

Agricultural BMPs, Nutrient Load Reductions, and Watershed Restoration – the Octoraro Creek Watershed and the Chesapeake Bay

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Abstract

The Octoraro Creek drains 208 square miles in Lancaster and Chester counties in Pennsylvania and Cecil County in Maryland, and enters the Susquehanna River at the head of the Chesapeake Bay. Land use is 75 percent agricultural, largely with Old Order Amish and English dairy farming and swine farming. Streamflow data over the last 9 years shows no change in nitrate concentrations in either branch of Octoraro Creek, with median nitrate concentrations in the 7.4 to 8.4 mg/L range. About 95 percent of the nitrates in Octoraro Creek are estimated to originate from nonpoint sources. Streamflow nitrates are highest during baseflow periods in winter, when biological uptake and denitrification rates are reduced. Nitrate concentrations in groundwater are also elevated, with the watershed being the epicenter in Pennsylvania for high groundwater nitrates. These high nitrate concentrations pose public health, herd health, and economic issues in the watershed.

The absence of any change in nitrate concentrations in the Octoraro over the last 9 years has occurred despite the aggressive implementation of agricultural Best Management Practices (BMPs) in the watershed. Nutrient and sediment load reductions predicted when BMPs are implemented are theoretical reductions that, in some cases, may take years to be realized in a watershed. This is germane to the Chesapeake Bay watershed model, which assumes no time lag for full BMP effectiveness. The current use of Bay model predictions as data that document progress in reducing nutrient loads to the Bay is not an appropriate measure of restoration success. The definition and measures of success in restoration have direct implications for how we proceed with restoration science, policy, politics, and the reality of TMDL attainment.

Introduction

The Octoraro Creek drains 208 square miles in Lancaster and Chester counties in southeastern Pennsylvania and Cecil County in northeastern Maryland, and enters the Susquehanna River at the head of the Chesapeake Bay. The watershed includes portions of 22 municipalities and 25 major tributaries. Thirty-six miles of stream have been designated as scenic and pastoral river segments under Pennsylvania's Scenic River Program. The stream is comprised of two major drainages, the East Branch and the West Branch of the Octoraro. Mean stream discharge measured periodically over the last 9 years has been 75 cfs and 47 cfs respectively.

Land use in the watershed is 75% agricultural, with both Old Order Amish and English production farming. The pastoral landscape is vital to the economy, making both a desirable living area and tourist attraction. With its rural character, the watershed is host to very little major industry, with farming being the primary source of revenue for the area. Consequently, the population centers are clustered around the areas zoned for industry and commercial development. The watershed's population has grown approximately 18.5% since 1990. A

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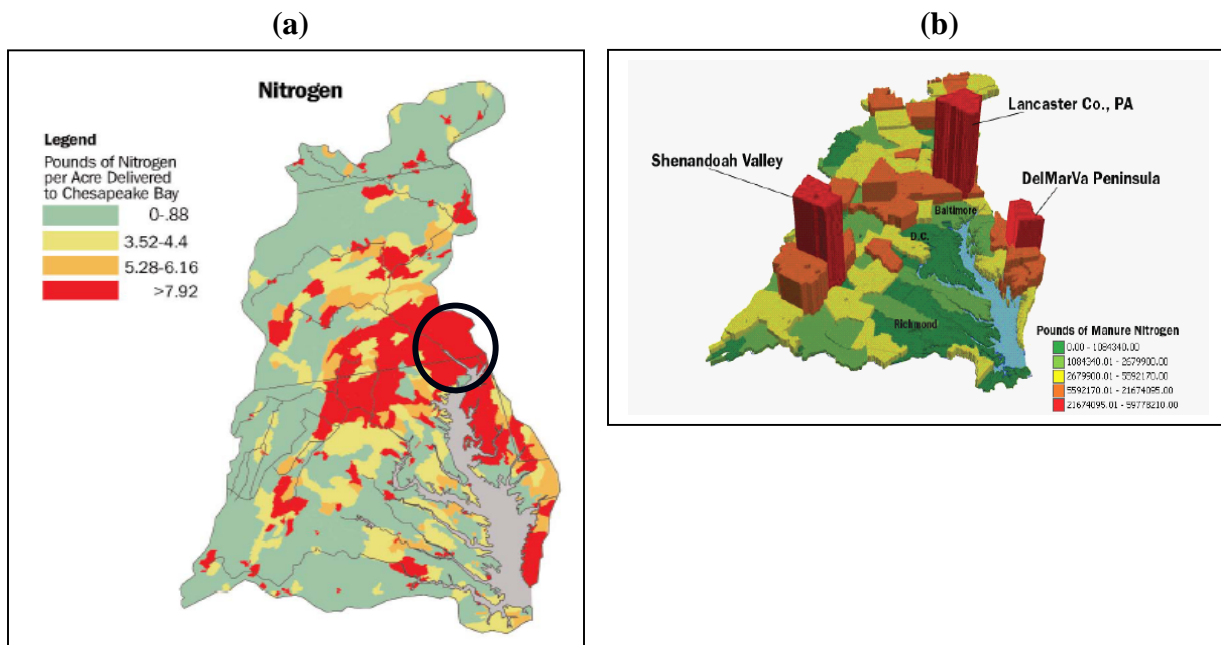
variety of flora and fauna that exist in the watershed have been designated by the Pennsylvania Department of Conservation and Natural Resources as rare, endangered and threatened.

The Octoraro Creek has very high nitrate concentrations that contribute significant nutrient loading to the Chesapeake Bay, and cause potable water quality problems for both public drinking-water systems and for residential wells in the watershed. An interagency and stakeholder nitrate task force was formed in 2002, and has been meeting monthly to secure funding for nitrate remediation projects and to educate the Octoraro watershed stakeholders on environmental and public health concerns with nitrates. Recent local and regional newspaper articles reflect the growing concern for nitrate loading to streams and estuaries. Nitrate loading to the Chesapeake Bay continues, with growing concern for the resulting dead zone (hypoxia) in the Bay.

A Prototype Watershed for Chesapeake Bay Restoration

A USGS study (USGS, 2002) of the upper East Branch of Octoraro Creek showed a near doubling of nitrate concentrations (5.1 mg/L to 9.0 mg/L) from 1981 to 1997. A study by the Chester County Water Resources Authority showed that total suspended solids concentrations are higher in Octoraro Creek than in any other creek in their county-wide assessment. Nitrogen and sediment loading to the Chesapeake Bay is a serious problem in the Lower Susquehanna River Basin, and has received substantial popular press and political attention over the last year. The Octoraro Watershed is in the epicenter for nitrogen loading to the Chesapeake Bay (Figure 1a).

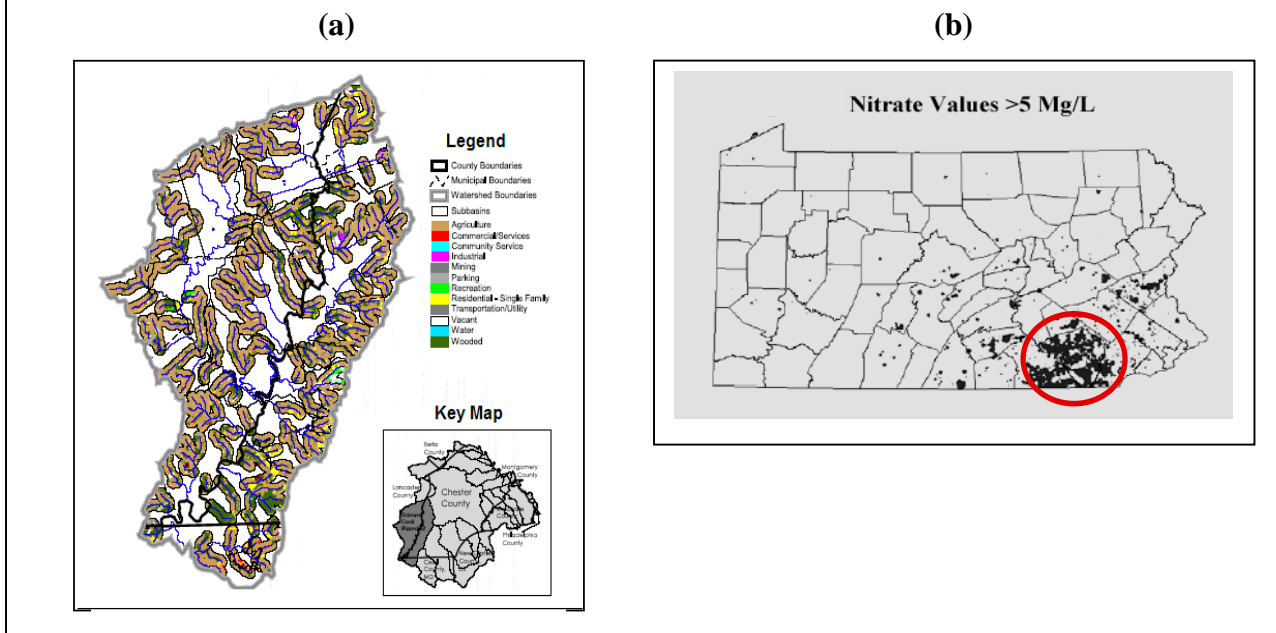
Figure 1. (a) Nitrogen loading (lbs/acre) to the Chesapeake Bay. The Octoraro Creek Watershed is located within the circle. Source: USGS, cited in Chesapeake Bay Foundation (2004). (b) Primary sources of manure nitrogen in the Chesapeake Bay. The Octoraro Creek Watershed in Lancaster and Chester counties, Pennsylvania. Source: EPA Chesapeake Bay Program, cited in Chesapeake Bay Foundation (2004).



It is clear that reaching nutrient reductions for the Chesapeake Bay will depend on substantial reductions in nitrate loading from the Lower Susquehanna River Basin. Agriculture accounts for about 41 percent of the total nitrogen load to the Chesapeake Bay from all source types and tributaries. Lancaster County, in which the Octoraro Watershed is partially located, has the second-highest agricultural production of any county east of the Mississippi River and ranks fifth in livestock production nationally. The county, which represents only 1.5 percent of the area in the watershed, produces more nitrogen from manure than any other county in the Bay's drainage area (Figure 1b; Chesapeake Bay Foundation, 2004).

Agriculture, which is by far the dominant land use (75 %) in the Octoraro Watershed, is the primary source of nutrients to both the Octoraro Creek and to the Chesapeake Bay. First order streams and their drainage areas comprise about 57 percent of the total watershed area of the Octoraro. Agriculture constitutes about 68 percent of the land use in first order stream drainage areas, and dominates the land use within one-quarter mile of first order streams (Figure 2a).

Figure 2. (a) Land use, dominated by agriculture, within 0.25 miles of first order streams in the Octoraro Creek Watershed. Source: Chester County Water Resources Authority (2002). (b) Ground water nitrate concentrations in Pennsylvania. Lancaster County, including the Octoraro Watershed, is the epicenter of ground water nitrate in the state. Source: Pennsylvania Department of Environmental Protection (2002).



An average of 48 % of the nitrogen load in streams in the Chesapeake Bay watershed, primarily in the form of nitrate, is transported through ground water (Phillips and Lindsey, 2003), with a range of 17 to 80 percent in different streams. The median nitrate concentration in ground water, in the crystalline agricultural subunit in the Piedmont Physiographic Province (encompassing the Octoraro Watershed), was 8.2 mg/L (Lindsey et. al., 1997). A state-wide synopsis of ground water nitrate concentrations in Pennsylvania shows Lancaster County as the epicenter of ground water nitrate (Figure 2b).

High nitrate levels in surface and ground water have led to economic, human health, and herd health concerns in the Octoraro Watershed. Drinking water nitrate levels above 10 mg/L are a concern for infant health and the potential for blue baby syndrome (methemoglobinemia). Public water suppliers in the watershed utilize Octoraro Creek water to supply over 200,000 homes. Many residents in the watershed utilize well water and are also potentially at risk. The economic impacts for home owners to treat for nitrate removal, and the costs for the public water companies to either treat or dilute surface water for nitrate reduction, is significant. One of the public water suppliers has been shut down for over a year because of high surface water nitrate concentrations. Herd health for the many dairy farmers in the watershed is also a concern, often requiring nitrate removal systems for farm animal health to mitigate reproductive impacts from nitrates in drinking water.

Numerous agencies, organizations and private commerce are committed to reducing nitrate concentrations in surface and ground water in the Octoraro Watershed. The Octoraro Nitrate Task Force, formed in 2002, is dedicated to promoting education and remediation projects for nitrate reduction. The Octoraro Watershed Association has a 37-year history of successful restoration projects in the basin, and has received national recognition from the EPA for its groundbreaking Amish Outreach Program to foster agricultural BMP implementation on Old Order Amish farmsteads. This outstanding organizational infrastructure and commitment further solidify the role of the Octoraro as a prototype watershed in which to focus restoration efforts that are critical for the Chesapeake Bay watershed.

Octoraro Creek Nitrate Dynamics

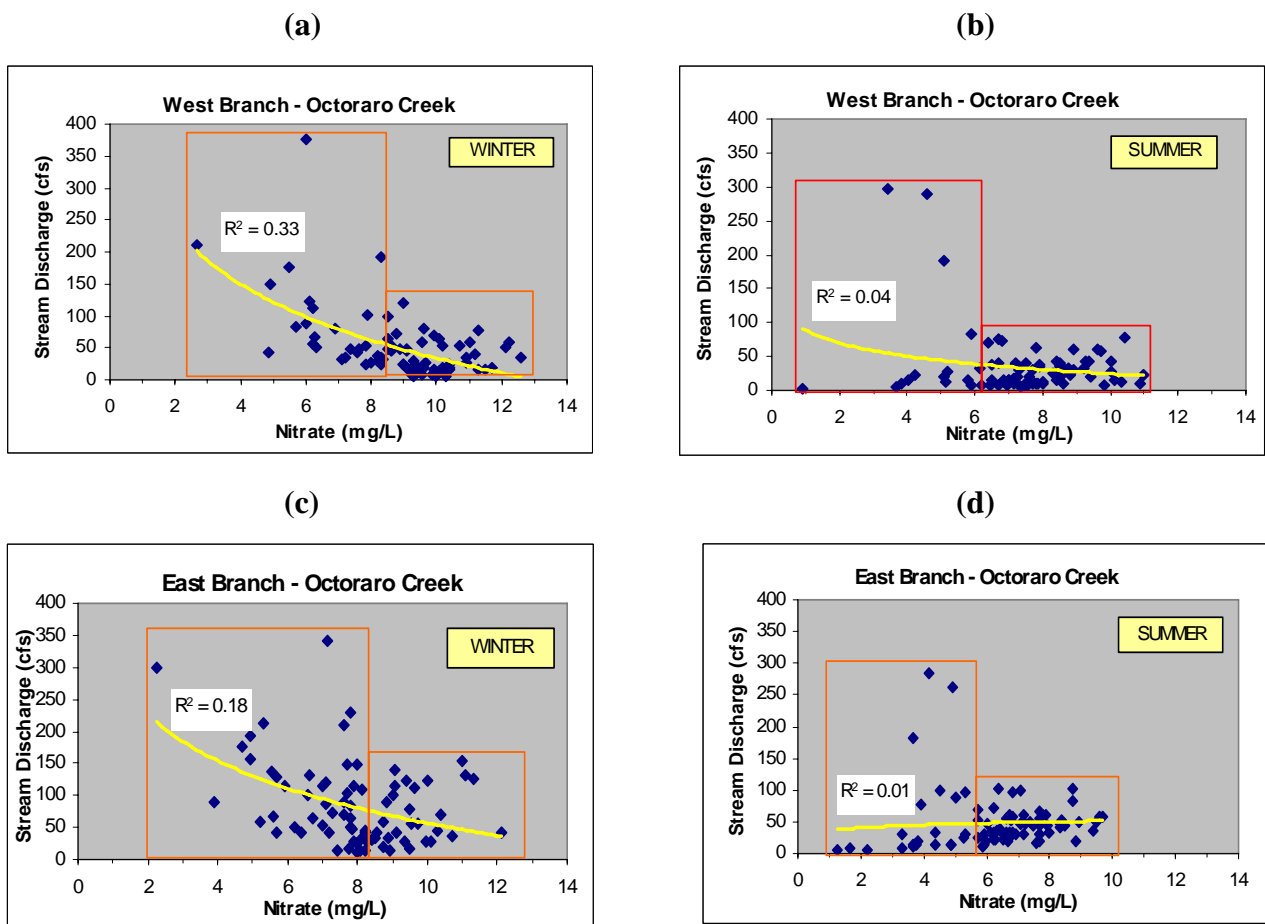
The median nitrate concentration in surface water in the West Branch and East Branch of the Octoraro Creek, from 1995 to 2004, was 8.4 and 7.4 mg/L respectively. On a seasonal basis, the highest nitrate concentrations are typically observed in winter, with median winter nitrate concentrations of 9.1 mg/L in the West Branch and 8.0 mg/L in the East Branch.

Observations made by the public water supply companies have indicated that nitrate concentrations seem to be highest during baseflow periods in winter. The relationships of stream discharge and nitrate concentration for the two stream branches are shown in Figures 3a to 3d for winter and summer periods. There are significant negative relationships of nitrate with stream discharge for the winter season for both Octoraro branches (Figures 3a and 3c), while there is no significant relationship with discharge during summer for either branch (Figures 3b and 3d). The absence of this relationship during summer is likely related to high rates of biological uptake and denitrification at higher water temperatures during baseflow periods, which reduce nitrate concentrations. During either season, the highest nitrate concentrations occur during baseflow and lower discharge flows, as denoted by the boxes in Figure 3. Lower nitrate concentrations are highly variable with discharge.

The negative relationships of nitrate concentrations with stream discharge in winter, while significant, explain a relatively small amount of the variability in nitrate concentrations as noted by the R^2 values in Figure 3. There are many factors affecting nitrate concentrations in streams in agricultural watersheds, and relationships are multivariate and complex. Nevertheless, the results shown here for winter seasons, with the highest nitrate concentrations during baseflow conditions, indicate that ground water is a significant source of high nitrates to streams. A

similar negative relationship of stream discharge with nitrate concentrations was found for the adjacent Conestoga River watershed in Lancaster County. Based on these results, remediation of high ground water nitrate concentrations is a critical component for restoration of this watershed and for the Chesapeake Bay.

Figure 3. Logarithmic relationships between stream discharge and surface water nitrate concentrations in the West Branch of Octoraro Creek during winter (a) and summer (b), and in the East Branch of Octoraro Creek during winter (c) and summer (d). Logarithmic regressions were significant in winter for both branches ($P < 0.001$), while they were not significant in summer for either the West Branch ($P = 0.07$) or the East Branch ($P = 0.62$). Boxes denote qualitative clusters of variability between low and high nitrate data points.



Agricultural BMP Implementations and Effectiveness

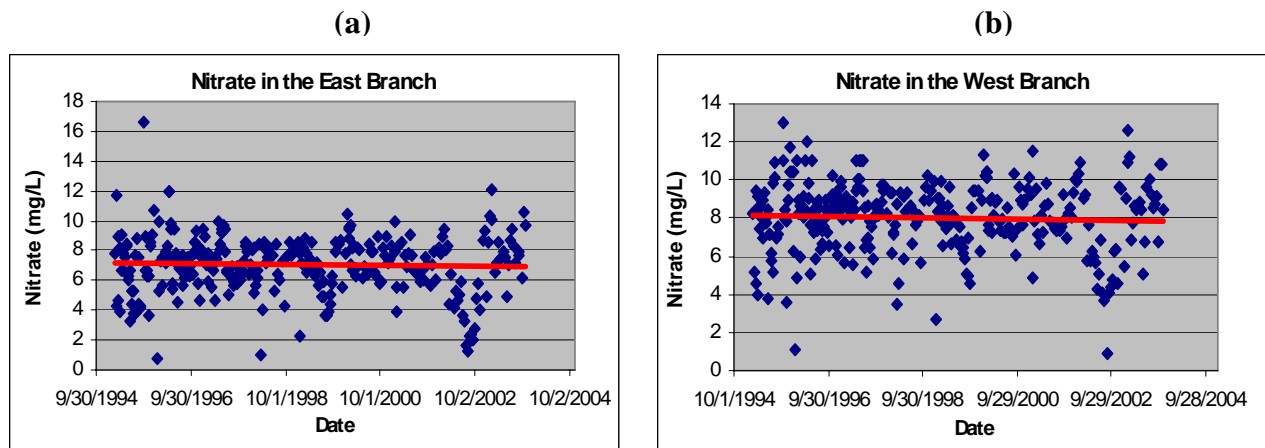
Significant watershed restoration efforts have been undertaken in the Octoraro Watershed by the Octoraro Watershed Association (OWA), the Lancaster County Conservation District, the Chester County Conservation District, and the Cecil County Conservation District. The OWA has received national recognition from the EPA for its groundbreaking Amish Outreach Program to foster agricultural BMP implementation on Old Order Amish farmsteads. Agricultural BMPs

have been implemented on numerous Amish and English farms in the Octoraro Watershed. These BMPs include forest buffers, cattle crossings, streambank stabilization, cropland practices (terraces, waterways, diversions, contour farming), waste management systems, and barnyard improvements. Over 20 stream miles of streambank fencing has been installed. These groups, as well as Ducks Unlimited and the Chesapeake Bay Foundation, have been actively implementing BMPs in the Octoraro Watershed.

The expected reduction in nitrogen by implementation of BMPs such as forest buffers, for example, is assumed to be 45 percent for the crystalline agricultural subunit in the Piedmont Physiographic Province in which the Octoraro Watershed is located. Riparian grass buffers are assumed to provide a 31 percent nitrogen reduction efficiency. Streambank fencing, used to exclude livestock from along streams, assumes a 60 percent nitrogen reduction efficiency (Chesapeake Bay Program, 2004). These reduction efficiencies are applied to pre-implementation loading rates for a given area of land that is affected by the particular BMP being implemented.

While agricultural BMPs have been actively implemented in the watershed, surface water nitrates in Octoraro Creek continue to be high. There is no significant trend in nitrate concentrations in either the East ($P = 0.57$) or West ($P = 0.93$) Branch of Octoraro Creek over the last 9 years (Figure 4). The benefits in nitrate reduction from implementation of these agricultural BMPs over this period have not been realized in the surface waters of Octoraro Creek. Similar results were found for the adjacent Conestoga River watershed, where no trends were found for either flow adjusted or flow weighted nitrate concentrations over the 1985 to 2002 time period (SRBC, 2003).

Figure 4. (a) Nitrate concentrations in the East Branch of Octoraro Creek from 1995 to 2004. There is no significant trend over this time period ($P = 0.57$). (b) Nitrate concentrations in the West Branch Octoraro Creek over the same time period, with no significant trend ($P = 0.93$).



A study on a nearby watershed suggests mixed results for surface water nitrate reductions, with one agricultural sub-basin showing reduced nitrates in streamflow, with the other agricultural watershed showing no change. The reductions for nitrates, however, could not be directly related to BMP implementation (USGS, 2000).

These results indicate that a more concentrated spatial sampling scale, on the farm level, may be necessary to capture the short-term BMP benefits for nitrate concentrations in surface water. Focused sampling of ground water, surface runoff, and in streams on or adjacent to farms where BMPs are implemented may be necessary to observe the nitrate reduction efficiencies of these BMPs. Alternatively, a longer temporal scale may be necessary to translate farm scale benefits of BMP implementation to surface waters in streams, as ground water plays a critical role in nitrate transport to the baseflow of streams. While BMPs are being implemented in the Octoraro Watershed, a greater level of implementation may need to be made, on the highest priority farms and with the best BMPs, in order to observe water quality improvements in the stream.

Chesapeake Bay Watershed Load Reduction Modeling

The Chesapeake Bay Watershed Model is designed to provide a tool to assess, among several things, how nutrient and sediment loads to the Bay are reduced through implementation of BMPs in the watershed. The model is also used by the Chesapeake Bay Program to document to the public the progress being made in reducing nutrient loads delivered to the Bay (CBWBRFP, 2004).

With respect to BMP nutrient and sediment load reductions, however, several model assumptions should be noted. The effectiveness of BMPs is assumed not to deteriorate over time, so that the BMP efficiency is assumed to remain constant. Adequate maintenance of BMPs is assumed to occur. For many BMPs, the same nutrient reduction efficiencies apply to broad regions of the Bay watershed. Subwatershed specific conditions that affect these efficiencies are not accounted for, as this information is largely unavailable.

The Bay model also assumes that the nutrient and sediment reduction efficiency is fully operational with the implementation of the BMP. There is no lag time incorporated in the model for a BMP to mature or become fully efficient. This is a critical assumption, particularly for BMPs that reduce sediments or nitrates. Realized sediment transport reductions are dependent on hydrologic conditions that influence sediment scour, and those may only occur on a periodic time frame or recurrence interval. There are seldom immediate reductions that occur in full when a BMP is implemented.

BMPs that reduce nitrate loading are similarly dependent on a time lag. Ground water with high nitrate concentrations may take months or years to travel to streams and enter as baseflow. BMPs that reduce ground water nitrate concentrations may similarly take years for the remediated ground water to travel to the stream (Lindsey et. al., 2003). This may be the process explanation for the lack of any trend in reduced streamflow nitrate concentrations in Octoraro Creek.

Forest buffers that are planted have another type of BMP time lag. It may take years for stem plantings to mature to the physiological state where nitrates are removed at the assumed efficiencies. Nevertheless, the Bay model assumes that these reduction efficiencies are achieved upon BMP implementation.

These time lags create two significant issues that must be recognized when utilizing the Chesapeake Bay Watershed Model, particularly with respect to nitrates and sediments: (1) the

nutrient and sediment load reductions predicted when BMPs are implemented are theoretical reductions that, in some cases, may take years to occur (time lag issue), and (2) it is inappropriate to utilize Bay model predictions as data that document reductions in nutrient loads to the Bay (predictions versus monitoring data issue).

Politics and Restoration - What is Success?

From the standpoint of public health, private homeowner wells, and public water suppliers, restoration success is found in reductions in nitrate concentrations in the water they utilize. For the Octoraro Watershed, nitrate concentrations are still high, not lowering, and unacceptable. While the implementation of BMPs in the watershed is a success from the standpoint of positive action taken, it is not restoration success. It is clear that lower nitrate concentrations are the measure of success for Octoraro Watershed stakeholders that depend on reasonable surface and ground water quality. The BMPs are the tools that, they hope, will eventually achieve success. It is inappropriate to conclude that a watershed is restored once BMPs are implemented. A watershed is restored when the field monitoring data documents that the metric-based goals have been achieved.

For the Chesapeake Bay, the public sees restoration success in this same way. Once water clarity goals are achieved, submerged aquatic vegetation reaches target coverage, and crab and oyster populations are restored, then success for the Bay has been attained. The Chesapeake Bay model is an outstanding restoration planning tool that allows us to develop restoration strategies that we think will achieve our goals. But restoration success for the Bay, and for the Octoraro Creek, lies in field-monitored performance metrics. For nitrates and sediment load reductions, these metrics may lag model predictions and BMP efficiency expectations.

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