Ground-Water Discharge and Nitrate Loadings to the Coastal Bays of Maryland

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In cooperation with the
U.S. Environmental Protection Agency
and the
Maryland Department of Natural Resources
Maryland Coastal Bays Program

Location of Delmarva Peninsula and the coastal bays of Maryland in Worcester County, Maryland.

Abstract

Nitrate in ground water discharged to the Atlantic coastal bays of Maryland enhances the growth of phytoplankton and algae in the bays, which in turn contributes to the process of eutrophication (changes in a body of water as nutrients and sediments accumulate), which is one of the principal environmental problems in the bays. Information on nitrate loading to the bays has been identified as a major data gap by State and Federal resource managers. This report presents results of a study to estimate ground-water discharge and potential nitrate loads to the coastal bays of Maryland, which include Chincoteague, Newport, Sinepuxent, Isle of Wight, and Assawoman Bays.

The nitrate load from the discharge of ground water to the coastal bays is dependent on the concentration of nitrate in the water and the volume of ground water being discharged. Data from 388 wells completed in the surficial aquifer that discharges to the bays were used to construct a map of the distribution of nitrate concentration in the ground water. On the basis of those data, and on several simplifying assumptions, the potential nitrate load to the coastal bays from direct discharge of ground water was estimated to be 272,000 pounds per year, distributed throughout the 108-square-mile surface area of the bays.

Nitrate from ground water can also enter the coastal bays by way of base flow to streams that discharge to the bays. The potential nitrate load to the bays from the base flow of streams was estimated to be 862,000 pounds per year, assuming that the concentration of nitrate in stream base flow is 3.2 milligrams per liter, which is the median concentration of nitrate in ground water in the study area.

Introduction

Nitrogen is an essential nutrient for plant growth. An abundant supply of nitrogen from sources such as agriculture, urban development, atmospheric deposition, and point-source discharges, however, results in excessive amounts of nitrogen in Maryland's coastal bays. Excessive amounts of nitrogen can lead to significantly increased growth of phytoplankton and epiphytic algae in the bays, which can harm the bays' ecosystems directly, by blocking sunlight to seagrasses, and indirectly, by removing dissolved oxygen from the water when dead phytoplankton and algae decompose. These effects are part of the process of eutrophication, currently one of the coastal bays' most important environmental problems (Maryland Coastal Bays Program, 1997).

Nitrogen is usually found in ground water in the form of nitrate-nitrogen, referred to as nitrate throughout this report. The amount of nitrate discharged from ground water to the coastal bays over time, referred to as the nitrate load, is unknown. This lack of data has been identified by State and Federal resource managers as a significant data gap that warrants immediate attention. Knowledge of the relative importance of ground-water sources of nitrate in comparison to other sources, as well as the spatial distribution of the nitrate load from ground water into the coastal bays, is needed to target areas for monitoring and for nitrate management.

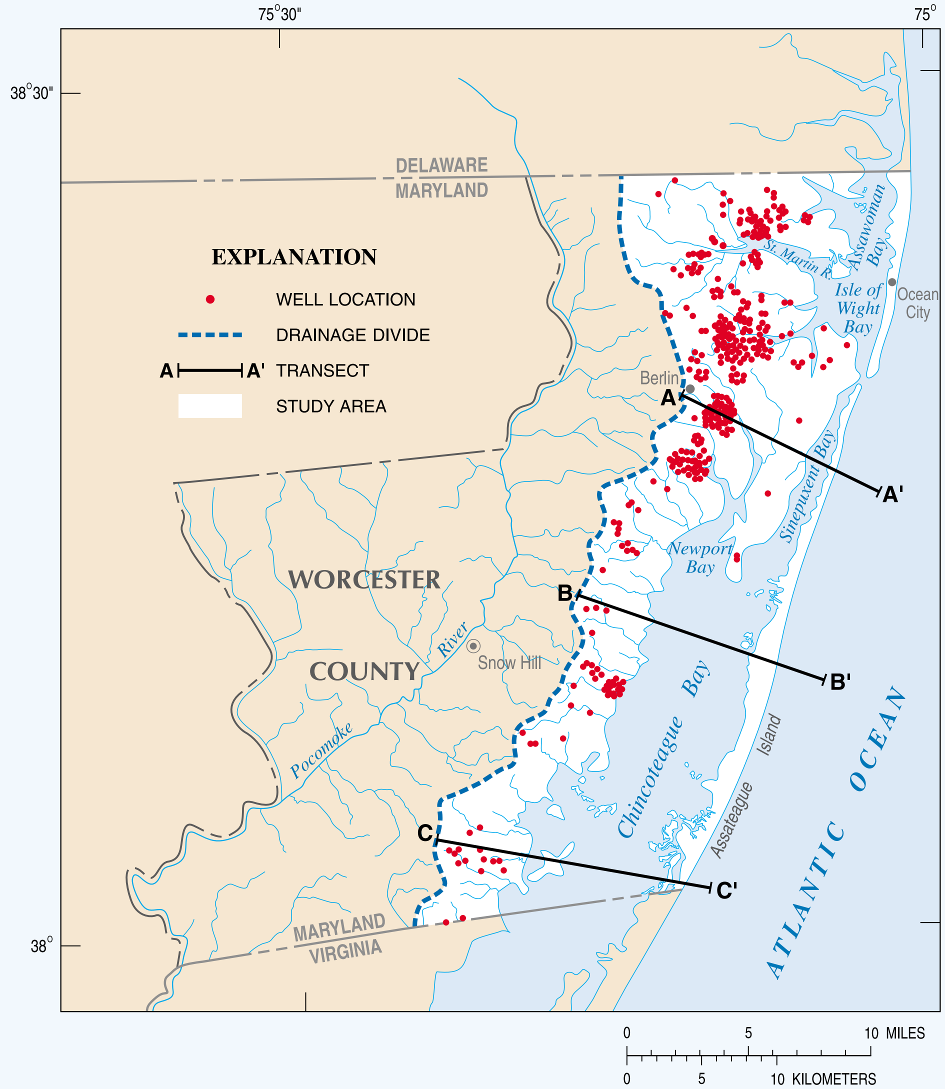

Figure 1. Location of wells, transects, and drainage divide in the study area.

Purpose and Scope

This report describes the results of a study performed by the U.S. Geological Survey in cooperation with the U.S. Environmental Protection Agency and the Maryland Department of Natural Resources Maryland Coastal Bays Program to estimate total ground-water discharge and potential nitrate loads from stream base flow and direct discharge to estuaries within Maryland's coastal bays. The study area consists of Assawoman, Isle of Wight, Sinepuxent, Newport, and Chincoteague Bays, and their combined surface-water drainage areas (fig. 1). A water-balance analysis was used to provide estimates of ground-water discharge to the coastal bays. Nitrate-load estimates resulting from direct ground-water discharge were determined by approximating the average ground-water nitrate concentration in the study area. These estimates can be used for planning purposes and the development of mechanisms for improvement of water quality in the coastal bays.

Several simplifying assumptions were made to estimate total ground-water discharge and potential nitrate loads to the coastal bays. The major assumption is that all ground water and nitrate discharged to the bays enters the ground-water-flow system within the surface-water drainage areas of the bays. A second assumption is that all significant ground-water contributions to nitrate loads in the bays are from the surficial aquifer, which ranges in depth from land surface to approximately 130 ft (feet) below mean sea level within the study area. A third assumption is that no denitrification takes place in the surficial aquifer. The final assumption is that no ground water discharges from the surficial aquifer directly to the Atlantic Ocean, although this assumption may not be valid in the vicinity of Sinepuxent Bay. The accuracy of the final assumption is dependent on the location of the subsurface freshwater-saltwater interface, which in part controls the location of ground-water discharge in a coastal environment. Because the location of the interface in the study area is currently unknown, the most conservative assumption of no ground-water discharge to the Atlantic Ocean was adopted.

Data obtained to physically define the study area include topography, surface-drainage features, subsurface geology and lithology, areal recharge, and nitrate concentrations. The nitrate concentrations used in this study were collected from 388 domestic wells in Worcester County, Maryland, between 1981 and 1997 (fig. 1).

Previous Investigations

Several investigations have documented elevated levels of nitrate in ground water throughout much of the Delmarva Peninsula (Bachman, 1984; Denver, 1986; Denver, 1989). In addition, these studies have shown that elevated concentrations of nitrate occur at depths in the surficial aquifer that range from near land surface to more than 90 ft below land surface. Although there are no previously published investigations of nitrate loads from ground-water discharge to Maryland's coastal bays, studies concerned with the estimation of direct ground-water discharge (Andres, 1987) and of nitrate loads (Andres, 1992) to Rehoboth and Indian River Bays in Delaware have been published. A discussion comparing the results of these two studies with those of the current study is included in a later section of this report.

Hydrologic Framework

The surficial aquifer is defined as the uppermost layer of geologic material not overlain by any relatively continuous, impermeable layer of geologic material. Within the study area, the surficial aquifer is known as the Columbia aquifer, and consists mainly of the Beaverdam Sand, the Omar Formation, the Ironshire Formation, and the Sinepuxent Formation, with the Beaverdam Sand being the largest component. Each unit represents material identified by time period and depositional environment. The physical arrange-

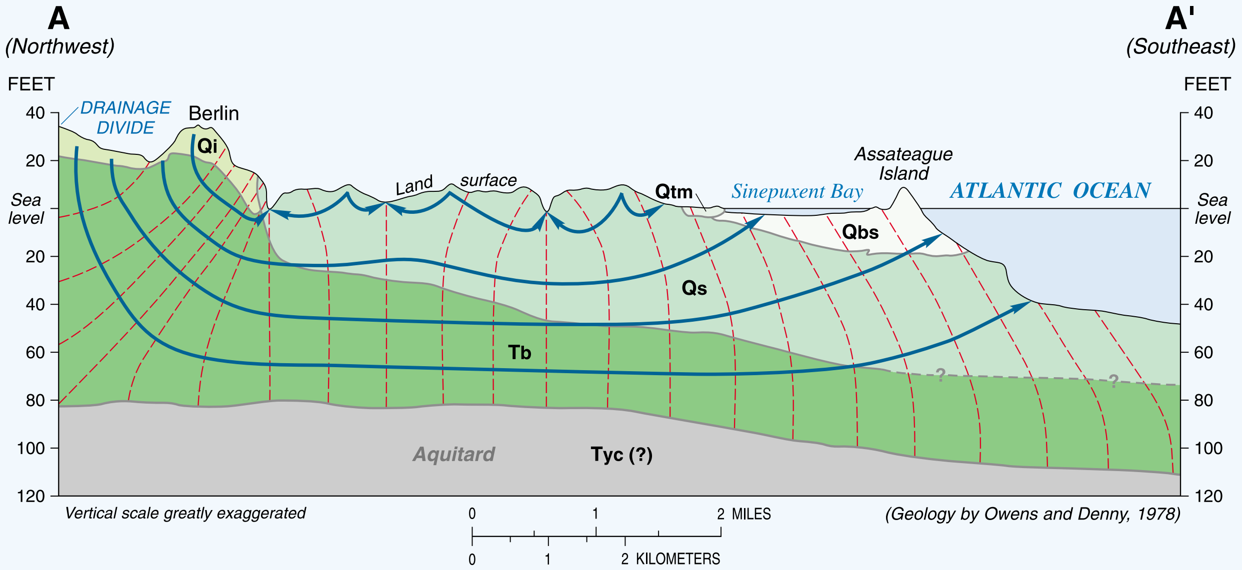

Figure 2a. Geologic units and flow net for transect A-A' on Figure 1.

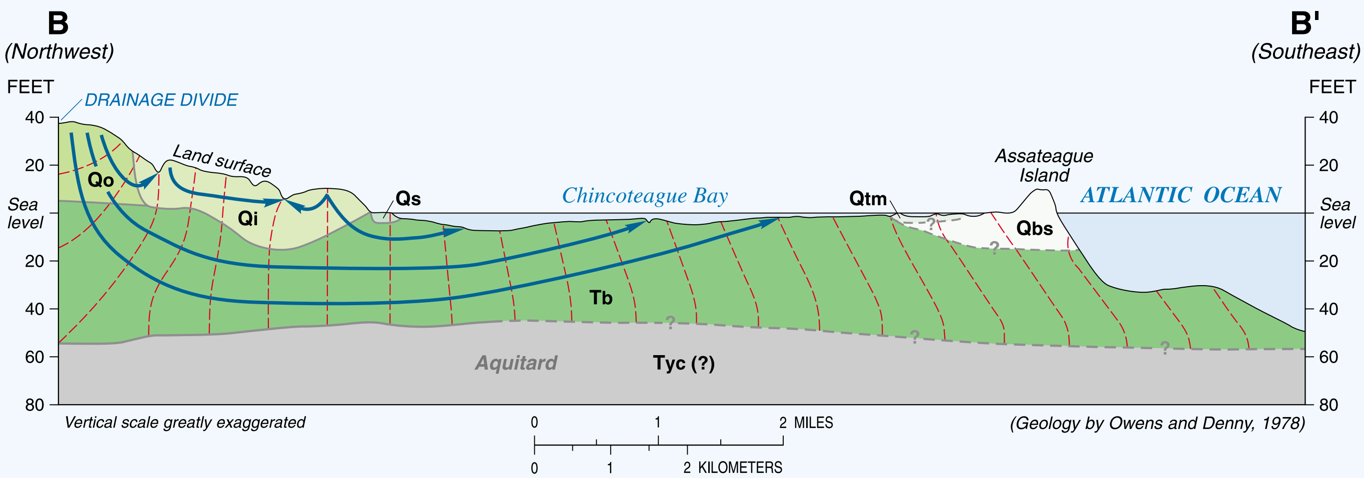

Figure 2b. Geologic units and flow net for transect B-B' on Figure 1.

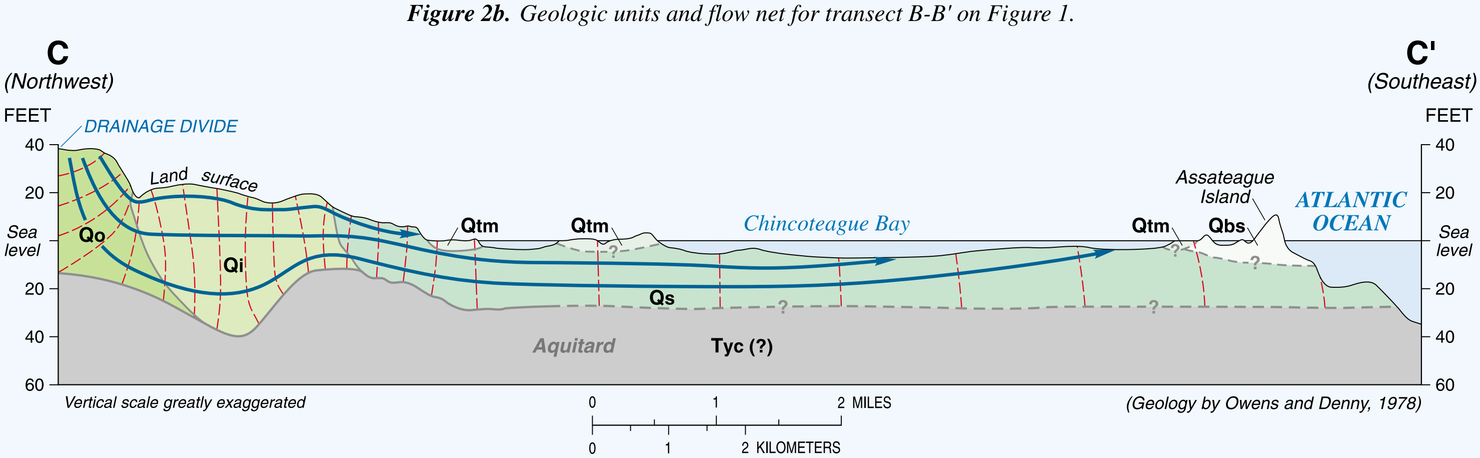

Figure 2c. Geologic units and flow net for transect C-C' on Figure 1.

EXPLANATION

GEOLOGIC UNITS

COLUMBIA AQUIFER:

- **Qtm** TIDAL MARSH
- **Qbs** BEACH SAND
- **Qs** SINEPUXENT FORMATION
- **Qi** IRONSHIRE FORMATION
- **Qo** OMAR FORMATION
- **Tb** BEAVERDAM SAND

AQUITARD:

- **Tyc (?)** YORKTOWN-COHANSEY FORMATION

EQUIPOTENTIAL LINE

GROUND-WATER FLOW LINE AND DIRECTION OF FLOW

GEOLOGIC CONTACT (Dashed and queried where inferred) ment of these units can be seen in figures 2a-2c, with a more complete discussion available in Owens and Denny (1979).

In contrast to an aquifer, which by definition can transmit significant quantities of water under ordinary hydraulic gradients, an aquitard is significantly less permeable and is not capable of transmitting significant quantities of water to a well (Freeze and Cherry, 1979). The lower limit of the surficial aquifer is defined by its contact with the upper aquitard of the Yorktown-Cohansey Formation (Owens and Denny, 1978). In this study, the aquitard is significant because it does not allow an appreciable amount of water to flow vertically into or out of the surficial aquifer.

The horizontal hydraulic conductivity of the Columbia aquifer near Ocean City, Maryland, ranges from 25 to 75 ft/d (feet per day) (Achmad and Wilson, 1993), whereas that reported for the upper part of the underlying Yorktown-Cohansey Formation aquitard ranges from 3.3 to 60.4 ft/d (Richardson, 1994). The vertical hydraulic conductivity of the Columbia aquifer is assumed to be within one to two orders of magnitude of its horizontal values. Though differences between the horizontal hydraulic conductivities of the Columbia aquifer and the underlying aquitard are not great, Richardson (1994) reports that the vertical hydraulic conductivity of the aquitard is more than five orders of magnitude less than the horizontal hydraulic conductivity of the overlying surficial aquifer. In theory, the low value of vertical hydraulic conductivity of the aquitard prevents most ground water recharged to the surficial aquifer from flowing into the aquitard. It should also eliminate any of the underlying hydrologic units as sources of significant amounts of water to the surficial aquifer. On the basis of these findings, it is assumed that all water recharged to the surficial aquifer discharges to the coastal bays, and does not flow to the underlying aquitard. Though this assumption may not be completely accurate, it is sufficiently accurate for the purposes of this study.

Water-table elevations in the surficial aquifer are generally considered to reflect the overlying topography, which is characterized as having a maximum elevation of approximately 40 ft near the Berlin scarp at the western boundary of the study area. Thus, the regional flow of ground water is assumed to progress from northwest to southeast— from the western flow boundary (drainage divide) down to the coastal bays and the Atlantic Ocean. In addition to the regional flow pattern, local patterns of ground-water flow are dictated by the surface drainage of the study area. All creeks and rivers in the study area are locations of ground-water discharge. This ground-water component of streamflow is referred to as base flow.

Isle of Wight Bay (left), Route 50 into Ocean City, Maryland, Ocean City Inlet, Assateague Island, and Sinepuxent Bay (right). (Photo courtesy of Andy Serrell, Aero Graphics)

Methods of Study

Estimates of ground-water discharge and nitrate loads were developed by compiling geologic and hydrologic data from existing maps, drillers' logs, and previous regional and local hydrologic studies. These data were used to characterize the hydrogeology of the watersheds of the coastal bays and to determine the boundaries of the ground-water-flow systems.

Estimation of Ground-Water Discharge

Direct ground-water discharge entering the coastal bays from the surficial aquifer was determined by calculating a water balance using available precipitation and evaporation data, by assuming that the water-table elevations are in a steady-state condition, and by using qualitative flow-net analysis concepts to determine generalized ground-water-flow paths. A flow net is a graphical solution of the two-dimensional ground-water-flow field. When constructed to extend through the thickness of the aquifer, it can be used to calculate volumetric flow rates, velocities, and hydraulic conductivity distribution (Domenico and Schwartz, 1990; Kresic, 1997). Qualitative flow-net analysis was used to distinguish areas within the study region contributing direct ground-water recharge to the coastal bays from those contributing ground water to stream base flow. Because a suitable water-table map of the study area was not available, all flow lines drawn in support of this effort were based on assumed water-table elevations.

Flow nets consist of flow lines and equipotential lines. As shown in figures 2a-2c, flow lines represent the paths of individual ground-water particles from points of entry into the ground-water system to points of discharge, such as streams and the coastal bays. Equipotential lines are lines along which hydraulic heads in the ground-water system are equal. Figures 2a-2c provide examples of qualitative flow nets constructed along three vertical sections in the study area.

In addition to the vertical flow nets shown in figures 2a-2c, flow lines were also drawn for the entire study area to show the two-dimensional, horizontal flow field. As in figures 2a-2c, some flow lines terminate at stream beds,

Figure 3. *Location of recharge areas associated with direct ground-water discharge.*

where ground water is discharged to streams, while other flow lines terminate at the bottom of the coastal bays, indicating direct discharge of ground water to the bays.

Estimation of Nitrate Loads

In order to estimate nitrate loads, it is necessary to estimate a spatially continuous distribution of nitrate concentrations in ground water within the drainage areas of the coastal bays. Kriging, which is a geostatistical method for spatial interpolation of data, was used to estimate the distribution of nitrate concentrations within the surficial aquifer. The kriging method used the nitrate-concentration point data measured between 1981 and 1997, and is based on the work of Journel and Huijbregts (1978), Clark (1979), and D'Agostino and others (1998).

The nitrate loads from ground water were then determined by combining the distribution of nitrate concentrations in ground water with the associated ground-water discharge rate for the study area.

Ground-Water Discharge

Calculation of the rate of ground-water discharge to the coastal bays is based on the assumption that there is no net change in the volume of ground-water storage in the coastal bays' drainage areas over time. This allows the rate of ground-water discharge into the coastal bays from the surficial aquifer to be equated to the average amount of water that recharges the aquifer per year. Total recharge to the aquifer is dependent on two factors—the amount of precipitation available for recharge, and the effective surface recharge area of the aquifer. In this application, the effective recharge area is defined as the area from which recharge to the aquifer is discharged directly to the coastal bays. Areas receiving recharge that is subsequently discharged as base flow to streams emptying into the coastal bays are not considered to be effective.

A review of the published literature addressing ground-water recharge in and near the study area showed estimates of ground-water recharge ranging from 8 to 16 in/yr (inches per year) (Andreasen and Smith, 1997; Cushing and others, 1973; Johnston, 1973; Johnston, 1977; U.S. Department of Agriculture, 1973). On the basis of this review, an average recharge rate of 12 in/yr was assumed to apply to the entire study area. Using flow-net analysis and the best available topographic and hydrographic data, the total effective recharge area of the surficial aquifer to the coastal bays was determined to be 20.28 mi^2 (square miles). As shown in figure 3, the effective recharge areas to the coastal bays consist of discontinuous zones interspersed within areas in which ground-water recharge is discharged to streams.

On the basis of the total size of the effective recharge area, direct discharge of ground water into the coastal bays is calculated to be approximately 11.6 Mgal/d (million gallons per day). By comparison, ground-water discharge to streams in the study area is estimated to be 88.6 Mgal/d, and originates from a total recharge area of 155 mi^2.

Nitrate Loads

The nitrate load from direct discharge of ground water to the coastal bays is the product of the concentration of nitrate in ground water discharged to the coastal bays and the volume of ground water discharged. The total volume of direct ground-water discharge into the coastal bays was estimated in the preceding section. Kriging of the domestic-well nitrate-concentration data provided by the Worcester County, Maryland, Health Department provided a ground-water nitrate-concentration distribution for the study area (fig. 4). As shown in figure 4, nitrate concentrations between 0 and 1 mg/L (milligrams per liter) are prevalent. In several areas, however, nitrate concentrations are higher.

The vertical distribution of nitrate

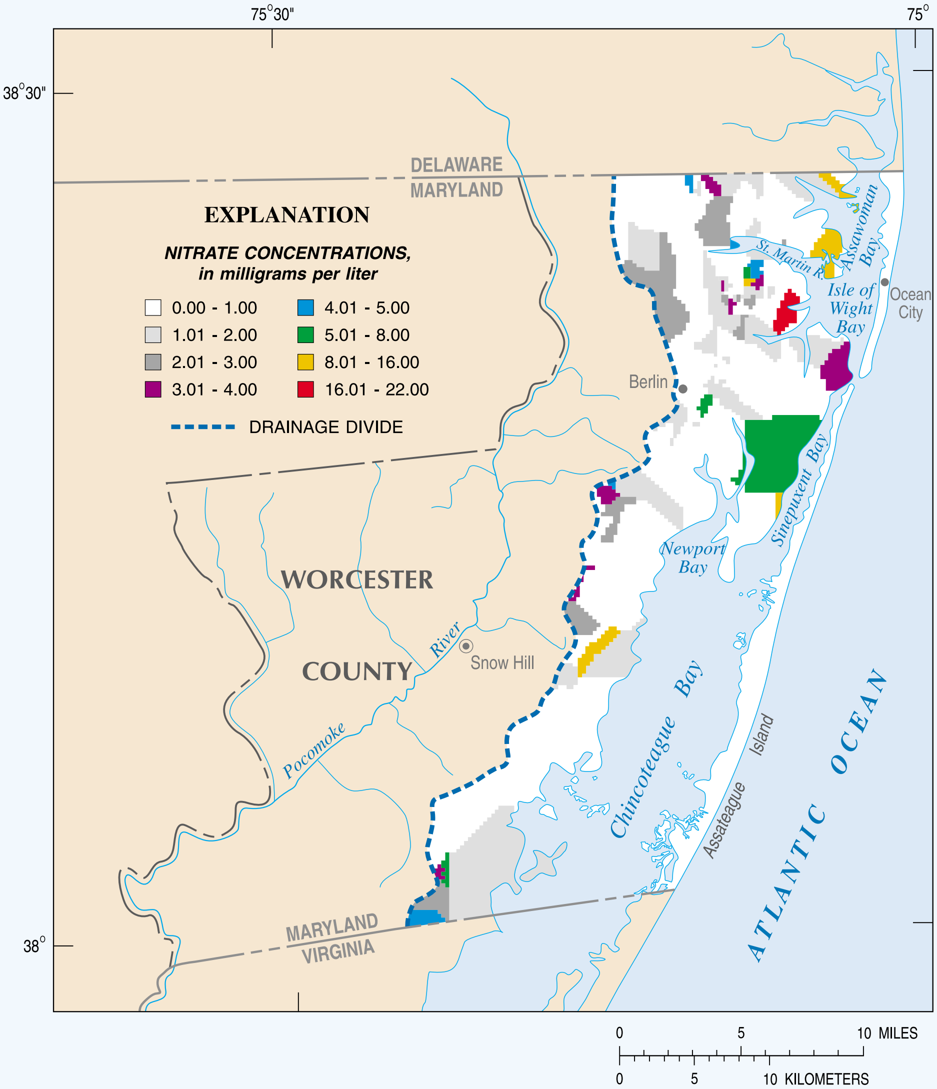

Figure 4. *Ground-water nitrate-concentration distribution in the surficial aquifer.*

concentrations indicated by the well data is shown in figure 5. It should be noted that some wells with elevated nitrate levels have probably not been completed as domestic wells, and thus are not included in the current data base. For the purposes of this study, comparison of the median nitrate-concentration data presented in figure 5 indicates no significant variation in nitrate concentration with depth within the study area.

The total nitrate load is calculated as the sum of the loads from each effective recharge area. The average-annual nitrate load for each effective recharge area is calculated by multiplying its average nitrate concentration by the total recharge to the area. This approach assumes that the characteristic nitrate concentration in ground water from each effective recharge area is determined as the recharged water percolates into the surficial aquifer, and is transported conservatively along a northwest-to-southeast flow path to the coastal bays. According to the assumptions used in this study, the potential nitrate load to the coastal bays from direct discharge of ground water is approximately 272,000 lbs/yr (pounds per year), distributed throughout the 108-mi^2 surface area of Maryland's coastal bays.

By comparison, applying the average recharge rate of 12 in/yr to the 155 mi^2 of the coastal bays' drainage area that does not contribute to direct ground-water discharge, and assuming that the nitrate concentration of the discharge is equal to 3.2 mg/L (the median concentration found in wells in the study area), the potential total nitrate load to the coastal bays from stream base flow is 862,000 lbs/yr, distributed over the 108-mi^2 area of Maryland's coastal bays.

Comparison With Results From Similar Studies

Because no investigations of nitrate loads in ground-water discharge to Maryland's coastal bays have been previously published, no direct comparisons with the results of any previous studies can be made. Studies concerned with the estimation of direct ground-water discharge (Andres, 1987) and the estimation of ground-water nitrate loads (Andres, 1992) to Rehoboth and Indian River Bays in Delaware, an area that is hydrologically similar to and geographically contiguous with the study area of this report, have been published. A comparison of the results of this study with those published for Rehoboth and Indian River Bays will provide some basis for judging the validity of the estimates of nitrate load from direct discharge of ground water to Maryland's coastal bays.

As in this study, the earlier investigations assumed that all ground-water discharge was to the coastal bays, and none to the Atlantic Ocean. All of the studies also assumed that all ground-water discharge to the bays comes from the Columbia aquifer. Also in each study, the nitrate concentrations were derived from nitrate-concentration data for wells in the Columbia aquifer, and are based on the assumption that no denitrification takes place to reduce the amount of nitrate in the ground water. The nitrate data used by Andres (1992) were collected between 1988 and 1990.

Andres (1987) assumes that an average-annual recharge rate of between 10.5 and 12.6 in/yr is applied uniformly throughout the Rehoboth and Indian River Bays' ground-water drainage basin, which has a surface area of 57 mi^2. The area contributing direct ground-water discharge was calculated to be 40 mi^2. Thus the calculated ground-water discharges range from 28.5 to 34.2 Mgal/d for the entire drainage area, and from 20.0 to 24.0 Mgal/d from the area contributing to direct ground-water discharge to the Delaware coastal bays. When normalized by the size of the contributing drainage areas, the ground-water fluxes for the current study fall within the ranges reported by Andres (1987).

Andres (1992) also reports estimated ranges of nitrate load for the Rehoboth and Indian River Bays of

Delaware. The ranges reported apply to the load from direct ground-water discharge and to the combined load from direct and stream base-flow contributions, both distributed over the 23-mi^2 surface area of the Delaware bays. The estimated load from direct ground-water discharge ranged from 476,000 to 816,000 lbs/yr. The estimated combined load from direct and stream base-flow discharge ranged from 693,000 to 912,000 lbs/yr.

In comparison to the results of the current study, the load estimates from Andres (1992) are an order of magnitude higher for direct ground-water discharge, and three to four times higher for combined direct and stream base-flow discharge. The differences in the results of the current study when compared to those of Andres (1992) may be explained by different amounts of nitrate in the ground water of the two study areas, differences in the estimation methods used in the two studies, or a combination of both factors.

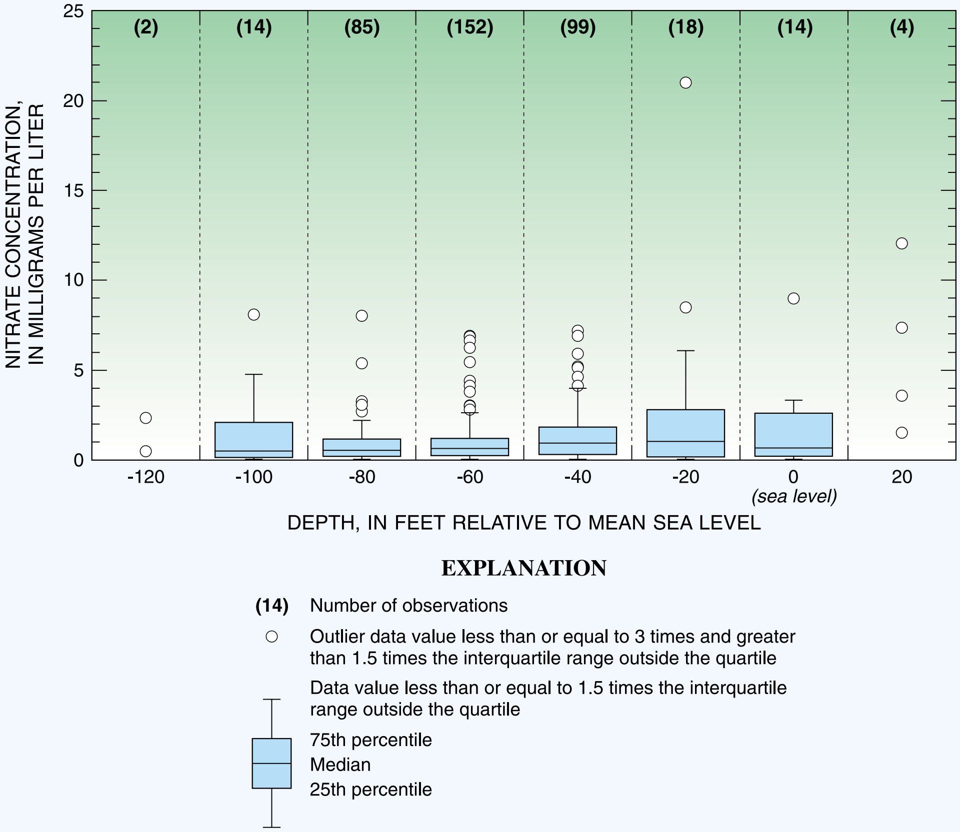

Figure 5. *Vertical distribution of the concentrations of nitrate in water in the surficial aquifer.*

Summary and Conclusions

Excessive nitrogen loads are a known causative factor in the eutrophication process, currently one of the most important environmental problems in the coastal bays of Maryland. Estimates of the potential nitrate load from ground-water discharge were made for Chincoteague, Newport, Sinepuxent, Isle of Wight, and Assawoman Bays. The estimation method employed estimates of ground-water discharge based on a water-balance analysis and the best available hydrogeologic and topographic data for the study area, and estimates of the distribution of nitrate in ground water in the study area based on data from 388 wells completed in the surficial aquifer.

The potential nitrate loads to the coastal bays from ground water were calculated to be 272,000 pounds per year from direct ground-water discharge, and 862,000 pounds per year from stream base flow, both distributed over the combined areas of Maryland's coastal bays, an area of 108 square miles. The estimates of the potential loads were based on a number of assumptions, some of which may be refined by further investigations as detailed below.

The assumption of an average-annual ground-water recharge rate may be refined or substantiated by the measurement of discharge, both direct and stream base flow, to the coastal bays. The assumption that all of the ground water discharging from the surficial aquifer system enters the surface watershed of the coastal bays could be refined or substantiated by building a three-dimensional ground-water-flow model for the coastal bays' ground-water/surface-water system. The assumption that no denitrification occurs in the subsurface could be refined by collecting data that defines the parts of the surficial aquifer that exhibit ground water with elevated dissolved organic carbon and low dissolved oxygen, which would signify a denitrifying environment.

(Photo courtesy of Dave Wilson, Maryland Coastal Bays Program)

(Photo courtesy of Dave Wilson, Maryland Coastal Bays Program)

References Cited

Achmad, Grufron, and Wilson, J.M., 1993, Hydrogeologic framework and the distribution and movement of brackish water in the Ocean City-Manokin aquifer system at Ocean City, Maryland: Maryland Geological Survey Report of Investigations No. 57, 125 p.

Andreasen, D.C., and Smith, B.S., 1997, Hydrogeology and simulation of ground-water flow in the Upper Wicomico River Basin and estimation of contributing areas of the City of Salisbury well fields, Wicomico County, Maryland: Maryland Geological Survey Report of Investigations No. 65, 87 p.

Andres, A.S., 1987, Estimate of direct discharge of fresh ground water to Rehoboth and Indian River Bays: Delaware Geological Survey Report of Investigations No. 43, 37 p.

____1992, Estimate of nitrate flux to Rehoboth and Indian River Bays, Delaware, through direct discharge of ground water: Delaware Geological Survey Open File Report No. 35, 36 p.

Bachman, L.J., 1984, Nitrate in the Columbia Aquifer, central Delmarva Peninsula, Maryland: U.S. Geological Survey Water-Resources Investigations Report 84-4322, 36 p.

Clark, I., 1979, Practical geostatistics: London, Applied Science Publishers, 129 p.

Cushing, E.M., Kantrowitz, I.H., and Taylor, K.R., 1973, Water resources of the Delmarva Peninsula: U.S. Geological Survey Professional Paper 822, 58 p.

D'Agostino, Vito, Greene, E.A., Passarella, Giuseppe, and Vurro, Michele, 1998, Spatial and temporal study of nitrate concentration in ground-water by means of coregionalization: Environmental Geology, v. 36, p. 285-295.

Denver, J.M., 1986, Hydrogeology and geochemistry of the unconfined aquifer, west-central and southwestern Delaware: Delaware Geological Survey Report of Investigations No. 41, 100 p.

____1989, Effects of agricultural practices and septic-system effluent on the quality of water in the unconfined aquifer in parts of eastern Sussex County, Delaware: Delaware Geological Survey Report of Investigations No. 45, 66 p.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and chemical hydrogeology: New York, New York, John Wiley, 824 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, New Jersey, Prentice-Hall, 604 p.

Johnston, R.H., 1973, Hydrology of the Columbia (Pleistocene) deposits of Delaware: An appraisal of a regional water-table aquifer: Delaware Geological Survey Bulletin No. 14, 78 p.

____1977, Digital model of the unconfined aquifer in central and southeastern Delaware: Delaware Geological Survey Bulletin No. 15, 47 p.

Journel, A.G., and Huijbregts, C.J., 1978, Mining geostatistics: London, Academic Press, 600 p.

Kresic, Neven, 1997, Quantitative solutions in hydrogeology and ground-water modeling: New York, New York, Lewis Publishers, 461 p.

Maryland Coastal Bays Program, 1997, Today's treasures for tomorrow: An environmental report on Maryland's coastal bays: Annapolis, Maryland, Maryland Department of Natural Resources, Maryland Coastal Bays Program 97-02.

Owens, J.P., and Denny, C.S., 1978, Geologic map of Worcester County: Maryland Geological Survey, 1 sheet, scale 1:62,500.

____1979, Upper Cenozoic deposits of the central Delmarva Peninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067-A, 28 p.

Richardson, D.L., 1994, Hydrogeology and analysis of the ground-water-flow system of the Eastern Shore, Virginia: U.S. Geological Survey Water-Supply Paper 2401, 108 p.

U.S. Department of Agriculture, Natural Resources Conservation Service [formerly Soil Conservation Service] 1973, Soil survey of Worcester County, Maryland: U.S. Department of Agriculture, 78 p.

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