Choptank River

Conservation Effects Assessment Project

NRCS Special Emphasis Watershed
Research Findings and Recommendations
2004—2008

Conservation Effects Assessment Project

USDA - Agricultural Research Service

Choptank River Watershed Project Final Report

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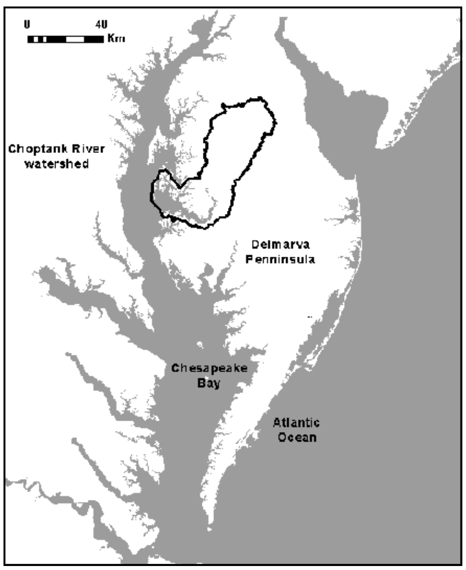
NRCS Special Emphasis Watershed

As part of the USDA-Natural Resources Conservation Service (NRCS) Special Emphasis Watershed Program, the Choptank River Watershed project was initiated in 2004 and was continued through 2008.

The Choptank River Watershed project has now been converted to a USDA-ARS Benchmark Watershed for long-term study. This document serves as the final report to NRCS for the special emphasis watershed project.



Choptank River Watershed

Watershed Description

The Choptank River is a major tributary of the Chesapeake Bay and is located on the Delmarva Peninsula. The 1756 square km (675 square mi) Choptank River Watershed is 58% agricultural (cropland and extensive poultry production), 33% forested, and only 9% urban. Portions of the Choptank River have been identified as “impaired waters” under Section 303(d) of the Federal Clean Water Act due to high levels of nutrients and sediments.

The Choptank River Watershed Project provides several unique aspects to the national CEAP effort. The river itself is tidal for much of its length and includes an ecologically delicate estuarine ecosystem. The soils in the region are poorly drained and the topography is especially flat; therefore, farmers have historically utilized a network of drainage ditches to facilitate the movement of water into streams. Urban influences are growing rapidly.

Project Goals

- Improve estimates of nutrient reduction efficiency values for the widely accepted agricultural Best Management Practices (BMPs) within the Choptank.
- Develop innovative remote sensing tools for estimate cover crop biomass/nutrient uptake and to examine wetland hydroperiod and connectivity on a watershed scale.
- Examine land use and hydrology effects on pesticide and nutrient loads to streams.
- Utilize watershed water quality models to examine conservation practice implementation scenarios to achieve water quality improvements.
- Foster positive relationships with farmers, stakeholders, and customers to preserve the natural resources of the Chesapeake Bay Watershed.

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Recommendations to Achieve Water Quality Improvement Goals

Increase implementation of early planted winter cover crops of barley and rye. *This approach significantly increases nutrient uptake when compared with late planted cover crops. The recommended target cover crop biomass for control of root zone nitrate is about 1 ton per acre.*

Strategically place controlled drainage structures to reduce nutrient flows into ditches. *These structures enhance the process of denitrification in soils. Storm events, however, can still result in nutrient flushing into waterways. Further optimization of this practice is required.*

Protect existing wetlands within the Choptank watershed utilizing newly-developed tools. *These tools can show connectivity with adjacent agricultural areas and monitor wetland function. Targeted expansion of existing wetland areas and restoration of historic wetlands could be used as an effective management strategy to reduce nutrient and pesticide loads prior to entering streams.*

Project Outcomes

Linking Land use with Nutrient and Pesticide Concentrations. Nutrient concentrations were negatively correlated with percent forest content. NO_3^- concentrations varied little over time which is consistent with the more steady delivery groundwater flow. Phosphorus, however, was delivered primarily via overland flow. Both atrazine and metolachlor showed spikes in concentration during early spring when those herbicides are typically applied. Pesticide concentrations did not follow the same land use correlations as nutrients indicating that pesticide transport is more complicated. Delivery can occur via leaching, overland flow, and atmospheric delivery to riparian corridors via drift, volatilization, and/or deposition.

Forested Wetland Function Revealed. A combination of RADAR and LiDAR remotely sensed data was used to develop fine resolution maps of forested wetlands within the Choptank Watershed and to monitor their hydrology (i.e., inundation and soil moisture). This work provides a powerful new approach to examine wetland connectivity and to monitor wetland function on a landscape scale. These tools also can be used to assess ecological services provided by wetlands. For example, information gained on the biogeochemical status and landscape connection of wetlands provides an important indication of the role of wetlands in retention or removal of agricultural nutrients or pesticides from agricultural production areas. Furthermore, these tools can be used to monitor the effectiveness of broad scale wetland hydrologic restoration.

Improving Cover Crops. Remote sensing technologies were combined with agronomic practice data to determine biomass and nutrient uptake by winter cover crops. Critical factors governing uptake were planting date, crop species, and planting method. A threshold cover crop biomass of about 1 ton per acre was observed to control root zone nitrate. Results of this work have been used to improve the effectiveness of the Maryland Cover Crop Program, and improved nutrient efficiency values have been developed with the Chesapeake Program Office Nutrient subcommittee for use in the Chesapeake Bay water quality model.

Controlled Drainage for Nutrient Reduction. Drainage ditches are extensively used in the Choptank and provide a rapid pathway for nutrients to move into streams. Studies have shown that an average of 6% of nitrate applied to agricultural fields can be transported in drainage water to receiving surface waters. Water control structures installed at the drainage outlet were evaluated as a potential conservation practice. Proper management of these structures not only reduces water flow, but also nutrients, mainly N, due to enhanced denitrification. Drainage control structures are often managed to increase water levels to just below the root zone during the growing season and to near the bottom of the drainage ditch during planting and harvesting. Proper management of these structures can potentially reduce nitrate losses in drainage water from 15% to 30%. These results have led to the addition of controlled drainage to the Maryland cost share program.

Modeling the Future of the Choptank. One subwatershed of the Choptank, the German Branch, was used to test two different watershed water quality models: AnnAGNPs and SWAT. The German Branch covers nearly 12,000 acres and is primarily dominated by corn and soybean production receiving poultry manure and fertilizer applications.

Among the nutrients, nitrate losses are of particular concern, much of which escapes through leaching from the crop land via subsurface flow from this dominantly flat landscapes that persist throughout the watershed. In one assessment, the SWAT model was used for analyses of alternative management practice and/or cropping system scenarios. Evaluation of cover crop effects on nitrogen reduction from the watershed was the primary objective of this model evaluation. Simulation results demonstrated that cover crops could potentially reduce large amounts of nitrate in streams. Specifically, 5 to 30% of nitrate could be reduced in streams if cover crops are implemented on up to 50% of the conventional croplands in the watershed. Furthermore, the model simulations showed that nitrogen loss reductions could also be more effective if cover crop implementation followed a targeted watershed management approach.

Land use, Conservation Programs, and Conservation Concerns

Land Use. The Choptank River is located in the Delmarva Peninsula in the Mid-Atlantic Region of the United States. The Choptank basin has an area of 794 sq. mi. At present, approximately 60% of land area in the watershed is dedicated to crop production of corn, soybean, wheat, and barley.

Small to medium animal feeding operations are also located in the watershed. Poultry production is the most prevalent animal production industry. Chicken litter from poultry houses is routinely recycled as a fertilizer on the corn and soybean production fields.

Federal Programs. Several federal and state conservation programs are available to farmers in the Choptank River Watershed. The Maryland Natural Resources Conservation Service (NRCS) provides technical and financial assistance for NRCS programs throughout Maryland and in the Choptank River watershed counties. In addition to these programs, NRCS provides technical assistance for other U.S. Department of Agriculture programs, such as the Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP), which are administered by the Maryland Farm Service Agency (FSA). A list of selected conservation practices implemented by farmers during federal fiscal year 2006, with technical and/or financial assistance provided by NRCS, FSA, Maryland Department of Agriculture (MDA), the Soil Conservation Districts, and other partner agencies, is shown in table 1.

State Programs. Maryland Department of Agriculture (MDA) also implements cost-share programs to promote agricultural conservation. Programs such as the Maryland Agricultural Water Quality Cost-Share (MACS) Program which supports implementation of 30 different agricultural BMPs including the Cover Crop Program, Manure Transport Program, and Nutrient Management Cost-Share Program provide additional financial assistance to farmers within the watershed (table 2).

Ecosystem Concerns. 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 acres) which represents approximately 11 % of the total watershed area *(Maryland Department of Natural Resources (MD-DNR) 2002)*. This loss of wetlands is large when compared with other similar 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, but pesticides and other inputs of organic contaminants are also a concern *(Chesapeake Executive Council 2000)*.

Nutrient Load Estimates. The U.S. EPA Chesapeake Bay Program model (Phase 4.3) estimated that in 2000 agricultural sources contributed 73% of the nitrogen (N) and 62% of the phosphorus (P) load to the Choptank River, whereas agricultural loading estimates in 1985 were 82% of N and 72% of P *(MD-DNR 2005a)*. Urban sources were predicted 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 greater impact on fertilizer application of phosphorus than nitrogen with a 24% decrease in fertilizer phosphorus application *(Sprague et al. 2000)*.

Nutrient Management Plans. In 1998, the Maryland legislature enacted the Water Quality Improvement Act which mandated improved nutrient management by producers. 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 3629 kg (8,000 lb) or more of live animal weight are now required to use a nutrient management plan that addresses both nitrogen and phosphorus inputs. In 2006, 94% of Maryland farmland was covered under a nutrient management plan *(MDA 2007a)*.

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 (ha)	Crop Residue Management Seasonal (ha)	Field Border (mi)	Filter Strip (ha)	Nutrient Management (ha)	Riparian Forest Buffer (ha)	Streambank & Shoreline Protection (mi)	Tree/Shrub Establishment (ha)	Wetland Restoration (ha)
Caroline	83	1538	73	6592	6	1579	0	34	10	66
Dorchester	2563	45	7232	5056	79	223	4	0	0	23
Queen Anne's	1006	1061	29	1203	113	1446	8	358	4	10
Talbot	3771	1936	7	2271	8	2241	1	0	31	28
Total	**7422**	**4580**	**7341**	**15122**	**207**	**5489**	**14**	**392**	**45**	**127**

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**

	MACS Program		Cover Crop Program			Nutrient Management Cost-Share		
County	**Projects**	**Payment**	**Applications**	**Area (ha)**	**Payment**	**Applications**	**Area (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**

* NRCS, 2006 Performance Results System Report on conservation practices (http://ias.sc.egov.usda.gov/prsreport2006/).

** MDA, the Maryland Agricultural Water Quality Cost-Share (MACS) 2006 Annual Report (http://www.mda.state.md.us/pdf/macsar06.pdf)

Hydrologic and Morphological Characteristics

Summary of Activities:

- *15 study sub-watersheds selected for intensive study—each with differences in land use and conservation practice implementation*
- *Stream height measured every 30 minutes at outflow of each sub-watershed*
- *Rating curves developed for each sub-watershed to estimate discharge rates*
- *Nutrient and pesticide concentrations measured monthly at the sub-watershed outflows under baseflow conditions*
- *Land use data and geospatial data layers developed for each subwatershed including CREP implementation.*
- *Nutrient and pesticide concentrations measured at downstream locations in the river less frequently.*

Stream gauging activities using an acoustic doppler current profiler

Soil types. The Tuckahoe Creek and Upper Choptank River sub-basins (figure 1) are located on Mid-Atlantic Coastal Plain soils with parent materials defined by the superposition of upper-delta-plain sands and gravel on marine-inner-shelf sands. Local soil types under cropland production include the Othello series (fine-silty, mixed, active, mesic typic endoaquults) which are poorly-drained with moderately low-permeability, and the Mattapex series (fine-silty, mixed, active, mesic aquic hapludults) which are moderately well-drained with moderate or moderately-low permeability.

Subwatershed gauging. Sampling stations were established at the outlets of 15 upland sub-watersheds drained by 3rd and 4th order streams (figure 1). Each stream was gauged using a Solinst Levelogger Model 3001 F15/M5 with stage data recorded on a 30-min recording interval. Stage-discharge rating curves were developed over a wide range of baseflow and event flow conditions. On sampling days, stream flow was calculated based on average daily stage data and converted to flow with the appropriate rating curve. Together, the 15 subwatersheds drain 322 km^2 of upland making up 16% of the Choptank River basin.

Water quality measurements. 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.

Recent Publication

McCarty et al. 2008. Water quality and conservation practice effects in the Choptank River watershed. *Journal of Soil and Water Conservation. 63(6):461-474.*

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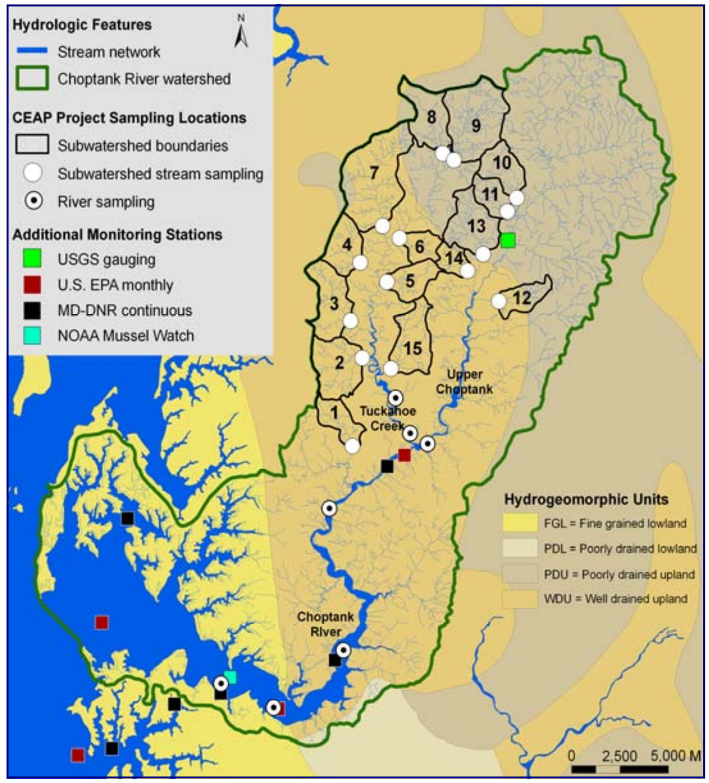


Figure 1. *Locations of study subwatersheds and sampling stations. Hydrogeomorphic regions are designated. Monitoring stations maintained by other state and federal agencies are also indicated.*

Table 3. Area, hydric soil, and land use and soil for the 15 study subwatersheds in the Choptank River

Sub-basin*	Area (km^2)	% hydric soils	% Agriculture†	% Developed†	% Forest†	% CREP‡	% 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

* Sub-basin numbers correspond to the subwatersheds shown in Figure 1.
† Land use as of 1990, determined from Landsat images
‡ Conservation Reserve Enhancement Program (CREP)

Nutrients and Pesticides Follow Different Paths

Land Use. Land use within the subwatersheds varies considerably (Table 3), providing opportunities to discern the influence of land use on the pollutant transport. Agriculture and forest are the two land use classifications that account for more than 90% of the land area within all the sub-watersheds. The percent agricultural lands ranged from approximately 50 to 80% while forested lands ranged from 10 to 40%. Many of the areas within the sub-watersheds 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).

Temporal Data. The temporal variance in the average nutrient and herbicide baseflow concentrations for the 15 monitored streams during an annual cycle is shown in Figure 2. 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 (ppb)] and metolachlor [1.56 µg/L (ppb)] during the spring were 21 and 11 times greater, respectively, than mean concentrations during all other sampling periods.

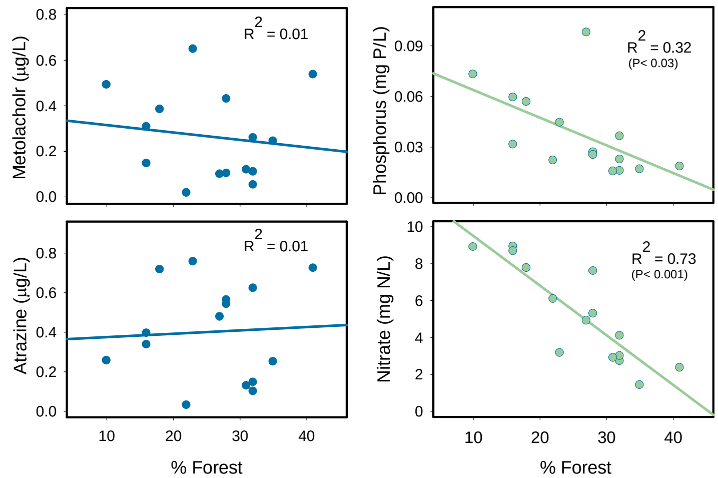


Figure 3. *Relationship between percent forest land use in the 15 subwatersheds and the annual average agrochemical content in stream water.*

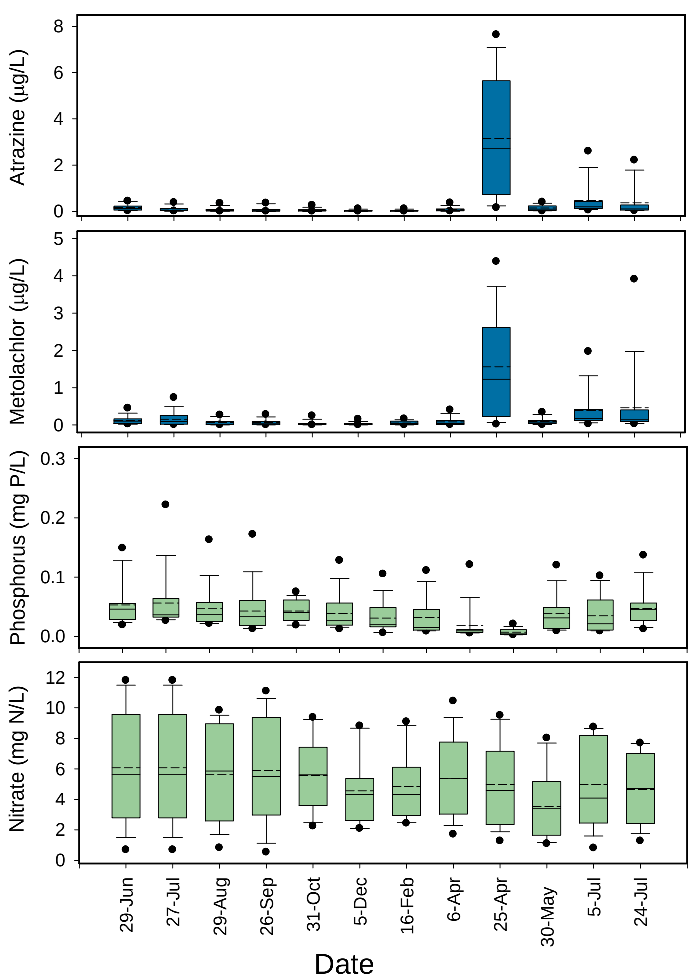


Figure 2. *The distributions in stream water concentration of herbicide and nutrient for the 15 monitored subwatersheds during an annual cycle (June 2005 to July-2006). The dashed and solid lines indicate mean and median values, respectively.*

Temporal data for average nutrient concentrations did not show similar spikes, although PO_4^{3-} showed a slight springtime minimum in median and mean values. Mean or median NO_3^- concentrations for the subwatersheds displayed little temporal variance.

Agrochemical Sources. The lack of temporal variability in NO_3^- concentrations is consistent with a more steady delivery of 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/re-deposition.

Examining Land Use Connections. Figure 3 shows the relationship between percent forest content in the subwatersheds and the 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. Further investigation is needed.

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.

Using Radar to Monitor Forested Wetland Hydrology

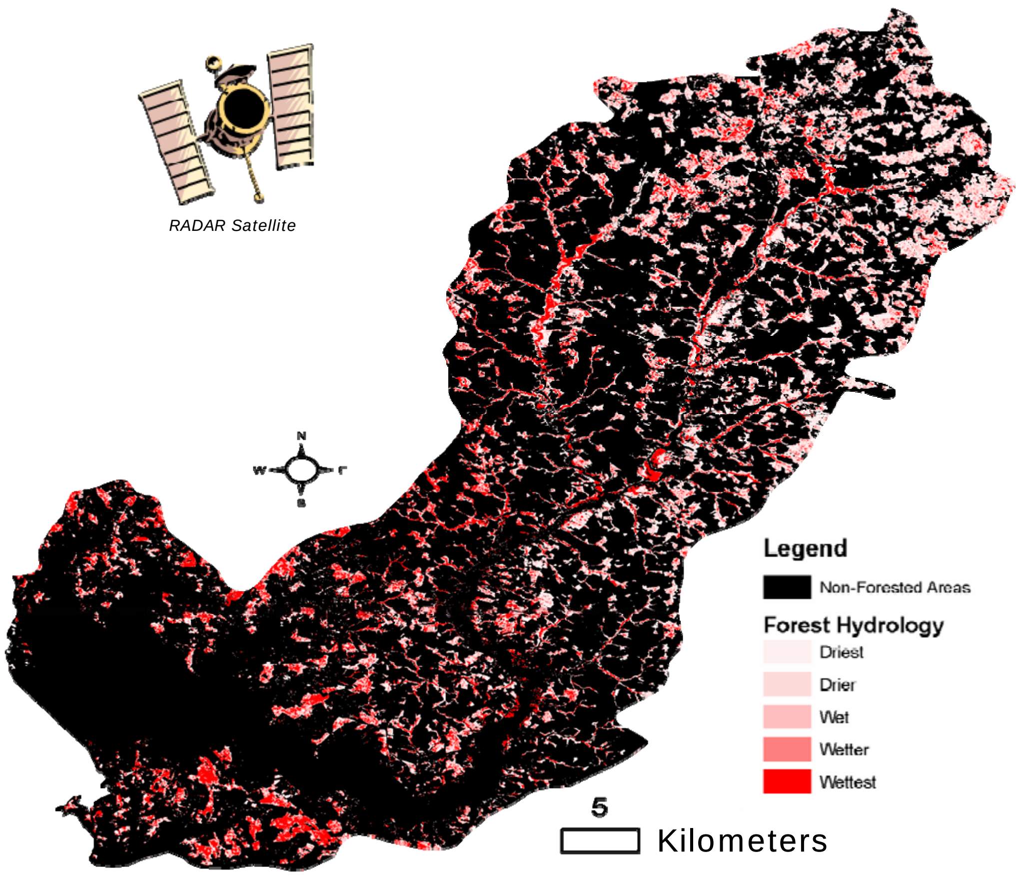
Delmarva Bays in the Choptank. Wetland restoration is an important component in water quality improvement strategies in the Choptank River and for the Chesapeake Bay. Large sections of the Choptank River watershed have extensive ditch networks so that many historic wetlands are now drained. Geographically isolated wetlands called Delmarva Potholes or Bays are abundant in parts of the Choptank watershed. 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.

Monitoring Hydroperiod in Forested Wetlands. Wetland hydroperiod (temporal fluctuations in soil moisture and wetland inundation) controls wetland distribution and the biogeochemical processes (e.g., denitrification) that strongly influence the provision of wetland water quality services. Monitoring forested wetland hydroperiod at a broad scale is difficult using ground-based and traditional optical remote sensing methods. The ability to locate forested wetlands accurately is vital to the management of wetlands in the Chesapeake Bay Watershed where over half of all wetlands are forested.

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 potential can be assessed more accurately.

Using Synthetic Aperture Radar. 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 (Figure 4).

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.



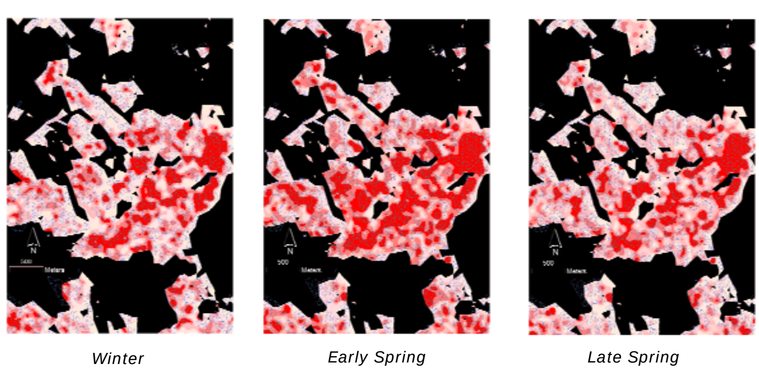


Figure 4. *Map of Choptank River Watershed developed using synthetic aperture radar data. Higher intensity of red color indicates wetter areas. Temporal differences in forest hydrology can be detected through frequent monitoring.*

Recent Publication

Lang, et al. 2008. Assessment of C-band synthetic aperture radar data for mapping Coastal Plain Forested Wetlands in the Mid-Atlantic Region. *Remote Sensing of Environment*. 112:4120-4135.

Using LiDAR to Map Inundation and Wetland Connectivity

Locating Delmarva Bays. Variations in elevation are relatively small on the Eastern Shore of Maryland. Subtle differences in topography can result in the formation of wetlands. The LiDAR-derived digital elevation map shown in Figure 5 illustrates the prevalence of Delmarva Bays and wetland flats in Caroline County.

Connectivity between Wetlands. Our research has demonstrated that the intensity of LiDAR signals can also be used to reveal significant surface flow pathways between Delmarva Bays, which have generally been considered to be isolated wetlands, and intermittent streams (Figure 6).

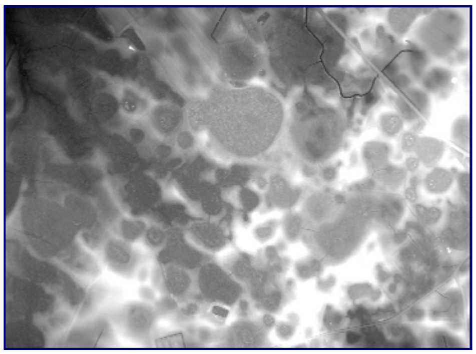


Figure 5. *LiDAR digital elevation map. Darker areas are lower and may be wetlands or pathways for water movement. Circular darkened areas are Delmarva Bays.*

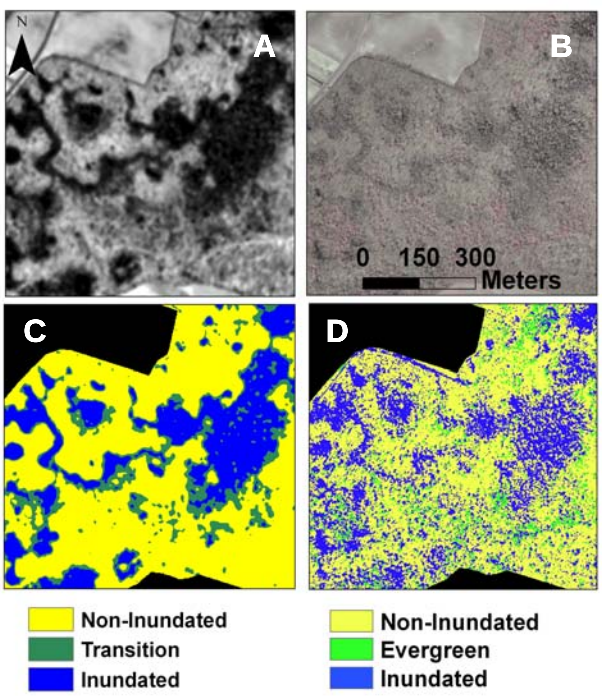


Figure 6. *Comparison of LiDAR intensity (A) and traditional aerial photography (B) of the same forested wetland areas. Wetland maps created using these two types of data are shown in C and D. Inundated areas are better delineated by LiDAR and surface flow pathways between wetlands are much clearer.*

Exploiting the Synergy of Information Gained from Active Sensors

Seeing through the Canopy. Both RADAR and LiDAR are similar in that they are active (energy emitting) sensing technologies based on the detection of reflected energy, however information gained from each sensor is unique and synergistic for wetland characterization. Both sensors have the ability to see through the forest canopy which makes them ideal for revealing under canopy surface hydrology.

The Choptank River Watershed studies have provided opportunities to identify the strengths of each sensor for forested wetland characterization. For example, RADAR can provide detailed temporal information on wetland hydroperiod over a broad expanse such as the Choptank Watershed. LiDAR can provide very detailed surface elevation maps and point-in-time inundation maps which are extremely useful for fine scale mapping of wetlands. The combined high resolution temporal and spatial datasets from these sensors can greatly improve understanding of ecological services that wetlands provide and will likely have bearing on the management and conservation of wetland ecosystems in agricultural landscapes.

Building Better Wetland Maps. An example of the synergistic advantage of these two tools is provided in Figure 7. The top image shows a farm with agricultural fields and a small forested area in the right hand bottom corner. This area has been drained through the use of ditches.

The bottom image is the digital elevation maps of the same area in black and white developed from LiDAR. The DEM is overlaid with the radar maps shown in red. The DEMs can be used to estimate how much surface water leaves the agricultural fields.

These maps can also be used to determine where this water goes. Pathway A leads straight to a ditch and into the Choptank. Pathway B leads to a forested wetland where nutrients, sediments, and pesticides may be removed prior to entering the Choptank River.

The ability of these wetlands to reduce certain pollutants can be estimated utilizing the radar images. This information can be used then to best conserve wetland function and to implement other best management practices properly.

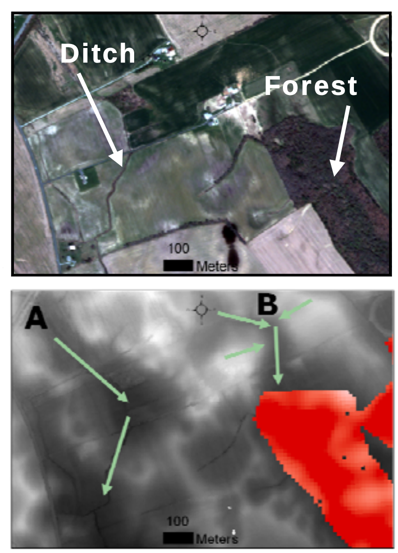
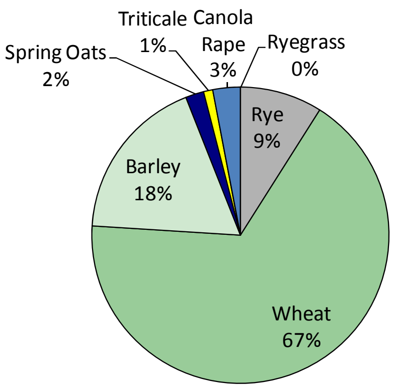


Figure 7. *Aerial photo of farm compared with LiDAR and RADAR maps and flow paths*

Winter Cover Crop Programs



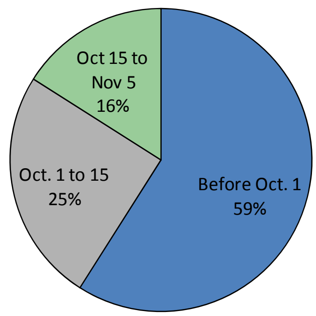


Figure 8. *2007/2008 Maryland Cover Crop Program Acres by species (above) and by planting date (right)*

Conventional Cover Crop Cost-Sharing. Farmers who enroll in the Maryland conventional cover crop cost-share program are compensated at a variable rate that pays more for early-and standard-planting dates (Sept 15 - Oct 15) than for late-planting dates (up to Nov 5) (Figure 8). Nutrient application is prohibited prior to March 1st of the following year, and the cover crop may not be harvested for sale.

Commodity Cover Crops. Additional cost-share programs support the implementation of commodity cover crops (grain crops grown for market without fall fertilizer application) and legume-grass cover crop mixes for use on certified organic farms. This combination of cover crop cost-share programs receives considerable annual funding. It is expected to make a significant contribution to the reduction of non-point source agricultural nutrient pollution to the Chesapeake Bay.

Cover Crop Benefits. Rye cover crops have been shown to decrease leaching of soil N by up to 80% by reducing available soil nitrate concentrations during winter months (Staver and Brinsfield 1998; Shipley et al. 1991; Strock et al. 2004). Cover crops have also been shown to have beneficial effects on soil aggregate stability and mycorrhizal colonization, soil phosphorus management, erosion prevention (Kaspar et al. 2001), farm profitability (Watkins et al. 2002), pest control (Staver and Brinsfield 1998), and yield of following crops (Hively and Cox 2001; Kabir and Koide, 2002; Snapp et al. 2005). These positive environmental effects, however, can be limited if the cover crops are not established in a manner that promotes the growth of abundant biomass prior to the winter season.

Satellites Provide a Watershed View of Cover Crop Performance

Estimating Cover Crop Effectiveness. Current estimates of cover crop effectiveness and nutrient uptake efficiency rely heavily upon small-plot (e.g., Shipley et al. 1991) and catchment-scale experimental data (Staver and Brinsfield 1998) extrapolated to match implementation acreages. In practice, however, landscape-scale variability in physical, environmental, and farm management parameters makes estimation of the actual magnitude of cover crop N uptake complex.

Normalized Difference Vegetation Index. Remotely-sensed data have long been used to estimate vegetation abundance in the landscape (Lu 2006; Pinter et al. 2003). A commonly used measure (Tucker 1979), the Normalized Difference Vegetation Index (NDVI), is calculated as a ratio of red and near-infrared (NIR) reflectance: [NDVI = (NIR – red) / (NIR + red)]. The NDVI, which correlates closely to plant leaf area index (Weigland et al. 1992), has been used successfully to measure the biomass, yield, N status, chlorophyll content, and photosynthetic capacity of wheat crops (Bendetti and Rossini 1993; Hansen and Schjoerring 2003; Reyniers and Vrindts 2006; Weigland et al. 1992).

Combining Techniques. The current study derived estimates of cover crop N uptake efficiencies at the landscape scale by using a combination of satellite remote sensing imagery, on-farm sampling, and acquisition of agronomic data from cost-share program implementation records (Figure 9). This innovative methodology allowed the direct evaluation of agronomic factors (species choice, planting date, and planting method) affecting cover crop productivity. It also allows accurate cost-benefit analysis of cover crop programs (Figure 10).

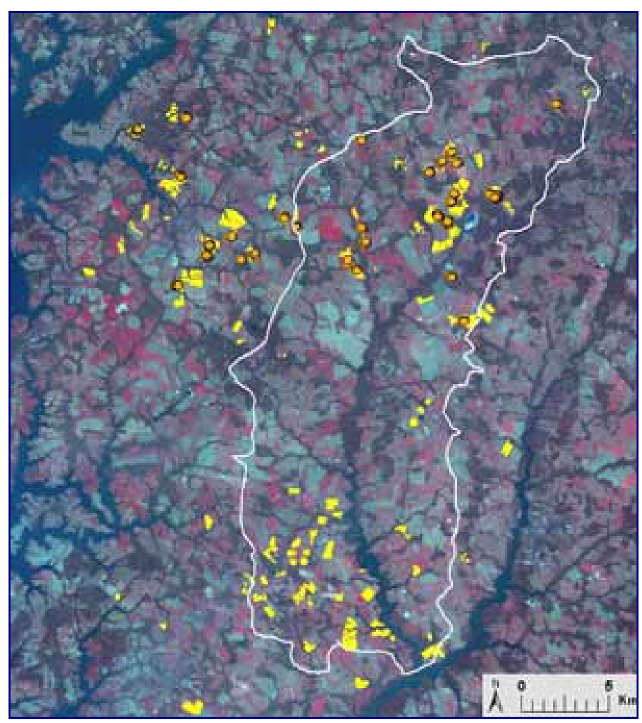


Figure 9. *SPOT satellite image of the Tuckahoe Creek Branch, Choptank River. Red areas indicate vegetation. Cover crop fields are shown in yellow. Biomass and soil sampling locations are shown in orange.*

Nitrogen Uptake by Cover Crops Governed by Species and Planting

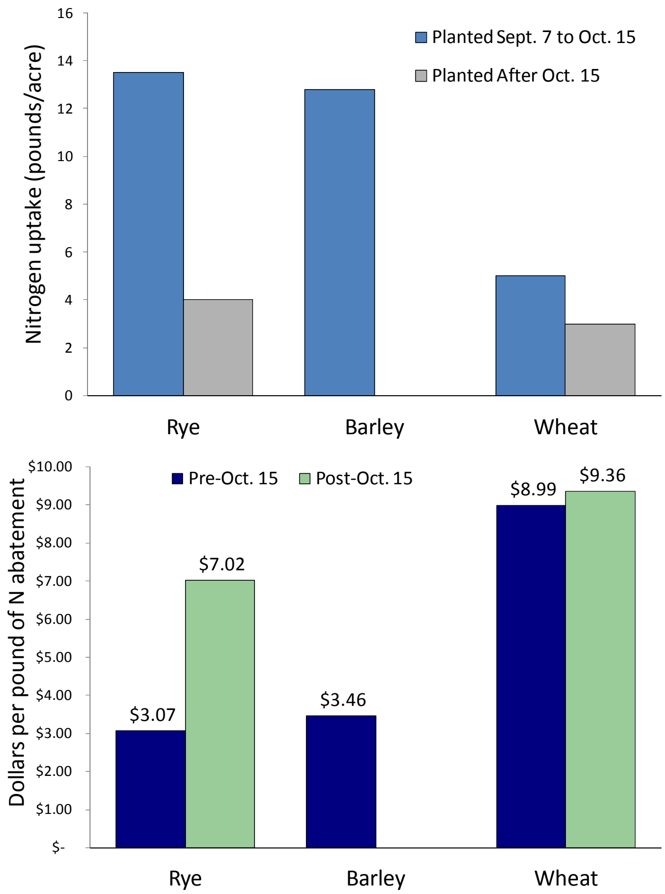


Figure 10. *Nitrogen uptake by cover crops and cost of N abatement relative to planting date*

Overall Findings

- The combination of satellite remote sensing with conservation practice implementation data allows the evaluation of cover crop performance on a landscape scale and the identification of most successful management strategies.
- Early planted rye and barley cover crops produce a greater biomass and therefore take up significantly more nitrogen than early planted wheat cover crops.
- An emphasis on early planted rye and barley will increase the efficiency of cover crop cost-share programs by reducing the cost of nitrogen removal.
- The recommended target cover crop biomass for control of root zone nitrate is about 1 ton per acre.

Future Goals

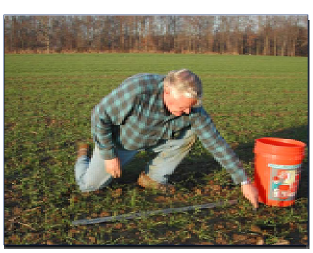
- Develop an operational monitoring tool allowing watershed managers to effectively manage winter cover crops, including the ability to target implementation to achieve environmental endpoints.
- Expand the use of remote sensing and GIS technologies to monitor erosion control in the upland Piedmont landscape.
- Begin scale-up of technology transfer by working with Soil Conservation Districts to develop operational GIS tools for cover crop monitoring and management.

Upcoming Publication

Hively, W.D. et al. 2009. Using satellite remote sensing to estimate winter cover crop nutrient uptake efficiency. *Journal of Soil and Water Conservation*. (in press)

Leveraging Resources: Two Targeted Watersheds Grants Awarded

Scientists working on the Choptank River CEAP project cooperated with Maryland Department of Agriculture staff received two grants from the National Fish and Wildlife Foundation's Targeted Watersheds Program. Funding was supplied by the U.S. EPA and the Chesapeake Bay Trust.



Innovative BMP Implementation Strategies to Improve Water Quality within the Choptank River Watershed with a Targeted Effort in the Tuckahoe Sub-Basin
Grant Period: 3/2006 to 9/2009
Funding: $ 982,000
Objectives:

- Increase cover crop implementation on the Tuckahoe Creek Brach by 6000 acres.
- Develop improved nutrient reduction efficiencies for conventional cover crop, commodity cover crop and drainage control structures.
- Develop a flexible, user-friendly planning tool that may be used by conservation program managers to optimize BMP implementation

Implementing and Evaluating Small Grain Commodity Cover Crops for Water Quality Protection and Bio-Energy Production: Chester River Watershed
Grant Period: 4/2008 to 9/2010
Funding: $ 375,400
Objectives:

- Evaluate the environmental and economic benefits associated with barley and wheat commodity cover crops grown within the Choptank River and Chester River Watersheds.
- Utilize remote sensing and on-farm research to quantify nutrient uptake by winter small grain commodity cover crops, assess yield reductions and economic cost/benefit associated with eliminating fall fertilization on small grains.

Assessing the Effectiveness of Controlled Drainage Structures

Controlled Drainage Structures. Because of the extensive ditch drainage network in the watershed, the potential exists for substantial reduction of nitrogen export from agricultural 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.

Pilot Programs. 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 Bay Water Quality model (Palace et al. 1998; Osmond et al. 2002).

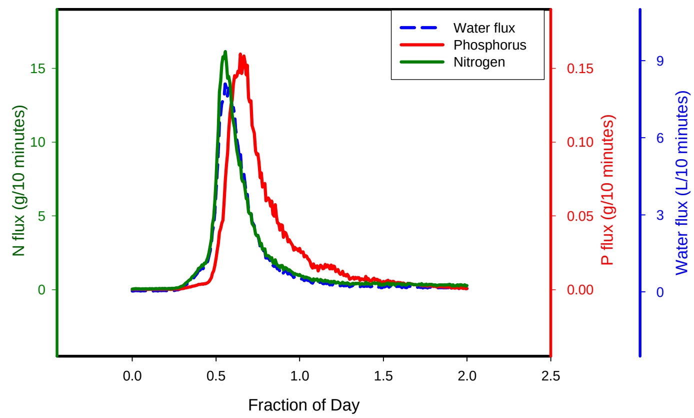


Figure 12. *Flux of water and nutrients through a drainage control structure during a storm event. Water flux in the controlled drainage structure was monitored by use of a V-notch weir (90°) with water height monitored using a bubbler flow meter. Water samples were collected hourly during the event by auto-sampler.*

Conference Proceeding

Sadeghi et al. Watershed Model Evaluation of Agricultural Ditch Drainage Control Structures for Improved Water Quality, *21st Century Watershed Technology: Improving Water Quality and Environment Conference Proceedings*, 29 March - 3 April 2008, Concepcion, Chile 701P0208cd.

Results. Several control drainage structures were 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.

However, significant flushing of groundwater nitrate through these structures takes place with storm flow events. As storm flow increased, the nitrate concentration and flux increased markedly (Figure 12). Increases in phosphorus concentration 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 and 0.007 kg P from an estimated drainage area of 2.6 ha.

Figure 11. *Controlled drainage structure and ditch equipped with flow monitoring and sampling equipment (above). Top view of controlled drainage structure. Boards can be added and removed to adjust water levels (right).*

Examining Denitrification Using Nitrogen Isotope Signatures

Denitrification Assessment 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. Such assessments, however, 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).

Isotopic signals. 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.

Results. 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 sub-watersheds in the Choptank River watershed showed a strong linear relationship between nitrate concentration and the percentage of land area under crop production (Figure 13A).

The residuals between measured nitrate concentrations and estimated concentrations taken from the regression line in plot Figure 13A were roughly correlated with enrichment of the heavy oxygen isotope ($\delta^{18}O$) (Figure 13B). 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.

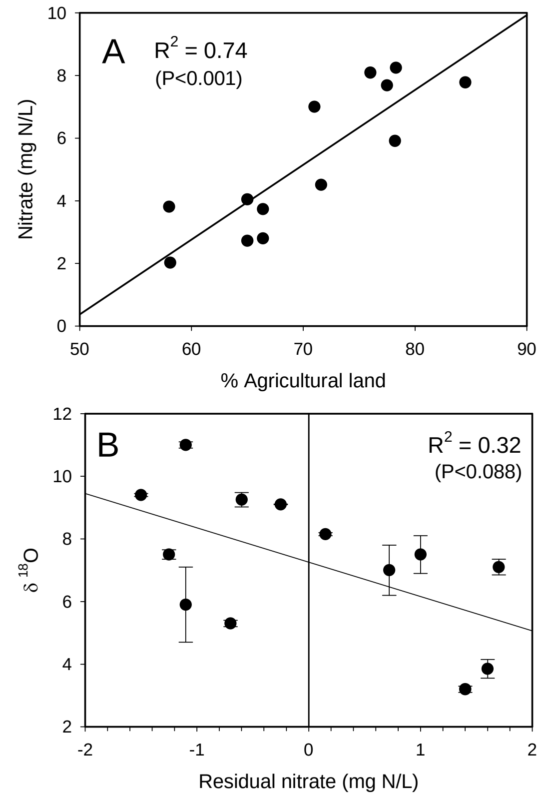


Figure 13. *A. Nitrate concentration in stream water versus percentage of agricultural land in the sub-watersheds. The displayed line is fit by linear regression. B. The ^{18}O abundance in nitrate in stream water vs. the residual nitrate. Residual nitrate is the observed nitrate minus the nitrate predicted by a linear regression of nitrate concentration vs. the percentage of agricultural land in the watershed.*

Leveraging Resources: Water Quality Grant Awarded to Partners

During this project, Co-PIs Thomas Fisher, Thomas Jordan along with collaborator Kenneth Staver received funding ($493,000) from AFRI (formerly CSREES) for the project entitled, "Effects of agricultural conservation practices on nitrate losses from croplands of the Choptank River basin".

The project focused on detailed studies of denitrification within the same 15 subwatersheds using a combination of dissolved gas measurements (N_2, O_2 and Ar) and the isotopic composition of nitrate in groundwater and stream water. This project expanded upon but did not duplicate the work described above.

Groundwater sampling for dissolved gases and nitrate

AnnAGNPs Model Calibration of German Branch

About AnnAGNPS. AnnAGNPS is a model designed to evaluate risk and cost/benefit analyses at the watershed scale. The model was developed to specifically simulate long-term sediment and nutrient transport from ungauged agricultural watersheds. It runs on a continuous, daily time step, and can be used to estimate surface runoff quantities and associated pollutant loadings for watersheds of various scales, from small to very large.

The basic modeling components are hydrology, sediment, nutrient, and pesticide transport. The pollutants are routed from their origin within the land area and are either deposited within a stream channel or transported out of the watershed. This approach provides a watershed model capable of simulating most of the management practices that are applied on farms. AnnAGNPS, like most other watershed models, uses the SCS curve number technique to generate daily runoff and RUSLE 1.05 technology (Renard et al, 1997) to generate daily estimates of sheet and rill erosion from fields (Geter and Theurer, 1998).

Land Use Inputs for Modeling the German Branch. Initial modeling was focused on the German Branch subwatershed (Figure 14) which has a long-term record of water quality data. All AnnAGNPS inputs reflect those occurring during the simulation period (1991-1995). Model calibration and subsequent validation were performed using 1990-1995 water quality data records provided by Primrose et al. (1997).

Determining exact management practices for farms is difficult because of the inherent privacy of farm owners. This information, however, is critical for accurately applying the model in developing and assessing future scenarios. Therefore, to calibrate AnnAGNPS for the German Branch, farm management schedules were derived from NASS data and supplemented with information gathered from County Extension Offices. Management schedules for the AnnAGNPS cells reflect as closely as possible management practices that were implemented within 1991-1995. Evaluation of the 1994 DOQQs (digital orthophoto quarter-quadrangle) was also used to pinpoint spatial information such as the location of poultry houses.

Crop Rotation and Management Schedules. Two typical crop rotation and management schedules were identified. Neither rotation included a cover crop because there were no programs promoting their use in place during that time period. All small grains were assumed to be grown as commodity and were fertilized in the fall and again in spring. The first rotation accounts for the 70% of the cropland being under conservation tillage management, and the second rotation accounts for the 30% of the watershed in conventional tillage management.

Nutrient Content in Poultry Litter. Poultry litter was assumed to be applied to all cropped fields because interviews with extension agents suggested about 95% of German Branch farmers used some poultry litter on their farms. The nutrient content of the litter was estimated from literature provided by the MD Extension Service. Both inorganic and organic N and P ratios were needed for the poultry manure and is a sensitive parameter to N and P outputs of the model (Leon et al, 2004).

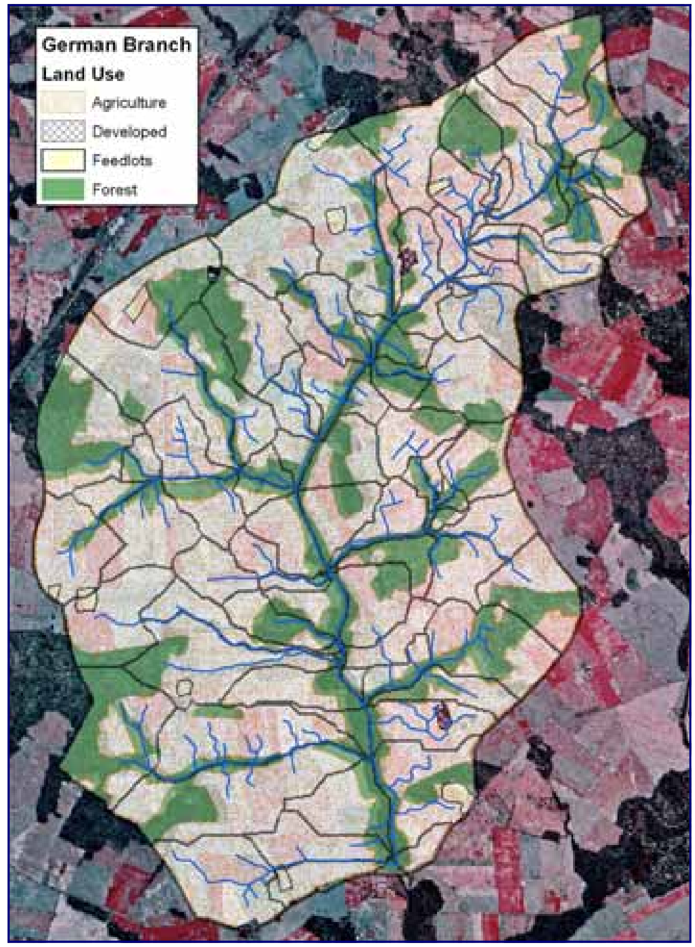


Figure 14. *Detailed landuse overlaid with AnnAGNPS cells (black boundaries) for the German Branch subwatershed*

Riparian Buffers. Natural riparian buffers have been simulated in AnnAGNPS by increasing the time of concentration (Tc) and adjusting the RUSLE sub-P factor in cells that contain riparian areas. Identification of these areas was performed through visual inspection of the overlay of the landuse map, 1994 DOQQ's and AnnAGNPS Topaz generated cells. The adjustment of those parameters was used as a point of calibration. For cells containing buffers, the Tc was initiated at a 25% increase for the cells containing buffers (over a no-buffer scenario) and the RUSLE sub-P factor was adjusted to 0.78.

Calibration and Validation. Within the 1991-1995 time period, AnnAGNPS was calibrated using the first 3 years of climate and water quality data. The last two years (1994 and 1995) were used for validation. The Nash-Sutcliffe coefficient of efficiency (NS) was used to evaluate model performance. In recent literature, Nash-Sutcliffe values have been used to successfully evaluate AnnAGNPS performance for watersheds in Canada (Leon et al., 2004) and New South Wales Australia (Baginska et al., 2003).

Predicting Cover Crop Effects in the German Branch

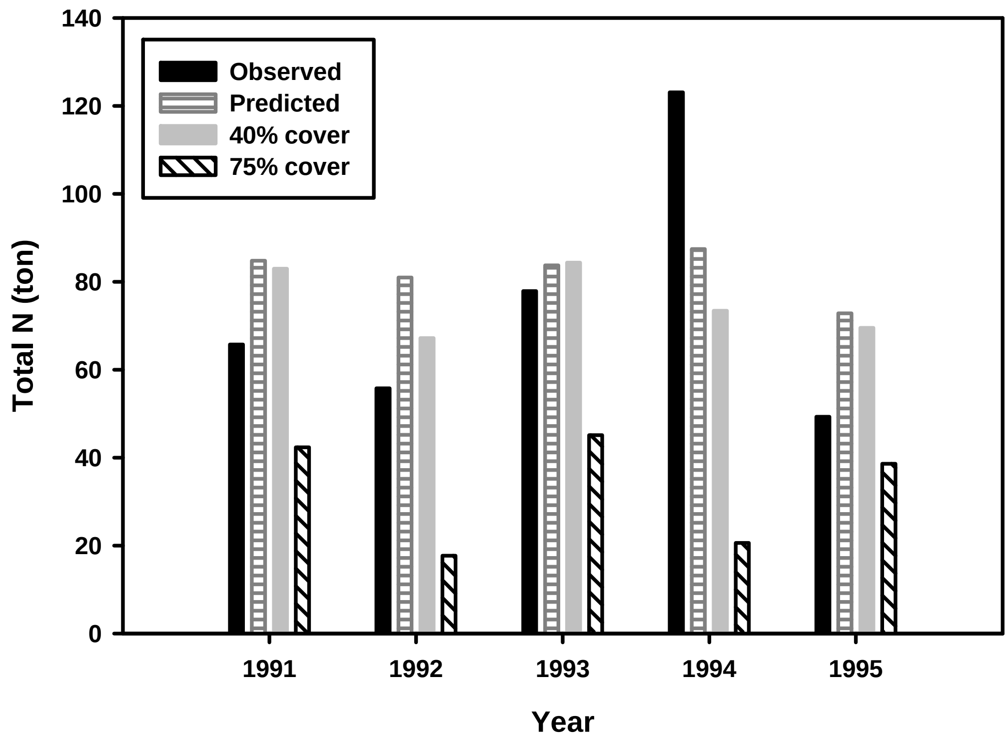


Figure 15. *Total N exported from the German Branch subwatershed—observed, model prediction using actual land use data, and simulation with land use changed to 40% and 75% cover crop*

Results. In the German Branch, AnnAGNPS calibration and validation of monthly flow resulted in final NS values of 0.61 and 0.71 respectively. These values indicate that the model performed well at estimating monthly flows. The final curve numbers after calibration were as follows: corn-no-till-73, corn-conventional-till-76, wheat-72, soybean-72, and fallow-83.

Although monthly total N loads were calibrated to a low NS value of 0.51, trends were fairly well simulated. While this calibration level is only slightly above an acceptable 0.5 value, further adjustments to the input parameters did not improve the calibration.

In many cases, AnnAGNPS underpredicted observed N loads, particularly during the summer months. This may be attributable to the patchy spatial distribution of summer storms. Given the quick response time of the German Branch stream, it is not unreasonable to assume that an isolated thunderstorm producing significant rain within the subwatershed might not be recorded by the off-site climate station, but could result in runoff.

AnnAGNPS does allow for multiple climate stations, however, another reliable station near or within the watershed boundary was not found. A second source of error in the model predictions is undoubtedly the result of uncertainty in the spatial and temporal variability of management practices.

Gathering spatial data for modeling efforts

Cover Crops Effects. The effect of cover crops on nutrient loads was evaluated by randomly assigning cover crop practices to agricultural land use cells until 40% and 75% acreage was achieved. This cover crop simulation assumes 1) that winter grain crops are not fertilized and 2) that cover crops replace both winter conventional grain crops and winter fallows.

In this scenario, 40% cover cropping resulted in little yearly reduction in total N, however **increasing the percentage of cover crop to 75% yielded a dramatic decrease in total N at the outlet** (Figure 15). The response in N runoff to percent cover crop does not appear to be linear. The reason for this is not well understood, but may be related to the placement of cover crops within the watershed during the simulation.

With 40% of the land area in cover crops, the AnnAGNPS cells containing cover crops were not well connected spatially; therefore, the mitigation effect on runoff would be expected to be limited. When the acreage of farmland in cover crops increases to 75%, more of the AnnAGNPS cells with cover crop are connected, multiplying the mitigation effects on runoff.

Conclusion. Simulation of two different cover crop levels in the watershed revealed that a high level of cover crop implementation is needed (more than 40%) before any significant effect on N loads in the German Branch can be observed.

Customer Workshops and Outreach Activities

A number of different types of outreach activities have been carried out as part of this project to keep our customers informed.

CUSTOMER WORKSHOPS

October 19, 2006— A 1-day workshop was held in Ruthsburg, Maryland within the Choptank River Watershed. Attendance was around 60 people including producers, county extension personnel, Maryland Department of Agriculture, other government agencies such as US EPA, US Forest Service, USGS, and other ARS and university scientists. Presentations were provided on the various aspects of the project, and a field tour demonstration of different sampling techniques was given for attendees.

March 25, 2008— Another 1-day workshop was attended by approximately 100 people including congressional staffers, scientists from several states, and representatives of all the groups listed above. This workshop included field demonstrations and a panel discussion to identify agricultural research efforts are critical to the restoration of Chesapeake Bay tributaries.

Additional Outreach Activities included:

- Queen Anne's County Agronomy Day—2006-2007
- Caroline County Public Drainage Association Annual Meeting — 2006-2008
- Choptank River Tributary Strategies Team Meeting—2006
- USEPA Targeted Watersheds Workshops 2006-2008
- Queen Anne's County Maryland Extension—2007
- Caroline County Maryland Extension Office—2007
- Ditch Drainage Tour of Eastern Shore - 2007
- Maryland Chesapeake Bay Restoration Fair—2007
- Maryland Pesticide Network—2007-2008
- Maryland Soil Conservation Districts Tour of Choptank Watershed sponsored by Maryland Department of Agriculture —2008
- Chesapeake Bay Commission Cover Crop Enhancement Workshop—2008
- CRC Ecosystem Based Management Workshop—2009
- March 2009 – Association of State Wetland Managers: State/Tribal/Federal Coordination Meeting Presentation—2009

SCIENTIFIC CONFERENCES

- American Chemical Society National Meetings: 2006—2008 including Symposium on Water Quality in Chesapeake Bay 2008
- Soil and Water Conservation Society National Meetings: 2005—2008
- American Society of Agronomy National Meetings: 2005—2008
- International Geoscience and Remote Sensing Symposium: 2008
- Society of Wetland Scientists Presentations: 2008

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