2010 Trust Fund
Water Quality Monitoring Strategy

PREPARED BY THE TRUST FUND EVALUATION WORKGROUP

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Executive Summary

This Monitoring Strategy was designed to identify nutrient reduction efficiencies of best management practices (BMPs) and provide information to determine what type of monitoring is needed by Trust Fund recipients to evaluate the effectiveness of BMP implementation. The main objective is to provide a comprehensive protocol that serves all water quality assessment needs when monitoring urban and agricultural nonpoint nutrient and sediment fluxes. The methods and results of several intensively monitored case studies indicate that BMP implementation can be highly effective at reducing nutrient and sediment fluxes to receiving waters, but that similar efforts to obtain these results are not practical for Trust Fund projects. Accordingly, the recommendations made in this Monitoring Strategy are for Trust Fund recipients to select the correct sampling designs, frequency of sampling, and appropriate constituents to measure in order to minimize monitoring efforts and costs and still allow for the detection of nutrient and sediment reductions, when possible. Sampling on larger scales (i.e., rivers draining large watersheds) should only be done in the event that estimates suggest more than a 30% reduction in nutrient or sediment loads to receiving waters will be achieved through BMP implementation of one or more projects in the same basin. Otherwise, monitoring the effectiveness of BMPs should be done as close to the implementation site as possible according to the guidelines provided in this booklet. Appendices provide nutrient reductions efficiencies for a wide range of BMPs, as well as information on quality assurance, data analysis, and communicating results.
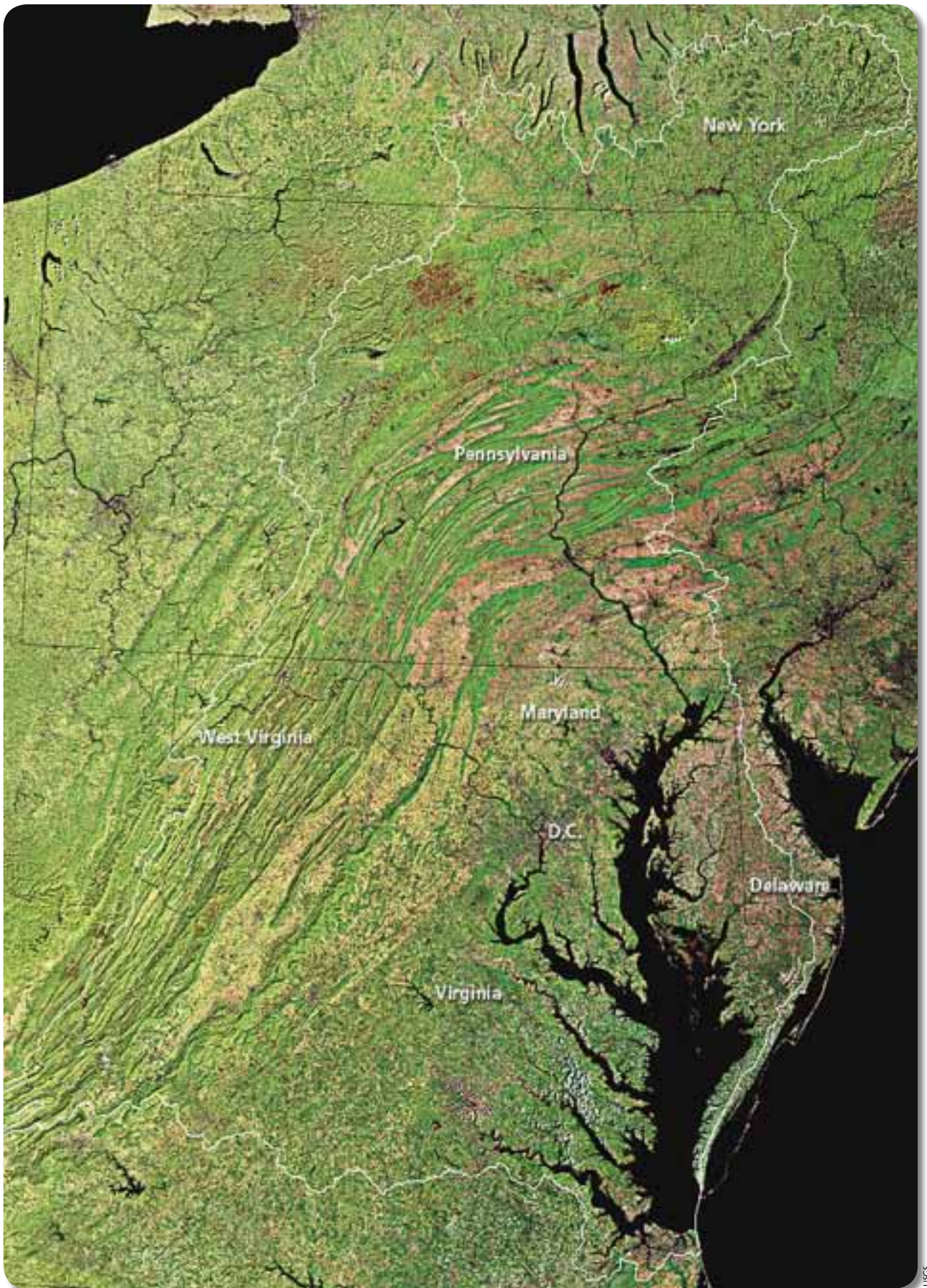

Principio Creek, Cecil County, Maryland.

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New York

Pennsylvania

West Virginia

Maryland

D.C.

Delaware

Virginia

USGS

The six states that comprise the Chesapeake Bay watershed.

Section 1

BACKGROUND AND OBJECTIVES

KEY POINTS

Key recommendations of this monitoring strategy document:

➤ **The water quality problem where the project is proposed needs to be clearly identified.**

➤ **Potential nutrient reductions of the project need to be quantified using identified nutrient reduction efficiencies.**

➤ **The potential for detecting these nutrient reductions through water quality monitoring needs to be evaluated.**

➤ **If it is deemed that nutrient and sediment reductions from BMP implementation will likely be detected with low-frequency monitoring, applicants must determine whether pre-existing data can be used in lieu of or in conjunction with proposed monitoring efforts and what monitoring design is best suited for their particular application.**

A monitoring strategy is needed for Trust Fund recipients in order to assess the effectiveness of best management practices (BMPs) implemented in target areas that are intended to reduce nutrient and sediment inputs to Chesapeake Bay and its tributaries. Consequently, the 2010 Trust Fund Water Quality Monitoring Strategy was developed by scientists from the University of Maryland Center for Environmental Science (UMCES), the University of Maryland Wye Research and Education Center (UMD), the Maryland Department of Natural Resources (MD DNR) and the Maryland Department of the Environment (MDE) to identify: 1) effective BMPs and their respective nutrient reduction efficiencies that can be used in priority watersheds, 2) methods needed to evaluate whether the effects of BMP implementation can be measured, and 3) effective monitoring designs if monitoring is deemed feasible.

The monitoring strategy document can be used by agencies, institutions and organizations both writing Trust Fund proposals and those already involved in implementation projects. This document is meant to guide applicants and help awardees apply appropriate and effective monitoring techniques in order to determine and evaluate the success of nutrient and sediment reduction methods in implementation areas, which is a requirement of Trust Fund support. The ultimate goal is to provide a comprehensive monitoring protocol that serves all water quality assessment needs relative to urban and agricultural nonpoint nutrient and sediment fluxes. This protocol is applicable to all BMPs (i.e., stormwater retrofits, stream restorations, riparian buffers, cover crops, etc.) that improve the water quality of streams, rivers, lakes, reservoirs, estuaries, groundwater and coastal bays that are located in high-priority areas. Monitoring could involve measuring the success of individual pollution control practices at the sub-basin level or a more comprehensive assessment of an entire system (i.e., the effect of multiple or larger-scale implementation projects on downstream receiving waters such as rivers and estuaries). Monitoring in implementation areas is meant to yield data and information that will result in better management decisions and allow data to be compared to and shared with those from other projects.

Section 2

METHOD USED TO DETERMINE HIGH-PRIORITY WATERSHEDS

KEY POINTS

Priority watersheds for BMP implementation used to reduce nonpoint pollution were selected using several assessment tools.

➤ Maryland tributaries of the Chesapeake Bay were ranked from worst to best in terms of a Water Quality Index.

➤ Locations for targeted implementation within their watersheds were determined using N loading estimates from the SPARROW watershed model.

➤ Analysis using the Water Quality Index and SPARROW model allowed scientists to create a map indicating where Trust Fund grants should be targeted in order to achieve the largest reduction of nonpoint nutrient and sediment inputs to receiving waters.

High-priority watersheds are those responsible for proportionally more nutrient and sediment inputs to receiving waters than other watersheds. Nonpoint or diffuse nutrient and sediment inputs to waterways generally occur from urban and agricultural land use. These pollutants commonly originate from fertilizers, septic systems, atmospheric deposition and urban runoff. Nutrient and sediment inputs are responsible for water quality problems in receiving waters such as increased turbidity and hypoxia or anoxia that can harm and decrease the distribution of submerged aquatic vegetation, fish and other aquatic life (Kemp et al., 2005; Fisher et al., 2006).

Priority watersheds for BMP implementation used to reduce nonpoint pollution were selected using several assessment tools. First, Maryland tributaries of the Chesapeake Bay were ranked from worst to best (Figure 2.1) in terms of a Water Quality Index (WQI). The WQI is comprised of three water quality metrics (i.e., dissolved oxygen, chlorophyll-*a*, and Secchi depth to determine water clarity). The WQI is robust and has a strong negative correlation with the total amount of urban and agricultural land use in tributary watersheds. The methods of this ecosystem health assessment tool are described in detail elsewhere (www.eco-

Figure 2.1. Procedure used to identify which tributaries are most degraded according to the Water Quality Index score. Subsequently, the watersheds of these tributaries were ranked by their diffuse nitrogen sources.

check.org/reportcard/chesapeake/2008/methods; Williams et al., 2009). Once the tributaries were ranked, the locations for targeted implementation within their watersheds was determined using the SPARROW watershed model (water.usgs.gov/nawqa/sparrow) that estimates where the highest levels of terrestrial nitrogen are exported to receiving waters given watershed characteristics (Figure 2.2), such as current land use scenarios (note that similar analyses using phosphorus and sediments will be done in future efforts to determine high-priority watersheds for those specific pollutants). These tools allowed scientists to create a map (Figure 2.3) indicating where Trust Fund grants should be targeted in order to achieve the largest reduction of nonpoint nutrient and sediment inputs to receiving waters. It is anticipated that the cumulative effect of multiple projects in priority areas will ultimately have a measureable, positive effect on the health of aquatic systems.
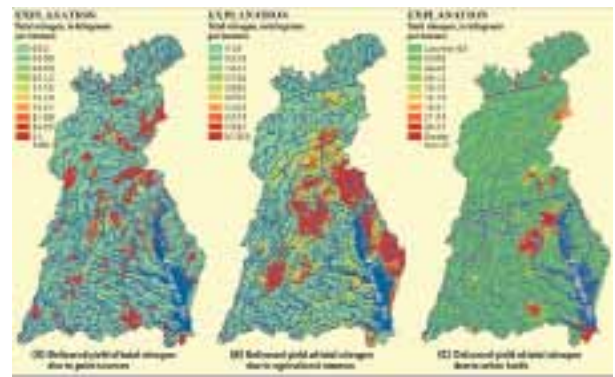
Figure 2.2. Map of SPARROW model output indicating where the highest nitrogen sources are located in the Chesapeake Bay watershed. Source: USGS.

Targeted Ecological Areas (TEAs) intersected with Trust Fund Watersheds

priority tributary basins
high priority watersheds
medium priority watersheds
low priority watershed

0   25   50 km
0   25   50 mi
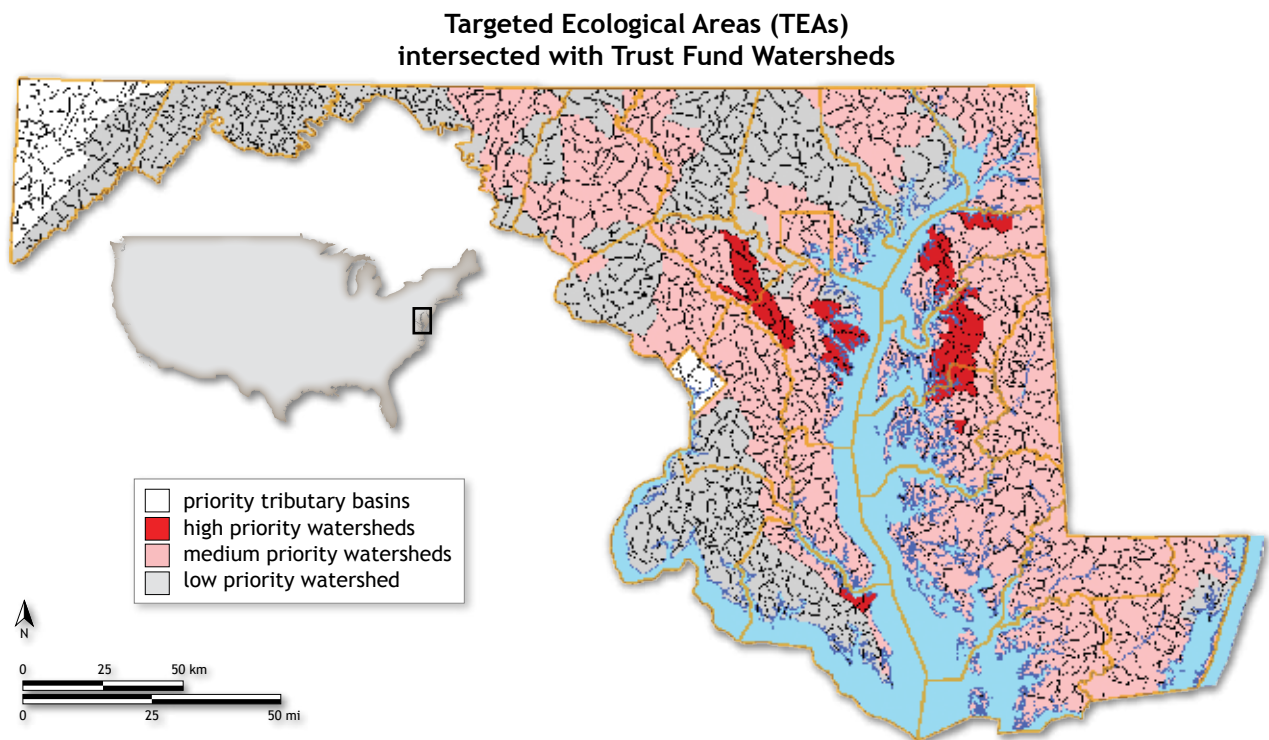
Figure 2.3. Map of the high-priority watersheds determined using the Water Quality Index developed for tributaries of the Chesapeake Bay and SPARROW watershed model output.

Section 3

CHALLENGES OF DEVELOPING A MONITORING PLAN

KEY POINTS

There have been bew documented reductions in nonpoint source nutrient loads from BMPs in the Chesapeake Bay watershed. More examples will become available with successful Trust Fund projects.

➤ Monitoring streamwater will unlikely show the effects of small-scale implementation at larger scales because of solute dilution and lag-time effects.

➤ Monitoring should be done only when there is a reasonable chance that it will be possible to observe water quality change over several years.

➤ Where monitoring is less likely to succeed, standardized nutrient reduction efficiencies provided in the Appendices can be used to estimate the potential effectiveness of implementation activities.

It has been difficult to document the reductions in nonpoint source nutrient loads from BMPs in the Chesapeake Bay watershed. Some people have suggested that this is due to over-estimation of the effectiveness of implementation procedures or the result of a time lag between implementation and when the effects become apparent in water quality. These issues are particularly relevant in the Maryland Coastal Plain region (Figure 3.1) of the Chesapeake Bay watershed where high-priority watersheds are located.

Accordingly, there are several challenges that should be considered while planning a successful and effective monitoring plan. It is necessary to recognize that monitoring streamwater will unlikely show the effects of small-scale implementation

MARYLAND

Fall line

0   20   50 km

0   20   50 mi

N

Appalachian Plateau   Ridge and Valley   Blue Ridge   Piedmont Plateau   Atlantic Coastal Plain

Figure 3.1. Physiographic regions of Maryland.

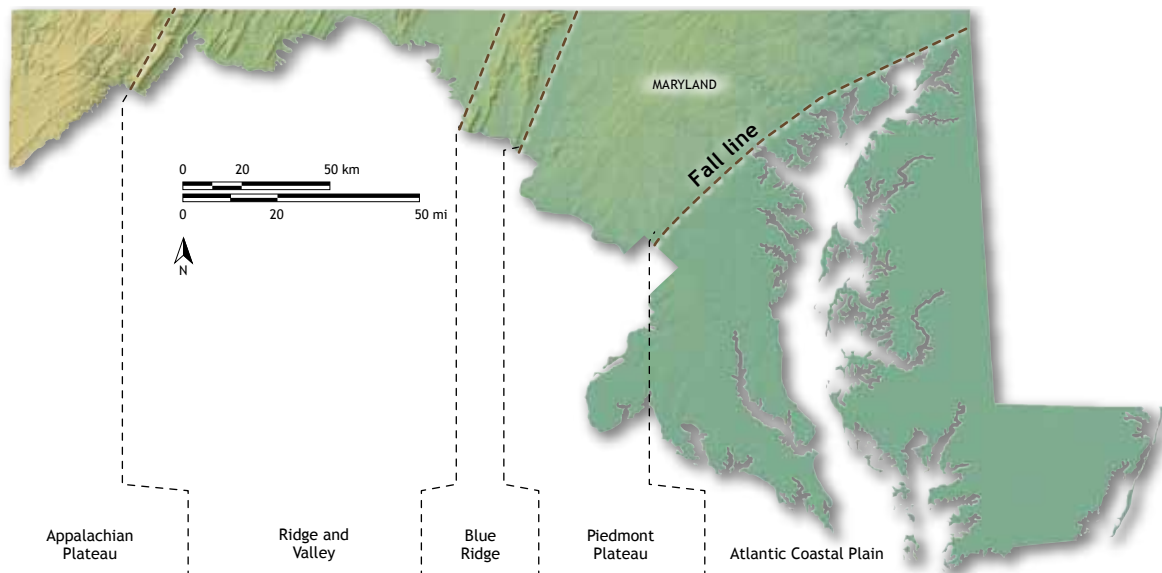at larger scales because of solute dilution and lag-time effects (i.e., the delay of a pollution signal that generally occurs as a result of slow transport times in groundwater). For instance, there is an average lag time of 10 years for nitrogen in groundwater to travel to streams in the Chesapeake Bay watershed (Lindsey et al., 2003), and long flow paths allow for considerable solute dilution. Therefore, targeting basins that have shorter lag times and flow paths may be more amenable to measuring the effects of BMPs.

Another challenge is to define measureable goals of BMP effectiveness. Determining nutrient and/or sediment load reduction in pounds or tons or nutrient and/or sediment load reduction per restoration dollar are minimum Trust Fund goals. Given the project goals of demonstrating water quality response to BMP implementation within a 3-year time period, it is important that monitoring be done only when there is a reasonable chance that it will be possible to observe water quality change over several years. It is important to recognize that intensive baseflow and stormflow (i.e., rain events) sampling is generally needed to detect small differences in nutrient and sediment concentrations from BMP implementation in watersheds, and intensive sampling is not recommended or supported in Trust Fund projects. Moreover, while measuring nutrient and sediment concentrations at monitoring sites, it is important to recognize that although nitrogen (N) can generally be characterized with baseflow monitoring (except urban watersheds with a high proportion of impervious surfaces), phosphorus (P) and sediment fluxes are commonly associated with stormflow runoff and are more difficult to quantify. Consequently, a thorough assessment of monitoring BMP implementation effectiveness should include issues of: 1) monitoring capability (i.e., resources), 2) monitoring frequency and intensity (i.e., stormflow), 3) seasonal variability, 4) pre-existing conditions, and 5) lag times. Where monitoring is less likely to succeed, standardized nutrient reduction efficiencies provided herein can be used to estimate the potential effectiveness of implementation activities.
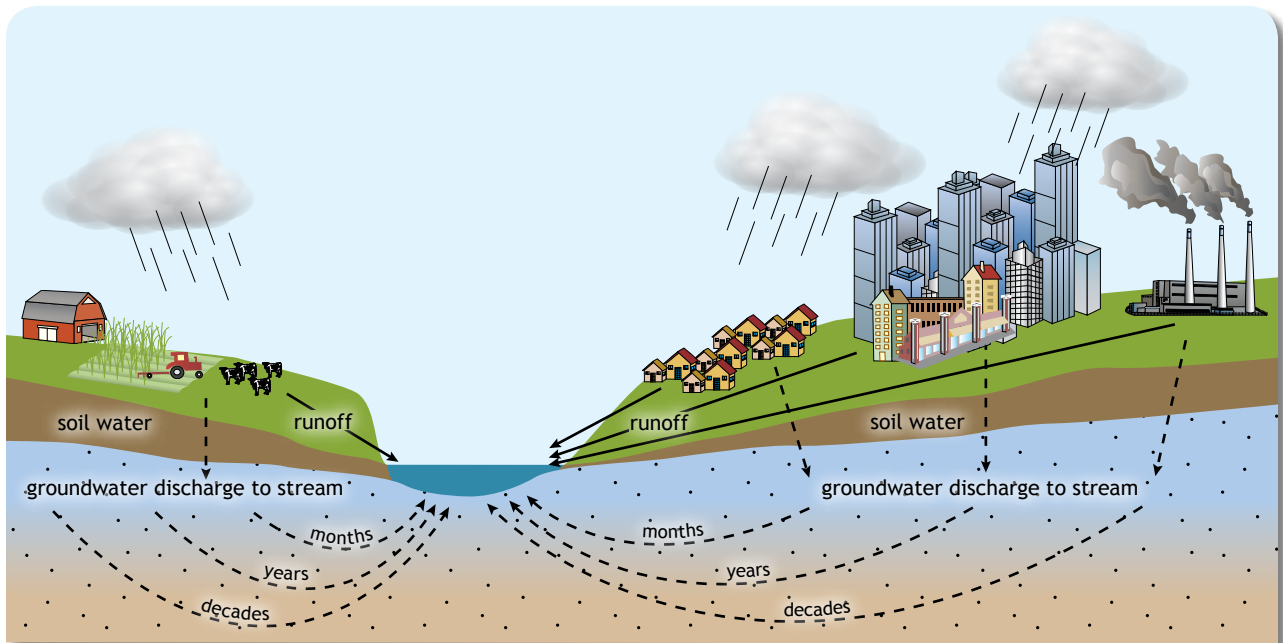

Figure 3.2. Conceptual diagram of the water cycle and major sources of nitrogen, phosphorus and sediment pollution to Chesapeake Bay. Once in groundwater, nitrogen can take from months to years to be transported to rivers and the estuary.

Section 4

CASE STUDIES

KEY POINTS

Case studies indicate that high sampling intensity and methodological complexity are commonly employed by researchers to accurately determine the effects of various BMPs in watersheds. The following case studies and their monitoring implications are described below:

➤ **Assessing the impact of changes in managment practices on nutrient transport from coastal plain agricultural systems**

➤ **Evaluating changes in subsurface nitrogen discharge from an agricultural watershed into Chesapeake Bay after implementation of a groundwater protection strategy.**

➤ **Upper Pocomoke agricultural best management practices evaluation project.**

➤ **Assessing restored stream effectiveness at reducing nitrogen loads.**

➤ **Corsica River Restoration project.**

➤ **The effect of agricultural best management practices on subsurface nitrogen transport in the German Branch watershed.**

Several case studies of how agricultural and urban nonpoint source BMPs were implemented and monitored, and what results were achieved, are summarized in the following pages. These case studies can be reviewed by applicants in order to derive a sense of the sampling intensity and methodological complexity that are commonly employed by researchers to accurately determine the effects of various BMPs in watersheds. The intensity and comprehensive nature of the monitoring commonly used in these targeted watershed studies are not meant to be emulated in Trust Fund projects because these are prohibitively intensive and, therefore, expensive. Rather, these projects (i.e., examples 1-6) demonstrate how an effective monitoring strategy is conducted with ample resources, and management and monitoring implications for Trust Fund projects are provided for each case study.

Stream restoration in the Coastal Plain of Maryland.

CASE STUDY #1:   *Assessing the impact of changes in managment practices on nutrient transport from coastal plain agricultural systems.*

K. Staver and R. Brinsfield. 1995. Wye Research and Education Center

Project objectives

Detail how hydrologic processes and nutrient availability patterns interact to determine rates of nutrient transport from Coastal Plain agricultural systems.

Project details

Design

Nutrient transport through both surface and subsurface flow paths was monitored in Coastal Plain agricultural fields in which several of the most highly promoted management practices for controlling nonpoint source nutrient loads were implemented (October 1984 - September 1995). Nitrate leaching patterns also were evaluated for the major cropping sequences with both inorganic and organic nutrient sources.

Methodology

Edge-of-field surface runoff volume from the experimental watersheds was measured using calibrated flumes instrumented with a flow meter connected to automated samplers. Discrete samples were collected at constant volume intervals. Generally, the elevation of the flumes remained above the water table. Consequently, surface runoff occurred only in close association with precipitation. Samples were transported from the field immediately after each event and frozen in polyethylene bottles until analysis. Root zone leachate was monitored using gravity lysimeters installed approximately 60 cm below the soil surface. Lysimeters were constructed from PVC well casing slotted on one side, and were installed parallel to the soil surface by auguring horizontally through the wall of a 1.2 m deep pit. The installation procedure required no disruption of the soil profile above the lysimeter collection area and allowed execution of agronomic activities using commercial-scale equipment. Samples were collected immediately after lysimeter flow ceased,
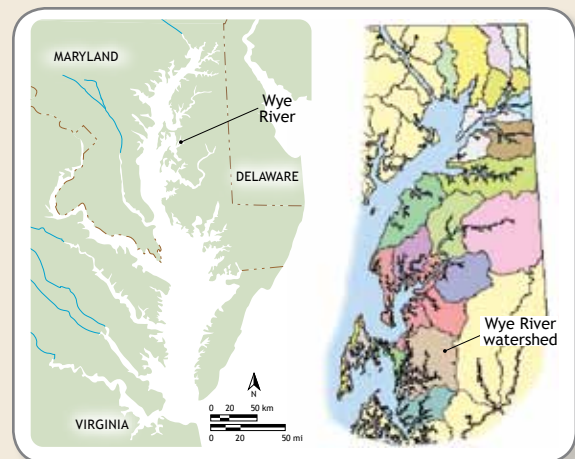
Figure 4.1. LEFT: Location of Wye River. RIGHT: Wye River watershed (source: MD DNR).

Surface runoff following a summer thunder storm flowing through a monitoring flume.

which generally occurred within 24 hr of the end of the precipitation event. Lysimeter samples were filtered through a polycarbonate filter (nominal pore size 0.45 μm) and frozen until analysis.

Groundwater elevation and quality within the experimental watersheds was monitored via a network of 18 wells, with 1.5 m screens centered approximately 2 m above sea level, which corresponded to the approximate position

of the annual minimum elevation of the water table. Groundwater discharge into tidal waters was measured from an agricultural field located directly adjacent to the Wye River. Intensive hydraulic monitoring and groundwater sampling were used to quantify nitrate discharge from the unconfined aquifer into the Wye River.

Surface runoff samples were analyzed for total, and total dissolved (<0.45 μm) nitrogen and phosphorus using a persulfate digestion followed by colorimetric analysis of phosphate content and nitrate analysis using high-pressure liquid chromatography. Filtered groundwater and lysimeter samples also were analyzed for nitrate using high-pressure liquid chromatography.

Figure 4.2. Cross section of gravity-fed lysimeter in an agricultural plot.

Management implications

1. For the soil types considered in this study, no-till methods, winter cover crops, and grassed waterways had little apparent effect on long-term surface runoff volume.

2. The low potential for soil erosion from Coastal Plain agricultural systems minimizes the role that erosion control strategies can play in reducing phosphorus transport. No-till methods consistently reduced surface runoff sedim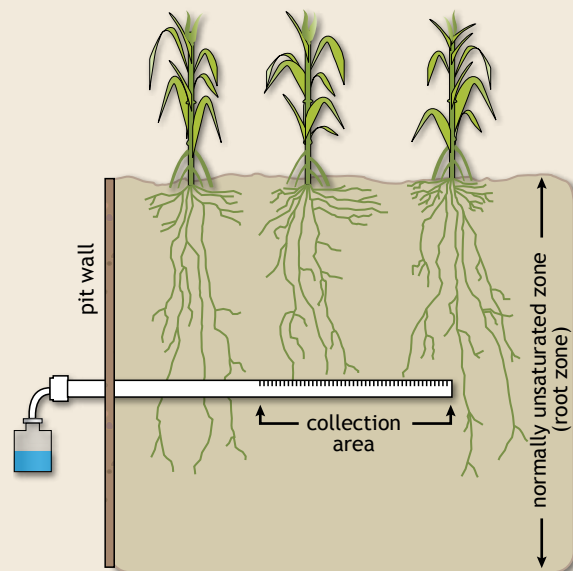ent loads over 70%. However, reductions in particulate phosphorus transport were much less, and were more than offset by increases in dissolved phosphorus transport that resulted from intensification of phosphorus availability near the soil surface under continuous use of no-till practices.

3. Annual surface runoff nitrogen losses were highly dependent upon the fraction of surface runoff volume occurring shortly after nitrogen applications, suggesting that application techniques that place nitrogen fertilizers below the soil surface will reduce the potential for runoff losses. No-till methods reduced surface runoff losses of nitrogen approximately 10%, primarily through reductions in particulate nitrogen transport. However, surface runoff nitrogen transport rates under baseline conditions were less than 20% of nitrate leaching losses. Thus, even highly effective control of surface runoff nitrogen transport will not result in a 40% reduction in combined nitrogen losses.

4. Nitrate leaching losses under winter fallow conditions following corn and soybean production were similar. Drought suppression of corn nitrogen utilization and fall organic nitrogen applications greatly increased leaching losses. Leaching losses were highly concentrated during winter months, and cereal grain cover crops planted in early fall were highly effective in controlling nitrate leaching losses in all systems. Leaching results indicate that in the long-term, cereal grain winter cover crops alone can be used to achieve a 40% reduction in nitrogen transport from the major Coastal Plain agricultural systems. Properly managed, cereal grains planted for grain production can also be used to reduce nitrate leaching losses.

5. Nitrate levels in stream baseflow and direct groundwater seepage indicate a wide range in the potential for subsurface nitrate transport from agricultural systems into tidal waters. This suggests that prioritizing implementation of strategies to reduce nitrate leaching rates will be most effective if based on both agricultural and delivery system factors.
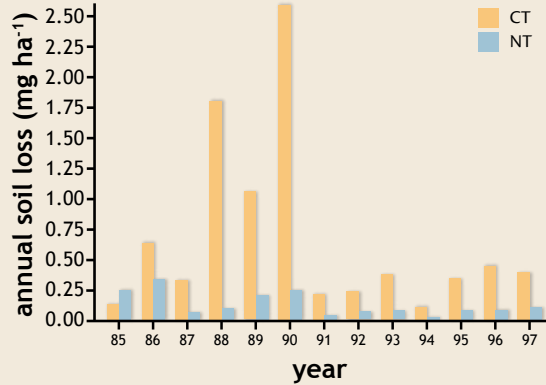
Figure 4.3. Annual (May 1-April 30) edge-of-field surface runoff soil erosion from adjacent corn fields under conventional tillage (CT) and no-till (NT) management. Winter cover crops were used starting in 1988 and grass waterways were installed in the fall of 1990.
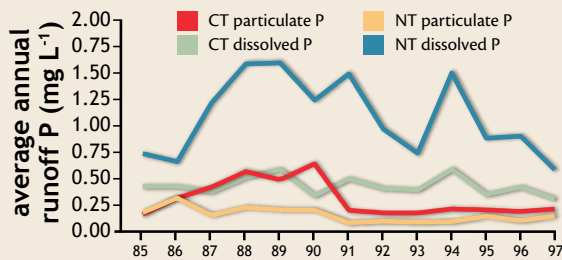
Figure 4.4. Volume-weighted annual average phosphorus (P) concentrations in surface runoff from adjacent corn fields under conventional tillage (CT) and no-till (NT) management. P was applied identically in both watersheds. No P was applied from 1992-1997.

Monitoring implications

1. Extreme variability in edge-of-field surface runoff patterns minimizes the potential for low-intensity edge-of-field or stream water quality sampling to accurately characterize phosphorus transport rates. Development of watershed phosphorus budgets, coupled with compilation of watershed soil phosphorus data, may provide the most accurate gage of progress toward reducing nonpoint source phosphorus loads.

2. The dominant role of subsurface flow paths in controlling nonpoint source nitrogen loads in Coastal Plain watersheds makes it necessary to consider residence time when evaluating implementation/water quality relationships. Evaluating the effect of specific practices on nitrate leaching rates can best be accomplished using measurements in, or just below, the root zone.

3. Monitoring base streamflow nitrate levels can be used to evaluate long-term changes in watershed subsurface nitrate discharge rates. However, many years will be required for the effects of implementation of practices that reduce root zone nitrate leaching to become evident in nonpoint source nitrogen loads.
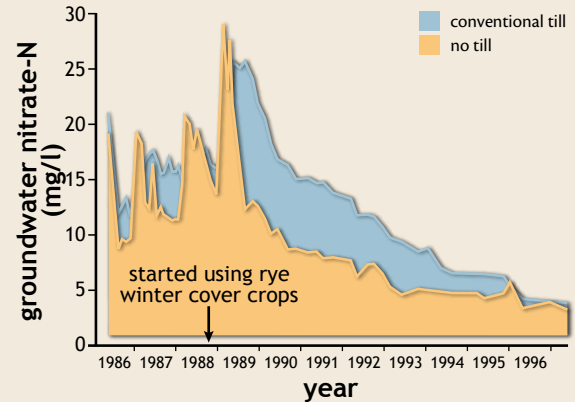
Figure 4.5. Average groundwater nitrate-nitrogen (N) concentrations under two adjacent corn fields. Annual N applications were 156 kg ha^{-1}. Rye cover crops were planted after corn harvest starting in 1988.
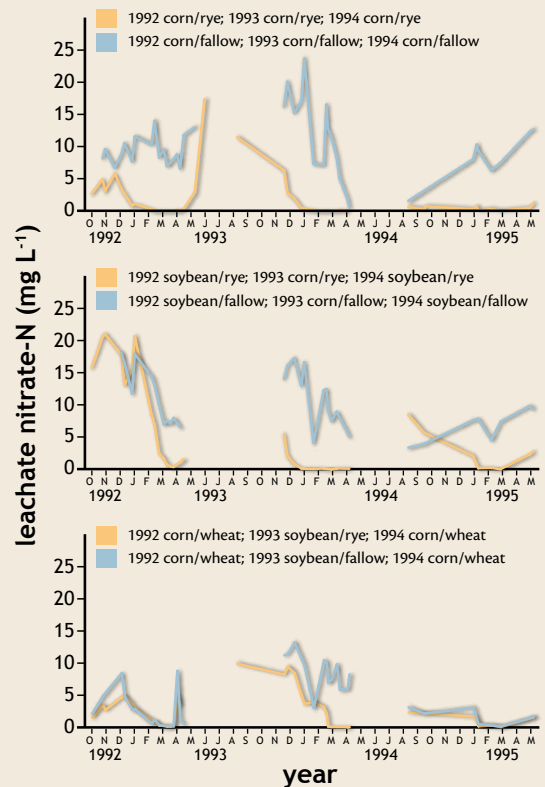
Figure 4.6. Root zone leachate nitrate-nitrogen (N) concentrations collected in gravity lysimeters (see Fig. 4.2) at a depth of 60 cm in the major crop sequences in Maryland with and without rye winter cover crops. N application rates for corn were 156 kg ha^{-1}. N applications for wheat were 90 kg ha^{-1} applied in a single application in late March.

CASE STUDY #2: *Evaluating changes in subsurface nitrogen discharge from an agricultural watershed into Chesapeake Bay after implementation of a groundwater protection strategy.*
K. Staver and R. Brinsfield. 2000. Wye Research and Education Center

Project objectives

This project evaluated the effect of cereal grain winter cover crops on subsurface transport of nitrate from cropland into the Wye River on the eastern shore of Maryland.

Project details

Design

Rye winter cover crops were planted following the 1993-98 growing seasons in a field planted in a corn-soybean rotation. Changes in the transport of nitrate through the subsurface flow system into the Wye River were monitored.

Background—site description

This research was conducted at the University of Maryland Wye Research and Education Center located in Queen Anne's County. The study site was located on the north shore of the Wye Narrows approximately 12 km upriver of where the Wye River empties into Eastern Bay. The Wye River is a tidal sub-estuary of Chesapeake Bay.

Background—agricultural practices

The cropland in the drainage basin has been in a corn (*Zea mavs L.*) - soybean (*Glvcine max L.*) rotation at least since 1991 (1991 - corn, 1992 - full-season soybeans). Nitrogen applications during corn production in 1993, 1995, and 1997 were approximately 200 kg ha^{-1}, with 34 kg ha^{-1} applied at planting and the remainder as a surface banded sidedress application in late June. No-till planting methods were used for corn, soybean and rye cover crop planting. Prior to 1993 the drainage basin remained fallow from grain harvest in the fall until planting the following spring. From 1993 through 1998, a rye cover crop was planted immediately following grain harvest at a rate of 188 kg ha^{-1}. Cover crop planting dates were September 28, 1993, October 18, 1994, and September 22, 1995, October 23, 1996, October 5, 1997, and October 29,
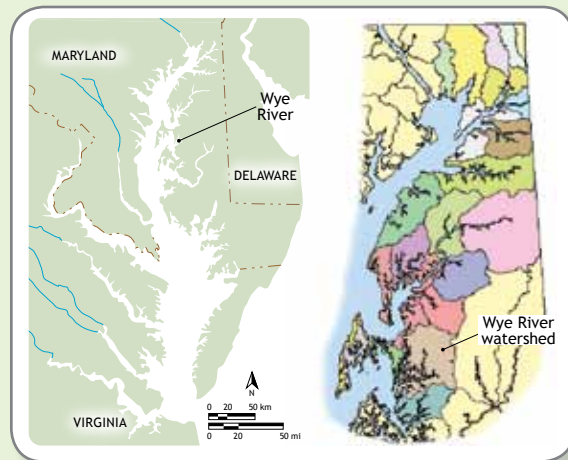
Figure 4.7. LEFT: Location of Wye River. RIGHT: Wye River watershed (source: MD DNR).

Aerial view of crop fields adjacent to the Wye River where study was conducted.

1998. Cover crops were sprayed with glyphosate in mid-April each year. Three 10 m strips were left fallow during winter months for comparing cover crop effects on crop yields and nitrate leaching patterns.

Methodology

The data collection system used to monitor groundwater discharge into the Wye River

consisted of a stratified network of wells within the groundwater discharge zone for monitoring water chemistry in discharging groundwater, and collecting continuous hydraulic data needed for calculating groundwater discharge rates.

In addition to data collection within the groundwater discharge zone, 5-cm diameter cores were taken from the soil surface into the surface of the unconfined aquifer in 15 cm depth increments at 10 sites within the groundwater drainage basin. Sampling of pore-water nitrate concentrations in the surface of the unconfined aquifer was part of the core sampling. Moreover, a transect of wells was installed through the center of the study site in 1993 with four additional wells installed in 1997. These wells were sampled to evaluate changes in groundwater nitrate concentrations at several depths within the subsurface flow system. Nitrate analysis was performed colorimetrically on 2 M KC1 soil extracts. Groundwater samples were placed in a cooler and immediately taken to the water quality laboratory located at the Wye Research and Education Center, and filtered (polycarbonate, 0.45 μm nominal pore size). Nitrate, chloride and sulfate concentrations were determined using high-pressure liquid chromatography.

Results

Nitrate leaching from the root zone was calculated to be approximately 80% less where a cover crop was planted in comparison to adjacent plots that remained fallow during winter months. The reduction in vertical nitrate transport varied annually depending on precipitation/groundwater recharge patterns, which varied by more than a factor of two during the seven years of monitoring. During the first two years following the initiation of cover crop use, decreases in subsurface nitrate concentrations were limited primarily to shallow regions of the profile, and little change in nitrate discharge rates into the Wye River was observed. However, low-nitrate leachate eventually penetrated most of the subsurface flow system, resulting in a gradual decrease in nitrate concentrations in groundwater discharging into the Wye River. From 1993 through 1998, total nitrate storage decreased approximately 75% in the unsaturated region of the profile and 45% in the underlying aquifer (at the time of water table minimum elevation). Annual rates of nitrate

discharge into Wye River were highly dependent on discharge volume which varied approximately two-fold from 1993 through 1999. Average nitrate-N concentrations in subsurface discharge into the Wye River decreased from approximately 15 mg L^{-1} in 1993 to 5 mg L^{-1} in 1999, resulting in proportionate reductions in rates of nitrate discharge when discharge volumes were similar. Temporal patterns of nitrate concentrations in the unsaturated zone suggest that discharge nitrate-N concentrations will eventually stabilize in the 3 - 4 mg L^{-1} range if winter cover crops are used annually.

Wells equipped with pressure transducers for measuring hydraulic gradients in the intertidal groundwater discharge zone in the Wye River.
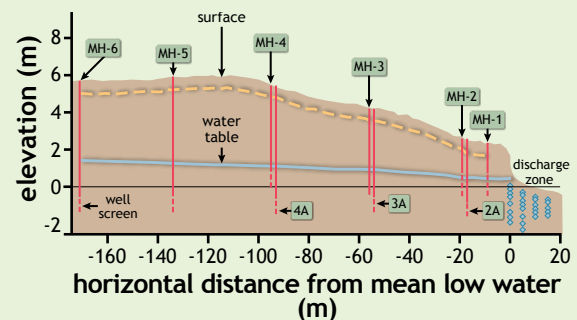
Figure 4.8. Cross-sectional schematic of the study site and the monitoring system for tracking groundwater nitrate movement from under the crop field to the intertidal discharge zone in the Wye River.
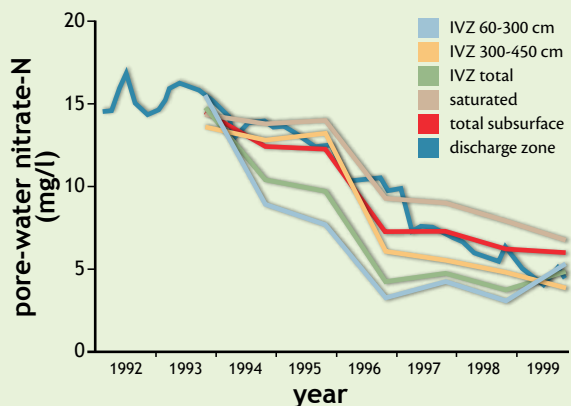
Figure 4.9. Changes in autumn nitrate-nitrogen (N) concentration in different regions of the subsurface flow system after the use of rye winter cover crops was initiated in 1993. Intermediate vadose zone (IVZ) concentrations were obtained using post-harvest soil coring.

Management implications

Results of this study indicate that strategies which reduce nitrate leaching rates can be used to achieve substantial reductions in nonpoint source N loads from cropland in the Coastal Plain. Although site hydrogeologic conditions will dictate the precise temporal dynamics of this process, in settings where cropland is located directly adjacent to surface waters, reductions in root zone nitrate leaching rates will result in minor reductions in subsurface N discharge rates within 3 to 5 years and major reductions in 5 to 10 years.
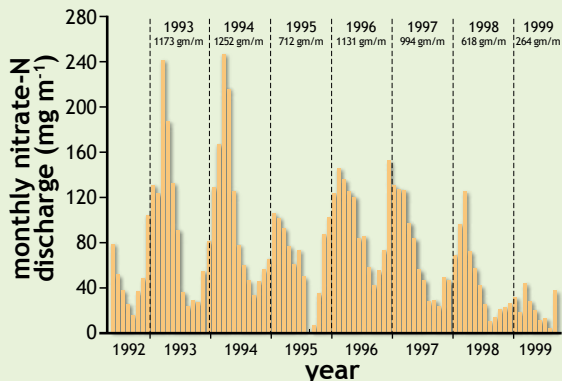
Figure 4.10. Monthly groundwater nitrate-nitrogen (N) discharge per unit length of shoreline into the Wye River from an adjacent crop field planted in a corn-soybean rotation. Rye cover crops were planted after grain harvest starting in 1993.

Monitoring implications

1. Evaluating the effect of specific practices on nitrate leaching rates can best be accomplished using measurements in, or just below, the root zone.

2. Monitoring nitrate levels in groundwater is an effective method that can be used to evaluate long-term changes in watershed subsurface nitrate fluxes and BMP effectiveness.

3. The time lag associated with subsurface flow and fluxes of N in Coastal Plain watersheds suggests that there will commonly be a multi-year delay in signal detection of implementation/water quality relationships. Many years will be required for the effects of implementation of practices that reduce root zone nitrate leaching to become evident in nonpoint source nitrogen loads.

Well nest for monitoring shallow groundwater at different depths in a crop field.

CASE STUDY #3: *Upper Pocomoke agricultural best management practices evaluation project.*
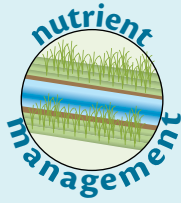
J. McCoy, M. Sigrist, and J. Jaber[1]. 2003. Maryland Department of Natural Resources and National Resources Conservation Service (NRCS)[1]

Project objectives

A paired watershed study was conducted to determine the effect of the implementation of agricultural best management practices (BMPs) within the watershed.

Project details

Design

The Pocomoke River is located on the Eastern Shore and is one of Maryland's four major tributaries draining to the Chesapeake Bay. In 1994, the Wicomico Soil Conservation District (SCD) invited Maryland Department of Natural Resources (MD DNR) and United States Geological Survey (USGS) to join in a project demonstrating the effect of nutrient and poultry litter management on water quality.

The control basin was a 2,342-acre sub-watershed of the North Fork of Green Run that extends into Delaware. The experimental watershed was a 1,779-acre sub-watershed of the South Fork of Green Run. Land use was similar in both watersheds, and soils in both watersheds were level, poorly drained soils in the Pocomoke-Fallsington association. The animal population in the control watershed was larger than in the treatment watershed, but both watersheds had high densities of poultry relative to the rest of the state.

The agricultural BMPs evaluated by this study include nutrient management and cover crops. The nutrient management evaluation was focused on the use of poultry litter as a nutrient source. Nutrient management plans were developed for all of the cropland in the treatment watershed based on cropping history and soil tests. All poultry litter generated in the treatment watershed was transported out of the basin, and no litter was applied as a nutrient source during the treatment period. Nitrogen and phosphorus applications were applied at rates recommended by nutrient management plans and used inorganic fertilizer
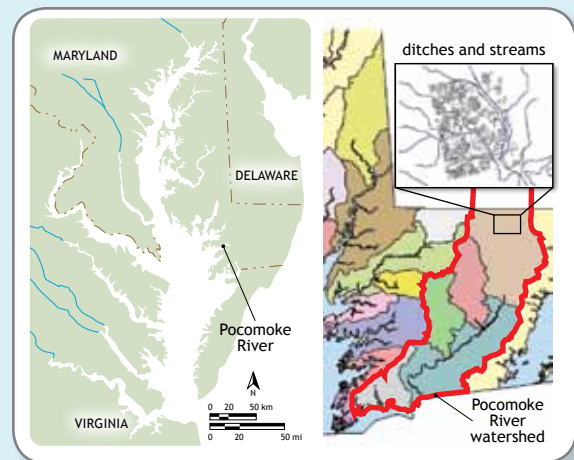
Figure 4.11. LEFT: Location of Pocomoke River. RIGHT: Pocomoke River watershed (source: MD DNR) and streams study area.

Poultry farms like these on the Delmarva Peninsula grow nearly 11 million chickens per week (source: dpichicken.org).

as the source. Cover crops were applied to all available cropland.

Methodology

Crop type, nutrient application rates, yield data, and soil test results were collected directly from farm operators or crop consultants working in the treatment and control watersheds. Crop

Drainage ditches in the Pocomoke study watershed.

Automated stage recording device used to calculate stream discharge.

acreage was calculated from Farm Services Agency records. Septic tank loads were estimated using loading rates of 12.87 lbs P capita^{-1} yr^{-1} and 8.92 lbs N capita^{-1} yr^{-1}. Atmospheric deposition estimates were based on National Atmospheric Deposition Program model data (nadp.sws.uiuc.edu).

Weekly grab and composited samples were collected at the two automated water quality monitoring sites. The composited nutrient samples were preserved in sulfuric acid. The preservation technique prevents distinguishing between particulate and dissolved N and P constituents, but the weekly grab samples were used to evaluate the distribution of N and P species. Flow was measured at the two automated water quality monitoring sites by USGS. Level data were collected at 15 minutes intervals, and cross-sectional velocity data were collected on a bi-weekly basis. Basic water quality characteristics measured at each station

included: dissolved oxygen, pH, conductivity, temperature, total nitrogen (TN), total phosphorus (TP), orthophosphate, nitrate+nitrite, ammonia, and total suspended solids (TSS).

Annual and monthly load estimates were calculated for each station. TN, TP and TSS loads were calculated by multiplying the total weekly flows for each site by the weekly mean concentration. Loading estimates for all other parameters were generated using Beale's Ratio Estimator. Beale's Ratio Estimator was developed for situations with an abundance of flow information and relatively little concentration data. The Ratio Estimator assumes a positive relationship between concentration and flow, and that the variance in concentration is proportional to the magnitude of flow. The estimate was derived by multiplying the mean measured loads (concentration x flow) by the ratio of the average flow for the year, divided by the average flow on days when concentrations were measured.

Paired Watershed Design
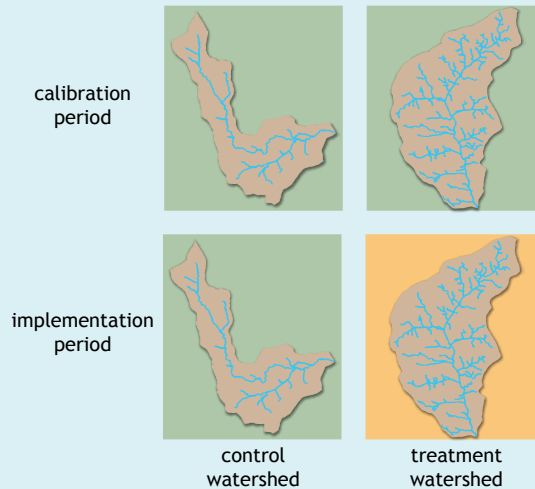
Figure 4.12. Monitor changes in water quality relationships between control and treatment watersheds from calibration to implementation periods.

Paired Watersheds

Treatment watershed acres	**1779**
crop acres	1170
chicken capacity (birds/year)	225,000
Control watershed acres	**2342**
crop acres	1554
chicken density (birds/year)	490,000

Station 111 Composites TN mg N/l
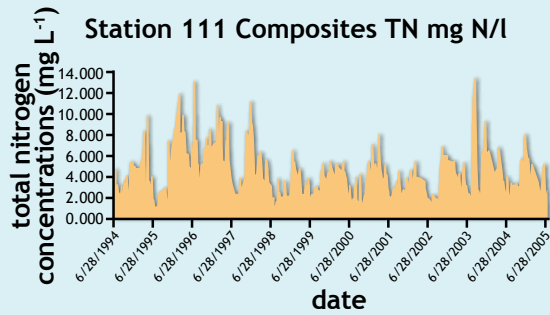
Figure 4.13. Total nitrogen concentrations from Station 111 in the treatment watershed.

TN concentrations in the discharge from the treatment watershed have decreased 30% during the treatment period and TP concentrations have remained steady.

Simple linear regressions were used to describe the relationships between the treatment and control watersheds during the calibration period. The regression equations were in turn used to determine the percent change required in that relationship to detect a significant change in nutrient concentrations.

Results

Nutrient budgets developed from 1994 to 1998 indicated that both treatment and control watersheds had net surpluses of N and P in excess of crop uptake. Net surpluses of N and P applied to cropland during the calibration period averaged 195 lbs acre^{-1} and 41 lbs acre^{-1}, respectively, in the control watershed, and 113 lbs acre^{-1} and 45 lbs acre^{-1}, respectively, in the treatment watershed. N and P yields at the outlet of the watersheds averaged 13.37 lbs acre^{-1} yr^{-1} and 0.85 lbs acre^{-1} yr^{-1},

respectively, from the control watershed and 21.36 lbs acre^{-1} yr^{-1} and 3.38 lbs acre^{-1} yr^{-1}, respectively, from the treatment watershed. The analysis of the paired data indicates that a 13% change in the difference between the mean TN concentrations at the outlet of the control and treatment watersheds and a 63 % change in the difference between the mean TP concentrations would be required to detect a significant difference in surface waters.

The treatment period began in 1998. To date, cover crops have been planted on an average of 850 acres of cropland each year, and 5,879 tons of poultry litter have been removed from the treatment watershed. Nutrient budgets developed from 1998 to 2001 indicate that nutrient surplus in the control watershed remained relatively constant. Net surpluses of N and P on cropland

Treatment Watershed
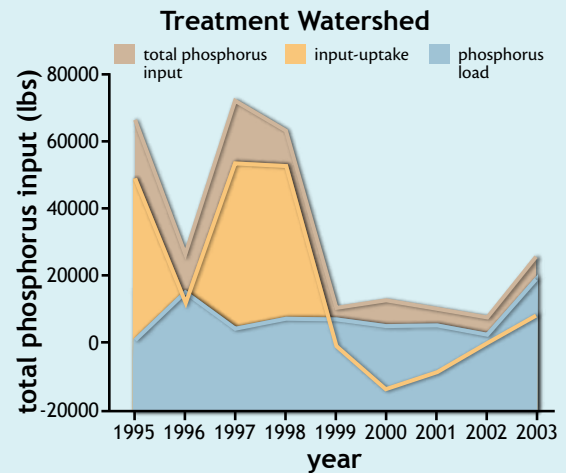
Figure 4.14. Total phosphorus input, input-uptake, and load in the treatment watershed.
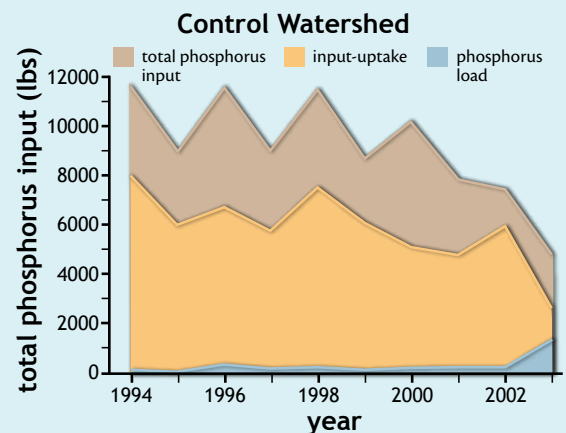
Control Watershed

Figure 4.15. Total phosphorus input, input-uptake, and load in the control watershed.

averaged 130 lbs acre^{-1} and 29 lbs acre^{-1}, respectively, in the control watershed. Net surpluses of N and P on cropland in the treatment watershed decreased to an average of 9 lbs acre^{-1} and -8 lbs acre^{-1}, respectively. The removal of poultry litter and replacement with inorganic fertilizer reduced the nutrient surpluses in the treatment watershed by approximately 92% for N and approximately 120% for P.

Total nitrogen concentrations at the outlet of the control watershed remained constant, whereas TN concentrations at the outlet of the treatment watershed decreased 30% since the beginning of the treatment period. Total phosphorus concentrations remained steady at the outlet of the treatment watershed and declined at the outlet of the control watershed. The change in the N concentrations appears to be related to the treatment program. The magnitude of the change was measured as the difference between average concentrations at the outlet of the treatment and control watersheds was significant. Recently observed trends in the TP concentrations may be related to ditch maintenance activities in the control watershed, which will require closer examination. Yields at the outlet of the watersheds during the treatment period averaged 17.41 lbs N acre^{-1} yr^{-1} and 0.81 lbs P acre^{-1} yr^{-1} from the control watershed and 13.93 lbs N acre-1 yr^{-1} and 3.43 lbs P acre^{-1} yr^{-1} from the treatment watershed.

Management Implications

The decrease in N concentrations in watershed outflow appears to be related to the treatment program. Recently observed positive trends in the TP concentrations may be related to ditch maintenance activities.

Monitoring Implications

A 13% change in the difference between the mean TN concentrations at the outlet of the control and treatment watersheds and a 63% change in the difference between the mean TP concentrations are required to detect a significant difference in surface waters.

CASE STUDY #4:   *Assessing restored stream effectiveness at reducing nitrogen loads.*

S. Filoso and M. Palmer, 2009. Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science

Project objectives

This project was an assessment of the effectiveness of restored urban streams at reducing N loads exported to downstream waters.

Project details

Design

The study was conducted in the western Coastal Plain of the Chesapeake Bay. The capacity of restored streams at attenuating loads of N in dissolved and particulate forms was evaluated during baseflow discharge periods, which is when the potential for streams to affect N concentrations is likely to be detectable.

Background—site description

This study was conducted in headwater streams (first- and second-order) of Maryland's Coastal Plain, which is part of the Chesapeake Bay watershed. The study streams were located within a radius of 40 km in Anne Arundel County, MD (38º51' N, 76º32' W), and drained dominantly urban and sub-urban watersheds where annual precipitation and temperature average 1130 mm and 13.2ºC, respectively. The public wastewater system in Anne Arundel County consists of septic tanks and sewage drainage networks, so study site streams combined watersheds serviced by both systems.

Headwater streams make up the majority of the channel lengths in the Coastal Plain drainage networks and, despite relatively low gradients, their channels are free to adjust (no bedrock controls) and, therefore, are rapidly destabilized with urbanization. Degradation of these stream channels results in gully-like conditions, with high in-stream sediment loadings and poor environments for N processing. In the lower drainage network, non-tidal channels at the boundary of the estuary are degraded by large quantities of sediment transported from the landscape following land use
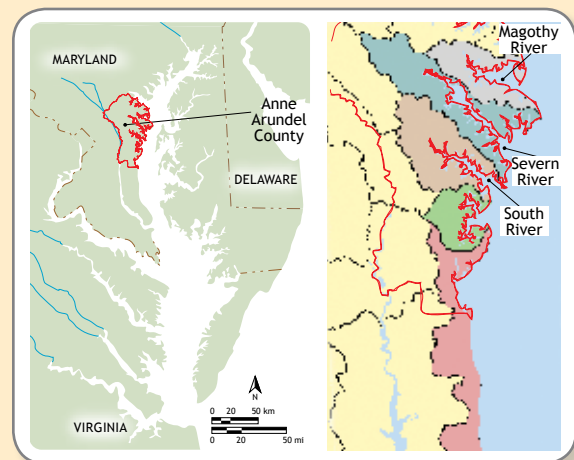
Figure 4.16. LEFT: Location of Anne Arundel County. RIGHT: Lower Western Shore rivers (source: MD DNR).

changes or from channel erosion upstream. This study includes stream reaches near the headwater zone, characterized by bank incision and the lack of adjacent floodplains, and reaches near the tidal zone at the boundary of the estuary, characterized by wide floodplains and gentle slopes. All streams included in the study have riparian buffers, but only four out of the six have been restored; two are non-restored degraded streams and were used as control sites.

Stream reaches near the headwater zone have been restored with frequently used methods such as the harnessing of stream banks to control erosion, and the placement of ripraps along the channel to increase hydraulic resistance. Stream reaches near the tidal zone have been restored with a combination of distinctive features such as step pool stream systems, floodplains and wetlands.

Methodology—sample collection and analyses

For two consecutive years between January 2007 and 2009, water samples were collected from the study streams biweekly at low to moderate flows during dry weather and relatively stable

flow conditions. Samples were collected at two or more sampling points along each stream reach monitored, corresponding to the input and output ends of each reach. For reliable comparisons to be made, all streams were sampled within 24 hours when instantaneous discharges were also measured at each site. Grab samples were collected in 1-L pre-leached polyethylene bottles and a portion of each sample was immediately filtered in the field through pre-rinsed glass-fiber filters (Whatman GF/F with nominal pore size of 0.7 μm)

V-notch weir used to measure discharge at a stream restoration site.

Stormflow event at the V-notch weir restoration site.

to separate dissolved from particulate N phases. Filtered water samples were stored in pre-washed high-density polyethylene bottles. The filtered and unfiltered samples were kept on ice and in the dark until returned to the laboratory (within 6 h). Filtered samples were frozen until analyzed for dissolved N concentrations. Particulate material in the remaining unfiltered samples was collected on pre-combusted (500°C for 1.5 hr) glass-fiber filters following the recommended sampling protocols used by EPA for the determination of particulate N (PN).

Nitrate plus nitrite concentrations were determined using a standard manual colorimetric method on a flow injection analyzer (Lachat QuikChem 8000). Dissolved organic N concentrations were calculated from the total dissolved N (TDN) content in filtered water samples analyzed using the persulfate digestion method. Particulate nitrogen (PN) was measured with a Perkin Elmer 2400 CHN elemental analyzer.

Methodology—hydrological measurements

Instantaneous discharge was measured at each sampling site immediately after water sampling using the cross section method (Stevens 1987). In addition, automated stage recorders were installed at each monitoring point so hydrologic rating curves could be constructed using a stage–discharge relationship. The rating curve (or stage-streamflow relation) for a specific stream location was developed through successive streamflow measurements at different stream stages. In the stream where the cross-section method did not seem suitable, we constructed a V-notch weir to measure discharge.

Results

The results of this study show that water discharge in channels near headwaters increased significantly between up and downstream monitoring points yet did not indicate that there was a net retention of nitrogen along the restored stream reaches. Much of the net export of N to the downstream monitoring points was a result of the increase in stream discharge. In contrast, channels restored near the tidal area showed a net retention of N and a much smaller increase in discharge over a similar stream reach compared to the headwater streams.
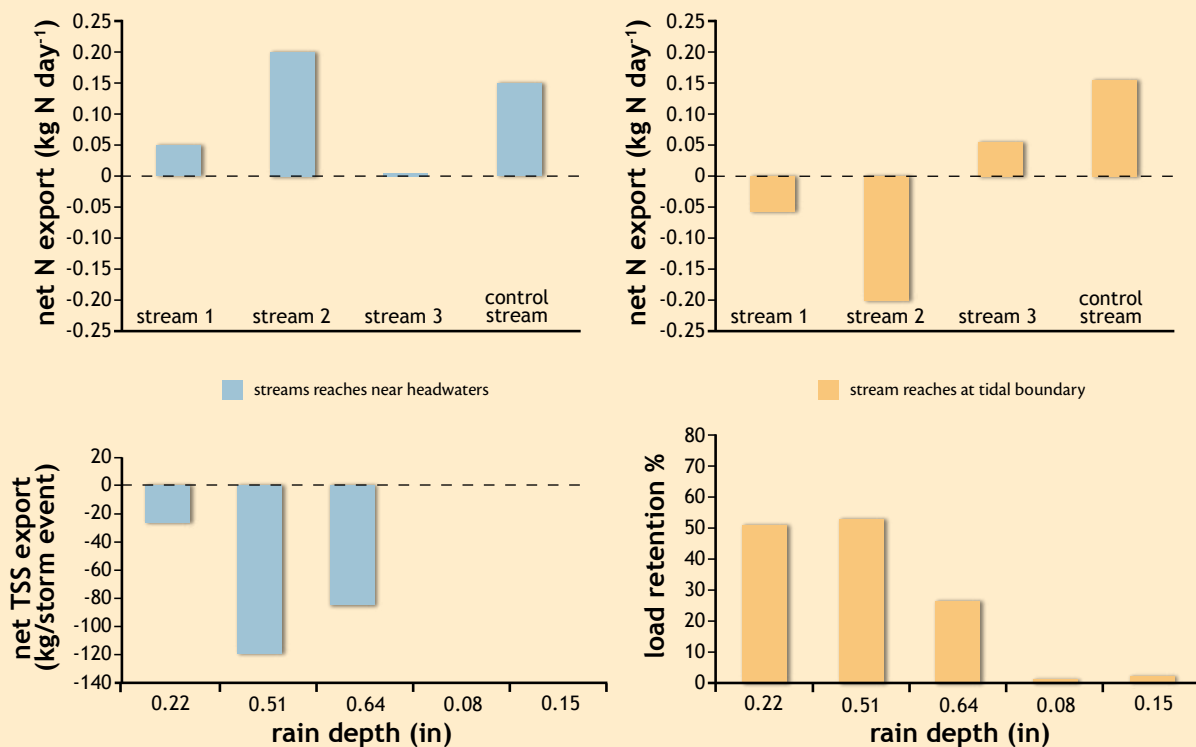
Figure 4.17. Comparison of net nitrogen export from stream restoration sites near the headwaters and at the tidal boundary of several Coastal Plain watersheds.   Net TSS export and load retention relative to rain depth (i.e., event size).

Table 4.1. Comparison of annual net export for various nitrogen fractions in the streamwater of a stream restoration site monitored in this study.

	Annual discharge (L)	NO$_3$ (kg N/yr)	NH$_4$ (kg N/yr)	DON (kg N/yr)	PN (kg N/yr)	TN (kg N/yr)	TSS (kg N/yr)
downstream	608,522,942	125	82	105	106	417	15,879
upstream	563,986,208	139	99	112	158	507	38,187
net export	44,536,734	-15	-17	-7	-52	-90	-22,308

Management implications

1. Restoration of headwater streams should include efforts to connect the groundwater table to the riparian forest zone to heighten N removal via denitrification.
2. Retention ponds are effective N retention features in stream restoration areas.
3. Stream wetland systems incorporated into restoration reaches are very effective at suppressing sediment export.
4. Inorganic to organic N conversion occurs in deeper pools and these should be avoided in restoration reaches.
5. Existing riparian forest in restoration reaches should remain undisturbed (i.e., regrading stream substrate should be strictly prohibited).

Stream restoration site with artificial stream bank installed to reduce further erosion.

Monitoring implications

1. Before-and-after are more effective than paired-watershed comparisons.

2. Good hydrologic measurements (e.g., flow) are critical for high accuracy that is needed to determine nutrient retention characteristics of a stream reach.

3. Septic systems and direct inputs from streets are responsible for large N inputs along stream reaches in urban areas and can overwhelm N retention capabilities. Attempts should be made to quantify these lateral inputs.

CASE STUDY #5: *Corsica River Restoration project.*

*J. McCoy, I. Spotts, J. Jaber, and M. Trice 2009.
Maryland Department of Natural Resources and
Maryland Department of the Environment*

Project objectives

The Corsica River Targeted Watershed Project is a prototype project designed to increase the level of BMP implementation in Maryland so that the Chesapeake Bay and its tributaries begin to meet water quality standards. The project is designed to develop the best business practices and implement the processes, partnerships, assessments and implementation tools needed to meet that threshold for a single sub-watershed of the Chesapeake Bay. Critical to this project are measurable results. The results drive the level of implementation and demonstrate the level of success achieved by the project. Results will also be used to develop a framework and the capacity to conduct implementation activities on a similar level in other systems.

Design

A Watershed Restoration Action Strategy (WRAS) was developed in 2003 that identified the practices necessary to improve water quality and habitat conditions. In 2005, an aggressive Implementation Plan was developed. In order to successfully address the priority nutrient and sediment Clean Water Act impairments (303(d) list) in the Corsica River, the following activities need to be implemented in the Corsica River Watershed:

- upgrade and maintain centreville sewage treatment plant at enhanced nutrient management;
- establish and maintain 4000 acres of cover crops and 2000 acres of small grain enhancements;
- treat 300 acres of urban lands with stormwater management;
- establish 100 acres of conservation reserve enhancement program buffers;
- implement 50 acres horse pasture management bmps;
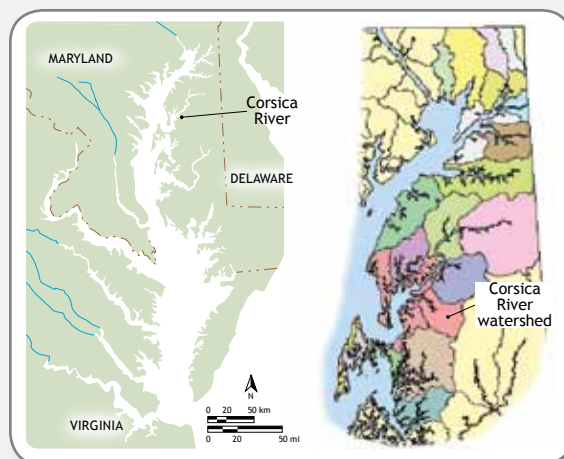
Figure 4.18. LEFT: Location of Corsica River. RIGHT: Corsica River watershed (source: MD DNR).

- retrofit 30 septic systems with denitrification technology;
- establish 200 acres of forested buffers on non-agricultural land;
- restore 50 acres of wetlands and 2 miles of stream channel;
- restore 10 acres of submerged aquatic vegetation and 20 acres of oysters beds; and
- monitor the effectiveness of all bmps and water quality parameters in the tidal corsica river.

Methodology

The monitoring plan for the Corsica River Targeted Watershed Project is designed to evaluate the project's progress towards meeting water quality criteria and designated uses. Water quality and quantity, habitat and living resource monitoring in tidal, non tidal and shallow groundwater and implementation monitoring provide the data needed to evaluate progress. Water quality in the tidal reaches of the river represents the cumulative impact of all of the activities in the watershed and the effect of all of
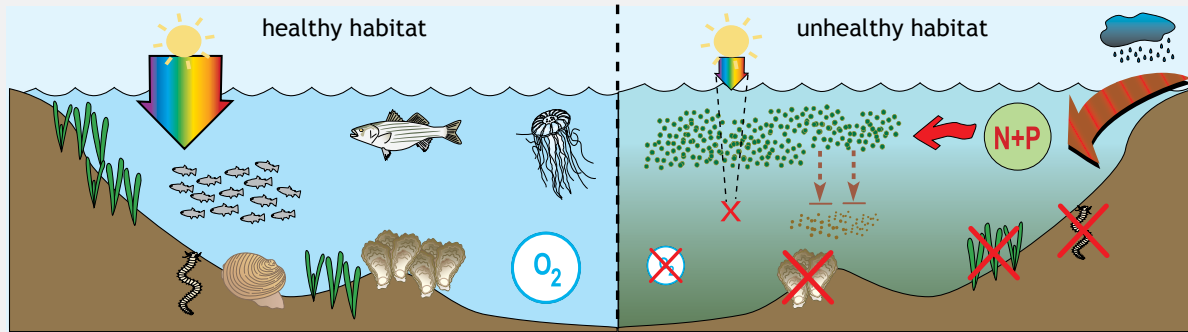
Figure 4.19. Conceptual diagram similar to that used in the annual report card for the Corsica River indicating the components of a healthy versus an impaired or unhealthy habitat.

the natural processes at work in the watershed and estuary. Tidal monitoring is conducted year round at automated sites and monthly during the spring, summer, and fall cruises. While the project's ultimate goal is to improve tidal water quality, it will take some time for detectable changes to occur. To provide the project with results that can be measured on a shorter time scale, monitoring is being conducted within the watershed to evaluate the impact of various implementation activities on the water quality of streams and shallow groundwater. Monitoring is also done to evaluate the effect of cover crops, septic system retrofits with denitrification systems, and non-structural stormwater management retrofits. In the three main freshwater tributaries of the Corsica River, monitoring is being conducted to evaluate stream health, locate dwarf wedge mussel populations, evaluate anadromous fish spawning and estimate nutrient and sediment loads to the tidal system. Integrated with the results of the implementation monitoring, the analysis of results from each level of monitoring will provide the information needed to evaluate the progress of the project towards meeting its goals.

Tidal monitoring

Water quality monitoring in the Corsica River will focus primarily on temporally intensive continuous monitoring and spatially intensive water quality mapping. Continuous monitoring captures events that occur on short time scales (hours to days) or during times when it is impractical to deploy field crews. Early morning lows in dissolved oxygen as well as daytime and nighttime values of water quality parameters are captured by continuous monitoring to provide

managers with the information necessary to fully assess water quality criteria attainment in shallow water habitats. Continuous monitoring is instrumental in documenting the water quality impacts of episodic storm events and provides early warning of potential harmful algal blooms and low-dissolved oxygen related fish kills, allowing managers to coordinate appropriate supplemental sampling (e.g., plankton sampling). Water quality mapping provides information on variability and patchiness that are invaluable in establishing water quality criteria, and in determining attainment of those criteria. For example, spatial information on turbidity can be correlated to the spatial coverage of living resources such as submerged aquatic vegetation (SAV). This information can be used to determine and assess water clarity criteria necessary to support SAV growth, address the progress of meeting ambitious SAV restoration goals, and target specific areas for successful SAV restoration. Spatial data can also be aggregated across watershed units to aid in the evaluation of entire systems. Water quality mapping data can also pinpoint localized areas of water quality concern, such as areas of low dissolved oxygen that can cause fish kills, and their possible links to nearby land uses or point sources.

Four additional components were developed in the tidal portion of the river to ensure a comprehensive understanding of the system. Sediment oxygen demand rates were measured, a box model was constructed to evaluate net hydrodynamic transport in the length of the river, the bottom was mapped using side scanning radar and groundwater discharging to the river through the river bottom was age dated.

Results

The results of the continuous monitoring and the water quality mapping (Figure 4.20) conducted by DNR are available at www.eyesonthebay. net. Various aspects of this project have yielded valuable insights. For instance:

1. Water quality mapping indicates in 2008, less than 20% of the river had average chlorophyll in the good (<15 µg L^{-1}) range and water clarity, reported as turbidity, remains poor along the entire length of the river.

2. Continuous chlorophyll and water clarity data were examined during the SAV growing season from April 1 to October 31. The data were compared to a chlorophyll criteria of 50 µg L^{-1}, which is generally indicative of algal bloom conditions. The Sycamore Point station (upriver station closest to non-tidal streams with highest nutrient inputs) had the most frequent occurrences of bloom conditions. In 2008, 77% of the chlorophyll observations at Sycamore Point were below the 50 µg L^{-1} criteria, compared to an attainment of over 95% at all other stations in the river.

3. The University of Maryland Center for Environmental Science (UMCES) has completed the box model indicating that a half meter increase in water clarity has the potential to dramatically improve the system by changing the majority of the Corsica River from a phytoplankton dominated to a benthic dominated estuary (Boynton et al., 2009).

4. Bottom mapping conducted by NOAA was completed and used to select oyster restoration sites.

5. Groundwater discharge and age dating work by USGS indicates that younger water (20-30 years old) discharges closer to shore and contains significant amounts of nitrogen, whereas deeper and older flow paths discharge groundwater containing little or no nitrogen.

Non-tidal monitoring

The Non-tidal water quality monitoring program is divided into two segments. The first is designed to provide the program with short-term results, the second providing a longer-term evaluation. The long-term monitoring is designed as a paired watershed with Jarmen Branch serving as a control (Spooner et al., 1985).

Short-term results

Shallow groundwater monitoring under cover crops conducted by the University of Maryland, Wye Research and Education Center indicates that there are 75% reductions in rootzone nitrate concentrations in cover crop areas compared to those with fallow corn (Figure 4.21).

Evaluation of the impact of on-site sewage disposal system denitrification retrofits is ongoing. Three years of pre-retrofit and 10 months of post-retrofit data have been collected (Figure 4.22).
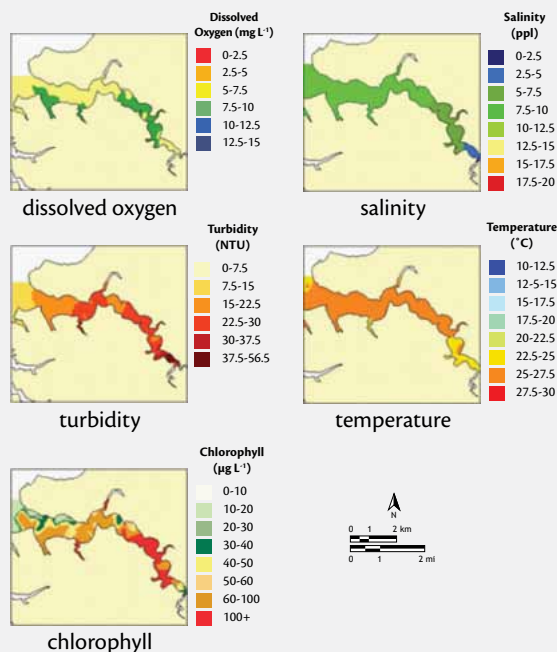
Figure 4.20. Water quality mapping results for September 2009 (data available at: mddnr.chesapeakebay.net/sim/dataflow_data.cfm#corsica).
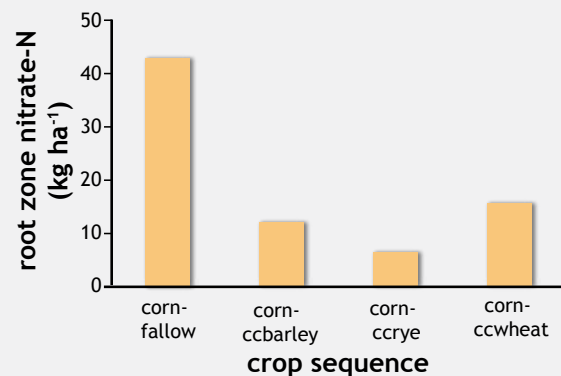
Figure 4.21. Root zone nitrate concentrations under selected fields following corn with and without cover crops in the Corsica watershed (Staver, 2008).
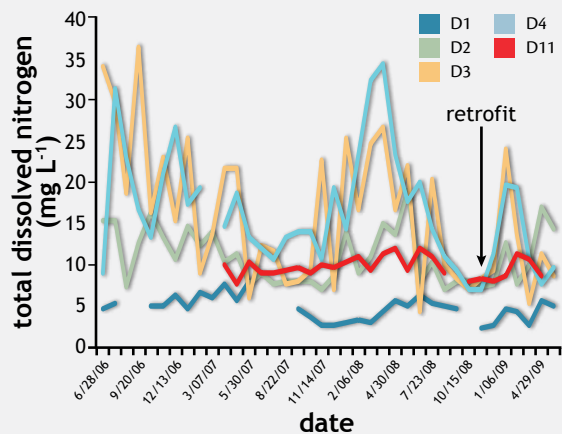
Figure 4.22. Total dissolved nitrogen in shallow groundwater above the drain field (D1-D2), in the drain field (D3-D4) and below the drain field (D11) of a septic system that was retrofitted with a denitrification system (McCoy et al., 2009).

Figure 4.23. Total nitrogen concentrations in Old Mill Stream (OMS), Gravel Run (GVL), and Three Bridges Branch (TBB) from 2006 to 2009.

Long-term results

Load estimates were made for 2007 to 2008 and nutrient concentrations in the three major tributaries (Old Mill Stream, Gravel Run and Three Bridges) have been measured for the period 2006 to 2009 (Figure 4.23).

Implementation monitoring

Implementation data related to the goals set for the project is collected from the various agencies on an annual basis. The data are used to assess progress towards meeting the specific implementation goals of the project and summarized in a report card to the public annually (Table 4.2).

Table 4.2. Summary table used in the Corsica River Report Card indicating the percent attainment toward the restoration goal of various implementation methods.

Resource management task	Goal	Attainment	% of Goal
stream miles restored	3 miles	RT&E locations	0%
forested buffer	200 acres	12 acres	6%
oyster restoration	20 acres	10 acres	50%
wetland restoration	50 acres	32 acres	64%
septic upgrades	30 septics	8 septics	27%
stormwater management	300 acres	28 acres	9%
wastewater treatment	ENR	operating at ENR	100%
horse pasture management	50 acres	23 acres	46%
conservation reserve enhancement program	100 acres	60 acres	60%
cover crops	4000 acres	1621 acres	41%
small grain enhancement	2000 acres	1371 acres	69%

Management implications

To date, long-term non-tidal and tidal monitoring results show no improvement in water quality in the Corsica or its tributaries. This is likely due to the fact that although nutrient reduction strategies have been aggressively implemented (e.g., wastewater treatment plant upgrades, wetlands, oysters, and cover crops), the total N reduction is only 30% of the total N load. In order to see a water quality response in the tidal system, it is estimated that a 50% reduction in N loading would yield a 70% reduction in chlorophyll and a 75% improvement in water clarity (Boynton et al. 2009). Lag times also contribute to a delayed response in the non-tidal and tidal systems from nutrient reductions that are implemented in the watershed because much of the nitrogen load is routed through the groundwater system. It is estimated that lag times could be on the order of 18 years in the Corsica watershed (Boynton et al., 2009; Bratton et al., *unpublished*).

Pier located in the Corsica River estuary with continuous monitoring devices attached.

Monitoring implications

To date the short-term monitoring results show that cover crops are effective in reducing nitrate concentrations in the root zone.

CASE STUDY #6:

The effect of agricultural best management practices on subsurface nitrogen transport in the German Branch watershed.
K. Staver 2001. University of Maryland College of Agriculture and Natural Resources, Wye Research and Education Center

Project objectives

This study was initiated in the fall of 1995 with the primary objectives being to evaluate recent changes in nitrate leaching rates associated with various crop, soil, and nutrient types, and also to provide estimates of the time required for changes in nitrate leaching rates to affect nitrogen discharge at the watershed scale.

Project details

Design

Extensive soil coring was conducted in agricultural fields in the German Branch watershed to determine water and nitrate levels in the groundwater flow system. Results from coring were combined with landuse, regional discharge, and hydrogeomorphic information to determine groundwater residence times throughout the watershed.

Background—site description

The German Branch watershed, a subwatershed of the Choptank River, was one of four watersheds selected in the Maryland Targeted Watershed Project for focused water quality restoration activities. One of the key objectives of this effort was to reduce nutrient losses from agricultural lands in the watershed. However, despite concentrated efforts through the early 1990s and projected reductions in nutrient losses, no downward trend in nitrogen discharge rates could be detected at the watershed outlet. This lack of progress raised many questions regarding the effectiveness of the overall effort to reduce nutrient losses from Eastern Shore cropland. The key question was whether the apparent lack of progress in reducing nitrogen discharge rates was due to ineffectiveness of the practices put in place or simply the long time period needed for changes in root zone leachate nitrate concentrations to be reflected in streamflow.
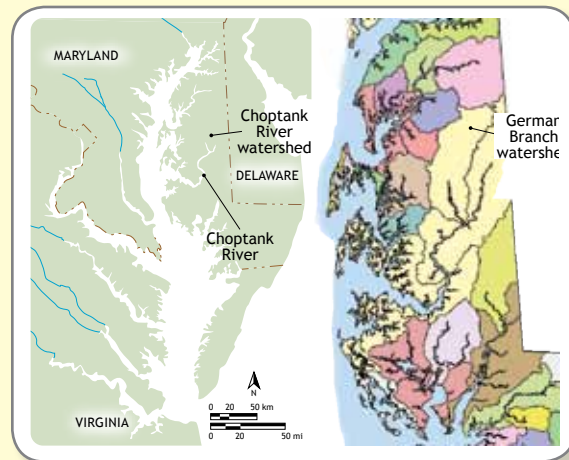
Figure 4.24. LEFT: Location of Choptank River. RIGHT: Choptank River watershed (source: MD DNR).

Methodology

Soil coring to a depth of approximately 0.3 m below the watertable was done following grain harvest in 1995-1997. Sampling was conducted in fields where inorganic fertilizers were used exclusively, and also where dairy manure and sewage sludge recently had been applied. Cores were analyzed in 15 cm increments for water and nitrate content. A total of 169 soil cores sectioned into 3216 individual samples were collected and analyzed.

Results

Subsurface nitrate concentrations varied widely between fields and also showed both increasing and decreasing concentrations with depth. The source of nutrients applied and the recent cropping sequence appeared to be the dominant factors determining both autumn root zone and intermediate vadose zone nitrate concentrations, overshadowing any effects on nitrate leaching patterns that may have resulted from development of nutrient management plans. The average pore water nitrate-N concentration between the

bottom of the root zone (60 cm) and the water table was 15.8 mg L^{-1} at sites where only inorganic nutrients had been used recently, 24.7 mg L^{-1} at sites associated with dairy operations, and 28.8 mg L^{-1} at sites with recent multiple sewage sludge applications. Nitrate concentrations in the surface of the unconfined aquifer also were highly variable but tended to be lowest where inorganic fertilizer was used and highest at sights with a recent history of multiple sewage sludge applications. The average nitrate-N concentration for all sights was 20.7 mg L^{-1}, with no apparent effect of soil type. At several sites there was evidence of denitrification within the unconfined aquifer associated with a layer of organic material. Weighting subsurface nitrate concentrations for the approximate nutrient use patterns in the watershed yielded an average pore-water nitrate-N concentration for all cropland of approximately 18.0 mg L^{-1} in both the intermediate vadose zone and the surface of the unconfined aquifer. Overall subsurface nitrate concentrations did not indicate that nitrate concentrations in leachate were declining during the mid-1990s in the German Branch watershed. However, uncertainties regarding how nutrient management plans changed nitrogen use patterns in the watershed make it difficult to determine why changes weren't apparent.

Coring data along with land use and regional discharge and hydrogeologic information were used to simulate storage and flow within the subsurface flow system in the German Branch watershed. Assistance with this effort was provided by Gordon Folmar and Bill Gburek from the USDA/ARS Pasture Systems and watershed Research Lab at State College, PA. Nitrate storage and residence time were found to vary spatially depending on surface elevation and location relative to stream channels. Maximum subsurface nitrate-N storage levels of approximately 1000 kg ha^{-1} were estimated for cropland at higher elevations near the water table divide. Approximately 90% of water and nitrate storage in the subsurface flow system is in the unconfined aquifer with the remainder being in the unsaturated part of the profile. The subsurface f low system contains approximately 18 times more water than the annual input/discharge volume. Average residence time in the subsurface flow system for cropland root zone leachate was calculated to be 17.8 years. However, leachate from approximately 22% of the cropland in the watershed is projected to be discharged in streamflow in less than five years. Leachate from 43% of the cropland is projected to have a subsurface residence time of less than 10 years.
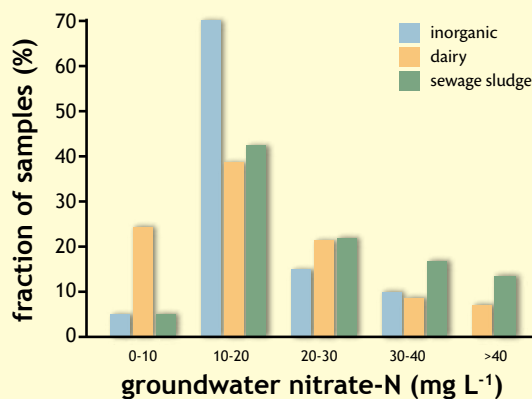

Figure 4.25. Distribution of groundwater nitrate-nitrogen (N) concentrations in groundwater collected from the surface of the unconfined aquifer under crop land in the German Branch watershed under differing nutrient application management systems.
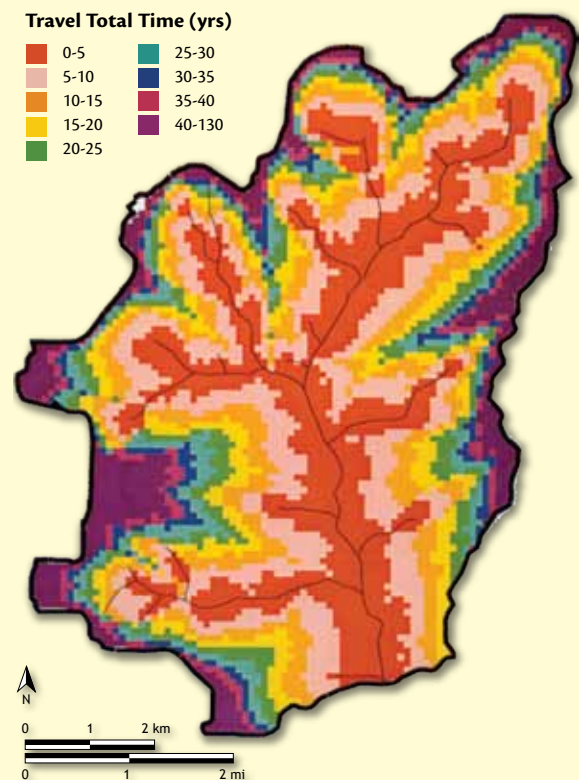
Figure 4.26. Map of travel time for groundwater in the German Branch watershed from the bottom of the root zone to discharge into stream flow.

German Branch cropland groundwater residence time
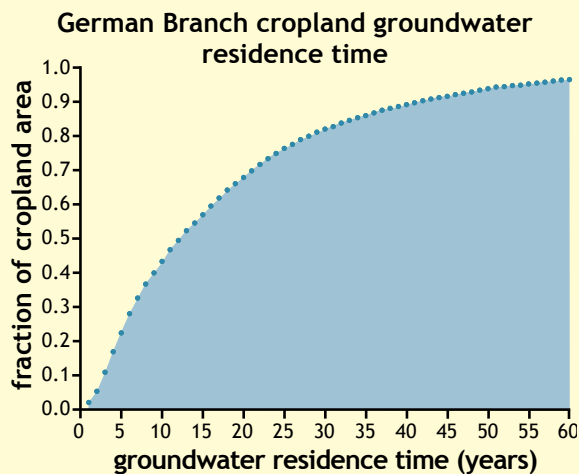
Figure 4.27. Cumulative distribution of groundwater residence time from cropland in the German Branch watershed.

Management implications

A lack of historical information on nitrate leaching patterns makes it difficult to determine if nitrogen losses to the subsurface flow system declined in the German Branch watershed during the mid 1990s as a result of the targeted implementation effort. The primary management question relates to whether efforts to improve nutrient management actually changed nutrient application practices in the watershed. A future effort should include much more emphasis on exactly how implementation efforts changed in field management. What is clear is that subsurface nitrate concentrations remain highly elevated and there appears to be potential for much better management of organic nitrogen sources. But whether the subsurface nitrate levels measured in this study represent an improvement over past conditions remains unknown. The failure to achieve even modest cover crop implementation goals made it unlikely that significant reductions in overall nitrogen losses could be achieved.

Monitoring implications

The long residence time for groundwater in the German Branch watershed makes stream monitoring of limited value for determining effectiveness of nutrient reduction strategies in the near term (<5 years). Even if highly effective practices for reducing nitrate leaching had been broadly implemented in the early 1990s, there would have been little impact on stream nitrate concentrations until well after the 5-year targeted implementation effort was completed. Stream nitrate concentrations in German Branch during the 1990s primarily reflected nitrate leaching rates from well before the targeted implementation effort began. A secondary issue in the German Branch watershed is that there appears to be significant losses of nitrate in the subsurface flow system between the root zone and the point of discharge into stream flow. This creates additional uncertainty regarding how reductions in nitrate leaching rates in crop fields will translate into reductions in watershed N losses delivered through stream flow. So even though stream flow monitoring provides the most definitive way to measure watershed nitrate discharge from the groundwater flow system, this integrated signal gives little indication of the effectiveness of ongoing or recent implementation efforts in watersheds with long groundwater residence times.

Section 5

LESSONS LEARNED AND MONITORING STRATEGY

KEY POINTS

There are a number of management and monitoring implications provided for each case study that should be recognized by Trust Fund applicants. Most importantly:

➤ These case studies indicate that high-intensity sampling can be very effective in evaluating BMP effectiveness.

➤ BMP effectiveness is commonly determined using pre-implementation baseline data or controls, although nested or synoptic sampling designs can be used as alternates.

➤ The decision tree in this section will help determine whether monitoring is appropriate and guide the selection of the most appropriate monitoring design(s) for a particular project.

Other than the management and monitoring implication provided for each case study above, probably the most important lesson to be learned from these case studies is that high-intensity sampling can be very effective in evaluating BMP effectiveness. Moreover, although it is generally agreed that the most effective evaluations of BMP effectiveness commonly use pre-implementation baseline data or controls, these are not essential because other effective monitoring designs exist (e.g., nested or synoptic sampling). However, even in projects were monitoring is emphasized, it can be difficult to observe an effect of BMP implementation because of lag times and other considerations mentioned previously. Consequently, a decision tree has been developed to assist Trust Fund recipients in determining whether monitoring is appropriate and, when monitoring is deemed necessary, help guide the selection of the most appropriate monitoring design(s) for a particular project. The decision tree is comprised of 6 separate sections that are discussed in detail on the subsequent pages.

Howard's Branch stream restoration site with ponding basin. This is one of the stream restoration sites monitored in Case Study #4

1. determine what monitoring data are available for project area

2. assess cumulative effect of BMP(s) on downstream receiving waters using nutrient reduction efficiencies and model output or data obtained in #1

LARGE-SCALE EFFECT OF BMP(S):

too small to measure

measurable

3a. individual or small-scale BMPs

3b. multiple or large-scale BMPs

urban

agricultural

> stormwater retrofit
> stream restoration
> riparian buffers

> cover crops
> precision agriculture
> riparian buffers

DEVELOP MONITORING STRATEGY

4. select effective monitoring design

5. determine what constituents to measure

6. measurement frequency and type

Figure 5.1. Decision tree that provides relevant information on experimental designs and monitoring methods that should be used by Trust Fund recipients.

1. **Determine what monitoring data are available for project area.**

   Projects funded by the 2010 Trust Fund can potentially use data from one of several other types of sampling networks not only to determine background or control concentrations of pollutants but also evaluate whether the projected BMPs will likely have a measurable effect at a downstream monitoring point. These monitoring networks include fixed (USGS non-tidal or DNR tidal) and targeted stream monitoring stations. Moreover, although the capabilities of volunteer organizations vary widely, many can provide reliable data on basic water quality variables, such as nitrogen measurements.

   More specifically, various types of data have and continue to be collected by numerous agencies in Maryland, and these data may be used as baseline information to help evaluate the effectiveness of implementation projects. In addition to the sampling networks mentioned above, other possible data sources can be identified on Google Earth maps that indicate where Maryland Biological Stream Survey (MBSS) and associated Sentinel sites, and CORE/Trend sites are located (www.dnr. state.md.us/streams/2010TrustFund.asp). There are links to reports and fact sheets at this web site that describe these surveys (and contact information of key personnel) and there will be links to the Maryland

Water Monitoring Council website (mddnr. chesapeakebay.net/MWMC) and many other water quality monitoring groups (federal, state, local, university, etc.). Information available at these sites will allow Trust Fund applicants and recipients to evaluate whether applicable monitoring data are available for their implementation site(s).

2. **Calculate expected effect of BMP(s) on water quality at proposed monitoring point using nutrient reduction efficiencies and model output or data obtained in #1.**
Initially, Trust Fund applicants need to evaluate whether the effects of a particular BMP or suite of BMPs intended to be used in their project area will result in a measureable effect on water quality. For instance, nutrient reduction efficiencies (Appendix A) can be used to estimate expected decreases in nutrients and sediments and what influence these potential reductions may have on solute concentrations at monitoring points in receiving waters. These efficiencies are derived from the scientific literature and many have been incorporated into watershed models to predict responses to BMP implementation on larger scales (i.e.,

the Bay Program Watershed Model - HSPF). Details of how nutrient reduction efficiencies were derived and used can be found at: www. chesapeakebay.net/marylandbmp.aspx.
All Trust Fund proposals require applicants to estimate gross nutrient and sediment reductions expected from their projects. Therefore, nutrient reduction efficiencies should be used by Trust Fund recipients to evaluate whether a monitoring program will be able to measure the effects of BMP implementation in a particular watershed, and monitoring should be conducted only in areas where BMPs (single or multiple) will likely achieve a measurable reduction of pollutant levels at monitoring points in receiving waters. Applicants should also provide an assessment of the expected time frame of change in nutrient and sediment reductions given their particular applications. Efficiency values used for Phase 5 of the watershed model supersede those for Phase 4.3, and Trust Fund recipients that have justifiable and defensible nutrient reduction efficiencies applicable to their particular application are encouraged to use them in place of the efficiencies provided in this document.

Grassed waterways and riparian buffers are effective agricultural BMPs that reduce overland runoff and nutrient and sediment loading to streams.

J. Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/)

The Little Patuxent restoration project is focused in an area of 25,600 acres (shown as green in figure insert). This project area is a hydrologic unit that includes the majority of the Maryland 8-digit (02131105) Little Patuxent River and includes the highest concentration of high-priority Trust Fund 12-digit subwatersheds in the state. The Little Patuxent area comprises 12 subwatersheds (14-digit USGS HUCs) beginning at the headwaters of the Little Patuxent River just north of Interstate 70. The downstream point of the project area is south of the intersection of Route 32 and Interstate 95 at the confluence with the middle Patuxent River. The project area essentially surrounds the planned community of Columbia and is bisected by Routes 29 and 175. Parts of Ellicott City in the north and Savage in the south are also included. The project area contains approximately 90 miles of stream and 2,150 acres of green infrastructure. Land surface in the project area is 20% impervious, and land use is 65% urban, 18% forested, 11% agricultural, 2% wetlands, and 4% other. Existing BMPs currently treat 9,447 acres (37% of the project area). Anticipated implementation in this project will include 75 separate BMPs, such as stream reach restorations and stormwater retrofits (Table 5.1).

As an example of how Trust Fund applicants or recipients could determine whether a monitoring plan would be effective at measuring nutrient reductions from a combination of these BMPs, nutrient reduction efficiencies for N and P derived from the Urban BMPs section of Appendix B (i.e., nutrient reduction efficiencies for Phase 4.3 HSPF model) could be multiplied by the area the BMPs will constitute when implemented. In this case, there are a total of 75 BMPs that will be implemented for a total of 1470 acres. The product of the "Nutrient Management, Mixed" values for N and P from
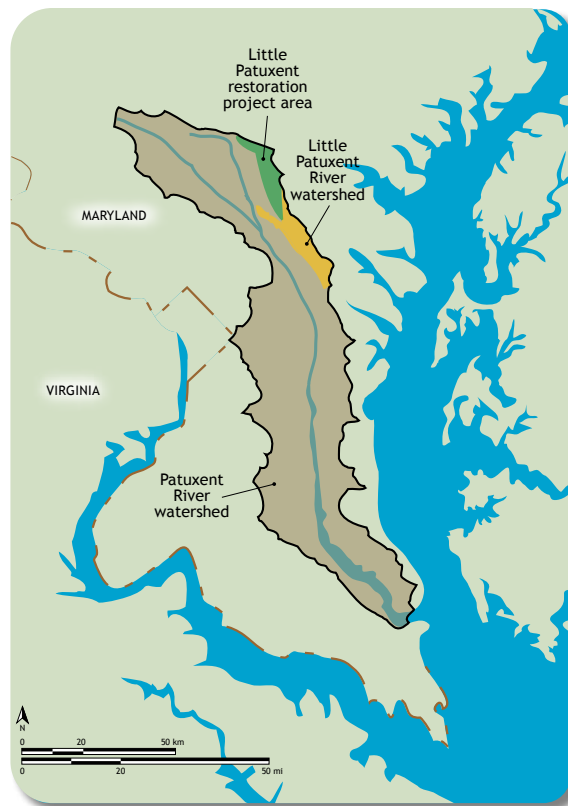
Figure 5.2. The Little Patuxent restoration project area (green) within the larger high-priority Little Patuxent River (yellow) and Patuxent River (brown) watersheds.

Appendix A (i.e., 0.97 and 0.17, respectively) and the total BMP area gives an estimated gross nutrient reduction of 1426 and 250 lbs N and P yr^{-1}, respectively. Comparing these numbers to estimates of total loads to the Little Patuxent (derived from the HSPF Chesapeake Bay watershed model; note that Phase 4.3 HSPF output by segment for relevant project areas are available at www.chesapeakebay.net/data_modeling.aspx) gives a back-of-the-envelope estimate of whether decreases in N and

Table 5.1. Projects within the Little Patuxent project area that have been identified for implementation with 2010 Trust Fund monies.

Project type	LPRP restoration projects				
	FY09	FY10	FY11	Future	Total
stormwater management (SWM) enhancements	7	9	5	20	41
stream enhancements	2	11	0	9	22
tree planting	2	3	0	1	6
public education	1	0	0	0	1
other	4	1	0	0	5
TOTAL	16	24	5	30	75

P concentrations in streamwater at the mouth of the Little Patuxent would be measurable. Given gross export from the Little Patuxent watershed of approximately 360,000 lbs TN yr^{-1} and 15,000 lbs TP yr^{-1}, expected N and P reductions from BMP implementation are the equivalent of 0.4 and 2%, respectively. Assuming that a >30% reduction in ambient loading is required to achieve a measurable effect at a monitoring point, we can conclude that the effect of these BMPs on water quality in the Patuxent River at Savage (site with available USGS flow and TN, TP and TSS data) will not be measurable.

> **Rule of Thumb:**
> Assume that >30% reduction in ambient loading is required to achieve a measurable effect on downstream receiving waters.

As in this case, most implementation will not be at the scale where an effect on larger streams, rivers and estuarine tributaries can be detected. And even at smaller scales, a BMP that targets nutrient and sediment removal in a watershed that is surface-water dominated will likely see a faster water quality improvement response than a project targeting watersheds that have lag times (i.e., groundwater) or legacy sediment influences. Nevertheless, if it is decided that monitoring is necessary, this should be conducted at a monitoring point within or as close to the implementation site as possible using the monitoring designs indicated in Table 5.2.

Little Patuxent River during baseflow.

3a) Individual or small-scale BMPs

In the case where small-scale BMPs are to be monitored, characterizing the land use of the project area should be done using GIS. Characterizing the proportion of land use (i.e., urban, agriculture, forest, water) for the project watershed as well as the surrounding area is important because this will allow recipients to determine whether certain types of monitoring designs, such as paired-watersheds, can be used to evaluate implementation effectiveness. Moreover, land use characterization is necessary to use in conjunction with HSPF load estimates (as shown in example above).

3b) Multiple or large-scale BMPs

In the case where it has been determined that individual or multiple BMPs in a watershed will have a measureable effect on a downstream river or tributary of Chesapeake Bay, then other data options available. For instance, there is a USGS network of flow and water quality monitoring stations situated throughout Maryland, and this information is generally available online (e.g., va.water.usgs.gov/chesbay/RIMP/). Moreover, there are many constituents and metrics monitored regularly in the tributaries of Chesapeake Bay, and several of these are used to assess a combined effect of several water quality constituents on the health conditions of estuarine tributaries (Williams et al., 2009). In larger-scale implementation areas, it would be possible to compare these measurements to long-term data (1986 to present) in order to determine possible effects of implementation. Examples of these metrics, data, and estimates of health conditions of Chesapeake Bay tributaries can be found at www.eco-check.org.

4a) Select effective monitoring design - small-scale BMPs.

There are several common and effective monitoring designs that can be used to detect possible changes in water quality from BMP implementation. Designs presented in Table 5.2 can be used to detect changes in water quality resulting from BMP implementation, yet the most appropriate design will depend on site-specific characteristics of the implementation area. For instance, determining the land use characteristics on the implementation site and surrounding area may indicate that there is an adjacent watershed that could be used as a control. Otherwise, the most effective approach is to monitor water quality at a location where an effect is likely to be measurable (i.e., downstream,

but as close as possible to the implementation area). Determining whether baseline data are available for the area to be monitored is critical because this will allow for more robust comparisons with changes in water quality resulting from BMP implementation. If an adequate baseline data set has been derived, then post-implementation monitoring can be used to determine if there is an effect of the BMP in the form of nutrient or sediment reduction. Although this type of baseline monitoring is unlikely to occur within the project itself due to financial and temporal constraints, there is the possibility that some baseline information could be obtained from monitoring done by other agencies prior to the implementation of a Trust Fund project.

Other monitoring options are also available in agricultural settings. For instance, in cover crop BMP areas where a measureable effect on streamwater is unlikely to occur (at least in the short term), groundwater wells or gravity lysimeters could be installed to determine the BMP's effect on nutrient leaching to the water table (see Case Study #2). These methods can be evaluated in greater detail with UMCES or DNR staff if the need arises for a particular project.

Demonstrating how groundwater quality measurements are taken from agricultural plots in Maryland.

4b) Select effective monitoring design - large-scale BMPs.

Projects where larger-scale or multiple BMPs in a watershed will likely have a measureable effect on downstream receiving waters may be able to use existing long-term data of flow and solute concentrations from USGS monitoring stations situated throughout Maryland (e.g., va.water.usgs.gov/chesbay/RIMP/). In these cases, nested above and below or before and after sampling designs are also recommended.

5a) What constituents to measure - small-scale

Water quality monitoring done at an implementation site should generally consist of conventional water quality analyses such as nitrogen (nitrate [NO_3], ammonium [NH_4] and total nitrogen [TN]), phosphorus (phosphate [PO_4^3] and total phosphorus [TP]) and total suspended solids (TSS). If all of these constituents cannot be measured, then the preference that should be give to the water quality constituents measured are listed

Table 5.2. Recommended designs for monitoring BMP effectiveness.

Design	Advantages	Disadvantages
Nested above/below or before/after	• can attribute water quality changes to BMPs • similar/same sampling sites	• takes several years to see effect if before/after design is used • upstream impacts can overwhelm effect of BMP • climatic variability could create artifacts if not before/after monitoring
Paired watersheds	• controls for hydrological variation • can attribute water quality changes to BMPs	• difficult to find paired watersheds • difficult to control land use/treatment in control • takes several years to see effect

below in descending order:

1. Measurement of concentration and load of TN or NO_3, TP, and TSS.
2. Measurement of concentration and load of TN or NO_3, TP.
3. Measurement of concentration and load of TN or NO_3.
4. Measurement of concentration of TN or NO_3 and TP.
5. Measurement of concentration of TN or NO_3.

Although stream discharge measurements, if not available from the United States Geological Survey (USGS) stream gages, can be done using a combination of flow meters and pressure transducers, or weir and flumes (Stevens, 1987), it is not recommended for Trust Fund recipients because this technique is very labor intensive. Therefore, it is recommended that water yields from the closest USGS gauging station or the USGS StreamStats model (water.usgs.gov/osw/streamstats) be used instead. However, if discharge measurements are available, these can be used to calculate pollutant mass loadings, as well as the impacts of low-flow conditions on stream biota.

In order to do chemical analyses on samples collected, there are a variety of commercial sampling kits available (www.lamotte.com) if some of the field monitoring and analysis is to be done by project staff. DNR and UMCES staff can assist in the selection of the proper analytical equipment or available commercial and non-commercial labs.

5b) What constituents to measure - large-scale

Other than those constituents indicated in 5a, larger-scale implementation where the implementation of BMPs in the watershed of interest is in close proximity to tidal waters, or the BMPs are expected to have a significant reduction in nutrient and sediment loading that may result in a measurable effect in tidal waters of Chesapeake Bay, can also use tidal water monitoring data to evaluate implementation effectiveness. These data, in addition to the constituents mentioned in the previous section, include chlorophyll-a and inorganic nutrient data (i.e., nitrate and phosphate) that may assist in determining implementation effectiveness. Long-term data (1986 to present) available in tidal areas will allow for an evaluation of before and after effects of implementation.

6a and b) Measurement type and frequency

The type of measurement and collection frequency must be prioritized according to the following list. As noted previously, much of the N discharged from disturbed areas moves as dissolved NO_3 in surface flow and, consequently, baseflow stream NO_3 sampling can be an excellent indicator of the total N response to BMP implementation in agricultural or low- to moderately-impervious (i.e., <50%) urban watersheds (note that highly impervious urban watersheds will require stormflow-oriented sampling even for N). Baseflow can be defined as any period following two days after storm activity. Nitrate concentrations can also provide relative measures (i.e., comparisons of mean solute concentrations) among watersheds even if flow data are not available. Moreover, because this constituent is easier and cheaper to sample and analyze, it should therefore be measured in place of TN if possible.

1. **Nitrogen measurements in order of preference:**
   Option 1: Nitrate base- and storm-flow collected monthly
   Option 2: TN base- and storm-flow collected monthly
   Option 3: Nitrate or TN baseflow collected quarterly (basic Trust Fund requirement)
2. **Phosphorus measurements in order of preference (use field sampling only for implementation areas that include organic nutrients or livestock dominated watersheds):**
   Option 1: Monthly in-stream and edge-of-field TP monitoring (both stormflow oriented) + In-field soil P saturation
   Option 2: Monthly in-stream and edge-of-field TP monitoring (both stormflow oriented)
   Option 3: Quarterly in-stream (done in conjunction with TN sampling)
3. **TSS measurements in order of preference:**
   Option 1: In-stream and edge-of-field (both stormflow oriented) + channel monitoring (i.e., note extent of erosion)
   Option 2: In-stream and edge-of-field monitoring (both stormflow oriented)
   Option 3: In-stream (done in conjunction with nutrient sampling)

Adaptive management

The challenges identified previously underscore the need for an adaptive management approach to implementation. For instance, at larger spatial scales and with assistance from DNR and UMCES staff, Trust Fund recipients are encouraged to utilize a combination of inherent sampling networks best suited to evaluate the effects of BMP implementation. Moreover, the creation of partnerships in monitoring and assessment efforts, such as the involvement of community partners in the use of data from citizen monitoring groups and other external sources for assessment purposes, is encouraged.
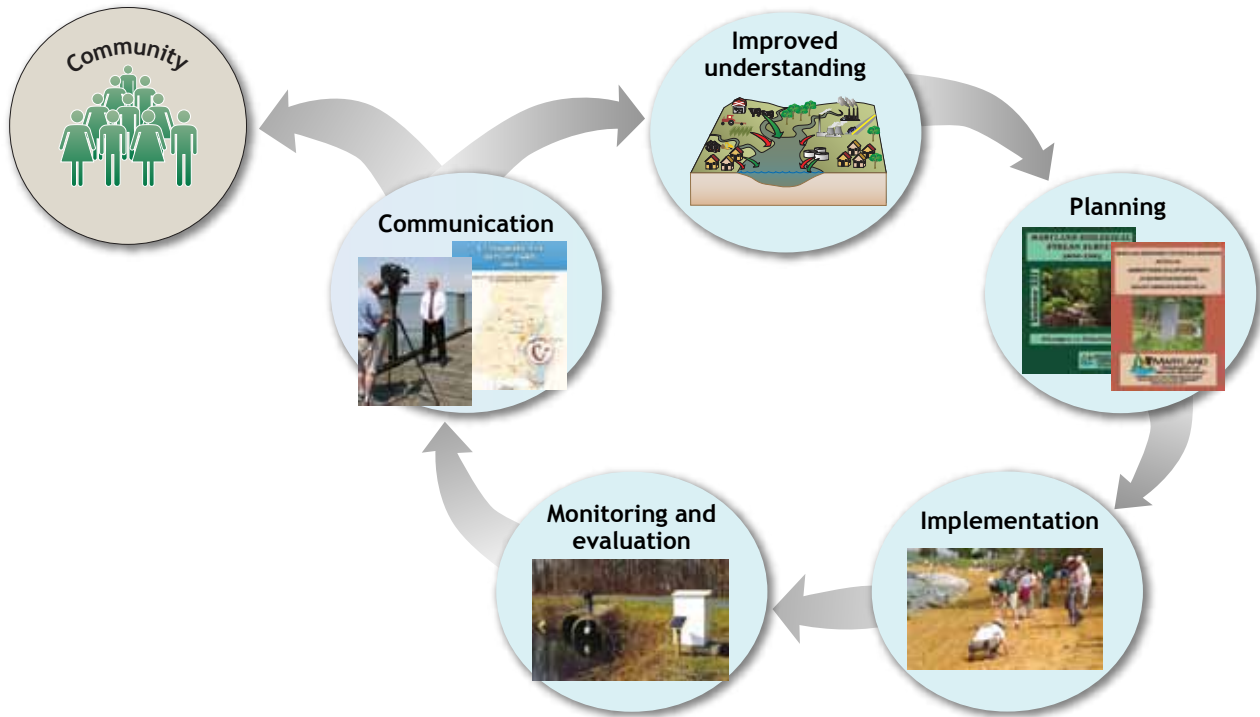

Figure 5.3. Diagram representing the process of adaptive management whereby effective communication leads to improved understanding, planning, implementation, monitoring and public awareness.

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Appendix A

NUTRIENT AND SEDIMENT REDUCTION EFFICIENCIES BY BMP

Below is a listing of defined BMPs and effectiveness estimates (same as those used in the Bay Program's Watershed Model, Phase 5). This approach does not reflect the natural variability of effectiveness estimates that occurs with various hydrologic flow regimes, soil conditions, climates, management intensities, vegetation, and BMP designs. The following information was adapted from the Chesapeake Bay Program website (www.chesapeakebay.net/marylandbmp.aspx).

Ammonia Emission Reduction

Litter treatment: a surface application of alum, an acidifier, to poultry litter to acidify and maintain ammonia in the non-volatile ionized form (ammonium). Ammonia Emission Reduction of 50%.

Biofilters: these are housing ventilation systems that pass air through a biofilter media that incorporates a layer of organic material, typically a mixture of compost and wood chips or shreds, that supports a microbial population and reduces ammonia emissions by oxidizing volatile organic compounds into carbon dioxide, water and inorganic salts. Ammonia Emission Reduction of 60%.

Covers: the use of a permeable plastic over liquid storage that is composed of non-woven fabric, thermally bonded, continuous polypropylene filaments. Covers create a physical barrier to prevent mass transfer of volatile chemical compounds from the liquid by covering manure storage facilities to decrease wind velocity (decrease surface area) and reduce radiation onto the manure storage surface (lower temperature). Ammonia Emission Reduction of 15%.

Conservation Plans

These are a combination of practices, other than conservation tillage or no-till, that reduces soil loss to or below tolerance.

Landuse	TN reductions	TP reductions	TSS reductions
conventional tillage	8%	15%	15%
conservation tillage	3%	5%	8%
hayland	3%	5%	8%
pastureland	5%	10%	14%

Conservation Tillage

This practice involves the planting, growing and harvesting of crops with minimal disturbance to the soil surface through the use of minimum tillage, mulch tillage, ridge tillage or no-till.

Landuse	TN reductions	TP reductions	TSS reductions
separate flow paths	surface 18% / subsurface 0%	22%	30%
combined flow paths	8%	22%	30%

Cover Crops

Non-harvested winter cereal cover crops, including wheat, rye and barley, designed for nutrient removal.

Planting date	TN values based on planting date, species, location, and seeding method	Cereal cover crop on conservation tillage (TP and TSS)	Cereal cover crop on conventional tillage	
			TP	TSS
early	see full report for table of values	0%	15%	20%
standard		0%	7%	10%
late		0%	0%	0%

Dairy Precision Feeding

This practice reduces the quantity of phosphorous and nitrogen fed to livestock by formulating diets within 110% of NRC-recommended levels in order to minimize the excretion of nutrients without negatively affecting milk production. Effectiveness estimates are determined via direct testing, however, without test results TP reduction is assumed to be 25% and TN reductions are assumed to be 24% with no TSS associated with dairy precision feeding.

Dry Detention Basins and Hydrodynamic Structures

Dry Detention Ponds are depressions or basins created by excavation or berm construction that temporarily store runoff and release it slowly via surface flow or groundwater infiltration following storms.

Hydrodynamic Structures are devices designed to improve quality of stormwater using features such as swirl concentrators, grit chambers, oil barriers, baffles, micropools and absorbent pads that are designed to remove sediments, nutrients, metals, organic chemicals, or oil and grease from urban runoff. Effectiveness estimates are 5% TN, 10% TP, and 10% TSS.

Dry Extended Detention Basins

These are depressions created by excavation or berm construction that temporarily store runoff and release it slowly via surface flow or groundwater infiltration following storms using a low flow control outlet that releases water over time, drying out between storm events. Effectiveness estimates: TN 20%, TP 20%, and TSS 60%.

Forest Harvesting Practices

A suite of practices that reduce sediment and nutrient pollution to water bodies originating from forest management activities to acceptable levels. Effectiveness estimate: 50% TN, 60% TP, and 60% TSS.

Infiltration and Filtration

The infiltration BMPs included bioretention, permeable pavement and pavers and infiltration trenches and basins. The filtration BMPs were filters and vegetated open channels.

Bioretention: excavated pit backfilled with engineered media, topsoil, mulch and vegetation.

Permeable Pavement and Pavers: excavated pit backfilled with engineered media, topsoil, mulch and vegetation.

Infiltration Trenches and Basins: excavated pit backfilled with engineered media, topsoil, mulch and vegetation.

Filters: capture and treat runoff by filtering through a sand or organic media.

Vegetated Open Channels: convey runoff and provide treatment; includes bioswales.

Planting date	EMC-based removal (PR)			Runoff reduction (RR)	Mass-based removal (TR) expressed as removal from collection area (acres)		
					TN	TP	TSS
Bioretention							
C/D soils, underdrain	37	10	50	15	25	45	55
A/B soils, underdtain	37	10	50	65	70	75	80
A/B soils, no underdrain	37	10	50	80	80	85	90
					= 20	= 15	= 15
Filters							
All (sand, organic, peat)	60	40	80	0	40	60	80
					= 10	= 15	= 10
Vegetated Open Channels							
C/D soils, no underdrain	10	10	50	0	10	10	50
A/B soils, no underdrain	10	10	50	40	45	45	70
					= 20	= 20	= 30
Bioswale	37	10	50	65	70	75	80
					= 20	= 15	= 15
Permeable Pavement (no sand/veg)							
C/D soils, underdrain	10	0	50	10	10	20	55
A/B soils, underdrain	10	0	50	45	45	50	70
A/B soils, no underdrain	10	0	50	75	75	80	85
					= 20	= 15	= 15
Permeable Pavement (with sand, veg)							
C/D soils, underdrain	10	10	50	10	20	20	55
A/B soils, underdrain	10	10	50	45	50	50	70
A/B soils, no underdrain	10	10	50	75	80	80	85
					= 20	= 15	= 15
Infiltration Practices (no sand/veg)							
A/B soils, no underdrain	25	0	95	80	80	85	95
					= 15	= 15	= 10
Infiltration Practices (with sand/veg)							
A/B soils, no underdrain	25	15	95	80	85	85	95
					= 10	= 15	= 10

Mortality Composters
Composting routine mortality in a designed, on-farm facility, with subsequent land application of the compost. Effectiveness estimates: TN 40%, TP 10%, and 0% TSS.

Offstream watering with fencing
This BMP incorporates both alternative watering and installation of fencing that excludes narrow strips of land along streams from pastures and livestock with management of the alternative watering area so it does not become a source of sediment or phosphorus. Effectiveness estimates: 25% TN, 30% TP, and 40% TSS.

Offstream watering without fencing
This BMP requires the use of alternative drinking water sources away from streams to reflect partial removal of livestock from near stream areas and relocation of animal waste deposition areas and heavy traffic areas surrounding water sources to more upland locations with management of the alternative drinking watering area so it does not become a source of sediment or phosphorus. Effectiveness estimates: 15% TN, 22% TP, and 30% TSS.

Riparian Forest Buffers
An area of trees at least 35 feet wide on one side of a stream, usually accompanied by shrubs and other vegetation, that is adjacent to a body of water which is managed to maintain the integrity of stream channels and shorelines. These buffers also reduce the impacts of upland sources of pollution by trapping, filtering, and converting sediments, nutrients, and other chemicals; they also supply food, cover, and thermal protection to fish and other wildlife.

Riparian forest buffers—nutrient and sediment reduction efficiencies	TN	TP	TSS
inner coastal plain	65	42	56
outer coastal plain well drained	31	45	60
outer coastal plain poorly drained	56	39	52
tidal influenced	19	45	60
piedmont schist/gneiss	46	36	48
piedmont sandstone	56	42	56
valley and ridge—marble/limestone	34	30	40
valley and ridge—sandstone/shale	46	39	52
Appalachian Plateau	54	42	56

Riparian Grass Buffers

An area of grasses that is adjacent to a body of water which is managed to maintain the integrity of stream channels and shorelines, to reduce the impacts of upland sources of pollution by trapping, filtering, and converting sediments, nutrients, and other chemicals, to supply food, cover, and thermal protection to fish and other wildlife.

Riparian grass buffers—nutrient and sediment reduction efficiencies	TN	TP	TSS
inner coastal plain	46	42	56
outer coastal plain well drained	21	45	60
outer coastal plain poorly drained	39	39	52
tidal influenced	13	45	60
piedmont schist/gneiss	32	36	48
piedmont sandstone	39	42	56
valley and ridge—marble/limestone	24	30	40
valley and ridge—sandstone/shale	32	39	52
Appalachian Plateau	38	42	56

Urban Erosion and Sediment Control

Protecting water resources from sediment pollution and increases in runoff associated with land development activities by retaining soil on-site so sediment and attached nutrients are prevented from leaving disturbed areas and polluting streams. Effectiveness estimates are 25% TN, 40% TP, and 40% TSS.

Urban Wetponds and Wetlands

Urban Wetponds: depressions or basins created by excavation or berm construction that receive sufficient water via runoff, precipitation and groundwater to contain standing water year-round at depths too deep to support rooted emergent or floating-leaved vegetation (in contrast with dry ponds, which dry out between precipitation events). Effectiveness estimates: 20% TN, 45% TP, and 60% TSS.

Urban Wetlands: wetlands have soils that are saturated with water or flooded with shallow water that support rooted floating or emergent aquatic vegetation (e.g., cattails). Effectiveness estimates: 20% TN, 45% TP, and 60% TSS.

Wetland Restoration and Creation

Wetland Restoration: returning natural/historic functions to a former wetland. Results in a gain in wetland acres.

Wetland Creation: developing a wetland that did not previously exists on an upland or deepwater site. Results in a gain in wetland acres. TN and TP removal depends on wetland size, see full report for effectiveness estimates (www.chesapeakebay.net/marylandbmp.aspx); TSS is 15% regardless of wetland size.

Nutrient reduction efficiencies for BMPs (Phase 4.3 HSPF Watershed Model).

Agricultural BMPs	unit	nitrogen (lbs y⁻¹)	phosphorus (lbs y⁻¹)
soil conservation and water quality plans	acres	0.93	0.14
stream protection with fencing	acres	6.79	0.91
stream protection without fencing	acres	3.4	0.46
retirement of highly erodible land	acres	9.55	0.25
buffers forested—agriculture	acres	27.28	2.15
buffers grassed—agriculture	acres	16.92	1.08
tree planting—agriculture	acres	13.57	1.19
wetland—agriculture	acres	27.28	2.15
horse pastue management	acres	11.12	1.6
alternative manure management	acres	15.4	3.42
ammonia emmissions	acres	400	0
phytase feed additive	acres	-	-
oyster aquaculture	acres	-	-

Urban BMPs	unit	nitrogen (lbs y⁻¹)	phosphorus (lbs y⁻¹)
SWM, new (40% TN, 60% TP)	acres	3.71	0.59
SWM, retrofits (20% TN, 30% TP)	acres	1.85	0.3
existing structural practices	acres	0.5	0.1
dry extended detention practices	acres	2.73	0.21
filtering practices	acres	3.9	0.59
infiltration practices	acres	4.84	0.68
roadway systems	acres	-	-
wetlands and wet ponds	acres	2.97	0.48
erosion and sediment control	acres	3.1	0.5
nutrient management, urban	acres	1.75	0.27
nutrient management, mixed	acres	0.97	0.17
buffers forested, urban	acres	9.69	1.41
tree planting, mixed open	acres	4.29	0.93
tree planting, urban pervious	acres	7.22	0.94
stream restoration, urban	feet	0.02	0.0035

Sprawl reduction and septic BMPs	unit	nitrogen (lbs y⁻¹)	phosphorus (lbs y⁻¹)
sprawl reduction	acres	7.32	0.56
enhanced septic denitrification	systems	6.01	0
septic connections	systems	10.51	0

Appendix B

QUALITY ASSURANCE

KEY POINTS

➤ The collection and use of environmental data and related information and is an essential component of this environmental monitoring strategy.

➤ Monitoring data used to support the various water quality assessment activities must be of known and documented quality as indicated in project-specific Quality Assurance Project Plans.

A systematic planning approach to the collection and use of environmental data helps to assure the reliability of these data and related information and is an essential component of any environmental monitoring strategy. All personnel involved in monitoring efforts and data collection must be committed to ensuring that the monitoring data used to support the various water quality assessment activities are of known and documented quality. This can be done by referring to a detailed and project-specific Quality Assurance Project Plan (QAPP). Essentially, this is a plan that addresses critical elements of the monitoring effort and contains information about planning, monitoring, communication, auditing, and programs and policies that support agency quality goals. There is guidance for each element of a QAPP available on EPA's website (www.epa.gov/QUALITY/qapps.html), and completing most QAPP elements provides a foundation for addressing specific goals and is a project roadmap that can simplify the review process and provide guidance for field, laboratory and management staff. Generally, QAPP elements include the following: problem definition, project/task organization and description, performance objectives/criteria, documentation, sampling design, sampling methods, sampling, handling/custody, analytical methods, quality control, equipment, testing/inspection/calibration/maintenance, requirements/inspection of supplies, non-direct measurements, data management (review, verification, validation), assessment summary and reports to management.

EPA QAPP website

www.wepa.gov/QUALITY/qapps.html

Appendix C

DATA ANALYSIS AND MANAGEMENT

KEY POINTS

➤ **Project personnel, in conjunction with UMCES and DNR staff, can identify the methods necessary to perform data analysis.**

➤ **Data and analysis results should be documented in electronic files or reports that address the acceptability and suitability of the data for their intended purpose.**

➤ **Data should be entered with applicable identifiers into electronic databases for storage and dissemination to interested parties.**

Volume-weighted mean (VWM) concentrations should be calculated when TN, TP and TSS concentrations are monitored in streams and rivers. The equation for calculating VWM concentrations for n (n = sample size) measured river or stream samples can be represented as:

$$VWM = \frac{\sum_{i=1}^{n} C_i V_i}{\sum_{i=1}^{n} V_i}$$

where C_i = the observed concentration of instantaneous river flow i, V_i = discharge volume (liters) for the sampling interval with the sample data as the midpoint of the period i, n is the sample size, and the denominator is the total discharge volume for the period i.

River or stream fluxes (i.e., inputs or outputs) of TN, TP and TSS can be calculated as:

$$F = (Q_r)(VWM)$$

where Q_r is river discharge in liters (total sum of the period of interest, usually a calendar or water year, the latter which is from October 1 to September 30) for the study site.

Mass balances for a stream reach in a study site watershed can then be calculated using inputs and outputs from stream fluxes as:

$$Net\ flux = Inputs - Outputs$$

where inputs are from the upper reach monitoring point and the outputs represent fluxes from the downstream monitoring point.

Each project will have access to assistance from either UMCES or DNR staff that can help to explain and interpret analyses and results of environmental monitoring data that can be used to determine implementation effectiveness. Data and analysis results should be documented in electronic files or reports that address the acceptability and suitability of the data for their intended purpose. Following this determination, data should be entered with applicable identifiers into electronic databases for storage and dissemination to interested parties. Monitoring results will assist in the accurate characterization of degraded water resources in Maryland and evaluating the success of implementation grants will help to improve the selection process for future Trust Fund efforts. Therefore, these data will be available to the regional community.

Appendix D

COMMUNICATING RESULTS

KEY POINTS

➤ **Results should be provided that address specific monitoring objectives.**

➤ **Initial, interim and final nutrient and sediment loads should be defined.**

➤ **Restoration costs should be presented.**

➤ **Change in nutrient/sediment loading per dollar expenditure should be summarized.**

➤ **Comparisons with other similar studies should also be provided.**

At a minimum, summary results should be provided that address each specific monitoring objective defined in the QAPP. At a minimum, initial, interim (if available), and final nutrient and sediment loads should be defined, both in terms of mass and percent change. Restoration costs also should be presented and change in nutrient/sediment loading per dollar expenditure should be summarized. Comparisons with other similar studies should also be provided.

Trust Fund projects will have summary results posted on the BayStat website (www.baystat.maryland.gov). Once it has been determined what data will be presented on the website, spreadsheet templates will be provided that will need to be updated with project results and returned to BayStat staff so that results can be uploaded.

www.baystat.maryland.gov

Baystat website.