Land Conservation, Restoration, and Management For Water Quality Benefits in Cecil County, Maryland

Technical Report for the Cecil County Green Infrastructure Plan

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ABSTRACT

Streams in Cecil County, Maryland provide the majority of the county's drinking water, drain into the nationally significant Chesapeake Bay, and support fish and other aquatic life. Yet many of the county's streams are impaired. The Conservation Fund examined biological and chemical stream data collected statewide and countywide, and compared these to watershed and site conditions to search for possible relationships. These analyses were consistent with previous studies that indicated that forest cover and impervious surfaces had a significant impact on water quality. As indicated by the benthic macroinvertebrate community, nitrate levels, and phosphorus levels, water quality in Cecil County was generally highest in watersheds with <7% imperviousness and >50% forest and wetland cover. We used these thresholds to develop goals and models for land conservation and restoration for water quality benefits. To meet water quality goals, Cecil County should minimize conversion of forest to development, limit house lot size, complete upgrades of the county's wastewater treatment plants, install denitrifying septic systems, construct tertiary treatment wetlands, restore riparian forest and wetlands in targeted watersheds, use low impact site design techniques, treat existing sources of stormwater and point source runoff, reduce nutrient and sediment runoff from agriculture, and implement other best management practices.

KEYWORDS: Cecil County, Maryland, Green Infrastructure, water quality, conservation, reforestation, watersheds, TMDL, best management practices, MBSS

INTRODUCTION AND BACKGROUND

Water quality in Cecil County

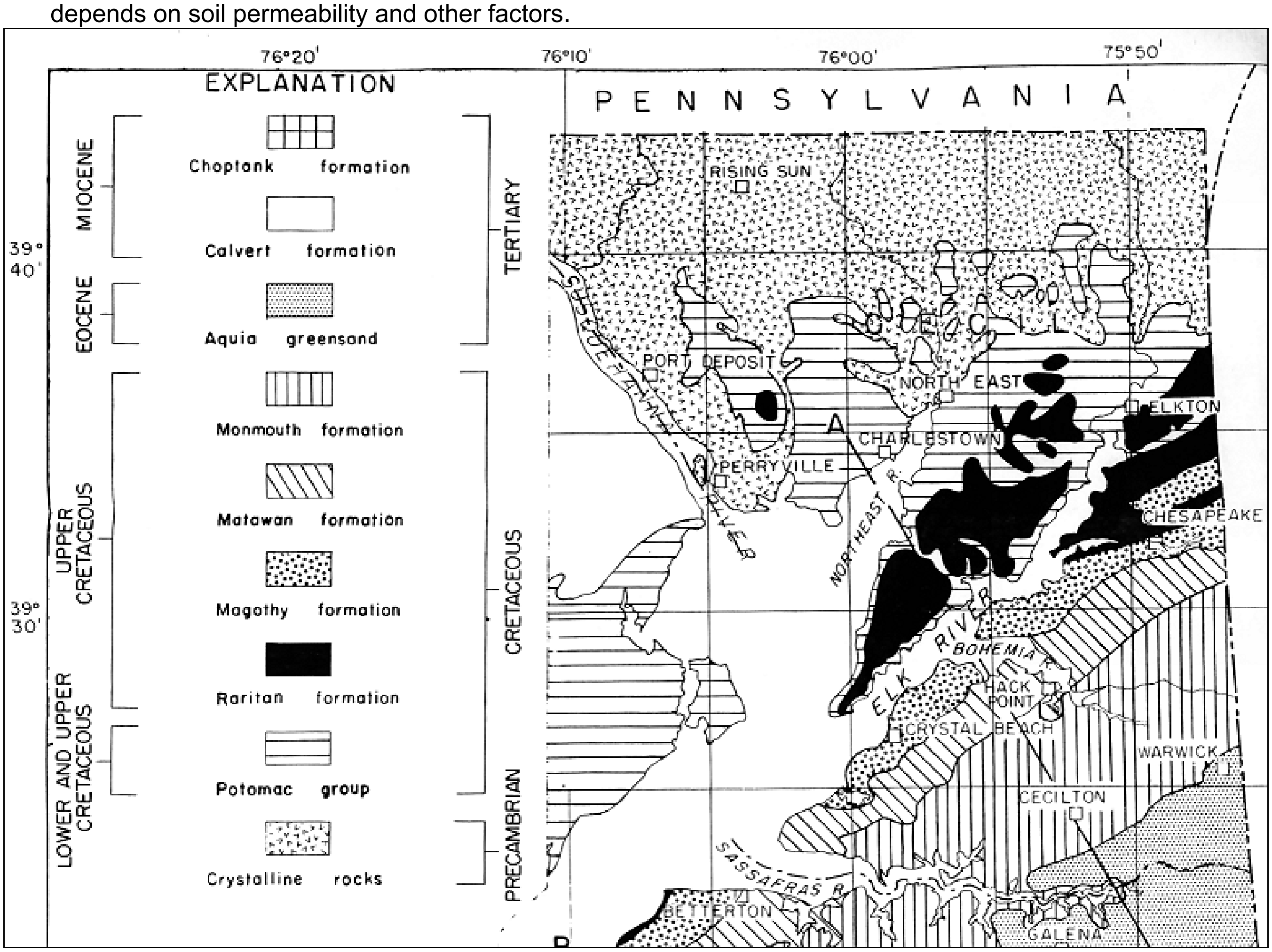
Water quality is a major issue throughout the Chesapeake Bay watershed. The Chesapeake Bay is the nation's largest estuary, and has enormous ecological, economic, and cultural significance, especially to the states of Maryland and Virginia. Unfortunately, excess nutrient input (primarily nitrogen and phosphorus from sewage and urban and agricultural runoff) has impaired the Bay by fueling algae blooms, a process known as eutrophication. Decay of these algae lowers dissolved oxygen levels to the point that fish and shellfish die. Large algae blooms also prevent sunlight from reaching submerged vegetation, eliminating habitat for crabs, fish and other organisms.

Cecil County, Maryland, borders the upper Chesapeake Bay. Not only do most of the streams in the county ultimately drain into the Chesapeake Bay (with the remainder draining to Delaware Bay), but they also provide 56% of public drinking water (2 million gallons per day) (City-data.com). Big Elk Creek and North East Creek supply the towns of Elkton and North East, respectively. The county's streams also provide important habitat for fish and other aquatic organisms.

Groundwater is the other important source of drinking water in Cecil County. Its availability depends on location. Cecil County straddles two physiographic regions, the Piedmont and the Coastal Plain. The Piedmont region in Cecil County is underlain by ancient Precambrian and Paleozoic igneous and metamorphic rocks such as granite, gabbro, serpentinite, schist, and gneiss (Maryland Geological Survey, 1968). The Coastal Plain region is composed of unconsolidated sediments like gravel, sand, silt, and clay, dating from the Cretaceous period to the recent Quaternary (Maryland Geological Survey, 1968).

The crystalline rocks of Cecil's Piedmont region do not facilitate large-scale groundwater withdrawal (Overbeck et al., 1958). Limited withdrawal has been possible for individual farm and household use (Overbeck et al., 1958). In contrast, the Coastal Plain aquifers, occurring in the saturated sand and gravel layers, are relatively porous, and therefore suitable for public water supplies (Otton et al., 1988). The main aquifers in Cecil County are the Potomac aquifers (top to bottom: Raritan, Patapsco, and Patuxent formations), which yield a median of 30 gal./min. (Otton et al., 1988). The Magothy formation is the second most productive aquifer, followed by the Monmouth (Otton et al., 1988). Fig. 1 depicts the approximate spatial distributions of these formations.

Fig. 1. Aquifer locations in Cecil County (Overbeck et al., 1958). The Potomac group and Raritan formation are the most important for water supply, followed by the Magothy and Monmouth. Recharge depends on soil permeability and other factors.



The source of freshwater in Cecil County is precipitation, either directly within the county, or upstream in Pennsylvania or Delaware. Groundwater recharge is decentralized, with rainfall soaking into the soil and moving downward. Soil permeability plays a major role. In the Piedmont, almost all groundwater then moves slowly between interstream drainage divides (Otton et al., 1988). In the Coastal Plain, deeper interbasin flow is also significant (Otton et al., 1988). Groundwater discharge is almost entirely through seeps and springs, mostly along the sides and bottoms of streams (Overbeck et al., 1958). This provides the base flow that keeps streams flowing between rainfall events.

A growing population and water use has caused widespread lowering of the Coastal Plain aquifers. Groundwater withdrawals increased by 31% between 1980 and 1985 (Otton et al., 1988). Between 1983 and 1986, the aquifer serving Elkton dropped by 20 feet (Otton et al., 1988).

The Clean Water Act requires states to develop water quality standards for all surface waters; monitor these waters; and identify and list those waters not meeting water quality standards. A water quality standard is the combination of its designated use and the water quality criteria designed to protect that use. Designated uses include recreational activities (fishing and swimming), drinking water supply, and support of fish and shellfish. An impairment is identified when water quality monitoring data suggest that a water body does not meet or is not expected to meet water quality standards. The 303(d) list reports a jurisdiction's impaired surface waters. All of Cecil County’s watersheds are on this list for biological impairment, excess nutrient or sediment input, or metal or toxic contamination (Maryland Department of the Environment, 2004a). PCB contamination was found in the Bohemia and Sassafras Rivers in 2001 (Maryland Department of the Environment, 2004a). In a document prioritizing the state’s wetlands, Maryland Department of the Environment (2006b) describes the resources and water quality of each “8-digit” watershed in the county, along with recommendations for protection and restoration.

Some of the 303(d) listings for impairment are dated. For example, Back Creek was listed as impaired by arsenic, cadmium, and silver, but recent sampling found only low concentrations of these elements (Maryland Department of the Environment, 2005a). Similarly, Northeast River was listed for zinc, but this was subsequently de-listed (Maryland Department of the Environment, 2005b).

The Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup (2005) examined water quality monitoring data from 1985-2003 in many of the Chesapeake Bay's tidal tributaries. Total nitrogen and phosphorus concentrations have been improving in the Bohemia River, and were Good as of 2003. Nitrogen concentrations were Fair in the Northeast River, Elk River, Back Creek, and Sassafras River. Phosphorus concentrations were Good in the Northeast and Elk Rivers, and Fair in Back Creek and Sassafras River. Algae abundance was Good (i.e., low) in Back Creek and Elk River, and Poor (i.e., high) in Northeast, Bohemia, and Sassafras Rivers. Suspended solids were Good in the Sassafras River, and Fair in all the other rivers. Water clarity (Secchi depth) was Good in the Elk River, Fair in Back Creek, Bohemia River, and Sassafras River, and Poor in Northeast River. Dissolved oxygen was Good at all locations.

Data collected in the Octoraro watershed between Dec. 2005 and Feb. 2007 by Maryland Dept. of the Environment and the Octoraro Nitrate Task Force showed that nitrate levels in the three Cecil County tributaries (Stone Run, Green’s Run & Basin Run) generally varied between 2 and 5 mg/l (Octoraro Watershed Association, 2007). Stone Run exceeded 5 mg/l twice, with a maximum in April 2006 of 7 mg/l. Land use in the Cecil County portion of the Octoraro watershed is mostly rural, with about 50% agriculture, 30% forests and wetlands, predominantly along the stream corridors, and 20% residential (Octoraro Watershed Association, 2007).

Total Maximum Daily Loads (TMDLs) establish the maximum amount of an impairing substance or stressor that a waterbody can assimilate and still meet water quality standards, and allocate that load among pollution contributors. A TMDL is the sum of the allowed pollutant loads for point sources, non-point sources, projected growth and a margin of safety. Load allocations are determined from monitoring data and watershed modeling (Maryland Department of the Environment, 2007). TMDLs were established in three of the county’s rivers for nitrogen and phosphorus to reduce algal blooms and ensure adequate dissolved oxygen.

In the Northeast River, the low flow TMDL for nitrogen is 6365 lbs/month, and the low flow TMDL for phosphorus is 673 lbs/month (Maryland Department of the Environment, 2004b). Nonpoint sources are allocated 1886 lbs/month of total nitrogen, and 113 lbs/month of total phosphorus. Point sources, primarily Northeast River WWTP, are allocated 4316 lbs/month of nitrogen, and 550 lbs/month of phosphorus. Future urban development is allotted 102 lbs/month of nitrogen and 6 lbs/month of phosphorus. The average annual TMDL for nitrogen is 168,344 lbs/yr, and the average annual TMDL for phosphorus is 12,110 lbs/yr. Of these, nonpoint source loads are allocated 74,749 lbs/year of nitrogen and 3,763 lbs/year of phosphorus; 77% of N and 95% of P attributed to agriculture. Point sources are allocated 84,268 lbs/year of nitrogen and 7,906 lbs/year of phosphorus. Future urban development is allotted 5,829 lbs/month of nitrogen and 276 lbs/month of phosphorus. An explicit margin of safety makes up the balance of the allocation.

In the Bohemia River, the low flow TMDL for nitrogen was set to 1201 lbs/month, and the low flow TMDL for phosphorus to 154 lbs/month (Maryland Department of the Environment, 2001). These TMDLs apply during the period May 1 through October 31. Of this, nonpoint sources were allocated 794 lbs/month of total nitrogen and 49 lbs/month of total phosphorus. Cecilton Wastewater Treatment Plant (WWTP) was allocated 365 lbs/month of nitrogen and 102 lbs/month of phosphorus. Average annual TMDLs were not set.

In the Sassafras River, the low flow TMDL for phosphorus is 747 lbs/month (Maryland Department of the Environment, 2002). This river does not have a TMDL for nitrogen. Nonpoint sources are allocated 169 lbs/month of total phosphorus. Point sources (Betterton and Galena WWTPs in Kent County) are allocated 569 lbs/month. The average annual TMDL is 13,875 lbs/yr. Of these, nonpoint source loads are allocated 6,839 lbs/year, mostly to agriculture. Point sources are allocated 6,824 lbs/year. Future urban development and a margin of safety make up the balance of the allocation.

The Maryland Biological Stream Survey (MBSS) rated the overall condition of streams in Cecil County as "Fair", based on fish and benthic macroinvertebrate data[1] collected between 2000-04 (Kazyak and Brindley, 2005). Table 1 lists the percentage of streams in Cecil County falling into Good, Fair, Poor, or Very Poor categories, or their equivalents, for various indices. Detailed descriptions of these categories and indices can be found in Kazyak and Brindley (2005) and Roth et al. (2005).

Table 1. Percentage of streams in Cecil County by condition (from Kazyak and Brindley, 2005)

	Stream health categories and % of stream sites in each category 2000-04			
Metric	Good	Fair	Poor	Very Poor
Fish Index of Biotic Integrity	40%	30%	19%	7%
Benthic Index of Biotic Integrity	32%	34%	20%	14%
Combined Index of Biotic Integrity	29%	47%	12%	12%
	Minimally Degraded	Partially Degraded	Degraded	Severely Degraded
Physical Habitat Index	5%	38%	41%	16%
	Optimal	Suboptimal	Marginal	Poor
Trash Rating	50%	35%	10%	5%
Eroded Banks	42%	28%	10%	20%
Bar Formation	22%	25%	37%	15%
	Low (<1 mg/l)	Moderate (1-5 mg/l)	High (>5 mg/l)	
Nitrate Concentrations	23%	77%	0%	
	Low (<0.025 mg/l)	Moderate (0.025-0.07 mg/l)	High (>0.07 mg/l)	
Phosphorus Concentrations	27%	37%	36%	

[1] Based on three ecological health indicators: Fish IBI, Benthic IBI, and Combined IBI.

Although stream conditions vary from optimal to poor in Cecil County, the county has several streams and rivers that are among the best in the state. Mill Creek supported the richest benthic macroinvertebrate community (45 taxa from a 100 specimen sub-sample) in the entire state according to MBSS sampling from 1994-2004 (Kazyak et al., 2005). This site had the highest benthic IBI (4.7) in Maryland's Coastal Plain. An MBSS Sentinel Site is located in Cecil County: an unnamed tributary to Principio Creek, in the Furnace Bay watershed. Sentinel sites represent the best remaining streams in the state (Prochaska, 2005). Although there are no longer any pristine streams in Maryland, sentinel sites are high quality streams, with minimal anthropogenic influences (Prochaska, 2005). The Bohemia River is home to species of rare mussels. Finally, there are two state-recognized Natural Heritage Areas in the county: Plum Creek; and along southern Grove Neck.

Stressors to aquatic biological communities

The Benthic Index of Biotic Integrity (IBI) measures water quality and stream conditions by examining the diversity of the benthic macroinvertebrate community, and the prevalence of sensitive vs. pollution-tolerant species. One advantage of using biological indicators like benthic macroinvertebrates is that they integrate stream conditions over time. Stream morphology, chemistry, and habitat are heavily influenced by storm events, when flow, sediment, and pollutant loads are highest. Chemical sampling during baseflow conditions may not record peak levels of pollutants, especially sediment-bound ones like phosphorus. But stormflow influences on stream morphology and biota can be recorded after the event. Blaha et al. (data unknown) list some advantages of benthic invertebrate data over fish data:

> "Benthic invertebrates are less mobile than fish and are unable to move in response to habitat degradation. Fish, on the other hand, can temporarily leave a stream or can satisfy various life stage requirements elsewhere. Second, habitat impacts, especially sedimentation, affect benthic macroinvertebrates life requisites more directly and immediately, whereas fish are affected more indirectly or seasonally through feeding and reproductive mechanisms. As a result, fish communities may have a lag or delay factor in reflecting habitat degradation."

Southerland et al. (2005) listed ten stressors of concern to aquatic biological communities, shown below with the threshold values indicating degradation risk:

- Impervious surfaces (urban area > 5%)
- No riparian buffer
- Channelization
- High nitrate concentrations ([NO_3] > 5 mg/l)
- Low dissolved oxygen (DO < 3 mg/l)
- Acid deposition present
- Acid mine drainage present
- Unstable stream banks
- Invasive plants present
- Invasive fish or mussels present

The stressors most common in Cecil County, based on 2000-04 MBSS data on the percent of stream miles affected (Kazyak and Brindley, 2005), were:

- Invasive plants present in the riparian zone (100% of stream miles)
- Invasive aquatic fauna present (66% of stream miles)
- Eroded stream banks (29% of stream miles)
- Urban area >5% (21% of stream miles)
- Acid deposition present (15% of stream miles)
- No riparian buffer (11% of stream miles)
- Low dissolved oxygen (5% of stream miles)
- Channelization (3% of stream miles)

Presence of invasive species is mostly a management issue, although invasive plants are found more often close to disturbances such as land clearing. Exotic plant invasions often begin from edges, or along roads or trails. Thus wider riparian buffers, along with removal of existing invasives, might decrease the prevalence of exotic plants. Channelized streams can be restored on-site, although not easily. Acid deposition is a result of air pollution from power plants, factories, and cars; much (perhaps most) of it originating outside the county. A quarter of the nitrogen entering the Chesapeake Bay and its tributaries also comes from air deposition (Conservation Fund, 2006).

On the other hand, many of Cecil County's aquatic stressors relate at least partly to land cover, and can be addressed by appropriate land conservation and restoration measures. For example, excess nutrient input leads to eutrophication and low dissolved oxygen. The Chesapeake Bay Program Tidal Monitoring and Analysis Workgroup (2005) reported that as of 2002, the most significant contributor of nitrogen to rivers in Maryland's Upper Eastern Shore (which includes most of Cecil County) was agricultural sources (74%). Following that were point sources (9%) and urban runoff (6%). For phosphorus, the largest contributor was also agriculture (73%). This was followed by mixed open lands (11%), urban runoff (9%), and point sources (6%). Agriculture was also the largest source of sediment, contributing 89%.

Vegetation, especially in forests, can prevent excess nutrient and sediment flows into water bodies by absorbing nutrients from groundwater and slowing surface runoff. Both fertilizer application and air deposition of nitrogen can be mitigated this way. Thresholds of watershed forest cover, riparian forest, and imperviousness relating to water quality are discussed below.

Catchment percent forest

Forests help control hydrology in a watershed by absorbing and recycling rainfall, with the potential to control runoff and flooding. Floodplains and wetlands can absorb and store stream and river overflows, and also reduce flow velocity through friction. Heavy vegetation can slow the runoff of precipitation into waterways, permitting some of the runoff to seep into groundwater aquifers and reducing peak flows. An analysis by American Forests (1999) estimated that the total storm water retention capacity of the remaining forest in the Baltimore-Washington region in 1997 was worth $4.68 billion. This was down from 1973's value of $5.7 billion (American Forests, 1999).

In contrast to natural land, developed land has little ability for absorption, and instead creates a large volume of fast moving (and more polluted) runoff (Weber, 2003). American Forests (1999) estimated that between 1973 and 1997 tree losses in the Baltimore-Washington area resulted in a 19% increase in stormwater runoff - an estimated 540 million cubic feet of extra water. Replacing the lost stormwater retention capacity with engineered systems would have cost $1.08 billion (American Forests, 1999).

By slowing surface runoff and providing opportunities for settling and infiltration, forests help remove nutrients, sediments and other pollutants. Infiltration rates 10-15 times higher than grass turf and 40 times higher than a plowed field are common in forests (Chesapeake Bay Program, 2000). Tree roots remove nutrients from settled runoff and groundwater, and store them in leaves and wood. Through the process of denitrification, bacteria in the forest floor convert harmful nitrate to nitrogen gas, which is released into the air (Chesapeake Bay Program, 2000). In stream and river floodplains, vegetation traps and removes water-borne particulates during storms.

For sites sampled statewide by the Maryland Biological Stream Survey (MBSS) between 1995 and 1997, benthic IBI scores increased with increasing forest cover in the catchment. The Hilsenhoff Biotic Index, a macroinvertebrate indicator of organic pollution tolerance, was also significantly correlated with catchment forest cover. Fewer pollution-tolerant organisms were found in catchments with more forest cover, indicating less stream degradation. Aquatic salamander richness was also higher in catchments with higher amounts of forest cover. (Roth et al., 1999).

Allen and Weber (2007) found that forest cover had a significant impact on water quality in Baltimore County, Maryland. As indicated by the benthic macroinvertebrate community, watersheds with >50% forest cover generally had the best stream conditions, followed by watersheds with 40-50% forest. This trend was consistent with other studies in Maryland. The MBSS Sentinel Site in Cecil County is in a watershed that is 86% forested, with 9% agriculture and 3% barren (Prochaska, 2005).

Stream nitrate concentrations in Maryland are generally higher in watersheds with more agricultural land use. In Baltimore County, agricultural land use had the highest concentrations of [NO_x] and total nitrogen. As little as 20% agricultural use resulted in concentrations >1 mg/l. Forest cover had the lowest nitrogen concentrations, with urban in between the two (Baltimore County, 2005). Jones et al. (2001) found that the area of agriculture draining to stream sites throughout the Chesapeake Bay watershed explained half the variation of nitrate levels. Since this was inversely correlated (-96%) with the area of forest (Jones et al., 2001), the less forest there was in a watershed, the higher the nitrate concentration was in the stream. Data analyzed by Harding et al. (1998) suggested that past watershed land use (in the 1950's) was the best predictor of stream invertebrate and fish diversity. Reforestation of riparian zones was insufficient to recover stream fauna extirpated by past forest clearing and the flushes of sediments that resulted, especially in watersheds where agriculture was still the primary overall land use at the time of the study (Harding et al., 1998).

A study of watersheds in Charles County, Maryland, found that conversion of forests to development increases the discharges of water, nitrogen, phosphorus, and organic carbon, while conversion of forests to cropland increases the discharges of nitrate (Jordan et al., 2000). Studies of Coastal Plain watersheds draining to the Chesapeake Bay suggested that a watershed with 100% cropland discharges 18 kg total N/ha during a year of average runoff (Jordan et al., 2000). The Charles County study results suggested that 100% cropland discharges 5.9-14.0 kg nitrate-N/ha annually (ranging from dry to wet years) (Jordan et al., 2000).

Catchment impervious surface

Impervious surfaces include roads, parking lots, sidewalks, rooftops, other solid structures, and hard-packed soils such as dirt roads. Whereas natural vegetation slows runoff from rain, absorbs some of this water, and allows much of the rest to percolate downward through soil pores, impervious surfaces allow this water to run off freely. There are numerous studies relating watershed imperviousness to hydrologic response, stream stability, and aquatic habitat. Southerland et al. (2005) write:

> "The proliferation of impervious surfaces fundamentally alters the timing of precipitation runoff, resulting in higher peak flows during storms and lower base flows. During storm events, water on impervious surfaces is routed more quickly to the stream, resulting in current velocities unsuitable for many organisms. The energy associated with high flows also results in greater scouring and movement of bedload, increasing mortality of less mobile species. The extra energy associated with high flows may also precipitate channel incision through accelerated downcutting. When downcutting occurs, the stream becomes less connected to its floodplain and streambank vegetation is less able to protect against bank erosion. When the energy of the stream is focused laterally, channel widening occurs, resulting in an increase in the width-to-depth ratio and a reduction in habitat quality for many species. During dry periods, the less water percolating into the soil during storms results in reductions in baseflow. This reduction further exacerbates the shallowing of habitat and may markedly slow current velocity. Consequently, urban streams tend to have wide, silty channels with relatively little water.
>
> "Higher flows during storms also more readily transport sediment, nutrient-laden surface runoff, toxic contaminants, large woody debris, rootwads, Coarse Fine Particulate Organic Matter (CPOM), Fine Particulate Organic Matter (FPOM), and Dissolved Organic Matter (DOM) downstream. These flows also result in decreased nutrient spiraling, increased turbidity/siltation, reduced amounts of habitat refugia, and potentially lethal contaminant concentrations. In urban areas … that feature combined storm and sewer drains, high flow events result in elevated bacterial and nutrient levels, including potentially lethal concentrations of ammonia. When high flow events occur after extended periods of dry weather, a first flush of polycyclic aromatic hydrocarbons (PAHs) can kill many organisms. When high flow events occur during hot summer conditions, the heated water running off hot pavement and rooftops can result in unlivable stream temperatures. During and after winter storm events, concentrations of chlorides and heavy metals can far exceed tolerance limits for freshwater biota. In total, increased imperviousness from urbanization causes numerous deleterious changes to stream habitats, often resulting in severely impaired biological communities."

The increased impervious surface associated with development has major impacts on stream biota. According to the Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division (1999), when watershed imperviousness exceeds 25%, only hardy, pollution tolerant organisms can thrive. Other species decline or become extinct. Above 15% impervious cover in a watershed, fish and benthic macroinvertebrate community condition, as measured by the indices of biotic integrity, is fair to poor (i.e., never good). Even very low levels of imperviousness can have detrimental effects. Many fish, salamander, and invertebrate species disappear from watersheds with greater than 5% impervious surface (Southerland et al., 2005). When upstream impervious land cover is above 2%, pollution sensitive brook trout are lost (Maryland Department of Natural Resources, Monitoring and Non-tidal Assessment Division, 1999).

For sites sampled statewide by MBSS between 1995 and 1997, Fish Index of Biotic Integrity (IBI) scores decreased with increasing urban land use. Nearly all sites with >50% of the catchment in urban land use had IBI scores of poor to very poor (i.e., IBI < 3.0). Benthic IBI scores were even more sensitive to urban land use. Nearly all sites with greater than 30% of the catchment in urban land use had benthic IBI scores of poor to very poor (IBI < 3.0). Salamander richness was never higher than two species at sites with more than about 5% urban land use in the upstream catchment. Of the 29 aquatic or riparian species of amphibians and reptiles found in the surveys, only seven occurred in heavily-urbanized areas (>25% impervious land cover in the catchment). Four species of salamanders never occurred where impervious surface exceeded 3% (Roth et al., 1999).

Blaha et al. (data unknown) found that imperviousness was “by far the best predictor” of stream conditions in southwest Montgomery County, Maryland. It explained between 52 to 66 percent of IBI score variability, and was included in nearly all the regression models. Streams in excellent condition generally had <6% imperviousness; good, <12%; and fair, <28%. Riparian buffers (if >67% of stream length) and stormwater management systems compensated somewhat for impervious surfaces, but not completely. All watersheds with >28% imperviousness had poor quality streams. Benthic invertebrates in first order streams were negatively affected by localized disturbances to surface and subsurface hydrology (from increased imperviousness and decreased wetlands), inputs of sediment (from cropland), and excess nutrients (from cropland and septic systems). Benthic invertebrates in larger (second and third order) streams were more affected by in-stream processes and channel hydraulics, which were indirectly affected by imperviousness (Blaha et al, date unknown).

Jordan et al. (2000) found that water discharge from Charles County streams increased linearly with the percentage of developed land in the watershed, and that the effect was strongest in the year with the most precipitation. They wrote that increased runoff from developed areas is probably caused by impervious surfaces. Stream depth fluctuated much more rapidly in developed watersheds than undeveloped watersheds, with gradual changes in undeveloped watersheds and rapid rises and falls in developed watersheds after storm events. Discharges of total organic carbon and all forms of nitrogen and phosphorus increased significantly with increasing proportions of developed land.

Extrapolating from linear regressions, Jordan et al. (2000) predicted total phosphorus discharge from 100% developed land to range from 0.93-2.84 kg P/ha from the dry year to the wet year (averaging 1.89 kg P/ha), and total nitrogen discharge to range from 6.54-19.4 kg N/ha (averaging 13.0 kg N/ha). In contrast, for 0% developed land, predicted total phosphorus discharge ranged from 0.22-0.34 kg P/ha from the dry to the wet year (averaging 0.28 kg P/ha), and predicted total nitrogen discharge ranged from 1.48-1.57 kg N/ha (averaging 1.53 kg N/ha). For mixtures of developed land, cropland, and other land types, predictions of discharge can be obtained by linear interpolation of the predictions for 0 and 100% of the relevant land use type (Jordan et al., 2000).

In Baltimore County, stream condition declined significantly in watersheds with >10% imperviousness (Baltimore County, 2005). No sampling sites with >10% impervious cover in their upstream catchment had a benthic IBI score of Good or Fair; all these sites scored Poor or Very Poor. In contrast, the majority of sites with <10% impervious surface upstream scored Fair or Good. A significant relationship was also found between percent impervious cover and seven water quality parameters (Total Solids, Chloride, TKN (Patapsco Basin only) nitrate/nitrite nitrogen (Gunpowder Basin), Total Copper, Total Zinc, Dissolved Zinc and Hardness) (Baltimore County, 2005). Allen and Weber (2007) found that watersheds with <5% imperviousness generally had the least impacted streams, followed by watersheds between 5-10%.

Catchment percent riparian forest

Streams are strongly dependent on the surrounding terrestrial environment, which serves as both a buffer and a source of organic matter, especially for small (low-order) streams. Natural vegetation in the riparian zone has been shown to stabilize stream hydrology; maintain the integrity of stream channels and shorelines; intercept nutrients, sediment, and chemicals; moderate water temperature; and supply food, cover and thermal protection to fish, amphibians, invertebrates, and other wildlife. This is especially true when overall catchment forest is suboptimal. Riparian forest buffers have proven to be effective at reducing nutrient loads in areas that have largely been deforested. Studies have demonstrated reductions of 30 to 98 percent for nitrogen, phosphorus, sediments, pesticides, and other pollutants in surface and groundwater after passing through a riparian forest. Retaining buffers is one of the least expensive strategies for reducing nitrogen loads, costing approximately $5 per pound of nitrogen removed. Stream buffers are most effective when they are continuous and sufficiently wide (Weber, 2003).

Jones et al. (2001) found that the percentage of stream miles with riparian forest at the watershed scale was one of the most important predictors of nutrient levels in Chesapeake Bay tributaries. The percentage of forest buffers was by far the leading predictor of total nitrogen, dissolved phosphorus, total phosphorus, and suspended sediment concentrations (Jones et al., 2001). In Delaware, Weber (2007) found that streams were likely to be in better physical condition if their upstream catchment had >45% riparian forest or wetland (within 30m of the stream bank). Streams were rated according to their sediment load, bank stability, and eutrophication.

In Baltimore County, trees not only benefited water quality at the watershed scale, but when adjacent to streams and shorelines as well. Watersheds with more than about 70% riparian forest had the best stream conditions, followed by watersheds between 40-70%. It appeared that riparian forest was most important in largely deforested watersheds. Riparian forest had a more noticable impact along along perennial streams and shorelines than along intermittent streams. It did not seem to matter where in the watershed riparian forest was located; the buffering of headwater streams did not improve water quality any more than buffering larger streams (Allen and Weber, 2007).

Large forest patches

Baltimore County considered subwatershed significance in their ranking of forest patches for conservation. Forest patches were placed in five categories based on their size, protection status, relative size compared to other watershed forest land, and their percent of watershed streams or riparian buffers.

Painton-Orndorff et al. (2004) considered forest patch size to be an important consideration when addressing water quality in the Chesapeake Bay watershed. They wrote,

> "It is a commonly held hypothesis among forest science researchers that the ability of a forest to achieve its full ecological potential is compromised by greater degrees of fragmentation by non-forest land uses such as agricultural and urbanization. Although these relationships are well documented in relation to a variety of wildlife habitats, research has only begun to turn its attention to the potential affects on watershed function. Current theories support the premise that higher fragmentation may affect precipitation patterns, moisture storage, interior forest temperature, nutrient transformation processes, and species composition and growth. Ultimately, alteration of these processes can affect [nitrogen] storage and leaching, something of interest to the Bay Program."

There are few studies documenting the effect of patch size on water quality. The Conservation Fund (unpublished data, 2006) found that benthic IBI scores in Baltimore County were 40% correlated with mean forest patch size in the catchment, 25% correlated with the largest forest patch size in the catchment, 33% correlated with forest patch density, and 30% correlated with the proportion of the largest forest patch to total forest area in the catchment. Benthic IBI scores were uncorrelated with total catchment area or the number of forest patches in the catchment. These metrics were correlated with catchment percent forest as follows: mean forest patch size, 64%; largest patch size, 52%; patch density, 43%; and largest patch proportion, 28%. The proportion of the largest forest patch to total forest area in the catchment was a significant contributor to multivariate models explaining IBI variation.

Riparian forest at the site level

At the site level, at least two stressors in Cecil County are related to the absence of riparian forest: unstable stream banks, and (obviously) no riparian buffer. As mentioned above, buffers are most effective when they are continuous and sufficiently wide. Gaps in the buffer allow nutrients, sediments, and other pollutants, as well as elevated water discharges, to bypass the filtering effect of natural vegetation. If unvegetated areas are combined with converging slopes and erodible soils, gullies can form, worsening the problem.

Effective buffer widths vary depending on the topography, soils, geology, hydrology, and other factors. For example, where soils are well drained and water is transported readily to streams via groundwater flow, wide buffers help extend the residence time for surface and subsurface flows; optimize the opportunity for buffer/groundwater interaction in low topographic areas near initiation of subsurface flow paths; and increase surface roughness to runoff on erodible, steeply sloped soils (Smith, 2000). Seepage areas, often found at the base of valley or hill slopes, should also be kept vegetated to remove nitrates and other solubles. Finally, Wenger (1999) states, “the slope of the land on either side of the stream may be the most significant variable in determining effectiveness of the buffer in trapping sediment and retaining nutrients. The steeper the slope, the higher the velocity of overland flow and the less time it takes nutrients and other contaminants to pass through the buffer.”

A literature search of studies on specific buffer performance “found that for sediment removal, necessary widths ranged from 10 to 60 m; for nutrient and metals removal, widths ran from 4 to 85 m; for species distribution and diversity protection, from 3 to 110 m was required; and for water temperature moderation, requirements ranged from 15 to 28 m” (North Carolina State University, 1998). Castelle et al. recommended minimum buffer widths around 30 m under most circumstances to provide both basic physical and chemical buffering to maintain biological components of wetlands and streams (North Carolina State University, 1998). They noted that fixed-width buffer approaches are easier to enforce, but that variable-width buffers are more likely to provide adequate protection on a specific-case basis (North Carolina State University, 1998).

Soil erosion

Standing vegetation stabilizes soils, especially along stream banks, on steep slopes, and where soils are highly erodible. Forests and forest buffers help protect streams by sheltering and anchoring their banks. Trees and vegetation also intercept driving rain and slow the flow of water over the ground, thereby reducing scouring and preventing soil from eroding into water bodies and roads. Increased sediment loads in steams and lakes can impact fish and invertebrate populations and habitats, alter stream channels, and reduce water quality. Erosion also leads to poor soil productivity (Moore, 2002).

Wetlands

Wetlands provide many services to humans. Among these, they moderate the effects of floods, and improve water quality. In a draft 2006 document, the Maryland Department of the Environment (MDE) described three processes in wetlands that maintain or improve water quality of adjacent surface waters. These processes comprised nutrient removal, transformation, and retention; retention of toxic materials; and storage of sediment transported by runoff or floods.

The document is quoted below:

> Nutrient Cycling: Addition, Removal and Transformation

Nutrients are carried into wetlands by hydrologic pathways of precipitation, river flooding, tides, and surface and ground water inflows. Outflows of nutrients are controlled primarily by outflow pathways of waters. The inflow and outflow of water and nutrients are important processes that effect wetland productivity.

Wetland biological and chemical processes remove suspended and dissolved solids and nutrients from surface and ground water and convert them into other forms, such as plant or animal biomass or gases. Debris and suspended solids (fine sediment or organic matter) may be removed by physical processes, such as filtering and sedimentation.

Soil characteristics, landscape position, and hydrology all contribute to the relative ability of a wetland to perform nutrient removal and transformation. Sufficient organic matter must be present for microorganisms in the soil to consume or transform the nutrients. Wetlands are often depressions in the landscape that hold water, transported sediment, and attached or dissolved nutrients for a longer period of time than a sloping area or areas with relatively higher elevations. A longer retention time allows for chemical interactions and plant uptake to occur.

Nitrogen undergoes some chemical transformations and may be taken up in soluble form, absorbed by plants through their roots, or consumed by anaerobic microorganisms that convert the nitrogen to organic matter. Anaerobic microbes may also convert the nitrogen from a nitrate form to nitrogen gas. Phosphorus is often bound to clay particles, and these fine sediments are transported into wetlands by riparian flooding and tidal action. Phosphorus may be stored in a wetland attached to the clay particles; however, phosphorus becomes available for plant uptake in its soluble form after flooding, saturation and anaerobic conditions typical of a wetland occur. Nutrient processes vary seasonally. Cooler temperatures slow microbial activity and plant uptake while higher flows of water transport more materials out of non-isolated wetland systems. The transported organic material is critical for downstream food chain support.

Tidal wetlands are highly effective sinks and/or transformers of nutrients, as nutrients are taken up and stored by plants or released as nitrogen gas into the atmosphere. However, the uptake and transformation occurs on a seasonal basis during the growing season. At the end of the growing season, as plants die and decompose, nutrients are released back into the aquatic system.

Wetlands are most effective at nutrient transformation and uptake when there are seasonal fluctuations in water levels. Wetlands that are temporarily flooded (saturated or inundated for brief periods early in the growing season) and those that are permanently inundated would generally be less effective than seasonally wet areas (saturated or inundated for longer periods during the early-mid growing season but are drier by the end of the growing season).

Toxics Retention

Retention of heavy metals has been reported most often in studies of tidal wetlands, though most wetlands are believed to serve as sinks for heavy metals. Accumulation is primarily in soils, with plants playing a more limited role … As is the case for nutrient transformation and sediment retention, soil characteristics, landscape position, vegetation, and hydrology all contribute the relative ability of a wetland to retain toxic materials. The longer the duration that water and transported materials remain in the wetland, the greater the likelihood that the materials will be retained…

Sediment Reduction

Wetlands along rivers, streams and coastal areas are important for removing sediment from surface and tidal waters. During large flood events, rivers frequently overtop their banks and water flows through adjacent floodplains and wetlands. Flood waters carry large volumes of suspended sediment, mostly fine sand, silt and clay. Because floodplains and wetlands provide resistance to flow - from dense vegetation, microtopography, and woody debris - the flow of water is slowed and sediment is deposited and stored in these areas. Similarly, coastal marshes and estuaries retain sediment brought in by tides and residual suspended sediment from rivers.

Lack of dense vegetation in some floodplains, and narrow width of floodplains, would reduce the ability of wetlands to slow velocities of floodwaters and allow settling of transported sediments.

METHODS

Tidal stream data

We examined tidal stream data from the Chesapeake Bay Citizens Monitoring Program Water Quality Database (http://www.acb-online.org/monitoring/site.cfm). This data was collected between May 2005 and April 2006, at nine freshwater tidal stream locations (Stoney Run, North East Creek, Mill Creek, Conowingo Creek, Rock Run, Octararo Creek, Basin Run, Stone Run, and Principio Creek). Because only nine locations were sampled, this data was not used to infer nutrient loadings to the Bay from the county as a whole. However, it illustrates conditions and problems in these watersheds.

Nontidal stream data

We examined chemical, physical, and biological stream site data collected statewide by MBSS during two rounds of random sampling (1995-7 and 2000-4), and compared these to watershed and site conditions to search for possible relationships. Upstream catchments for sample sites were delineated by MBSS. For a description of MBSS data, see Mercurio et al. (1999). Data collected in Cecil County were examined in more detail than data collected statewide. GIS analyses were conducted using ArcGIS 9.2. Statistical analyses were conducted using NCSS: employing scatter plots, Spearman correlations, linear regressions, analyses of variance (ANOVA), Chi-square comparisons, Tukey-Kramer Multiple-Comparison tests, stepwise regressions, all possible regressions, and discriminant analyses. Stream sites were defined as impaired for analysis purposes if their benthic IBI score was < 3 (Poor or Very Poor), nitrate concentrations > 5 mg/l (High), <u>or</u> total phosphorus concentrations > 0.07 mg/l (High). High-quality sites were defined as having benthic IBI ≥ 4 (Good), nitrate concentrations < 1 mg/l (Low), <u>and</u> total phosphorus concentrations <0.025 mg/l.

Catchment percent forest or wetland

We compared statewide and countywide stream data from MBSS to upstream catchment conditions. Forest and wetland cover were obtained from the National Land Cover Database (NLCD), which had a 30m resolution and was classified based on 2000-01 satellite imagery (see Appendix A for data sources). The percentage of forest and wetland cover was calculated within each catchment. Some catchments fell partly outside the Maryland boundary, but NLCD data were examined for the entire watershed.

Catchment impervious surface

Impervious surface data was also obtained from NLCD, also having 30m resolution and based on 2000-01 imagery. The overall imperviousness percentage was calculated within each catchment, and compared to stream conditions.

Catchment percent riparian forest or wetland

We compared MBSS data collected both statewide and in Cecil County to the percentage of riparian forest or wetland in the upstream catchment. Forest and wetland cover was obtained from NLCD, as described above, but converted to a grid with 10m resolution. The riparian zone was defined as 30m from streams, rivers, ditches, and other water bodies. These were obtained from the National Hydrography Dataset (NHD), a 1:24,000 stream layer, for all watersheds falling entirely or partly in Maryland. Flowlines other than pipelines and connectors were buffered 30m on either side, and the percent forest or wetland cover within these buffers calculated within each MBSS catchment.

Large forest patches

We attempted to identify the size of the forest and wetland block upstream of each sample point, using 2002 land use data from the Maryland Department of Planning. However, because the catchments overlapped, an automated process to identify such blocks did not work well. We selected blocks manually where there was no ambiguity or double-counting such as overlapping watersheds or part of the forest and wetland block being outside Maryland (where there was no data). Block size was compared to the benthic IBI score.

Site level conditions

We also compared stream chemical and biological data to physical conditions measured at the site. These parameters are listed in Table 2, and described in Mercurio et al. (1999).

Table 2. MBSS site physical data compared to chemical and biological data.

Parameter name	Description
TEMP_FLD	Stream temperature
INSTRHAB	Instream Habitat Structure
EPI_SUB	Epifaunal Substrate
VEL_DPTH	Velocity/Depth Diversity
POOLQUAL	Pool/Glide/Eddy Quality
RIFFQUAL	Riffle/Run Quality
CHAN_ALT	Channel Alteration
BANKSTAB	Bank Stability
EMBEDDED	Embeddedness
CH_FLOW	Channel Flow Status
SHADING	Shading
REMOTE	Remoteness
DIST_RD	Distance to nearest road (often estimated)
WOOD_DEB	Number of woody debris pieces
NUMROOT	Number of rootwads
RIP_WID	Vegetated riparian buffer width (m) (estimated, to max. of 50m, and averaged from either side)
MIN_RIP_WIDTH	Minimum buffer width on either side of the stream (m)
MAXDEPTH	Maximum stream depth (cm)
ST_GRAD	Stream gradient (% slope)
AVGWID	Average wetted width (m)
AVGTHAL	Average thalweg depth (cm)
AVG_VEL	Average stream velocity (m/s)
FLOW	Stream flow (cfs)
PHI_05	Physical Habitat Index

Multivariate analyses

In addition to the site parameters described above, nine watershed parameters (Table 3) were examined to see which variables had the most influence on chemical and biological conditions at MBSS sample sites. We used stepwise regressions, all possible regressions, and discriminant analyses to search for significant relationships.

Table 3. Watershed parameters examined in multivariate models

Parameter name	Description
ACREAGE	catchment area in acres
URBAN	catchment % urban land in 1991-3
AGRI	catchment % agriculture in 1991-3
PCT_FORWET92	catchment % forest and wetland in 1991-3
BARREN	catchment % barren in 1991-3

PCT_IMPERV	catchment % impervious in 2000-1
PCT_FORWET	catchment % forest and wetland in 2000-1
PCT_RIPFOR	catchment % riparian forest or wetland in 2000-1
DIFF_FORWET	Change in % forest/wetland 1991-3 to 2000-1

Soil erosion

We wished to identify areas with high potential for soil erosion (and sedimentation of water bodies). The Revised Universal Soil Loss Equation (RUSLE), is a soil erosion-prediction tool: A=RKLSCP, where:

A, the predicted soil loss, is the product of
R = rainfall erosivity
K = soil erodibility
L = slope length
S = slope gradient or steepness
C = cover and management
P = erosion control practices

The best land cover to prevent soil erosion (variable C in RUSLE) is forest. We wished to identify sites where retaining existing forest or restoring forest would maximize erosion prevention.

Unfortunately, Soil Survey Geographic (SSURGO) detailed soil data were unavailable for Cecil County. Instead, we used Natural Soil Groups (NSG) data, and assigned the K-value listed in Maryland Department of State Planning (1973), Table 1. G1, G2, and G3 soils (floodplain and tidal wetland soils) were given a K-value of 0.17, equivalent to a rating of very low (i.e., stable). K-values were then linearly reclassed to a value between 1 and 10, with 10 being most erodible (K=0.43), and 1 being least erodible (K=0.17). This was converted to an integer grid, rcl_soil_k, with 10m cells.

We could not calculate slope length, but slope (S) was reclassified linearly as follows, taking into account the relative flatness of the county, the rarity (152 ha) of slopes >30% and taking into account the correction to R due to ponding on flat surfaces:

>30 degrees = 10
26-30 degrees = 9
21-25 degrees = 8
17-20 degrees = 7
13-16 degrees = 6
9-12 degrees = 5
5-8 degrees = 4
3-4 degrees = 3
1-2 degrees = 2
0 degrees = 0

This grid was saved as rcl_slope. Stream banks (cells adjacent to, i.e. within 10m of, streams or shorelines) were also given a value of 10. We multiplied the slope-streambank grid (slope_strmbnk) and soil erodibility grid (rcl_soil_k) to create an overall erodibility index, erode_index.

Wetlands

Because of their ability to store flood waters, trap sediments, and remove nutrients and other pollutants, we wished to identify areas where wetlands could be restored. Wetlands often have hydric soils, which are “formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part. The concept of hydric soils includes soils developed under sufficiently wet conditions to support the growth and regeneration of hydrophytic vegetation”

(Natural Resources Conservation Service, 2007). These conditions facilitate chemical transformations and nutrient cycling such as reduction of nitrate.

Because hydric soils can persist long after a wetland has been drained and converted to intensive human use like agriculture, their presence indicates where wetlands used to exist, and where restoration is likely to succeed if pre-disturbance hydrology and vegetation are returned.

As discussed earlier, we were reliant on Natural Soil Groups data. According to Maryland Department of State Planning (1973) and comparing these groupings with soil series listed in Natural Resources Conservation Service (1995), hydric soils are classified in the Maryland natural soils groups as F1, F2, F3, G2, and G3. E1, E2, E3 and G1 soils are not listed as NRCS hydric soils. Maryland Department of State Planning (1973) describes F1 soils as the wettest sandy soils in the state, with a water table at or near the surface much of the year. F2 and F3 soils are poorly or very poorly drained. G1 and G2 soils are deep, well drained or moderately well drained riparian floodplain soils. G3 soils are in marshes or swamps. They are saturated, and have standing water most or all of the year.

We compared this hydric soil data to the location of existing wetlands, farmed wetlands, and land cover. Wetlands were delineated by Maryland Department of Natural Resources (DNR), and land cover was obtained from NLCD.

RESULTS

Tidal stream data

Four of the nine stream stations (Stoney Run, Conowingo Creek, Rock Run, and Principio Creek) exceeded state dissolved oxygen (DO) standards of ≥5 mg/L.

Nitrate levels were unnaturally elevated in eight of the streams. Conowingo Creek exceeded the human health standard for nitrate of >10 mg N/L. Only Stoney Run was consistently below 1 mg N/L. The mean and median values were around 3 mg N/L. Four streams (Conowingo Creek, Basin Run, Stone Run, and Mill Creek) had high ammonium levels (>0.5 mg N/L).

Stone Run had consistently high orthophosphate (PO_4) concentrations (>0.1 mg P/L). Conowingo Creek, Mill Creek, Octararo Creek, and Basin Run exceeded this value at least once during the sample period. Only Stoney Run and Principio Creek had consistently low concentrations (<0.01 mg P/L).

Maryland standards for single sample maximum allowable densities of *E. coli* in designated (permitted) beach areas are 235 colonies per 100 ml. All sample sites exceeded this standard except Rock Run. Principio Creek and Stoney Creek had spikes in April 2006 of >1000 colonies per 100 ml.

Catchment percent forest or wetland

MBSS statewide data from 1994-7 and 2000-4 showed >50% correlations between the percent of forest and wetland cover in the catchment, and nitrate levels (54%), nitrite (57%), total dissolved nitrogen (78%), and total nitrogen (70%), particulate phosphorus (51%), and chloride (56%). Increasing forest and wetland cover was associated with lower nutrient and salt loads. Impaired stream sites statewide had significantly less forest or wetland cover in the upstream catchment (mean 36%, std. error 1%) than unimpaired sites (mean 52%, std. error 1%) ($F = 192.8$, $p < 0.0001$, df = 2195). Conversely, high-quality sites statewide had more forest or wetland cover in the upstream catchment (mean 68%, std. error 2%) than sites not meeting the high-quality criteria (mean 41%, std. error 1%) ($F = 210.1$, $p < 0.0001$, df = 2195).

In Cecil county, looking at data collected during the second round of sampling (2000-04) (n=38), watershed percent forest and wetland cover was significantly related to stream nitrate levels ($r^2 = 0.34$, $p = 0.0001$), total nitrogen ($r^2 = 0.48$, $p < 0.0001$), total phosphorus ($r^2 = 0.25$, $p = 0.0014$), and benthic IBI

(r^2 = 0.17, p = 0.011). Looking at all data (n=71), forest and wetland cover was less strongly related to nitrate (r^2 = 19, p = 0.0001) and benthic IBI (r^2 = 13, p = 0.0021). Total nitrogen and phosphorus data were not collected in the first round of sampling (1995-7).

Tables 4 and 5 show watershed percent forest or wetland range, mean, and standard deviation within each stream health category for benthic IBI, nitrate, and phosphorus. Ranges within categories overlapped quite a bit. However, all sites with high nitrate levels, high phosphorus levels, or very poor IBI scores had ≤26% forest cover. Impaired stream sites in Cecil county had significantly less forest or wetland cover in the upstream catchment (mean 21%, std. error 4%) than unimpaired sites (mean 32%, std. error 3%) (F = 6.05, $p < 0.05$, df = 66). Only 1 of 11 sites with >40% forest or wetland catchment cover was impaired, compared to 25 of 56 with <40% (Chi-square = 4.9, $p < 0.05$). Conversely, high-quality sites in the county had more forest or wetland cover in the upstream catchment (mean 62%, std. error 5%) than sites not meeting these criteria (mean 23%, std. error 2%) (F = 44.48, $p < 0.0001$, df = 66). Six of the 7 high-quality sites had >50% forest or wetland catchment cover, and 6 of 8 catchments with >50% forest or wetland cover were associated with high-quality sites (Chi-square = 40.5, $p < 0.0001$).

Table 4. Watershed % of forests and wetlands (min.-max., mean ± standard deviation, number of sites) for each stream health category in Cecil County

Metric	Stream health categories and % of forest and wetland cover in the catchment			
Benthic Index of Biotic Integrity*	Good	Fair	Poor	Very Poor
	12-81 (37±21) (n=26)	10-50 (20±9) (n=21)	8-91 (26±19) (n=15)	1-26 (12±9) (n=5)
Nitrate Concentrations*	Low (<1 mg/l)	Moderate (1-5 mg/l)	High (>5 mg/l)	
	8-91 (49±28) (n=13)	1-66 (23±11) (n=49)	8-19 (15±4) (n=5)	
Phosphorus Concentrations*	Low (<0.025 mg/l)	Moderate (0.025-0.07 mg/l)	High (>0.07 mg/l)	
	8-91 (32±21) (n=44)	12-32 (23±7) (n=13)	1-23 (6±2) (n=10)	

* regression of metric vs. raw score (BIBI, NO3, TP) significant ($p<0.05$).

Table 5. Watershed % of forests and wetlands (approx. range from histogram) for each stream health category in Cecil County

Metric	Stream health categories and % of forest and wetland cover in the catchment			
Benthic Index of Biotic Integrity	Good	Fair	Poor	Very Poor
	>15	10-25	<45	<20
Nitrate Concentrations	Low (<1 mg/l)	Moderate (1-5 mg/l)	High (>5 mg/l)	
	>25	10-35	<20	
Phosphorus Concentrations	Low (<0.025 mg/l)	Moderate (0.025-0.07 mg/l)	High (>0.07 mg/l)	
	>15	15-30	<20	

Catchment impervious surface

MBSS sampling in Cecil County was primarily in rural areas. Only one of 67 sample sites had >10% imperviousness in its upstream catchment (14%), and one other site between 5-10% (8%). Because of this low data variability, we relied on statewide analyses for imperviousness.

MBSS statewide data from 1994-7 and 2000-4 showed >50% correlations between the percent of impervious cover in the catchment, and chloride (72%). Increasing impervious surface was associated with higher salt loads. Impaired stream sites statewide had significantly more impervious surface in the upstream catchment (mean 6%, std. error <1%) than unimpaired sites (mean 2%, std. error <1%) (F = 141.3, $p < 0.0001$, df = 2195). Conversely, high-quality sites statewide had less impervious surface in the upstream catchment (mean 2%, std. error 1%) than sites not meeting the high-quality criteria (mean 4%, std. error <1%) (F = 22.42, $p < 0.0001$, df = 2195). 95% of Benthic IBI ratings of Good (≥4) were found in catchments with <7% imperviousness, and 95% of Benthic IBI ratings of Fair (3-4) were found in catchments with <14% imperviousness. The Tukey-Kramer Multiple-Comparison Test showed a strong difference between Good and Fair, Poor, and Very Poor sites, with a less significant difference between Good and Fair (Table 6).

Table 6. Relationships between benthic IBI and impervious surface in Maryland.

Benthic IBI	# of sites	Mean imperv. surface	Different From Groups (95% confidence)
Good	586	1.44	Poor, Very Poor
Fair	614	2.20	Poor, Very Poor
Poor	577	4.57	Good, Fair, Very Poor
Very Poor	411	8.94	Good, Fair, Poor

Catchment percent riparian forest or wetland

MBSS statewide data from 1994-7 and 2000-4 showed >50% correlations between the percent riparian forest or wetland cover in the catchment, and total dissolved nitrogen (62%), and total nitrogen (57%), but not other metrics. Increasing riparian forest or wetland cover was associated with lower nitrogen loads. The correlation between riparian cover and total forest and wetland cover at the watershed scale was fairly high (74%). Impaired stream sites statewide had significantly less riparian forest or wetland cover in the upstream catchment (mean 38%, std. error 3%) than unimpaired sites (mean 67%, std. error 3%) ($F = 38.3$, $p < 0.0001$, df = 2195). Conversely, high-quality sites statewide had more riparian forest or wetland cover in the upstream catchment (mean 82%, std. error 7%) than sites not meeting high-quality criteria (mean 49%, std. error 2%) ($F = 18.4$, $p < 0.0001$, df = 2195).

Tables 7 and 8 show watershed percent riparian forest or wetland range, mean, and standard deviation within each stream health category for benthic IBI, nitrate, and phosphorus. Ranges within categories overlapped quite a bit. However, impaired stream sites in Cecil county had significantly less riparian forest or wetland cover in the upstream catchment (mean 51%, std. error 4%) than unimpaired sites (mean 62%, std. error 3%) ($F = 4.22$, $p < 0.05$, df = 66). Conversely, high-quality sites in the county had more riparian forest or wetland cover in the upstream catchment (mean 88%, std. error 6%) than sites not meeting all these criteria (mean 55%, std. error 2%) ($F = 24.02$, $p < 0.0001$, df = 66). There did not appear to be any obvious thresholds of riparian forest at the watershed scale in Cecil County.

Table 7. Watershed % of riparian forest buffers (min.-max., mean ± standard deviation, number of sites) for each stream health category in Cecil County

Metric	Stream health categories and % of forest and wetland cover in the catchment			
Benthic Index of Biotic Integrity*	Good	Fair	Poor	Very Poor
	32-100 (68±19) (n=26)	15-87 (48±15) (n=21)	34-93 (60±17) (n=15)	7-72 (26±12) (n=5)
Nitrate Concentrations*	Low (<1 mg/l)	Moderate (1-5 mg/l)	High (>5 mg/l)	
	56-100 (80±15) (n=13)	7-94 (54±17) (n=49)	34-51 (38±7) (n=5)	
Phosphorus Concentrations*	Low (<0.025 mg/l)	Moderate (0.025-0.07 mg/l)	High (>0.07 mg/l)	
	15-100 (60±21) (n=44)	38-79 (58±14) (n=13)	7-88 (49±22) (n=10)	

* regression of metric vs. raw score (BIBI, NO3, TP) significant ($p<0.05$).

Table 8. Watershed % of riparian forest buffers (approx. range from histogram) for each stream health category in Cecil County

Metric	Stream health categories and % of forest and wetland cover in the catchment			
Benthic Index of Biotic Integrity	Good	Fair	Poor	Very Poor
	>50	25-60	Range broad	Range broad
Nitrate Concentrations	Low (<1 mg/l)	Moderate (1-5 mg/l)	High (>5 mg/l)	

	>60	30-80	<50
Phosphorus Concentrations	Low (<0.025 mg/l)	Moderate (0.025-0.07 mg/l)	High (>0.07 mg/l)
	>40	40-80	Range broad

Large forest patches

We did not discern a relationship between benthic IBI and forest block size.

Site level conditions

MBSS statewide data did not show >50% correlations between concentrations of chloride, nitrogen, or phosphorus and any parameters related to local conditions (stream dimensions or flow, riparian buffer width, bank stability, etc.). Fish IBI scores were 50% correlated with average stream width, and >40% correlated with measurements of stream depth. Benthic IBI scores were not >40% correlated with any local parameters. Riparian width was not >30% correlated with any chemical or biological metrics.

In Cecil County, nitrate levels were 52% correlated with stream shading, and 41% correlated with riparian width (the minimum on either side). Total phosphorus was 54% correlated with channel alteration, and 50% with embeddedness. Fish IBI scores were >50% correlated with measurements of stream habitat quality like velocity/depth regime, pool quality, and riffle quality. Benthic IBI scores were not >40% correlated with any local parameters. Minimum riparian width was 41% correlated with nitrate, and 77% with particulate and dissolved phosphorus.

Multivariate analyses

Tables 9 and 10 report the mean and standard deviation of variables used in stepwise regressions of MBSS stream data vs. physical and land cover variables. Table 11 reports predictive variables in Maryland's Piedmont and Coastal Plain physiographic regions, using stepwise regression. Table 12 reports predictive variables in Cecil County, using all possible regressions. Table 13 shows the results of discriminant analyses for benthic IBI and total phosphorus in Cecil County.

Table 9. Stepwise regression variable means in the Coastal Plain:

Variable	Count	Mean	Std. Dev.
TEMP_FLD	463	20.49	2.90
CHAN_ALT	463	10.73	5.51
DIST_RD	463	272.79	270.58
RIP_WID	463	36.78	19.65
MIN_RIP_WIDTH	463	38.54	17.43
MAXDEPTH	463	54.49	29.29
ST_GRAD	463	0.44	0.50
AVGWID	463	3.24	3.63
AVGTHAL	463	24.25	16.86
AVG_VEL	463	0.11	0.10
FLOW	463	1.48	3.99
ACREAGE	463	2029.83	4679.32
URBAN	463	11.36	19.07
AGRI	463	38.17	26.83
PCT_FORWET92	463	48.73	26.06
BARREN	463	1.46	5.59
PHI_05	463	70.91	11.63
PCT_IMPERV	463	5.05	9.55
PCT_FORWET	463	43.10	25.16
PCT_RIPFOR	463	54.01	113.73
DIFF_FORWET	463	-5.63	8.47
NO3_LAB	463	1.53	2.10

Table 10. Stepwise regression variable means in the Piedmont:

Variable	Count	Mean	Std. Dev.
TEMP_FLD	435	18.88	2.75
CHAN_ALT	435	11.40	4.50
DIST_RD	435	197.23	225.69
RIP_WID	435	30.87	22.13
MIN_RIP_WIDTH	435	33.63	20.02
MAXDEPTH	435	61.18	32.73
ST_GRAD	435	1.15	1.09
AVGWID	435	4.85	4.51
AVGTHAL	435	27.01	18.89
AVG_VEL	435	0.18	0.13
FLOW	435	5.75	13.61
ACREAGE	435	6511.39	14895.44
URBAN	435	8.70	16.45
AGRI	435	54.93	24.11
PCT_FORWET92	435	35.64	19.71
BARREN	435	0.51	2.23
PHI_05	435	67.78	13.61
PCT_IMPERV	435	4.18	6.81
PCT_FORWET	435	29.37	18.13
PCT_RIPFOR	435	49.10	75.52
DIFF_FORWET	435	-6.27	8.18
NO3_LAB	435	2.58	1.65

Table 11. Stepwise regressions of MBSS stream data by physiographic region in Maryland (Coastal Plain and Piedmont only) vs. physical and land cover variables.

Dependent variable	Predictive variables (in order of selection)	n	r^2
Nitrate (Coastal Plain)	AGRI, PCT_RIPFOR, AVG_VEL, PCT_FORWET	463	0.46
Nitrate (Piedmont)	AGRI, URBAN, TEMP_FLD, AVG_VEL	435	0.49
Phosphorus	No models had r^2 > 0.20; models for TP were <0.10		
Turbidity	No models had r^2 > 0.10		
Physical Habitat Index (Coastal Plain)	DIST_RD, PCT_FORWET92, CHAN_ALT, DIFF_FORWET, RIP_WID, URBAN, ACREAGE, AVGWID	463	0.35
Physical Habitat Index (Piedmont)	MIN_RIP_WIDTH, PCT_FORWET, DIST_RD, AVG_VEL, PCT_RIPFOR	435	0.33
Benthic IBI (Coastal Plain)	PCT_IMPERV, MAXDEPTH, AVG_VEL, RIP_WID, PCT_FORWET92	463	0.33
Benthic IBI (Piedmont)	PCT_IMPERV, PHI_05, PCT_FORWET, RIP_WID, TEMP_FLD	435	0.34
Fish IBI (Coastal Plain)	MAXDEPTH, PCT_IMPERV, ST_GRAD, RIP_WID, TEMP_FLD, PCT_RIPFOR, AVG_VEL	463	0.43
Fish IBI (Piedmont)	MAXDEPTH, URBAN, PHI_05, ST_GRAD, AVG_VEL, MIN_RIP_WIDTH	435	0.44

Table 12. All possible regressions of MBSS stream data in Cecil Co. vs. physical and land cover variables.

Dependent variable	Predictive variables (in order of decreasing individual r^2)	n	r^2
Nitrate	PCT_RIPFOR, SHADING, PCT_FORWET	66	0.53
Phosphorus	PCT_FORWET, CHAN_ALT, AVG_VEL, MAXDEPTH, PCT_IMPERV	37	0.45
Turbidity	CHAN_ALT, TEMP_FLD, PCT_FORWET, RIP_WID, AVGTHAL, PCT_IMPERV, AVGWID	66	0.66
Bank stability	CHAN_ALT, AVG_VEL, AVGTHAL, PCT_RIPFOR	66	0.33

Physical Habitat Index	AVG_VEL, TEMP_FLD, AVGWID, AVGTHAL, FLOW	37	0.30
Benthic IBI	PCT_FORWET, PCT_IMPERV, AVGTHAL, FLOW	66	0.43
Fish IBI	MAXDEPTH, AVGWID, PCT_IMPERV, AVG_VEL	66	0.35

Table 13. Discriminant analyses for benthic IBI (BIBI) and total phosphorus (TP) in Cecil County.

Linear Discriminant Functions

	BIBI_group			
Variable	Good	Fair	Poor	Very Poor
Constant	-2.649364	-0.5393245	-0.8202161	-2.260698
PCT_IMPERV	-0.0111325	0.0426928	0.2684516	0.8409192
PCT_FORWET	0.1276172	0.0557691	0.0528146	0.0142340

Classification Count Table for BIBI_group

	Predicted				
Actual	Good	Fair	Poor	Very Poor	**Total**
Good	10	7	0	0	17
Fair	1	9	0	0	10
Poor	0	3	2	1	6
Very Poor	0	1	1	2	4
Total	11	20	3	3	37

Reduction in classification error due to X's = 49.5%
Reduction in classification error due to X's = PCT_IMPERV, PCT_FORWET

Linear Discriminant Functions

	TP_group		
Variable	Low	Moderate	High
Constant	-11.19986	-4.906842	-9.523827
CHAN_ALT	0.177347	0.562758	0.8521988
MIN_RIP_WIDTH	0.2143303	0.0942792	0.1506077
PCT_IMPERV	1.020783	0.1064459	0.1521756
PCT_FORWET	0.1792149	0.0584776	0.0047581

Classification Count Table for TP_group

	Predicted			
Actual	Low	Moderate	High	**Total**
Low	14	0	0	14
Moderate	1	9	3	13
High	0	2	8	10
Total	15	11	11	37

Reduction in classification error due to X's = 75.7%
Reduction in classification error due to X's = PCT_IMPERV, PCT_FORWET, CHAN_ALT, MIN_RIP_WIDTH

Discriminant analysis was unable to produce a predictive model for nitrate. The model for benthic IBI had only a 50% fit, but the coefficients were consistent with other tests (i.e., increasing forest cover and decreasing impervious surface increases benthic IBI scores). The model for phosphorus fit the data well (76%), but the coefficients for riparian width and imperviousness were inconsistent (i.e., the value for the Moderate group not being between the values for Low and High).

Soil erosion

Natural breaks (Jenks classification) separated the erosion index (the combination of soil erodibility, slope, and adjacency to streams or shorelines) into the following five groups: 0-8, 9-21, 22-36, 37-70, and 71-100. Stream banks tended to have high erosion indices unless they were in floodplains identified by the soil data.

Wetlands

Only 2 acres of farmed wetlands (code Pf) were identified by DNR. This area was identified as having hydric soils. The correspondence between hydric soils and wetlands according to available data was extremely poor. Only 12% of wetlands occurred on hydric soils, and only 2% of hydric soils contained wetlands.

DISCUSSION

Forest and wetland cover had a significant impact on water quality in Cecil County. As indicated by the benthic macroinvertebrate community, nitrate levels, and phosphorus levels, watersheds with >50% forest and wetland cover generally had the best stream conditions, followed by watersheds with 40-50% forest. This trend was consistent with other studies in Maryland. Impervious surface also affected water quality. We found significant thresholds at 7 and 14% statewide. Watersheds with <7% imperviousness generally had the least impacted streams, followed by watersheds between 7-14%. Riparian forest was also strongly related to water quality, with high quality streams averaging 88% riparian cover in the upstream catchment, and impaired sites averaging 51%. There did not appear to be any obvious thresholds of riparian forest at the watershed scale in Cecil County, though.

At the site level in the county, both nitrate and phosphorus levels were higher in reaches without adequate riparian buffers. Phosphorus levels were also higher in channelized streams with high sediment loads. The fish community was most affected by in-stream habitat quality, with depth playing a major role. The benthic community did not appear to be related to any in-stream parameters, even though many species require suitable substrates, water chemistry and temperature, dissolved oxygen levels, presence of woody debris, and influx of organic matter.

Examining the full suite of available data, stream condition as indicated by the benthic community was most affected by the percentage of forests and wetlands, and percent impervious surface, in the watershed. These same watershed variables were also related to levels of phosphorus, nitrate, and turbidity. Riparian forest was also related to water quality and stream stability. The fish community was mostly affected by stream depth, size, and water velocity, but was also impacted by watershed imperviousness.

Available soil data (Natural Soils Groups) was worthless for predicting wetland occurrence. Therefore, the use of hydric soils to target wetland restoration should wait until better data (i.e., SSURGO) is available.

MANAGEMENT IMPLICATIONS

Application to land conservation

We envisioned three approaches to addressing water quality and stream habitat in Cecil County:

- prioritize conservation of existing land important for protecting water quality (i.e., forests and wetlands that if converted to development or other incompatible uses would significantly impair good water quality);
- prioritize restoration of land important for improving water quality (i.e., areas where streamside buffers or wetlands would significantly improve water quality); and,
- identify other management practices to maintain and improve water quality.

Based on the analyses above, we identified the following water quality goals for land conservation:

- Watersheds with >40% forest and <7% imperviousness should be targets for forest and wetland conservation to maintain high water quality. Keep conditions above these thresholds.
- Streams feeding drinking water supplies need forest buffers to reduce non-point pollution.
- Maintain existing riparian forest and wetlands.
- Highly permeable soils, especially in the Coastal Plain, may be important for groundwater recharge, and sensitive to pollution.
- Maintain forest cover on land with high erosion potential.

We developed an overlay model valuing existing forests and wetlands in Cecil County for their maintenance of water quality. The model was a continuous integer grid (cell size of 10 meters) with values between 0 and 100: 100 being the highest possible score, and therefore the highest conservation priority. All forest and wetland cells in the county[2] were scored based on watershed conditions, contribution to drinking water, wetland characteristics, proximity to streams and shorelines, soil characteristics, geology, and slope. Land cover other than forest and wetland received a score of 0. The parameters were then added together (i.e., score for watershed forest and wetland cover + score for impervious surface + … + score for soil erodibility). Parameter values and their associated model scores are listed in Table 14. Some factors that might be considered important contributors to water quality, such as BMP implementation, were not considered in this model because data were unavailable. Model output is shown in Fig. 2.

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[2] Forest and wetland cover were obtained from the National Land Cover Database (NLCD), which had a 30m resolution and was classified based on 2000-01 satellite imagery.

Table 14. Land conservation model for maintaining water quality in Cecil County.

Scale	Parameter	Parameter Values	Model Score
DNR 12-digit (3rd order) watershed	% forest or wetland in watershed	>50%	20
		40-50%	10
		<40%	0
	% impervious surface in watershed	<7%	20
		7-14%	10
		>14%	0
	Watershed drains to drinking water supply?[3]	Yes	10
		No	0
MBSS catchment	Highest FIBI or BIBI score	≥4	10
		3-4	3
		<3, or no data	0
Wetland	Human modification	No special modifier codes (except beaver)	0
		Ditched, drained, farmed, impounded, filled, or excavated	-5
	Flooding regime	Seasonally or regularly flooded or saturated (C, D, E, N, R)	10
		Semipermanently flooded (F, G, M, T)	6
		Permanently flooded or saturated (H, K, L, V)	4
		Temporarily flooded or saturated (A, B, J, P, S)	2
Soil group	Soil permeability[4]	>6.0 inches/hour	5
		2.0-6.0 inches/hour	3
		0.6-6.0 inches/hour	2
		0.6-2.0 inches/hour	1
		<0.6 inches/hour, or wetland[5]	0
	Physiographic region[6] (multiplier with soil permeability)	Coastal Plain	1X
		Piedmont	0.5X
Grid cell (proximity)	Proximity to streams and shorelines	0-15m, or riparian wetland[7]	20
		Upland, 15-30m	15
		Upland, >30m	0
	Soil erodibility, slope, and streambank/shoreline index	(Divide by 10)	0-10

[3] Big Elk Creek and North East Creek watersheds, which supply the towns of Elkton and North East, respectively.

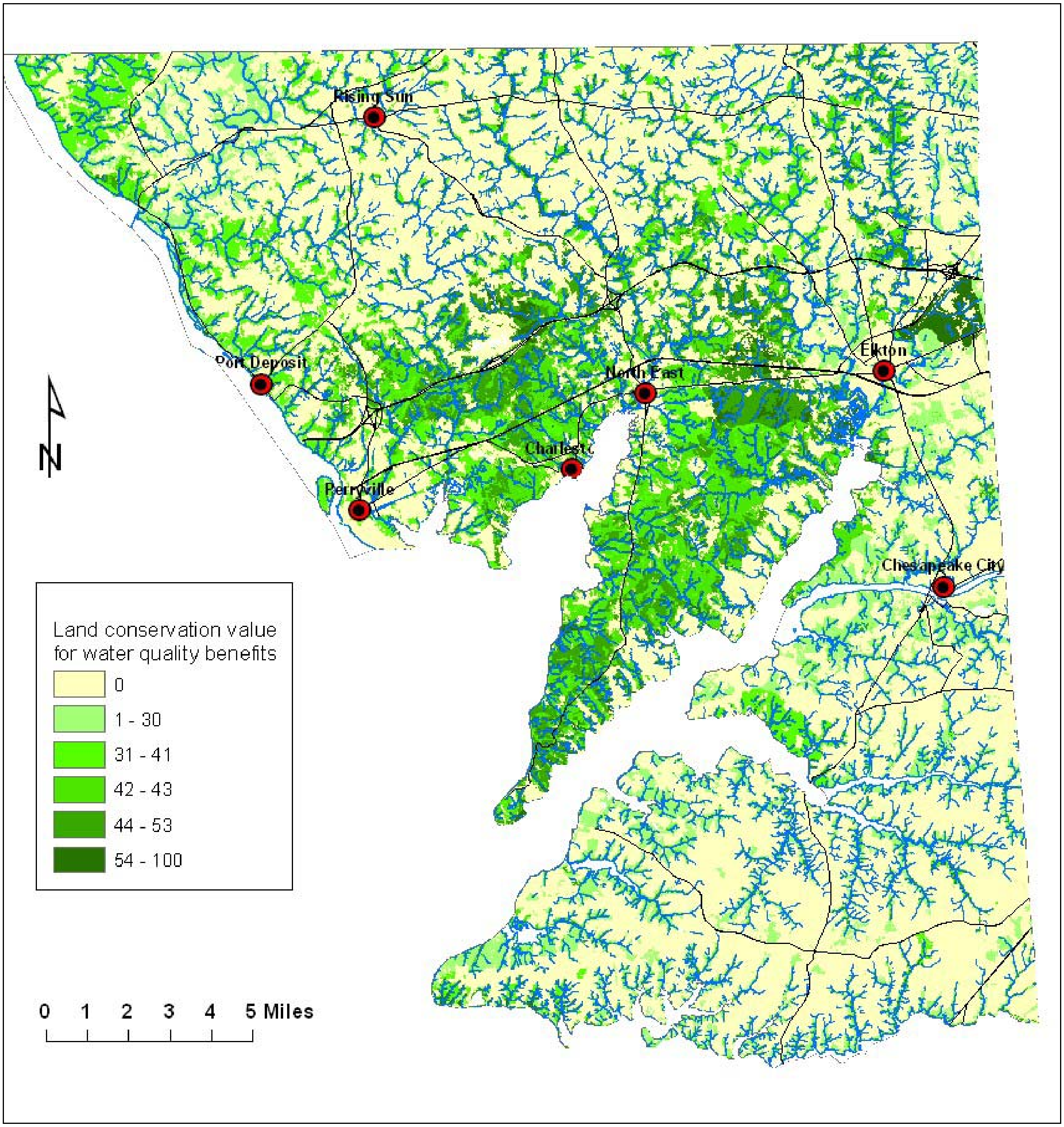
[4] See Maryland Department of State Planning (1973) for details. This parameter was given a lower score than wetlands due to its coarser resolution.

[5] Wetlands identified by DNR (used in this model) are usually discharge points, or slow recharge at best.

[6] Obtained from Omernik ecoregion data (Woods et al., 1996). Physiographic region data from Maryland Dept. of Natural Resources did not correspond as well to Fig. 1, and no available data set was very satisfactory.

[7] Riparian wetlands were identified by spatially aggregating DNR wetlands in the county (i.e., wetlands adjacent to each other were combined), and selecting those aggregations of wetlands that intersected streams or shorelines from Cecil county hydrology data.

Fig. 2. Land conservation model output for maintaining water quality in Cecil County.



Application to reforestation

We also identified water quality goals for reforestation:

- Restore forest, especially along streams and shorelines, in watersheds that can attain good water quality by doing so (<14% imperviousness; feasible to attain 40% forest in watershed).
- Restore riparian forest along streams supplying drinking water.
- Restore forest cover on eroding land.

For reforestation, all agricultural, lawn, and barren cells in the county (from NLCD) received a score between 0 and 100, based on watershed and site conditions. NLCD sometimes erroneously classified marsh as agriculture, so this data set was corrected by subtracting unfarmed DNR wetlands (i.e., not coded Pf). Parameter values and their associated model scores are listed in Table 15.

Table 15. Reforestation model for improving water quality in Cecil County.

Scale	Parameter	Parameter Values	Model Score
Watershed	Current percent forest in watershed	>50	0
		40 - 50	10
		39 - 40	20
		38 - 39	18
		37 - 38	16
		36 - 37	14
		35 - 36	12
		34 - 35	10
		33 - 34	8
		32 - 33	6
		31 - 32	4
		30 - 31	2
		<30	0
	% impervious surface in watershed	<7%	20
		7-14%	12
		>14%	0
	Watershed drains into drinking water supply?	Yes	10
		No	0
MBSS catchment	Benthic IBI score	3-4	5
		2-3	3
		<2	1
		>4, or no data	0
Grid cell (proximity)	Proximity to streams and shorelines	0-15m, or riparian wetland	30
		Upland, 15-30m	25
		Upland, >30m	0
	Soil erodibility, slope, and streambank/shoreline index	(Divide by 6.67)	0-15

Reforestation can also contribute to biodiversity. Maryland's Green Infrastructure (GI) is a network of the state's most important ecological areas and connections between them. Restoring disturbed or converted areas (or "gaps") within the GI would enhance the functionality of this network. Weber et al. (2004) describe a methodology for assessing GI gaps and prioritizing them for restoration based on the ecological functions restored or enhanced. This report also describes methodologies for assessing and targeting impaired wetlands and streams, acid mine drainage, fish blockages, potential road and railroad underpasses, ditch removal, forest condition and management, invasive exotic species, and other ecological stressors in the GI.

The reforestation model in the above table (model output shown in Fig. 3) could therefore be supplemented by adding points for areas within the GI. This could be enhanced by also considering adjacency or distance to existing forest blocks, the increase of interior forest that the project would create, whether the project would create suitable habitat for indicator species like forest interior birds, and proximity to known forest-dependent wildlife, especially rare or sensitive species. Restoring areas that provide multiple benefits, like enhancing wildlife habitat, might also increase funding eligibility from multiple sources.

Fig. 4 shows reforestation model output for just riparian areas (within 30m of a stream or shoreline) that are currently agricultural fields, lawns, or barren. Because of the fine resolution, only a subset of the county (in the North East Creek watershed, which ranked in the top tier of the reforestation model) is shown in Fig. 4, although the entire county was analyzed. From the county hydrology layer, streams, shorelines, lakes, ponds, and reservoirs were buffered 30 m. Stormwater ponds were not included because almost all water is piped in rather than flowing overland. Most ditches were alongside roads and impractical to set aside riparian buffers.

Fig. 3. Reforestation model output for improving water quality in Cecil County.

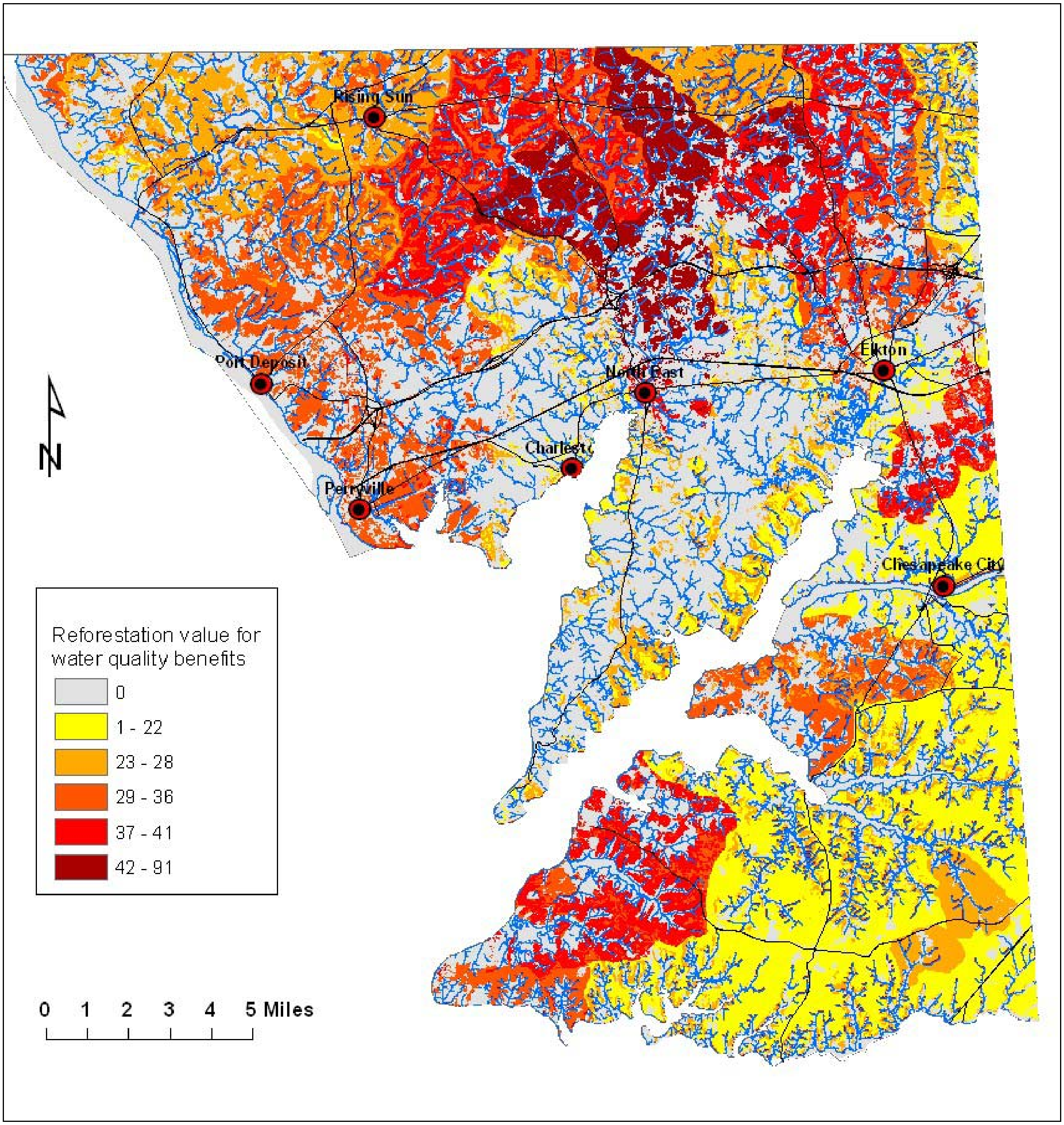
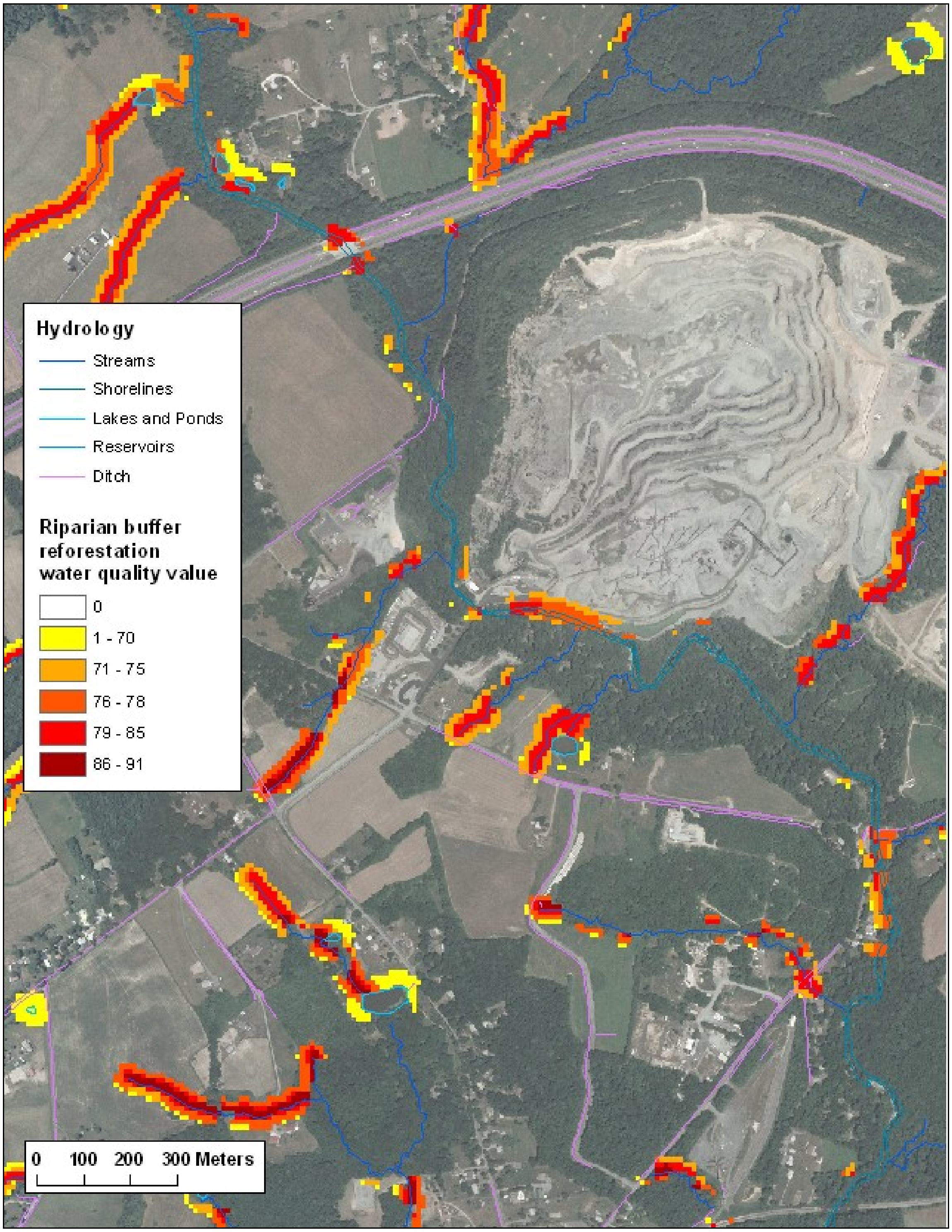


Fig. 4. Riparian reforestation model output for improving water quality in a subset of Cecil County.



Application to wetland restoration

As discussed in the introduction, wetlands can moderate the effects of floods and improve water quality. We identified the following water quality goals for wetland creation:

- Restore wetlands, especially along streams and shorelines, in watersheds that can attain good water quality by doing so (<14% imperviousness; feasible to attain 40% forest in watershed).
- Restore wetlands along streams supplying drinking water.

Table 16 depicts a model for targeting wetland creation for water quality improvement. Wetlands that have been converted to farmland or other non-paved uses, all agricultural, lawn, and barren cells in the county with hydric soils receive a score between 0 and 100, based on watershed and site conditions. Unfortunately, available soil data (Natural Soils Groups) was unreliable, and this analysis cannot be performed until digital SSURGO data is completed.

Table 16. Wetland restoration model for improving water quality in Cecil County.

Scale	Parameter	Parameter Values	Model Score
Watershed	Current percent forest and wetland in watershed	>50	0
		40 - 50	10
		39 - 40	20
		38 - 39	18
		37 - 38	16
		36 - 37	14
		35 - 36	12
		34 - 35	10
		33 - 34	8
		32 - 33	6
		31 - 32	4
		30 - 31	2
		<30	0
	% impervious surface in watershed	<7%	20
		7-14%	12
		>14%	0
	Watershed drains into drinking water reservoir?	Yes	10
		No	0
Contiguous patch of hydric soil	Adjacent to stream or shoreline?	Yes	20
		No	0
Grid cell	Soil drainage class	Poorly drained	15
		Very poorly drained	10
		Somewhat poorly drained	5
		Well drained	Not a candidate
	Classified as farmed wetland?	Yes	15
		No	0

Wetland restoration can also contribute to biodiversity. Restoring wetlands within Maryland's Green Infrastructure would enhance the functionality of this network. The wetland restoration model in the above table could therefore be supplemented by adding points for areas within the GI. This could be enhanced by also considering adjacency or distance to existing unmodified wetlands, whether the project would create suitable habitat for wetland indicator species like prothonotary warblers, waterfowl, amphibians, etc., and proximity to known wetland-dependent wildlife, especially rare or sensitive species. Restoring areas that provide multiple benefits, like enhancing wildlife habitat, might also increase funding eligibility from multiple sources.

Restoration could also take the form of enhancing existing but impaired wetlands; for example, correcting hydrologic impairments like ditching or draining. Disturbed or fragmented wetlands often have exotic species like Japanese honeysuckle (*Lonicera japonica*), which should be removed as resources permit.

Other best management practices

Use of best management practices (BMPs) is an important consideration, as this can mitigate some problems associated with land use and historic impacts. Some general recommendations follow:

- Developers should not increase the pre-development runoff of a site. Low impact design (LID) techniques can reduce stormwater runoff and protect water quality by making the built environment function like the natural environment. On-site LID utilizes natural features (like native vegetation) and low-cost, engineered controls (like rain barrels and gardens) to maintain predevelopment stormwater flows.
- New development should also maintain pre-development groundwater recharge, especially in the Coastal Plain.
- Construct retention ponds, wetlands, or rain gardens in locations where runoff concentrates into channels.
- Retrofit existing stormwater ponds to meet LID standards.
- “Green” roofs on new buildings can reduce peak stormwater runoff (and can also save air conditioning costs in the summer).
- Identify point sources of pollution and take action to reduce their impact.
- Fence livestock out of streams.
- Remove exotic species from sensitive aquatic habitat.
- Implement effective animal waste and nutrient management strategies.
- Use conservation tillage and cover crops to reduce erosion and runoff.
- Treat and retire highly erodible land, especially areas that are marginally productive.
- Reduce phosphorus and protein in animal feed.
- Fermenting manure, wastewater sludge, solid waste, and other biodegradable matter under anaerobic conditions produces methane, which can be collected and burned for energy. Methane should be consumed rather than released because it is a highly potent greenhouse gas (warming the Earth 25 times as much as an equivalent mass of CO_2).
- Consider restoration of degraded streams and wetlands to reduce stream bank erosion, especially where erosion is severe or the channel is incising.
- Channelizing streams and ditching agricultural fields decreases water quality and aquatic habitat. Identify channelized streams that can be restored to a more natural condition, and locations where ditch runoff can be treated in constructed wetlands or ponds.

Landers (2006) compared 11 types of BMPs side-by-side, and found that constructed wetlands were the most effective at treating parking lot runoff. The wetland removed 100% of suspended solids, 99% of nitrate, 100% of zinc, and 100% of petroleum byproducts, and reduced peak flows by 85% (Landers, 2006). This greatly exceeded the performance of standard retention ponds, as well as expensive manufactured devices (Landers, 2006). Langland and Cronin (2003) reported that wetland restoration and tree planting were the most effective BMPs at reducing sediment runoff from agricultural fields (96% from high-till fields).

Reduction of nutrient loads to the Chesapeake Bay

As discussed in the Introduction, Total Maximum Daily Loads (TMDLs) were established in three of the county’s rivers for nitrogen and phosphorus to reduce algal blooms and ensure adequate dissolved oxygen. The Maryland Department of the Environment (2006a) provides guidance on estimating non-point source pollution loads to the Chesapeake Bay and developing plans to meet TMDL requirements.

The Chesapeake Bay Program uses a watershed model (currently Phase 4.3) to estimate sources and loads of nutrients and sediments to the Bay under different scenarios. The drainage basin is divided into

94 model segments, corresponding to subwatersheds. Each segment contains information generated by a hydrologic submodel, a nonpoint source submodel and a river submodel. The hydrologic submodel uses rainfall, evaporation and meteorological data to calculate runoff and subsurface flow for all the basin land uses including forest, agricultural and urban lands. The nonpoint source submodel simulates soil erosion and pollutant runoff. The river submodel simulates the flow of this runoff to the Bay (Chesapeake Bay Program, 2002).

Five Chesapeake Bay model segments are partly within Cecil County: subbasins 140, 370, 450, 800, and 810. Of these, only two (370 and 800) are primarily within the County (84% and 71% respectively); the others are only 3-17% within the County. Different watersheds (or model segments) have different nutrient loads[8] per unit area (Table 17) because of different management practices, hydrology, etc. Comparing different land use categories, forest has by far the lowest nutrient export per unit area in Cecil County. Urban land has the highest nitrogen runoff, and agriculture has the highest phosphorus runoff.

Table 17. Total nitrogen (TN) and total phosphorus (TP) non-point source loads by land use category and Chesapeake Bay model segment, for watersheds mostly within Cecil County.

SEGMENT	MAJOR LAND USE	TN lbs/ac/yr	TP lbs/ac/yr
370	AGRICULTURE	8.41	0.85
370	FOREST	1.33	0.02
370	URBAN	13.81	0.70
800	AGRICULTURE	8.59	0.98
800	FOREST	1.43	0.02
800	URBAN	10.90	0.72

We combined segments 370 and 800 based on their relative area in the county (Table 18). Segment 370 covers 15,497 ha in Cecil County, and Segment 800 covers 49,819 ha.

Table 18. Total nitrogen (TN) and total phosphorus (TP) non-point source loads by land use category, averaged within Cecil County.

MAJOR LAND USE	TN lbs/ac/yr	TP lbs/ac/yr
AGRICULTURE	8.55	0.95
FOREST	1.41	0.02
URBAN	11.59	0.71

According to data from the Maryland Department of Planning (2006), Cecil County's population is projected to rise 64% between 2005 and 2030, from 97,250 to 159,950. The number of households is projected to rise 74% in the same period, from 35,250 to 61,175. If present development trends continue (85% of housing units being single-family homes, with an average lot size of 1.144 ac), this would consume an additional 25,209 ac of land. Development between 1997 and 2002 was 77% on farm land and 23% on forest land[9]. If these trends continue, 19,411 ac of agriculture and 5,798 ac of forest will be converted between 2005 and 2030. Using loads from Table 18, this will decrease phosphorus export to streams, rivers, and the Bay by about 660 lbs/year, but increase nitrogen export by 118,000 lbs/year.

Other major sources of nutrient export include wastewater treatment plants and septic systems. Maryland's Point Source Strategy for the Bay aims to upgrade Maryland's wastewater treatment plants with the latest Enhanced Nutrient Removal (ENR) technology to meet concentrations of 3.0 mg/l or less of

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[8] Calculated from scenario s66mdts06 (Maryland Tributary Strategy 06 - FINAL), to edge of nearest stream. Data was downloaded from the Chesapeake Bay Program data hub at http://www.chesapeakebay.net/datahub.htm. Major land uses were examined, not refined land use categories, because GIS data for the latter was insufficient, and crops change from year to year on a given field.

[9] Analysis of GIS land use data created by Maryland Department of Planning.

total nitrogen and 0.3 mg/l or less of total phosphorous. All three of Cecil County's major wastewater treatment plants (Elkton, Northeast River, and Perryville) are being upgraded to meet these standards. When construction is finished (projected in 2010), 80% less nitrogen will be discharged into the Chesapeake Bay (Tables 19 and 20). Even increasing discharge by a factor of 2.16 from 2002 (i.e., at full capacity), these plants would discharge 72,000 fewer lbs/year of nitrogen than in 2002.

Table 19. Nitrogen discharge from Cecil County's wastewater treatment plants in 2002 (data from Chesapeake Bay Foundation).

Wastewater Plant	2002 flow (mgd)	2002 nitrogen concentration (mg/l)	2002 nitrogen load (lbs)
Perryville	1.1	5.3	17,283
Northeast River	0.5	16.9	27,103
Elkton	1.5	19.3	90,533
TOTAL	3.1		134,919

Table 20. Nitrogen discharge from Cecil County's wastewater treatment plants at capacity with and without Enhanced Nutrient Removal (ENR) technology.

Wastewater Plant	Design capacity (mgd)	2002 nitrogen concentration (mg/l)	Capacity nitrogen load (lbs)	ENR goal (TN mg/l)	ENR nitrogen load (lbs)
Perryville	1.65	5.3	25,925	3.0	14,674
Northeast River	2.00	16.9	108,412	3.0	19,245
Elkton	3.05	19.3	184,084	3.0	28,614
TOTAL	6.70		318,420		62,533

Cecil County also has 17 minor wastewater treatment plants, with a design capacity of 1.319 million gallons per day (mgd) to surface waters (Cecil County, 2007). Current caps are set at projected 2020 capacity (0.994 mgd), 18 mg/l N, and 3 mg/l P; or 52,041 lbs/year of nitrogen and 8,672 lbs/year of phosphorus (Cecil County, 2007). Tertiary treatment, or biological nutrient removal (BNR) could reduce effluent to 8 mg/l N. Upgrade to ENR would reduce this further, but at much greater expense. Alternatively, outflow from minor plants could be routed to major plants for ENR treatment.

However, 69% of new residential units were on private septic (1000 Friends of Maryland). If this trend continues, and given an average household size of 2.64 (the midpoint between 2005 and that projected by Maryland Department of Planning for 2030), a nitrogen load of 9.5 lbs/yr/person to the septic drain field (MDE, 2006a), and a 40% loss of nitrogen during transport from the septic field to the surface water (MDE, 2006a), the 17,888 new households on septic will export an additional 180,000 lbs/year of nitrogen into the water. This could be cut in half by using denitrifying septic systems (MDE, 2006a). Unfortunately, such systems are expensive and must be properly monitored and maintained.

Ecologically engineered wetlands are an effective, low-maintenance, and low-cost alternative to ENR and denitrifying septic systems. For example, the City of Orlando, Florida, constructed a 1,250 acre wetland in a former cattle pasture to remove nutrients from 20 mgd of wastewater treatment effluent. Survey maps indicated that the site had been a natural wetland in the 19^{th} century. Earthen berms divided the site into "cells" for the water to pass through, and 2.1 million aquatic macrophytes were planted. This system has been operating successfully since 1987; after a hydraulic detention time of 30 days, nitrogen concentrations discharged have been consistently below 1.0 mg/l and phosphorus concentrations below 0.1 mg/l. This wetland also operates as a regional park, and is home to more than 150 plant species, more than 140 bird species, and numerous mammals (including otters, foxes, and deer), amphibians and reptiles (City of Orlando, 2006).

A strategy therefore to keep nitrogen discharge at current levels, faced with an increase from septic and sewage systems and 118,000 lbs/year from additional non-point runoff is to:

1. Complete the ENR upgrades of the county's wastewater treatment plants (decrease of 72,000 lbs/year from 2002 levels even with a doubling of service).
2. Require all new septic systems to be denitrifying (addition of 90,000 lbs/year rather than 180,000 lbs/year); or direct growth to areas with sewer service; or extend sewer service. If ENR sewer service is used, nitrogen loads will be reduced 70% rather than 50%, and proper maintenance is more likely.
3. Construct wastewater treatment wetlands to reduce nutrient levels in effluent to background levels.
4. Limit conversion of forest to development as much as possible.
5. Plant 0.43 acres of riparian forest for each acre of agriculture developed, and 1.43 acres of riparian forest for each acre of forest developed. If current trends continue (i.e., if suggestion #4 is ignored), 19,411 ac of agriculture and 5,798 ac of forest will be converted between 2005 and 2030, meaning 16,637 ac of forest would have to be planted just to offset the increase in non-point loads. To offset point sources (net from #1 and #2 of 18,000 lbs/year), an additional 2500 ac of forest would be required. Thus, the total would be approximately 19,000 ac of reforestation.
6. Implement BMPs as described earlier.

If Cecil County is to meet the 40% nitrogen reduction goal set by the State of Maryland and its Chesapeake Bay Program partners, the above strategies must be strengthened accordingly. Because there are only 85,700 acres of farmland in the county, reforesting 19,000 ac of this (22%) just to keep nitrogen runoff at current levels, not to mention the amount needed to meet the 40% reduction goal, is probably unfeasible. Thus a major part of the county's strategy to meet water quality goals has to be to limit lot size and minimize conversion of open space, especially forest (which has by far the lowest nutrient export rates).

CONCLUSIONS

Data collected in Maryland and Cecil County indicate a significant relationship between water quality and land use. As indicated by the benthic invertebrate community, nitrate levels, and phosphorus levels, stream conditions in Cecil County were best in watersheds with >50% forest and wetland cover. Statewide, watersheds with <7% imperviousness generally had the least impacted streams. In Cecil County, watersheds with >40% forest and <7% imperviousness should be high-priority targets for forest and wetland conservation to maintain high water quality. Within these watersheds, riparian forest and wetlands should be the highest priority. Restoration should attempt to attain 40% forest in watersheds with <14% imperviousness, and focus first on streamside buffers and floodplains. From these goals, we developed models at a fine scale (10m) to prioritize land conservation and restoration for water quality benefits. A possibility for model improvement is to calculate runoff and nutrient loads from fertilized agricultural fields and lawns, which would better inform where restoration or other BMPs are most needed. A wetland restoration model was developed, but requires better soil data to run. To meet water quality goals, Cecil County should minimize conversion of forest to development, limit house lot size, complete upgrades of the county's wastewater treatment plants, install denitrifying septic systems, construct tertiary treatment wetlands, restore riparian forest and wetlands in targeted watersheds, use low impact site design techniques, treat existing sources of stormwater and point source runoff, reduce nutrient and sediment runoff from agriculture, and implement other best management practices.

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APPENDIX A. GIS DATA USED IN CECIL COUNTY WATER QUALITY ANALYSES

Data Layer	Original Source	Ground Condition Date	Spatial Resolution	Comments
Watersheds	Maryland Dept. of Natural Resources (DNR) 12-digit watersheds, Delaware Department of Natural Resources and Environmental Control (DNREC) subwatersheds, and U.S. Environmental Protection Agency (EPA) HUC-14 watersheds.	N/A	Unknown	Each state had different watershed boundaries. These were merged and manually interpolated and cleaned at the state borders.
Hydrography (county)	Cecil County Planning and Zoning Department	Unknown	Unknown, but appeared accurate	This data set was much more accurate than other available hydrography data, and aligned well with aerial photos.
Hydrography (state)	National Hydrography Dataset (NHD)	Unknown	40 ft	Best available statewide data
Non-tidal stream site biological, chemical, and physical data	Maryland Biological Stream Survey (MBSS)	1995-2004	Unknown	Data was collected along a 75-m stream reach at randomly sampled sites
Catchments to non-tidal stream sample sites	Maryland Biological Stream Survey (MBSS)	1995-2004	Unknown	Catchments were manually delineated as drainage area to each stream sample site
Tidal stream chemical data	Chesapeake Bay Citizens Monitoring Program Water Quality Database	2005-2006	Unknown	Collected at nine freshwater tidal stream locations (Stoney Run, North East Creek, Mill Creek, Conowingo Creek, Rock Run, Octararo Creek, Basin Run, Stone Run, and Principio Creek)
Sentinel watersheds	Maryland Biological Stream Survey (MBSS)	2004	Unknown	Sentinel sites represent the best remaining streams in the state.
Land cover	US Geological Survey (USGS) National Land Cover Dataset (NLCD)	1999-2001	30 m	
Impervious surface	US Geological Survey (USGS) National Land Cover Dataset (NLCD)	1999-2001	30 m	
2002 land use	Maryland Dept. of Planning	2002	106 ft	10 acre minimum mapping unit
Soils	Natural Soil Groups (Maryland Office of Planning)	Unknown	106 ft	Not accurate at site scale
Elevation and slope	U.S. Geological Survey (National Elevation Dataset)	N/A	30 m	
Wetlands	Maryland Dept. of Natural Resources (DNR)	1988-1995	20 ft	0.5 acre minimum mapping unit
Roads	Maryland State Highway Administration	2000	167 ft	
Physiographic regions	Maryland Geological Survey	N/A	~400 ft	
Cecil County updated Green Infrastructure network	Developed by The Conservation Fund for this project	2005	<10 m	See *An Assessment of Cecil County's Green Infrastructure.*