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# Water quality and conservation practice effects in the Choptank River watershed

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**Abstract:** The Choptank River is an estuary, tributary of the Chesapeake Bay, and an ecosystem in decline due partly to excessive nutrient and sediment loads from agriculture. The Conservation Effects Assessment Project for the Choptank River watershed was established to evaluate the effectiveness of conservation practices on water quality within this watershed. Several measurement frameworks are being used to assess conservation practices. Nutrients (nitrogen and phosphorus) and herbicides (atrazine and metolachlor) are monitored within 15 small, agricultural subwatersheds and periodically in the lower portions of the river estuary. Initial results indicate that land use within these subwatersheds is a major determinant of nutrient concentration in streams. In addition, the $^{18}O$ isotope signature of nitrate was used to provide a landscape assessment of denitrification processes in the presence of the variable land use. Herbicide concentrations were not correlated to land use, suggesting that herbicide delivery to the streams is influenced by other factors and/or processes. Remote sensing technologies have been used to scale point measurements of best management practice effectiveness from field to subwatershed and watershed scales. Optical satellite (SPOT-5) data and ground-level measurements have been shown to be effective for monitoring nutrient uptake by winter cover crops in fields with a wide range of management practices. Synthetic Aperture Radar (RADARSAT-1) data have been shown to detect and to characterize accurately the hydrology (hydroperiod) of forested wetlands at landscape and watershed scales. These multiple approaches are providing actual data for assessment of conservation practices and to help producers, natural resource managers, and policy makers maintain agricultural production while protecting this unique estuary.

**Key words:** best management practices (BMPs)—Chesapeake Bay—Conservation Effects Assessment Project (CEAP)—denitrification-riparian buffers—watershed—wetland—winter cover crop

**The Chesapeake Bay is the largest estuary in the United States and is an important national asset; however, the Bay is faced with significant ecosystem health issues.** In 2006, dissolved oxygen concentrations were low with only 37% of the bay meeting the goals designed to protect aquatic life (US Environmental Protection Agency 2006a). Also, only 7% of the bay met the goals for water clarity, which is a critical requirement for maintaining healthy submerged aquatic vegetation that serves as habitat for many diverse species. The low water clarity is exacerbated by decreased populations of filter feeders such as oysters and clams in the bay (Ulanowicz and Tuttle 1992). At the height of ecosystem health, bay waters were filtered once every four days, but the depleted filter feeder populations now require more than a year to filter the same volume (Newell 1988). Blue crab (*Callinectes sapidus*) abundance has been below management targets for the past ten years; in 2006, the population was at 57% of targeted goal of 232 million crabs (Chesapeake Bay Program 2007). Improvements in water quality and living resources in the Chesapeake Bay will require implementation of agricultural, urban, and natural resource best management practices (BMPs) throughout the watershed.

Limited watershed-scale data are available on the effectiveness of many important agricultural conservation practices for the Mid-Atlantic region. When compared to expensive wastewater treatment plant improvements, agricultural BMPs have been identified as some of the most cost-effective measures for water quality protection (Chesapeake Bay Commission 2004). Improved understanding of the processes influencing the effectiveness of practices such as riparian buffers, wetlands restoration, and winter cover crops is required to enhance conservation programs in the region. An overall goal of the current project is to develop a set of measurement and modeling tools for assessing the effectiveness of these commonly-used conservation practices at a watershed scale.

The Delmarva Peninsula, comprised of eastern Maryland, Delaware, and a small portion of northeastern Virginia, is part of the Chesapeake Bay watershed. The hydrological and geographical characteristics of this area present certain challenges for natural resource conservation management, since it is also an area of intensive agricultural production. The Choptank River watershed is located on the Delmarva Peninsula and serves as our study site. Approximately 60% of land area in the Choptank River Watershed is dedicated to production of corn (*Zea mays*), soybean (*Glycine max*), wheat (*Triticum aestivum*), and barley (*Hordeum vulgare*). The watershed also has small to medium animal feeding operations, with poultry production being the

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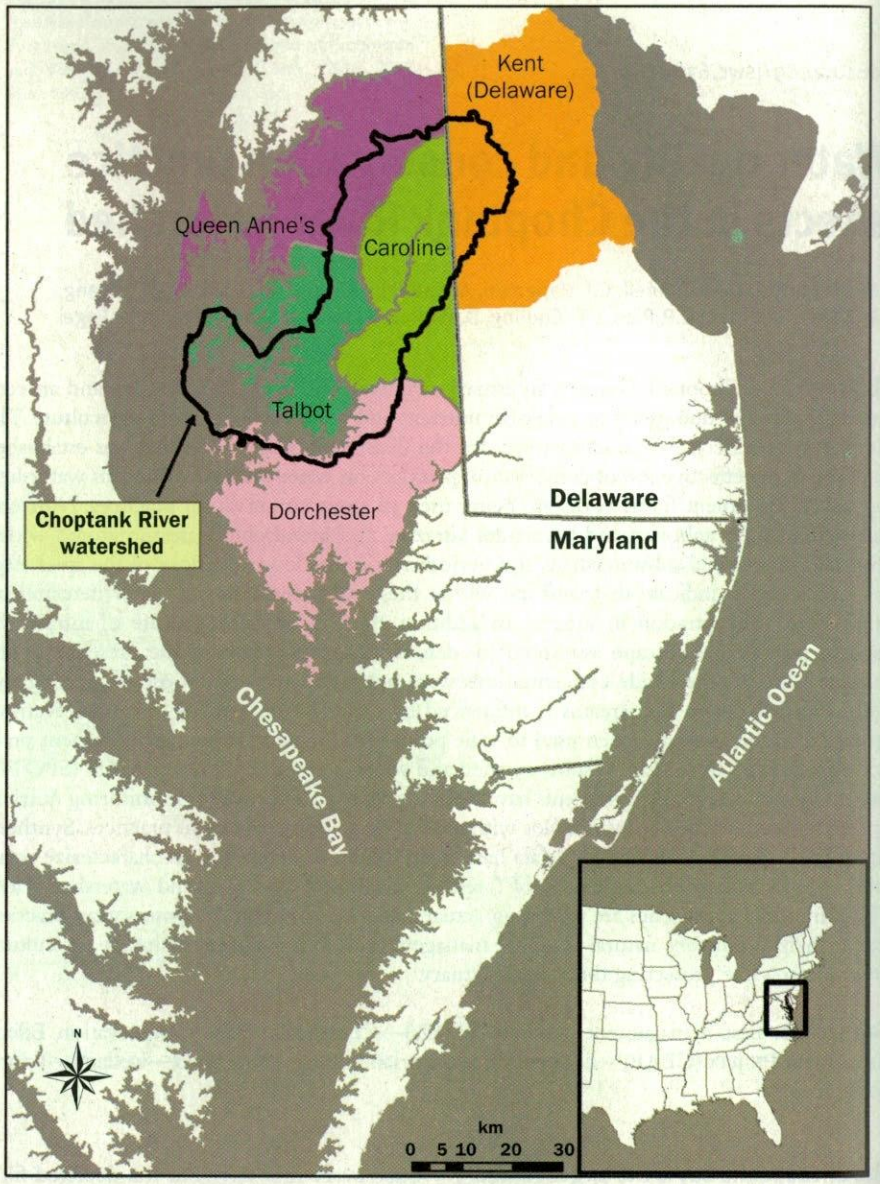
most prevalent animal production industry. In 2005, Maryland ranked ninth among the states in broiler production at $7.4 \times 10^8$ kg ($1.6 \times 10^9$ lb) (USDA National Agricultural Statistics Service 2007). Chicken litter from poultry houses is routinely recycled as a fertilizer on corn and soybean fields.

The major conservation concerns of the Choptank River watershed are water, soil, and air quality as well as loss of wildlife habitat. The historical loss of wetlands in the Upper Choptank River subwatershed is estimated to be 19,200 ha (47,400 ac) which represents approximately 11% of the total Choptank watershed area (Maryland Department of Natural Resources [MD DNR] 2002). This loss of wetlands is large when compared with other Maryland watersheds (MD DNR 2002). Water quality is the greatest conservation concern in the watershed as it centers on health of aquatic ecosystems of the Choptank River. Nutrient, sediment, and bacterial contamination are considered the most critical water quality problems in the Choptank, but pesticides and other inputs of organic contaminants are also a concern (Chesapeake Executive Council 2000).

The Choptank River Watershed project has been undertaken in an effort (1) to synthesize the water quality data available from the Choptank River; (2) to examine these datasets within the context of ongoing conservation practices in the watershed; (3) to provide information on the primary transport and biogeochemical processes controlling the fate of agriculturally-related pollutants within the watershed; and (4) to consider strategies to improve conservation measures. This report brings together historical and more recent water quality data and examines the state of the knowledge with respect to the functionality of winter cover crops, riparian buffers, wetlands, and ditch drainage management.

**Figure 1**
**The Choptank River watershed located on the Delmarva Peninsula.**




Note: Counties overlapped by the watershed in Maryland and Delaware are highlighted.

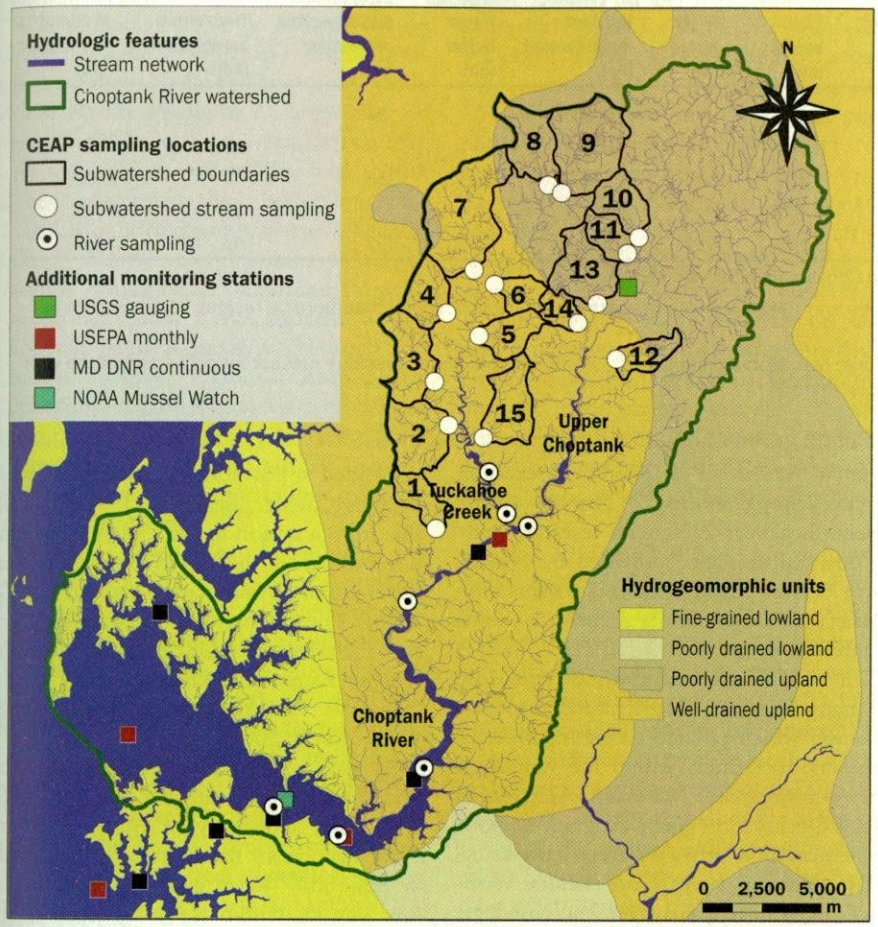
## Materials and Methods

***Study Site Description: Hydrologic and Morphological Characteristics.*** The Choptank River is an estuary and tributary of the Chesapeake Bay located in the Coastal Plain on the Delmarva Peninsula in the Mid-Atlantic Region of the United States. It originates in Kent County, Delaware, and flows southwest (figure 1). The lower estuarine segment of the Choptank River is a tidal embayment; its ecosystem status is reflective of the greater Chesapeake Bay. The single US Geological Survey (USGS) monitoring station on the main stem of the Choptank River near Greensboro, Maryland, (USGS station 014910000) (figure 2) roughly marks the transition to non-tidal reaches for the main branch and above which drains 14% of the watershed. The Tuckahoe Creek subbasin, where much of this research is conducted, enters the main stem of the Choptank in the tidal region. The Tuckahoe Creek subbasin is 690 km$^2$ (266 mi$^2$) and represents 34% of the Choptank River basin (2,057 km$^2$ [794 mi$^2$]).

Ator et al. (2005) classified a large section of the Delmarva Peninsula including most of the Choptank River watershed as belonging to the Middle Coastal Plain. This region was defined by the superposition of upper-delta-plain sands and gravel that overlay marine inner shelf sands. The drainage network has not been fully developed, with original flat upland surface being only partly dissected by streams. In the absence of underlying restric-

**Figure 2**

**Hydrogeomorphic units and water quality sample collection sites used in this study and in other regional and national monitoring networks in the Choptank River watershed.**




Notes: Hydrogeomorphic units data were obtained from Phillips et al. (1993). Data are available from the US Geological Survey gauging stations (USGS 2008b), US Environmental Protection Agency and Maryland Department of Natural Resource stations (MD DNR 2008), and National Oceanographic and Atmospheric Administration Mussel Watch program (National Oceanographic and Atmospheric Administration 2007).

tive layers, good drainage is expected in the region because of moderate topographic relief and underlying sands and gravel with good permeability. Streams and groundwater in this region are considered to be highly susceptible to contamination by chemicals applied to the landscape.

Considerable hydrogeological variability is found within the Coastal Plain including the Choptank River watershed (figure 2) and has been detailed by Phillips et al. (1993). The lowland subregions cover the coastal margins of the Choptank River watershed. The hydrology in these regions is heavily influenced by tides. The fine-grained lowland subregions have surficial sediments composed of silts, sands and organic muds that were deposited on the landscape with changes in sea level. The near-surface sediments in this region have low permeability. The poorly-drained lowland region consists of coarser grained sediments (mostly sands) than those found in fine-grained lowland.

The upland areas of the Choptank watershed can be divided into well-drained unit (WDU) and poorly drained unit (PDU) subregions. The WDU subregions are characterized by well-drained land areas on topographic highs and poorly-drained soil on floodplains in stream valleys. Streams are more highly incised with the topography being relatively flat to gently rolling within this hydrogeomorphic subregion. Land use consists mostly of agricultural crop production on upland portions of watersheds with wooded areas found along the narrow riparian zones associated with incised streams. The typical groundwater flow paths in WDU subregions range from 1 to several kilometers (0.6 to several miles) (Lowrance et al. 1997).

The PDU subregions are characterized by a mixture of poorly drained forests and moderately well-drained to well-drained agricultural land (Shedlock et al 1999). Streams are small and slow running in these uplands with shallow incision of valleys with low gradients. Riparian zones are forested and usually contain wetlands. This region also contains many seasonally inundated depressions under forest vegetation. An extensive ditch drainage network has been developed for large parts of this region allowing conversion of wetlands to cropland agriculture. The typical groundwater flow paths in PDU subregions range from 100 m to about 1 km (110 to 1,100 yd) (Lowrance et al. 1997).

The major soil types found under cropland production in the Choptank River watershed are typified by the Othello soil series (fine-silty, mixed, active, mesic typic endoaquults) and the Mattapex soil series (fine-silty, mixed, active, mesic aquic hapludults). These soils formed from parent material consisting of silty eolian sediments underlain by coarser marine, eolian, fluvial, or alluvial sediments. Othello soils are poorly-drained with moderately slow permeability and Mattapex soils are moderately well-drained with moderate or moderately slow permeability.

***Ditch Drainage.*** The Delmarva Peninsula contains over 1,300 km (808 mi) of Public Drainage Association (PDA) or tax ditches that drain over 58,000 ha (143,000 ac) of land (Bell and Favero 2000). Caroline County, which is part of the Choptank River watershed, holds the greatest number of tax ditches in the Eastern Shore of the Chesapeake Bay, draining over 28,000 ha (69,000 ac) of cropland. The oldest PDA in the United States, which was chartered by the State of Maryland in 1789 to drain the Long Marsh area, is located within the watershed. Over 100 PDAs are responsible for maintenance of the tax ditches on the Eastern Shore. Maryland Drainage Law requires an approved operation and maintenance plan implemented to minimize environmental impacts of agricultural drain-

**Table 1**

**Selected best management practices reported that were implemented during fiscal year 2006 in Caroline, Dorchester, Queen Anne's, and Talbot Counties, Maryland.**

| County | Cover crop (ha) | Crop residue management, full year* (ha) | Crop residue management, seasonal† (ha) | Field border (m) | Filter strip (ha) | Nutrient management (ha) | Riparian forest buffer (ha) | Streambank and shoreline protection (m) | Tree/shrub establishment (ha) | Wetland restoration (ha) |
|---|---|---|---|---|---|---|---|---|---|---|
| Caroline | 83 | 1,538 | 73 | 6,592 | 6 | 1,579 | 0 | 34 | 10 | 66 |
| Dorchester | 2,563 | 45 | 7,232 | 5,056 | 79 | 223 | 4 | 0 | 0 | 23 |
| Queen Anne's | 1,006 | 1,061 | 29 | 1,203 | 113 | 1,446 | 8 | 358 | 4 | 10 |
| Talbot | 3,771 | 1,936 | 7 | 2,271 | 8 | 2,241 | 1 | 0 | 31 | 28 |
| Total | 7,422 | 4,580 | 7,341 | 15,122 | 207 | 5,489 | 14 | 392 | 45 | 127 |

Note: Data compiled from the USDA Natural Resource Conservation Service (2006).

* Refers to NRCS practice codes 329 and 345 (Residue and Tillage Management standards), which require that there be residue year-round for all crops in the rotation.

† Refers to NRCS practice code 344 (Residue and Tillage Management standards), which requires surface residue present for only a part of the year (often winter) then fields are conventionally tilled before planting.

age. Maryland Department of Agriculture (MDA) provides cost-share assistance to PDAs for drainage ditch best management practice implementation.

***Conservation Programs within the Choptank River Watershed.*** A number of federal and state conservation programs are available to farmers in the Choptank River Watershed. The Maryland state office of the USDA Natural Resources Conservation Service (NRCS) provides technical and financial assistance for NRCS programs, such as the Agricultural Management Assistance program, Conservation Security Program, Environmental Quality Incentives Program, Wetlands Reserve Program, and Wildlife Habitat Incentives Program, throughout Maryland, including Choptank River watershed counties. The NRCS also provides technical assistance for other USDA programs, such as the Conservation Reserve Program and the Conservation Reserve Enhancement Program (CREP), which are administered by the Maryland Farm Service Agency. A list of selected conservation practices implemented by farmers during federal fiscal year 2006, with technical and/or financial assistance provided by NRCS, Farm Service Agency, the soil conservation districts, and other partner agencies, is shown in table 1.

The MDA also administers cost-share programs to promote agricultural conservation and which provide additional financial assistance to farmers within the watershed. For example, the Maryland Agricultural Water Quality Cost-Share Program supports implementation of 30 different agricultural BMPs inluding cover crop, manure transport, and nutrient management cost-share programs (table 2).

***Available Long-Term Water Quality Monitoring Data Sets.*** The Choptank River has been included in a number of ongoing Chesapeake Bay monitoring efforts conducted by state and federal agencies and universities (figure 2). A historical water quality dataset of monthly nutrient and suspended solids concentration and water discharge, which began in 1975, is available from a station in the Upper Choptank River as part of the USGS Chesapeake Bay River Inputs Monitoring Program (USGS 2008a). The Choptank River watershed was also included in a USGS National Water Quality Assessment Program study of the Delmarva Peninsula from 1999 to 2001 (Denver et al. 2004).

As part of the larger Chesapeake Bay Water Quality Monitoring Program, MD DNR and University of Maryland Horn Point Laboratory have carried out monthly or bimonthly water quality monitoring at four stations within the main stem of the Choptank River since 1984 (MD DNR 2008). Samples have been characterized for temperature, pH, salinity, dissolved oxygen, total suspended solids, Secchi depth, nutrients, and chlorophyll. In addition, three continuous water quality monitoring stations along the main stem have been maintained by University of Maryland and MD DNR

**Table 2**

**Summary of Maryland Department of Agriculture conservation grants program for fiscal year 2006 in Caroline, Dorchester, Queen Anne's, and Talbot Counties, Maryland.**

| | Maryland agricultural water quality cost-share program | | Cover crop program | | | Nutrient management cost-share | | |
|---|---|---|---|---|---|---|---|---|
| County | Projects | Payment | Applications | ha | Payment | Applications | ha | Payment |
| Caroline | 28 | $510,376 | 51 | 1,819 | $226,079 | 32 | 5,400 | $38,345 |
| Dorchester | 20 | $262,608 | 57 | 5,908 | $564,264 | 22 | 7,047 | $34,374 |
| Queen Anne's | 36 | $207,992 | 64 | 4,644 | $391,803 | 6 | 1,340 | $6,825 |
| Talbot | 18 | $123,011 | 52 | 5,668 | $540,888 | 16 | 2,710 | $21,157 |
| Total | 102 | $1,103,987 | 224 | 18,039 | $1,723,034 | 76 | 16,497 | $100,701 |

Note: Data from MDA (2007c).

providing dissolved oxygen, salinity, water temperature, pH, and turbidity.

The Choptank River is covered by the National Oceanographic and Atmospheric Administration National Status and Trends, Mussel Watch Program. A large suite of organic and inorganic contaminants have been measured in oysters from one station in the lower estuary since 1986 (Center for Coastal Monitoring and Assessment Science Serving Coastal Communities 2007). A National Atmospheric Deposition Program monitoring station exists adjacent to the Choptank basin at the Wye Research and Education Center (National Atmospheric Deposition Program station MD13 [National Atmospheric Deposition Program 2008]) where weekly, composite rainfall quantity and chemistry have been monitored continuously since 1982.

***Current Base Flow Monitoring of Subwatersheds.*** In 2004, the Choptank River watershed project initiated approximate monthly base flow monitoring of 15 subwatersheds in the upper part of the Choptank watershed for nutrients ($PO_4^{3-}$ and $NO_3^-$) and currently used pesticides including the herbicides atrazine and metolachlor. Eight-liter (2.1 gal) samples of water were collected by using a bailer lowered into the stream. Samples were stored on ice in stainless steel containers during transport to the laboratory. Subsamples (100 mL [0.026 gal]) of the raw water were taken for nutrient analysis; $PO_4^{3-}$ and $NO_3^-$ were measured colorimetrically using a Lachat QuikChem 8000 flow injection analyzer (Lachat Instruments, Milwaukee, Wisconsin). Four-liter (1.05 gal) subsamples of the raw water were filtered and then extracted using a solid phase cartridge containing a copolymer extraction resin (hyper-crosslinked styrene-divinyl benzene). The extracts were analyzed for herbicide parent compounds by gas chromatography mass spectrometry using an Agilent Model 6890 gas chromatograph coupled to an Agilent Model 5973 inert mass spectrometer (Agilent, Santa Clara, California) as described previously by McConnell et al. (2007). Box-plot analysis was used to assess temporal and spatial variability in agrochemical content in streams for the 15 subwatersheds. Linear regression analysis was used to assess the relationships between land use within the 15 subwatersheds and agrochemical content in stream water.

## Results and Discussion

***Water Quality in the Choptank River—A Historical Perspective.*** The US Environmental Protection Agency Chesapeake Bay Program model (phase 4.3) estimated that in 2000, 73% of the nitrogen and 62% of the phosphorus loads to the Choptank River were from agricultural sources, whereas the model estimated that in 1985 agriculture contributed 82% of the nitrogen and 72% of the phosphorus loads (MD DNR 2005a). By simulation, urban sources were considered to account for 10% and 15% of annual loading for nitrogen and phosphorus, respectively. During the period 1985 to 2000, improved nutrient management plans had a greater impact on fertilizer application of phosphorus than of nitrogen with a 24% decrease in fertilizer phosphorus application (Sprague et al. 2000).

Since 1985, MD DNR has monitored water quality and living resource habitat within the watershed, and their results have revealed increasing nitrate, chlorophyll *a*, and total suspended solids, and decreasing Secchi depth values over time (MD DNR 2005a). Seasonally during late summer, low oxygen concentrations have been observed in the deeper estuarine portions of the Little Choptank River and Lower Choptank River. Low oxygen concentrations (also called hypoxia) occur when biochemical oxygen demand depletes oxygen in the water column. This most often occurs in the bottom waters of estuarine systems where density-based stratification of the water column prevents re-aeration of the system. However, organic waste inputs or, more commonly, decaying algal blooms, which can be enhanced by excess nutrient inputs to the system, will increase biochemical oxygen demand, exacerbating the hypoxia condition. Excess nutrient inputs in the Choptank River watershed originate from agricultural lands, atmospheric deposition, and human wastewater inflows from septic systems and the 11 small wastewater plants within the watershed (Lee et al. 2000).

In 1998, the state of Maryland enacted the Water Quality Improvement Act, and since 2001, Maryland farmers and agricultural operators have been required to develop and to implement nutrient management plans. All farmers grossing $2,500 a year or more or livestock producers with 3,629 kg (8,000 lb) or more of live animal weight are now required to use nutrient management plans that address both nitrogen and phosphorus inputs. In 2006, 94% of Maryland farmland was covered under a nutrient management plan (MDA 2007a).

Large portions of the Choptank River have been identified as "impaired waters" under the Federal Clean Water Act. The Lower Choptank River was listed in Maryland's 1996 Section 303(d) list as being impaired by bacteria (fecal coliform), nutrients, and sediments. In 2002, portions were placed on the Section 303(d) list for biological impairments, and in 2004, eleven shellfish restricted areas were identified. Since then, Maryland and Delaware have developed total maximum daily load determinations for fecal coliform for various portions of the river (US Environmental Protection Agency 2005, 2006b, 2006c). A total maximum daily load reflects the total amount of a pollutant from point, nonpoint, and natural background sources, including a safety margin that may be discharged to a water quality-limited water body. These total maximum daily loads are used a guide for water quality improvement efforts.

Agricultural pesticides, especially corn and soybean herbicides and their degradation products, have been found in ground and surface waters of the Choptank main stem and in precipitation collected from a site in the lower estuary (Goel et al. 2005; Kuang et al. 2003; Lehotay et al. 1998). The concentration and overall annual flux of herbicides to the lower Choptank Watershed was governed by the timing of precipitation during the corn and soybean planting season, but the pesticide found most frequently and in the highest concentrations in rain was the fungicide, Chlorotalonil (Goel et al. 2005). Herbicide concentrations were highest in surface water collected from one location in the Choptank River estuary from late June to mid-July of 1997 with a maximum concentration of 0.43 $\mu g\ L^{-1}$ (0.43 ppb) and 0.048 $\mu g\ L^{-1}$ for atrazine and metolachlor, respectively (Lehotay et al. 1998). In 2000, a separate surface water study of lower Tuckahoe creek and the Choptank River estuary showed maximum herbicide concentrations in May and June of 3.1 and 0.85 $\mu g\ L^{-1}$ for atrazine and metolachlor, respectively (Kuang 2001). Herbicide concentrations decreased with increasing salinity down the estuary, reflecting dilution by cleaner water from the Chesapeake Bay main stem.

**Table 3**
Land use information for 15 study subbasins in the Choptank River watershed, Maryland.

| Subbasin* | Area ($km^2$) | Percent hydric soils | Percent agriculture† | Percent developed† | Percent forest† | Percent CREP‡ | Percent feedlot |
|---|---|---|---|---|---|---|---|
| 1 | 14 | 26% | 64.3% | 2.0% | 32.1% | 0.7% | 0.9% |
| 2 | 26 | 15% | 75.1% | 4.0% | 18.4% | 1.1% | 1.3% |
| 3 | 25 | 33% | 69.6% | 1.8% | 23.1% | 5.2% | 0.4% |
| 4 | 17 | 34% | 63.3% | 0.0% | 28.3% | 8.1% | 0.3% |
| 5 | 15 | 24% | 78.0% | 3.6% | 16.2% | 0.6% | 1.6% |
| 6 | 10 | 17% | 83.8% | 4.4% | 10.3% | 0.2% | 1.3% |
| 7 | 51 | 45% | 67.8% | 0.2% | 26.8% | 4.2% | 0.9% |
| 8 | 23 | 64% | 62.3% | 0.8% | 32.2% | 4.6% | 0.0% |
| 9 | 40 | 64% | 54.1% | 0.4% | 40.8% | 4.2% | 0.5% |
| 10 | 16 | 58% | 61.5% | 2.3% | 35.1% | 0.4% | 0.7% |
| 11 | 12 | 60% | 54.3% | 8.4% | 32.3% | 3.7% | 1.2% |
| 12 | 12 | 32% | 74.3% | 0.3% | 21.6% | 3.5% | 0.3% |
| 13 | 25 | 51% | 59.6% | 2.1% | 30.7% | 7.4% | 0.2% |
| 14 | 8.5 | 34% | 62.9% | 5.3% | 28.2% | 2.2% | 1.4% |
| 15 | 23 | 19% | 76.8% | 5.1% | 15.6% | 0.8% | 1.7% |

Note: Average of results from monthly, base flow, grab samples collected at the outlet of the subbasin in 2003.

* Subbasin numbers correspond to those shown in figure 1.

† Land use as of 1990, determined from Landsat images.

‡ Conservation Reserve Enhancement Program.

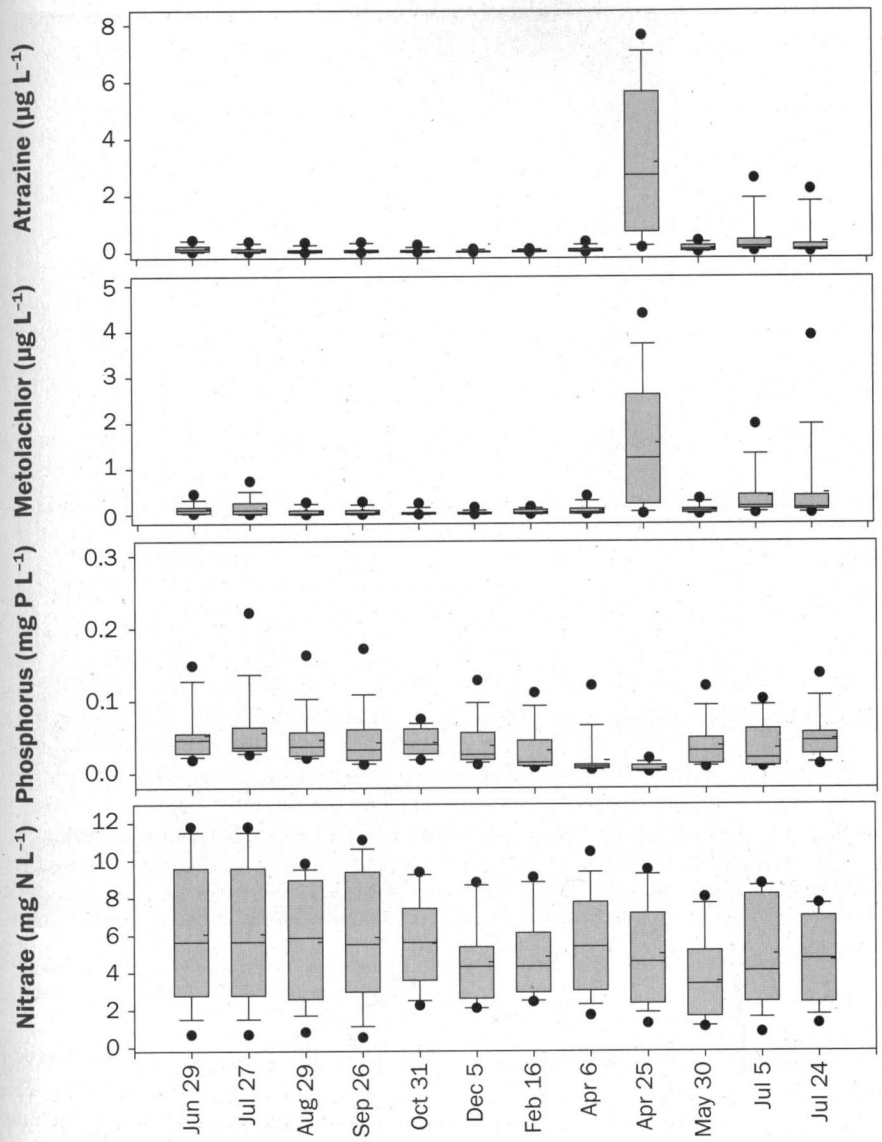
Fifteen subwatersheds (figure 2) in the upper portion of the Choptank River watershed have been the subject of several studies by Fisher and associates and are a major focus of the current project. Each subwatershed has been characterized with respect to land use, percent hydric soils, and the location of CREP/Conservation Reserve Program buffers (table 3). Monthly base flow samples have been collected at these stations since January 2003. In one of the earlier studies conducted in 1986 to 1987 (Norton and Fisher 2000), the effectiveness of forests and forested riparian buffers in reducing nutrient load in stream waters within the Choptank River watershed was assessed. They found strong correlation ($r^2 \approx 0.7$) between increasing forest cover and decreasing nitrogen loads. They also found some evidence that forest placement along streams was important for maintaining low stream nitrogen ($r^2 \approx 0.35$).

***German Branch—A Case Study within the Watershed.*** A long-term monitoring project of nutrients, sediment, and discharge was carried out within the German Branch subwatershed (labeled as subwatershed 7 on figure 2) from 1990 to 1995. The German Branch Targeted Watershed project (Primrose et al. 1997) spearheaded by the MD DNR provides an informative case study of comprehensive implementation of a set of conservation practices within a watershed and the ability to detect impact on water quality. The objectives of this multi-agency project were (1) to establish baseline water quality and biotic conditions, (2) to establish pollution loads, and (3) to evaluate temporal dynamics in water quality and to attempt to detect changes in biota related to implementation of BMPs within the study period. The BMPs implemented included conservation tillage systems, crop residue management, and comprehensive nutrient management plans. Nutrient management plans were developed for essentially all cropped land in the watershed with evidence of good participation by all farmers in the watershed.

The degree of producer involvement within the watershed was nearly complete as Comprehensive Soil Conservation and Water Quality Plans were developed for 4,843 ha (11,968 ac) of 4,888 ha (12,079 ac) in production within the watershed. Monitoring of plan implementation was based on operator surveys and indicated good cooperation by the producers. However, a confounding factor during the study period was that the cropping intensity increased because new rotations involving double-cropped soybeans were utilized. This led to increased nutrient inputs on the same area of cultivated land. Annual stream export of N from the subwatershed (22.4 kg $ha^{-1}$ [20 lb $ac^{-1}$] of cropland) accounted for approximately one third of the estimated residual N after harvest (71.7 kg $ha^{-1}$ [64 lb $ac^{-1}$]), which was based on detailed nutrient input and crop yield data. The researchers were unable to detect any influence of nutrient management plan implementation on stream flux of nitrate. This was attributed in part to the substantial residence time of leached N in groundwater within the region. In all likelihood, the timeline of the study was too short to measure detectable changes in nitrate delivery by the groundwater. These results demonstrate the difficulty in detecting the influence of conservation practices at scales larger than edge-of-field.

***Current Subwatershed Monitoring within the Choptank River Watershed.*** In the current project, stream water in the 15 subwatersheds has been analyzed monthly for nutrients ($NO_3^-$ and $PO_4^{3-}$) since 2003 and for currently used pesticides since 2005. Land use within the subwatersheds varies considerably (table 3), providing opportunities to discern the influence of land use on the pollutant transport. The temporal and subwatershed variance in nutrient and herbicide concentrations during an annual cycle for the 15 monitored streams is shown in figure 3. Both atrazine and metolachlor showed spikes in concentration during early spring when those herbicides are typically applied. Mean concentrations for atrazine (3.15 μg $L^{-1}$) and metolachlor (1.56 μg $L^{-1}$) during this period were 21 and 11 times

**Figure 3**
**The distributions in stream water concentration of herbicide and nutrients for the 15 monitored subwatersheds during an annual cycle (June 2005 to July 2006).**




Notes: Solid lines = medians. Dashed lines = means. Boxes = 25th/75th percentiles. Whiskers = 10th/90th percentiles. Dots = individual outlying data points.

greater, respectively, than mean concentrations during all other sampling periods. Temporal data for nutrient concentrations did not show similar spikes but rather $PO_4^{3-}$ showed a springtime minimum in median and mean values for the 15 subwatersheds. Mean or median $NO_3^-$ concentrations for the subwatersheds displayed little temporal variance, which is consistent with more steady delivery of $NO_3^-$ via groundwater flow. This contrasts with the predominantly overland flow delivery for phosphorus. Pesticide transport from the fields to the streams is more complicated as delivery can occur via leaching, overland flow, and atmospheric delivery to riparian corridors via drift and/or volatilization/redeposition.

Agriculture and forest are the two land-use classifications that account for more than 90% of the land area within all the subwatersheds. Moreover, many of the areas within the subwatersheds that have remained forested are also wetlands as supported by the high positive correlation between areal extent of hydric soil and forests ($r^2 = 0.72$). Figure 4 shows the relationship between percent forest content in the subwatersheds and average annual concentrations of nutrients and herbicides in the stream water. No apparent relationship exists between percent forested lands for atrazine or metolachlor, which may reflect complex delivery mechanisms for pesticides. However, nutrient concentrations were negatively correlated with percent forest content. This indicates the strong influence of land use on nutrient loading. It is noteworthy that current levels of CREP implementation in these subwatersheds have no detectable influence on nutrient concentration. This could indicate that threshold levels have not been obtained for implementation of buffers or that the buffers were not functional.

***Evaluating Conservation Practices within the Choptank River Watershed.*** Of the various federal and state conservation programs that are available to farmers in the Choptank River Watershed (table 1), the Choptank River Watershed project has focused on several prominent conservation practices that are expected to have substantial impact on water quality in the basin.

***Winter Cover Crops.*** Planting small grain cover crops is considered to be a highly cost-effective management practice for sequestering excess nutrients in the field after row crop harvest (Staver and Brinsfield 1998) and is an important BMP for nutrient reduction to the Chesapeake Bay (Chesapeake Bay Commission 2004). The MDA promotes planting of winter cover crops via an annual cost share program (MDA 2007b) where the payment rate is adjusted according to planting date, i.e., higher payments for earlier plantings. The traditional winter cover crop program does not permit harvest, and often the farmer kills the winter crop in early spring using herbicides. Maryland has recently been testing more flexible approaches to increase participation in the program such as a commodity cover crop program that allows grain harvest without fall fertilization of the winter crop. In this way, the crop acts as a nutrient sink during the winter, and the farmer applies fertilizer in the spring.

Estimates of cover crop effectiveness have previously relied on plot scale experimental data extrapolated to match implementation acreages. However, landscape-scale variability in physical, chemical and biological parameters as well as farm management makes

estimation of the actual magnitude of cover crop N uptake complex. Remote sensing analysis using satellite imagery can provide a viable solution for real-time estimation of cover crop productivity at watershed or regional scales and thereby improved estimates of N uptake by the winter cover.

In a collaborative effort with MDA, the effectiveness of winter cover crops for sequestration of residue soil nitrogen is being evaluated at the landscape scale. This approach uses remotely-sensed data, field sampling, and cost share program enrollment data (field locations, planting date, method, species, previous crop) provided by farmers to derive real-time estimates of cover crop biomass production and nitrogen (figure 5). Images with four wavelength bands and 10-m (10.9 yd) resolution were acquired by the SPOT 5 satellite for the area of interest within the Choptank River watershed. From the analysis of the remotely-sensed data, a vegetative index (Normalized Difference Vegetative Index, [NDVI]) measurement was calculated using the following equation:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}, \quad (1)$$

where NIR and RED are the spectral reflectance in the near infrared and red regions. The NDVI was then correlated to the in-field biomass and nitrogen uptake measurements using a subset of fields within the program. The derived relationships were extrapolated to the entire population of cost-share program fields within the image to estimate biomass production and nutrient uptake. Figure 6 illustrates the influence of planting date and planting method on NDVI, or biomass production by the cover crops. As expected, the earlier the planting date, the larger the biomass production, and concomitantly, the more nitrogen uptake. In addition, aerial seed application had the largest variability in biomass production suggesting that this method would afford variable effectiveness for nitrogen uptake. Use of the NDVI for cover crops will allow program and watershed managers to optimize implementation of the winter cover crop program at watershed and regional scales.

***Riparian Buffers and Forest Cover.*** Preservation of forest lands and increasing the coverage of riparian buffers along streams has been viewed as important for health of the Chesapeake Bay ecosystem (Lowrance et al.

**Figure 4**

**Relationship between percent forest land use in the 15 subwatersheds and the annual average agrochemical content in stream water.**

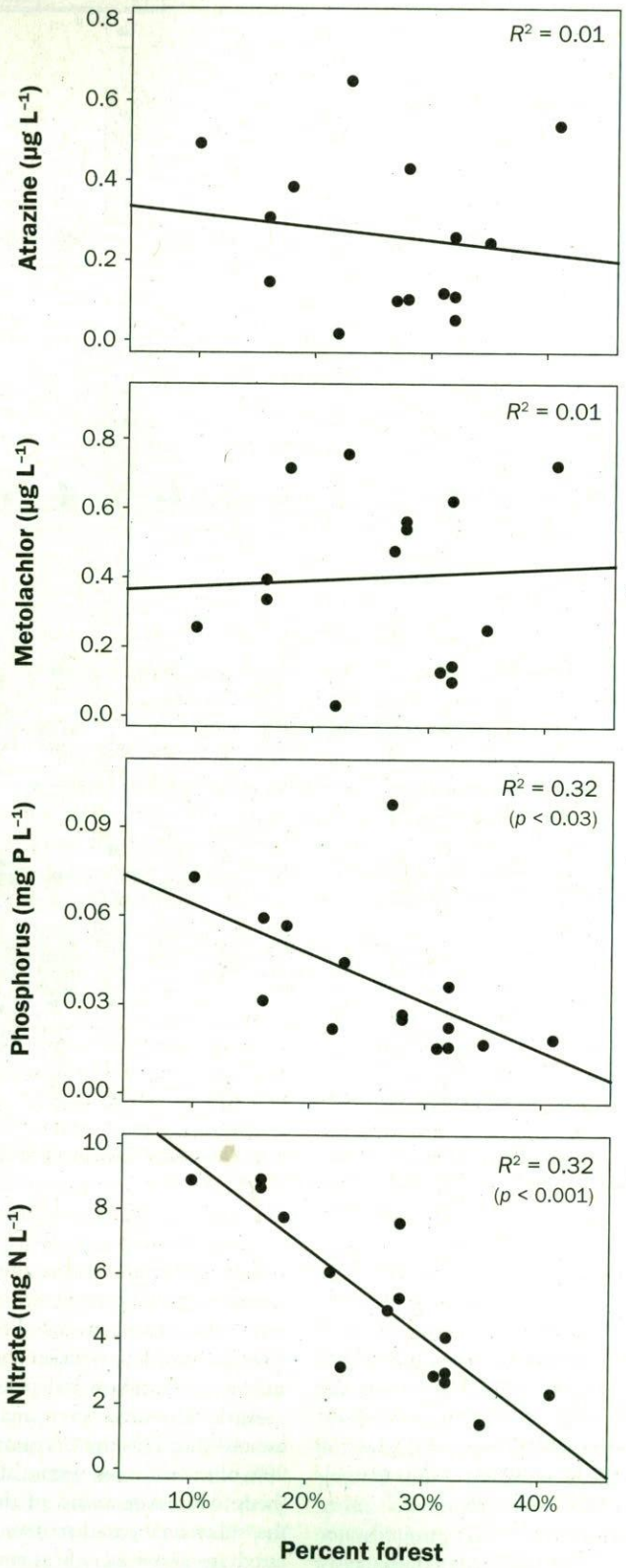
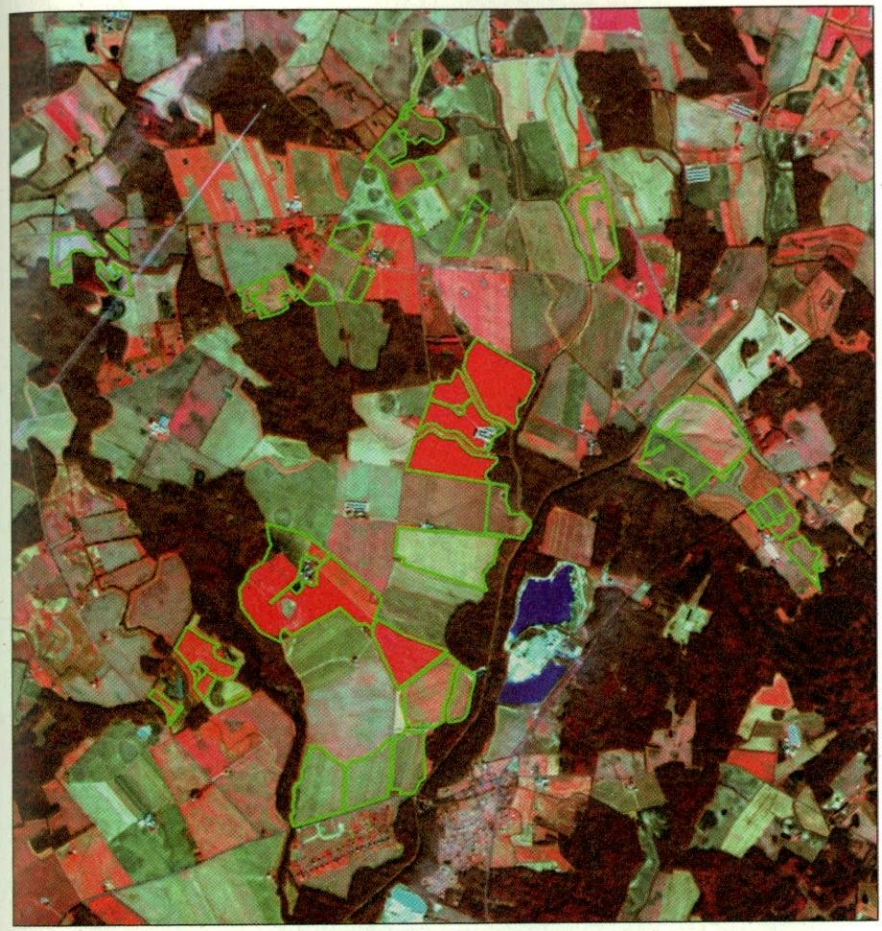


**Figure 5**
**False color SPOT satellite image of a portion of the Choptank River watershed (red indicates vegetation).**



Notes: The image was acquired in December 2005. The fields enrolled in Maryland cover crop cost-share program are outlined in green.

1997). Currently, forests cover 33% of the land area within the Choptank River watershed, which compares to an estimated 58% forest land cover for the entire Chesapeake Bay watershed. A survey of the Upper Choptank River watershed found that approximately 50% of stream reaches were not buffered by forests (MD DNR 2002).

The ecological value of forested riparian buffers is well established (Lowrance et al. 1997). Much of the remaining forest areas in the Choptank River watershed are within riparian areas and/or wetlands that have not been drained for agricultural use. A major initiative within the Chesapeake Bay watershed as a whole is reestablishment of riparian buffers. In 2003, the Chesapeake Bay Program established an expanded riparian forest buffer goal that commits the region to restoring 16,093 km (10,000 mi) of buffer along the edge of streams by 2010 (Lowrance et al. 1997). Agricultural lands are widely available for riparian reforestation; the Conservation Reserve Program and CREP conservation programs have supported over 90% of the riparian reforestation completed to date within the Chesapeake Bay region.

Lowrance et al. (1997) characterized the expected function of riparian buffers based upon the generalized hydrology of these different hydrogeomorphic subregions (figure 7). They concluded that the main difference between riparian buffer function in these subregions was the ability to remove nitrate as groundwater exfiltrates into the riparian buffer/stream ecosystem. In WDU subregions, bypass flows due to deeper aquifers and long flow paths are predicted to deliver groundwater directly to the stream channel, whereas more effective ecosystem interception of nitrate flow paths are expected in PDU subregions. Little difference is expected in riparian buffer function relative to removal of sediment, sediment-borne pollutants, or dissolved phosphorus in surface runoff.

The differences in the lengths of groundwater flow paths for the various hydrogeomorphic subregions will likely affect the responsiveness of stream chemistry to changes in land management within the subregion (Phillips and Lindsey 2003). For example, the stream chemistry in PDU regions with relatively short groundwater flow paths would be expected to respond to land use and land management changes faster than in WDU regions. Phillips and Lindsey (2003) concluded that generally decadal lag periods can be expected between implementation of agricultural BMPs and resulting reduction in nonpoint source pollutants delivered to streams via groundwater within the Chesapeake Bay region. Their results also indicated that the location of the source area in the watershed will influence the lag time between implementation of the BMP and improvement in water quality. Thus, targeting implementation to the highest nutrient sources and in areas closest to the Chesapeake Bay may provide a more rapid water quality benefit.

***Wetland Management and Restoration.*** Wetland restoration is an important component in water quality improvement strategies in the Choptank River and for the Chesapeake Bay. An estimated 800,000 ha (1,980,000 ac) of wetlands have been lost from the Chesapeake Bay Basin. Large sections of the Choptank River watershed have extensive ditch networks so that many historic wetlands are now drained. Geographically isolated wetlands called Delmarva potholes or bays are abundant in parts of the Choptank watershed (Tiner 2003). These unique landscape features provide much of the amphibian habitat for the region and harbor a number of endangered amphibian and plant species within the Choptank River watershed region (MD DNR 2005b).

The MD DNR (2002) has developed a protocol for identifying candidate sites for wetland restoration within the Choptank River watershed. Historic wetland areas are identified based on the presence of hydric soils and on land use with priority given to open land (i.e., agricultural fields and bare ground). Additional priority is given to hydric soils on open land that are close to

existing wetlands or streams. Such sites are further screened for criteria such as habitat enhancement and sensitive species protection. This approach has also been used to identify lands adjacent to streams that are composed of hydric soils but lack stream buffers. This classification takes into account the potential for groundwater/root zone interaction based on drainage class (poorly drained versus well drained setting). Using this method, over 10,700 ha (26,400 ac) of wetlands and nearly 17,300 ha (42,700 ac) of hydric soils have been identified in the Upper Choptank River watershed.

***Satellite-Based Radar for Forested Wetland Detection and Characterization.*** Forested wetlands are one of the most difficult types of wetlands to map using optical imagery, such as aerial photographs and Landsat. Ground-based approaches are resource prohibitive over the large areas often necessary for watershed management. In addition, existing wetland maps, such as the US Fish and Wildlife Service National Wetland Inventory, are difficult to update and represent conditions at one point in time. Better methods are needed to map and to characterize the hydrology of these ecosystems so that their pollutant mitigation can be assessed more accurately.

Satellite-based radar sensors have the capability to monitor changes in the status of the key hydrologic characteristics of wetlands throughout the year and with greater frequency than optical sensors, in part due to the ability of radars to collect images regardless of cloud cover or time of day (Lang and Kasischke 2008). Data collected from the Choptank River watershed (figure 8) demonstrate that the radar-derived wetland delineation is well correlated with the National Wetlands Inventory (NWI) data. More importantly, the use of readily acquired multi-temporal radar data provides access to seasonal dynamics of wetland hydrology that static wetland maps cannot. Not being restricted by clouds is also important when collecting data during rainy periods when wetlands are often easier to discriminate. The sensitivity of radar energy to water and its ability to penetrate forest canopies make radar sensors ideal for the detection of hydrologic patterns in forested wetlands.

***Ditch Drainage Management.*** Because of the extensive ditch drainage network in the watershed, the potential exists for substantial reduction of nitrogen export from agri-

**Figure 6**

**Effect of planting date and seeding method on winter wheat biomass production (December 2005 measurement).**

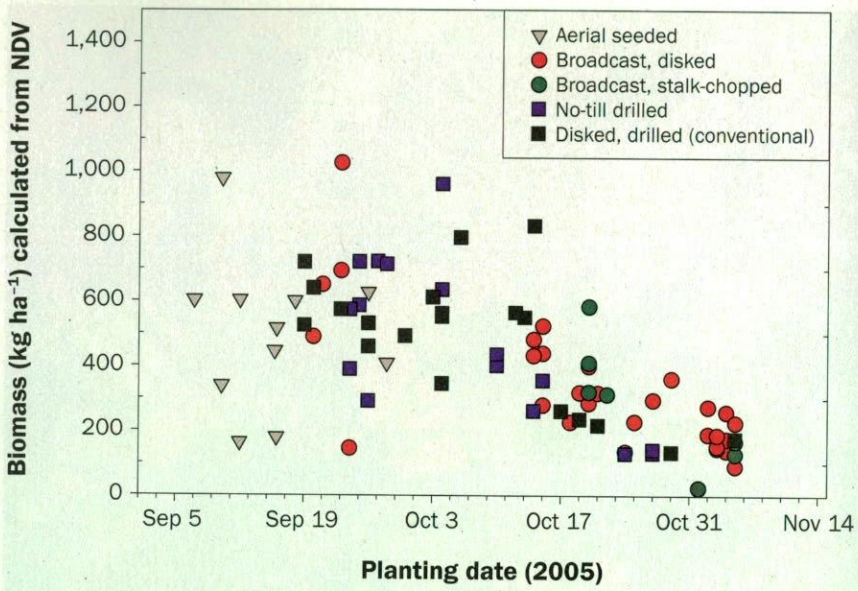
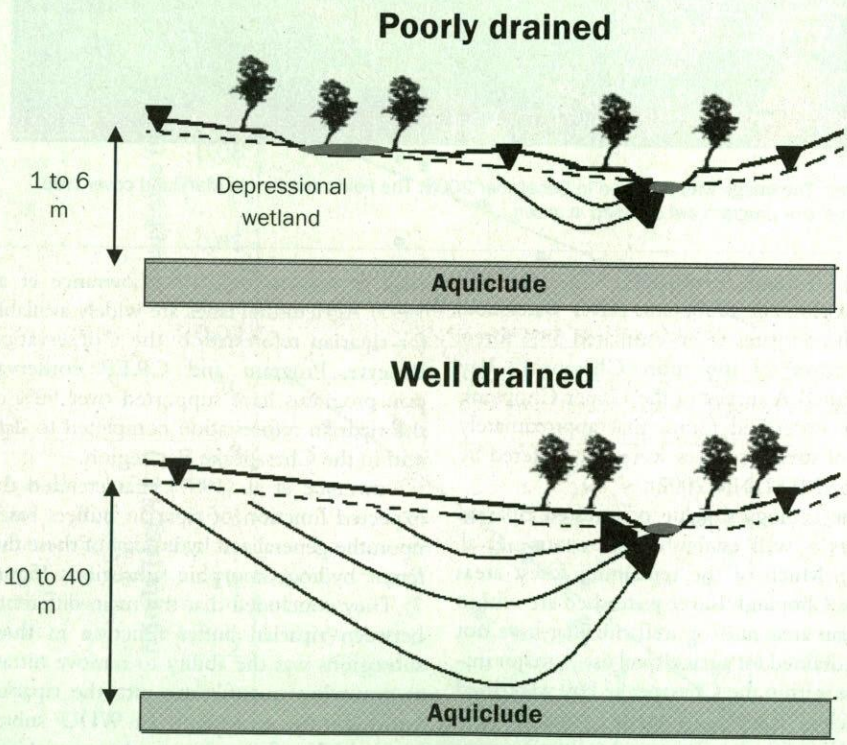



**Figure 7**

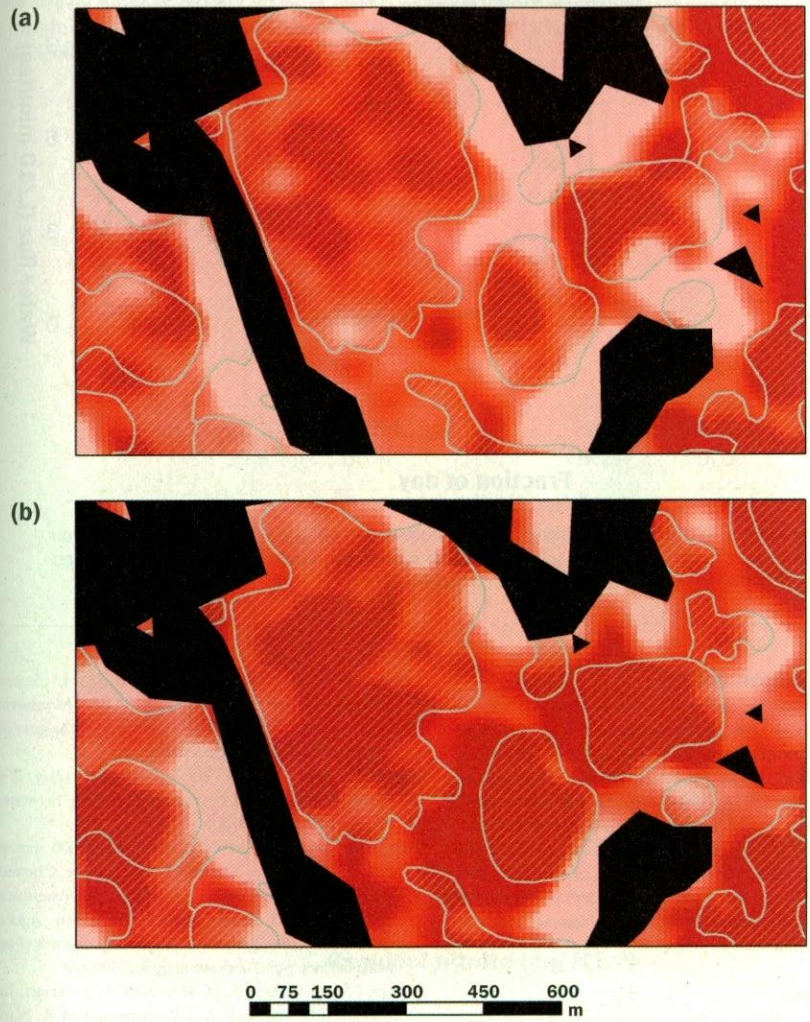
**Predicted flow paths for groundwater exfiltrating to riparian buffer/stream ecosystem in well-drained and poorly drained upland regions.**




Notes: Flow paths in well drained regions may range from 1 to several km and can largely bypass the zone influenced by the riparian buffer. Flow paths in poorly drained regions range between 100 m to 1 km with greater interaction with the buffer ecosystem (Lowrance et al. 1997).

**Figure 8**

**Multitemporal radar-derived maps of forest hydrology (i.e., inundation and soil moisture) collected over a small subset of the Choptank River watershed.**




Notes: The maps represent two different time periods: (a) winter 2005 and (b) spring 2006. Both have been overlaid with palustrine forested wetlands as indicated by the US Fish and Wildlife Service's National Wetland Inventory. Maps depict wetter areas as redder and drier areas as lighter. Black areas are not forested. Note that the forests are wetter during the spring after snow melt and a longer period of low evapotranspiration. Information on hydrology can be used to locate wetlands and predict wetland functions.

cultural fields using flow control structures installed in these ditches. By restricting ditch water flow, these structures can promote the formation of anoxic conditions in the elevated groundwater and the ditch water behind the structure, which is necessary for denitrification. The MDA has a pilot program to introduce the controlled drainage structures in the watershed, but very limited data exists to support their effectiveness on the Delmarva Peninsula. Results from field experiments conducted in North Carolina indicated that up to a 60% reduction in nitrogen export is possible (Osmond et al. 2002). Delaware has proposed using a 45% efficiency factor, and the Chesapeake Bay Program has accepted a recommendation of 33% reduction to be used in their Water Quality Model (Palace et al. 1998; Osmond et al. 2002).

As part of this study, several control drainage structures had been installed in the Choptank River watershed in 2006 and 2007. Nutrient concentrations were measured under base flow and storm flow conditions. The data suggest that the increased denitrification occurs under no or base flow conditions with little or no nitrate in ditch water (data not presented). However, significant flushing of groundwater nitrate through these structures takes place with storm flow events (figure 9). As storm flow increased, the nitrate concentration (not shown) and flux increased markedly. Increases in phosphorus concentration (not shown) and flux lagged slightly behind those of nitrate and may indicate slower overland flow delivery due to preferential flow mechanisms flushing groundwater nitrate. This event represented export of 0.53 kg N (1.2 lb N) and 0.007 kg P (0.015 lb P) from an estimated drainage area of 2.6 ha (6.4 ac) (figure 9).

***Assessing Denitrification in Conservation Technologies.*** Assessing the role of denitrification in the fate of agricultural nitrogen at landscape and watershed scales has been nearly an intractable problem, but such assessments are needed to measure more accurately the effectiveness of BMPs, such as riparian buffers, wetlands, and controlled drainage management, to mitigate nutrient pollution. The isotopic composition of nitrogen and oxygen in nitrate can signal nutrient source and/or extent of biogeochemical processing of the nitrate pool by denitrifiers within ecosystems (Mayer et al. 2002). Denitrification will cause enrichment of $^{15}N$ and $^{18}O$ in nitrate with an accompanying decrease in nitrate concentrations. The amount of denitrification can be calculated from the changes in isotope abundances according to known Rayleigh fractionation relationships (Lindsey et al. 2003).

Separation of the different isotopic signals may be challenging, but in cases where sources such as commercial fertilizers are well characterized, the biogeochemical signal can be differentiated. For groundwater samples, dissolved gas analysis ($N_2$ and Ar) was used to detect the excess dissolved $N_2$ resulting from denitrification (Bohlke 2002; Mookherji et al. 2003), which was then correlated with the isotopic signatures in the nitrate pool. These combined measurements for groundwater can also provide calibration for the isotopic signatures for nitrate found in ditches and streams, which integrates denitrification measurements to the scale of drainage.

Landscape-scale assessments of denitrification based on isotopic data have proven useful for assessing effects of land use on nitrogen export. Analysis of stream water from 13 subwatersheds in the Choptank

River watershed showed a strong linear relationship between nitrate concentration and land area under crop production (figure 10a). The residuals between measured nitrate concentrations and estimated concentrations (from regression line in plot figure 10a) were roughly correlated with enrichment of the heavy oxygen isotope ($\delta^{18}O$) (figure 10b). These findings suggest that denitrification can account for the observed residuals in nitrate concentration and that the isotopic approach has merit for landscape scale assessment of denitrification.

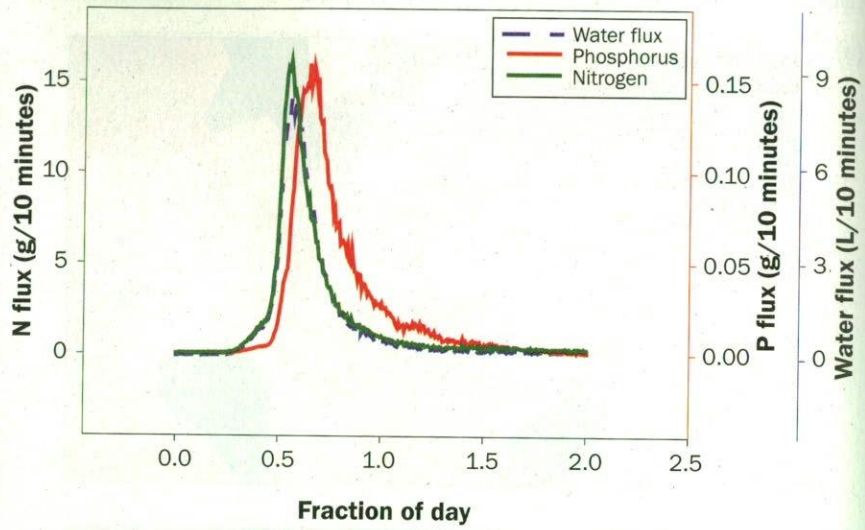
## Summary and Conclusions

In 2004, the Choptank River Watershed project was initiated as part of a national effort to assess effectiveness of conservation practices on a watershed scale. This project brings together the resources of several federal, state, and county agencies and institutions and universities along with local farmers and producers to address conservation practices commonly used within the watershed. The regional goal of improving water quality in the Chesapeake Bay is an additional incentive for success and provides a network of organizations ready to utilize the outcomes of this research.

The infrastructure of scientific expertise, equipment, and on-going monitoring activities will be used to address the emerging issues related to ecosystem health of Choptank River and the Chesapeake Bay estuaries. Studies concerning the interplay of agriculture with carbon sequestration, air quality, and wildlife habitat have also been initiated. These new projects have leveraged the synergies of the broad scientific expertise engaged within the currently described project and the existing network of monitoring stations. Furthermore, as the agricultural paradigm shifts to the production of food, feed, fiber, and fuel, land use and cropping patterns are expected to change with unknown effects on our fragile natural resources. With all the principle partners and stakeholders working together to face these new challenges, practical, effective, and environmentally sound solutions can be found.

**Figure 9**

**Flux of water and nutrients through a drainage control structure during a storm event.**




Notes: Water flux in the controlled drainage structure was monitored by use of a V-notch weir (90°) with water height monitored using a bubbler flow meter. Water samples were collected hourly during the event by auto-sampler (Isco Model 6500).


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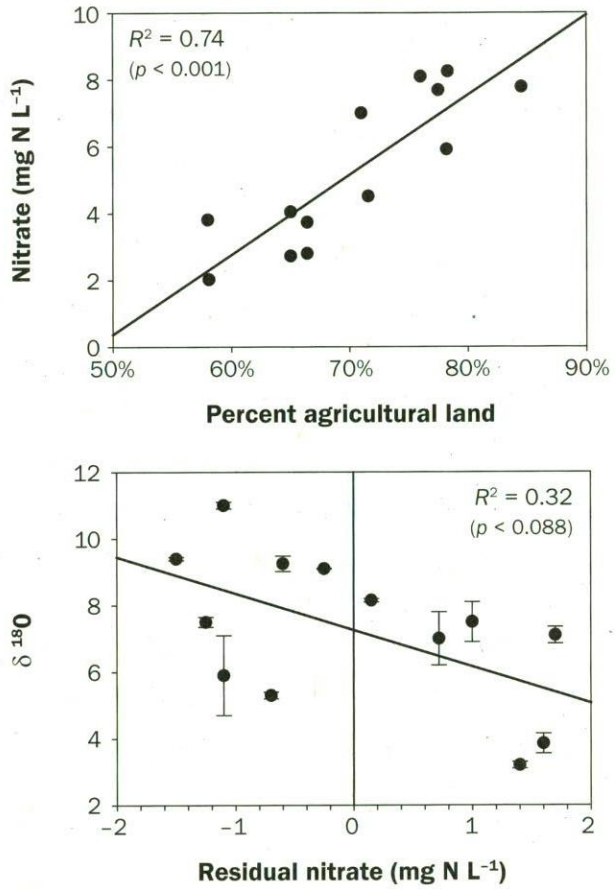
**Figure 10**

**(a) Nitrate concentration in stream water versus percentage of agricultural land in the subwatersheds. The displayed line is fit by linear regression. (b) The $^{18}O$ abundance in nitrate in stream water versus the residual nitrate. Residual nitrate is the observed nitrate minus the nitrate predicted by a linear regression of nitrate concentration versus the percentage of agricultural land in the watershed.**





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