United States Geological Survey

Fact Sheet FS-241-96

National Water-Quality Assessment Program (NAWQA)

Nitrate-Nitrogen Concentrations in Shallow Ground Water of the Coastal Plain of the Albemarle-Pamlico Drainage Study Unit, North Carolina and Virginia

by Timothy B. Spruill, Jo Leslie Eimers, (U.S. Geological Survey) and A.Elizabeth Morey (North Carolina Division of Water Quality)

Introduction

The Albemarle-Pamlico Drainage Study Unit is one of 20 National Water-Quality Assessment (NAWQA) studies begun in 1991 by the U.S. Geological Survey (USGS) to assess the Nation's water quality. This report presents findings on nitrate and related constituents from studies conducted between 1991 and 1995 by the USGS's Albemarle-Pamlico NAWQA and the North Carolina Division of Water Quality (NCDWQ). The purpose of this Fact Sheet is to show the distribution of nitrate-nitrogen concentrations in shallow ground water of the Coastal Plain and present some factors which may affect its occurrence.

Nitrate and Health Concerns

In 1945, H.H. Comly first reported that elevated concentrations of nitrate in rural ground-water supplies could cause oxygen stress or even death of infants (Comly, 1945). Nitrate ingested in baby formula mixed with well water can be converted by bacteria into nitrite in an infant's stomach. Because the nitrite actually changes hemoglobin, which normally carries oxygen in the bloodstream, into methemoglobin, which has no capacity to carry oxygen, oxygen distress or death can result (Metzler and Stoltenberg, 1950). This condition results in a bluish hue in an infant's skin which is called "blue-baby syndrome," infant cyanosis or, more specifically, methemoglobinemia. Because of this potential hazard of nitrate to the health of infants less than 1 year old, a public drinking-water standard, referred to as the maximum contaminant level (MCL), of 10 milligrams per liter (mg/L) for nitrate-nitrogen has been adopted by the U.S. Environmental Protection Agency (1994) for the protection of public drinking-water supplies. This standard has remained virtually unchanged since it was first established by the U.S. Public Health Service in 1962 (U.S. Public Health Service, 1962). Elevated nitrate concentrations in rural ground water also have been associated with the occurrence of non-Hodgkin's lymphoma (Weisenburger, 1990).

Nitrate can occur in ground water from a variety of nitrogen sources. Nitrogen inputs into the Albemarle-Pamlico Drainage Basin were grouped by McMahon and Lloyd (1995) into five general categories– precipitation, point-source discharges, crop-fixed nitrogen, commercial fertilizer, and animal wastes. Nitrate, the common water-soluble oxidized form of nitrogen from these sources, can enter ground water as a point (localized) source, such as leakage from a tank or pipe, or as a non-point (dispersed) source such as from areally applied fertilizer, biological fixation, animal waste, and precipitation.

In general, nitrate concentrations are highest in ground water nearest the land surface when nitrogen sources are present (Hallberg and Keeney, 1993). Ground water from shallow wells (less than 100 feet deep) in the Coastal Plain of the Albemarle-Pamlico Study Unit had higher nitrate concentrations and greater variability than wells deeper than 100 feet (Harned and others, 1995), indicating the presence of sources of nitrate.

Nitrate-nitrogen concentrations in shallow ground water in the Coastal Plain of the Albemarle-Pamlico Study Unit are shown in figure 1 for 71 wells sampled between 1993 and 1995. The nitrate samples for 50 of these wells were collected by the U.S. Geological Survey as part of the NAWQA Program. Nitrate samples from 21 wells were sampled by the NCDWQ Groundwater Section.

Significant Findings

- Nitrate-nitrogen concentrations in shallow ground water under the well-drained soils of the inner Coastal Plain indicate contamination from agriculture.
- Nitrate-nitrogen concentrations in shallow ground water of the inner Coastal Plain are significantly higher than nitrate-nitrogen concentrations in the outer Coastal Plain.
- Low nitrate-nitrogen concentrations in shallow ground water of the outer Coastal Plain are probably a result of nitrate reduction processes in the aquifer, as indicated by high ammonia and dissolved organic carbon concentrations.

Shallow Aquifers and Soils of the Coastal Plain

Aquifers are saturated rocks or sediments that transmit usable quantities of water. Aquifers in the Coastal Plain of the Albemarle-Pamlico Drainage study unit are composed of unconsolidated sand, silt, and clay and consolidated to partly consolidated limestone, sandstone, and shell beds. Principal aquifers in the Study Unit and their lithology are shown in table 1. The shallowest aquifers in North Carolina and Virginia are typically composed of Pleistocene sediments and are collectively called the surficial aquifer in North Carolina and the Columbia aquifer in Virginia (table 1). The base of the surficial aquifer is the Yorktown confining unit, and it is present throughout most of the Coastal Plain in the Albemarle-Pamlico Study Unit. The Yorktown aquifer is confined by the Yorktown confining unit.

Aquifers of the Coastal Plain are overlain by a variety of soil types (fig. 1). The soils of the Coastal Plain vary in permeability characteristics (the ability to transmit water), and these variations can affect relative amounts of ground-water or surface-water contamination that may occur. In general, well drained soils overlay the Cretaceous sands near the western edge of the inner Coastal Plain. Moderately well-drained soils are dispersed throughout most of the remainder of the inner Coastal Plain. The outer Coastal Plain mainly contains poorly drained soils with large amounts of organic material. The inner Coastal Plain has more than 45 percent well-drained and moderately well-drained soils compared to less than 17 percent in the outer Coastal Plain. It is in the areas of well drained and moderately drained soils that shallow aquifers are most susceptible to contamination from nitrate.

Nitrate Concentrations and Dissolved Organic Carbon

The presence of organic carbon in ground water in low-oxygen environments appears to be a major factor governing the presence or absence of nitrate. Based on data collected by the Albemarle-Pamlico Drainage NAWQA in 1994 and 1995 (Smith and others, 1996), nitrate-nitrogen concentrations are limited by concentrations of dissolved organic carbon (DOC) in ground water, as shown in figure 2. When an electron donor, such as organic carbon, is present in a low-oxygen environment, bacteria may use it to reduce nitrate dramatically and convert it to nitrogen gas, nitrogen oxides, or ammonia (Korom, 1992). Therefore, ground water with high DOC tends to have low nitrate concentrations.

Based on the data presented for the Albemarle-Pamlico Drainage NAWQA, water in shallow aquifers having more than 2-3 mg/L of DOC did not have more than 2 mg/L of nitrate-nitrogen (fig. 2). Conversely, where there is a source of nitrate, such as fertilizer or manure in areas with low (<(less than) 3 mg/L) DOC concentrations, high nitrate-nitrogen concentrations (>(greater than) 3 mg/L) occurred in the ground water. Figure 2 shows the maximum observed nitrate-nitrogen concentrations for the observed range of DOC concentrations. Generally, the shaded boundary shown in figure 2 indicates the maximum expected nitrate-nitrogen concentrations for various DOC concentrations in shallow ground water of the Coastal Plain.

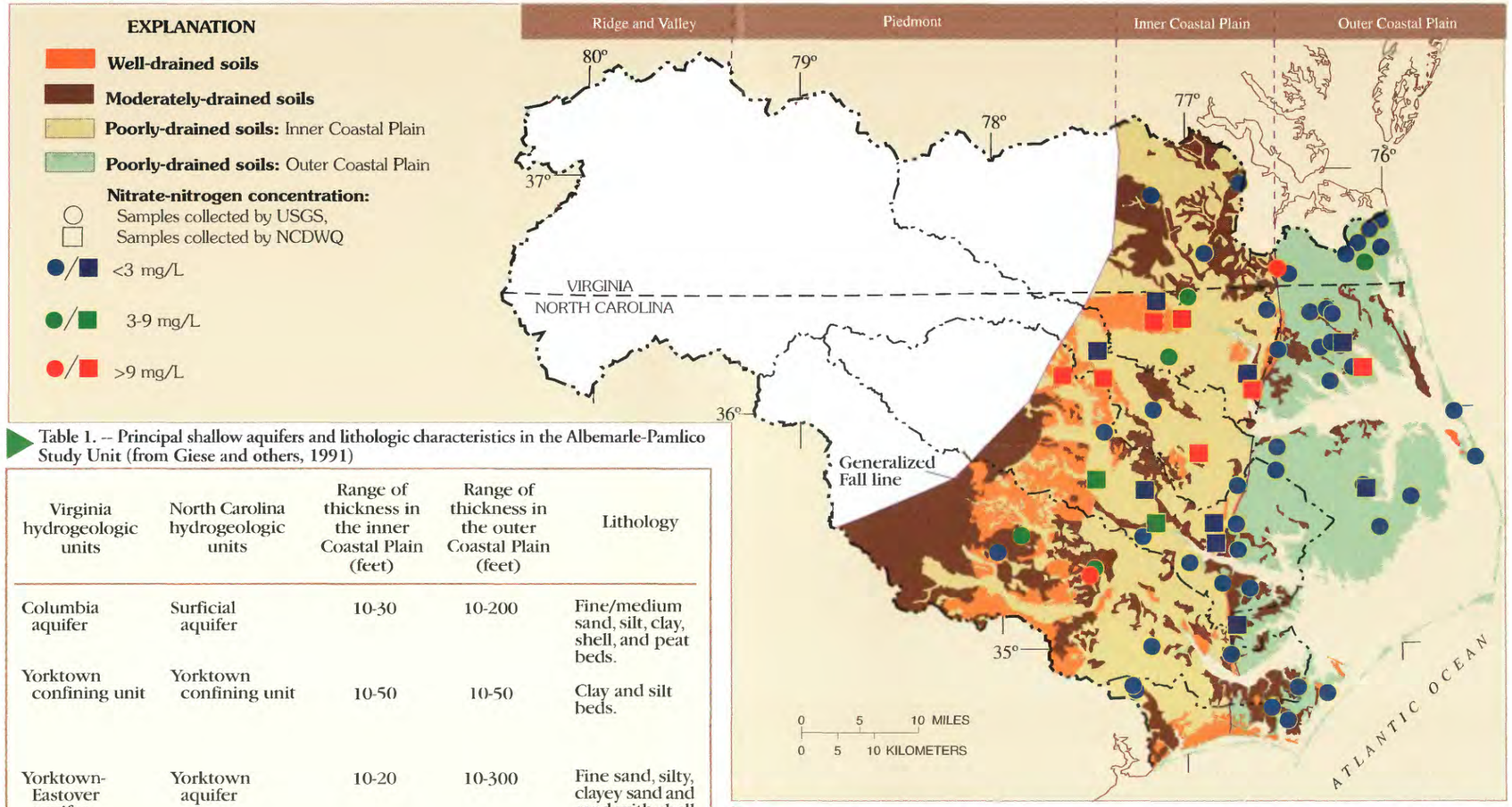

Figure 1. –Distribution of nitrate-nitrogen concentrations in shallow ground water of the Coastal Plain of the Albemarle-Pamlico Drainage Study Unit.

Table 1. -- Principal shallow aquifers and lithologic characteristics in the Albemarle-Pamlico Study Unit (from Giese and others, 1991)

Virginia hydrogeologic units	North Carolina hydrogeologic units	Range of thickness in the inner Coastal Plain (feet)	Range of thickness in the outer Coastal Plain (feet)	Lithology
Columbia aquifer	Surficial aquifer	10-30	10-200	Fine/medium sand, silt, clay, shell, and peat beds.
Yorktown confining unit	Yorktown confining unit	10-50	10-50	Clay and silt beds.
Yorktown-Eastover aquifer	Yorktown aquifer	10-20	10-300	Fine sand, silty, clayey sand and sand with shell beds.

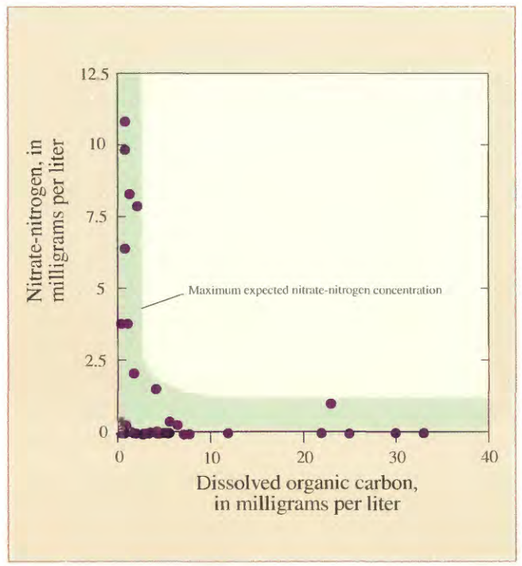

Figure 2. –Dissolved nitrate-nitrogen and dissolved organic carbon in shallow aquifers of the Coastal Plain.

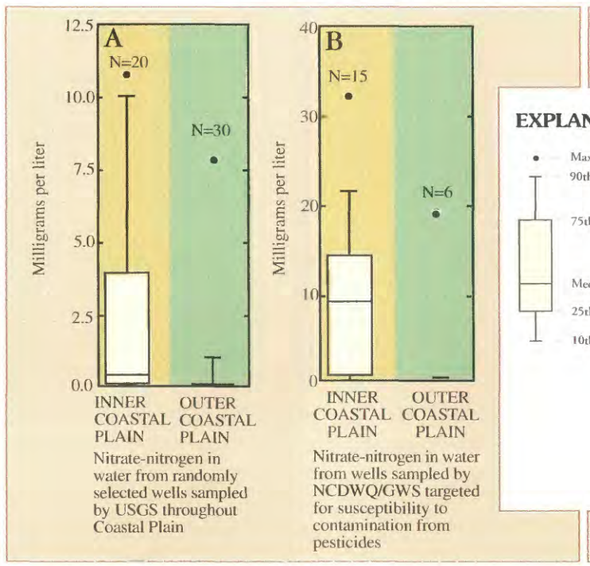

Figure 3. –Comparison of nitrate-nitrogen concentrations between inner and outer Coastal Plain using random and targeted sampling approaches.

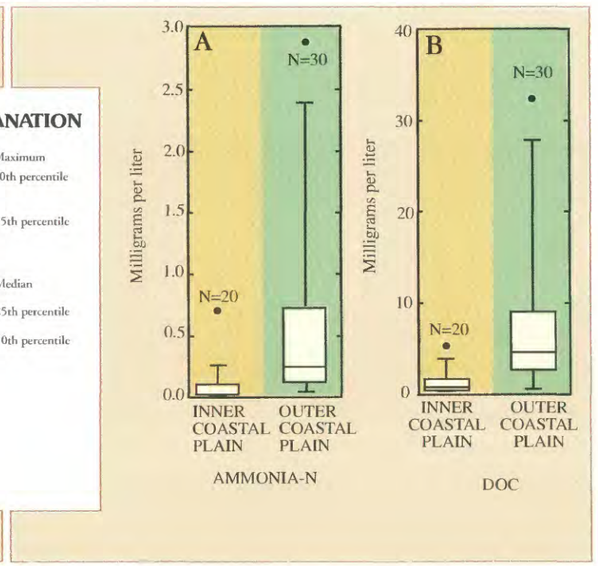

Figure 4. –Dissolved organic carbon (DOC) and ammonia-nitrogen concentrations in shallow ground water of the inner and outer Coastal Plain.

Nitrate-Nitrogen Distribution in Shallow Ground Water of the Coastal Plain

The distribution of nitrate concentrations in shallow ground water of the Coastal Plain indicates that highest concentrations occur in areas having the most well-drained soils (fig. 1). Typically, highest nitrate concentrations (shown in red) occur in the inner Coastal Plain and lowest concentrations (shown in blue) occur in poorly drained soils of the outer Coastal Plain. Based on a random sampling of wells throughout the Coastal Plain by the U.S. Geological Survey (Spruill and others, 1995), ground water in shallow aquifers of the inner Coastal Plain has a median nitrate-nitrogen concentration of about 0.4 mg/L (fig. 3A). Ten percent (2 wells) of 20 wells sampled in the inner Coastal Plain exceeded the MCL of 10 mg/L (U.S. Environmental Protection Agency, 1994). The maximum nitrate-nitrogen concentration detected in these 20 wells was 11 mg/L .

Ground water from wells sampled by NCDWQ in areas identified as most susceptible to ground-water contamination by selected pesticides had the highest observed nitrate concentrations (median nitrate-nitrogen of about 9 mg/L, fig. 3B). Concentrations greater than 3 mg/L are usually associated with anthropogenic sources (Madison and Brunett, 1985). About 40 percent of 15 wells sampled in the inner Coastal Plain of the Albemarle-Pamlico Drainage produced water which exceeded the 10 mg/L MCL. Because the sandy deposits that compose these soils have little or no capacity to slow infiltration or sorb contaminants from contaminated recharge water, ground water in these areas also is likely to contain other agricultural chemicals, such as pesticides or their breakdown products, which could pose environmental or public health hazards.

Based on Albemarle-Pamlico NAWQA data (Smith and others, 1996), nitrate-nitrogen is nearly undetectable (median = 0.05 mg/L) in ground water underlying the poorly drained soils of the outer Coastal Plain (fig. 3A) even though fertilizer application rates (> 100 pounds per acre) are similar to those in other areas where corn is grown. Nitrate-nitrogen concentrations in ground water from wells in susceptible areas of the outer Coastal Plain are also low (median = 0.2 mg/L), although only six wells in the outer Coastal Plain were included in the Albemarle-Pamlico Drainage (fig. 3 B). Ground water in the outer Coastal Plain contains more abundant carbon than in the inner Coastal Plain. Abundant carbon allows extensive denitrification or, more probably dissimilatory nitrate reduction to ammonium (Korom, 1992), to occur in the aquifer, resulting in significantly higher concentrations of ammonium in ground water of the outer Coastal Plain (fig. 4).

Conclusions

Data collected by the NAWQA Program and the NCDWQ indicate that shallow aquifers of the inner Coastal Plain are most susceptible to contamination in areas of well-drained soils. Based on the NAWQA random well sample, nitrate-nitrogen concentrations in the inner Coastal Plain are higher (median = 0.4 mg/L) than concentrations in the outer Coastal Plain (median = 0.05 mg/L). Concentrations of nitrate-nitrogen in the inner Coastal Plain, particularly in areas of well-drained soils, show that ground water concentrations can exceed the 10 mg/L MCL. Low nitrate-nitrogen concentrations of the outer Coastal Plain are coincident with high ammonium and high dissolved organic carbon. Nitrate-nitrogen concentrations in ground water are generally less than 2 mg/L where dissolved organic carbon concentrations exceed 2-3 mg/L.

The median concentration of nitrate nitrogen in ground water from wells in areas identified as being susceptible to contamination from pesticides in the inner Coastal Plain, which were sampled by NCDWQ, had a median nitrate-nitrogen concentration of about 9 mg/L, significantly higher than that from the NAWQA wells. Nitrate-nitrogen concentrations were also much lower (median = 0.2 mg/L) in areas of poorly to moderately drained soils of the outer Coastal Plain. Ground water beneath sandy, well-drained soils, within the Albemarle-Pamlico Drainage and particularly near the Fall Line when nitrogen sources at the land surface are present, had generally higher nitrate-nitrogen concentrations than beneath moderately or poorly drained soils.

Both NAWQA and NCDWQ ground-water data indicate that nitrate-nitrogen concentrations are more likely to occur above the 10 mg/L MCL in shallow aquifers beneath sandy soils where nitrogen sources are present than beneath moderately or poorly drained soils. These concentrations pose possible health and environmental problems. Management options include restriction of farming practices in areas of sandy soils to protect ground water from additional contamination. In addition, where such areas are contaminated, residents in these areas could be made aware of potential health hazards to infants associated with nitrate in ground water and be encouraged to use deeper water-supply wells or bottled water. Use of vegetative buffers to protect surface water from nitrate-contaminated baseflow or carbon supplements to artificially reduce nitrate in nitrate-contaminated ground water are possible areas of further research.

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For additional information, contact the following:

U.S. Department of the Interior
U.S. Geological Survey
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For Albemarle-Pamlico NAWQA
Chief, Albemarle-Pamlico NAWQA
U.S. Geological Survey
3916 Sunset Ridge Road
Raleigh, NC 27607

For National NAWQA
Deputy Assistant Chief Hydrologist
National Water-Quality Assessment Program.
U.S. Geological Survey, National Center, MS 413
Reston, VA 22092.
Phone 703-648-5716

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J. Gass, Illustrator