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Nutrient and Total Suspended Solids
Data for Back Bay (1986-1989)

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Abstract: Surface water samples from Back Bay, Virginia were analyzed for nutrient and total suspended solids on a monthly basis from April, 1986 through December, 1989. The concentrations of total phosphorus, orthophosphate, nitrite and nitrate nitrogen, and total ammonia generally fell within the "normal" range and did not indicate high nutrient loading. However, the concentrations of total suspended solids and total Kjeldahl nitrogen were high, exceeding EPA reference levels. Soil particles kept in suspension by wind driven wave action was the primary factor for the high concentration of total suspended solids. The high concentration of total Kjeldahl nitrogen was due to an abundance of organic matter, primarily plant detritus and plankton. Seasonal patterns were noted for nitrite and nitrate nitrogen, total ammonia, total suspended solids and total Kjeldahl nitrogen.

Introduction
Water quality has been perceived to be poor in Back Bay for several years. However, there has not been a comprehensive study of water quality in Back Bay since the period 1959-1963 (Sincock, 1966). The Virginia Water Control Board (VWCB) has monitored selected water quality parameters on some of the bay's tributaries on an irregular basis; but no sampling in the open bay was conducted. Mann (1984) reported the results of water quality monitoring at 20 stations (8 in open bay and 12 in tributaries) in 1983. However, this sampling effort was limited to two dates following a 0.73 inch rainstorm. Results of this survey showed high concentrations of phosphorus, nitrate nitrogen, and suspended solids. However, the limited amount of sampling and its occurrence shortly after a rainstorm invalidates Mann's data as representative of the bay's water quality over an extended period. Our study was initiated in 1986 to ascertain nutrient levels in Back Bay and establish a comprehensive long term data base for future reference. Results of the first year's nutrient analyses were reported by Southwick and Norman (1987).

Methods
Surface water samples were collected at six stations on Back Bay (Figure 1) on a monthly basis from April, 1986 through December, 1989. Samples were sent to the Virginia Consolidated Laboratory in Richmond for analyses. Water quality parameters analyzed by the lab were suspended solids, ammonia, nitrite, nitrate, total Kjeldahl nitrogen, total phosphorus, and orthophosphate. For this manuscript, the data were averaged to provide monthly and annual means. These were compared with the literature, particularly with EPA reference levels (VWCB, 1976).

Results and Discussion
Total Suspended Solids - Total suspended solids (TSS) include: 1) "fixed" matter which is inorganic colloidal clay and course suspensions of soil particles, and 2) "volatile" matter which is organic. The concentration of suspended solids varies greatly between waters, depending on numerous factors including geomorphology of the watershed, atmospheric sources, equilibrium-exchange with sediments within the water body, evapotranspiration, and human activity within the watershed. Evaporation from waters in closed basins raises the concentration of dissolved solids as does saltwater infusion. Due to the host and complexity of factors influencing TSS, a meaningful comparison for this water quality parameter cannot be made between Back Bay and other waters. Therefore, we compared the concentration of TSS in Back Bay only with the EPA reference level (80 mg/l).

Annual means for TSS were: 50 mg/l, 1986; 69 mg/l, 1987; and 84 mg/l, 1988 and 1989 (Figure 2). These values exceed the EPA reference level for two of the four study years. On an individual station basis, TSS exceeded the EPA reference level in 33.3% of the samples. The primary sources for this high level of TSS were: 1) an abundance of inorganic material in suspension, (Southwick and Norman, 1987) and 2) an abundant plankton population (Marshall, 1988 and
Marshall, et al., 1988). The monthly levels followed a distinct seasonal trend (Figure 3) with a peak in late winter-early spring and a low in summer. Total suspended solids was generally highest from January through March when the level routinely exceeded 75 mg/l and reached as high as 216 mg/l (March, 1987). The more intense winds at Back Bay during the winter and spring (Mann, 1984) increased the wave action which increased the amount of sediment in suspension. As the winds subsided during the summer, TSS declined to levels generally ranging from 40 to 50 mg/l. With increased wind velocity in the fall, the level of TSS increased to approximately 50-100 mg/l.

**Total phosphorus** - Phosphorus is a major cellular constituent and key metabolic element. It is essential for energy transfer within the living cell. Phosphorus is usually considered to be the element which most frequently limits aquatic production.

The total phosphorus concentration in natural, unpolluted waters ranges widely from 0.01 to more than 200 mg/l in some closed, saline lakes (Wetzel, 1975). However, the concentration in most unpolluted, surface waters is between 0.1 and 0.5 mg/l with the level seldom exceeding 1.0 mg/l (Boyd, 1979). Even in fertilized fish ponds, the concentration averaged only 0.17 mg/l (Boyd, 1976). Rulifson (1990) stated that the concentration in the lower Roanoke River ranged from 0.14 to 0.17 mg/l. The EPA reference level for total phosphorus is 0.3 mg/l.

The concentration of total phosphorus in Back Bay averaged 0.1 mg/l each year of this study (Figure 4). There was little spatial or temporal difference. The highest individual reading was 0.3 mg/l which occurred only twice during this 45-month study (Stations 5 and 9; December, 1989). Since the annual means fell within the "accepted or normal" range and were less than the EPA reference level, it appears that Back Bay is not overloaded with phosphorus. However, the level did exceed the VWCB standard of 0.05 mg/l for class II B waters.

Total phosphorus did not show any distinct seasonal trend (Figure 5). It was generally highest for a few months in late winter-early spring. Explanations for this could include 1) a decrease in phosphorus assimilation with the waning of the phytoplankton population and, 2) the re-suspension of sediment bound phosphorus by heavy wave action. When a phytoplankton population becomes senescent and declines, phosphorus is released from the dead cells. A portion of this is incorporated by other phytoplankton species, which become more abundant as others decline. But when the entire phytoplankton population declines, the concentration may increase considerably. Marshall (1988) noted that the phytoplankton population in Back Bay declined during the winter. Phosphorus very readily binds to soil particles and as such may flocculate to the bottom where it is utilized by various benthic organisms but is unavailable to plankton within the euphotic zone. The strong winds during the winter-spring period would bring this sediment bound phosphorus back into suspension. A second "peak" occurred in late summer-early fall. Sediment bound phosphorus washed into the bay from the watershed could be an explanation for this increase. In a normal year, the Back Bay watershed receives the greatest monthly rainfall in July and August (29.5 cm of an annual average of 113.5 cm). Most of the agricultural fertilizers used in the watershed are applied during the spring and have not been completely assimilated by agricultural crops by summer (personal communication, Louis Cullipher). Therefore, the sediment bound agricultural phosphorus is available for rainfall erosion into the bay.

**Orthophosphate** - Orthophosphate is the simplest form of phosphorus in water and may be considered as ionization products of orthophosphoric acid. Orthophosphate is essential for energy transfer and other functions within the cell. It is an inorganic form of phosphorus and is soluble, thus making it readily available for plant utilization. As such, it is cycled very rapidly in the zones of utilization.

In natural, unpolluted waters orthophosphate is present in very minute quantities, usually ranging between 0.05 and 0.2 mg/l but seldom exceeding 0.1 mg/l even in highly eutrophic waters (Boyd, 1979). In fertilized fish ponds, orthophosphate averaged 0.2 mg/l (Boyd, 1976). Rulifson (1990) reported that orthophosphate averaged 0.05 to 0.08 mg/l in the lower Roanoke River. The EPA reference level is 0.1 mg/l.

The annual mean for orthophosphate in Back Bay during this study ranged from 0.04 mg/l in 1988 to 0.07 mg/l in 1989 (Figure 6). This concentration was within expected values (Boyd, 1979) and below the EPA reference level. Therefore, orthophosphate level was not excessively high during this study period.

There does not appear to be a distinct seasonal pattern in the orthophosphate concentration in Back Bay, except that it was generally higher during the latter half of each year (Figure 7). At least two factors could have contributed to the relatively high concentration during the summer. First, summer is the major period of algal growth in Back Bay (Marshall, 1988). Since orthophosphate and organic esters constitute the majority of the phosphorus released into the water during active algal growth, one would expect the level of these forms of phosphorus to be higher during the summer. The second plausible explanation
for the higher level in the summer is sediment bound ortho phosphate washed into the bay by rainfall.

The relatively low level of orthophosphate during the late winter-early spring is puzzling. This ion is very readily trapped in the sediment of aquatic systems by flocculation with positively charged soil particles. It is then released back into the water when the sediment is brought back into suspension. Since the wind intensity at Back Bay is greatest from December through April, one would expect the level to be seasonally high during this period. However, the reverse was true for Back Bay.

Orthophosphate constitutes a very small portion (considerably less than 5%) of the total phosphorus in natural waters (Wetzel, 1983). However, it constituted about 50% of the total phosphorus in Back Bay. The explanation for this could be a high level of non-point pollution, which is the primary source of orthophosphate in aquatic systems.

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Total Kjeldahl Nitrogen - Total Kjeldahl Nitrogen (TKN) includes ammonia and organic (amino acids, polypeptides, urea, uric acid, etc.) nitrogen.

According to Boyd (1979), the concentration of TKN is usually well below 1.0 mg/1 in unpolluted waters. Rulifson (1990) reported values ranging from 0.34 to 0.45 mg/1 in the lower Roanoke River. The EPA reference level for TKN is 0.9 mg/1.

Annual TKN means during this study were: 2.5 mg/1, 1986; 2.2 mg/1, 1987 and 1989; and 1.8 mg/1, 1988 (Figure 8). Individual station readings were as high as 3.8 mg/1 (Station 3; August, 1986). These values were high relative to the literature cited. Since the ammonia nitrogen was not high in Back Bay, the explanation for the high TKN is the organic fraction. A lot of detritus is washed into Back Bay, where it sits for an extended period due to the slow flushing rate (1.51 years according to Mann, 1984). Much organic nitrogen is found in the sediment which is frequently re-suspended by wave activity.

Generally TKN was highest during the fall and winter (Figure 9). The most plausible explanation for this is re-suspension of organic nitrogen in the sediment by wave action during this windy season. However, it is very difficult to explain seasonal changes in nitrogen since the proportions of the various forms are likely to vary in association with seasonal fluctuations in the populations of several types of bacteria, with variations in oxygen content and temperature, and with changing populations of plants and animals. The nitrogen cycle is a very complex and inconstant one. Without a totally ecological study, one can only speculate about the cause and effect relationships.

Nitrate as Nitrogen - Nitrate is normally the most common form of inorganic nitrogen in lakes and streams. The concentration and rate of supply of nitrate is intimately connected with land use practices within the watershed. Nitrate ions move easily through soils and are rapidly lost from the land even in natural drainage systems.

Concentrations of nitrate range from undetectable levels to nearly 10 mg/1 in unpolluted fresh waters, but are highly variable seasonally and spatially (Wetzel, 1983). Reid (1961) stated that the world average nitrate level was 0.3 mg/1. Boyd (1979) compared nitrate concentrations in unfertilized woodland ponds with fed catfish ponds; nitrate averaged 0.075 mg/1 in the former and 0.25 mg/1 in the latter. Rulifson (1990) reported that nitrate in the lower Roanoke River averaged 0.17 mg/1. The EPA reference level for nitrate is 0.9 mg/1.

The annual mean concentrations of nitrate were: 0.06 mg/1 1986; 0.11 mg/1, 1987; 0.05 mg/1, 1988; and 0.10 mg/1, 1989 (Figure 10). These values indicate relatively unpolluted water and fall well below the EPA reference level.

The mean nitrate level for most months of this 45-month study was 0.05 mg/1 (Figure 11). There were district peaks in late winter-early spring of 1987 and 1989 and again in December, 1989. These peaks were probably caused by decrease in primary production during periods of cold water temperature and high turbidity. Since nitrate is rapidly taken up by aquatic plants (after conversion to ammonia), the increased phytoplankton activity during the warmer months would account for the lower level during these periods.

Nitrite as Nitrogen - Nitrite is the partially reduced form of nitrate. In unpolluted oxygenated waters, it is present in only trace amounts. Wetzel (1975) stated that the concentration in natural waters ranged from undetectable levels to 0.01 mg/1. The nitrite level increases in waters receiving contamination from organic matter. Heavily polluted streams can contain up to 2 mg/1 nitrite. Nitrite accumulates in the bottom sediments, especially under cold temperature and anoxic conditions. Levels as high as 1.0 mg/1 were found in the interstitial waters of deep sediments of Lake Mendota (Konrad, et al. 1970). Rulison (1990) reported that nitrite in the lower Roanoke River averaged 0.007 mg/1. The EPA reference level for nitrite is 0.9 mg/1.

The annual means for nitrite in Back Bay varied only from 0.01 to 0.02 mg/1 (Figure 12). Many of the individual station readings were below the minimum detectable level (0.01 mg/1). The highest reading was 0.5 mg/1, which was found at stations 5 and 9 in March, 1987. This relatively high concentration could be due to sewage discharge. Station 9 is in North Bay near the
mouth of Hell Point Creek, which has received considerable organic pollution in the past. Station 5 is immediately downstream of a large campground and housing development which depend on septic tanks for sewage disposal. Although the nitrate annual means are well below the EPA reference level, there is reason for concern since the individual readings routinely exceeded the maximum for the "normal" range.

Nitrate levels were generally higher during the fall and winter (Figure 13). Explanations for this could be reduced phytoplankton uptake and re-suspension of nitrite bound sediment. A third factor could be ground water inflow. Evapotranspiration in the Back Bay area is so great in the summer months that there is essentially no ground water discharge (Mann, 1984). Rather, ground water discharge commences in the fall as the temperature decreases. This discharge continues to the following summer. Nitrite is readily transported with ground water and released in lakes or streams. Therefore, one would expect the level to increase with ground-water discharge.

Total Ammonia - Ammonia is present in aquatic systems primarily as the dissociated ammonium ion. It is very rapidly taken up by phytoplankton and other aquatic plants and persists in small quantities because it is the major excretory product of aquatic animals.

The concentration of ammonia in unpolluted, surface waters is usually less than 1.0 mg/1. With reduced oxygen due to organic pollution, the level of ammonia will increase. In extreme cases the concentration can increase to 12 mg/1. Boyd (1979) found ammonia levels of 0.052 mg/1 in unfertilized woodland ponds and 0.5 mg/1 in fed catfish ponds. Ammonia in the lower Roanoke River averaged 0.1 mg/1 (Rulifson, 1990). The EPA reference level for ammonia is 0.89 mg/1.

The annual mean concentration of ammonia ranged from 0.1 to 0.3 mg/1 (Figure 14). Although these values are considerably below the EPA reference level and fall within the expected range, there is cause for concern. Stations 5 and 9 generally had the higher ammonia levels, reaching 0.8 mg/1. This indicates some organic pollution from those watersheds, as was noted for nitrite. Also, the concentration for several months exceeded the VWCB standard (0.02 mg/1) for Class II B waters.

The ratio of nitrate to ammonia is also of concern. In unpolluted, calcareous sedimentary land forms, the ratio is generally 25:1 (Wetzel, 1983). With slight to moderate sewage contamination or agricultural application of nitrogen fertilizer influence in a water, the nitrate to ammonia ratio can be 1:10. The ratios for Back Bay from 1986-89 ranged 1:1 to 1:3. These ratios indicate some organic pollution in the bay.

Ammonia was highest each year during the winter and generally the lowest during the spring and summer (Figure 15). This seasonal trend with peak levels during the cold months was unexpected. Normally ammonia is higher in the summer than in the winter. Since ammonia is an end product of the bacterial decomposition of organic matter and an excretory product of aquatic animals, the concentration is generally higher during the warmer months as these activities are going on at an accelerated pace. However, the reverse was observed during this study period. A plausible explanation for the considerably higher ammonia concentration during the winter could be declined phytoplankton abundance, which allowed the ammonia to increase both through bacterial decomposition of the algal cells and reduced plankton assimilation.

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Figure 1. Map of Back Bay showing the location of nutrient sampling stations, April, 1986 - December, 1989.
Figure 2. Annual mean concentration (mg/I) of total suspended solids in Back Bay, 1986-1989.

Figure 3. Monthly mean concentration (mg/I) of total suspended solids in Back Bay, 1986-1989.
Figure 4. Annual mean concentration (mg/l) of total phosphorus in Back Bay, 1986-1989.

Figure 5. Monthly mean concentration (mg/l) of total phosphorus in Back Bay, 1986-1989.
Figure 6. Annual mean concentration (mg/l) of total ortho phosphorus in Back Bay, 1986-1989.

Figure 7. Monthly mean concentration (mg/l) of total ortho phosphorus in Back Bay, 1986-1989.
Figure 8. Annual mean concentration (mg/l) of total Kjeldalh nitrogen in Back Bay, 1986-1989.

Figure 9. Monthly mean concentration (mg/l) of total Kjeldalh nitrogen in Back Bay, 1986-1989.
Figure 10. Annual mean concentration (mg/l) of total nitrate nitrogen in Back Bay, 1986-1989.

Figure 11. Monthly mean concentration (mg/l) of total nitrate nitrogen in Back Bay, 1986-1989.
Nitrite nitrogen (mg/l)

Figure 12. Annual mean concentration (mg/l) of total nitrite nitrogen in Back Bay, 1986-1989.

Mean nitrite concentration (mg/l) in Back Bay, VA

Figure 13. Monthly mean concentration (mg/l) of total nitrite nitrogen in Back Bay, 1986-1989.
Figure 14. Annual mean concentration (mg/l) of total ammonia nitrogen in Back Bay, 1986-1989.

Figure 15. Monthly mean concentration (mg/l) of total ammonia nitrogen in Back Bay, 1986-1989.