbid water, as a consequence of suspended and colloidal matter (silt, clay, organic matter, plankton, etc.) in the water from erosion, runoff, algal blooms, and bottom resuspension, diminishes light penetration. A decrease in light penetration can impair photosynthesis by submerged aquatic vegetation and algae, thereby disrupting the food chain upon which fish depend and decreasing the level of dissolved oxygen. Additionally, turbidity can hinder the ability of fish to locate food or reproduce successfully. Turbidity also causes safety and aesthetic problems for recreationists. Whereas TSS measures the concentration of suspended solids, turbidity measures the water's optical properties - the ability of light to penetrate through the water. Turbidity was measured on the Chincoteague-Sinepuxent Bay complex by recording the maximum depth at which a Secchi disk could be seen. The deeper the depth, the less turbid (more clear) the water.

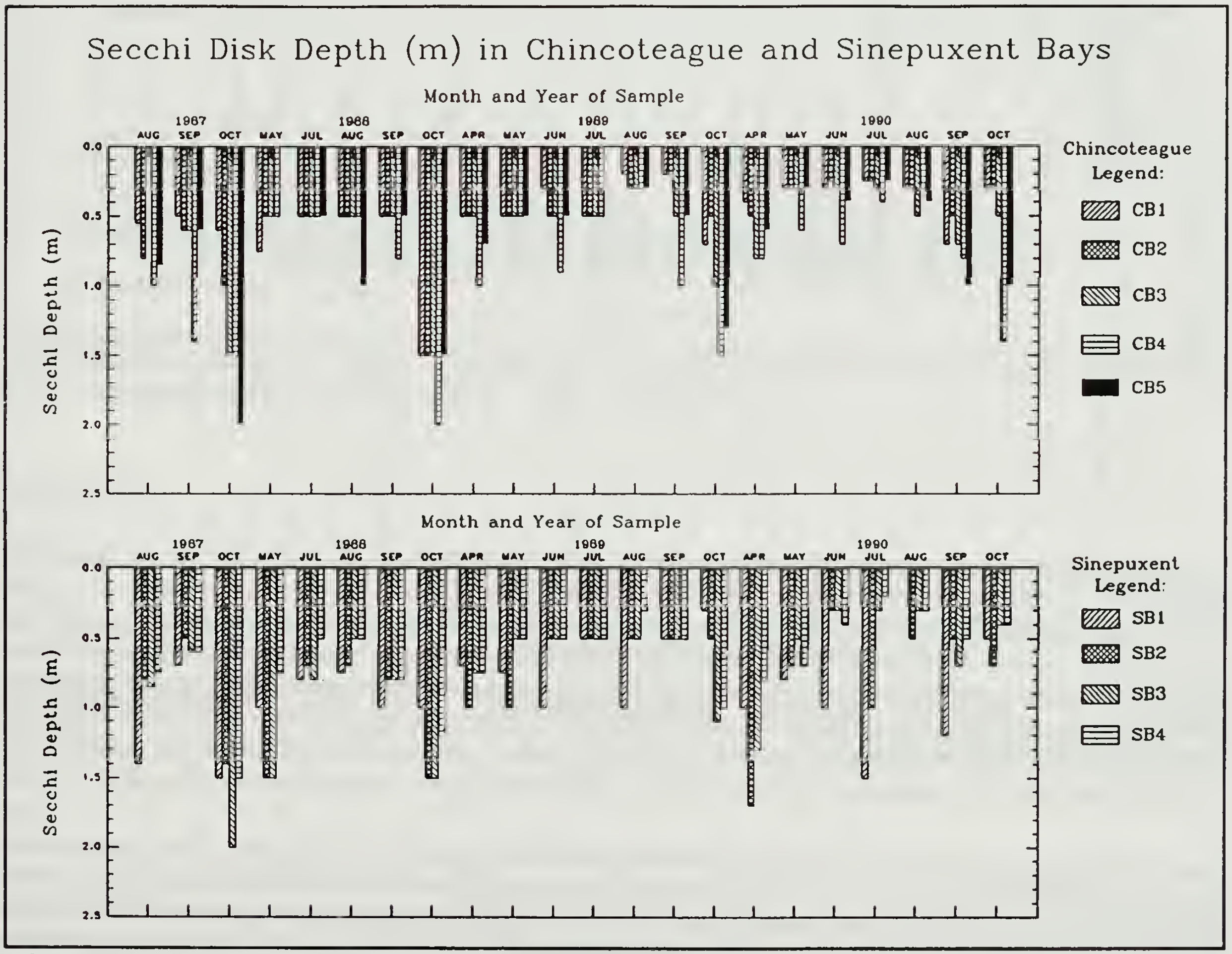

Figure 20. Seasonal Secchi Disk Depth in the Chincoteague-Sinepuxent Bay Complex.

Secchi disk depths in the Chincoteague-Sinepuxent Bay complex were greatest during October (Figure 20), the last month of sampling each year, and lowest during the summer. Depths on the Chincoteague ranged from 0.2 m at CB1 and CB2 to 2.0 m at CB4 and CB5 (Figure 21). Arithmetic mean Secchi disk depths ranged from 0.49 m (S.D.=0.28) at CB1 to 0.86 m (S.D.=.46) at CB4. Mean Secchi disk depth at CB4 and CB5 was significantly greater than other Chincoteague sample locations (σ=.05). On the Sinepuxent, Secchi disk depths ranged from a minimum of 0.2 m at SB4 to a maximum of 2.0 m at SB3. The maximum arithmetic mean Secchi disk depth of 0.90 m occurred at SB1 (S.D.=.33), while the minimum of .63 (S.D.=.30) occurred at SB4. The water clarity at SB1 was significantly greater than the clarity at SB4 (σ=.05). The overall mean Secchi disk depth level on the Sinepuxent was .77 m (S.D.=.38) which was statistically greater than the overall mean of .64 m (S.D.=.39) on the Chincoteague - indicating the waters of the Sinepuxent are less turbid than the Chincoteague.

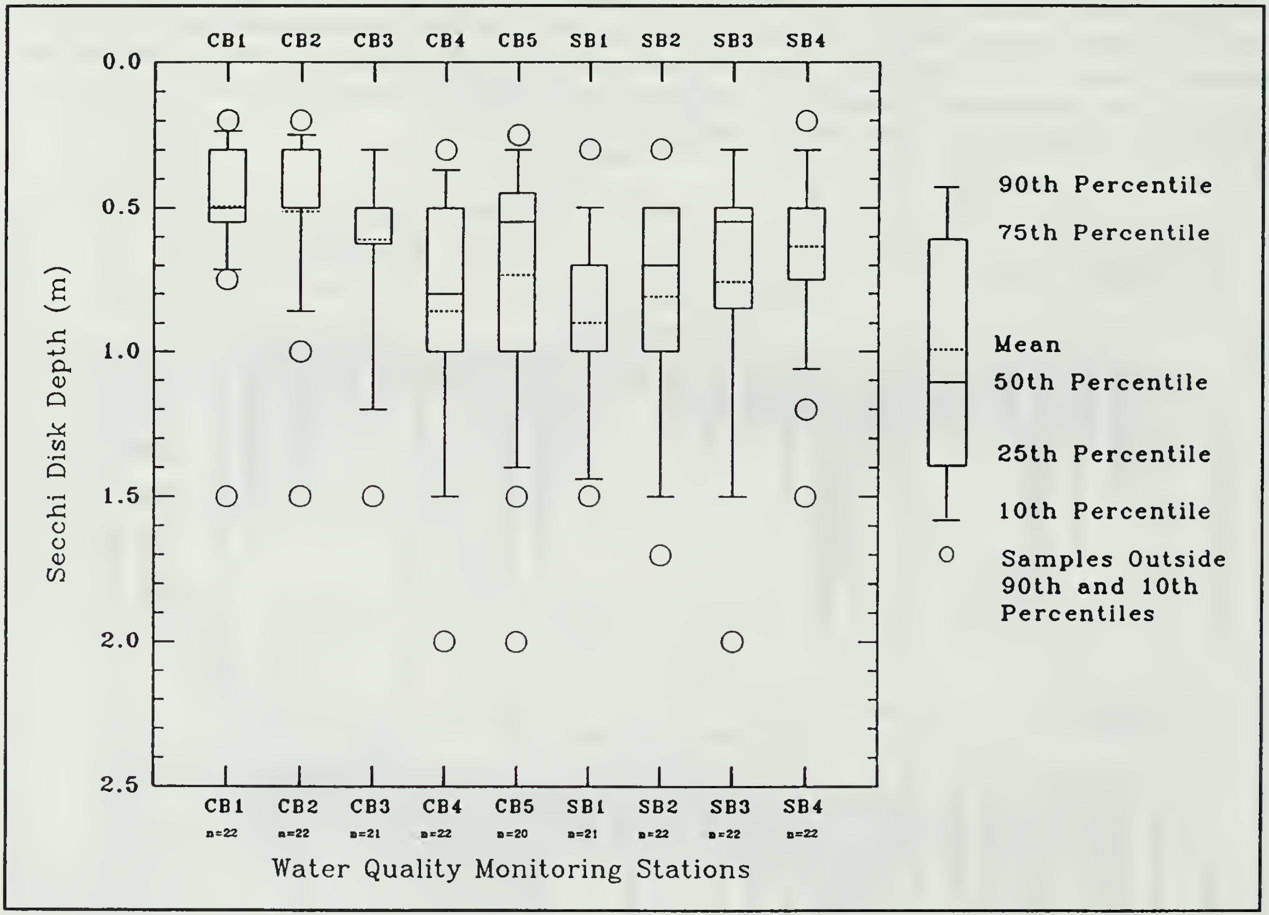

Figure 21. Secchi Depth Distributions in the Chincoteague-Sinepuxent Bay Complex.

Figure 22 displays graphically the relationship between Secchi disk depth and station depth. This figure enables one to discern how much of the water column is visible. For example, on the Chincoteague, the bottom of the bay was visible (Secchi disk depth=station depth) at five different sampling times (four times at CB4). On the Sinepuxent, the bottom was visible twice - both from station SB2. The average percent of the water column visible ranged from 24% at CB1 to 55% at CB4 on the Chincoteague; and from 30% at SB1 to 42% at SB2 on the Sinepuxent.

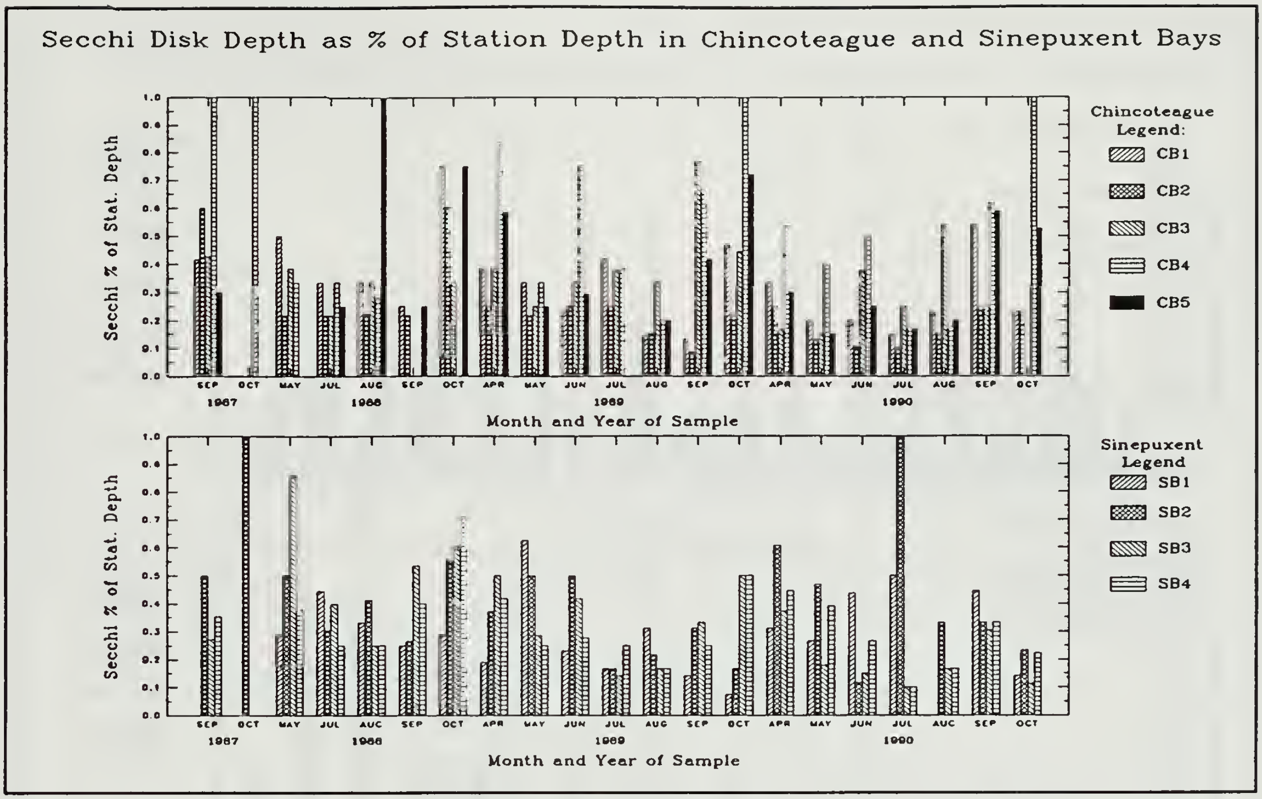

Figure 22. Secchi Disk Depth as a Percentage of Station Depth in the Chincoteague-Sinepuxent Bay Complex.

Chlorophyll a:

Chlorophyll a is a convenient measure of algal biomass in water. Although limited concentrations of algae are usually not troublesome in surface waters, overproduction of certain species can be undesirable for many water uses. Dense, abundant growth of planktonic algae can inhibit photosynthesis and shade bottom mud, thereby preventing germination of aquatic vegetation - an important food source for water fowl. Certain types of algae can generate odors or scum, rendering the water undesirable for contact recreation. Algae can also impair fishing nets, tangle lines, and clog intake pipes and valves. Additionally, under certain conditions algae may die and their decomposition can deplete dissolved oxygen. Chlorophyll a (as a measure of algal biomass), primary productivity, oxygen deficit, indicator communities, and nutrient levels are all considered measures of a waterbody's trophic level.

The concentration of chlorophyll a in the Chincoteague-Sinepuxent Bay complex exhibited a slight seasonal trend during the sampling periods (May-Oct. 1988, Apr.-Oct. 1989, and Jun.-Oct. 1990) (Figure 23), with higher concentrations generally occurring during the summer when conditions are more favorable for algal growth. Chlorophyll a levels were greatly elevated at CB1 three times prior to 1990: July 1988, April 1989, and August 1989. In fact, CB1 experienced the greatest single (37.4 μg/l) and arithmetic mean (19.67 μg/l, S.D.=10.02) concentrations for the entire Chincoteague. The level of chlorophyll a at CB1 was significantly greater than CB3, CB4, and CB5 (σ=.05). Sample point CB4 posted the lowest single (1.02 μg/l) and arithmetic mean (5.92 μg/l, S.D.=3.64) concentrations on the Chincoteague. The concentration of chlorophyll a at CB4 was significantly less than CB1, CB2, and CB3 at σ=.05. On the Sinepuxent, chlorophyll a concentrations ranged from 0.94 μg/l at SB2 to 43.40 μg/l at SB4. The two greatest concentrations of chlorophyll a in the Chincoteague-Sinepuxent Bay complex occurred on the Sinepuxent at SB4 in successive months (August and September) of 1990.

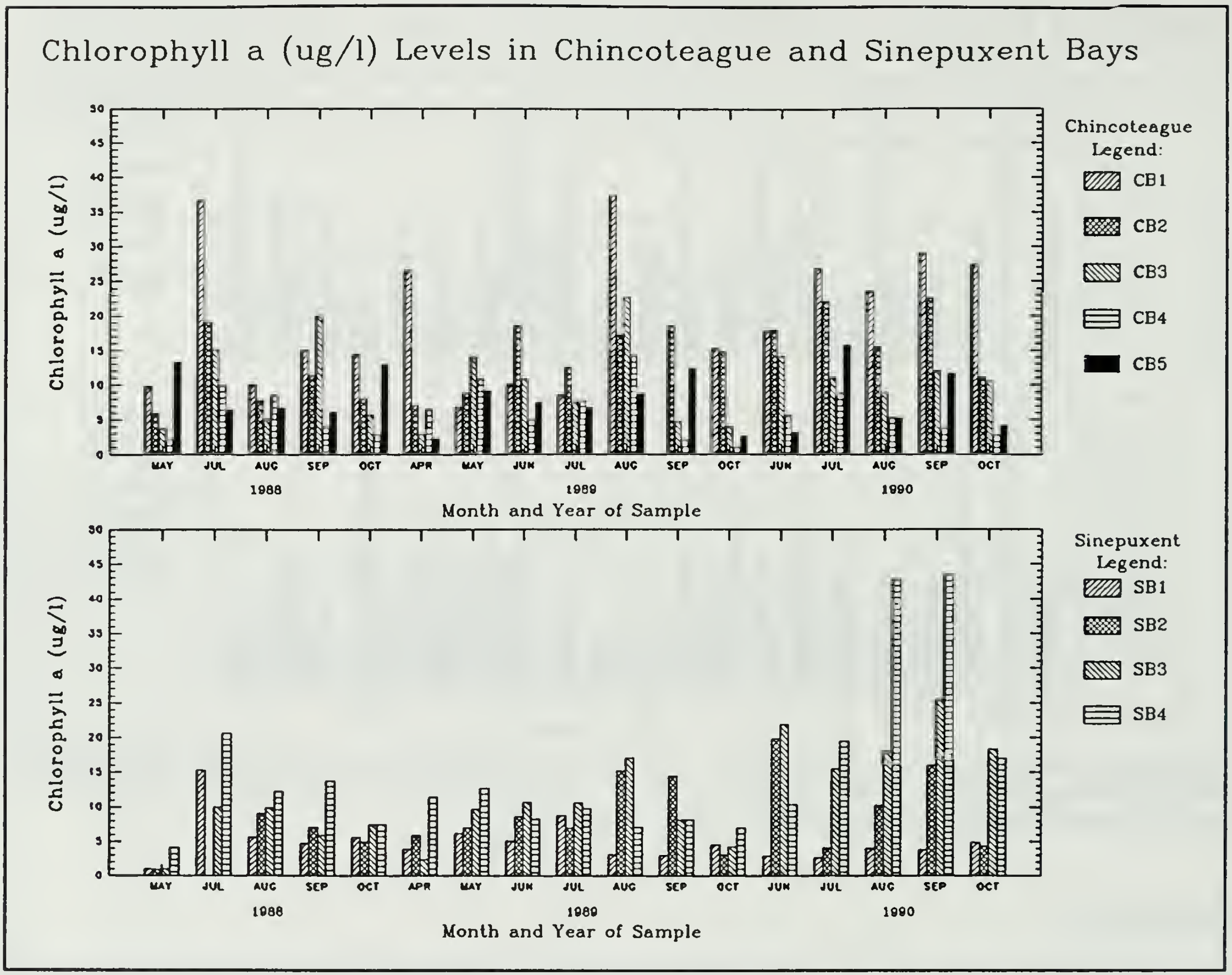

Figure 23. Seasonal Chlorophyll a Distribution in the Chincoteague-Sinepuxent Bay Complex.

Arithmetic mean concentrations of chlorophyll a ranged from 5.02 μg/l (S.D.=3.15) at SB1 to 15.03 μg/l (S.D.=11.46) at SB4. The mean concentration of chlorophyll a at SB1 was significantly lower than all other sample locations on the Sinepuxent. The level of chlorophyll a at SB4 was significantly greater than SB1 and SB2 ($\sigma=.05$).

Overall, there was no significant difference in mean chlorophyll a concentrations between the Chincoteague (11.43 μg/l, S.D.=7.71) and the Sinepuxent (10.07 μg/l, S.D.=8.12). Chlorophyll a concentrations appear to be much more variable at CB1 and SB4 than at the other sample locations. The concentration at SB1 is typically the lowest and least variable (Figure 24).

Overall chlorophyll a concentrations appear to have been much more elevated in 1990 than the prior years, particularly at CB1 in Newport Bay at the outlet of Trappe Creek and at SB4 in the southern Sinepuxent Bay.

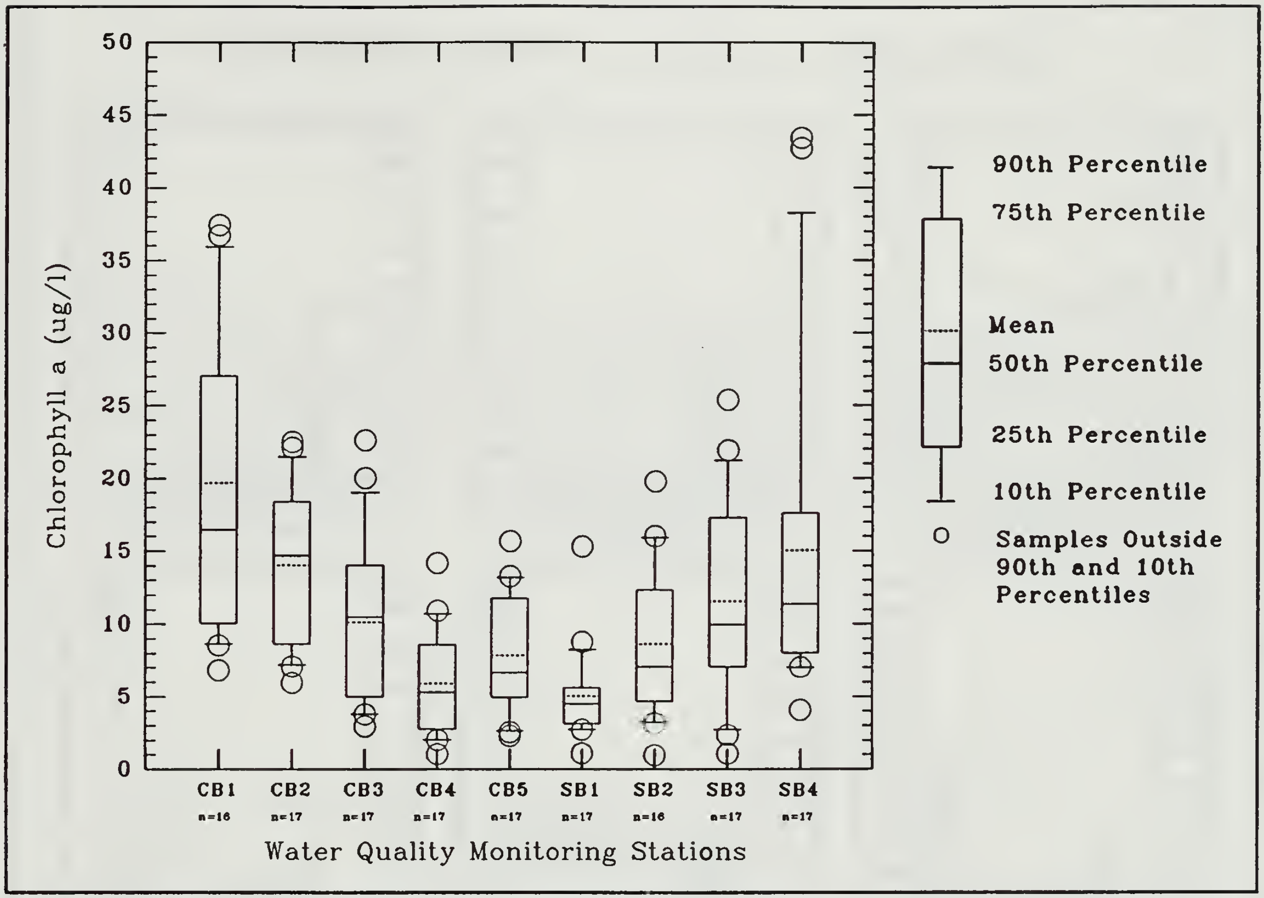

Figure 24. Chlorophyll a Distributions in the Chincoteague-Sinepuxent Bay Complex.

The expected inverse relationship of chlorophyll a to turbidity/water clarity (Secchi disk depth) is displayed for each sample location in Figure 25 which shows the simple linear regression and 95% confidence bounds of chlorophyll a and Secchi disk depth. For each sample location, as chlorophyll a concentration increases, water clarity decreases - although the relationship appears weakest at CB5. The relationship between TSS and chlorophyll a, displayed in Figure 26, is mixed. Generally, as TSS increases, chlorophyll a also increases. At CB1, however, there is an inverse relationship between TSS and chlorophyll a; and at CB5 there is no relationship between TSS and chlorophyll a[12].

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[12] Thus, at CB5, there was no relationship between chlorophyll a concentration and turbidity/water clarity, TSS and turbidity/water clarity, and TSS and chlorophyll a concentration.

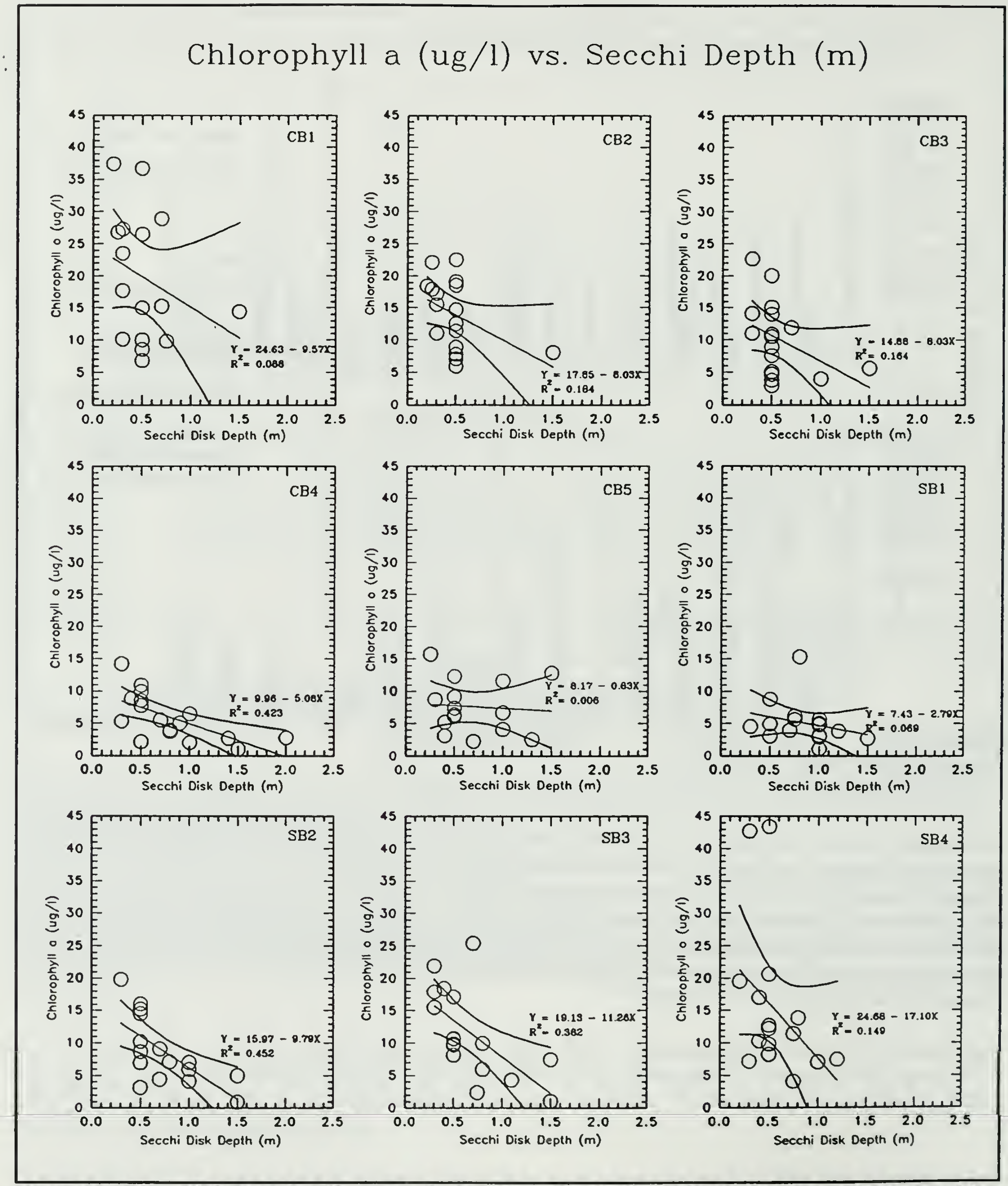

Figure 25. Chlorophyll a and Secchi Disk Depth Relationship in the Chincoteague-Sinepuxent Bay Complex.

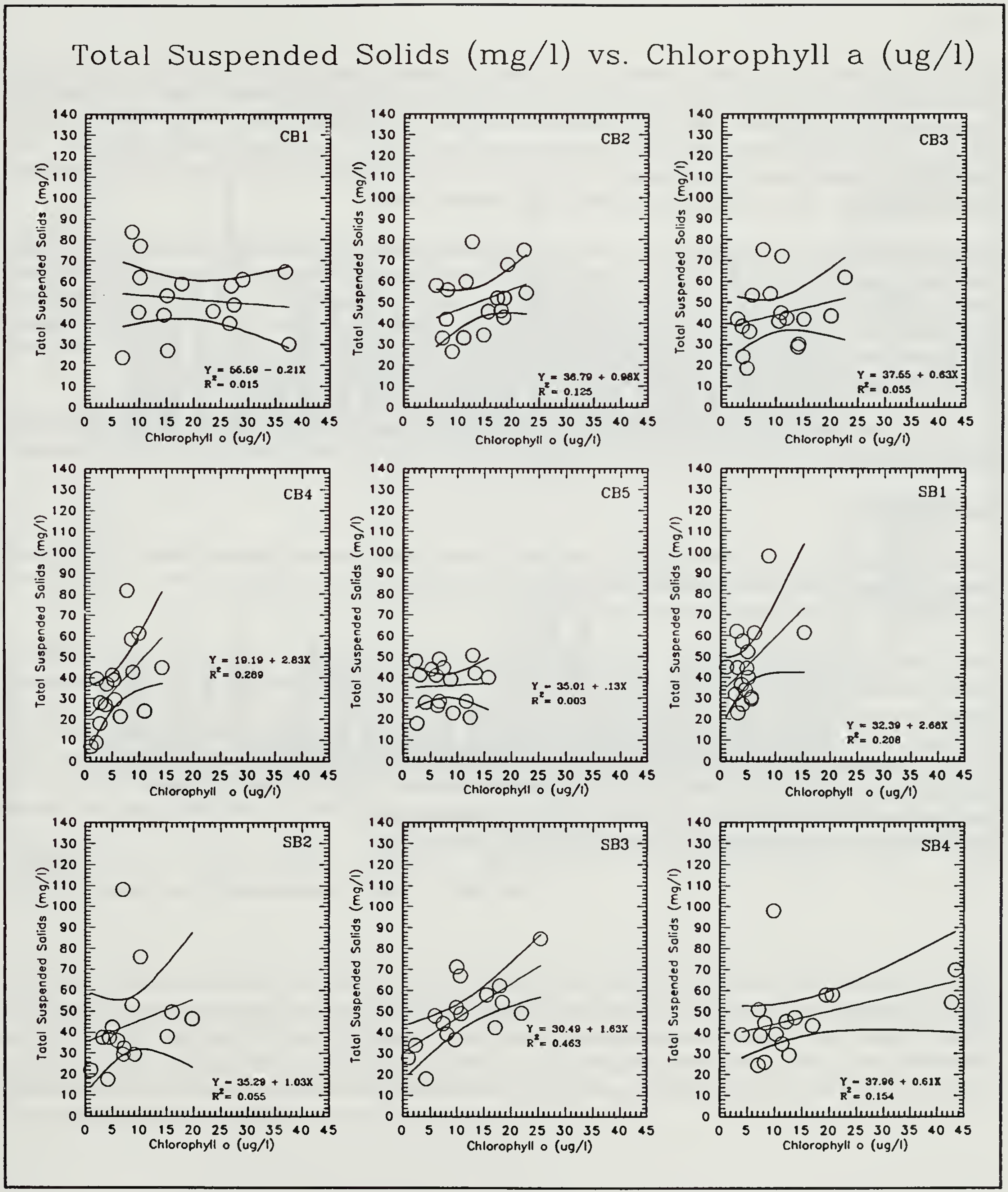

Figure 26. TSS and Chlorophyll a Relationship in the Chincoteague-Sinepuxent Bay Complex.

Nitrogen:

Approximately 78% of the earth's atmosphere by volume is inorganic, elemental nitrogen (N_2). Nitrogen also exists throughout the ecosystem - in rocks, plants, animals, and decaying organic matter. Bacteria and blue-green algae convert N_2 to ammonia (NH_3) or ammonium ions (NH_4^+) - a process called nitrogen fixation. Other bacteria convert ammonia to nitrite (NO_2^-) or nitrite to nitrate (NO_3^-) via a process called nitrification. In a reverse of this process, denitrification, certain bacteria can convert nitrates to nitrites and then to inorganic, elemental nitrogen. These processes are all part of the nitrogen cycle.

Nitrogen, in its many chemical forms, is a critical water quality parameter in estuarine systems. In association with proper concentrations of other nutrients (particularly phosphorus), excessive nitrogen stimulates plant growth. This can lead to lower dissolved oxygen levels, accelerated eutrophication, and deleterious impacts on the aquatic biota. Certain forms of nitrogen in water can be hazardous to human health, particularly infants. The atmosphere, sewage treatment plants, animal and plant processing wastes, manure, fertilizer, industrial effluent, and agricultural runoff are the primary contributors of nitrogen to aquatic systems.

On the Chincoteague-Sinepuxent Bay complex, measurements were made of total nitrogen, total nitrogen filtered, dissolved ammonium, and nitrates/nitrites. The concentration of each of these pollutants is discussed below.

Total Nitrogen:

Total nitrogen is the total concentration of nitrogen in a water quality sample without filtering which would remove nitrogen bound up in particulate matter that was too large to pass through the filter. This provides a measure of the total nitrogen present in the system.

Total nitrogen fluctuated seasonally. The highest levels of total nitrogen were recorded during the summer months, tapering off into the spring and fall (Figure 27). Total nitrogen concentrations in the Chincoteague ranged from a minimum of 23.8 μm at CB3 to a maximum of 121 μm at CB1 in Newport Bay near the outlet of Trappe Creek. Arithmetic mean values ranged from 41.78 μm (S.D. = 12.90) at CB4 to 77.78 μm (S.D. = 19.02) at CB1. The mean level of total nitrogen at CB1 was significantly greater ($\sigma = .05$) than the mean levels at the other four sample locations on the Chincoteague and all the locations on the Sinepuxent. The mean level at CB4 was significantly lower than the other Chincoteague sample sites, except CB5. On the Sinepuxent, the range of total nitrogen concentrations was 11.0 μm at SB2 to 89.7 μm at SB3.

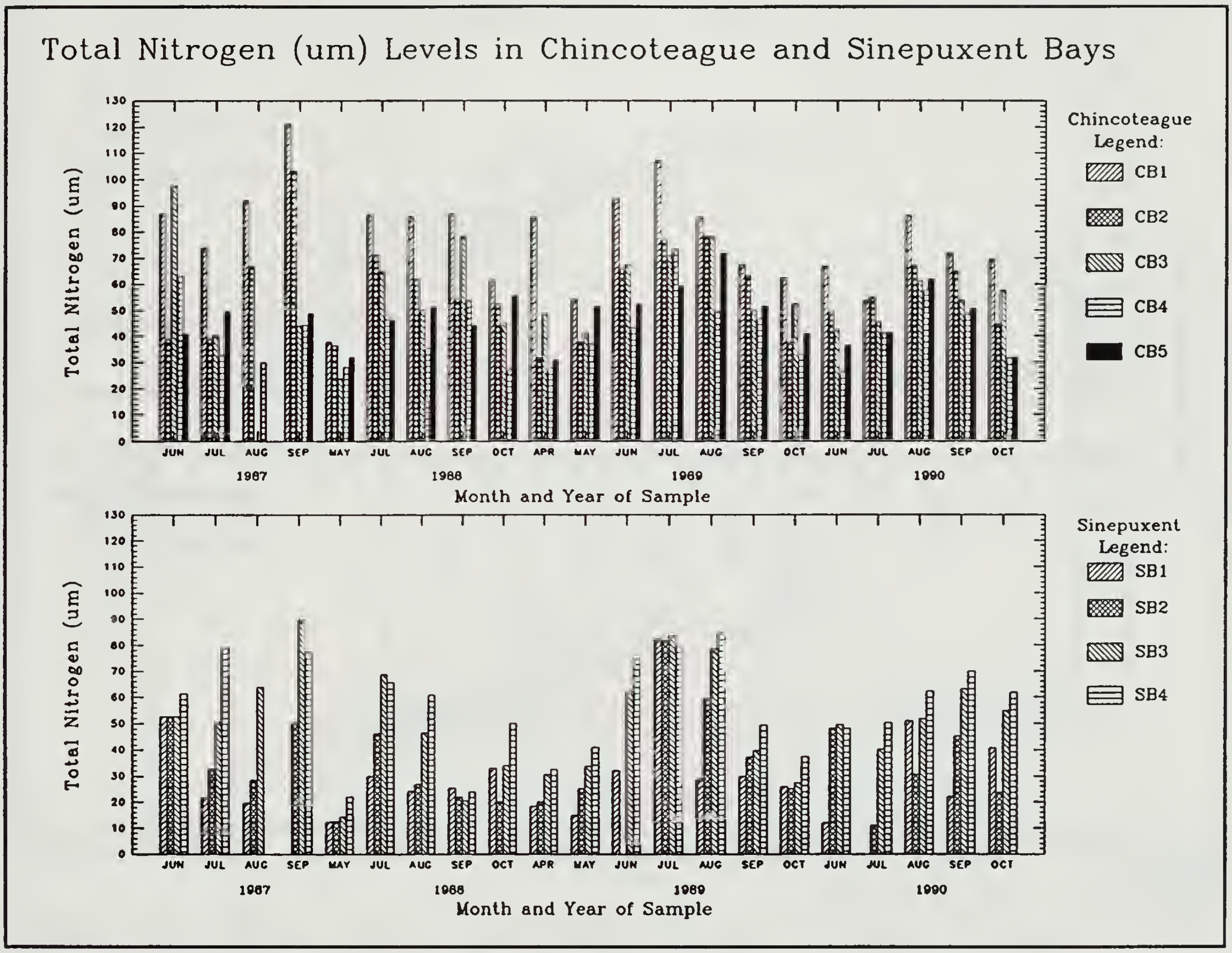

Figure 27. Seasonal Total Nitrogen Distribution in the Chincoteague-Sinepuxent Bay Complex.

Arithmetic mean levels varied from 30.28 μm (S.D.=16.84) at SB1 to 56.51 μm (S.D.=18.56) at SB4. The mean concentrations of total nitrogen at SB3 and SB4 were significantly greater (σ=.05) than the concentrations at SB1 and SB2. In fact, SB1 and SB2 had significantly lower (σ=.05) mean concentrations than any sample locations on both the Chincoteague and Sinepuxent (Figure 28). In comparing the mean levels of total nitrogen between the two bays, the mean total nitrogen concentration in the Chincoteague is significantly greater (σ=.05) than the Sinepuxent (55.95, S.D.=19.83 vs. 43.24, S.D.=20.97).

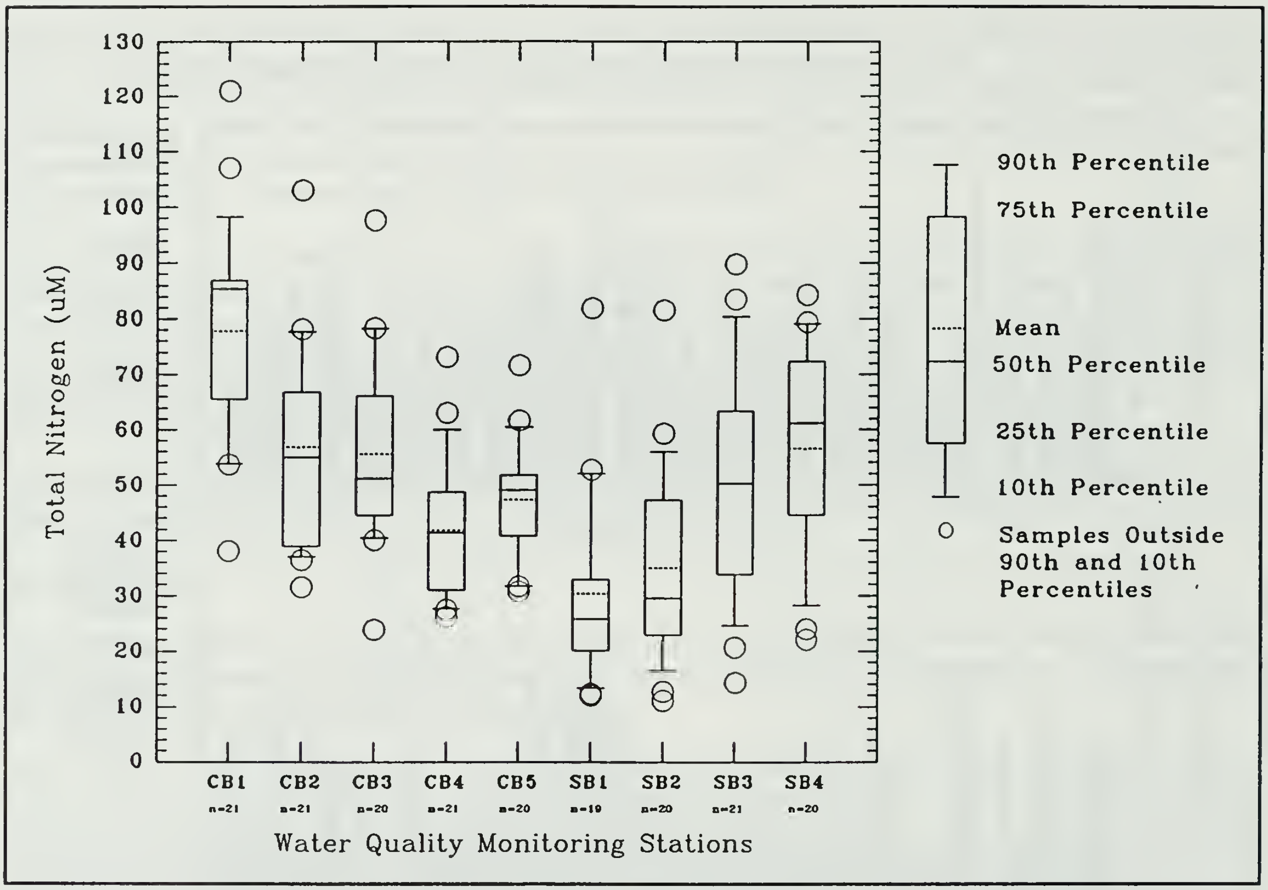

Figure 28. Total Nitrogen Distributions in the Chincoteague-Sinepuxent Bay Complex.

Total Filtered Nitrogen:

Total nitrogen filtered (TNF) is the total concentration of nitrogen in a water quality sample that is dissolved in solution and small enough to pass through a filter of a given size. TNF, which should generally be less than and directly related to total nitrogen, is a better measure of plant available nitrogen than total nitrogen. The close, positive relationship of total nitrogen and TNF is displayed in Figure 29.

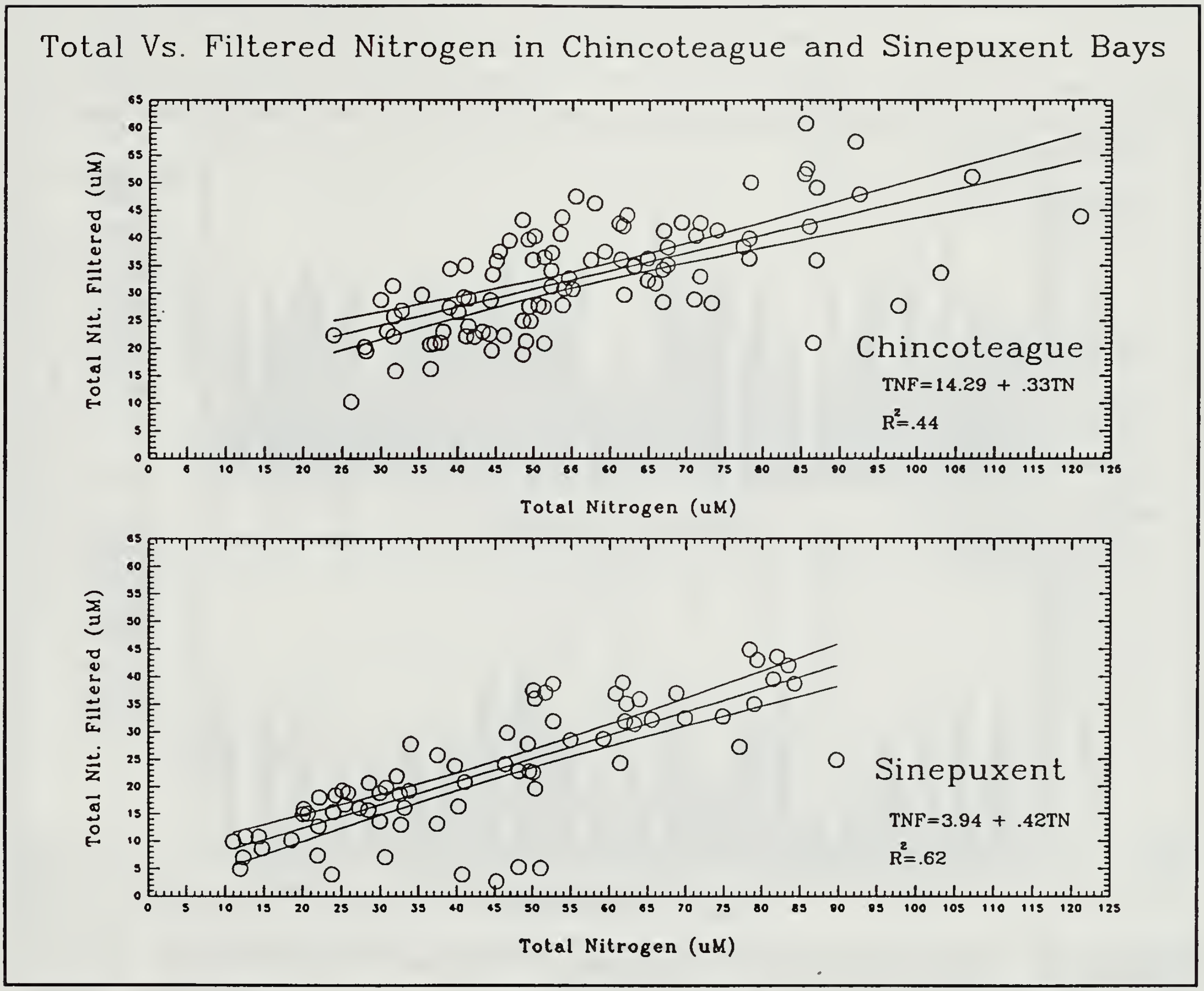

Figure 29. Total and Filtered Nitrogen Relationship in the Chincoteague-Sinepuxent Bay Complex.

As with total nitrogen, TNF was generally higher during the summer throughout the Chincoteague-Sinepuxent Bay complex (Figure 30). TNF on the Chincoteague ranged from 10.20 µm at CB4 to 60.7 µm at CB1. The sample point with the lowest arithmetic mean TNF concentration on the Chincoteague was CB4 (29.08 µm, S.D.=9.28); while CB1 registered the highest mean TNF concentration (41.62 µm, S.D.=10.35). As with total nitrogen, the concentration of TNF at CB1 was significantly greater ($\sigma=.05$) than the concentration at the other four sample sites in the Chincoteague and the four locations in the Sinepuxent. On the Sinepuxent, the level of TNF ranged from a minimum of 2.70 µm at SB2 to a maximum of 44.9 µm at SB3 (Figure 31). Arithmetic mean concentrations varied from 14.96 µm (S.D.=9.29) at SB1 to 28.19 µm (S.D.=9.02) at SB4. Although each sample point on the Sinepuxent registered a maximum concentration of TNF in a range from 39-45 µm, both SB3 and SB4 exhibited significantly ($\sigma=.05$) greater mean TNF concentrations than SB1 and SB2. In fact, as with total nitrogen, the arithmetic mean concentrations of TNF at SB1 and SB2 were significantly lower than the concentration at any other location on the Chincoteague-Sinepuxent Bay complex. Comparing the overall mean of the two Bays, the mean level of TNF in the Chincoteague (32.91 µm, S.D.=9.66) was significantly ($\sigma=.05$) greater than the Sinepuxent (22.46 µm, S.D.=11.07).

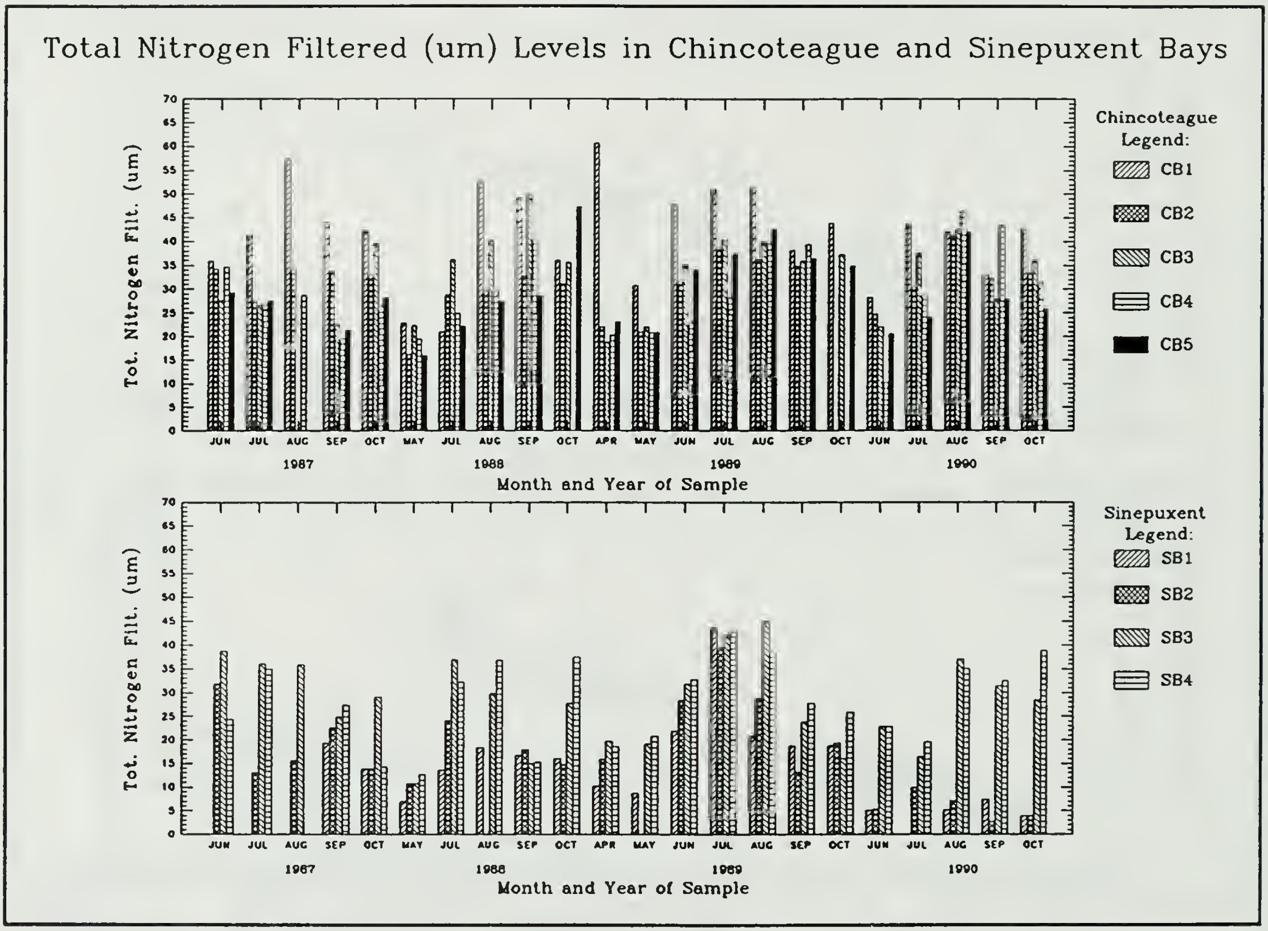

Figure 30. Seasonal Total Nitrogen Filtered Distribution in the Chincoteague-Sinepuxent Bay Complex.

The positive, linear relationship between TNF and total nitrogen portrayed in Figure 29 is of interest. On the Chincoteague, TNF averaged approximately 61% of total nitrogen, ranging from an average of 55% at CB1 to 70% at CB4. The minimum and maximum percentages of total nitrogen as TNF also occurred at CB1 (24%) and CB4 (99.6%), respectively. The percentage of total nitrogen as TNF was significantly ($\sigma = .05$) greater at CB4 than CB1. On the Sinepuxent, TNF averaged approximately 54% of total nitrogen. The means were quite consistent among sample locations on the Sinepuxent, ranging from 52% (SB1 and SB2) to 59% (SB3). The minimum and maximum percentages were 10% at SB1 and 90% at SB2, respectively.

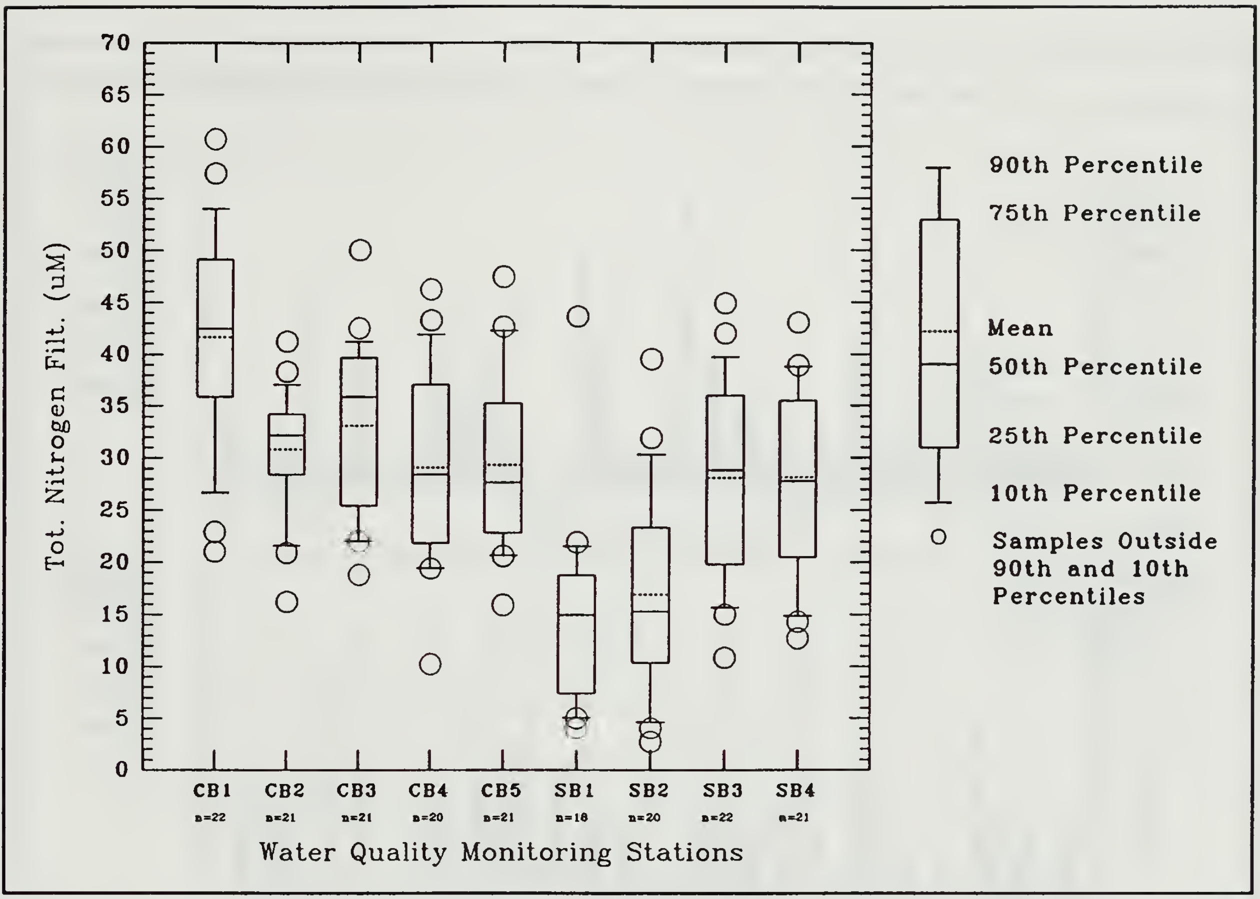

Figure 31. Total Nitrogen Filtered Distributions in the Chincoteague-Sinepuxent Bay Complex.

Dissolved Ammonium:

Ammonia, including both dissolved ammonia (NH_3) and dissolved ammonium (NH_4^+), is the most reduced inorganic form of N_2 in water. Ammonia in aquatic ecosystems derives from many disparate sources: nitrogen-fixation, decomposition of nitrogenous organic matter, microbial reduction of nitrates and nitrites under anaerobic conditions, raw and treated sewage, soil erosion, fertilizer runoff, industrial and cleaning operations, paper mills, metal refineries, and atmospheric precipitation and deposition. Ammonia, as with other nitrogen compounds, can promote aquatic vegetation growth and accelerate eutrophication. Excessive levels of ammonia may suffocate fish since it reduces the ability of hemoglobin to combine with oxygen.

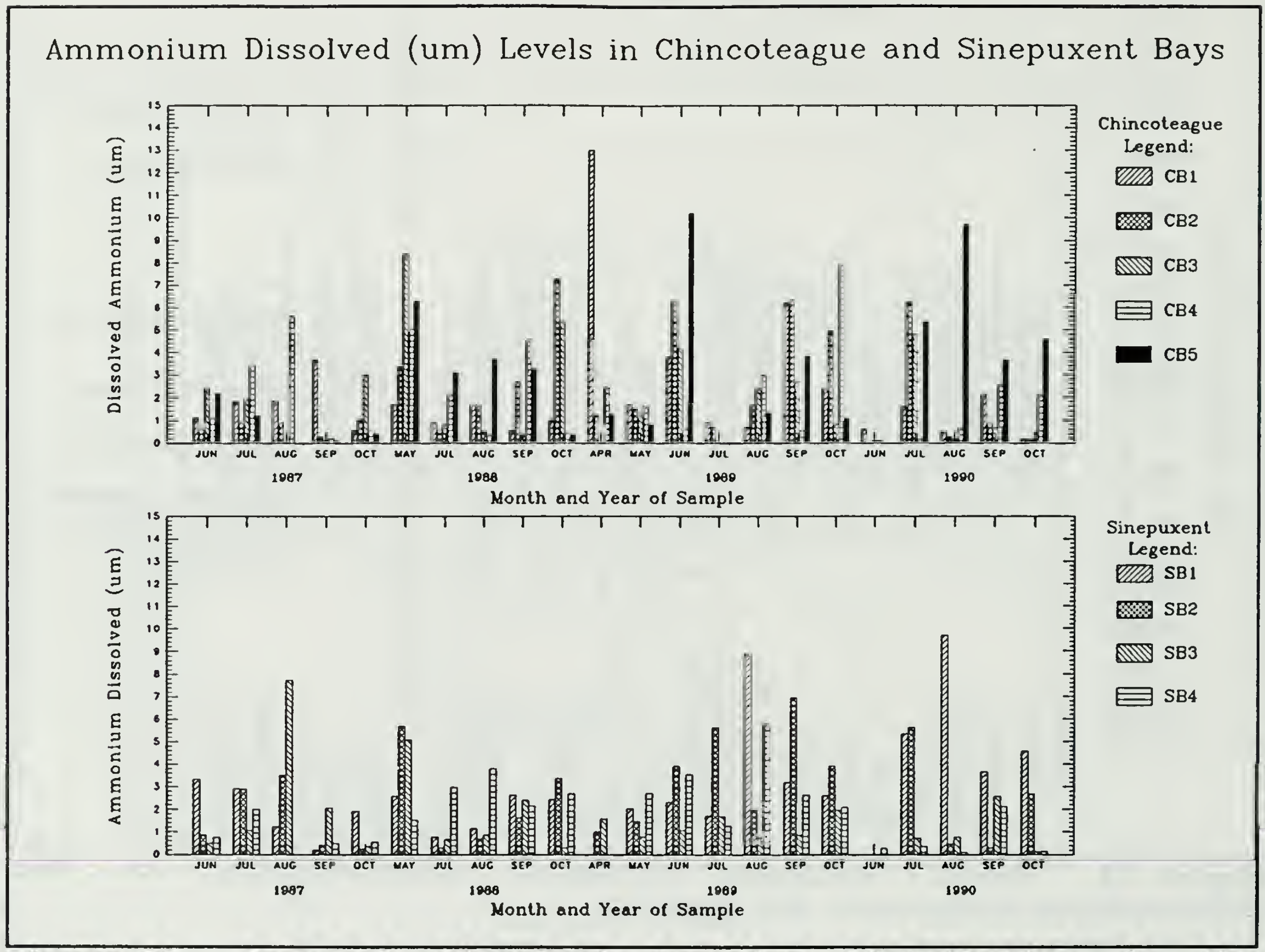

Figure 32. Seasonal Dissolved Ammonium Distribution in the Chincoteague-Sinepuxent Bay Complex.

No apparent seasonal fluctuation in the concentration of dissolved ammonium is apparent in the data (Figure 32). On the Chincoteague, the level of dissolved ammonium ranged from 0.07 μm at CB3 and CB4 to 13.0 μm at CB1. The arithmetic mean concentrations of dissolved ammonium ranged from 2.10 μm (S.D.=2.78) at CB3 to 3.28 μm (S.D.=2.95) at CB5. There was no significant difference in mean dissolved ammonium values across the Chincoteague, although there was a great deal of variability (Figure 33) in the observations (high coefficient of variations). On the Sinepuxent, the dissolved ammonium concentrations ranged from 0.10 μm to 9.71 μm, both at SB1. The lowest and highest arithmetic mean values were 1.62 μm (S.D.=1.78) at SB3 and 3.16 μm (S.D.=2.42) at SB1. As with the Chincoteague, mean concentrations were fairly consistent across the Sinepuxent (Figure 33). Overall, the Chincoteague exhibited a higher mean concentration (2.40 μm, S.D.=2.50) than the Sinepuxent (2.30, S.D.=2.03), although the difference wasn't statistically significant (σ=.05).

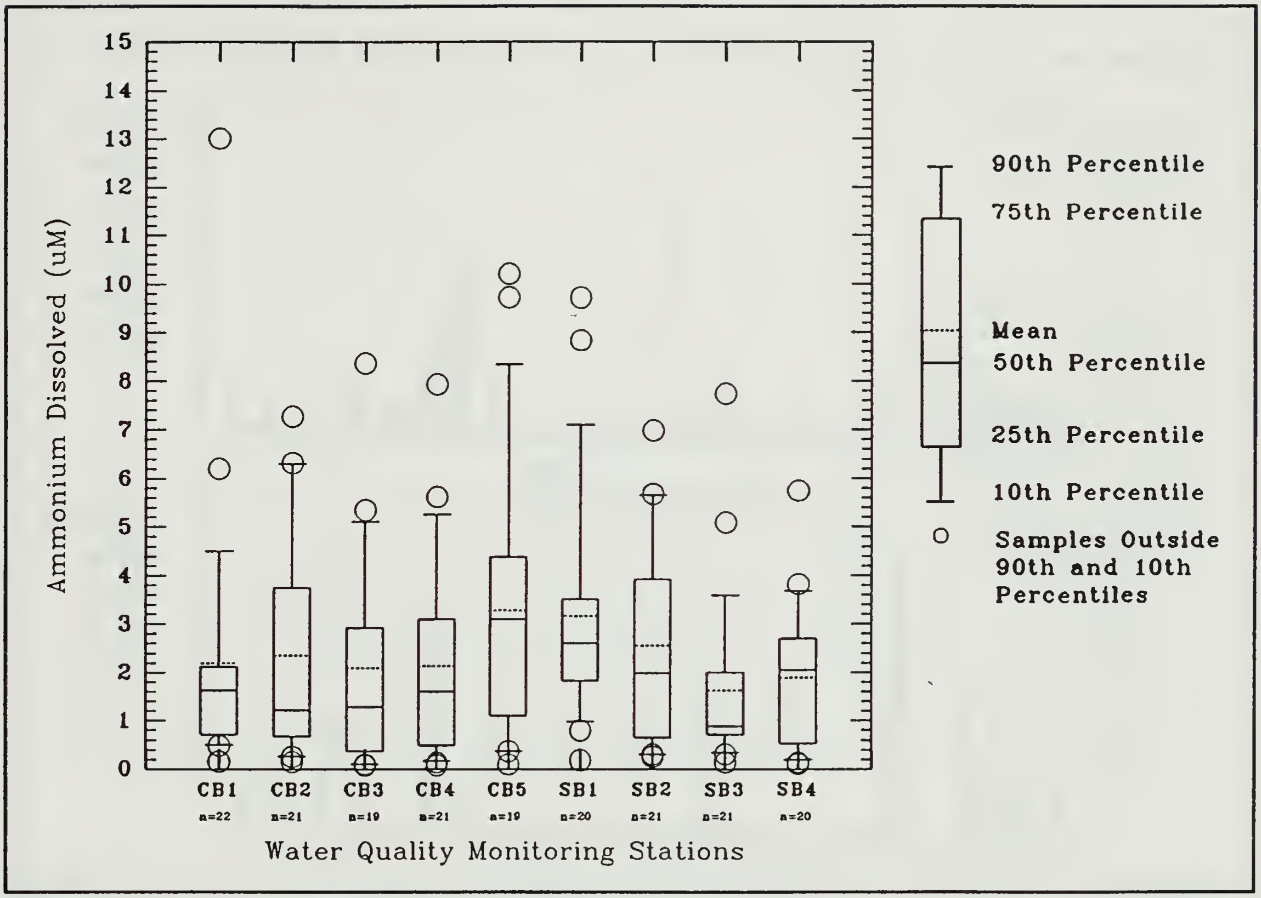

Figure 33. Dissolved Ammonium Distributions in the Chincoteague-Sinepuxent Bay Complex.

Nitrates and Nitrites:

Nitrates are the primary and most stable form of combined nitrogen in surface waters. Nitrates occur naturally through nitrification of ammonia or nitrite. Ingesting high levels of nitrates in water (>10 mg/l) can cause methemoglobinemia[13] in infants by reducing the oxygen-carrying capacity of the blood. At higher concentrations of nitrates, livestock may also be negatively affected. Since plants are capable of converting nitrates to organic nitrogen, the presence of nitrates in water can stimulate prolific algal and plant growth. The primary inputs of nitrates to surface waters are: municipal (sewage) and industrial discharges, inorganic nitrogen fertilizer runoff, oxidation of plants and animal wastes, rainwater, and leachate. Nitrites are an unstable, chemical form of nitrogen occurring naturally in water as the result of nitrification (ammonia to nitrites to nitrates) or denitrification (nitrates to nitrites to nitrogen gas). Nitrites are introduced into aquatic ecosystems from the same sources contributing nitrates. Although nitrites occur in very minute quantities in water, they are much more toxic to humans and animals than nitrates.

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[13] Actually it is the nitrite ion that is responsible for causing methemoglobinemia. As a consequence, nitrates and nitrites are frequently lumped together as a single standard of 10 mg/l (N) of nitrate ion plus nitrite ion.

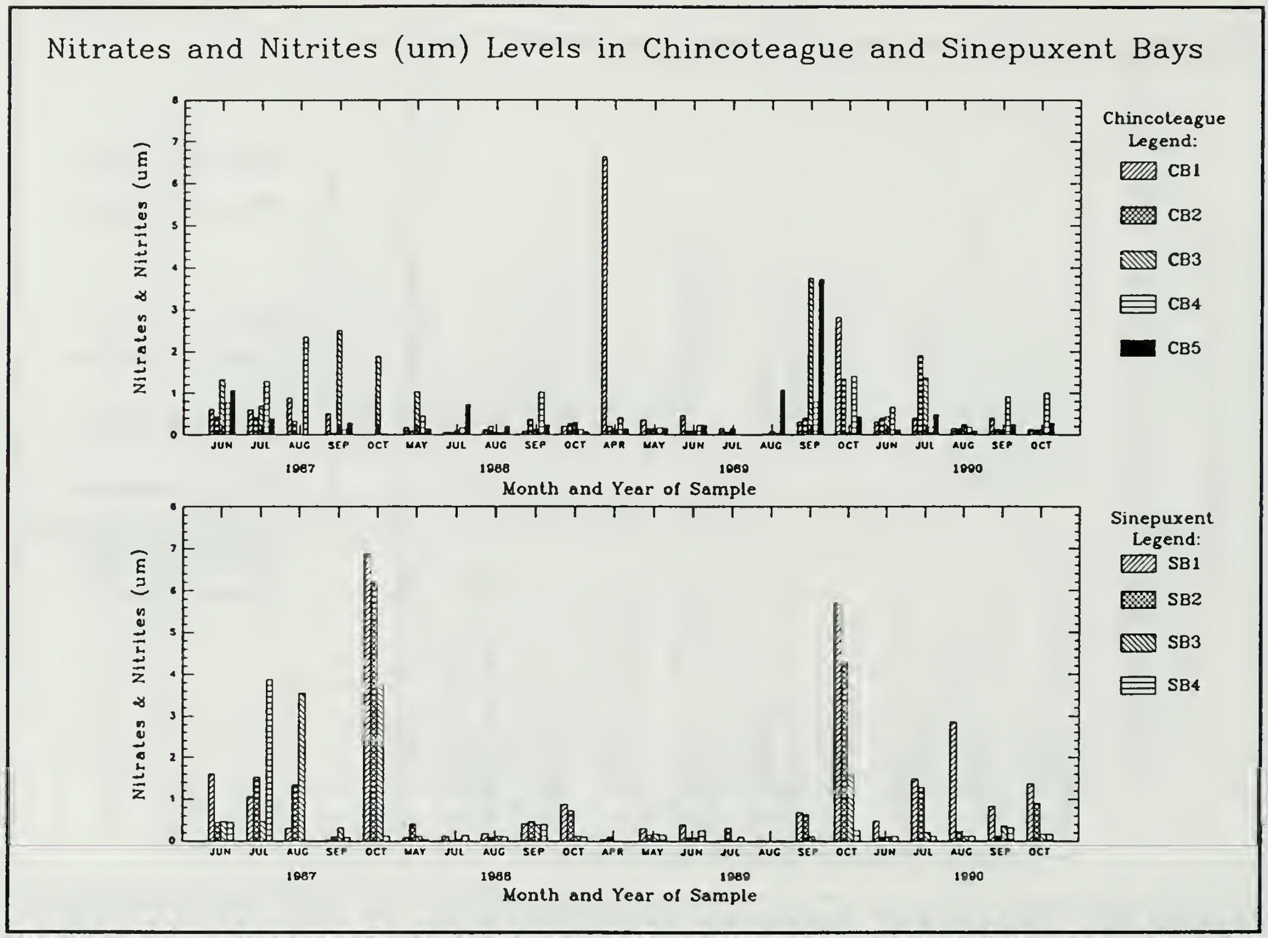

Figure 34. Seasonal Nitrates and Nitrites Distribution in the Chincoteague-Sinepuxent Bay Complex.

The concentration of nitrates and nitrites in the Chincoteague-Sinepuxent Bay complex varied greatly over time (Figure 34). For every sample point, the standard deviation exceeded the mean (coefficient of variation greater than 1). Although 6 observations on the Chincoteague and 4 on the Sinepuxent were below the detectable limit of nitrates and nitrites, there were also a few elevated observations (Figure 35) which substantially skew the mean. On the Chincoteague, the level of nitrates and nitrites ranged from below the detection limit to 6.63 μm at CB1 on April 7, 1989. Arithmetic mean concentrations ranged from 0.35 μm (S.D.=.46) at CB2 to 0.73 μm (S.D.=1.47) at CB1. There was no statistically significant difference (σ=.05) between the means on the Chincoteague. With the exception of the maximum reading at CB1 in April of 1989, nitrate and nitrite levels on the Chincoteague were uniformly low until September and October of 1989 when they were elevated at half the sample points. On the Sinepuxent, the concentration of nitrates and nitrites ranged from below the detection limit to 6.86 μm at SB1 and 6.19 μm at SB2 on October 20, 1987. Arithmetic mean levels ranged from 0.35 μm (S.D.=.84) at SB4 to 1.17 μm (S.D.=1.80) at SB1. As with the Chincoteague, the Sinepuxent nitrate and nitrite data was tremendously variable. There was no statistically significant (σ=.05) difference in mean concentration levels on the Sinepuxent. Although nitrate and nitrite levels were fairly high in 1987 on the Sinepuxent, the measured concentrations in 1988 and 1989 were very low until September and October of 1989. Nitrates and nitrite concentrations were higher at SB1 during 1990 than at any other sample location that year on the Sinepuxent. Overall mean nitrate and nitrite concentrations between the two bays were not significantly different: Chincoteague .58 μm (S.D.=.093) and Sinepuxent .78 μm (S.D.=1.39).

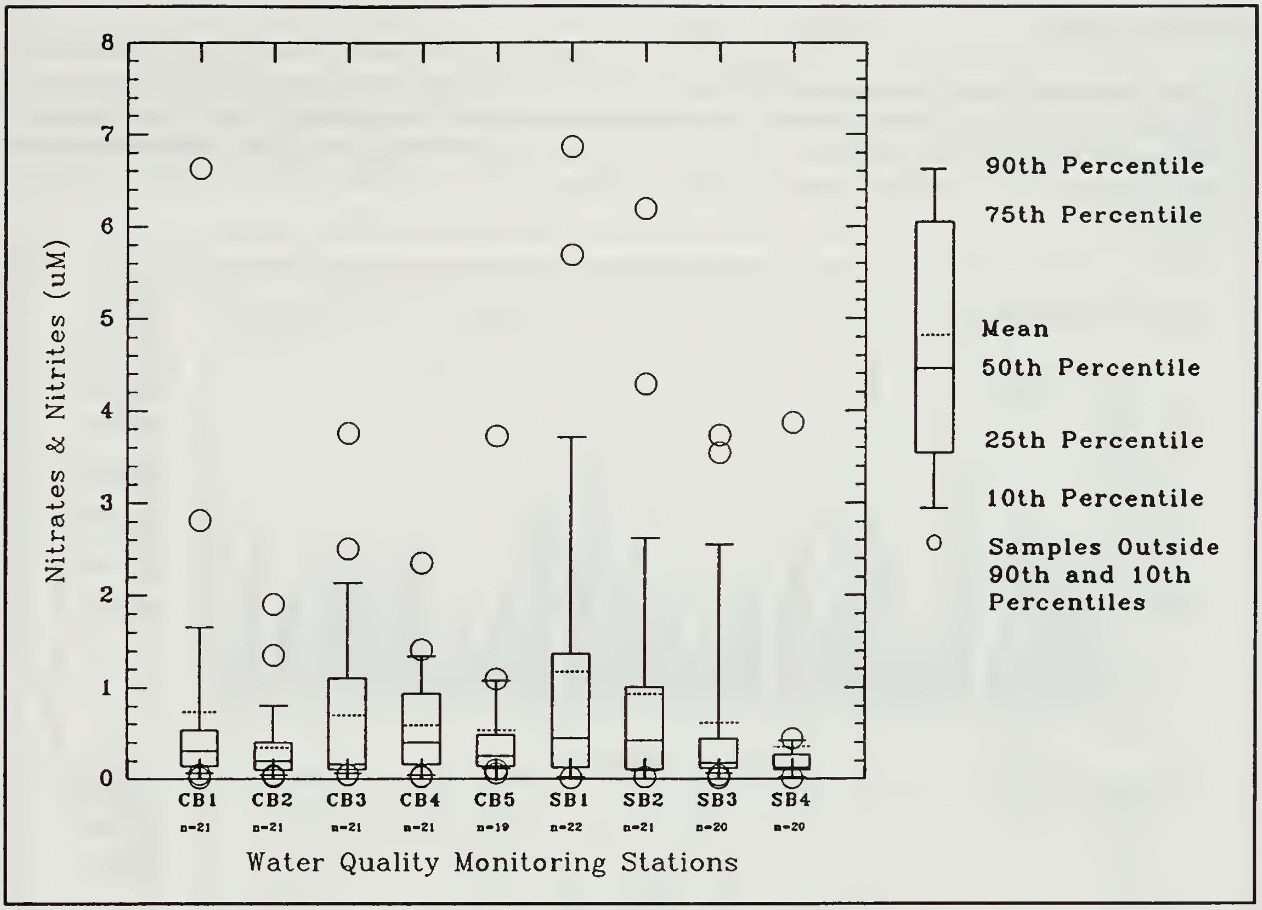

Figure 35. Nitrates and Nitrites Distributions in the Chincoteague-Sinepuxent Bay Complex.

Phosphorus

Like nitrogen, phosphorus is an essential nutrient for plant growth. In freshwater systems, phosphorus is often considered the most easily controllable nutrient in the effort to eliminate undesirable plant growth. Phosphorus exists in many organic and inorganic forms and is present as both dissolved and particulate matter in water. In water, phosphorus is constantly changing due to the processes of decomposition and synthesis between organically bound forms and oxidized inorganic forms.

Phosphorus is usually found at much lower concentrations than nitrogen in surface waters since it is so actively taken up by plants. The primary contributors of phosphorus to aquatic systems are domestic sewage effluent, phosphates from detergents, animal and plant processing wastes, fertilizer and chemical spillage and runoff, industrial effluent, and erosion. Excessive inputs of phosphorus from these sources can occasion algal blooms, quick plant growth, oxygen depletion, and accelerated eutrophication.

On the Chincoteague-Sinepuxent Bay complex, measurements were made of total phosphorus, total phosphorus filtered, and orthophosphate (soluble reactive phosphate). Although orthophosphate is more immediately available for plant uptake, total phosphorus, as the "reservoir" of phosphorus in the aquatic system, is considered to drive the system. The ratio of total phosphorus to orthophosphate varies by season, temperature, and plant growth. The concentration of each of these pollutants in the Chincoteague-Sinepuxent Bay complex is discussed below.

Total Phosphorus:

Total phosphorus (the sum of inorganic phosphorus, dissolved organic phosphorus, and particulate phosphorus) is the total concentration of phosphorus in a water quality sample without filtering which would remove phosphorus bound up in particulate matter that was too large to pass through the filter. Total phosphorus provides a measure of the total phosphorus "reservoir" present in the system that could be made available for plant growth.

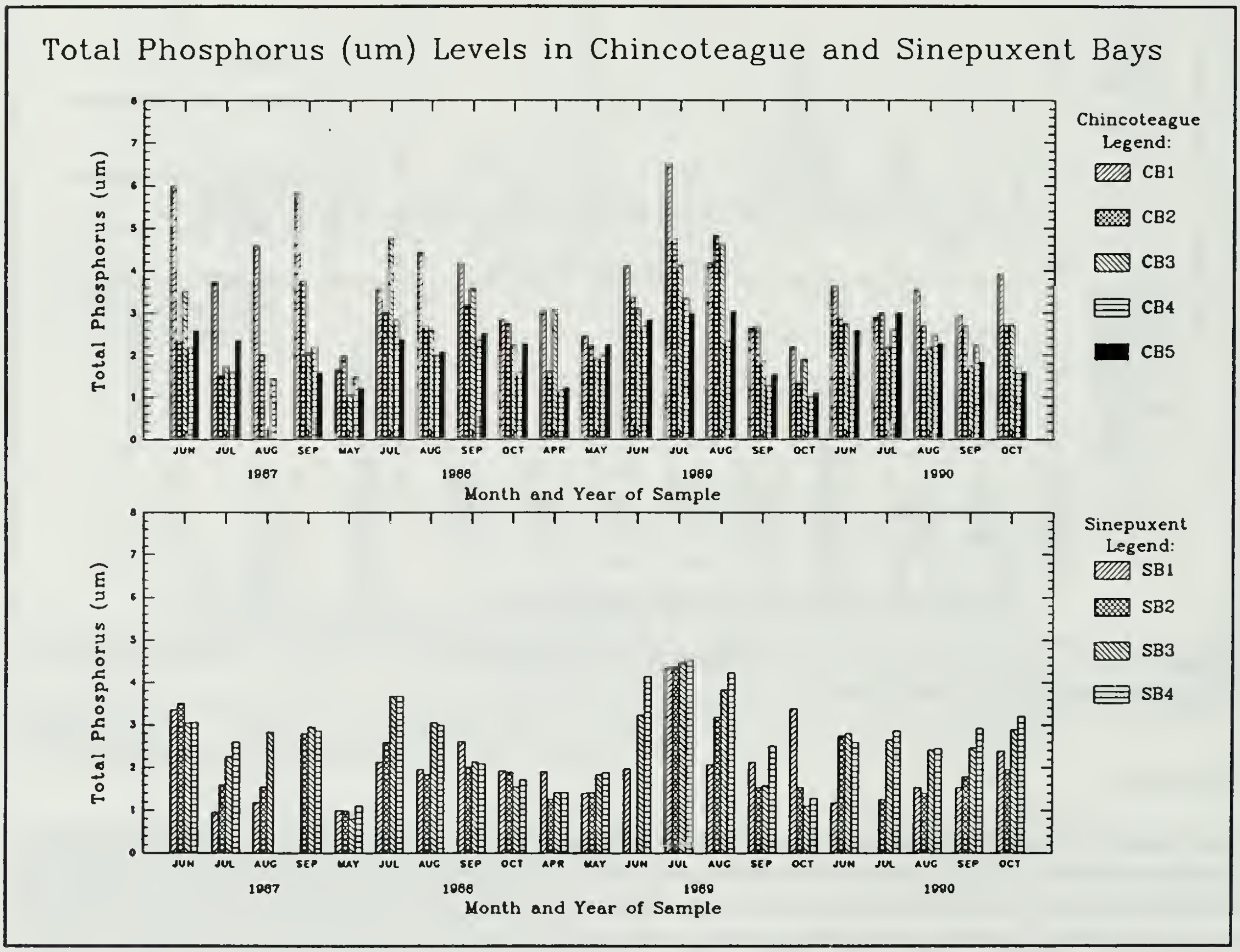
Total Phosphorus (um) Levels in Chincoteague and Sinepuxent Bays

Figure 36. Seasonal Total Phosphorus Distribution in the Chincoteague-Sinepuxent Bay Complex.

Total phosphorus concentration in the Chincoteague-Sinepuxent Bay complex exhibited the same seasonal trend (Figure 36) as total nitrogen: higher in the summer, somewhat lesser in spring and fall. Total phosphorus on the Chincoteague ranged from 1.00 μm at CB4 to 6.51 μm at CB1. Arithmetic mean levels varied between 2.00 μm (S.D.=0.61) at CB4 and 3.75 μm (S.D.=1.25) at CB1. The mean concentration of total phosphorus at CB1, in Newport Bay near the outlet of Trappe Creek, was significantly (σ=.05) greater than the concentration at any other sample point in the Chincoteague. Additionally, the total phosphorus concentrations at CB4 and CB5 are significantly (σ=.05) lower than the mean concentrations at CB1 and CB2. Mean, standard deviation, maximum, and minimum total phosphorus values on the Sinepuxent were remarkably consistent among sample points (Figure 37). The minimum concentration on the Sinepuxent was 0.81 μm at SB3; while the maximum was 4.52 μm at SB4. Arithmetic mean total phosphorus concentrations on the Sinepuxent ranged from 2.05 μm

(S.D.=0.88) at SB1 to 2.71 μm (S.D.=0.96) at SB4. The mean concentration of total phosphorus at SB4 is significantly greater (σ=.05) than the concentrations at SB1 and SB2. The mean concentration of total phosphorus at SB3 is also significantly greater than SB1 and SB2 but only at σ=.10. The overall mean concentration of total phosphorus on the Chincoteague (2.67 μm, S.D.=1.09) was significantly (σ=.05) greater than the Sinepuxent (2.34 μm, S.D.=0.94).

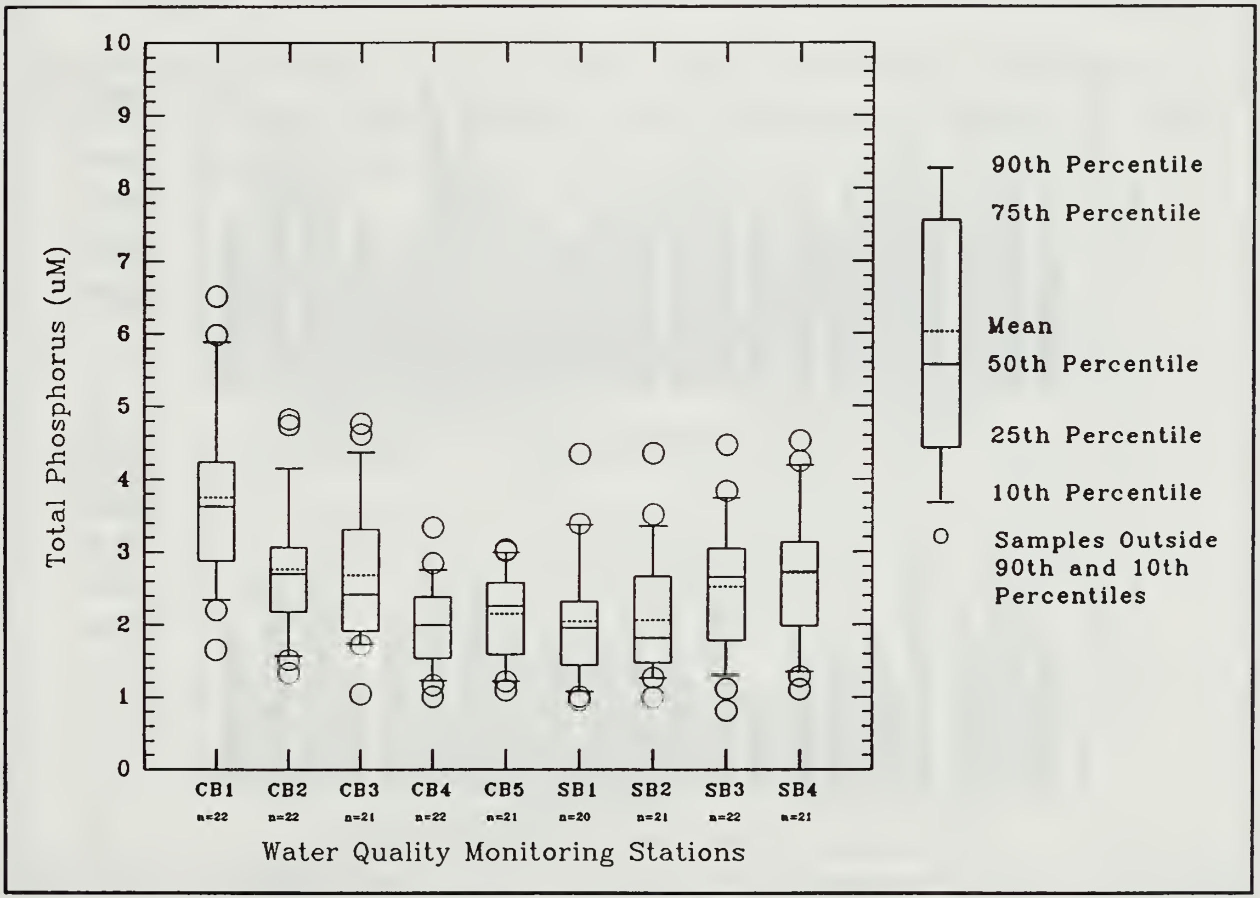

Figure 37. Total Phosphorus Distributions in the Chincoteague-Sinepuxent Bay Complex.

Figure 38 displays the ratios of total nitrogen to total phosphorus (TN:TP) in the Chincoteague-Sinepuxent Bay complex. Although TN:TP ratios typically vary with water, season, temperature, and geologic formation[14], mean TN:TP ratios were fairly consistent, particularly on the Chincoteague. There was no significant difference (σ=.05) in the TN:TP ratios on the Chincoteague. The greatest average TN:TP ratio was at CB5 (23:1), the lowest at CB2 (21:1). Extreme values on the Chincoteague ranged from 38:1 at CB5 to 14:1 at CB3 and CB5. The maximum and minimum TN:TP ratios on the Sinepuxent both occurred at SB1 (33:1 and 8:1). The greatest average TN:TP ratio on the Sinepuxent was manifested at SB4 (22:1), the lowest at SB1 (15:1). The mean TN:TP ratios at SB1 and SB2 were significantly (σ=.05) less than the ratios at any other sample location on the Chincoteague-Sinepuxent Bay complex. In fact, the TN:TP ratios decrease in magnitude as one heads south from

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[14] The TN:TP ratio may range from 1:1 upwards to 100:1. In natural waters the ratio is typically on the order of 10:1 (U.S. Department of Interior, Federal Water Pollution Control Administration 1968).

the Ocean City Inlet on the Sinepuxent. Overall, the TN:TP ratio on the Sinepuxent (18:1) was significantly ($\sigma = .05$) less than the Chincoteague (22:1), although most of the difference appears to result from the lower TN:TP ratios at SB1 and SB2.

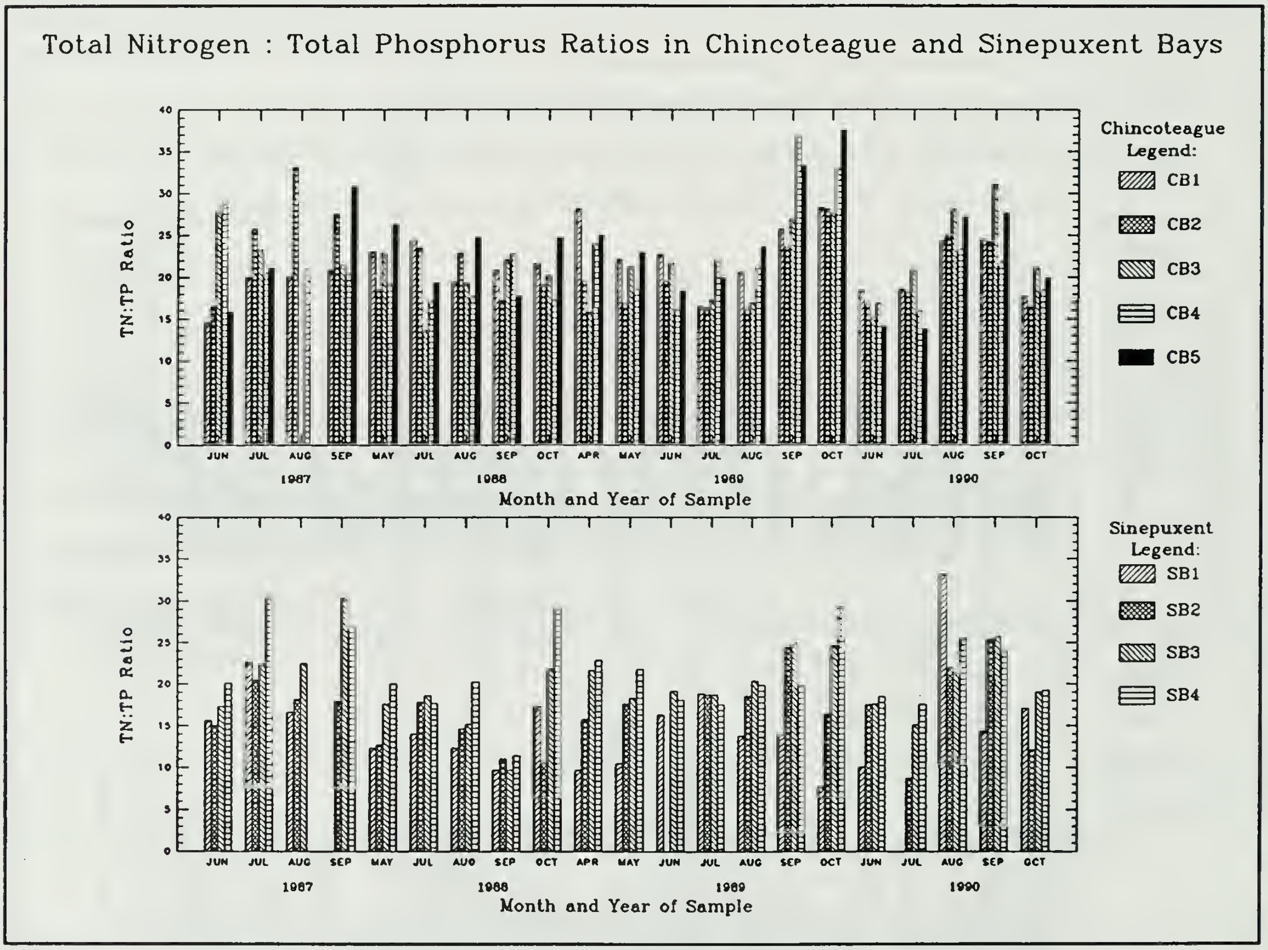


Figure 38. Total Nitrogen - Total Phosphorus Ratios in the Chincoteague-Sinepuxent Bay Complex.

Total Phosphorus Filtered:

Total phosphorus filtered (TPF) is the total concentration of phosphorus in a water quality sample that is dissolved in solution and small enough to pass through a filter of a given size. TPF, which should generally be less than and directly related to total phosphorus, is a better measure of plant available phosphorus than total phosphorus. The close, positive relationship of total phosphorus and TPF is displayed in Figure 39.

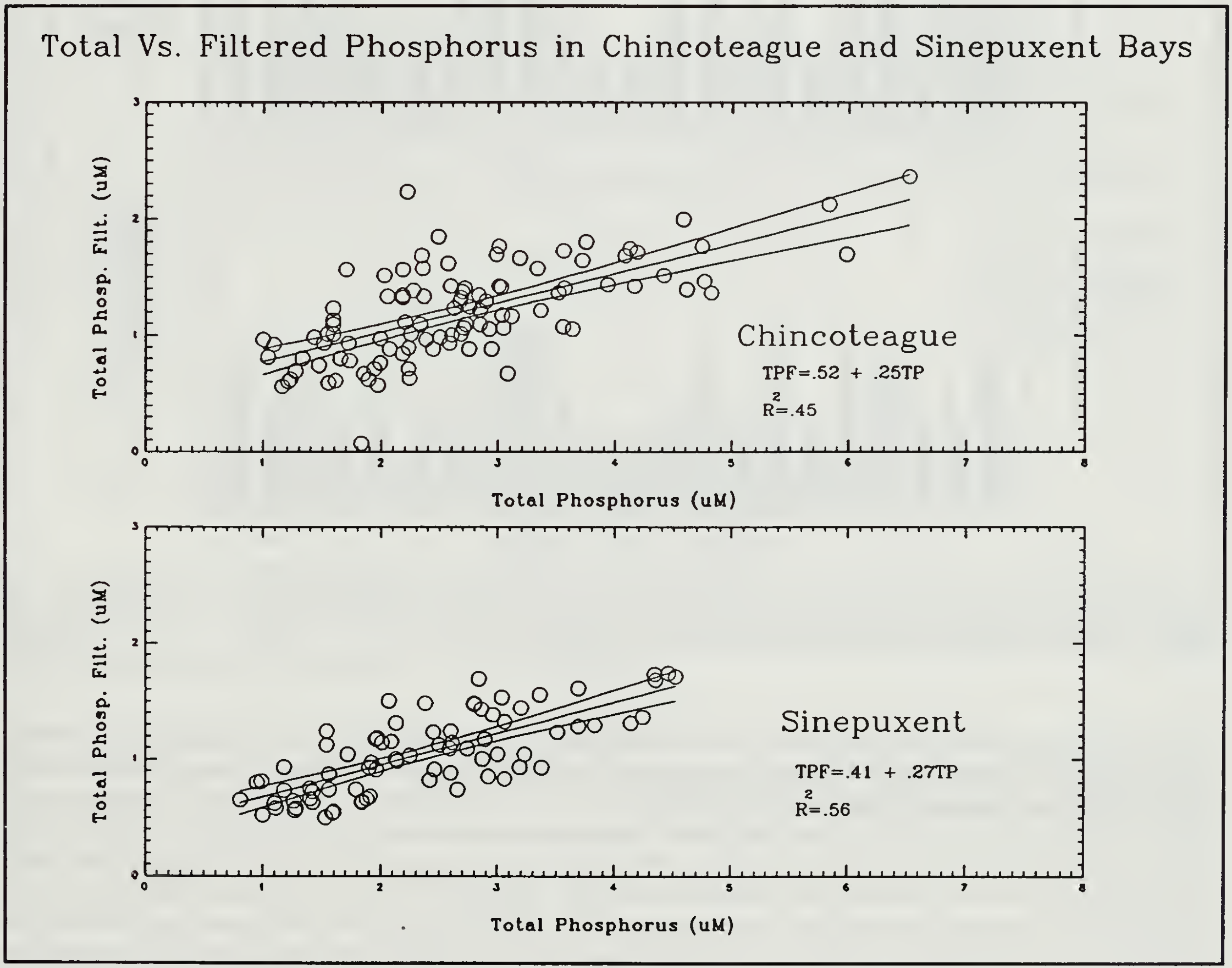


Figure 39. Close Relationship Between Total Phosphorus and Total Phosphorus Filtered on the Chincoteague-Sinepuxent Bay Complex.

The concentration of TPF manifested the same seasonal trend as total phosphorus and total nitrogen (Figure 40). TPF concentrations were elevated during the summer months and diminished during the spring and fall months. The concentration of TPF at each sample location was not very variable as evidenced by low coefficients of variation (Figure 41). On the Chincoteague, TPF ranged from 0.07 μm at CB5 to 2.36 μm at CB1. Arithmetic mean TPF concentrations ranged from 1.06 μm (S.D.=0.32 and S.D.=0.41) at CB3 and CB5 to 1.44 μm (S.D.=0.42) at CB1. The mean level of TPF at CB1 was significantly (σ=.05) greater than the mean TPF level at CB3 and CB5. TPF on the Sinepuxent ranged from 0.50 μm at SB2 to 1.74 μm at SB3. TPF arithmetic mean concentrations varied between 1.07 μm (S.D.=0.39) at SB3 to 1.11 μm (S.D.=0.30) at SB4. The mean

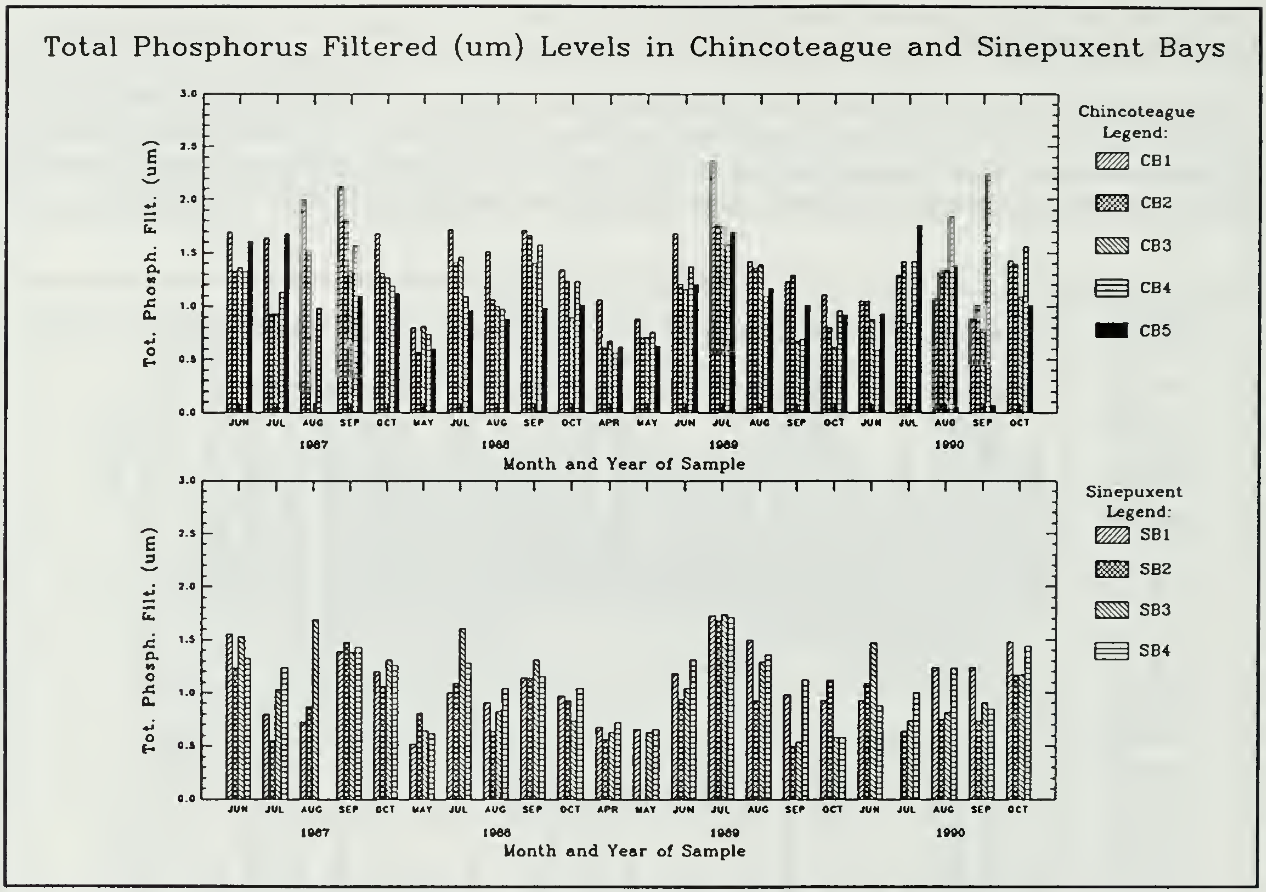


Figure 40. Seasonal Distribution of Total Phosphorus Filtered in the Chincoteague-Sinepuxent Bay Complex.

concentration of TPF was not significantly ($\sigma = .05$) different at any sample point on the Sinepuxent. Overall, the mean level of TPF on the Chincoteague (1.20 μm, S.D. = 0.40) was significantly ($\sigma = .05$) greater than the mean TPF level on the Sinepuxent (1.05 μm, S.D. = 0.33).

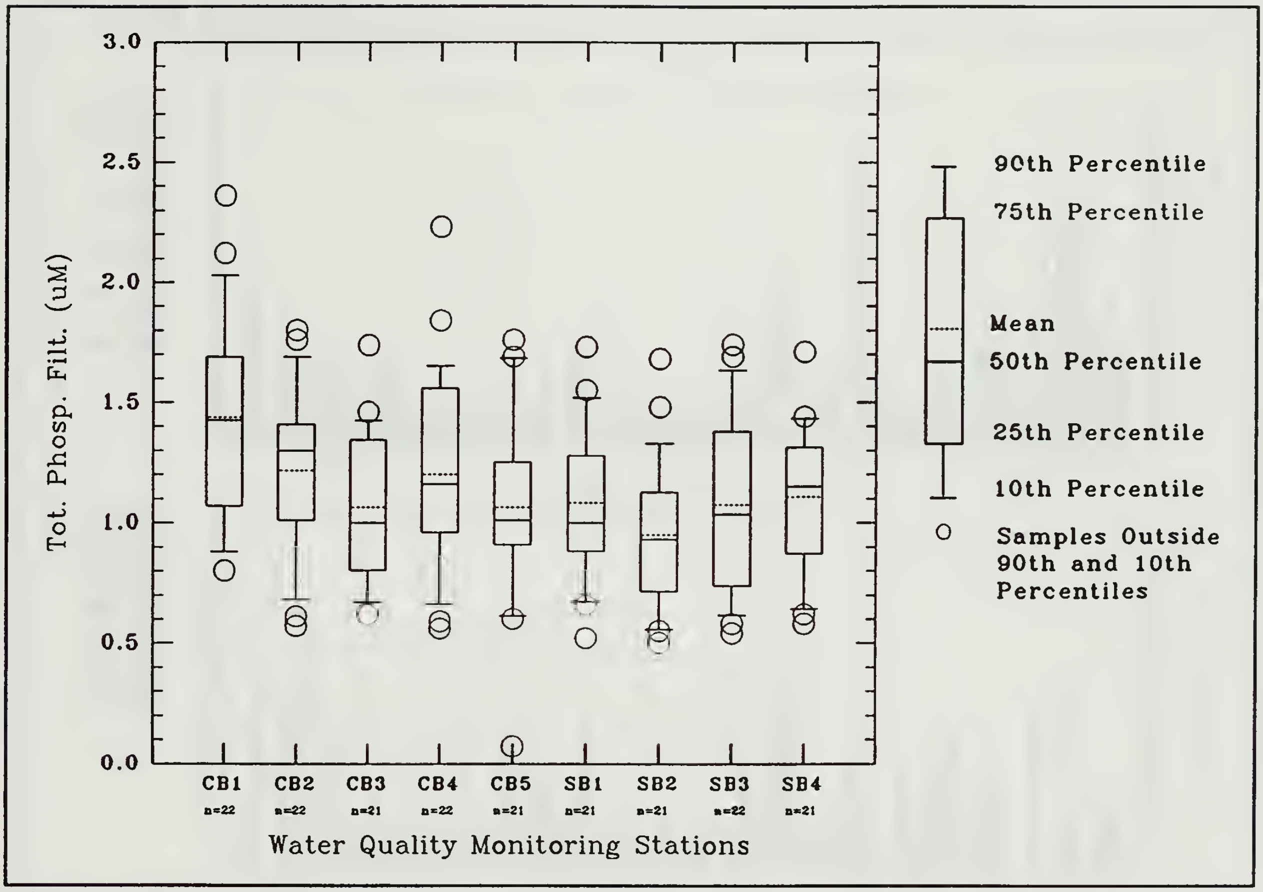


Figure 41. Total Phosphorus Filtered Distributions in the Chincoteague-Sinepuxent Bay Complex.

The positive, linear relationship between TPF and total phosphorus is portrayed in Figure 39. On the Chincoteague, TPF averaged approximately 47% of total phosphorus, ranging from an average of 39% at CB1 to 60% at CB4. The minimum and maximum percentages of total phosphorus as TPF occurred at CB5 (4%) and CB4 (96%), respectively. The percentage of total phosphorus as TPF was significantly (σ=.05) greater at CB4 than at CB1, CB2, and CB3. On the Sinepuxent, TPF also averaged approximately 47% of total phosphorus. The means ranged from 43% at SB4 to 56% at SB1. The minimum and maximum percentages were 27% at SB3 and 84% at SB1, respectively. The mean percentage of total phosphorus as TPF was significantly (σ=.05) greater at SB1 than at SB3 and SB4.

Orthophosphate:

Orthophosphate, or soluble reactive phosphorus, is a form of phosphorus that is immediately available for plant uptake. Although nontoxic to humans and aquatic organisms, orthophosphate in the presence of sufficient nitrate or other nitrogen compounds can stimulate excessive plant and algal growths. Primary orthophosphate sources are detergents; treated and untreated human and animal wastes; industrial effluent; and agricultural drainage.

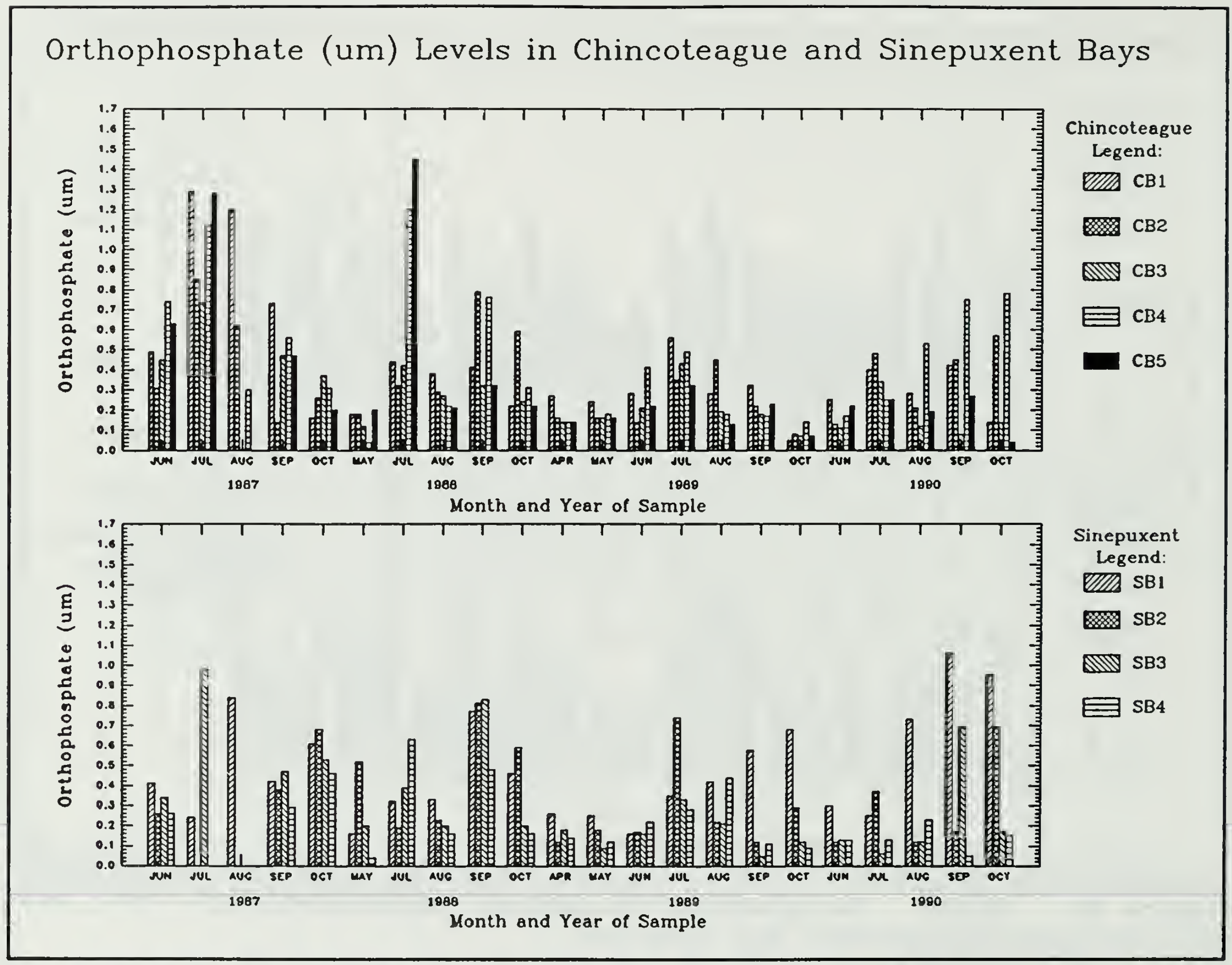


Figure 42. Seasonal Orthophosphate Distribution in the Chincoteague-Sinepuxent Bay Complex.

Orthophosphate levels in the Chincoteague and Sinepuxent Bay complex were generally higher in the summer months (Figure 42). On the Chincoteague, the minimum concentration of orthophosphate was 0.04 μm at CB4 and CB5; while the maximum concentration, 1.45 μm, occurred at CB5. Arithmetic mean values ranged from 0.26 μm (S.D.=.17) at CB3 to 0.44 μm (S.D.=.33) at CB4. The concentration of orthophosphate at CB4 was significantly (σ=.05) greater than the concentration at CB3. On the Sinepuxent, the lowest concentration of orthophosphate was 0.04 μm at SB4; while the highest concentration was 1.06 μm at SB1. Arithmetic mean concentrations ranged from 0.23 (S.D.=.16) at SB4 to 0.48 μm (S.D.=.26) at SB1 (Figure 43). The concentration of orthophosphate at SB1 was significantly greater (σ=.05) than the concentration of orthophosphate at SB3 and SB4. Overall, throughout the entire Chincoteague-Sinepuxent Bay complex, there was no statistically significant difference (σ=.05) in the mean concentrations of orthophosphate on the Chincoteague (0.36 μm, S.D.=.29) and the Sinepuxent (0.34 μm, S.D.=.24).

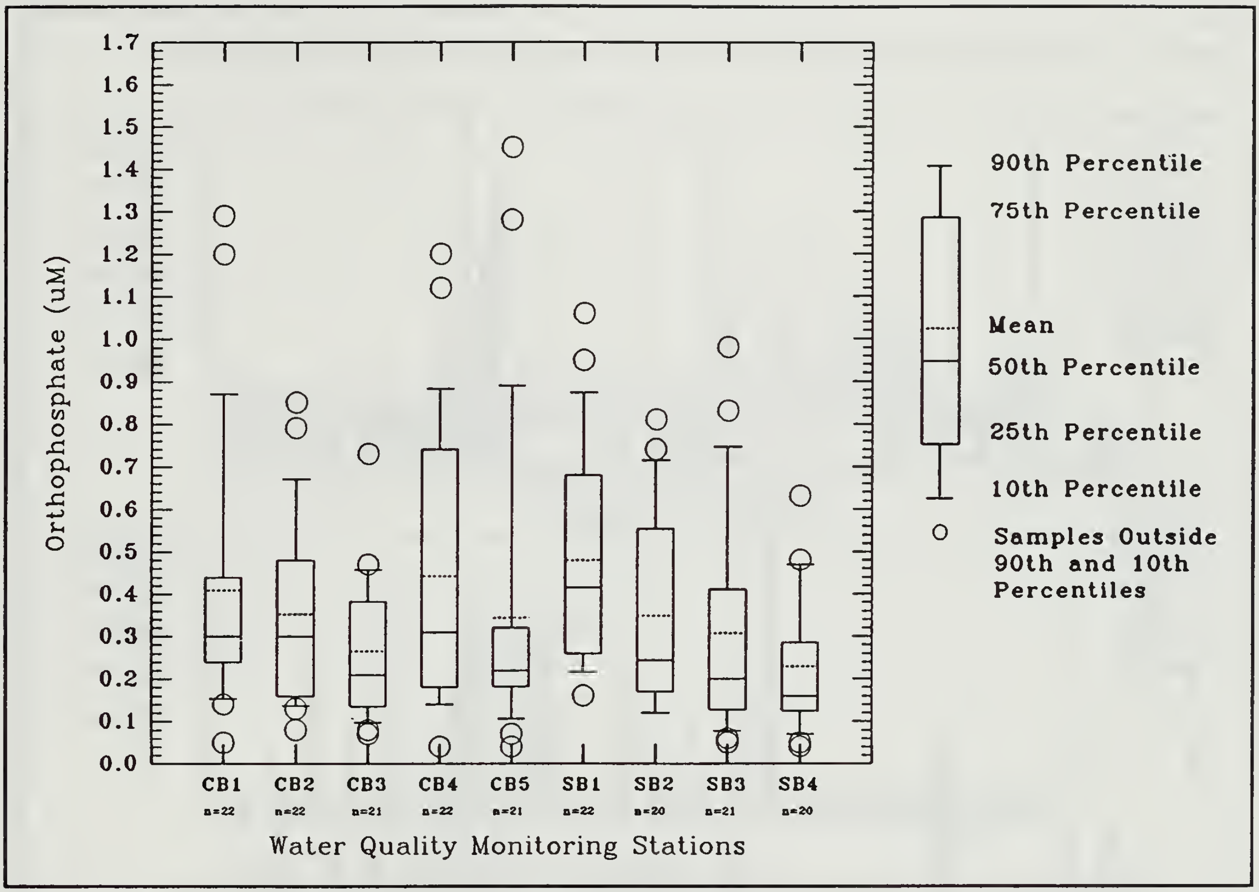


Figure 43. Orthophosphate Distributions in the Chincoteague-Sinepuxent Bay Complex.

Figure 44 displays the ratios of nitrates and nitrites to orthophosphate (NO3:PO4) in the Chincoteague-Sinepuxent Bay complex. Unlike TN:TP ratios which were fairly consistent, mean NO3:PO4 ratios were extremely variable throughout the system, although there was no significant difference in means between any of the sample locations on the Chincoteague or Sinepuxent; nor was there a significant difference in NO3:PO4 ratios between the bays. The greatest average TN:TP ratio was at CB1 (5), the lowest at CB2 (2). Extreme ratios on the Chincoteague ranged from 56:1 at CB1 to 0.04:1 at CB1 and CB2. The maximum NO3:PO4 ratio on the Sinepuxent occurred at SB2 (15); while the minimum ratio occurred at SB4 (0.02). The greatest average NO3:PO4 ratio was manifested at SB2 (2), the lowest at SB4 (1). Overall, the NO3:PO4 ratio on the Chincoteague was 3:1; while the overall ratio on the Sinepuxent was 2:1. Evident from Figure 44 is the fact that the mean NO3:PO4 ratios are heavily influenced by extreme values. Reliance on the mean would lead one to conclude that nitrates usually exceed phosphates in the system. In reality, however, orthophosphate equalled or exceeded nitrates in approximately 59% of all samples.

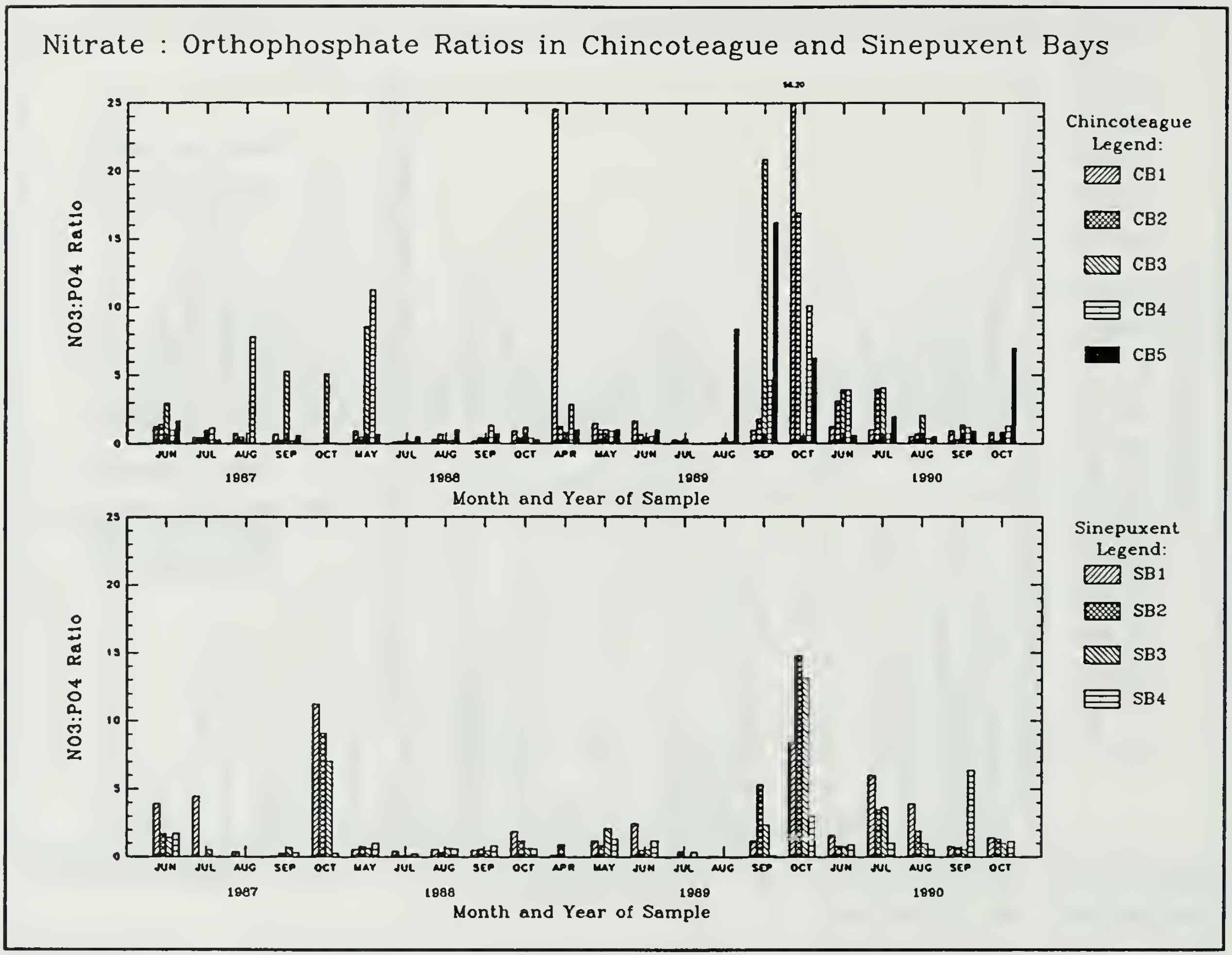
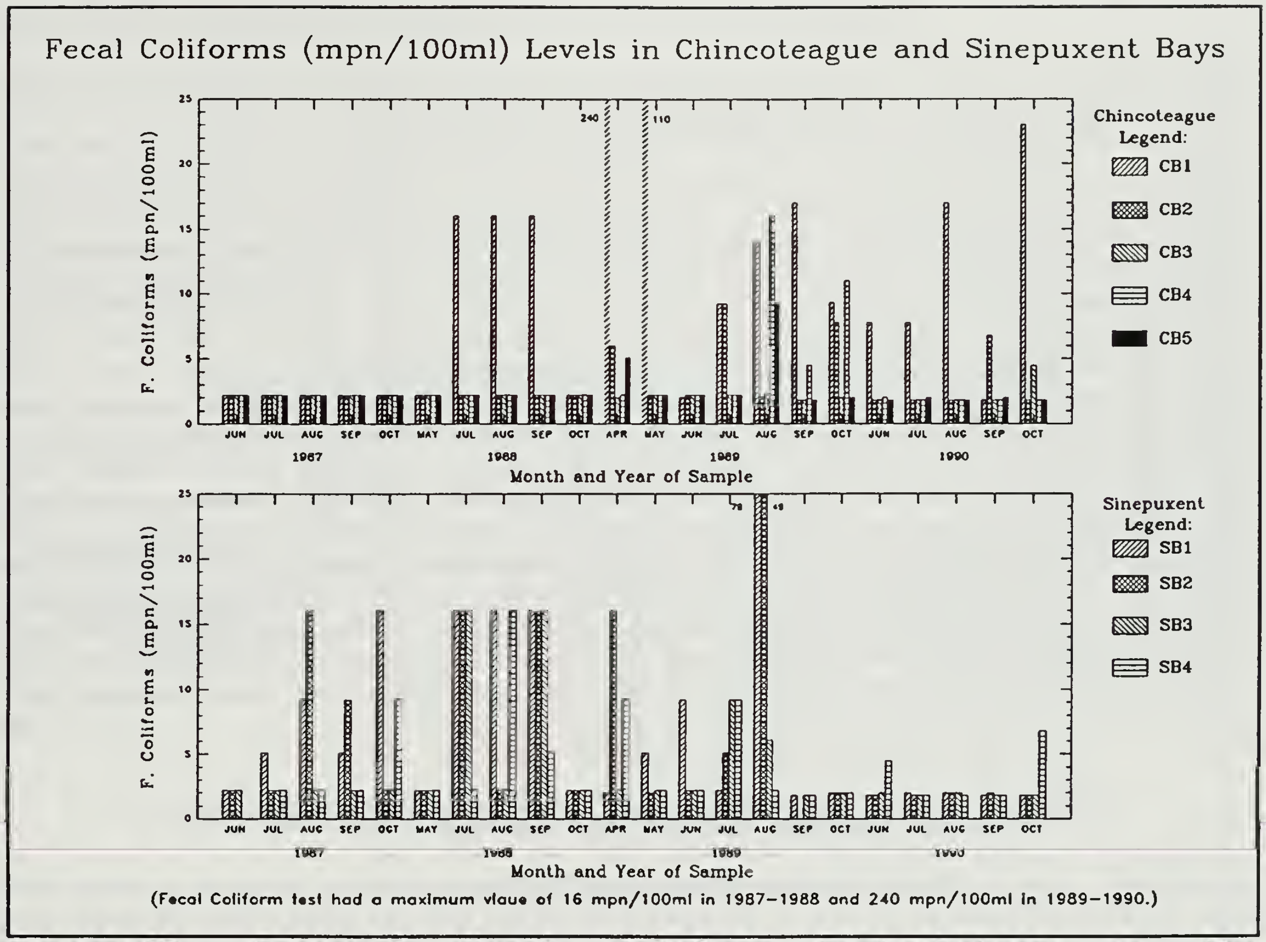


Figure 44. Nitrates/Nitrites to Orthophosphate Ratios in the Chincoteague-Sinepuxent Bay Complex.

Fecal Coliform:

Fecal coliform (FC) are one group of coliform bacteria that reside predominantly in the intestinal tract and feces of humans and other warm-blooded animals. The existence of FC in surface waters is generally indicative of contamination from treated municipal wastewater and runoff from farmlands and feedlots containing animal wastes. Elevated FC counts may indicate the presence of pathogenic organisms capable of causing a number of water-borne communicable diseases such as cholera, dysentery, typhoid, hepatitis, and others. Humans can contract these diseases by drinking contaminated water, using or consuming products cleansed with contaminated water, or inadvertently ingesting contaminated water while swimming. The U.S. Environmental Protection Agency (1976) recommends that waters used for contact recreation not exceed a log mean of 200 organisms per 100 ml (based on a minimum of five samples taken over a 30-day period), nor should more than 10% of the total samples during any 30-day period exceed 400 organisms per 100 ml.



(Fecal Coliform test had a maximum vlaue of 16 mpn/100ml in 1987–1988 and 240 mpn/100ml in 1989–1990.)

Figure 45. Seasonal Fecal Coliform Distribution in the Chincoteague-Sinepuxent Bay Complex.

FC counts on the Chincoteague-Sinepuxent Bay complex were extremely variable (Figures 45 and 46). FC counts on the Chincoteague ranged from the minimum detectable, 1.80 mpn/100ml, at all sample locations to 240 mpn/100 ml at CB1 in April 1989. Geometric means on the Chincoteague ranged from 2.15 mpn/100ml at CB3 to 7.84 mpn/100ml at CB1. The geometric mean at CB1 in Newport Bay at the outlet of Trappe Creek is approximately 3 times greater than the geometric means at the other Chincoteague sample locations. FC counts at CB3 and CB5 have much smaller ranges than the other sample locations (Figure 46). FC counts on the Sinepuxent ranged from the minimum detectable, 1.80 mpn/100ml, at all sample locations to 79 mpn/100 ml at SB1 in August of 1989. Geometric means on the Sinepuxent ranged from 2.80 mpn/100ml at SB3 to 4.49 mpn/100ml at SB1. Geometric mean FC counts on the Sinepuxent were generally greater than on the Chincoteague, except at CB1 which had the highest geometric mean FC count on the entire complex. FC counts on the Sinepuxent in 1990 were very low (Figure 46); while FC counts on the Chincoteague were low in 1987 and 1988, except for CB1.

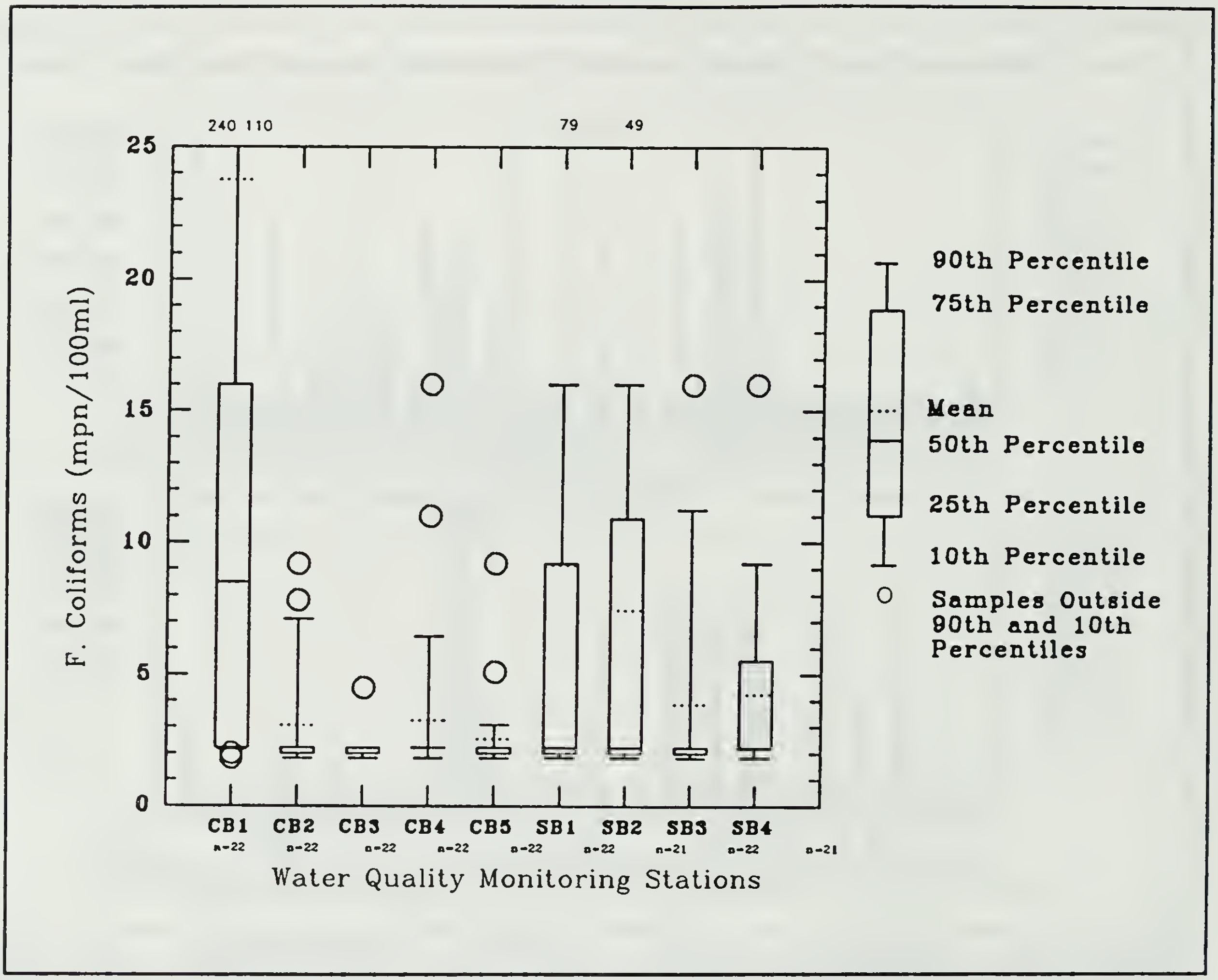


Figure 46. Fecal Coliform Distributions in the Chincoteague-Sinepuxent Bay Complex.

Tidal Stage:

Whenever a water quality sample was collected, the times of high tide and low tide at Ocean City Inlet and Public Landing were recorded to investigate any correlation between tidal stage and the parameters measured. Although tidal stage and time varies throughout the Chincoteague-Sinepuxent Bay complex, from 0.12 m (0.4 ft.) in the center of the bay to 1.07 m (3.5 ft.) near the inlets (Pritchard 1960), for simplicity sake, the time of high tide at Ocean City Inlet was assumed to be the time of high tide at each Sinepuxent station; while the time of high tide at Public Landing was assumed to be the time of high tide at each Chincoteague station. To analyze the concentrations of various parameters at high tide, low tide, and intertidal periods, it was further assumed that high tide and low tide were delimited by 1 and 2 hour intervals before and after the high or low tide recorded at Ocean City or Public Landing[15]. Due to the limited and variable number of observations at each station

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[15] Thus, two separate analyses were performed for each parameter to examine differences in concentrations. The first analysis defined high tide as the two hour period one hour before and after high tide. The low tide was the two hour period one hour before and one hour after low tide. Anything else was defined as intertidal. The second analysis was identical to the first except the high and low tides were four hour

location, the analysis was confined to examining differences in parameter concentrations in either the Chincoteague or Sinepuxent Bays under high tide, low tide, and intertidal periods.

Subject to these caveats, the influence of tidal stage on parameter concentrations is mixed. For example, during the four-hour tidal periods, pH was significantly less during high tide than low tide and intertide in the Chincoteague; while pH was significantly greater during high tide than low tide on the Sinepuxent. During the two-hour tidal periods, however, pH in the Chincoteague was lower during high tide than intertide; while on the Sinepuxent, pH was lower during low tide than intertide. For most parameters there was no significant difference in mean concentrations between the defined two-hour high and low tide periods[16]. In fact, differences during the two-hour high and low tide periods were typically found only when contrasted with the intertidal period. For example, during the two-hour tidal periods, water temperature and dissolved oxygen was significantly greater during high tide than the intertidal period in the Sinepuxent; but there was no difference in the Chincoteague. Extending this example to the four-hour high and low tide periods, no significant difference in water temperature or dissolved oxygen was evident in either bay. There was no significant difference in salinity or conductivity during the two-hour tides on either bay. During the four-hour tides, no significant differences were manifested on the Sinepuxent; while on the Chincoteague intertidal salinity and conductivity were significantly greater than at low tide. Although there was no significant difference in total suspended solids during any tidal period; the four-hour high tide chlorophyll a concentration was greater in the Sinepuxent than the low tide or intertide. Perhaps as a consequence of the greater chlorophyll a concentration in the Sinepuxent during high tides, Secchi disk depth was significantly lower during high tides in the Sinepuxent. Secchi disk depth in the Chincoteague, however, was significantly greater during high tide than low tide. There was no significant difference in nutrient concentration in either bay during the two- and four-hour high, low, or intertidal periods, except that the concentration of nitrates in Chincoteague Bay were greater during high tide than intertide.

NPS CHINCOTEAGUE-SINEPUXENT BAY WATER QUALITY DISCUSSION

Water quality is necessarily a subjective, relative concept considering the myriad uses of water. Therefore, to assess objectively water quality, one must specify the intended use or uses: (1) recreation/aesthetics; (2) water supply; (3) fish, other aquatic life, and wildlife; (4) agriculture; or (5) industrial. These uses are not mutually exclusive; nor is one standard necessarily appropriate to the entire range of activities in a classification[17]. Additionally, different waterbodies have widely disparate "natural" water quality (i.e. a mountain stream as opposed to an estuarine ecosystem). As a result, the appropriate water quality standard to apply usually devolves to the lowest (highest tolerable) common denominator supported by the intended use. For the purposes of the Chincoteague-Sinepuxent Bay complex, the primary water uses are recreation/aesthetics, fish (including shellfish), other aquatic life, and wildlife.

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periods - two hours before the high or low tide and two hours after.

[16] The only exception to this statement occurred in the Sinepuxent where the level of fecal coliforms was greater during low tide than high tide.

[17] For example, within the recreational/aesthetic use classification, different standards exist for swimming, boating, and fishing. Within the industrial classification different standards would be applied for manufacturers whose industrial processes may be sensitive to certain parameter levels. An excellent discussion of water quality standards and uses is the National Academy of Sciences (1972) Water Quality Criteria.

The water quality standards governing the majority of the Chincoteague-Sinepuxent Bay complex were promulgated by the state of Maryland and are published in the Code of Maryland Regulations (COMAR 26.08.02). The pertinent standards governing fecal coliform, dissolved oxygen, water temperature, pH, and turbidity for the predominant water uses (Class I and Class II) in the Chincoteague-Sinepuxent Bay complex are displayed in Tables 4 and 5[18].

The overall water quality of the Chincoteague-Sinepuxent Bay complex, as characterized by the four years of data at nine different sample locations collected from the NPS water quality monitoring program, is good. As discussed below, the primary pollution problems appear to be somewhat localized in confined tidal areas and event related.

Dissolved oxygen (DO) concentration provides the most concise, easily-measured barometer of overall water quality. Only three different observations fell at or below the Maryland DO criterion of 5.0 mg/l. DO concentrations at every sample location averaged greater than 7.0 mg/l. The healthy DO levels in the Chincoteague-Sinepuxent Bay complex are in contrast to the Chesapeake Bay which typically has significant areas of anoxic and hypoxic waters (Chesapeake Bay Program 1989).

Fecal coliform bacteria levels are also frequently employed as gauges of water quality. Fecal coliform levels in the Chincoteague-Sinepuxent Bay complex were relatively low in comparison with the Maryland standard of a geometric mean of 200 mpn/100 ml. Geometric means were all less than 10 mpn/100 ml, although there was one instance when a single fecal coliform measure at CB1 near Trappe Creek was 240 mpn/100 ml.

Comparisons of the results presented here for water temperature and pH with the applicable Maryland standards indicates that all observations recorded were within the regulatory ranges for these parameters, except for the last pH measurements at SB2 and SB3 during the June 1989 diel sampling. Both of these observations were significantly higher than the measurements taken just two hours earlier. Barring alternative explanations, these measurements may be explained by error or some anomalous condition. Otherwise, water temperature and pH are well within Maryland standards.

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[18] Table 10 in the Appendix provides Maryland's water quality criteria for toxic materials in all surface waters.

Table 4. State of Maryland Water Quality Criteria for Class I Waters: Water Contact Recreation, Aquatic Life, and Water Supply (COMAR 26.08.02).

Parameter	**Water Quality Criteria**
Fecal Coliform	(i) log mean of 200/100 ml based on a minimum of not less than five samples taken over any 30-day period; (ii) 10% of the total samples taken during any 30-day period should not exceed 400 per 100 ml
Dissolved Oxygen	not less than 5 mg/l at any time
Water Temperature	(i) maximum temperature outside the mixing zone may not exceed 32°C (90°F) or the ambient temperature of the surface surface waters, whichever is greater; (ii) thermal barriers that adversely affect aquatic life may not be established
pH	not less than 6.5 or greater than 8.5
Turbidity	(i) not to exceed levels detrimental to aquatic life; (ii) turbidity resulting from a discharge may not exceed 150 units at any time or 50 units as a monthly averages as measured in Nephelometer Turbidity Units

Table 5. State of Maryland Water Quality Criteria for Class II Waters: Shellfish Harvesting (COMAR 26.08.02).

Parameter	Water Quality Criteria
Fecal Coliform	(i) most probable number (mpn) of fecal coliform organisms should not exceed a median concentration of 14 mpn per 100 ml; (ii) no more than 10% of samples should exceed 43 mpn per 100 ml for a 5-tube decimal dilution test or 49 mpn per 100 ml for a 3-tube decimal dilution test
Dissolved Oxygen	same as Class I waters
Water Temperature	same as Class I waters
pH	same as Class I waters
Turbidity	same as Class I waters

Other commonly used indicators of water quality are the concentrations of nitrogen, phosphorus, and chlorophyll a in the system. The concentrations of these parameters vary in different ecosystems and there are no applicable state standards. A comparison of these parameters with results obtained from the Chesapeake Bay Program (1989), however, indicates that the Chincoteague-Sinepuxent Bay complex fairs well. Nitrogen, phosphorus, and chlorophyll a values for the Chincoteague-Sinepuxent Bay complex are typically much less than levels for the Chesapeake. The primary water quality problem areas for both the Chincoteague-Sinepuxent and Chesapeake Bays appear to occur where tributaries contribute loadings from point and nonpoint sources and in confined tidal areas with poor flushing characteristics.

An interesting means of comparing the relative water quality within the Chincoteague-Sinepuxent Bay complex is afforded by Table 6 which ranks the arithmetic and geometric means[19] for each parameter at each location in terms of lowest (1) to highest (9) relative water quality[20]. The last row in the table sums the arithmetic mean rankings to provide a very "quick and dirty" measure (lower sum indicates lower relative water quality) of the overall relative condition of the water at the various sample locations in the Chincoteague-Sinepuxent Bay complex. Reference to this table reveals that sample locations CB1, CB2, and SB1 had the lowest relative water quality by large margins. In particular, CB1 posted the lowest relative water quality results. CB1, located at the mouth of Trappe Creek in Newport Bay, had the highest relative values for fecal coliform, total phosphorus, total phosphorus filtered, total nitrogen, total nitrogen filtered, chlorophyll a, total suspended solids, Secchi disk

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[19] Tables of the arithmetic mean, standard deviation, standard error, geometric mean, maximum value, and minimum value are included in the Appendix.

[20] It is important to remember the relative nature of this comparison. Even the "worst" sample locations were well within Maryland water quality standards. A lower relative water quality means the sample location measured greater levels of undesirable parameters and lower concentrations of favorable parameters. The intent of this analysis is to examine the spatial distribution of water quality in the Chincoteague-Sinepuxent Bay complex.

depth, and water temperature. SB1 had the highest relative values for nitrates & nitrites, orthophosphate, salinity, and conductivity. SB1 also had the second highest relative values in terms of ammonium and fecal coliform. CB2, while not having the lowest relative water quality for any particular parameter, did generate higher relative values for total phosphorus, total phosphorus filtered, total nitrogen, total nitrogen filtered, chlorophyll a, total suspended solids, Secchi disk depth, and water temperature.

The locations of these particular sample locations help explain their relative standings. The outlet of Trappe Creek and Newport Bay (near CB1) has long been a recognized water quality problem area. The series of Maryland Water Quality Reports prepared pursuant to Section 305(b) of the Federal Water Pollution Control Act and the Ocean Coastal Basin "208" Water Quality Management Plan have documented the water quality problems in the Newport Bay area. While the overall water quality of Newport Bay is good, the quality deteriorates with proximity to the mouth of Trappe Creek and other confined tidal waters. This is due to the presence of municipal (Berlin and Newark) and industrial discharges upstream, agricultural and urban runoff, failing septic systems, and impaired flushing conditions. These sources account for the more elevated nutrient and bacteria levels found at CB1. Sample location CB2, situated one-third of the distance across the Chincoteague Bay off the Public Landing, suffers from the same impacts as CB1, with the exception of fecal coliform. Numerous small streams draining the mainland empty into the Chincoteague Bay near CB2. It is likely that these streams are carrying point and nonpoint source pollution causing the elevated nutrient, chlorophyll a, and total suspended solids levels measured at CB2. The levels of these parameters tend to decrease with distance across the bay toward ASIS. The sample location at SB1, located in the northern Sinepuxent Bay near Ocean City, exhibited the greatest relative salinity and conductivity measurements owing to its proximity to the Ocean City Inlet. Elevated nitrate, orthophosphate, ammonium, and fecal coliform levels likely stem from agricultural and urban runoff, dredge spoil disposal, failing septic systems, construction, boating, and other activities occurring in this area.

Table 6. Arithmetic Mean Rank, Geometric Mean Rank, and Total Samples of Water Quality Measurements in the Chincoteague- Sinepuxent Bay Complex 1987-1990. Lower Rank Value Indicates Worse Relative Condition.

Parameters	**CB1**	**CB2**	**CB3**	**CB4**	**CB5**	**SB1**	**SB2**	**SB3**	**SB4**
Fecal Coliform mpn/100 ml	1	7	4	4	4	2	3	5	4
	1	6	3	7	6	2	3	5	4
	22	22	22	22	22	22	21	22	21
Total Phosphorus Filtered μm	1	2	4	3	4	8	8	8	4
	1	2	6	3	4	9	9	7	4
	22	22	21	22	21	21	21	22	20
Total Phosphorus μm	1	2	4	6	6	9	7	5	3
	1	2	4	3	6	9	9	8	3
	21	21	21	21	20	19	22	21	20
Total Nitrogen Filtered μm	1	3	2	6	4	9	8	7	6
	1	3	2	5	4	9	8	7	6
	22	21	21	20	21	18	22	22	21
Total Nitrogen μm	1	2	4	7	4	8	8	5	8
	1	2	3	7	6	9	8	6	4
	21	21	21	21	20	19	21	21	20
Nitrates & Nitrites μm	3	9	3	6	2	1	2	5	8
	6	4	5	4	4	1	2	7	9
	21	21	21	21	19	22	21	20	20
Ammonium μm	5	9	4	6	1	2	3	6	8
	5	4	9	7	7	1	3	8	6
	22	21	19	21	19	20	21	21	20
Ortho-Phospate μm	3	4	8	2	6	1	5	7	9
	3	4	8	2	6	1	5	7	9
	22	22	21	22	21	22	20	21	20

Table 6. Arithmetic Mean Rank, Geometric Mean Rank, and Total Samples of Water Quality Measurements in the Chincoteague- Sinepuxent Bay Complex 1987-1990. Lower Rank Value Indicates Worse Relative Condition.

Parameters	**CB1**	**CB2**	**CB3**	**CB4**	**CB5**	**SB1**	**SB1**	**SB3**	**SB4**
Chlorophyll a ug/l	1	3	8	8	7	9	6	4	2
	1	2	9	8	7	9	6	4	3
	16	17	17	17	17	17	16	17	17
Total Suspended Solids mg/l	1	2	9	9	8	6	5	3	4
	1	2	9	9	8	6	5	3	4
	22	22	21	22	22	22	21	22	21
Secchi Disk Depth m	1	2	3	8	5	5	7	4	4
	1	2	3	8	5	7	7	6	4
	22	22	21	22	20	21	22	22	22
pH[21]	6	8	2	3	9	1	5	7	4
	6	8	2	3	9	1	5	7	4
	24	24	23	24	23	24	23	24	24

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[21] Since the pH standard represents a range (6.5-8.5), pH was ranked based on deviation from the overall mean pH (7.88). Thus, lower rankings for pH indicate greater absolute deviations from the overall mean.

Table 6. Arithmetic Mean Rank, Geometric Mean Rank, and Total Samples of Water Quality Measurements in the Chincoteague- Sinepuxent Bay Complex 1987-1990. Lower Rank Value Indicates Worse Relative Condition.

Parameters	**CB1**	**CB2**	**CB3**	**CB2**	**CB5**	**SB1**	**SB2**	**SB3**	**SB4**
Salinity ppt	9	7	6	4	2	1	3	5	8
	9	7	6	5	3	1	2	4	8
	24	23	22	23	22	23	22	23	24
Dissolved Oxygen mg/l	9	4	8	1	2	3	5	4	7
	9	4	8	1	2	3	5	4	7
	24	24	23	23	23	24	23	24	23
Conductivity mmhos/ cm	9	7	6	4	2	1	3	5	8
	9	7	6	5	2	1	3	6	8
	24	23	22	23	22	23	22	23	23
Water Temperature °C	1	2	5	4	7	9	3	6	3
	1	2	6	4	7	9	3	5	3
	24	23	24	23	22	24	23	24	24
Arithmetic Mean Rank Sum	**53**	**70**	**87**	**85**	**88**	**76**	**87**	**89**	**85**

RECOMMENDATIONS

The data analyzed and discussed in this report represent the culmination of a four year monitoring project that was initiated in 1987 with the assistance of the Water Resources Division This section contains the Water Resources Division's recommendations for continuation of the water quality monitoring program, and is structured to include recommendations for monitoring stations; parameters and field methodologies; and interpretation of the data in a regional context.

Monitoring Stations

Overall, the monitoring stations that were selected in 1987 have yielded the data and interpretive information that was expected of them. Stations SB1 and SB2 in Sinepuxent Bay, and CB1 and CB4, which were all selected for their proximity to existing or potential sources of water pollution, have revealed areas of degraded water quality conditions as evidenced by elevated nutrient and fecal coliform concentrations. An excellent baseline has also been established at all of the bay complex monitoring stations.

The park has proposed in their 1991 proposal to modify the Chincoteague-Sinepuxent Bay monitoring program by maintaining only two stations to provide continuity background readings. In addition, it was proposed that three stations be moved closer to potential sources of contamination, and eight new stations be established in the Virginia portion of Chincoteague Bay and Tom's Cove. This would raise the number of total stations to 13. The result of these modifications would be to terminate data collection at four existing monitoring stations in the Chincoteague-Sinepuxent Bay complex. The WRD agrees with the expansion of the program to the southern portion of Chincoteague Bay. However, because of the excellent data baseline that has been established at monitoring stations CB1-CB5 and SB1-SB4, the WRD recommends that monitoring continue at the existing sites for the next two years. Maintaining the existing nine stations would still allow the monitoring program to expand by four or more stations, depending on available funds, in the Virginia portion of Chincoteague Bay.

A list of recommended monitoring sites in Southern Chincoteague Bay is provided in Table 7. The seven monitoring sites, identified by the same alpha-numeric code system utilized thus far for consistency, have been selected based on both the need to establish baseline data in an area where water quality is largely undocumented and a review of historical water quality problems in southern Chincoteague Bay. Coliform counts which exceeded 70 coliforms per 100 milliliters have prompted at least temporary closures of waters to shell fish harvesting in the tributaries of Swans Gut Creek and Mosquito Creek, and in the bay waters surrounding Chincoteague Island, specifically Chincoteague and Assateague Channels. The source of the coliforms in the tributaries have been attributed to sewage and industrial discharges to these waters (Army Corps of Engineers, 1976).

Table 7. Recommended Water Quality Monitoring Stations in Southern Chincoteague Bay.

Station	Location	Purpose
CB-6	Chincoteague Bay at Greenbackville	Influence of Industrial Discharges and Marina at Greenbackville
CB-7	Chincoteague Bay East of Sinnickson	Historical Water Quality Problems Associated With Industrial & Municipal Discharges to Swans Gut Creek
CB-8	Chincoteague Bay East Mosquito Point	Historical Water Quality Problems Associated With Industrial & Municipal Discharges to Mosquito Creek
CB-9	Chincoteague Bay Mid-Way Between Sinnickson and Chincoteague Island	Southern Chincoteague Bay Water Quality
CB-10	Chincoteague Channel Near Channel Marker #28	Impact of Septic Systems and Marinas on Chincoteague Island
CB-11	Assateague Channel at Horse Marsh	Impact of Septic Systems and Marinas on Chincoteague Island
CB-12	Tom's Cove Near Assateague Point	Influence of Chincoteague Island

Water quality degradation around Chincoteague Island may, in part, be related to its role as a regional center for water-based recreation. Chincoteague Island supports a year round population of 5,000 which increases to 20,000 during the summer recreational season. Septic systems which are utilized island-wide, coupled with sandy soils and a high water table create the conditions for the island to be a source of coliforms and nutrients to Chincoteague Bay. The several marinas and associated recreational and fishing fleets, which dot the shoreline of the island, are additional threats to water quality, by being potential sources of black water and petroleum contaminants. The overall significance of these potential pollution sources will be better understood by implementing the expanded Chincoteague Bay water quality monitoring program.

Parameters and Field Methodologies

The following modifications to the parameter list and field methodologies are recommended:

- Eliminate the field determination of specific conductivity and the laboratory analyses of total dissolved nitrogen and total dissolved phosphorous.

- Begin to analyze water samples for total dissolved silicate and enterococcus bacteria.
- Begin to conduct regular vertical depth profiles for the field determined parameters of temperature, dissolved oxygen and salinity.
- If feasible, begin to sample at least once during the winter season (Nov.-March).

Specific conductance is highly correlated with salinity. Collection of this parameter simply replicates the salinity measurement. On the other hand, salinity is a fundamental parameter that is germane to almost all marine investigations, and is, therefore, much more useful for comparative analyses with other regional investigations. Dissolved nitrogen and dissolved phosphorous are likewise recommended for termination in this monitoring program because they are somewhat strongly correlated with the total concentrations of these nutrients. Total nitrogen and phosphorous are also fundamental parameters to almost all marine investigations, and thus form a much broader basis for comparative analyses of similar studies. Monitoring of dissolved silica is recommended because of its significant role in the succession and productivity of diatom algae.

The park has proposed to add enterococcus as the fecal indicator bacteria of choice for the determination of surface water quality. This is an excellent idea, and is in agreement with the Environmental Protection Agency's 1986 Water Quality Criteria that cites enterococci as the fecal-indicator bacteria of choice in marine waters.

Initiation of vertical depth profiles of temperature, dissolved oxygen and salinity is recommended to provide valuable water quality assessment information about the entire water column, including information on whether anoxic bottom conditions occur at any of the monitoring stations. This field technique may also provide us with some understanding of the movement of the freshwater-saltwater interface in the Chincoteague-Sinepuxent Bay complex. Measurements of these field parameters should occur every 0.5 meters from the surface to the bottom material.

Initiation of limited winter season monitoring would serve to more clearly identify seasonal trends in the data. Also, this would enable ASIS to document effects from potential natural or human-induced events that may occur during that time of year and contrast the water quality during high recreational use periods with the water quality during low recreational use periods.

Special Studies

The 24 hour diel studies for dissolved oxygen should be continued at the rate of two 24 hour studies per year at stations SB1, SB2, SB3, SB4, and CB1. The diel studies should be conducted during periods when cyclic physical, environmental, and biological processes, which tend to limit oxygen solubility (high ambient water temperature and salinity) or utilize dissolved oxygen from the aquatic system (algal productivity), are at their peaks. The monitoring data collected thus far indicates that peak ambient water temperatures and chlorophyll a concentrations have occurred in the months of July or August in the Chincoteague-Sinepuxent Bay complex. Peak salinity values have been observed to occur in June and July, although more recently salinity has tended to peak during the months of September and October. Based on these observations, it is recommended that one diel study be conducted in mid-July, and a second study be conducted in mid-August.

Regional Analyses

The primary objective of this report was to present a basic assessment of the Chincoteague-Sinepuxent Bay complex water quality based on the samples that have been collected by ASIS staff to date. While the WRD considers the report comprehensive in this manner, it is much less comprehensive in discussing the results of this work relative to the large volume of work that has and is being conducted by private and public institutions on similar aquatic ecosystems in the region. To discuss the results of this work in such a manner, however, is beyond the scope of this report.

Ultimately, however, one data analysis goal for all the data collected from the Chincoteague-Sinepuxent Bay monitoring program must be to relate it to the results of other ongoing monitoring programs in similar estuarine-bay environments. Such a comparative analysis would help determine the relative degree of water quality degradation or improvement in the Chincoteague-Sinepuxent Bay complex, and could also be used to predict when dangerous thresholds in the concentrations of key parameters are surpassed. To facilitate such an analysis, it is recommended that the park commit about one to two work-months of a summer seasonal's time to conduct the necessary coordination and literature searches to obtain the results of water monitoring programs and studies being conducted in the following areas:

- Delaware Bay Studies by Delaware River Basin Commission
- Chesapeake Bay Studies (Pocomoke Sound Area)
- Upper Sinepuxent/Assawoman Bay studies by the State of Delaware
- Horn Point Marine Laboratory Studies being conducted by the University of Maryland

Information and interpretations that should be obtained from these studies include concentrations of total phosphorous, total nitrogen, chlorophyll a, Secchi disk depth readings, and any interpretations or classifications relating to the trophic state indices of any bay complex. This information should be compiled graphically and tabularly in relation to the results of the Chincoteague-Sinepuxent Bay investigations.

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APPENDIX

The following pages include support materials likely to be useful to ASIS. Tables 8 and 9 present the raw summary statistics (arithmetic mean, standard deviation, standard error, geometric mean, maximum, and minimum) for each water quality parameter at every sample location. Table 10 furnishes the names and mailing addresses of Environmental Protection Agency National Point Discharge Elimination System Permit Holders in the Chincoteague-Sinepuxent Bay complex as of 1990. Table 11 presents the State of Maryland surface water quality criteria for toxic materials. Figures 47-60 replicate figures in the text except that micromoles have been converted to milligrams per liter. Tables 12 and 13 replicate Tables 8 and 9 for parameters that were measured in micromoles. The descriptive statistics for these parameters have been converted from micromoles to milligrams per liter.

Table 8. Arithmetic Mean, Standard Deviation, and Standard Error of Water Quality Parameters Measured in the Chincoteague-Sinepuxent Bay Complex 1987-1990.

Parameters	**CB1**	**CB2**	**CB3**	**CB4**	**CB5**	**SB1**	**SB2**	**SB3**	**SB4**
Fecal Coliform mpn/100 ml	23.74	3.16	8.42	3.25	2.55	1.80	7.43	3.85	0.23
	53.32	2.19	0.09	3.45	1.63	16.52	11.03	0.24	3.78
	11.37	0.08	0.09	0.21	0.35	3.52	2.41	0.91	0.07
Total Phosphorus Filtered µm	1.80	0.20	8.42	0.21	0.09	0.35	0.95	1.07	1.11
	0.42	0.34	0.42	0.42	0.09	0.32	0.33	0.91	0.96
	0.06	0.08	0.09	0.09	0.09	0.08	0.07	0.91	0.07
Total Phosphorus µm	3.16	0.20	8.42	0.21	0.21	1.00	2.06	2.53	2.71
	1.25	0.08	0.21	0.21	0.08	0.08	0.07	0.62	0.96
	0.07	0.20	0.21	0.13	0.13	0.20	0.19	0.26	0.07
Total Nitrogen Filtered µm	41.62	30.81	33.10	29.08	29.37	14.96	16.95	28.13	28.19
	10.35	1.80	8.42	0.21	0.21	9.29	9.81	0.91	0.07
	2.21	0.20	0.09	0.21	0.21	2.19	2.19	0.91	0.07
Total Nitrogen µm	77.78	56.90	55.58	41.78	47.31	30.28	34.92	50.23	56.51
	19.67	17.74	16.88	12.90	10.54	16.84	17.52	20.19	18.56
	2.19	0.08	3.77	0.21	0.09	3.16	0.07	0.91	0.19
Nitrates & Nitrites µm	0.73	0.35	0.42	0.42	0.42	1.80	0.33	0.62	0.35
	1.47	0.35	0.42	2.55	0.42	1.80	8.63	1.09	0.23
	0.32	0.00	0.21	0.13	0.21	0.08	0.33	0.24	0.19
Ammonium µm	2.19	0.35	2.14	2.14	0.21	3.16	2.56	1.62	1.90
	0.73	0.35	0.21	2.14	2.55	0.35	2.11	1.78	1.47
	0.06	0.52	2.55	0.21	0.42	0.54	0.46	0.39	0.33
Ortho-Phosphate µm	0.41	0.35	0.21	0.42	0.34	0.35	0.35	0.31	0.23
	0.41	1.80	0.42	0.09	0.34	0.20	0.24	0.26	0.19
	0.07	0.06	0.09	0.09	0.08	0.06	0.35	0.26	0.96
Chlorophyll a ug/l	19.67	14.02	10.15	8.42	0.09	5.02	8.63	11.54	15.03
	10.02	5.39	5.74	3.64	4.06	3.15	5.26	6.85	11.46
	2.50	1.31	1.39	0.88	0.98	0.76	1.32	1.66	2.78

Table 8. Arithmetic Mean, Standard Deviation, and Standard Error of Water Quality Parameters Measured in the Chincoteague-Sinepuxent Bay Complex 1987-1990.

Parameters	CB1	CB3	CB3	CB3	CB5	SB1	SB2	SB3	SB4
Total Suspended Solids mg/l	54.40	50.96	43.90	37.85	42.15	46.06	47.75	50.94	49.11
	16.45	15.73	14.34	20.58	16.71	22.10	27.05	19.47	49.11
	3.56	3.35	3.13	1.33	3.56	4.71	5.90	4.15	4.18
Secchi Disk Depth m	0.49	0.61	0.61	3.56	0.74	0.90	0.88	0.76	0.63
	0.06	0.29	1.36	1.36	0.06	0.33	0.00	0.10	0.30
	0.06	1.36	0.97	3.56	0.97	0.07	0.08	0.10	0.07
pH	7.92	7.90	8.61	8.61	7.00	7.92	7.83	7.91	7.94
	1.006	1.006	1.028	1.028	1.006	1.043	1.041	1.031	1.029
	1.006	1.006	1.028	1.028	1.006	1.043	1.008	1.006	1.006
Salinity ppt	25.00	28.10	28.10	29.64	29.64	30.36	29.58	28.39	27.70
	5.37	0.29	4.70	1.36	4.64	1.83	2.35	3.22	3.94
	1.12	0.97	1.36	4.70	0.97	0.33	5.90	0.67	0.87
Dissolved Oxygen mg/l	7.80	7.00	7.77	7.00	7.32	7.37	7.54	7.54	7.65
	0.06	1.33	0.29	1.33	0.29	0.07	1.01	0.10	0.30
	0.06	0.29	0.29	0.29	7.00	0.07	0.08	0.24	0.28
Conduct-ivity mmhos/ cm	39.19	43.90	43.90	44.48	45.66	46.72	45.19	44.07	43.04
	7.56	7.00	0.29	0.61	7.00	2.54	3.66	4.49	5.49
	1.58	1.36	1.36	0.29	1.36	1.83	0.08	0.10	4.18
Water Temperature °C	21.87	21.55	21.45	21.54	21.30	19.34	20.80	21.44	21.54
	5.68	5.58	5.83	5.65	5.76	4.91	5.36	5.54	5.63
	1.16	1.14	1.19	1.15	1.23	1.00	1.12	1.13	1.15

Table 9. Geometric Mean, Maximum, and Minimum of Water Quality Parameters Measured in the Chincoteague-Sinepuxent Bay Complex 1987-1990.

Parameters	CB1	CB2	CB3	CB4	CB5	SB1	SB2	SB3	SB4
Fecal Coliform mpn/100 ml	0.80	0.07	2.15	0.57	2.32	4.49	3.96	1.80	3.23
	240.00	9.20	4.50	16.00	9.20	79.00	49.00	16.00	16.00
	0.80	0.80	0.80	0.80	0.80	0.80	0.50	1.80	1.80
Total Phosphorus Filtered µm	2.38	1.74	0.01	1.13	3.33	0.00	0.90	0.01	1.00
	8.35	1.90	1.74	0.73	1.74	3.33	0.50	1.74	1.71
	0.80	0.57	0.07	0.80	0.00	0.52	0.50	0.81	0.58
Total Phosphorus µm	2.38	2.62	2.51	0.99	2.38	2.38	1.62	2.34	2.53
	0.01	0.04	1.74	3.33	3.33	3.33	4.35	0.81	4.52
	8.35	1.90	0.00	0.00	8.35	0.35	0.90	0.81	1.71
Total Nitrogen Filtered µm	10.80	30.18	32.01	27.52	18.80	12.55	13.92	26.44	26.65
	60.70	41.20	50.00	18.80	47.40	43.60	39.50	44.90	43.00
	21.00	18.80	18.80	10.80	18.80	0.00	2.70	10.80	12.70
Total Nitrogen µm	75.42	54.35	53.17	40.02	46.18	26.84	30.99	45.87	53.04
	121.00	103.00	97.60	73.20	71.70	81.90	81.40	89.70	84.20
	38.00	31.50	18.80	18.80	30.10	81.90	11.00	14.30	22.00
Nitrates & Nitrites µm	0.29	0.29	0.29	2.38	2.30	3.33	6.97	0.23	0.18
	3.33	1.90	1.74	8.35	3.72	6.86	0.25	3.73	3.87
	0.01	0.04	0.04	0.01	0.00	0.00	0.50	0.01	0.01
Ammonium µm	1.37	1.37	0.99	1.13	2.38	2.38	1.62	1.06	1.21
	18.00	1.74	8.35	0.01	10.80	3.33	6.97	3.73	0.18
	0.35	0.04	0.07	0.00	0.00	0.80	0.25	0.13	0.10
Ortho-Phospate µm	2.38	0.29	0.01	2.38	0.29	0.01	0.28	0.23	0.18
	1.74	1.90	0.73	0.29	1.45	2.38	0.28	0.98	0.58
	0.35	0.04	0.07	0.01	0.04	0.35	0.12	0.98	0.58
Chlorophyll a ug/l	17.23	12.96	8.61	4.81	6.81	4.33	6.96	9.09	12.25
	37.40	22.50	22.60	14.20	15.70	15.30	19.80	25.40	43.40
	6.82	5.92	2.92	1.02	2.26	1.06	0.94	1.04	4.06

Table 9. Geometric Mean, Maximum, and Minimum of Water Quality Parameters Measured in the Chincoteague-Sinepuxent Bay Complex 1987-1990.

Parameters	CB3	CB2	CB3	CB4	CB4	CB3	SB2	SB3	SB4
Total Suspended Solids mg/l	51.78	48.67	42.01	32.53	39.20	42.17	42.53	47.43	45.83
	24.00	58.00	75.00	51.70	18.00	108.30	129.60	18.00	98.00
	24.00	26.50	18.50	7.20	18.00	24.00	42.53	18.00	24.50
Secchi Disk Depth m	0.44	0.46	1.50	0.75	0.63	0.44	0.73	0.66	0.57
	1.50	1.50	1.50	7.20	2.00	1.50	1.70	0.66	1.50
	0.20	0.20	0.30	0.30	0.75	0.30	0.30	0.30	0.20
pH	7.92	7.90	8.44	7.20	7.20	7.29	9.80	7.91	7.94
	8.30	7.90	8.30	8.30	8.30	8.20	8.30	8.20	8.30
	8.30	7.90	8.44	7.20	7.36	8.44	6.80	7.20	7.94
Salinity ppt	24.00	27.72	27.99	28.19	29.27	30.30	29.49	28.21	27.42
	33.50	36.80	35.70	39.20	36.40	34.10	34.20	18.00	35.10
	13.20	19.90	24.00	28.20	10.00	28.20	23.80	21.10	20.70
Dissolved Oxygen mg/l	7.75	7.90	7.64	7.20	7.17	7.29	7.48	7.45	7.94
	10.50	9.70	0.44	7.20	10.10	0.75	9.80	0.30	20.70
	5.23	5.60	8.44	5.03	7.20	0.75	9.80	5.75	0.20
Conductivity mmhos/cm	38.43	43.36	43.47	43.73	45.21	46.65	45.04	43.84	42.70
	51.10	58.00	54.00	56.00	18.00	51.70	52.00	53.20	53.20
	22.20	32.00	32.30	28.20	33.60	38.20	37.40	33.70	33.20
Water Temperature °C	21.12	20.81	20.63	20.79	20.50	18.66	20.06	20.72	20.80
	29.10	28.70	29.50	29.30	30.00	27.80	28.30	29.20	29.20
	12.60	12.50	11.00	12.30	10.80	8.00	9.70	12.40	12.40

Table 10. Names and Mailing Addresses of Environmental Protection Agency National Point Discharge Elimination System Permit Holders and Permit Numbers in the Chincoteague-Sinepuxent Bay Complex as of May 1990. Italics Indicate Greater Discharges.

American Original Corporation, 215 High Street, Seaford, DE, 19973 *MD0024422*
Assateague Island Nat. Seashore, Rt. 2 Box 294, Berlin, MD, 21811 *MD0021091*
Berlin WWTP, 10 Williams St., Berlin, MD, 21811 MD0022632
Kelly Foods Corporation, Rt. 3 Box 28, Berlin, MD, 21811 MD0001309
Sanofi Animal Inc., P.O. Box 6, Berlin, MD, 21811 MD0022560
Hudson Foods Inc., P.O. Box 7, Berlin, MD, 21811 *MD0002071*
Savage Ice Co. Inc., 305 Washington St., Berlin, MD, 21811 *MD0055107*
Berlin Shopping Center WWTP., P.O. Box 1150, Ocean City, MD, 21811 MD0024911
Martin Fish Company Inc., S. Harter Rd., Ocean City, MD, 21842 MD0050270
Ocean City WWTP, 6405 Seabay Ave., Ocean City, 21842 *MD0020044*
Worcester Cnty. San. Comm., 6405 Seabay Ave., Ocean City, MD, 21842 *MD0023477*
Campbell Soup Co., P.O. Box 89, Pocomoke City, MD, 21851 MD0002224
Chesapeake Corporation, P.O. Box 300, Pocomoke City, MD, 21851 MD0059242
Holiday Inn, Rt. 13, Pocomoke City, MD, 21851 MD0052761
Mid-Atlantic Foods Inc., P.O. Box 367, Pocomoke City, MD, 21851 *MD0060429*
Pocomoke City STP, P.O. Box 29 Dun Swamp Rd., Pocomoke City, MD, 21851 *MD0022551*
Quality Inn, Rt.2 US 12 South, Pocomoke City, MD, 21851 MD0023035
Twin Towers Motel & Restaurant, Rt. 2 Box 336, Pocomoke City, MD, 21851 *MD0023027*
Somerset Packing Co., RFD #1, Pocomoke City, MD, 21851 *MD0059056*
Chincoteague Shellfish Farms, Rt. 3 Box 90, Snow Hill, MD, 21863 MD0060208
Cody's Exxon, Rt. 2 Box 1, Snow Hill, MD, 21863 *MD0063231*
Holly Farms Foods Inc., P.O. Box 220, Snow Hill, MD, 21863 *MD0053643*
Moore Business Forms Inc., 201 Belt St., Snow Hill, MD, 21863 *MD0054011*

Table 10. Names and Mailing Addresses of Environmental Protection Agency National Point Discharge Elimination System Permit Holders and Permit Numbers in the Chincoteague-Sinepuxent Bay Complex as of May 1990. Italics Indicate Greater Discharges.

Public Landing Harbor, Rt. 3 Box 121A, Snow Hill, MD, 21863 *MD0060178*
Scarborough Oil Co. Inc., Rt. 2. Box 1A, Snow Hill, MD, 21863 MD0062227
Snow Hill Water & Sewer Dept., 103 Bank St., Snow Hill, MD, 21863 *MD0022764*
State Highway Admin., P.O. Box 268, Snow Hill, MD, 21863 *MD0063258*
Tr-State Oil Co. Inc., P.O. Box 334, Snow Hill, MD, 21863 MD0057819
Worcester Cnty. San. Comm., 303 N. Washington St., Snow Hill, MD, 21863 *MD0020630*
Showell Farms Inc., P.O. Box 158 Pitts Rd., Showell, MD, 21862 *MD0000965 and MD0063860*
Showell Growers Inc., P.O. Box 58, Showell, MD, 21862 MD0050849
Showell Milling, P.O. Box 158, Showell, MD, 21862 MD0061336
Pocomoke Truck Stop - Union Oil, 200 E. Golf Rd., Palatine, IL, 60067 MD0054330
Delmarva Oil Inc., P.O. Box 303, Salisbury, MD, 21801 MD0020591
Perdue Inc. No. 7 Hatchery, P.O. Box 1537, Salisbury, MD, 21801 *MD0063452*
Accomack Co. School BD-South, W. Corner RFD Rt. 620 & 7, Accomack, VA, 23301 *VA0027171*
Accomack Co. School BD-North, 691 NW CRN RFD Rt. 13, Accomack, VA, 23301 *VA0027162*
Perdue Inc., U.S. Rt. 13, Accomac, VA, 21301 *VA0003808*
Bonawell Bros., Saxis, VA, 23427 *VA0004201*
Evans Brothers Seafood Co., End of Rt. 695, Saxis, VA, 23427 VA0050482
HV Drewer & Sons Seafood, Saxis, VA, 23427 *VA0006009*
Linton & Lewis, End of Rt. 695, Saxis, VA, 23427 VA0050466
Miles, Aldon, & Sons, Saxis, VA, 23427 VA0050504
Paul Watkinson Seafood, Saxis, VA, 23427 VA0050491
Saxis Crab Co., Saxis, VA, 23427 VA0050164
C&M Shellfish Co. VA0071625

Table 10. Names and Mailing Addresses of Environmental Protection Agency National Point Discharge Elimination System Permit Holders and Permit Numbers in the Chincoteague-Sinepuxent Bay Complex as of May 1990. Italics Indicate Greater Discharges.

G&P Seafood Inc. VA0057673
Mason Seafood Co. VA0055298
Town of Onancock *VA0021253*
Town of Tangier VA0067423
VA Dept. of Highways, P.O. Box 278, VA *VA0023078*
Whispering Pines Motel VA0063371
William H. Marshall & Co. VA0058360
Carpenters Seafood, 700 S. Main St., Chincoteague, VA 23336 *VA0005916*
Chicnoteague Fish Co. Inc., Marlin St., Chincoteague, VA, 23336 VA0051462
Chincoteague Seafood Co., N. Main St., Chincoteague, VA, 23336 *VA0005096*
Conner and McGee Seafood, Eastside, Chincoteague, VA, 23336 VA0005746
D.L. Edgerton Co., P.O. Box 25 Main Street, Chincoteague, VA, 23336 VA0055239
F & G Laundry, 304 S. Main St., Chincoteague, VA, 23336 VA0005321
McCready Seafood, P.O. Box 562, Chincoteague, VA, 23336 VA0071650
Ralph E. Watson Seafood, N. Main St., Chincoteague, VA 23336 *VA0005762*
Russell Fish Co. Inc., P.O. Box 85, Chincoteague, VA, 23336 VA0054003
Stubbs Reginald E. Seafood Co., Eastside Rd., Chincoteague, VA, 23336 VA0056421
Thomas E. Reed Seafood, Chincoteague, VA, 23336 VA0005738
Town of Chincoteague, Chincoteague, VA, 23336 VA0051756
T & W Seafood Co. Inc., Kelly's Landing P.O. Box 23, Atlantic, VA, 23303 VA0050997
W.E. Jones Seafood, East Side, Chincoteague, VA, 23336 VA0051314
WM C Bunting Co. Inc., 102 S. Main St., Chincoteague, VA, 23336 *VA0005444*
John W. Taylor Packing, Hallwood, VA, 23359 *VA0002992*

Table 10. Names and Mailing Addresses of Environmental Protection Agency National Point Discharge Elimination System Permit Holders and Permit Numbers in the Chincoteague-Sinepuxent Bay Complex as of May 1990. Italics Indicate Greater Discharges.

Edgewood Trailer Park, U.S. 13, New Church, VA, 23415
VA0065196

Messick & Wessells Inc., Box 23, Parksley, VA, 23421
VA0053899

W.J. Bundick, Rt. 1 Box 185, Parksley, VA, 23421
VA0063606

Nandua Seafood, Hacksneck, VA, 23358
VA0051161

Messick & Wessells Laundromat, Rt. 13, Nelsonia, VA, 23308
VA0051403

Peter's Seafood, P.O. Box 46, Quinby, VA, 23423
VA0050881

Spence, Geoge D & Sons, Quinby, VA, 23423
VA0050148

Fisher Bros. Oyster Co., Sanford, VA, 23426
VA0005321

Holly Farms, P.O. Box 8, Temperanceville, VA, 23422
VA0004049

U.S. NASA Wallops Island, Wallops Flight Ctr., Wallops Island, VA, 23337
VA0024457

Integrated Fisheries Int'l, World Trade Center, Norfolk, VA, 23427
VA0077305

Wachapreague Seafood Co., 2155 Columbus Ave., Springfield, MD, 01104
VA0005011

Table 11. State of Maryland Water Quality Toxic Materials Criteria for All Maryland Surface Waters (COMAR 26.08.02).

Parameter	Water Quality Criteria
Aldrin-Dieldrin	0.004 microgram/liter
Benzidine	0.1 microgram/liter
DDT	0.004 microgram/liter
Endrin	0.004 microgram/liter
Polychlorinated biphenyls (PCB's)	0.001 microgram/liter
Toxaphene	0.005 microgram/liter
Tributyltin (TBT)	0.026 microgram/liter

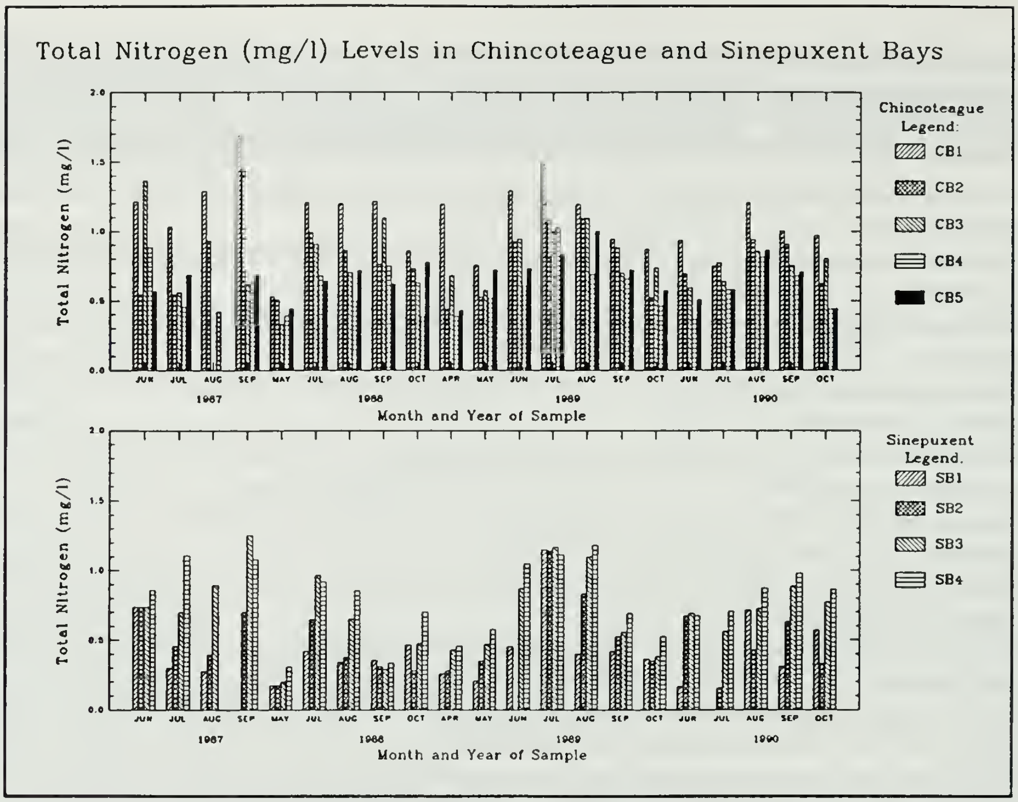

Figure 47. Seasonal Total Nitrogen Distribution in the Chincoteague-Sinepuxent Bay Complex.

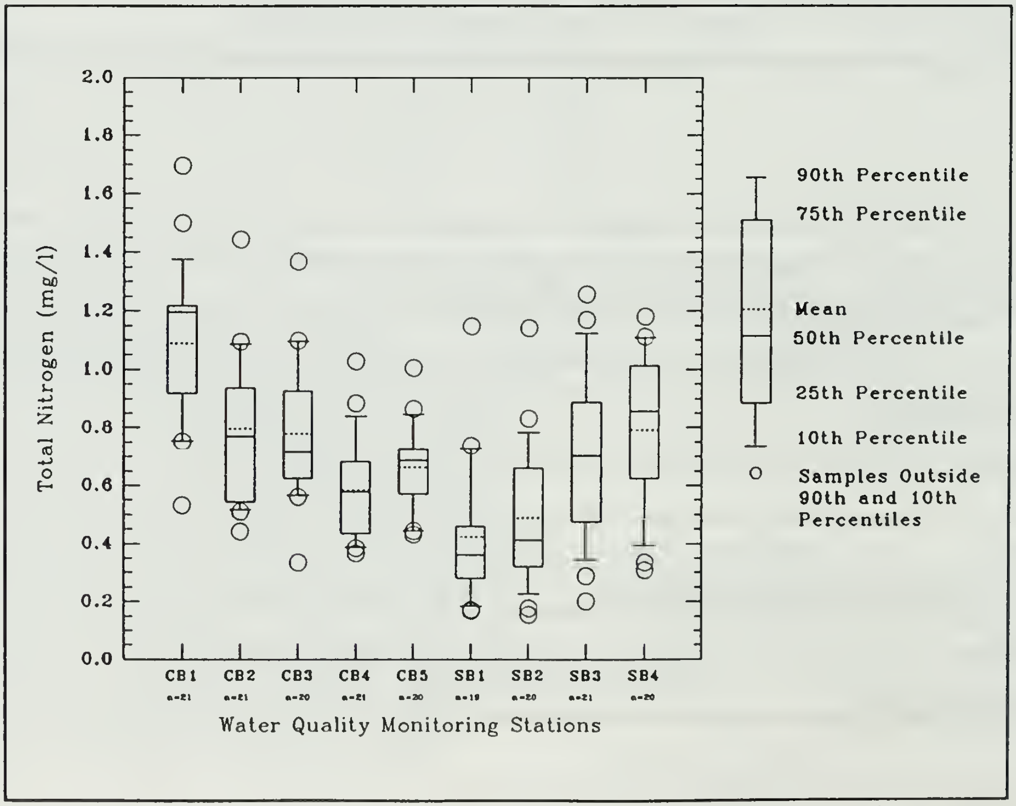

Figure 48. Total Nitrogen Distributions in the Chincoteague-Sinepuxent Bay Complex.

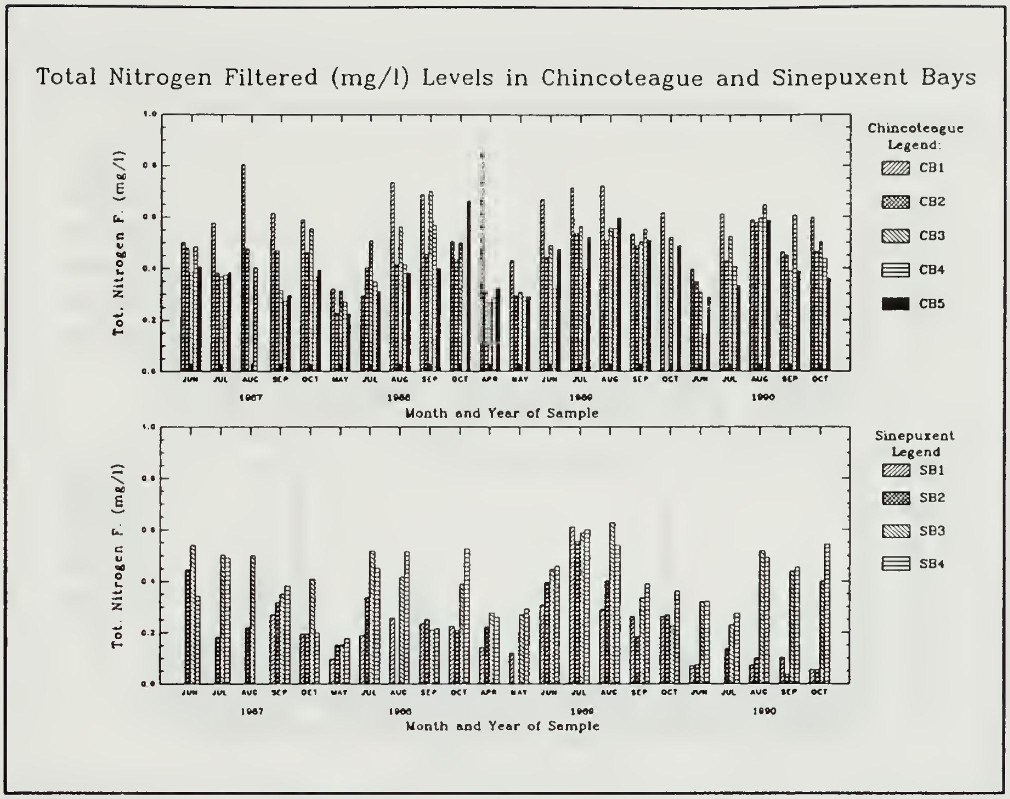

Figure 49. Seasonal Total Nitrogen Filtered Distribution in the Chincoteague-Sinepuxent Bay Complex.

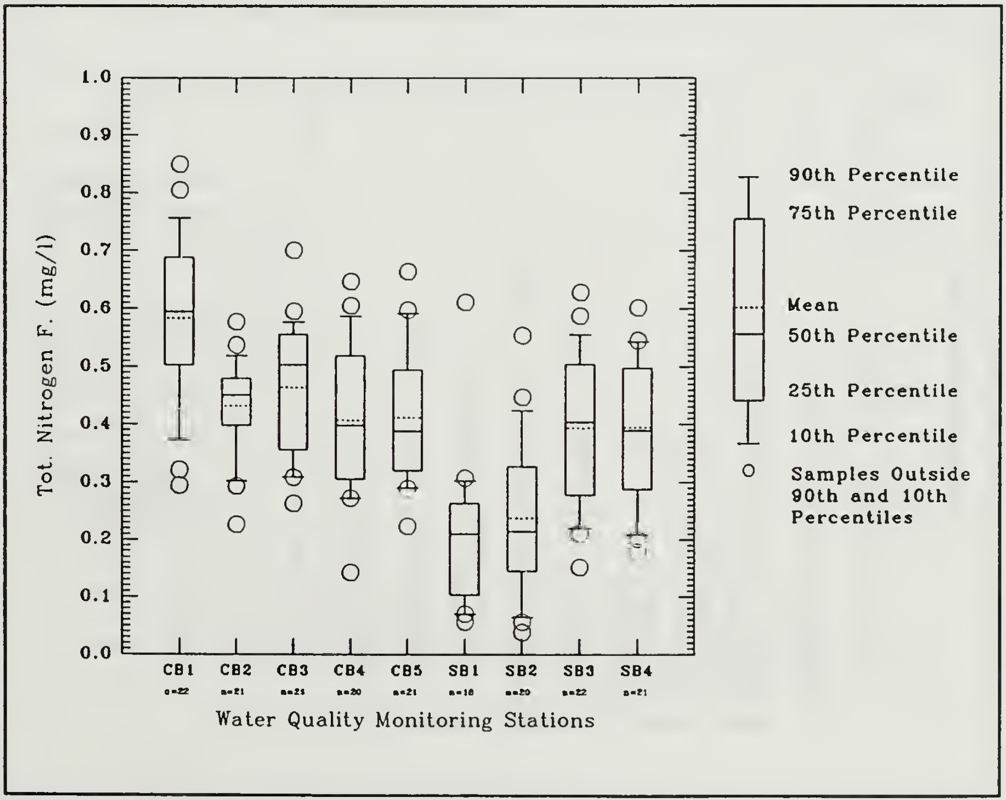

Figure 50. Total Nitrogen Filtered Distributions in the Chincoteague-Sinepuxent Bay Complex.

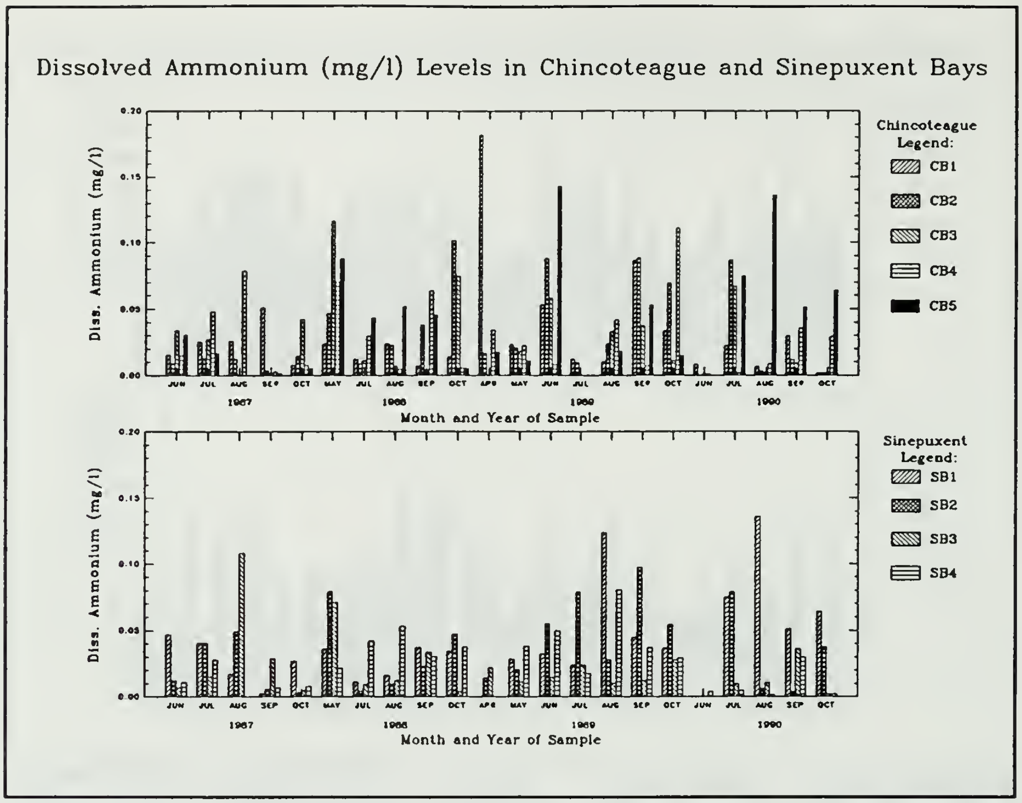

Figure 51. Seasonal Dissolved Ammonium Distribution in the Chincoteague-Sinepuxent Bay Complex.

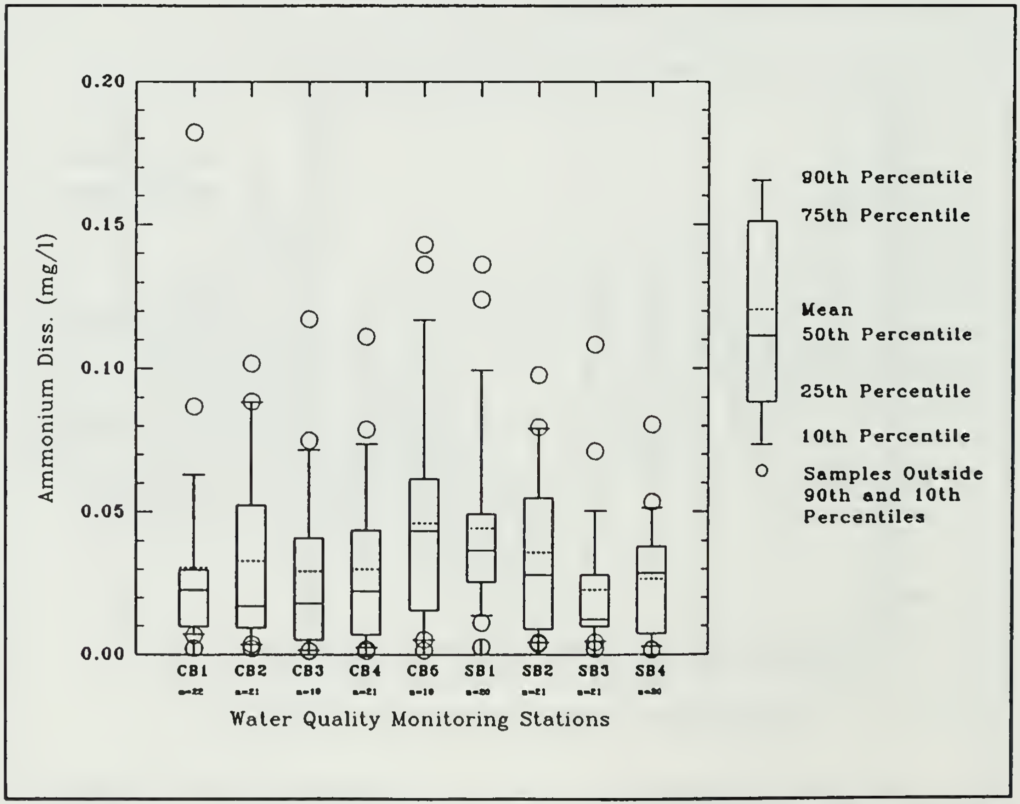

Figure 52. Dissolved Ammonium Distributions in the Chincoteague-Sinepuxent Bay Complex.

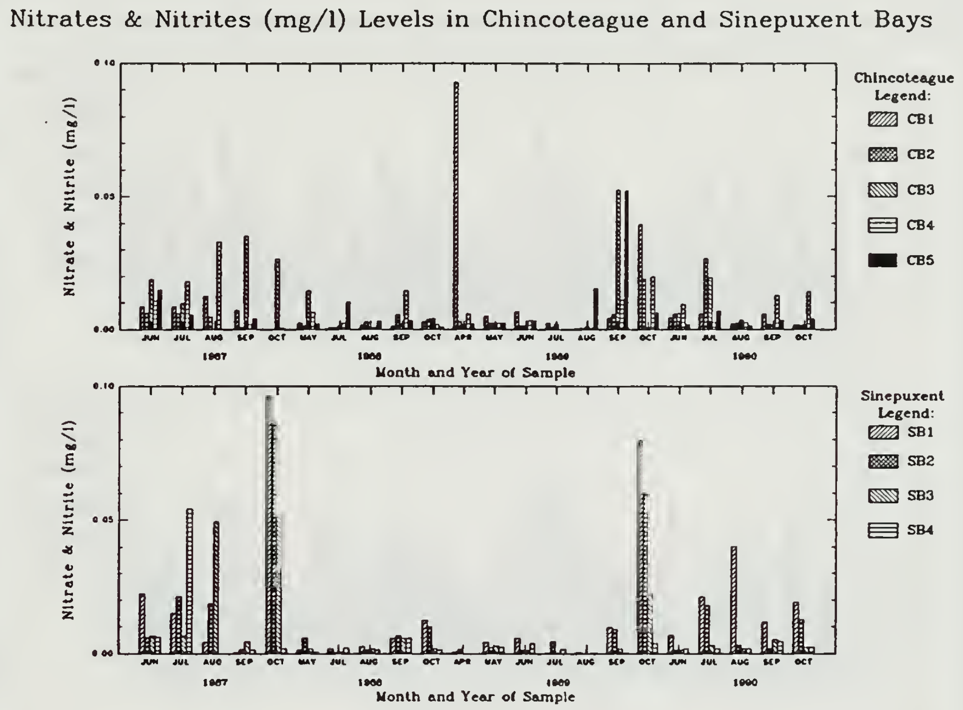

Figure 53. Seasonal Nitrates and Nitrites Distribution in the Chincoteague-Sinepuxent Bay Complex.

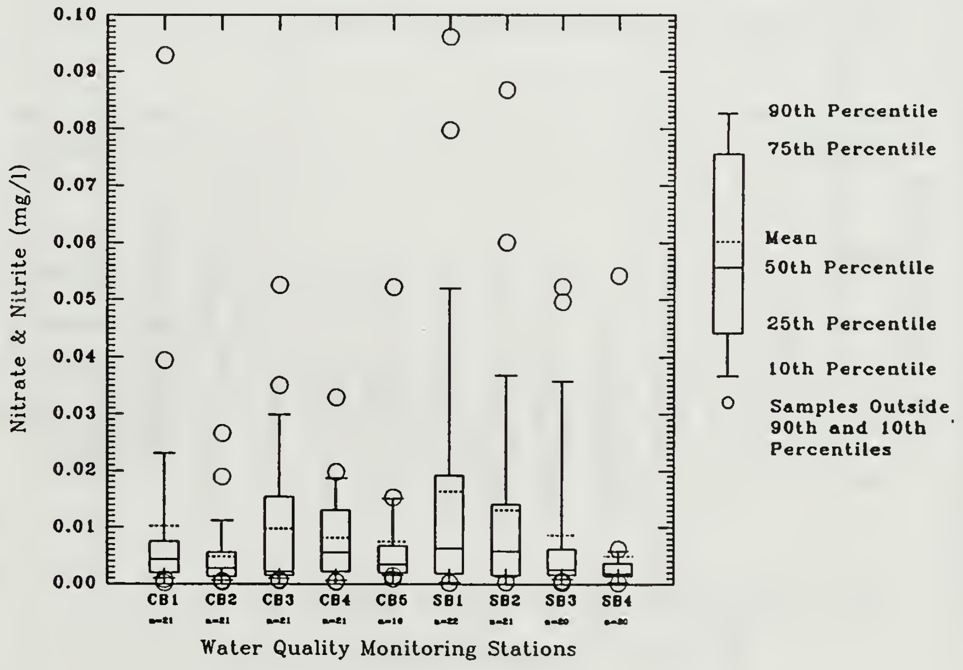

Figure 54. Nitrates and Nitrites Distributions in the Chincoteague-Sinepuxent Bay Complex.

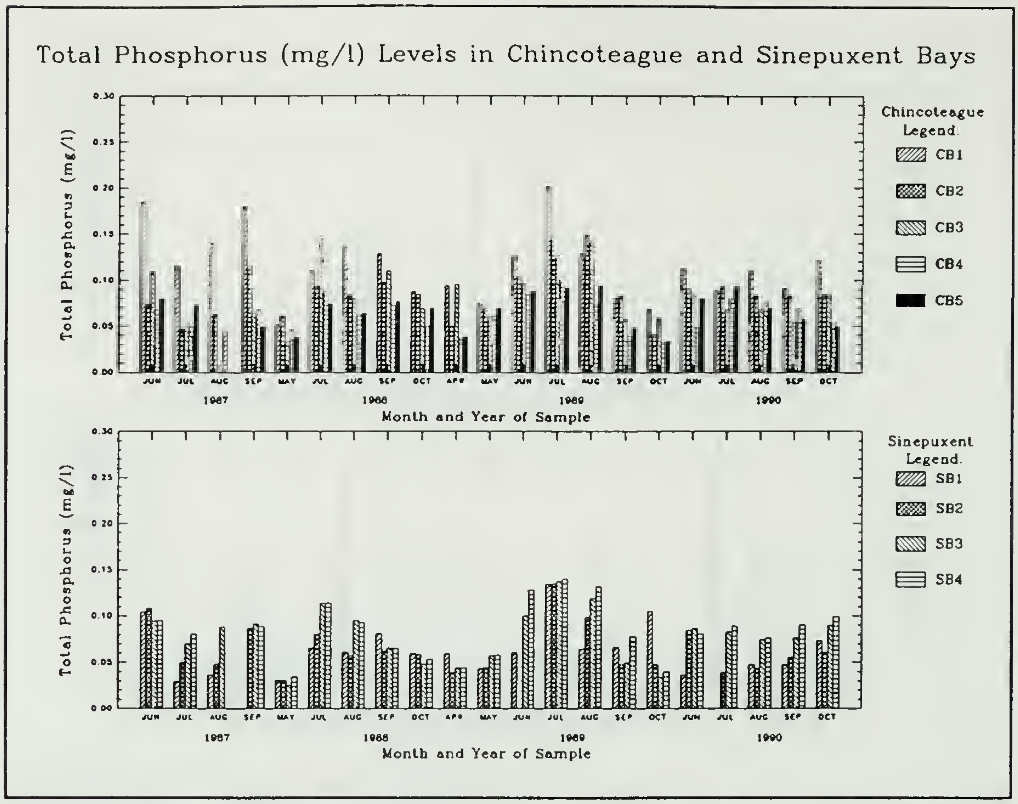

Figure 55. Seasonal Total Phosphorus Distribution in the Chincoteague-Sinepuxent Bay Complex.

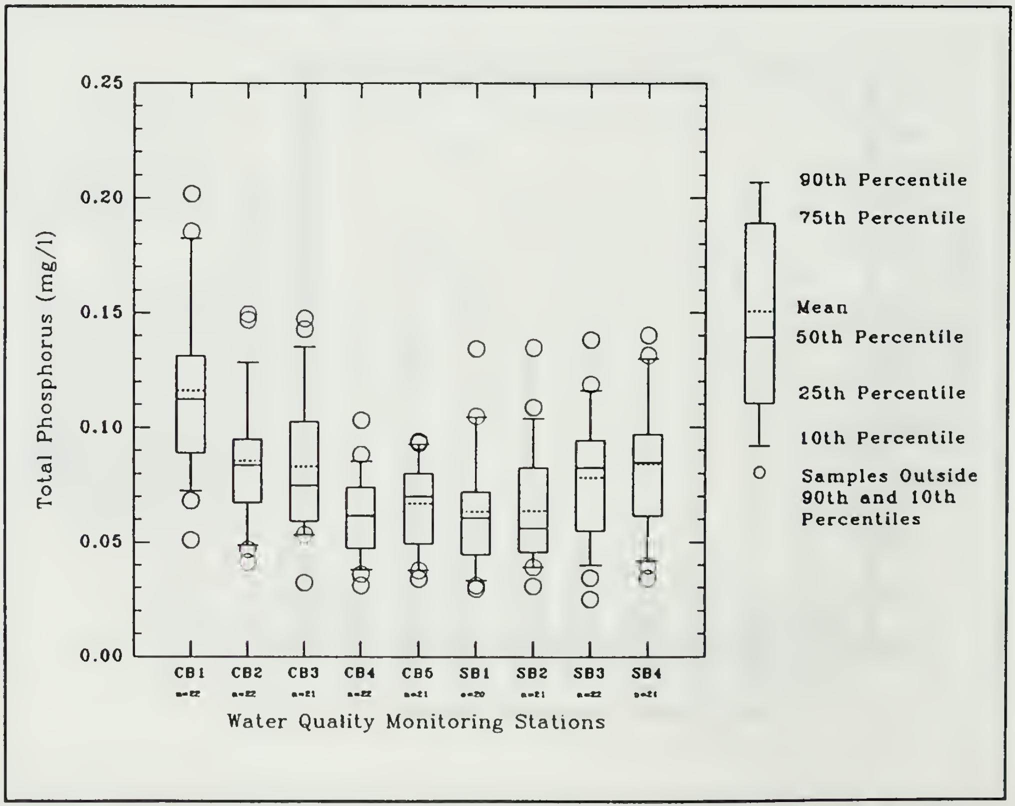

Figure 56. Total Phosphorus Distributions in the Chincoteague-Sinepuxent Bay Complex.

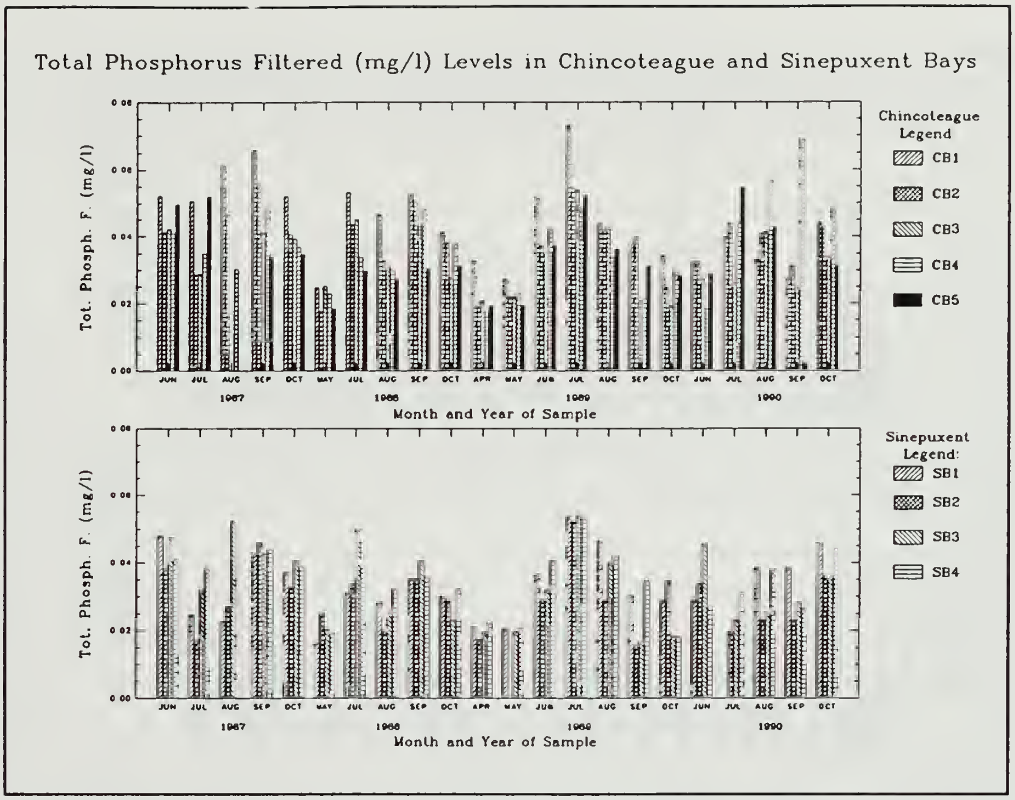

Figure 57. Seasonal Total Phosphorus Filtered Distribution in the Chincoteague-Sinepuxent Bay Complex.

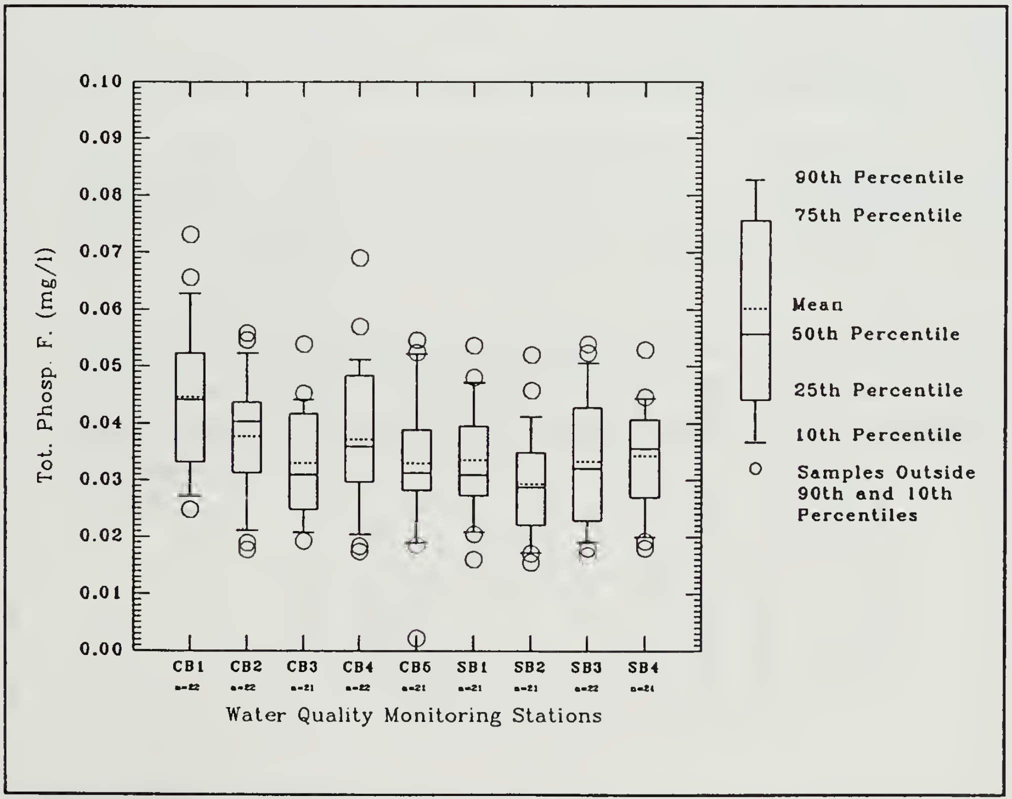

Figure 58. Total Phosphorus Filtered Distributions in the Chincoteague-Sinepuxent Complex.

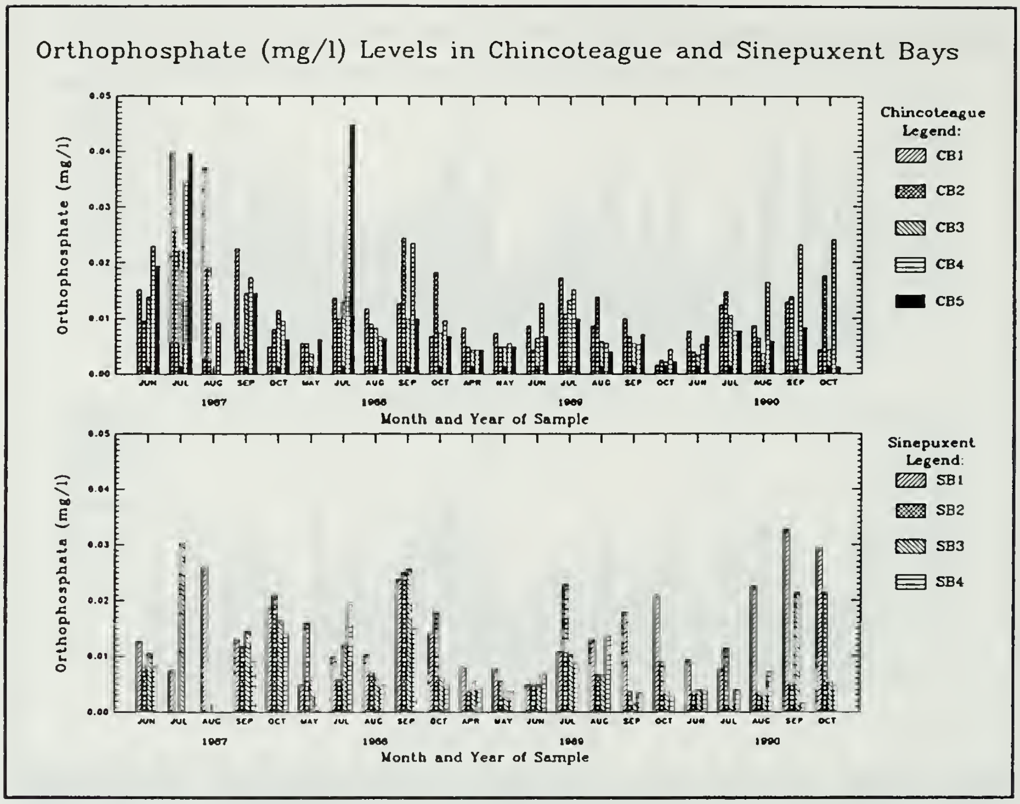

Figure 59. Seasonal Orthophosphate Distribution in the Chincoteague-Sinepuxent Bay Complex.

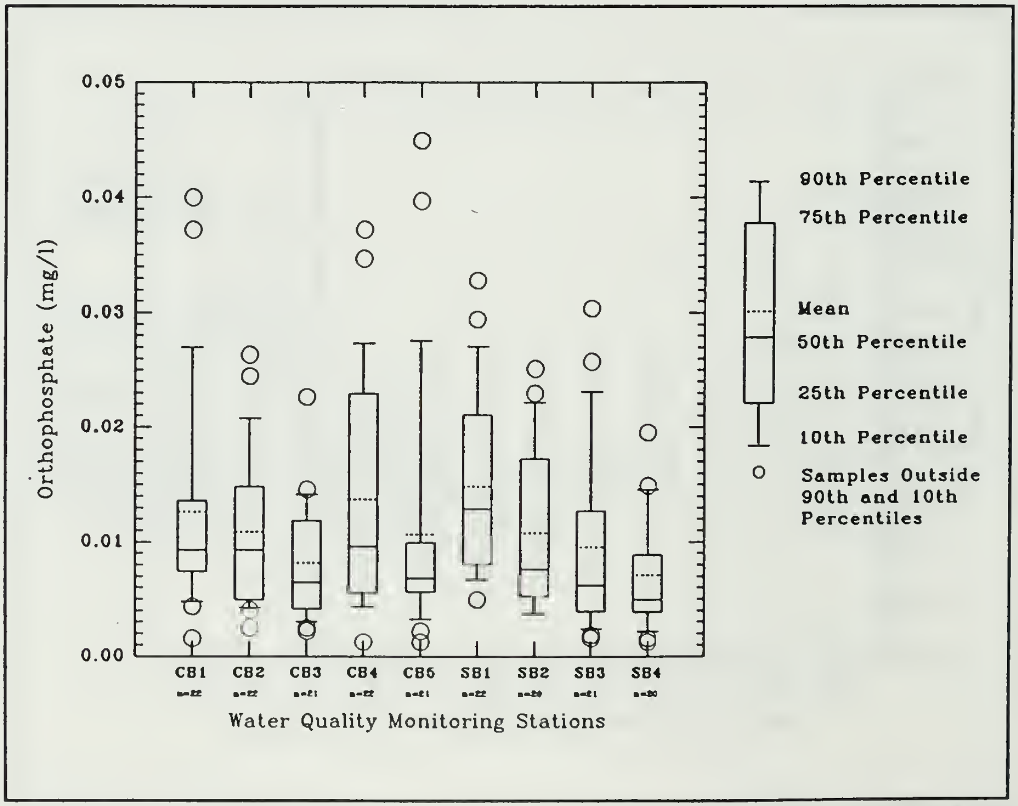

Figure 60. Orthophosphate Distributions in the Chincoteague-Sinepuxent Bay Complex.

Table 12. Nutrient Arithmetic Mean, Standard Deviation, and Standard Error of Water Quality Parameters Measured in the Chincoteague-Sinepuxent Bay Complex 1987-1990 Converted to MG/L.

Nutrient	CB4	CB2	CB3	CB4	CB4	SB1	SB2	SB3	SB4
Total Phosphorus Filtered mg/l	0.031	0.031	0.003	0.007	0.003	0.008	0.021	0.033	0.003
	0.003	0.014	0.014	0.003	0.003	0.000	0.009	0.012	0.003
	0.003	0.002	0.003	0.003	0.003	0.008	0.002	0.033	0.002
Total Phosphorus mg/l	0.116	0.014	0.083	0.062	0.007	0.064	0.064	0.033	0.027
	0.006	0.006	0.031	0.003	0.014	0.027	0.021	0.033	0.003
	0.006	0.006	0.007	0.014	0.014	0.008	0.006	0.033	0.003
Total Nitrogen Filtered mg/l	0.58	0.58	0.41	0.41	0.41	0.21	0.24	0.06	0.03
	0.15	0.08	0.08	0.13	0.08	0.13	0.14	0.13	0.13
	0.58	0.58	0.58	0.58	0.58	0.03	0.03	0.06	0.03
Total Nitrogen mg/l	0.58	0.50	0.78	0.59	0.66	0.42	0.49	0.70	0.03
	0.27	0.08	0.41	0.58	0.15	0.24	0.25	0.06	0.26
	0.08	0.08	0.05	0.41	0.41	0.05	0.05	0.06	0.26
Nitrates & Nitrites mg/l	0.010	0.006	0.014	0.014	0.007	0.008	0.013	0.033	0.003
	0.021	0.006	0.014	0.008	0.003	0.025	0.021	0.015	0.002
	0.006	0.002	0.003	0.007	0.003	0.008	0.005	0.033	0.003
Ammonium mg/l	0.039	0.031	0.083	0.031	0.014	0.008	0.006	0.023	0.027
	0.039	0.031	0.031	0.000	0.031	0.034	0.006	0.033	0.027
	0.010	0.003	0.007	0.007	0.014	0.008	0.006	0.033	0.003
Ortho-Phospate mg/l	0.013	0.011	0.008	0.014	0.011	0.015	0.011	0.010	0.007
	0.010	0.007	0.005	0.010	0.011	0.008	0.007	0.008	0.005
	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.001

Table 13. Nutrient Geometric Mean, Maximum, and Minimum of Water Quality Parameters Measured in the Chincoteague-Sinepuxent Bay Complex 1987-1990 Converted to MG/L.

Nutrient	CB1	CB2	CB3	CB4	CB5	SB1	SB2	SB3	SB4
Total Phosphorus Filtered mg/l	0.003	0.036	0.032	0.035	0.004	0.032	0.028	0.031	0.033
	0.073	0.054	0.054	0.069	0.055	0.054	0.052	0.054	0.053
	0.025	0.081	0.003	0.004	0.002	0.016	0.015	0.017	0.018
Total Phosphorus mg/l	0.110	0.081	0.003	0.059	0.004	0.059	0.059	0.003	0.079
	0.202	0.149	0.147	0.143	0.016	0.134	0.135	0.138	0.140
	0.004	0.081	0.032	0.031	0.004	0.029	0.098	0.025	0.033
Total Nitrogen Filtered mg/l	0.56	0.42	0.45	0.39	0.40	0.18	0.20	0.37	0.31
	0.85	0.58	0.70	0.65	0.65	0.61	0.55	0.63	0.10
	0.29	0.23	0.70	0.14	0.22	0.38	0.04	0.15	0.18
Total Nitrogen mg/l	1.69	0.76	0.70	0.65	0.65	0.38	0.43	0.64	0.18
	1.69	1.44	1.37	1.00	1.00	1.15	1.14	1.26	0.18
	0.53	0.44	0.33	0.39	0.40	0.17	0.15	1.26	0.31
Nitrates & Nitrites mg/l	0.004	0.003	0.003	0.004	0.004	0.029	0.028	0.003	0.002
	0.073	0.027	0.003	0.004	0.004	0.054	0.087	0.052	0.054
	0.0001	0.0003	0.0001	0.0008	0.0008	0.0001	0.0003	0.0001	0.000 1
Ammonium mg/l	0.014	0.014	0.014	0.016	0.027	0.033	0.023	0.015	0.017
	0.182	0.102	0.147	0.143	0.143	0.136	0.098	0.108	0.140
	0.202	0.032	0.004	0.004	0.004	0.029	0.028	0.017	0.054
Ortho-Phospate mg/l	0.010	0.009	0.007	0.010	0.008	0.013	0.009	0.007	0.006
	0.040	0.026	0.023	0.037	0.045	0.033	0.025	0.030	0.020
	0.002	0.002	0.002	0.001	0.001	0.005	0.004	0.002	0.001

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As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The department assess our energy and mineral resources and works to ensure that their development is in the best interest of all our people. The department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for the people who live in island territories under U.S. administration.

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