Monitoring Ground Water at Jefferson Patterson Park and Museum

The Effects of Agricultural Practices on Ground-Water Quality

Fact Sheet 185-96

by Martha A. Hayes and L. Joseph Bachman

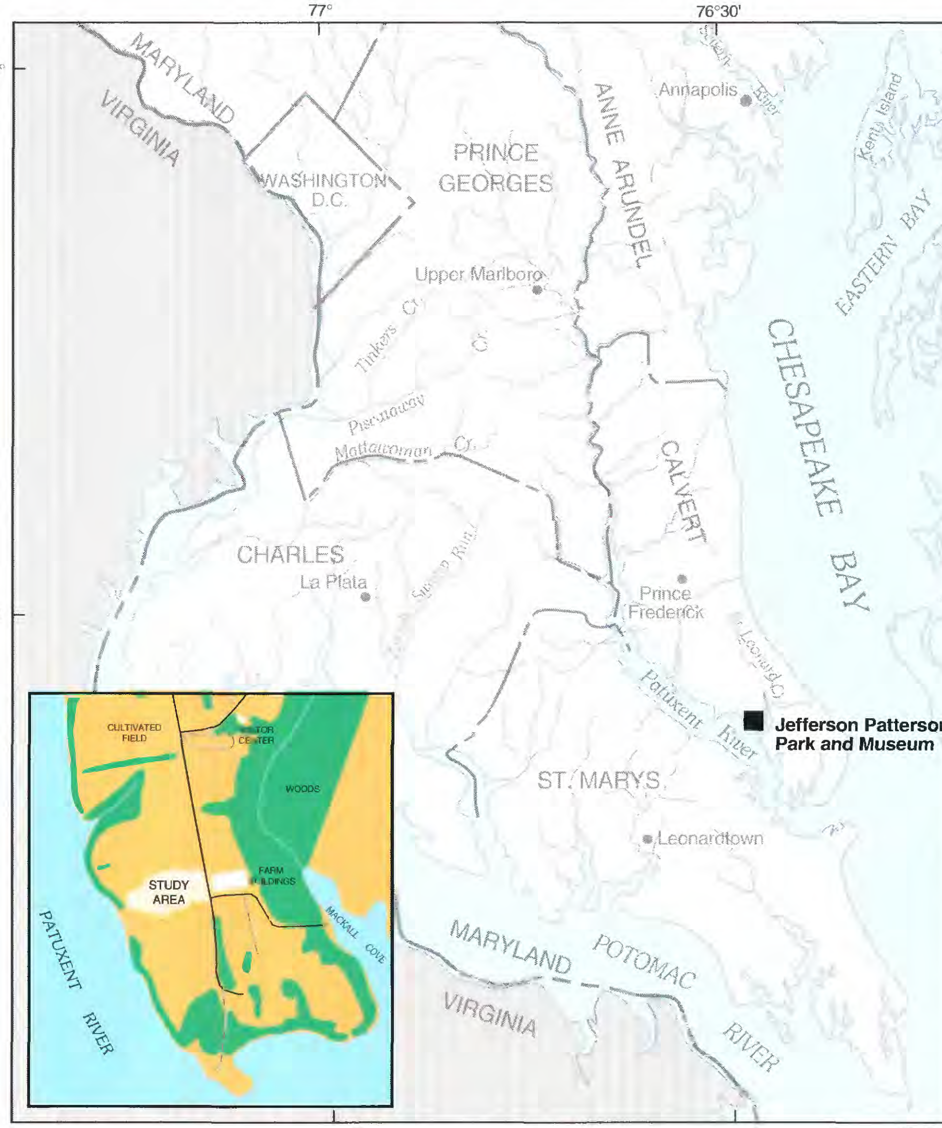

Figure 1. Location of study area at Jefferson Patterson Park and Museum in Calvert County, Maryland.

Nitrogen-containing compounds from agricultural fertilizers have been found in ground water in many areas. At Jefferson Patterson Park and Museum, it was found that the use of conservation tillage resulted in increased amounts of nitrogen in the ground water under an agricultural field studied by the U.S. Geological Survey.

In 1986, the U.S. Geological Survey (USGS) began an investigation at Jefferson Patterson Park and Museum in Calvert County, Maryland, to study the ways in which ground water serves as a transport medium for nitrogen into the Chesapeake Bay, the Nation's largest and most productive estuary (fig. 1; McFarland, 1995). Nitrogen is carried into the Chesapeake Bay by its tributaries, by ground-water discharge to tributaries and to the bay, and by deposition from the atmosphere. Once in the bay, excess nitrogen nourishes algal blooms that deprive aquatic grasses of sunlight and can lead to depletion of dissolved oxygen in the water. These effects can kill fish and other plants and animals that live in the bay, and adversely affect the bay's commercial and recreational industries. It is, therefore, important to improve the understanding of the ways in which nitrogen gets into water so that the amounts of nitrogen entering the bay can be minimized.

Sources of Nitrogen in Water

One of the principal sources of nitrogen in water is agricultural fertilizer. Fertilizer applied to the land surface is dissolved by precipitation or irrigation water. This nitrogen-laden water either soaks into the ground, where some of it is taken up by plants, or is carried away to streams in surface runoff. Nitrogen used by plants is largely in the form of nitrate and nitrite (Hem, 1992).

The amount of nitrogen applied to the land surface is determined by agricultural management practices. Agricultural management practices include changing the types of crops grown from year to year, varying the amounts of fertilizer applied to the crop, and using different cultivation methods. For example, corn, which is heavily fertilized, is often planted alternately with soybeans, which are lightly fertilized; thus, more nitrogen is likely to reach surface water and ground water from cornfields.

There is more net runoff from conventionally tilled fields (and potentially higher amounts of dissolved nitrogen) than there is from fields planted with "no-till" methods, which do not disturb the whole surface of the field. Therefore, the type of crop planted and the method of cultivation used will affect the amounts of nitrogen reaching the surface and ground waters. USGS research was conducted to determine how these agricultural practices affect ground-water quality at Jefferson Patterson Park and Museum.

How Ground Water Behaves

Ground water is a result of precipitation (rain and snowmelt). Precipitation flows downslope across the land surface, percolates through the soil and sand, or evaporates (fig. 2). Water that flows over the surface is called "runoff." Some water is returned to the atmosphere by plants in a process called "transpiration". As water moves below the land surface, it is either taken up by plants or continues to move slowly downward until it reaches a saturated zone (the "aquifer"). The upper surface of the saturated zone is called the "water table," and the water in the saturated zone is called "ground water." When water reaches the water table, it is said that the ground water has been "recharged."

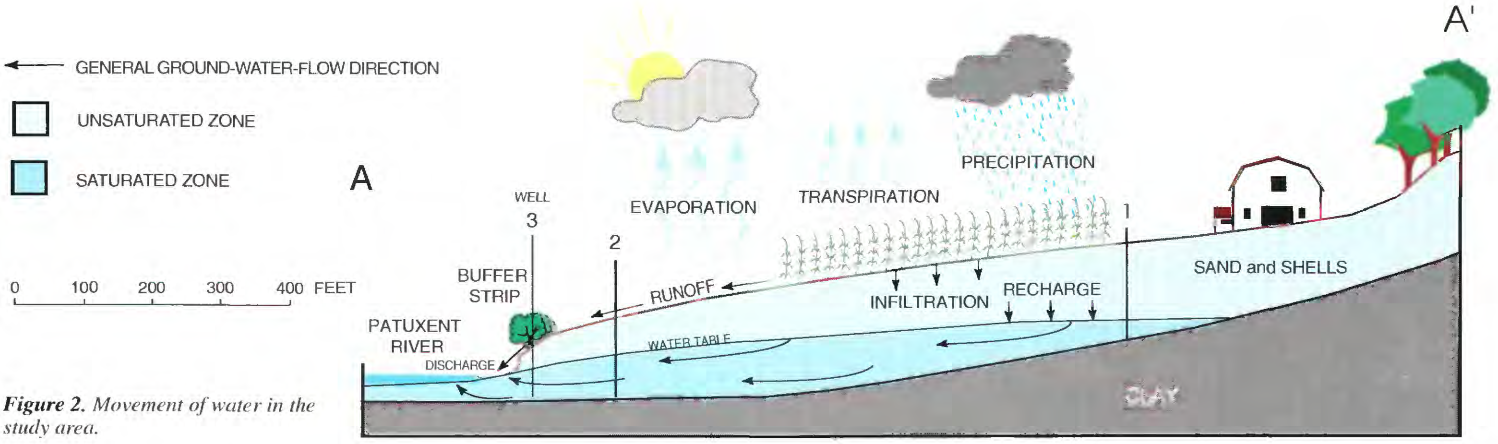

Figure 2. Movement of water in the study area.

Ground water, like runoff water in a river, flows downslope under the influence of gravity. However, runoff and surface water flow freely and fast. Ground water can move only in the spaces between sand grains, which are connected like the holes in a sponge, forming pathways through which water and air can flow. Therefore, ground water tends to move very slowly. For this reason, changes in the chemistry of ground water take years to move through the aquifer. Eventually, ground water will reach a location where it flows out of the aquifer, or is "discharged."

From the water-table surface, water moves along flow lines of different lengths depending on the distance to the downslope end of the site. The speed at which the water moves depends on the amount of water in the aquifer, the location of the water in the aquifer, and the properties of the aquifer materials. Wells that are next to one another, but that draw water from different depths, draw water samples that were recharged at different places and times. It is possible to estimate the age of a ground-water sample. By mapping the age of ground water, it is possible to determine patterns of ground-water flow and to learn how nitrogen is being carried through the aquifer.

Determining the Age of Ground Water

The age of a ground-water sample can be estimated by combining two analytical methods--(1) chemical and (2) mathematical. By use of these two methods, it is possible to interpret the record of the effects that past land use and other human activities have had on a site. Chemical-age analyses are based on the fact that water in contact with the atmosphere is in chemical equilibrium with the gases in the air, including natural and manmade elements and compounds. Once water flows below the water table, the relative amounts of the gases dissolved in the water remains the same. By measuring the amounts and types of gases in water samples and comparing the results to known concentrations in the atmosphere, it is possible to estimate the year in which the sample was recharged to ground water. Mathematical models combine information about the geology and water chemistry of a site to imitate what is believed to have happened at the study site during the period of data collection.

Mathematically derived age dates can be compared to chemically derived age dates in order to check the accuracy of the model. The calculations that are used by the model to describe what has happened can then be extended to predict what will happen in the future.

Description of the Study Site

The site selected for the study is in a farm field located on the banks of the tidal section of the Patuxent River (fig. 3), which is a tributary of the Chesapeake Bay. Jefferson Patterson Park and Museum is located in the Atlantic Coastal Plain Physiographic Province. The site is representative of Coastal Plain farmlands and was selected for the ground-water study because it offered the opportunity to institute a 5- to 10-year-long project at a secure site that had stable ownership. In addition, this site is not irrigated.

The land surface at the site slopes from a gravel road downward across a cultivated field (fig. 4). The cultivated part of the field is bounded on the downslope side by an uncultivated and vegetated buffer strip.

The soil at the site is underlain by 20 to 40 feet of sand mixed with shells (fig. 2). A clay layer under the sand acts like a liner and prevents any significant ground-water flow to areas beneath the sand layer.

Figure 3. Aerial view of the study area.

Collection of Data

The ground-water study at this site started in 1986 after a long period of no-till soybean cultivation. In 1989, the crop planted on the site was changed to conventional-till soybeans. No-till soybeans were planted in 1992-93, and conventional-till corn was planted in 1994. During 1995, the final year of the study, the site was planted in alternating strips of corn and soybeans. The strips were planted perpendicular to the slope of the field (parallel to the riverbank) using no-till methods.

The study was set up to monitor the effects that changes in agricultural management practices have on the transport of nitrogen in ground water (fig. 4). Most of the nitrogen dissolved in ground water is in the form of nitrate, so nitrate concentrations can be used for evaluating nitrogen transport.

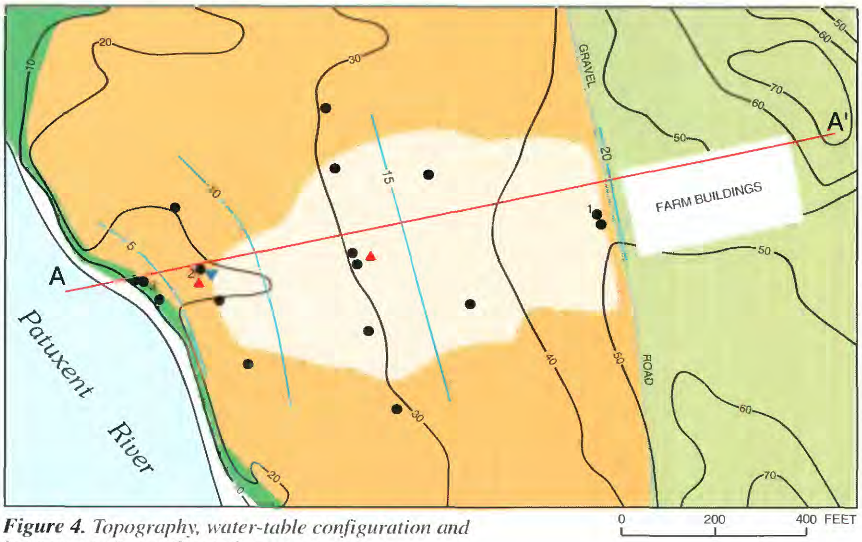

Figure 4. *Topography, water-table configuration and instrumentation at the study area.*

VEGETATED BUFFER STRIP

— 40 — LAND-SURFACE - Contour interval is 10 feet. Datum is sea level.

—10— APPROXIMATE WATER TABLE CONTOUR - Contour interval is 5 feet. Datum is sea level.

A——A' LINE OF HYDROGEOLOGIC SECTON (Figures 2 and 6)

● 3 OBSERVATION WELL AND NUMBER

▲ LYSIMETER NEST

▼ SURFACE-RUNOFF STATION

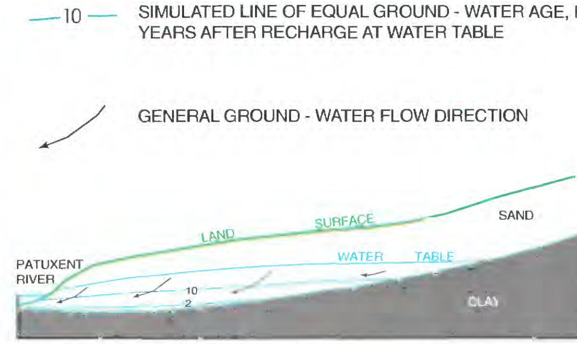

Figure 6. *Distribution of ground-water ages in cross-section.*

Sixteen observation wells on the site were used to map the water table and determine ground-water-flow directions and rates for the whole field. Water samples from 11 of these wells were analyzed in order to follow the changes in nitrate concentration in ground water as it recharged the aquifer and flowed to the discharge zone in the river. Soil-water samplers called "lysimeters" (shown in fig. 5a) were installed in two locations at different depths in order to follow the changes in nitrate concentration in soil water as it moved toward the water table. Equipment shelters (like the ones shown in figs. 5a and 5b) contained automatic water-level recorders installed on four observation wells. The recorders tracked the effects of seasonal precipitation on the water table. A weather station and flume equipped with an automatic runoff-water sampler were installed at the downslope end of the cultivated field to measure precipitation and to collect samples of water running off the field during storms (fig. 5a).

Water data were collected from the observation wells, precipitation gage, and runoff sampler at the site between 1986 and 1995. Soil-water data were collected from the lysimeters between 1987 and 1995. During the period of study, records of precipitation were made and surface runoff during storms was measured. Water levels were recorded every hour at two sites and every fifteen minutes at two other sites. Water samples were collected from the wells and lysimeters at regular intervals and analyzed for pH, specific conductance, and nitrate and dissolved oxygen content.

Rates of Ground-Water Recharge and Flow

The average amount of precipitation at the study site is about 42 inches per year (McFarland, 1995). Precipitation in this area typically is in the form of intense to steady rainfall lasting 1 to 2 days. All the runoff occurs under these conditions, but most of the water soaks into the soil, and only about 1 to 5 percent of the precipitation flows overland into the river. The recharge rate to the aquifer has been estimated to be 5 to 20 percent of precipitation, occurring mostly between January and May, before the main growing season. Between June and December, higher temperatures (resulting in direct evaporation) and plant transpiration prevent most recharge from taking place. At all times of the year, at least 75 percent of precipitation is returned to the atmosphere by evapotranspiration.

The rates of movement of water particles were estimated by use of a mathematical model (McFarland, 1995). A simplified diagram of the distribution of ground-water age is shown in figure 6. The average infiltration rate through the unsaturated zone is between 3 feet per year (ft/yr) near the river and 7 ft/yr at the uphill end of the site. It takes precipitation an average of 1 to 4 years to reach the water table. The estimated maximum amount of time it takes ground water to travel from the upslope recharge area to discharge into the river is 27 years. The average horizontal velocity during the study period was about 40 ft/yr, and the average residence time of ground water was 9.7 years. The age of the water in the shallowest wells on the site was between 4 and 5 years. Water from precipitation during the 1993-95 sampling period is not expected to reach the observation wells until sometime between 1997 and 1999.

(B)

Figure 5. *(A) Instrumentation at the site. (B) Automatic water-level recorder.*

(A)

Well with automatic water-level recorder | Lysimeters | Runoff sampler and rain gage

Ground-Water Quality Trends

The effects that changes in method of cultivation had on the amount of nitrogen in ground water could not be determined using the results of the study between 1986 and 1992 (McFarland, 1995). However, the amount of ground-water recharge was strongly affected by the method of cultivation that was used. After similar amounts of precipitation, the rate of recharge under no-till cultivation was more than three times higher than the rate of recharge under conventional-till cultivation. At the same time, according to the calculations made using the mathematical model, the amount of nitrogen recharged to the ground water was about 9 percent higher under no-till cultivation than under conventional-till cultivation.

Three trends were found in the amount of nitrate in ground water, depending on the position of the observation well. In samples collected from well 1, located at the top of the slope (figs. 2 and 3), a trend showing a slight decrease in concentrations of nitrate was found (fig. 7). This trend reflected the increase in runoff from conventional-till practices.

In samples collected from well 2, located in the downslope part of the field, a trend showing a slight increase in nitrate concentrations was observed (fig. 8). This trend reflected the movement of higher-nitrate water down from upgradient parts of the aquifer.

In samples collected from well 3, located in the vegetated buffer strip between the cultivated field and the river, a trend showing a sharp increase in nitrate concentrations was found (fig. 9). The presence of organic matter in sediments under the buffer strip, along with low concentrations of dissolved oxygen, indicate that some denitrification was taking place there before 1989 (McFarland, 1995). (Denitrification is the process by which nitrate in water not in contact with air is converted by soil bacteria to nitrous oxide or to nitrogen gas.) The steady increase of dissolved oxygen and nitrate in samples collected from well 3 since 1989 indicate that the process of denitrification has stopped. This is because the filter strip has eroded, exposing the soil bacteria that cause denitrification to the atmosphere; they do not live in oxygenated environments.

Both chemical information and recharge information were required for this evaluation. Analyses of water samples taken from the observation wells provided information about trends in the amount of nitrate in ground water from the 1989 change from no-till soybeans to conventional-till soybeans and from the return to no-till soybeans in 1992. Estimates of recharge rates were computed using the mathematical model.

Different Agricultural Practices Do Affect Ground-Water Quality

The amount of water recharged to ground water is a critical factor in determining the amount of nitrogen that reaches the ground water. Conservation tillage at the study site increased the amount of water that infiltrated to the aquifer by reducing the amount of runoff. Thus, the amount of nitrate that went into the aquifer was increased by use of the conservation tillage methods (McFarland, 1995).

TRENDS IN CONCENTRATIONS

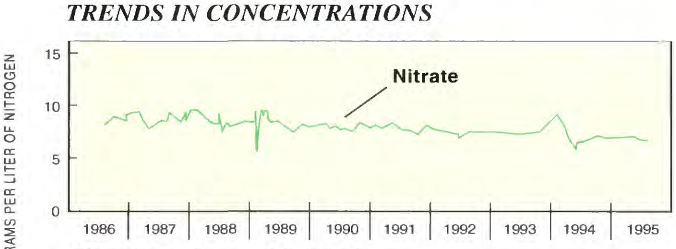

Figure 7. *Upslope well 1, 1986-95.*

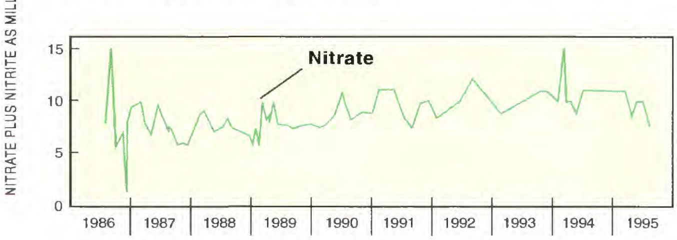

Figure 8. *Downslope well 2, 1986-95.*

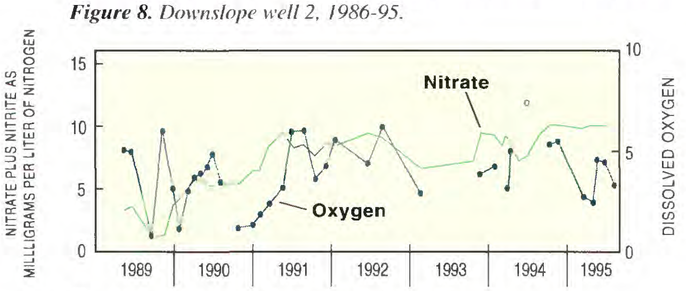

Figure 9. *In well 3 (in buffer strip) 1989-95.*

The results of this study are limited to an evaluation of tillage methods. Future investigations may show that the change to corn in 1994 may result in increased amounts of nitrogen in the aquifer because more fertilizer is used on corn crops than on soybeans.

Agricultural practices away from the river will eventually affect the river. The study period was brief compared to calculated traveltimes of nitrogen in ground water of several decades. Therefore, the effects of agricultural practices on ground water were observed only in part of the study site. The effects of corn cultivation and contour stripping in 1994-95 are expected to appear in the shallower wells by 1998-99, but will not reach the deeper wells or the estuary for several more years.

Acknowledgments

The authors are grateful for the assistance of Earl "Buddy" Hance and the staff at Jefferson Patterson Park and Museum for their help in conducting this study

Cooperating and supporting agencies

Calvert Soil Conservation District
U.S. Environmental Protection Agency
Maryland Department of the Environment
Maryland Department of Housing and Community Development

Additional Information

Bachman, L.J., Hayes, M.A., and McFarland, E.R., 1996, Extended monitoring of ground-water quality to evaluate the effect of agricultural best-management practices at Jefferson Patterson Park and Museum, Calvert County, Maryland 1993-95: Maryland Department of the Environment, Technical and Regulatory Services Administration, Report no. 96-005, 42 p.

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Publication date: August 1996
Fact Sheet FS-185-96