National Nonpoint Source Monitoring Program

TechNOTES 4

Through the National Nonpoint Source Monitoring Program **(NNPSMP)**, states monitor and evaluate a subset of watershed projects funded by the Clean Water Act Section 319 Nonpoint Source Control Program.

The program has two major objectives:

1. To scientifically evaluate the effectiveness of watershed technologies designed to control nonpoint source pollution
2. To improve our understanding of nonpoint source pollution

NNPSMP Tech Notes is a series of publications that shares this unique research and monitoring effort. It offers guidance on data collection, implementation of pollution control technologies, and monitoring design, as well as case studies that illustrate principles in action.

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# Lag Time in Water Quality Response to Land Treatment

## Introduction

Over the past three decades, some watershed land treatment projects have reported little or no improvement in water quality after extensive implementation of best management practices (BMPs) in the watershed. Factors contributing to such failure to achieve water quality objectives are nearly as numerous as the projects themselves—insufficient landowner participation, uncooperative weather, improper selection of BMPs, mistakes in understanding of pollution sources, poor experimental design, inadequate level of treatment, etc.

***Lag time is the time elapsed between installation or adoption of land treatment and improvement of water quality.***

Another important reason watershed projects may fail to meet our water quality expectations is ***lag time***. Lag time is an inherent characteristic of the natural systems under study that may be generally defined as the amount of time between an action and the response to that action. In this case, we define lag time as the time elapsed between installation or adoption of land treatment at a level projected to reduce nonpoint source pollution and the first measurable improvement in water quality in the target water body. Installation refers to the completion of the construction phase for structural practices; some vegetative practices will still need to mature over time. Adoption refers to the full use of an installed physical practice or management practice such as nutrient management. Land treatment-water quality monitoring projects—even those designed to be "long-term"—may not show definitive results if the lag time exceeds the monitoring period.

## Why Does Lag Time Occur?

There are both time and measurement components of lag time (Figure 1), and any or all of them may come into play in a watershed project.

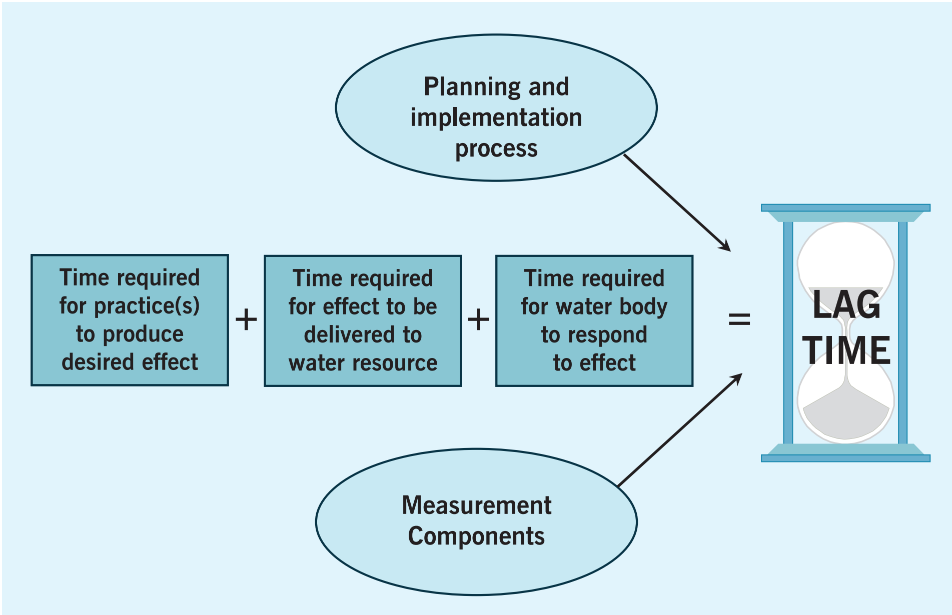


**Figure 1. Components of lag time experienced in land treatment—water quality projects.**

One factor that affects the perceived delay between the decision to act and the result is the time needed for planning and implementation. Although a project may be funded today, it will be some time—perhaps years—before that project will be planned and implementation begins. Even for point source control, it takes several years from the time a wastewater treatment plant upgrade is approved to when it is designed, constructed, and functioning. The lag time from planning to implementation of nonpoint source control practices can be even greater, considering the time required to identify pollution sources and critical areas, design management measures, engage landowner participation, and integrate new practices into cropping and land management cycles. While not a true time component of lag time as defined here, stakeholders—especially the general public –will experience the planning and implementation process as part of the wait for results. The planning and implementation process is, however, extremely critical for success in water quality restoration; following a logical and comprehensive watershed planning process (e.g., USEPA 2005) will help make the wait worthwhile.

# Time Components

## Time Required for Installed or Adopted Practice to Produce Effect

Practices are installed in watersheds to provide a wide range of effects, including:

- Reduce dissolved pollutant concentration or load
- Reduce particulate/adsorbed pollutant concentration or load

- Improve vegetative habitat
- Improve physical habitat
- Restock desirable species

The time required to produce these effects will vary depending upon the degree of impairment and the practices selected, as well as the nature of the effects themselves.

**BMP Development.** Once built, concrete and steel treatment works may begin to function almost at the flip of a switch, with little time lag before pollutant load is reduced. Some nonpoint source control measures may also take effect quickly (Figure 2). For example, in the **Lake Champlain Basin Watersheds** (VT) NNPSMP Project (1993–2000), implementation of livestock exclusion fencing over a three month period in the summer of 1997 resulted in significant nutrient concentration and load reductions and reductions of fecal bacteria counts in two study streams in the first post-treatment year (Meals 2001). This response probably resulted from the immediate prevention of new manure deposition in the stream and riparian zone and the availability of sufficient streamflow to flush residual manure through the system.

**Figure 2. Fencing immediately excludes livestock from a stream (left, VT NNPSMP project), while a forested riparian buffer may take years to develop (right, PA NNPSMP project)**

However, other nonpoint source management measures may take years to become fully effective. This is especially true of vegetative practices where plant communities need time to become established. For example, in the **Stroud Preserve (PA)** NNPSMP Project (1992–2007), it took nearly ten years to achieve reforestation of a riparian forest buffer and significant reductions in ground water nitrate through the buffer did not occur until forest growth had achieved a certain level (Szpir et al. 2005).

**Source Behavior.** Lag time between BMP implementation and reduction of pollutant losses at the edge-of-field scale varies by the pollutant type and source. Erosion controls such as cover crops, contour farming, and water/sediment control basins tend to have a fairly rapid effect on soil loss from a crop field as the forces contributing to detachment and movement of soil particles are quickly and drastically reduced.

However, the response time of runoff phosphorus (P) to nutrient management is likely to be very different. Runoff losses of dissolved P are strongly controlled by soil P levels; very high soil P levels promote high levels of dissolved P in surface runoff (Pote et al. 1996, Sims et al. 2000). Where soil P levels are excessive, even if nutrient management reduces P inputs to levels below crop removal rates, it may take years or decades to "mine" the P out of the soil to the point where dissolved P in runoff is effectively reduced.

## Time Required for Effect to Be Delivered to Water Resource

Practice effects initially occur at or near the practice location, yet usually watershed managers and stakeholders want and expect these effects to appear promptly in the water resource of interest in the watershed. The time required to deliver an effect to a water resource depends on a number of factors, including:

- The route for delivering the effect
    a. Directly in (e.g., streambed restoration) or adjacent to (e.g., shade) the water resource
    b. Overland flow (e.g., particulate pollutants)
    c. Overland and subsurface flow (e.g., dissolved pollutants)
    d. Infiltration to ground water (e.g., nitrate)
- The path distance
- The path travel rate
    a. Fast (e.g., ditches and artificial drainage outlets to surface waters)
    b. Moderate (e.g., overland and subsurface flow in porous soils)
    c. Slow (e.g., groundwater infiltration in absence of macropores)
    d. Very slow (e.g., transport in a regional aquifer)
- Precipitation patterns during the study period
    a. Wet periods generally increase volume and rate of transport
    b. Dry periods generally decrease volume and rate of transport

Once in a stream, dissolved pollutants like nitrogen and phosphorus can move rapidly downstream with flowing water to reach a receiving body relatively quickly. Even accounting for repeated uptake and release of nutrients by sediments, plants, or animals during downstream transport (i.e., nutrient spiraling, Newbold et al. 1981), dissolved nutrients are unlikely to be retained in a river or stream system for an extended period of time. Research in Vermont observed, for example, that despite active cycling of dissolved P between water, sediment, and plants in a river system, P inputs to the river were unlikely to be held back from Lake Champlain by internal cycling for much more than a year (Wang et al. 1999).

**Figure 3. Dissolved pollutants usually move downstream rapidly, while sediment and attached pollutants can take years to be transported as particles are deposited, resuspended, and redeposited.**

However, sediment and attached pollutants (e.g., P and some synthetic chemicals) can take years to move downstream as particles are repeatedly deposited, resuspended, and redeposited within the drainage network by episodic high flow events (Figure 3). This process can delay sediment and P transport (when P adsorbed to sediment particles constitutes a large fraction of the P load) from headwaters to outlet by years or even decades. This means that substantial lag time could occur between reductions of sediment and P delivery into the headwaters and those reductions being measured at the watershed outlet.

Pollutants delivered predominantly in ground water such as nitrate N or some synthetic chemicals move at the rate of ground water flow, typically much more slowly than the rate of surface water flow. About 40 percent of all N reaching the Chesapeake Bay travels through ground water before reaching the Bay. Relatively slow ground water transport introduces substantial lag time between reductions of N loading to groundwater and reductions in N loads to the Bay (STAC 2005).

## Time Required for Water Body to Respond to Effect

Another key factor is the speed with which the water resource responds to the effect produced by and delivered from the practice. For example, it may take a few years for algae production in a lake to decrease in response to reduced nutrient loading because of a lengthy flushing rate. If the response to be measured is fish populations rather than algae production, then even more time will be needed because fish need time to fill the newly improved habitat.

**Nature of the Indicator/Impairment.** Lag time in water quality response may depend on the indicator used or the impairment involved, especially if the focus is on biological water quality. If *E. coli* is the pollutant of concern, a relatively short lag time would often be expected between reductions of bacteria inputs and reduction in bacteria levels in the receiving waters because the bacteria generally do not tend to persist long in the environment compared to heavy metals or synthetic organic chemicals. Even where indicator bacteria may survive in aquatic sediments, without continual replenishment this stock would tend to be exhausted in a matter of months. The quantity in the receiving water could therefore reflect the incoming supply fairly quickly. Such response has been demonstrated in estuarine systems where bacterial contamination of shellfish beds has been reduced or eliminated through improved waste management on the land over a short period of time.

However, significant lag times have been observed in the response of benthic invertebrates and fish to land treatment. In the Middle Fork Holston River project (VA), Index of Biotic Integrity (IBI, a measure of the stream fish community) scores and *Ephemeroptera-Plecoptera-Trichoptera* (EPT, a measure of the benthic macroinvertebrate community) scores did not improve, even though the project resulted in a substantial reduction in the sediment, nitrogen, and phosphorus loadings there (Virginia Dept. Cons. and Rec. 1996). Altough undetected stressors could play a role, the lack of increase in the biological indicator scores indicates a system lag time between the actual BMP implementation and positive changes in the biological community structure (Figure 4).

**Figure 4. Significant lag time may occur between improvements in physical habitat and changes in the biological community.**

Exceptions to such lag in response of stream biota can occur where in-stream restoration is the BMP applied. The **Waukegan River** (IL) NNPSMP project installed vegetative and structural stabilization and habitat structures including a series of pool-and-riffle complexes using stone weirs to help restore the habitat functions within a channelized stream reach. Significant improvement in habitat, macroinvertebrate communities, and in the number and abundance of fish species were documented in the study reach.

In the **Lake Champlain Basin Watersheds** (VT) NNPSMP Project (1993–2000), the benthic invertebrate community did improve in response to reductions of sediment, nutrient, and organic matter inputs from the land within three years of treatment (Meals 2001). However, despite observed improvement in stream habitat and water temperature, no improvements in the fish community were documented. The project attributed this at least partially to a lag time in community response exceeding the monitoring period.

**Receiving Water Response.** Even when reductions of tributary pollutant loads are observed in a short time, the variable response times of receiving water bodies may introduce a significant lag time between treatment and restoration of impaired uses. In some cases, this lag time may be relatively short. For example, researchers anticipate that the Chesapeake Bay will respond fairly rapidly to reductions in nutrient loading, as incoming nutrients are quickly buried by sediment or exported to the atmosphere or the ocean. Even beds of submerged aquatic vegetation (SAV), critical to the Bay's aquatic ecosystem, can return within a few years after improvements in water clarity (STAC 2005). In the **Totten and Eld Inlets** (WA) NNPSMP Project (1993–2002), bacteriological water quality in shellfish beds in the estuaries improved rapidly in response to improved animal waste management in the drainage area, but unfortunately also deteriorated equally rapidly when animal waste management on the land deteriorated (Szpir et al. 2005).

However, St. Albans Bay (VT) in Lake Champlain tells a different story (Figure 5). From 1980 through 1991, a combination of wastewater treatment upgrades and intensive implementation of dairy waste management BMPs through the Rural Clean Water Program (RCWP) brought about a reduction of phosphorus loads to this eutrophic bay. Nonetheless, water quality in the bay did not improve significantly; this pattern was attributed to internal loading from sediments highly enriched in phosphorus from decades of point and nonpoint source inputs (Meals 1992). Although researchers at that time believed that the sediment P would begin to decline over time as the internal supply was depleted, subsequent monitoring has shown that phosphorus levels have not declined over the years as expected. Recent research has confirmed that a substantial reservoir of phosphorus continues to exist in the sediments that can be transferred into the water under certain chemical conditions and nourish algae blooms for many years to come (Druschel et al. 2005). In effect, this internal loading has become another source of P, one that cannot be addressed by treatment on the land.

**Figure 5. Aerial view of St. Albans Bay, Lake Champlain.**

# Measurement Components

Watershed project managers are routinely pressed for results by a wide range of stakeholders. The fundamental time components of lag time control how long it will take for a response to occur, but they do not address the effectiveness of measuring the response. In other words, it is possible for a response to occur without anybody noticing, unless the response is measurable and a suitable monitoring program is in place.

The magnitude of the potential effects produced by a watershed land treatment program depends on the effectiveness of each unit of installed or adopted practices, the number of practice units installed or adopted, the effectiveness with which the practices are targeted to the correct pollutants and sources, and numerous other factors. While not all responses can be measured, the design of the monitoring program is a major determinant of our ability to discern a response against the background of the variability of natural systems.

In the context of lag time, sampling frequency with respect to background variability is a key determinant of how long it will take to document change. In a given system taking n samples per year, a certain statistical power exists to detect a trend. If the number of samples per year is reduced, statistical power is reduced, and it may take longer to document a significant trend or to state with confidence that a concentration has dropped below a water quality standard. Simply stated, taking fewer samples a year introduces an additional "statistical" lag time before a change can be effectively documented.

## Magnitude of Lag Time

The magnitude of lag time is difficult to predict in specific cases and few generalizations are possible. A few examples can, however, illustrate some possible time frames for several categories of lag times.

The **Stroud Preserve (PA) NNPSMP Project** (1992–2007) is currently evaluating the development and performance of a newly established riparian forest buffer (Szpir et al. 2005). Reforestation of the riparian area took about eight to twelve years (Figure 6), considerably longer than anticipated due to drought and deer damage. Preliminary analysis of groundwater nitrate data indicate that, except for initial reductions due to taking the buffer area out of agriculture, significant nitrate removal from groundwater flowing toward the stream did not occur until a major increase in tree growth began about ten years after tree planting. The results of

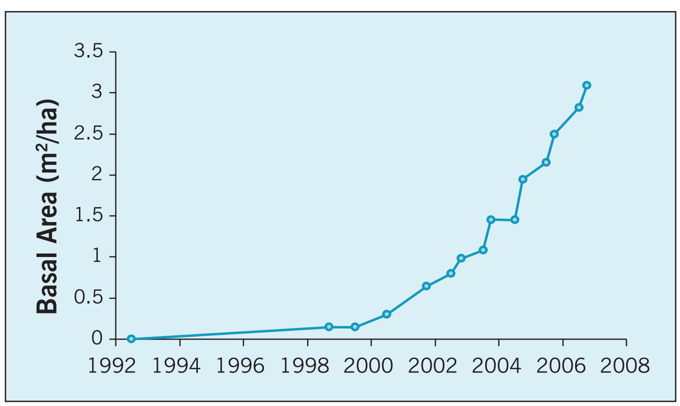


**Figure 6. Changes in basal area of trees in reforested riparian buffer, Stroud Preserve National Monitoring Program Project. (Newbold, 2005).**

the project so far suggest that water quality improvement from riparian reforestation may take on the order of a decade or more to be measurable.

The rate of ground water movement and pollutant transport can be a major contributor to lag time in water quality response to treatment. For example:

- **Delaware's Inland Bays**, thirty square miles of estuary on the state's southern Atlantic coast, suffer from excessive nutrient and sediment loading, resulting in degraded communities of benthic organisms, submerged vegetation, and fish. Nitrates delivered to the Bays in groundwater discharge from agricultural fields and poultry operations and from septic-system effluent in the watershed is one of the most severe stressors of the Inland Bays. Studies and efforts to reduce nitrate loading have been underway for two decades, from state, university, and USGS ground water studies in the 1970s to a USDA Hydrologic Unit Area (HUA) project in the 1990s to a TMDL in 2004. Unfortunately, restoration efforts are constrained by the 50 to 100 years required for ground water to travel from agricultural land in the watershed to the Bays.

- In the **Pequea and Mill Creek Watershed** (PA) NNPSMP Project (1994–2003), changes in fertilizer applications to cropland did not result in changes in nitrogen concentrations in streams due to lag time between applications and nutrients reaching the stream channel. Ground water age dating conducted during the study indicated that nitrogen applied to land reached springs in two to three years, but ground water flow to the stream channel took 15 to 39 years (Galeone 2005).

- **The Big Spring Basin (IA) Water Quality Monitoring Program** (1981–1998) was one of the longest-running ground water monitoring projects in the U.S. (Hallberg et al. 1989). The program was initiated in response to concerns about rising nitrate contamination of the Galena Aquifer, primarily from agricultural land use. In 1983, a national agricultural commodity program led to a 40 percent decline in fertilizer nitrogen applications in the basin for that year. A dramatic drop in groundwater nitrate was observed two years later, suggesting a two-year lag time in the response to decreased inputs. However, ground water nitrate concentrations did not respond to subsequent variations in nitrogen inputs (either increases following the end of the commodity program or decreases due to implementation of new BMPs) as much as they did to hydrologic variations including both drought and high-water years. Despite lower inputs of nitrogen to the agricultural system throughout the prior decade, the 1990s experienced consistently high levels of groundwater nitrate, illustrating the importance of climatic variation on lag time.

- Recent research in the **Chesapeake Bay Watershed** has confirmed that a substantial lag time between implementation of management practices and reductions in nitrogen loading to the Bay is very likely (Phillips and Lindsey 2003, STAC 2005). Ground water supplies a significant amount of water and nitrogen to streams in the watershed and about half of the nitrogen load in streams in the Bay watershed was transported through ground water. The age of ground water in shallow aquifers in the Chesapeake Bay watershed ranges from less than 1 year to more than 50 years. The median age of all samples was 10 years, with 25 percent of the samples having an age of 7 years or less and 75 percent of the samples having an age of up to 13 years. Based on this age as representative of time of travel, scientists estimated that in a scenario of complete elimination of nitrogen applications in the watershed, a 50 percent reduction in base flow nitrate concentrations would take about five years, with equilibrium reached in about 2040.

Finally, some insight into lag time may be gained from modeling. Drawing from the experience of the Rural Clean Water Program (RCWP), Clausen et al. (1992) used a simple dynamic mass-balance model to evaluate lag time in water quality response to nutrient management applied to agricultural land. The model predicted that even following complete elimination of fertilizer P inputs to a field starting at an excessive soil P level, 32 years would be required to reach 50 percent of the new equilibrium P concentration in runoff, and over 100 years needed to reach 90 percent of the new equilibrium. At a lower initial soil P level, the same reduction of P inputs would take 11 years to reach 50 percent of equilibrium, and 18 years to reach 90 percent of equilibrium.

A recent, more sophisticated P mass balance model of silage corn production in Vermont (Meals et al. 2008) shows a similar picture (Figure 7). The model accounts for all inputs and outputs of P, as well as the dynamics of soluble and particulate P runoff and leaching. As shown in Figure 7, restriction of P inputs in manure and fertilizer to below crop removal rate beginning in year 10 results in a downward trend in soil test P. However, 25 years elapse before soil test P declines below the “high” level (in year 35) and soil test P does not decline below “optimum” levels until 40 years have elapsed.

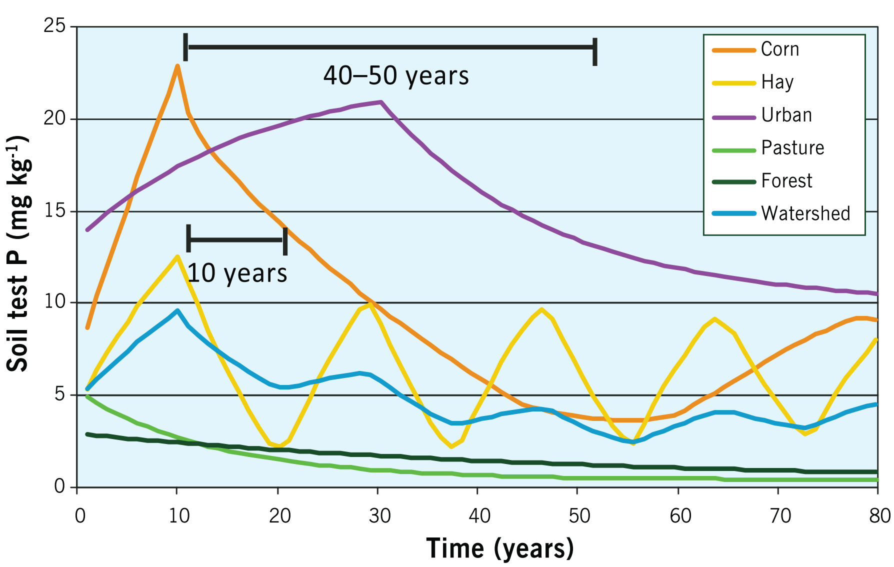


**Figure 7. Simulated changes in soil test P in response to nutrient management on silage corn and hay in a Vermont agricultural watershed (Meals et al. 2008).**

In sum, at best only broad ranges of lag times can be generalized. In the Chesapeake Bay watershed, where lag time issues have been examined closely, researchers have proposed some general guidelines for considering lag times in the Bay restoration program:

**Table 1.** Factors affecting lag times, and implications for improvement in water quality in the Chesapeake Bay

| Nutrient Source | Management Practice Implementation Time | Watershed Residence Time | Implications for Load Reductions in the Chesapeake Bay |
|---|---|---|---|
| **Point Sources** (About 20 percent of nutrient load delivered to the Bay) | Several years | Hours to weeks | Would provide the most rapid improvement of water quality due to immediate reduction of source. |
| **Nonpoint Sources** (About 80 percent of nutrient load delivered to the Bay) ***Dissolved nutrients*** | Several years | Hours to months if associated with runoff/soil water; years to decades if associated with ground water, with a median time of 10 years | Improvement in water quality would depend on the rate of implementation of nonpoint-source reduction and amount of nutrients still in soils. Once fully implemented, there would be a fairly rapid reduction of the load associated with runoff and soil water. Nitrogen load associated with ground water would have a median time of 10 years for water-quality improvements to be evident. |
| ***Nutrients associated with sediment*** | Several years | Decades or longer depending on location in watershed | Load reductions would be greatly influenced by streamflow variability. Storm events would deliver sediment and associated nutrients contained on land and in stream corridors. Loads to the Bay may not show reductions for decades due to long residence times. |

Source: Phillips and Lindsey 2005.

# Dealing with Lag Time

In most situations, some lag time between land treatment and water quality response is inevitable. Although it is nearly impossible to predict the exact duration of the lag, in many cases the lag time will probably exceed the length of the post-treatment monitoring period, making it problematic to document a water quality response to treatment. How can we deal with this unfortunate fact of life? Here are a few suggested approaches:

- **Recognize lag time and adjust expectations.** Once a water quality problem is recognized and action is taken, the public and political system usually want and expect quick results. Failure to meet such expectations may cause frustration, pessimism, and a reluctance to pursue further action. It is up to scientists, investigators, and project managers to recognize that some lag time between treatment and response is likely and to explain the issue to all stakeholders in realistic terms. It usually takes time for a water body to become impaired and it will take time to accomplish the clean-up.

**How to deal with lag time**

- Adjust expectations
- Characterize the watershed
- Select and site BMPs
- Monitor small watersheds
- Select indicators carefully
- Design effective monitoring programs

- **Characterize the watershed.** Before designing a land treatment program and an associated monitoring program, important watershed characteristics likely to influence lag time should be investigated. Determining the time of travel for ground water movement is an obvious example. Watershed characterization is an important step in the project planning process (USEPA 2005) and such characterization should especially address important aspects of the hydrologic and geologic setting, as well as documentation of nonpoint source pollution sources and the nature of the water quality impairment, all of which can influence observed lag time in system response.

- **Consider lag time in selection and siting of BMPs.** Recognition of lag time may require an adjustment of the approach to targeting land treatment. When designing a land treatment program, potential BMPs should be evaluated to determine which practices might provide the most rapid improvement in water quality, given watershed characteristics. For example, practices affecting direct delivery of nutrients into surface runoff and streamflow, such as barnyard runoff management, may yield more rapid reductions in nutrient loading to the receiving water than practices that reduce nutrient leaching to ground water, when ground water time of travel is measured in years. Fencing livestock out of streams may give immediate water quality improvement, compared to waiting for riparian forest buffers to grow in. Such considerations, combined with application of other criteria such as cost effectiveness, can help determine priorities for land treatment programs in a watershed project.

  Lag time should also be considered in locating treatment within a watershed. Where sediment and sediment-bound pollutants from cropland erosion are primary concerns, for example, implementing practices that target the largest sediment sources closest to the receiving water may provide a more rapid water quality benefit than erosion controls in the upper reaches of the watershed.

  It is important to point out that factoring lag time into BMP selection and targeting is not to say that long-term management improvements like riparian forest buffer restoration should be discarded or that upland sediment sources should be ignored. Rather, it is suggested that planners and managers may want to consider implementing BMPs and treating sources likely to exhibit short lag times first to increase the probability of demonstrating some water quality improvement as quickly as possible. "Quick-fix" practices with minimum lag time should not

> BAY JOURNAL
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> **Myriad reasons behind delays in cleanup results after actions are taken**
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> *By Karl Blankenship*
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> For anyone who expects a clean Chesapeake at the end of the decade, a new report from a team of scientists offers a word of advice: patience.
>
> The report says that even if billions of dollars become available to upgrade wastewater treatment plants, control farm runoff and undertake myriad other cleanup actions that have been proposed to meet cleanup goals, the Bay may not look significantly different in 2010.
>
> The reason is that most actions will take longer to show results, for a host of reasons, than most people realize. "We want instant gratification," said Kevin Sellner, of the Bay Program's Scientific and Technical Advisory Committee, which produced the report. "But we've taken 200 years to do what we've done. So if we put things in and it takes five years to show results, we should be willing to wait."
>
> ***http://www.bayjournal.com/article.cfm?article=2503***

automatically replace practices implemented in locations that can ultimately yield permanent reductions in soil loss.

- **Monitor small watersheds close to sources.** In cases where documentation of the effects of a treatment program on water quality is a critical goal, lag time can sometimes be minimized by focusing monitoring on small watersheds, close to pollution sources (Figure 8). Lag times introduced by transport phenomena (e.g., ground water travel, sediment flux through stream networks) will likely be shorter in small watersheds than in larger basins. In the extreme, this principle implies monitoring at the edge of field or above/below a limited treatment area, but small watersheds (e.g., less than 1500 ha) can also yield good results. In the NNPSMP, projects monitoring land treatment in small watersheds (e.g., the Morro Bay Watershed Project in California, the Jordan Cove Project in Connecticut, the Pequea/Mill Creek Watershed Project in Pennsylvania, and the Lake Champlain Basin Watersheds Project in Vermont) were more successful in documenting improvements in water quality in response to land treatment in the watershed than were projects that took place in large watersheds (e.g., the Lightwood Knot Creek Project in Alabama and the Sny Magill Watershed Project in Iowa) in the seven to ten year time frame of the NNPSMP (Szpir et al. 2005).

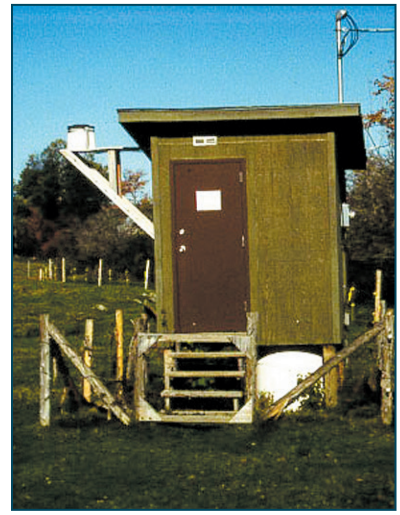

**Figure 8. Monitoring small watersheds, close to pollution sources can minimize lag time between land treatment and water quality response.**

The monitoring program itself can be designed to get a better handle on lag time issues. Monitoring indicators at all points along the pathway from source to response or conducting periodic synoptic surveys over the course of a project will identify changes as they occur and document progress toward the end response. Special studies of sediment transport, soil P levels, ground water dynamics, or receiving water behavior can shed light on phenomena that affect lag time in water quality response. For example, the **Long Creek Watershed** (NC) NNPSMP Project (1993–2002) conducted special studies of the effects of a wetland on PAH concentrations in an urban stream, the use of microbial indicators to assess land use impacts, and interactions between P and stream sediments to better explain the temporal and spatial water quality response to land treatment (Line and Jennings 2002). Supplementing a stream monitoring program with special studies can help project managers understand and predict potential lag times and can help explain delays in water quality improvement to stakeholders.

- **Select indicators carefully.** Some water quality variables can be expected to change more quickly than others in response to land treatment. As documented in the **Jordan Cove** (CT) NNPSMP Project (1996–2005), peak storm flows from a developing watershed can be reduced quickly through application of stormwater infiltration practices (Clausen 2004). Reductions in nutrient loads in surface waters might be expected to occur promptly in response to a ban on winter application of animal waste in northern states. NNPSMP projects in CA, NC, PA, and VT (Szpir et al. 2005) demonstrated rapid reductions in nutrients and bacteria by reducing direct deposition of livestock waste in surface waters through fencing livestock out of streams. However, improvements in stream biota appear to come much more slowly, beyond the time frame of many monitoring efforts. Where restoration of biological integrity is a goal, this may argue for a more sustained monitoring effort to document a biological response to land treatment. Failing that, however, selection of indicators that have relatively short lag times where possible will make it easier (and quicker) to demonstrate success.

- **Design monitoring programs to detect change effectively.** Monitor at locations and at a frequency sufficient to detect change with reasonable sensitivity. As soon as background variability is assessed (ideally before the project begins), conduct a minimum detectable change analysis (Spooner et al. 1987, Richards and Grabow 2003) to determine a sampling frequency sufficient to document the anticipated magnitude of change with statistical confidence. If the monitoring program is intended to detect trends, evaluate statistical power to determine the best sampling frequency for the project.

## Conclusions

Lag time between implementation of land treatment and water quality response is an unfortunate fact of life in many circumstances. Unless it is recognized and dealt with, the existence of lag time will frequently confound our ability to successfully document improved water quality resulting from treatment of nonpoint sources and may discourage vital restoration efforts. While ongoing and future research may provide us with better tools to predict and account for lag time, it is essential that watershed monitoring programs today recognize and grapple with this issue.

## References

Clausen, J.C., D.W. Meals, and E.A. Cassell. 1992. Estimation of lag time for water quality response to BMPs. Pages 173-180 in The National Rural Clean Water Program Symposium, September, 1992, Orlando, FL, US EPA ORD, EPA/625/R-92/006.

Clausen, J.C. 2004. Jordan Cover Urban Watershed Section 319 National Monitoring Program Project. Annual Report. College of Agriculture and Natural Resources, University of Connecticut, Storrs, CT.

Druschel, G., A. Hartmann, R. Lomonaco, and K. Oldrid. 2005. Determination of sediment phosphorus concentrations in St. Albans Bay, Lake Champlain: Assessment of internal loading and seasonal variations of phosphorus sediment-water column cycling. Final Report prepared for Vermont Agency of Natural Resources, Department of Geology, University of Vermont, Burlington.

Galeone, D.G. 2005. Pequea and Mill Creek Watersheds Section 319 NMP Project: Effects of Streambank Fencing on Surface-water Quality. *NWQEP Notes* 118: August, 2005. NC State University, Raleigh, NC.

Hallberg, G.R., R.D. Libra, D.J. Quade, J. Littke, and B. Nations. 1989. Groundwater monitoring in the Big Spring Basin 1984-1987: A Summary Review. Iowa Department of Natural Resources Technical Information Series Report 16, 68 p.

Line, D.E. and G.D. Jennings. 2002. Long Creek Watershed Nonpoint Source Water Quality Monitoring Project – Final Report. NC State University, Raleigh, NC.

Meals, D.W. 1992. Water quality trends in the St. Albans Bay, Vermont watershed following RCWP land treatment. pp 47-58 in The National Rural Clean Water Program Symposium, September, 1992, Orlando, FL, US EPA ORD, EPA/625/R-92/006.

Meals, D.W. 2001. *Lake Champlain Basin Agricultural Watersheds Section 319 National Monitoring Program Project, Final Project Report: May, 1994-September, 2000*. Vermont Dept. of Environmental Conservation, Waterbury, VT, 227 p.

Meals, D.W., E.A. Cassell, D. Hughell, L. Wood, W.E. Jokela, and R. Parsons. 2008. Dynamic spatially explicit mass-balance modeling for targeted watershed phosphorus management, II. Model application. *Agriculture, Ecosystems and Environment* 127:223-233.

Newbold, J.D., J.W. Elwood, R.V. O'Neil, and W. Van Winkle. 1981. Measuring nutrient spiralling in streams. *Can. J. Fish. Aquat. Sci.* 38:860-863.

Newbold, J.D. 2005. Personal communication. Stroud Water Research Center, Avondale, PA.

Phillips, S.W. and B.D. Lindsey. 2003. The Influence of Ground Water on Nitrogen Delivery to the Chesapeake Bay. USGS Fact Sheet FS-091-03. ***http://md.water.usgs.gov/publications/fs-091-03/html/***

Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, D.R. Edwards, and D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. *Soil Sci. Soc. Amer. J.* 60:855-859.

Richards, R.P. and G. L. Grabow. 2003. Detecting reductions in sediment loads associated with Ohio's Conservation Reserve Enhancement Program. *J. American Water Resour. Assoc.* 39(5):1261-1268.

Scientific and Technical Advisory Committee (STAC) Chesapeake Research Consortium. 2005. Understanding "Lag Times" Affecting the Improvement of Water Quality in the Chesapeake Bay. STAC Publication 05-001. Edgewater, MD. ***http://www.chesapeake.org/stac/Pubs/LagTimeReport.pdf***

Sims, J.T., A.C. Edwards, O.F. Schoumans, and R.R. Simard. 2000. Integrating soil phosphorus testing into environmentally based agricultural management practices. *J. Environ. Qual.* 29:60-71.

Spooner, J., C. J. Jamieson, R. P. Maas, and M. D. Smolen. 1987. Determining Statistically Significant Changes in Water Quality Pollutant Concentrations. *Lake Reserv. Manage.* 3:195-201.

Szpir, L.A., G.L. Grabow, D.E. Line, J. Spooner, and D.L. Osmond. 2005. 2005 Summary Report: Section 319 National Monitoring Program Projects. *National Nonpoint Source Watershed Project Studies, NCSU Water Quality Group, Biological and Agricultural Engineering Department, North Carolina State University, Raleigh, NC.*

USEPA. 2005. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. EPA 841-B-05-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Virginia Department of Conservation and Recreation. 1996. *Alternative Watering Systems for Livestock - The Middle Fork Holston River Builds on Success.* ***http://www.epa.gov/owow/NPS/Section319II/VA.html***

Wang, D., S.N. Levine, D.W. Meals, J.P. Hoffmann, J.C. Drake, and E.A. Cassell. 1999. Importance of in-stream nutrient storage to phosphorus export from a rural, eutrophic river in Vermont, USA. In *Lake Champlain in Transition: From Research Toward Restoration*, eds. T.O. Manley and P.L. Manley, pp. 205-223. Water Science and Application, Vol. 1, American Geophysical Union, Washington, D.C.