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IN THIS ISSUE

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PROJECT SPOTLIGHT

New York City Watershed: An eleven-year study of the effectiveness of agricultural BMPs in reducing farm pollutant losses

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Introduction

In 1992, in order to avoid the significant costs of constructing and operating a filtration system for its drinking water supplies, New York City (NYC) instituted an extensive, long-term, funded management program to address wastewater discharges, agricultural runoff, stormwater, and onsite septic systems in the watersheds of its upstate reservoirs. The drinking water supply for New York City consists of three major reservoir systems within a 200-km (125-mile) radius north and northeast of the City. Located in nine different counties, the total watershed area of the 19 individual reservoirs covers 1,950 square miles. For a drinking water system to qualify for filtration avoidance under the Surface Water Treatment Rule of the federal Safe Drinking Water Act, the system must meet certain coliform, turbidity and total trihalomethane limits. Filtration avoidance also requires that a watershed control program be implemented to minimize microbial contamination of the source water. The history and details of the NYC watershed filtration avoidance may be viewed at www.epa.gov/region02/water/nycshed/filtad.htm and www.nyc.gov/html/dep/watershed/html/regcontext.html.

NYC has also promulgated watershed regulations (http://www.nyc.gov/html/dep/watershed/html/regulations.html) to protect the reservoirs from the harmful effects of excess phosphorus (P) inputs. Several reservoirs that had average annual total P concentrations greater than an established guidance value of 20 ug/L were designated as P-restricted. As these regulations limit anthropogenic P discharges into the drainages of P-restricted reservoirs, towns and villages located in a P-restricted basin now face barriers to growth and development if that development could lead to an increase in the discharge of wastewater P into the system.

EDITOR'S NOTE

In this issue of *NWQEP NOTES*, we continue our series on National Nonpoint Source Monitoring Program (NMP) projects that have been completed and have documented improvements in water quality due to best management practice (BMP) implementation.

New York City's drinking water supply consists of three major reservoir systems, including 19 reservoirs spanning 9 counties, covering a watershed area of 1,950 square miles in upstate New York. The water supply is threatened by agricultural nonpoint source pollution, primarily pathogens and excess phosphorus. In order to avoid a costly filtration system, the City adopted a program that employs – as a voluntary, incentive-based approach – the concept of Whole Farm Planning in the watersheds of its upstate reservoirs. The goal is to reduce agricultural nonpoint source pollution while maintaining farm economic viability.

This issue of *NWQEP NOTES* reports on an 11-year, paired-watershed study conducted at an upstate NY dairy farm, which evaluated the effectiveness of the Whole Farm Planning process to reduce nutrients and sediment export. A suite of BMPs were implemented, including changes to farm infrastructure and farm management. The results indicated estimated reductions in ammonia-N (64%), dissolved P (53%), particulate P (36%), suspended sediment (28%), and nitrite+nitrate-N (23%). For long-term success with phosphorus reduction, the authors stress the importance of conservation and nutrient management, combined with practices, such as precision feeding, that address farm P mass balance and net P soil accumulation.

As always, please feel free to contact me regarding your ideas, suggestions, and possible contributions to this newsletter.

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Pathogens from animal waste and excess P are the key issues for agriculture in the NYC Watersheds because losses of these pollutants to the reservoirs could result in exceedence of contaminant limits, and thus threaten the city's avoidance of filtration. In 1992, the Watershed Agricultural Program (WAP) was created with the principal goals of reducing losses of nutrients, sediment and pathogens from farmland and keeping agriculture as a preferred land use in the watershed. The WAP adopted the concept of Whole Farm Planning (WFP) (http://www.nycwatershed.org/index_cleanwater.html) to protect NYC water supplies from agricultural nonpoint source (NPS) pollution without impairing farms' economic viability. Since its inception, the WAP has implemented best management practices (BMPs) on more than 85% of the farms located in the NYC Watershed using a voluntary, incentive-based approach.

Traditionally, BMP implementation programs have addressed farm pollution problems in a piecemeal manner because of limited resources and funding or unwillingness of the farmer to make major changes. In contrast, WFP selects BMPs in a holistic process that evaluates the environmental management and business aspects of participating farms, typically resulting in a variety of site-specific improvements to farm infrastructure, field drainage, cropland management, grazing intensity, manure management, and stream corridor protection (Porter et al. 1997, Watershed Agricultural Council 2003). The ample funding, extensive and comprehensive approach of this program presented an opportunity for researchers to measure the degree of pollutant reduction achievable with full treatment of all significant on-farm problems.

The WAP initially selected ten demonstration farms on which to develop, test and demonstrate the WFP method. One working dairy farm was chosen for intensive research and monitoring activities to quantify reductions in nutrient and sediment loading attributable to the suite of BMPs implemented on it through the WFP process. This aided in determining whether WFP: 1) correctly identified significant sources of on-farm pollution; and 2) implemented management practices that substantially reduced pollutant losses from those sources. A secondary goal was to produce water quality data that could be used to calibrate and verify watershed models. These models could then be applied to other farms in the basin treated under the WAP to estimate pollutant reduction accomplishments resulting from the entire program.

Monitoring began in 1993 on the selected demonstration farm and a nearby control site, and continued for two years before and nine years after implementation of BMPs recommended by the WFP process. The study was accepted by the U.S. Environmental Protection Agency (USEPA) into the Section 319 Nonpoint Source National Monitoring Program in June 1997. Researchers from the New York State Department of Environmental Conservation were the principal investigators for the study. Collaborators included New York City Department of Environmental Protection (NYCDEP), the Watershed Agricultural Council, Delaware County Soil and Water Conservation District, Cornell University, and private landowners. NYCDEP was the primary funding source for the water quality monitoring efforts and the sole funding source for planning and implementation of land treatment. The results of this study are discussed below.

Methods

Study Design

This study employed a paired watershed design to determine the effects of BMP implementation on sediment and nutrient export from the farm, while controlling for the effects of naturally-occurring variation in weather and water quality. The paired watershed approach uses two different time periods consisting of calibration and treatment phases. During calibration, two watersheds similar in size and location are monitored, with one acting as the control and the other as the treatment. During this period no land use changes occur and regressions are developed between paired observations of runoff and water quality variables. Once a satisfactory relationship with respect to hydrology and water quality variables has been determined, treatment of one of the watersheds can begin whereupon changes over time can be monitored and new regressions can be developed. Differences due to treatment are evaluated by statistical comparisons of calibration and treatment regressions (USEPA 1993). In this project, control for environmental variability was provided by a nearby forested watershed. A non-agricultural control was selected because no significant changes in the forested watershed were expected during the study period. In contrast, working farms may modify operational practices or go out of business altogether over the course of a long-term study, and cannot be relied upon to provide the consistent control necessary for describing natural environmental variability.

Study Sites

The two study watersheds are located in upper-headwater valleys northeast of Cannonsville Reservoir, in an area drained by the West Branch of the Delaware River (Fig. 1). Situated in Delaware County in the Catskill Mountains region of New York, the Cannonsville Reservoir is the third largest of New York City's drinking water reservoirs and most of the region's dairy farms are located within its basin. Historically, the reservoir has experienced eutrophic conditions in the summertime (e.g., Effler and Bader 1998) largely due to excess P loads from

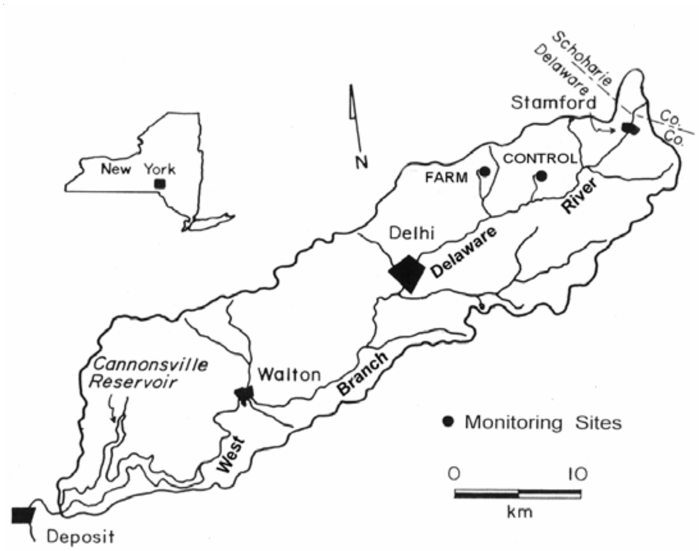

Figure 1. Map of Cannonsville Reservoir basin, Delaware County, New York, showing locations of the farm and control study watersheds.

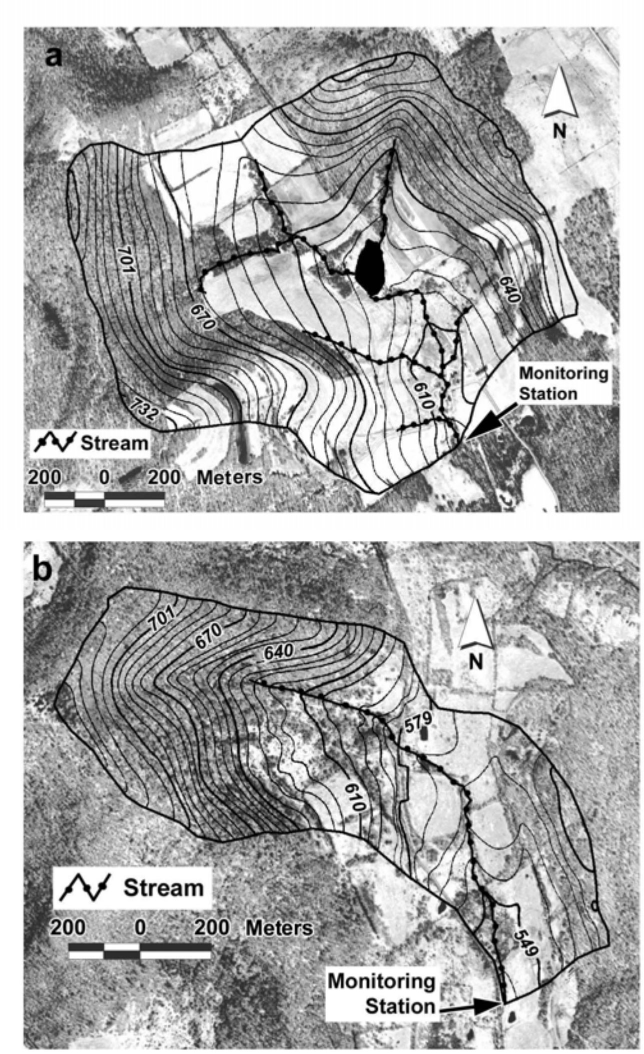

Figure 2. Maps of (a) farm site and (b) control site, showing watershed boundaries, 6-m contours, perennial stream channel, and monitoring stations.

both point and nonpoint sources (Brown et al. 1989). The climate of the basin is humid continental, with an average annual temperature of 8°C and an average annual precipitation of 104 cm (National Climatic Data Center 2005), approximately one-third of which falls as snow.

Both study watersheds occupy similar landscape positions, extending upward from a monitored point on a first-order stream to the tops of the surrounding hills. The 160 ha treatment watershed (Figs. 2a and 3) is occupied by a third-generation dairy farm that has grown from 60 milking cows and 40 heifers to 80 milking cows and 35 heifers over the study period. The farm is typical of upland dairy operations in the Catskills region in that the barn is located in the valley bottom, close to a central stream. Land use on the watershed is 53% deciduous forest, 25% improved pasture and hay, 7% corn rotation, 13% unimproved pasture, and 2% impermeable areas. Deciduous forest and unimproved pasture largely dominate the upper slopes of the watershed, while crop fields and improved pasture tend to be located on the lower slopes. Most impermeable surfaces such as barnyards, roads, and farm buildings are located near the stream. During the grazing season (May to October) cows frequently crossed the stream and adjacent wet meadows to reach pasture.

A multidisciplinary team that includes representatives from the USDA Natural Resources Conservation Service, Cornell Cooperative Extension and the county Soil and Water Conservation District conducts the planning and implementation process used in the NYC Watershed. Potential pollutant sources are identified mainly through observations while walking the farm, interviews with the farmer, and analysis of soils, feed, crops, manure, and herd data. The environmental audit, farmer business objectives, and the farm's location in the watershed are all factors that contribute to the whole farm plan developed for each operation. Primary sources of nutrients and sediment identified on the study farm during the WFP process included manure spreading on snow and frozen ground, certain crop fields exhibiting high soil-test phosphorus (STP) levels, corn too long in rotation, barnyard runoff, uncontrolled livestock access to the stream, milkhouse wastewater discharged into the stream, leachate from streamside silage storage, and erosion from farm roads and stream banks.

The control watershed (Figs. 2b and 3), located 6.4 km east of the treatment watershed, covers 86 ha and is comprised of mostly forest and old fields. The control watershed contains one permanent residence and several seasonal residences, but has no recent history of manure application and no significant anthropogenic P inputs, aside from atmospheric deposition. Land use is 78% deciduous forest, 22% shrub and grasses, and <1% impermeable areas. Soil samples collected throughout the control watershed in 2002 exhibited low to moderate STP values (New York State Water Resources Institute 2002).

BMP Implementation

During the two-year calibration period (June 1993–May 1995), stream water quality was monitored at both sites to establish the pre-BMP relationship between the farm and control watersheds for hydrologic response and pollutant loading. Following these two years during which farm operation remained essentially constant, an extensive suite of BMPs was implemented on the farm watershed. Treatments included physical changes to farm infrastructure as well as organizational changes to farm management, and affected both pollutant source areas and transport processes across much of the farm landscape. Stream monitoring was suspended during the implementation period (June 1995 – October 1996). Once physical disturbances had healed and the farm's operation under the new conditions had stabilized, monitoring resumed for the post-BMP period (November 1996 – October 2005).

Before BMP implementation, manure produced on the farm was spread daily. Limited access to hillside slopes during the winter often required spreading or stockpiling manure on fields adjacent to streams. After construction of a 2300-m^3 manure

Figure 3. Photographs of study farm (left) and control site (right) for New York City Watershed paired watershed study.

Figure 4. Before: stream in close proximity to barn; After: stream channel relocated away from barn.

storage lagoon, spreading was eliminated during the high-runoff winter and early spring months, with the exception of about one load per week of heifer manure. As heifers were housed in a separate barn that was not connected to the system that transported dairy barn manure to the lagoon, their manure was stockpiled in a temporary stack storage, then spread periodically on the least critical fields that conditions allowed.

Manure application on hydrologically-active areas (generally those areas within 15 m (50 ft) of a watercourse or prone to saturation excess, i.e., having a high groundwater table or hardpan at shallow depth) and on fields with high STP was reduced through adoption of a farm nutrient management plan containing field-specific timing and rate recommendations. Additionally, improvement of certain farm roads allowed access to upper slopes that had received little manure in the past. The suitability of several fields for manure spreading was enhanced by construction of upslope diversion ditches to prevent runoff from entering fields, and installation of tile drains to accelerate drying of fields and reduce the frequency of runoff from the fields. Although tile drains were considered to be a BMP at the beginning of the study, the WAP no longer promotes this practice due to the associated risk of increased nutrient loss via preferential flow pathways. Erosion potential was reduced by decreasing the duration of corn rotations, implementing contour stripcropping on one field, and improving drainage to reduce runoff. The WFP improved pasture management and reduced potential for overgrazing and associated soil erosion through the establishment of a rotational grazing system. A spring development project supplied water for grazing cows, and encouraged their movement away from streamside areas. Cows were fenced out of several near-stream wet meadows where they had previously grazed. Near the barn, several stream crossings and roadways were fenced and improved to keep the cows out of the stream. Although the main barnyard had been paved with concrete before the study period, barnyard water management was improved and a grassed filter area was constructed to intercept barnyard runoff that had previously flowed directly into the stream. A portion of the main stream that had run quite close to the barnyard, was diverted to a new channel about 46 m (150 ft) to the west (Fig. 4). Bagged silage was relocated away from the streamside, and milkhouse waste that had previously drained directly to the stream was routed to the manure storage lagoon.

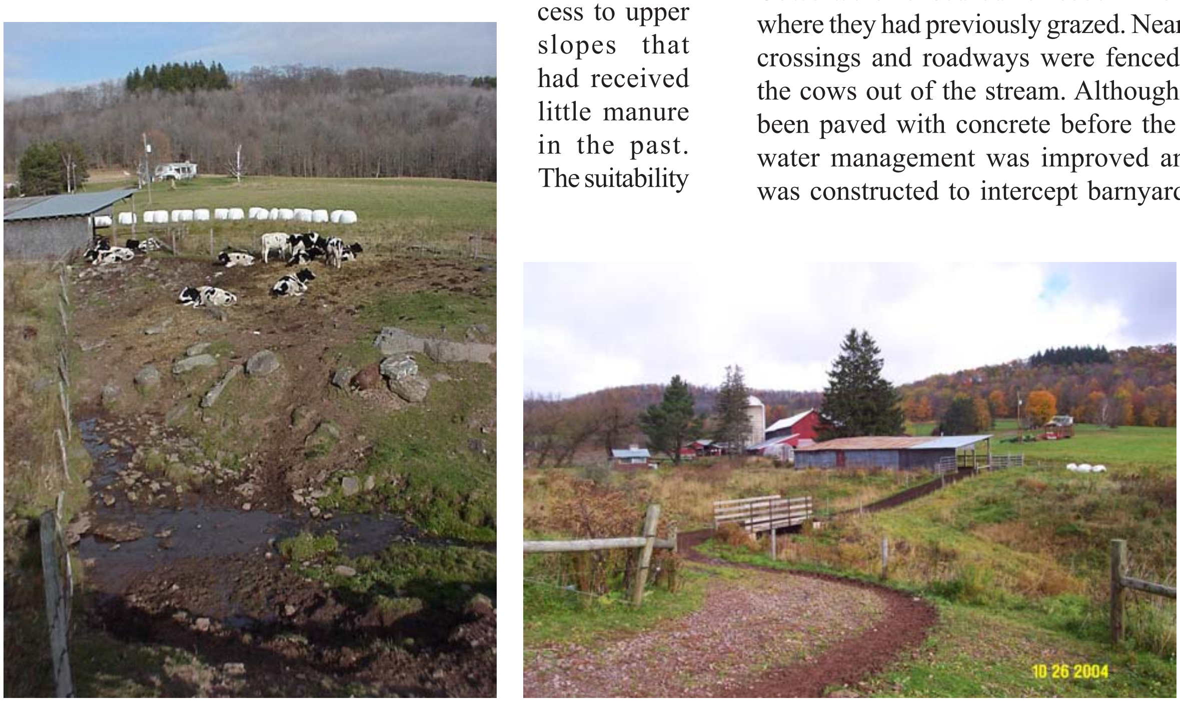

Figure 5. Before: Dry cow loafing area and crossing through the stream (Photo by D. Hively); After: Repaired dry cow area with vegetated banks and fenced bridge & cattle lane.

Additional BMPs were installed on the farm in a second phase following the original WFP implementation. In summer 2001, a streamside dry cow loafing and transit area was revegetated and fenced to protect the stream bank (Fig. 5). A cattle lane and crossing was also built to provide safe access across the stream to pasture. Beginning in January 2001, the farm participated in a pilot program of precision feeding aimed at reducing P imports to the farm in purchased feed. Feeds and homegrown forages were analyzed for protein, carbohydrate and mineral content. Diets were adjusted based on the nutritional needs of the herd, and as a result, dietary intake of P was reduced by an average of 25% while excretion of P was reduced by an average of 33% (Cerosaletti et al. 2004). Another spring development and remote watering system installed in summer 2002 resulted in less cattle traffic in and around the stream (Fig. 6).

Figure 6. Remote watering system installed on NYC Watershed study farm.

As it was expected that the second round of management practices would lead to additional improvements in water quality on the farm, the post-implementation period was split into Phase 1 (initial round of BMPs), and Phase 2 (BMPs after April 2001). This start date for Phase 2 represents the time manure produced under the precision feeding program and stored in the manure lagoon would first be applied to the farm's fields. Data analyses focused on changes in water quality between the pre-BMP period and Phase 1, and changes between Phase 1 and Phase 2.

Monitoring

An automated stream monitoring station was established at each watershed outlet (Fig. 2a, 2b). Each station consisted of a heated shelter housing a refrigerated automatic sampler, a data logger, and two parallel pipes containing sensing equipment and sampling lines, through which all stream flow was channeled. A 43-cm-diameter pipe provided accurate measurements of the low to moderate discharges that occurred most of the year, and a 2.1-m-diameter culvert pipe effectively handled high flows. The pipes were covered with soil and stone to form a dike and remained ice-free, thereby increasing accuracy of flow measurement during freezing weather. Stream discharge and stage were recorded every 10 minutes by the data logger, using input from combination level–velocity electromagnetic sensors located in the pipes. Flow rating curves were developed for each site through manual stream gauging and were updated annually. Heated and unheated rain gauges were installed at the sites to differentiate between rain and snowfall precipitation.

Water samples were collected at least weekly during baseflow periods, and more frequently during runoff events. Event-based sample collection was triggered by onset of precipitation, in the case of rainfall events, or by a rise in stream stage of at least 0.03 m. Sample collection frequency was directly related to the rate of stream rise and fall, up to a maximum rate of six samples per hour. The number of samples collected per event typically ranged from three to more than 20, depending on event magnitude and duration, which ranged from several hours to several days. Nearly all events that occurred during the study were sampled.

Stream-water samples were analyzed for total P (TP) and total dissolved P (TDP) using USEPA method 365.2 (USEPA 1979). Particulate P (PP) was computed as the difference between TP and TDP. Ammonia-nitrogen (NH_3), total Kjeldahl nitrogen (TKN), nitrate + nitrite-nitrogen (NOX), and total organic carbon (TOC) were analyzed using USEPA-approved methods 350.1, 351.2, 353.2, 415.2 (USEPA 1979), respectively. Total suspended sediment (TSS) was determined by a gravimetric method (APHA et al. 1992).

Load Calculations and Data Analysis

For baseflow periods, an average daily load was determined as the product of the mean daily flow (mean of the 144 measurements recorded by the data logger each day) and a concentration from the most recently collected baseflow sample. For event periods, loads were calculated every 10 minutes and then summed for a total daily and a total event load. Event loads were calculated as the product of 10-min flow volumes and either actual or estimated 10-min nutrient concentrations, summed over the duration of each event. Estimated 10-min nutrient concentrations were derived by interpolating between adjacent concentration observations. For the purpose of calculating event loads, an event was considered to start with the beginning of stream rise and was deemed over when concentrations of nutrients and sediment returned to approximately pre-event levels, or when another event began.

The study used multiple regression and analysis of covariance (ANCOVA) applied to matched event loads from control and treatment watersheds to determine effects of Phase 1 and Phase 2 BMPs. In addition to event load at the control site, several available covariates were utilized to explain variability in pollutant losses from the treatment watershed due to effects of hydrologic and watershed parameters. These included the ratio of event flow volumes at the farm and control sites, farm event instantaneous peak flow, and farm event average flow rate. A complete discussion of the development of the statistical model and its application to the paired watershed data may be found in Bishop et al. (2005).

Data from baseflow periods were analyzed by comparing concentrations from the pre-BMP period to those of the Phase 1 and Phase 2 post-BMP periods. Mean sample concentrations for each of the three study periods were calculated and compared for significant differences using a one-sided t-test. Differences in the geometric mean baseflow concentrations and their respective 95% confidence intervals were used to estimate full year reductions in baseflow concentrations.

In general, all statistical analyses were conducted on log-transformed data to satisfy the assumptions of parametric statistics.

Results

Annual Loading and Trends

Annual runoff and nutrients and sediment loads were substantially greater at the farm site than at the control site, most likely due to the more intensive land use and larger watershed area of the farm site. Periodic surveys that measured concentrations and flow at various points along the stream revealed that much of the pollutant load leaving the farm was generated on the most intensively utilized portions consisting of the farmstead area and fields spread with manure.

Runoff volume varied somewhat over the eleven monitored years due to differences in precipitation amounts and timing. Annual loads were variable at the farm, less so at the control, and tended to be smaller in years with less runoff (Fig. 7). Simple comparison of annual farm pre- and post-BMP loads did not indicate clear patterns of pollutant reductions with the exception of TDP loads, which were consistently lower throughout the post-BMP period regardless of the amount of annual runoff produced (Fig. 7). As a large amount of loading at both sites occurred during runoff events, and there appeared to be seasonal factors that strongly affected event losses, we focused on events in detail to better determine effects of BMP implementation.

Events

Throughout the study, runoff events accounted for a substantial portion of the annual loading of most analytes. Typically, 75 to 95% of the annual loads of particulate fractions such as PP and TSS were delivered during event periods. Dissolved analytes, such as TDP and NOX, tended to have 45 to 75% of the annual load associated with runoff periods. Runoff events delivered a greater percentage of annual loads at the farm site than at the control. On average, more of the annual loading was delivered during events in the post-BMP period than during the pre-BMP period at both the farm and control sites, although this disparity was more apparent at the farm.

Annual event runoff at the study sites was roughly comparable (farm: 14–36 cm; control: 8–27 cm) although the farm site was always higher in a given year, perhaps due to the greater amount of impermeable area and the greater tendency of summer storms to either occur at the farm or result in measurable runoff at the farm. In the pre-BMP period, event

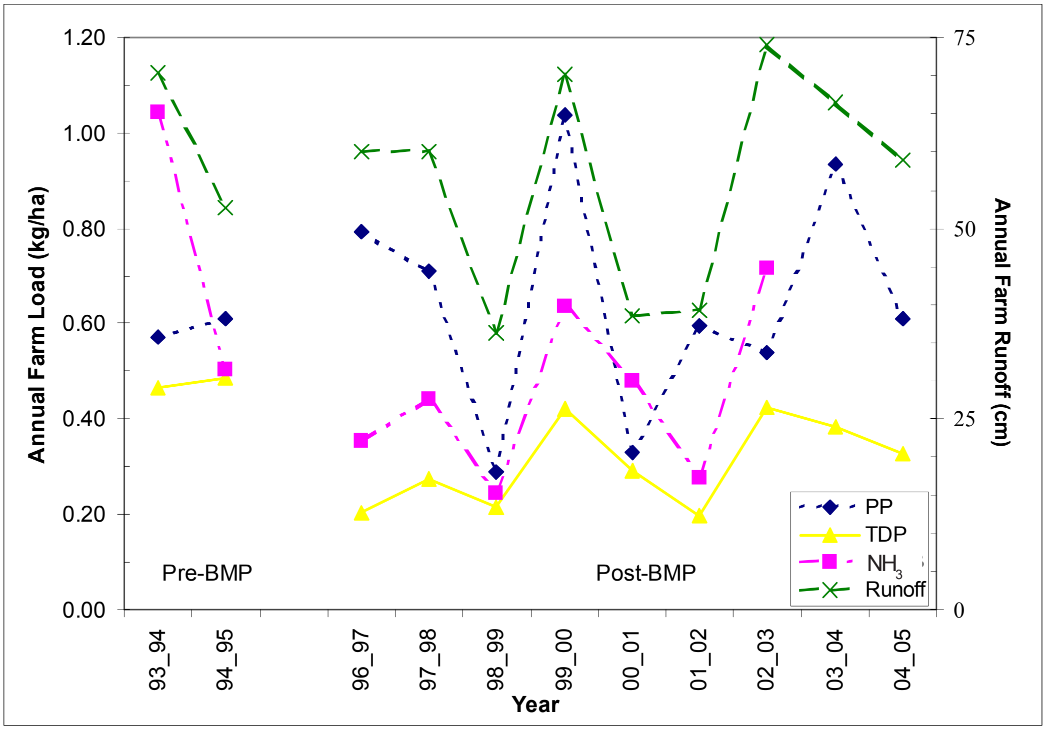

Figure 7. Annual farm loads of selected analytes during the eleven study years. PP = particulate phosphorus, TDP = total dissolved phosphorus, NH_3 = ammonia.

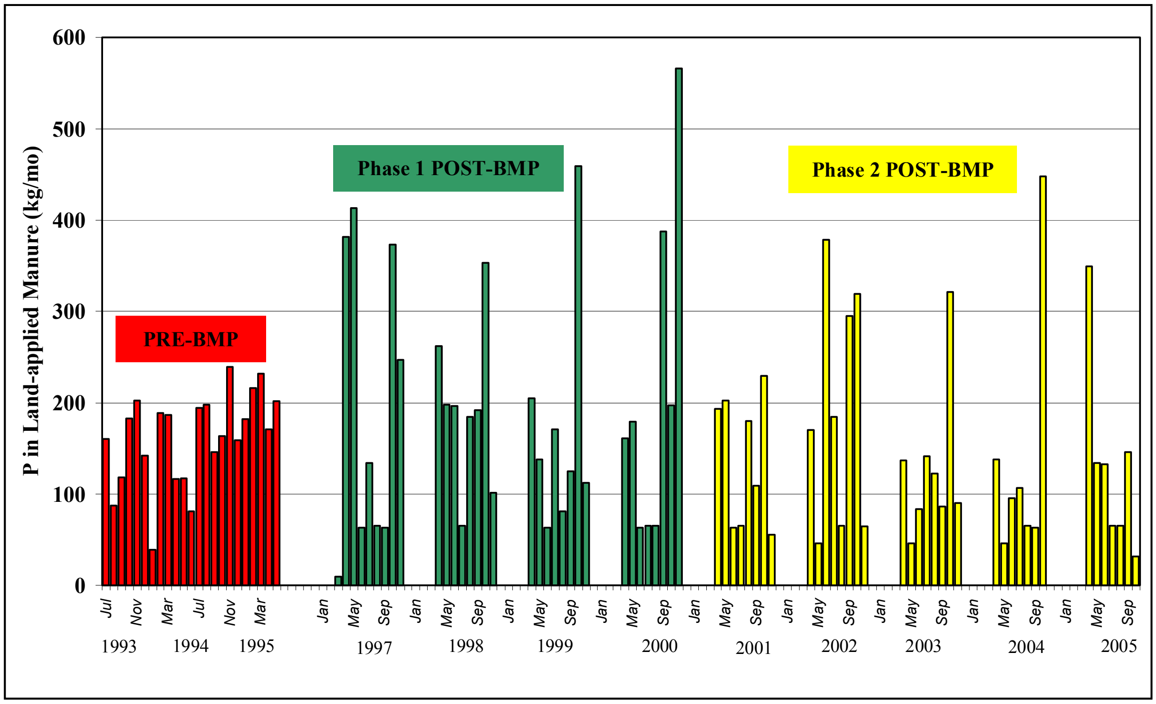

Figure 8. Monthly P in manure applied on the farm watershed from spreading and pastured cows, showing seasonality in the post-BMP period. One load manure = 4.6 kg P.

flow accounted for 35% of total stream discharge at the farm and 28% at the control site; in the entire post-BMP period, event flow averaged 46% of the total at the farm and 34% at the control. The remainder of stream discharge occurred as baseflow.

During the study period, 486 runoff events were observed and sampled. One hundred and eight of these events were excluded from the analysis because they were unmatched (event occurred at only one site). Unmatched events occurred mainly when event size was small, so analysis of seasonal loading trends for the farm watershed was not affected by their removal. One additional event was deleted because of a suspected laboratory error. The resulting dataset includes 74 events in the pre-BMP period, 167 events in Phase 1 of the post-BMP period, and 136 events in Phase 2.

For each sampled event, available data from the farm watershed included event pollutant loads, event flow volume, event instantaneous peak flow, and event average flow rate. Corresponding data from the control watershed were also available for each matched event. The control watershed variables reflect local characteristics of rainfall, runoff production, and pollutant loading processes in the absence of farm management practices, while the farm watershed variables represent the treatment effect, along with runoff production and loading processes associated with the farm landscape. Use of explanatory farm flow-related covariates was considered valid only if the BMPs had no significant and substantial effect on the relationship between precipitation and runoff production at the farm site. Statistical testing, in fact, found no significant ($p > 0.05$) pre- vs. post-treatment (Phase 1) differences in the matched watershed flow volume relationship for the full year or for any seasons, indicating that farm flow volumes were not altered by the BMP treatments (Bishop et al. 2005). The same result was obtained when this relationship was tested comparing Phase 1 to Phase 2.

Event data were grouped by season (Table 1) according to seasonal differences in land application of manure (considered a primary source of nutrients on the farm) following BMP implementation (Fig. 8) and hydrologic runoff processes (wet versus dry periods). Approximate begin and end dates for the dry period and timing of manure spreading were used to define seasonal date ranges (Table 1).

BMP Treatment Effects: Comparing Pre-BMP to Phase 1 Post-BMP Event Loads

The magnitude of Phase 1 post-BMP event load reductions, as well as 95% confidence intervals (CI_{95}), were computed for all analytes (Table 2). When data from the full-

Table 1. Seasonal definitions, with the number of matched events that occurred in each season and in the full year, for the pre-BMP, Phase 1 and Phase 2 post-BMP periods.

Season	**Number of Matched Events**			
	Pre-BMP†	**Phase 1**‡	**Phase 2**§	**Total**
Winter (16 December–13 April)	33	70	33	136
Spring (14 April–15 June)	12	33	27	72
Summer (16 June–30 September)	17	35	48	100
Fall (1 October–15 December)	12	29	28	69
Full year	74	167	136	377

† June 1993 – May 1995
‡ November 1996 – April 2001
§ May 2001 – October 2005

Table 2. Percent reductions in event loads between pre-BMP and Phase 1 post-BMP, and between Phase 1 with Phase 2 post-BMP*. Statistically significant (P>0.05) load changes are shown in bold followed by 95% confidence intervals; negative values indicate increase in event loads.

		Full Year	Summer	Fall	Winter	Spring
PP						
	Pre vs. Phase1	**34** (17/48)[†]	**44** (13/64)	5	**33** (17/46)	24
	Phase 1 vs. Phase 2	16	**33** (5/53)	**40** (5/62)	**-32** (-4/-66)[¶]	36
TDP						
	Pre vs. Phase1	**41** (32/48)	**51** (31/65)	6	**43** (32/52)	**38** (12/58)
	Phase 1 vs. Phase 2	**14** (4/30)	**32** (13/47)	11	-3	8
TSS						
	Pre vs. Phase1	**28** (8/44)	35	-7	**26** (3/43)	24
	Phase 1 vs. Phase 2	17	**36** (3/58)	**41** (3/65)	**-68** (-28/-119)[¶]	34
NH3						
	Pre vs. Phase1	**33** (17/46)	**54** (22/73)	-17	**36** (13/53)	19
	Phase 1 vs. Phase 2	**43** (28/54)	**55** (20/74)	38	28	26
NOX						
	Pre vs. Phase1	**-20** (-4/-38)	6	-21	**-22** (-1/-47)	-40
	Phase 1 vs. Phase 2	**26** (12/37)	**53** (32/67)	20	**-33** (-3/-72)	**45** (24/60)
TKN						
	Pre vs. Phase1	-1	-12	-9	18	-48
	Phase 1 vs. Phase 2	-5	27	15	**-27** (-3/-56)	-12
TOC						
	Pre vs. Phase1	**22** (13/29)	**30** (7/46)	18	**23** (16/29)	15
	Phase 1 vs. Phase 2	1	20	0	0	-1

* Phase 2 ended on October 31, 2005 for PP, TDP and TSS. It ended on October 31, 2003 for the remaining parameters.

[†] Percent reduction (bold) statistically significant (P>0.05) and 95% confidence interval (CL_L / CL_U).

[¶] Interaction term (see Bishop et al. 2005) is significant indicating BMPs may perform differently under high- versus low-flow conditions.

year were analyzed without separation into seasons, all analytes, with the exception of NOX and TKN, showed significant reductions ($p < 0.05$) in event loads after implementation of Phase 1 BMPs. Reductions ranged from 22% in TOC loads to 41% in TDP loads. NOX loads actually increased when compared to pre-BMP levels and TKN loads were essentially unchanged. Seasonally, most analytes showed significant reductions in winter and summer. No significant changes in fall event loads were noted for any analytes. Spring event loads were similarly unaffected with the exception of a 38% reduction in TDP.

BMP Treatment Effects: Comparing Phase 1 to Phase 2 Post-BMP Event Loads

Some additional pollutant reductions occurred after the second round of practices were installed on the farm (Table 2). In Phase 2, TDP and NH_3 decreased 14% and 43%, respectively, relative to loading in Phase 1. NOX decreased by about the same percentage it increased between the pre-BMP period and Phase 1, and thus, was essentially unchanged from the beginning of the study. Seasonally, reductions in summer loads were noted for PP, TDP, TSS, NH_3 and NOX. PP and TSS showed significant decreases in fall loads but corresponding increases in winter loads. NOX and TKN both increased significantly in winter when compared to Phase 1. It is unclear why winter event loads of these analytes would increase in Phase 2 as manure spreading in November, which is expected to have the most influence on winter loadings, appears somewhat reduced from 2001 to 2005 when compared to the Phase 1 years (Fig. 8). It remains to be determined if some other aspect of farm management changed in Phase 2 that would contribute to winter increases.

Seasonal Differences in Event Loading and BMP Performance

Summer (15 June–30 September)

BMPs implemented on the farm appeared to be most effective with respect to summer season event loads. After Phase 1, TDP and PP summer event loads were reduced by 51% and 44%, respectively, and after Phase 2, by 33% and 32%, respectively (Table 2). NH_3 summer event loads exhibited >50% reductions after each phase of BMPs. Significant reductions after Phase 2 were also observed in TSS and NOX. In the dry summertime, upper watershed slopes did not usually saturate, and nutrient and sediment loads were produced mainly from near-stream, impermeable, and slope-break sources. BMPs that would operate mostly in these areas included Phase 1 and 2 exclusion of cows from the stream corridor, relocation of the silage storage bag away from the stream bank, implementation of rotational grazing, improved pasture management, Phase 2 remediation of the dry cow loafing area and stream crossing improvement, and somewhat reduced manure spreading during summer months (Fig. 8).

Fall (1 October–14 December)

Significant event load reductions after Phase 1 were not observed during the fall season for any analytes (Table 2). Increased fall manure spreading in the post-BMP period (Fig. 8) when the farmer emptied the manure storage lagoon in preparation for the winter may have offset any P and N reductions attributable to other BMPs implemented on the farm. At this time of year there is little crop growth to utilize nutrients added to the soil, thus manure applied to the land would be expected to be available for loss during runoff events. The fall reductions observed after Phase 2 in PP (40%) and TSS (41%) may be somewhat attributable to the protection and re-vegetation of the dry cow loafing area near the stream, practices that would be expected to reduce losses of particulate fractions.

Winter (15 December–13 April)

Reductions in winter P and organic carbon event loads in the Phase 1 post-BMP period were most likely largely attributable to storage of manure and minimal spreading from mid-December to mid-April (Fig. 7). Sediment reductions may be linked to decreased farm vehicle traffic and farm road disturbance associated with extremely reduced manure spreading. Decreases in winter ammonia-N loads appeared to be largely offset by increases in nitrate-N loading, and suggest a transformation of N forms through nitrification. In the pre-BMP period, fresh surface-applied manure in cold weather would tend to retain N as ammonia, instead of being converted to nitrate, a process which occurs in the soil under warmer conditions. Low volatilization rates in winter would act to preserve ammonia as well. The reduction in ammonia loading observed after BMPs is likely due to the lack of fresh manure being applied daily to snow and frozen ground and subjected to runoff processes. Increases in nitrate event loads may be related to conversion of the ammonia contained in the large amounts of manure applied in the fall, when the storage was emptied, to nitrate in the soil. This nitrate could have still been available for loss during winter runoff events, N being more mobile in the soil than P. In addition, a portion of the ammonia in fall-applied manure was no doubt lost through volatilization during agitation of the storage, and subsequent spreading on fields. Thus, unlike P, winter loads of N appear unaffected by the BMPs installed in either Phase 1 or Phase 2.

Spring (14 April–14 June)

Spring TDP event loads were reduced by 38% in the Phase 1 post-BMP period, while PP, TSS, NH_3 and TOC event loads showed nonsignificant ($p > 0.05$) reductions ranging from 15 to 24%. Manure was heavily surface-applied in the spring months (Fig. 8) to empty the storage after winter, with some being incorporated into the soil during tillage. Losses from manure-spread fields and increased sediment availability resulting from spring tillage and increased farm traffic would potentially mask clear-cut reductions in sediment and nutrient loadings. It is encouraging that TDP, the most important nutrient contributing to eutrophication, was significantly reduced in springtime as a result of the Phase 1 BMPs. This may be a result of barnyard water management practices, improved field drainage, and manure spreading schedules that more evenly distributed manure over the farm. All of these practices may be expected to reduce event loadings of dissolved nutrients, but not necessarily the particulate fractions. Phase 2 BMPs did not appear to have a significant effect on spring event loadings, except for NOX, which was reduced by 45%. However, as NOX exhibited a non-significant increase of 40% after Phase 1 BMPs, the overall change in nitrate event loading from the pre-BMP period may be considered negligible.

Baseflow (Non-event) Reductions

Annual Loads

When compared to the pre-BMP period, the amount of stream discharge occurring annually as baseflow in the entire post-BMP period was, on average, 24% less at the farm and 16% less at the control site. Some of the farm reduction in baseflow may be due to the absence of the daily milkhouse waste discharge into the stream after BMP implementation. Annual farm baseflow loads of PP, TDP, TSS, and NH_3 were reduced by 50% or more, greater amounts than what could be explained simply by reductions in baseflow discharge. In contrast, at the control site, load reductions tended to be about the same as or less than the reduction in baseflow, although some parameters increased slightly. As observed during event periods, baseflow loads of NOX and TKN did not appear to decrease after implementation of management practices.

Analysis of Baseflow Concentrations

While there appeared to be differences in annual baseflow farm loads between the pre- and post-BMP periods, it made more sense to examine baseflow sample concentrations for any significant changes during the study period due to the confounding effects of interannual variability.

In the pre-BMP period, there were 125 baseflow samples collected; in Phase 1, there were 178 samples; in Phase 2 there were 255 for P forms and sediment, and 141 for N forms and TOC. Concentrations were analyzed both for the full year and seasonally.

When comparing Phase 1 post-BMP to the pre-BMP period, baseflow concentrations of all three forms of P and NH_3 were significantly reduced in the full year and in all seasons; TSS was significantly reduced in the full year and spring season; NOX was significantly reduced in the summer season, and significantly *increased* in the winter and spring seasons; and TKN significantly *increased* in the full year, fall and spring seasons (Table 3). Changes in mean baseflow concentrations between Phase 1 and Phase 2 of the post-BMP period included significant reductions in full-year TSS, summer TDP, TSS and NOX, and fall PP and TSS. Significant *increases* in full-year TKN and TOC, summer NH_3 and TKN, winter SRP and TKN, and spring NH_3 were also observed between Phase 1 and Phase 2 baseflow concentrations.

Overall full-year changes among the three study phases are summarized in Table 3. The significant reductions observed in post-BMP baseflow concentrations of P, sediment and ammonia would be expected to result in proportionally reduced baseflow loads. Pollutants in baseflow are typically derived from point discharges, leaching from field soils in subsurface flow, release from disturbed stream banks and resuspended bed sediments, and direct activity by cattle in the stream. For dissolved analytes, much of the reduction may be attributed to the elimination of the daily milkhouse waste discharge to the stream as well as decreased manure deposition in the stream. The reductions in particulate forms are likely due to the exclusion of livestock from the stream and associated reductions in direct manure deposition, stream bank erosion, and sediment resuspension and transport.

Table 3. Overall percent reductions calculated from differences in full-year baseflow geometric mean concentrations among the three study periods. Negative value indicates an increase in concentration.

	% Reduction and 95% Confidence Interval	
	Pre vs Phase 1	Phase 1 vs Phase 2
PP	**51** (39/58)[†]	-
TDP	**60** (51/66)	-
TSS	**16** (3/28)	**22** (13/30)
NOX	-	**35** (22/46)
NH3	**68** (61/74)	-
TKN	**-15** (-2/-28)	**-28** (-15/-42)
TOC	-	**-16** (-7/-26)

[†] Percent reduction (bold) and 95% confidence interval (CL_L / CL_U).

Discussion

Total Farm Reductions

The overall effect of BMPs on the farm may be estimated by adding the event reductions to the baseflow reductions. Table 4 shows the fraction of annual post-BMP loads delivered during events and baseflow periods, significant reductions ($p<0.05$) after Phase 1 and Phase 2 BMPs for both event and baseflow loads, and the combined effect of these reductions on the total annual loading. Loads of ammonia and dissolved P exhibited the greatest reductions as a result of the BMPs implemented under Whole Farm Planning. Farm losses reduced by 50% or more can be considered to be quite substantial and would be expected to have positive effects on receiving water bodies if also achievable on other farms in the watershed. Particulate P and sediment losses were reduced by 36% and 28%, respectively. While not as large as the decreases in ammonia and TDP, these reductions may help reduce eutrophication, turbidity and sedimentation in receiving water bodies. In the case of Cannonsville Reservoir, agriculture has been estimated to be responsible for 60 to 70% of the TP load; thus measures that reduce contributions from this source by a third to a half would be significant. Reductions in NOX of 23% and TOC of 5% were smaller, and TKN increased by 17%. These differences would be expected to have little effect on receiving waters.

Phosphorus. Certain changes in farm practices occurring in the post-BMP period may have counteracted the effect of BMPs to some degree. These included a gradual increase in herd size of about 30% and intensified use by cows of the streamside loafing yard in Phase 1 that created a concentrated nutrient-loading source area not far upstream of the monitoring station. In addition, none of the Phase 1 BMPs altered either the amount of P imported onto the farm as feed or fertilizer or the amount exported as products. Therefore, as the mass balance of P on the farm did not change appreciably during the first four years of the post-BMP period, presumably any reductions observed in stream losses of P resulted from more of it being retained on the farm. This outcome has the potential of accelerating net accumulation of P in the farm soils and eventually raising soil-P levels to the point of saturation of soil-P binding capacity. Studies indicate this saturation point represents a threshold of soil-P above which TDP concentrations in runoff can increase sharply (e.g., Beauchemin and Simard 1999; McDowell and Sharpley 2001), an effect that, in the absence of measures to reduce P inputs, would be expected to lead to increased loss of dissolved P from the farm in the future.

Beginning in 2001, the second phase of BMPs implemented on the farm not only corrected the concentrated nutrient source area but also addressed the P imbalance on the farm. The farm watershed P mass balance was improved with institution of a precision feeding program that lowered imports of dietary P by an average of 25% and reduced excretion of P in manure by 33% (Cerosaletti et al. 2004). Reductions of this magnitude in the amount of manure P applied to the farm soils should slow the rate of soil P accumulation and continue to reduce losses of P in runoff waters. The observed Phase 2 reductions in TDP and PP (Table 2) may be somewhat attributable to the institution of precision feeding, although, seasonally, reductions due to this practice would be expected to be associated more with runoff losses during fall and spring, when most of the manure is now spread, not in summer when the greatest reductions in both TDP and PP actually occurred.

Our study was somewhat unusual in its characterization of the changes in water quality from a single farm and may not be directly comparable to findings from other BMP effectiveness studies that monitored larger watersheds. Brannan et al.. (2000), however, demonstrated reductions of 35% in PP

Table 4. Overall effects of BMPs on annual farm loads. Negative value indicates an increase in loading.

		Avg % of Annual Load*	% Reduction		
			Phase 1	Phase 2	Total
PP					
	Event	90	34	0	31
	Baseflow	10	51	0	5
	Total				**36**
TDP					
	Event	68	41	14	34
	Baseflow	32	60	0	19
	Total				**53**
TSS					
	Event	93	28	0	26
	Baseflow	7	16	22	2
	Total				**28**
NOX					
	Event	51	-20	26	6
	Baseflow	49	0	35	17
	Total				**23**
NH3					
	Event	66	33	43	41
	Baseflow	34	68	0	23
	Total				**64**
TKN					
	Event	65	0	0	0
	Baseflow	35	-15	-28	-17
	Total				**-17**
TOC					
	Event	55	22	0	12
	Baseflow	45	0	-16	-7
	Total				**5**

* Average partitioning of loads in the entire 9-year post-BMP period between events and baseflow.

loading and 4% in TDP loading in a 10-year evaluation of improved animal waste practices (including manure storage, spreading schedules, and stream fencing) implemented in a 331-ha Virginia watershed containing two dairy farms. In the same study, the authors reported PP load reductions of 70%, but TDP load increases of 117% in a nearby 462-ha agricultural watershed composed mostly of cropland that received BMPs including nutrient management plans based on N needs, and field erosion control practices. Conversion of organic P to inorganic P in the manure storage and application of manure at rates based on N needs of crops, which typically result in overfertilization of P, were suggested as factors that could explain the ineffectiveness of the Virginia study in reducing TDP loads. The BMPs evaluated in our study produced overall PP reductions comparable with those Brannan et al. (2000) reported for the first watershed and about half of that observed in the second watershed, but were much more successful in reducing TDP loading. Findings of Brannan et al. (2000) may constitute evidence of the eventual P saturation of soil and subsequent release of dissolved P in runoff that is postulated to occur when conservation and nutrient management practices are implemented in the absence of efforts to improve whole-farm mass balance of P.

Nitrogen. The effects of the BMPs implemented under the Whole Farm Planning program on N losses were mixed. The two main components of N in manure are organic N and ammonia (Collins et al. 1995). In fresh manure, the inorganic portion is commonly in the form of ammonium. Storage of manure, especially in slurry form, generally results in conversion of organic N to ammonium through ammonification (Brannan et al. 2000). Loss to the atmosphere can occur through volatilization of ammonia N from either the storage or from surface-applied manure. Ammonia N is converted to nitrate by soil bacteria when manure is incorporated into the soil. If application is in excess of crop needs, nitrate can be quickly lost in surface and subsurface runoff. While manure storage has the benefit of producing more plant-available N by transforming organic N to inorganic forms, if crop needs are small or absent at time of application, as they are in the fall season when the storage is emptied, there is more potential for loss to the environment. This may explain the apparent increases seen in NOX loading after Phase 1. Ammonia loadings decreased, presumably through loss to the atmosphere and conversion to nitrate, and nitrates increased due to excess amounts in relation to plant needs. Brannan et al. (2000) reported results similar to ours in that reductions in ammonia concentrations of 30% - 70% were measured in their three study watersheds and nitrate loading showed the smallest reductions as a result of BMPs.

Conclusions

Overall, estimated decreases in nonpoint source loads from the farm were: 64% for ammonia-N, 53% for dissolved P, 36% for particulate P, 28% for suspended sediment, and 23% for nitrite+nitrate-N. These observed reductions are probably attributable to the many changes in farm infrastructure and management resulting from implementation of BMPs on the monitored farm. The results of the study quantitatively demonstrate that dairy farm BMPs can succeed in reducing losses during runoff events as well as baseflow periods.

The small-scale watershed monitoring approach was an effective method for evaluating treatments that potentially influence loading processes throughout the farm landscape. While the monitored farm has been more intensively managed from an environmental perspective than most other farms in the region that have adopted BMPs, our findings provide evidence that the Whole Farm Planning process used to identify and treat sources has successfully reduced P and ammonia loading to one of New York City's water supplies, Cannonsville

Reservoir. Presumably, initial decreases in P stream losses were associated with greater retention of P within the farm watershed, an outcome that could eventually lead to saturation of soil with P. Reductions in dissolved P occurring later in the study may be attributable to the implementation of precision feeding and reduction of P in excreted manure. Management programs that combine effective conservation and nutrient management measures with practices designed to improve farm P mass balance and slow net soil P accumulation would appear to have the best chance of protecting water quality over the long term. The observed decreases in ammonia loads are likely a result of both loss to the atmosphere through volatilization and conversion to nitrate in the soil with subsequent increases in loads of this N form during certain seasons. While N is not as important in this freshwater system as P, in ocean and estuarine systems where excess N is typically the nutrient of concern for eutrophication, other farm management practices that reduce inputs of N or utilize it more efficiently on the farm may be of more value than the ones implemented in this project.

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INFORMATION

New EPA Web Module Offers Watershed Outreach Training

EPA's Watershed Academy recently posted a free, updated online training module on *Getting In Step: A Guide to Conducting Watershed Outreach Campaigns*. This module offers a step-by-step system to help local governments, watershed organizations and others maximize the effectiveness of public outreach campaigns to help solve nonpoint source pollution problems and protect local waterways. The module is based on EPA's free, downloadable outreach guide *Getting in Step: Guide for Conducting Watershed Outreach Campaigns* (published in Dec. 2003 and posted at: www.epa.gov/owow/watershed/outreach/documents). To view the new *Getting in Step* online training module, visit www.epa.gov/watertrain/gettinginstep. Approximately 50 other free online Watershed Academy training modules are available at: www.epa.gov/watertrain.

New EPA Tool to Accelerate Watershed Planning

The Environmental Protection Agency has released the Watershed Plan Builder, an interactive, Web-based tool to improve efforts by states and local communities in protecting and restoring local water resources. The tool will help local watershed organizations develop integrated watershed plans to meet state and EPA requirements and promote water quality improvements.

Once the data are entered, the tool produces an outline of a comprehensive watershed plan tailored to a specific watershed. It features links to EPA, other federal agencies and state water programs.

The Watershed Plan Builder walks the practitioner through various watershed planning steps:

- watershed monitoring and assessment
- community outreach
- selection and application of available models
- best management practices
- implementation
- feedback

The Watershed Plan Builder will be available until September 30, 2007, for watershed organizations, federal and state agencies, tribes, universities and local governments to beta test the application and provide feedback.

Visit the Watershed Plan Builder website for more information: http://www.epa.gov/owow/watershedplanning/

EPA Releases Nonpoint Source Outreach Toolbox

The U.S. Environmental Protection Agency has released the Nonpoint Source Outreach Toolbox, a comprehensive set of Web-based resources designed to assist communities across the U.S. conduct watershed education and outreach activities. The Toolbox, online at www.epa.gov/nps/toolbox, includes a searchable catalog of nearly 800 print, radio, and TV ads and outreach materials in the following categories: lawn and garden care, motor vehicle care, pet care, septic system care, household chemicals and waste, and general stormwater and storm drain awareness. The Toolbox also provides EPA's publication *Getting in Step - A Guide to Conducting Watershed Outreach Campaigns,* as well as a comprehensive collection of surveys and evaluations of outreach programs from around the country and a collection of logos, slogans, and mascots to help unify a community's campaign.

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www.ncsu.edu/waterquality/issues/pub_order.html

MEETINGS

Meeting Announcements — 2007

June

2007 ASABE Annual International Meeting: June 17-20, 2007, Minneapolis, MN. Website: http://www.asabe.org/meetings/aim2007/index.htm

August

StormCon '07: August 20 - 23, 2007, Phoenix, AZ. Visit website at http://www.stormcon.com

15th National Nonpoint Source Monitoring Workshop: August 26-30, 2007, Austin, TX. See full announcement on Page 15.

October

WEFTEC.07: 80th Annual Technical Exhibition and Conference: October 13-17, 2007, San Diego, California. Visit website: http://www.weftec.org

November

43rd Mid-Atlantic Stream Restoration Conference: Science, Engineering, and Policy: November 7-8, 2007, Cumberland, MD. Sponsored by Canaan Valley Institute. Website: http://www.canaanvi.org/canaanvi_web/events_ed.aspx?collection=cvi_workshops&id=140

43rd AWRA Annual Water Resources Conference: November 12-15, 2007, Albuquerque, NM. Website: http://www.awra.org/

Meeting Announcements — 2008

November

2008 Southeast Regional Stream Restoration Conference, November 3-6, 2008, Asheville, NC. Website: http://www.ncsu.edu/sri

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Production of NWQEP NOTES is funded through U.S. Environmental Protection Agency (EPA). Project Officer: Tom Davenport, Office of Wetlands, Oceans, and Watersheds, EPA. 77 W. Jackson St., Chicago, IL 60604. Website: http://www.epa.gov/OWOW/NPS

15th National Nonpoint Source Monitoring Workshop

Monitoring for Decision Making
August 26-30, 2007
Austin, Texas
The Driskill Hotel
http://www.rivers.txstate.edu/NPS07

About the Conference: The 15th year of this workshop will once again bring together land managers and water quality specialists to share information on the effectiveness of BMPs in improving water quality, effective monitoring techniques, and statistical analysis of watershed data. The workshop will focus on the successes of Section 319 National Monitoring Program projects and other innovative projects from throughout the U.S. Topics include: Monitoring for decision making • NPS pollution and karst aquifers • Detecting change in water quality from BMP implementation • Modeling applications for NPS pollution and control strategies • Integrating social indicators monitoring with environmental monitoring • Innovative management strategies in agriculture and urban landscapes • Nonpoint source pollution TMDLs • River restoration projects • Presenting monitoring data to the Public • Monitoring the impacts of agricultural drainage management • Monitoring the long term impact of 319 projects • Innovative monitoring in agricultural and urban landscapes • Riparian area and stream protection/restoration • Programs and approaches for animal operations and nutrient management.

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