New York

New York City Watershed
Section 319
National Monitoring Program Project

Figure 30: New York City Watershed (New York) Project Location

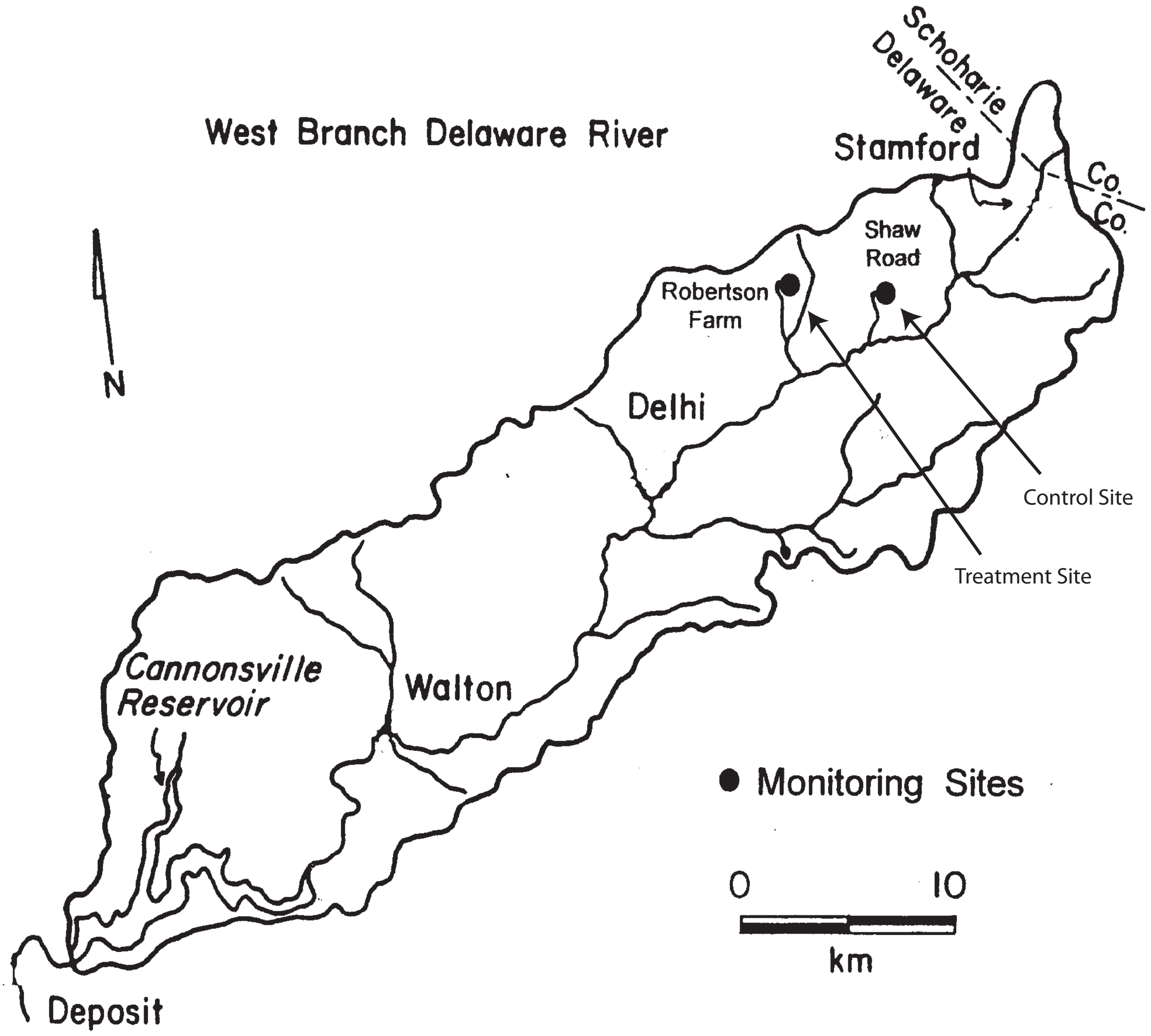


Figure 31: Water Quality Monitoring Stations for New York City Watershed (New York)

PROJECT OVERVIEW

New York City's three major systems of drinking water supply, the Catskill, Delaware, and Croton, are located to the north and northeast of the City within a 125-mile radius, and provide water for 9 million people. The total watershed area is 1,950 square miles, covering 8 New York counties and containing 19 surface water reservoirs. A major land use in the Catskill/Delaware portion of the watershed is agriculture; the approximately 350 farms located there are predominantly dairy and livestock enterprises.

The 1989 federal Surface Water Treatment Rule (SWTR) requires filtration for most water supply systems that draw water from surface sources. The SWTR provided for a waiver of the filtration requirement if the water supplier could meet certain objective and subjective criteria. As outlined in the SWTR, issues of concern fall into several categories: coliform bacteria, enteric viruses, *Giardia* sp., *Cryptosporidium* sp., turbidity, disinfection by-products, and watershed control. The City was able to demonstrate that the Catskill/Delaware supply met the objective criteria: (1) the source water met the turbidity and fecal coliform standards of the SWTR, (2) there were no source-related violations of the Coliform Rule, and (3) there were no waterborne disease outbreaks in the City. The subjective criteria of the SWTR required the City to demonstrate through ownership or agreements with landowners that it could control human activities in the watershed which might have an adverse impact on the microbiological quality of the source water. To demonstrate its eligibility for a filtration waiver, the NYC Department of Environmental Protection (DEP) advanced a program to assess and address water quality threats in the Catskill/Delaware system. This program has provided the basis for a series of waivers from the filtration requirements of the SWTR (January 1993; December 1993; January 1997; May 1997). The most recent waiver, issued in July 2007 for 10 years, is based on commitments by the City to provide $300 million for land acquisition, build a UV disinfection plant for the Catskill/Delaware supply, and continue to fund wastewater infrastructure initiatives, including residential septic system rehabilitation and maintenance programs, a new program for commercial septic systems, upgrades to existing wastewater plants, completion of ongoing projects for new wastewater treatment plants, three new community wastewater treatment projects, and two new sewer extension projects. The City will still be required to build a filtration plant by 2011 to treat water from the Croton system.

Based upon information collected through its extensive monitoring and research efforts, DEP designed a comprehensive watershed protection strategy, which focused on implementing both protective (antidegradation) and remedial (specific actions taken to reduce pollution generation from identified sources) initiatives. DEP's assessment efforts pointed to several key potential sources of pollutants: waterfowl on the reservoirs; wastewater treatment plants dischaging into watershed streams; failing septic systems; the approximately 350 farms located throughout the watershed; and stormwater runoff from development.

The NYC Watershed Agricultural Program (WAP), a voluntary incentive-based program, was established to implement the agricultural nonpoint source portion of the management program. Whole Farm Planning (WFP) was adopted by the WAP as the primary means of protecting NYC water supplies from farm-related nonpoint source pollution, as well as maintaining a viable agricultural community in the watershed. Beginning in 1993, ten demonstration farms in five counties were selected on which to develop, test and demonstrate the WFP method. Ultimately the WAP intended to have 85% of the farms within the watershed participating in WFP by 1997, a goal which has been met. While many of the Whole Farm plans for these farms have been completed, installation of the recommended practices is ongoing.

The New York State Department of Environmental Conservation (DEC) began studying one of the demonstration farms, the R. Farm, in 1993 in an effort to quantitatively evaluate the WFP approach for water quality protection and improvement. This study was later accepted into the Section 319 National Monitoring Program in June 1997.

The R. Farm, which is representative of upland agriculture in this hilly area is located in the West Branch of the Delaware River (WBDR) watershed where most of the dairy agriculture of the entire NYC watershed occurs. The WBDR, a class C[T] stream, is the primary tributary of Cannonsville Reservoir, which is used for NYC drinking water downstream water level maintenance, and trout fishing. Cannonsville Reservoir has had a long history of eutrophication problems due to excess loading of phosphorus from the WBDR associated primarily with dairy agriculture and point source discharges. Major sources of nonpoint phosphorus include land application of manure, barnyard runoff and overfertilization of cropland.

The project incorporated a paired watershed monitoring design, with the R. Farm as the treatment watershed and a forested watershed as the control. Monitoring included measurement of streamflow, precipitation, phosphorus, nitrogen, organic carbon, suspended sediment, pathogens and macroinvertebrates. In addition, records of farm activities before and after BMP implementation were kept.

The treatment and control sites were monitored for 2 years from June 1993 through May 1995, prior to BMP implementation at the treatment site in 1995-1996. Monitoring resumed in late 1996 and was originally scheduled to continue for 5 years. Another five years were added to the evaluation period for a total of ten years. The project ended in October 2006. The last three years of data will also be used to compare loadings from an upland to those of a monitored lowland farm in the Cannnonsville watershed. The final report is expected by December 2007.

PROJECT BACKGROUND

Project Area

The project consisted of two sites located in the Town of Kortright, Delaware County, New York, on tributaries to the WBDR. The treatment watershed is 396 acres (Fig. 1). The control watershed is 213 acres (Fig. 2).

Relevant Hydrologic, Geologic and Meteorological Factors

The WBDR watershed lies in the northwestern Catskill section of the Appalachian Plateau. The topography is rolling to mountainous; tributaries occupy steep-sided valleys, and the river's main stem occupies a broader valley. Elevation ranges from 1150 to 3315 feet above mean sea level. The average annual precipitation in the WBDR watershed is 40 inches; average annual temperature is 46°F. The climate is characterized as humid continental. Watershed geology consists of consolidated sedimentary bedrock overlain by unconsolidated glacial till and stratified deposits of clay, sand and gravel. Many soils in the WBDR basin are classified as highly erodible, are severely or very severely limited in their use for cultivation due to stoniness, excessive slope or wetness, and range from somewhat excessively drained to poorly drained.

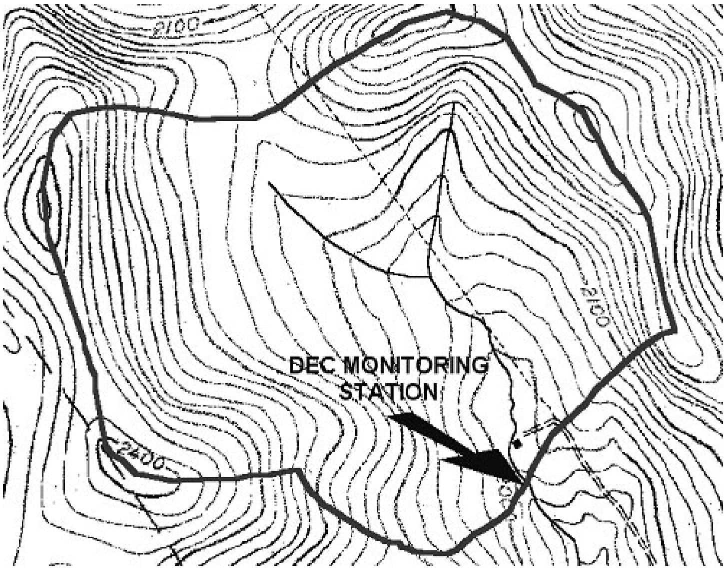
Land Use

The WBDR watershed covers an area of 350 mi^2 and comprises about 80% of Cannonsville Reservoir's total drainage area. Land use is approximately 73% forested, 25% agriculture and 2% urban/industrial.

Land use in the treatment watershed is improved pasture and hay: (25%); corn rotation (7%); unimproved pasture (13%), deciduous forest (53%) and impermeable (2%). At the beginning of the study, the farm had 70 dairy animals and 40 replacements, but has since increased herd size by about 15-20%. As is typical of upland dairy farms in the Catskills region, the barn is located in the valley bottom, close to a central stream. Intensively managed fields, which tend to be situated on the lower slopes of the watershed, include improved pasture, hay, and a rotation of tilled corn. Barnyards, roads, and farm infrastructure create impermeable surfaces, much of which is near the stream. During the grazing season (mid-May to end of October) cows must cross through or over streams and saturated areas to reach pasture.

The control watershed is comprised of forest land, abandoned field returning to forest, and shrub land. Several weekend residences and one permanent residence are located within the control watershed. In 2000, a landowner in the control watershed fenced an area and imported a small domestic deer herd.

Figure 1. Farm watershed.



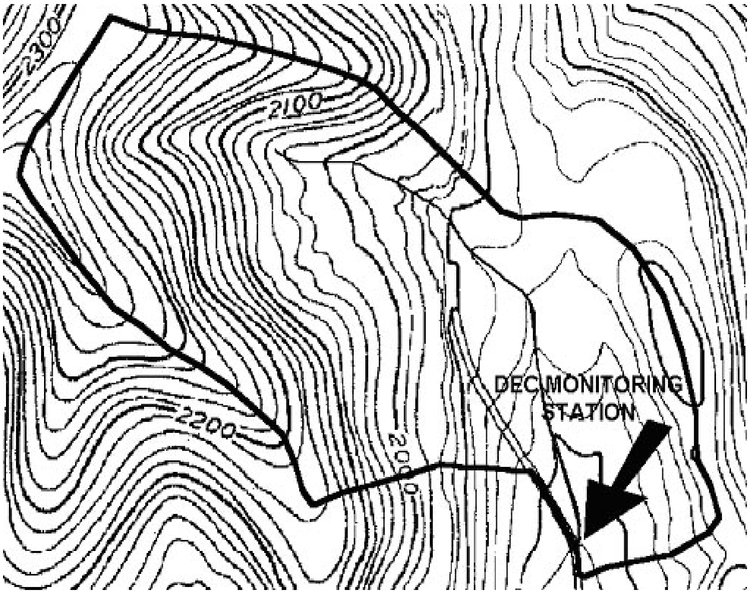


Figure 2. Control watershed.

Water Resource Type and Size

The study streams are small, first-order permanent streams that drain to theWBDR. Under baseflow conditions, they are generally 1-3 feet wide at the monitoring sites, but may increase to 15-20 feet wide during runoff events. Average annual stream discharge at the treatment site has ranged from 0.65 to 1.33 cfs during the study, while at the control it has ranged from 0.32 to 0.72 cfs.

The WBDR itself winds about a 50-mile course to the Cannonsville Reservoir and has an average annual discharge of 580 cfs. The reservoir has a total capacity of about 100 billion gallons and a surface area of about 5000 acres.

Water Uses and Impairments

The two study streams are the headwaters of tributaries that are classified C(T) or C(TS). However, they are too small to have been identified as having use impairments. It is unlikely that trout species travel as far upstream as the monitoring sites due to the shallowness and increased temperature of the water at those locations in the summer.

The WBDR is a highly regarded trout fishing resource in the county. Upstream of the reservoir, it has no use impairments. Cannonsville Reservoir is classified AA(T). It is used for NYC drinking water, trout fishing and maintenance of downstream river and temperature levels through hypolimnetic releases. However, throughout most of its history, eutrophication has impaired the designated uses of Cannonsville Reservoir for drinking water and trout survival and propagation. NYC uses Cannonsville less frequently for drinking water due to aesthetics problems associated with summer algal blooms. Higher temperatures in the epilimnion combined with hypoxia in the hypolimnion create difficult conditions for cold-water fish species. While the current water quality of the reservoir is sufficient to meet the filtration avoidance criteria, there is a continual threat of waterborne pathogens such as *Cryptosporidium* and *Giardia*, as well as sediment, entering and degrading the drinking water supply.

Pollutant Sources

In 1993 at the beginning of the study, the four largest municipal wastewater treatment plants in the WBDR watershed, along with dairy agriculture, were the primary pollutant sources in the Cannonsville basin. Point source phosphorus concentrations were in the 3 – 5 mg/L range. Major sources of nonpoint phosphorus included animal waste and fertilizers. Sources of the parasitic protozoa *Cryptosporidium* and *Giardia* were livestock, sewage, and wildlife.

By the end of the study, the four wastewater facilities had been upgraded to the highest levels of treatment such that phosphorus concentrations are now typically less than 20 ug/L in the effluent and removal of protozoan cysts is enhanced through use of microfiltration. Nearly all of the farms in the watershed have been improved through implementation of agricultural BMPs.

Pre-Project Water Quality

Event-based monitoring of the WBDR in the early 1980s, and again from 1991 to the present, has revealed that nonpoint sources typically contribute 70-80% of the annual load of dissolved phosphorus, which largely drives phytoplankton production in the Cannonsville Reservoir

Nutrient and sediment loadings from agriculture versus forested land are predictably unequal as illustrated by the results of the pre-implementation monitoring at the treatment and control sites (see Tables 4a and b). Estimated load rates from the agricultural portion of the treatment watershed, which is two-thirds forested, were considerably higher than those calculated for the entire watershed.

Water Quality Objectives

The main objective of this project was to test the ability of the WFP process to: a) correctly identify significant sources of on-farm pollution; and b) recommend and implement cost-effective management practices that will substantially reduce pollutant losses from those sources. This was done by quantifying reductions in nutrient and sediment loadings from the farm due to implementation of the Whole Farm Plan, and associating these reductions with specific changes made in management on the farm. In addition, modeling of the farm landscape, both temporally and spatially, has been accomplished in another effort to relate management decisions to changes seen in water quality over time.

Data have been used to test and calibrate watershed models that can predict the net effect on water quality after those farms in the WBDR watershed participating in the WAP complete BMP implementation. Ultimately, this is expected to produce estimates of changes in pollutant loads delivered to Cannonsville Reservoir as a result of this program.

Project Time Frame

1993-2006

PROJECT DESIGN

Paired Watershed

Although this study utilized a paired watershed approach (e.g., Wilm, 1949; Reinhardt; 1967, Clausen and Spooner, 1993; Galeone 1999), it differed from the traditional design in that the two watersheds were not alike in their land use. A non-farm control was selected because it was expected that no significant changes would be made in the watershed during the study period. In contrast, working farms often change operations during the course of a long-term study, or may go out of business altogether and, thus, may not provide the consistent control necessary for describing natural environmental variability. Located in Delaware County within five miles of each other at the headwaters of tributaries that drain to the WBDR, the two watersheds are similar in size, elevation, and soil conditions. The farm watershed was monitored before and after BMP implementation to assess changes in water quality. The non-farm site was monitored concurrently and provided control for with inter-annual and seasonal hydrologic variability. This design also enable an assessment of the degree to which water quality from the farm might approach "background" water quality after BMP implementation.

The treatment watershed is 396 acres (160 ha) and consists almost entirely of the R. farm itself (Fig. 1). The farm is situated at the headwaters of a small tributary that drains to Wright Brook, which then drains to the WBDR. Watershed elevation at the farm site ranges between 2400 ft. and 1800 ft. above sea level. Pollutant problem areas identified on the farm prior to WFP implementation included surface spreading of manure, particularly on snow and frozen ground, barnyard runoff, high soil phosphorus levels on certain crop fields, uncontrolled livestock access to stream, milkhouse waste discharged into the stream, silage leachate draining near the stream from an "ag bag", and sediment losses from farm roads and eroding stream banks. Further assessment of the farm in more recent years has identified importation of animal feed as an additional source of excess phosphorus on the farm.

At the control site, the watershed encompasses 213 acres (86 ha) (Fig. 2). Elevation ranges between 2380 ft. and 1760 ft. above sea level. Small modifications were made by a landowner in this watershed in 1997 which involved collection of overland runoff and diversion into a pipe emptying to the road ditch. This likely did not change the amount of runoff reaching the monitoring station as the flow pattern was previously spread out over the road, but eventually reached the ditch.

The treatment and control sites were monitored for two years, from June 1993 to May 1995, prior to implementation of any practices. The BMPs recommended in the farm's Whole Farm Plan were then installed at the treatment site (Table 1). These practices were, for the most part, completed by the fall of 1996 and totaled nearly $300,000 in cost. However, additional BMPs have been installed at this farm since the initial round (see below: Modifications Since Start).

Table 1. Best management practices (BMPs) implemented on the farm watershed in Phase 1.

Near-barn improvements:
Installation of manure storage lagoon
Barnyard improvement including outside water management
Filter area established for barnyard runoff
Stream corridor relocated away from barnyard
Grazing cows excluded from stream/swale areas
Milkhouse washwater diverted from stream discharge to manure storage
Relocation of silage storage bag away from stream
Improvement of stream crossings and roadways
Watershed scale improvements:
Access roads constructed to allow manure spreading on upper slopes
Distributed manure spreading according to nutrient management plan
Fencing improvements to support rotational grazing
Spring development to supply drinking water away from the stream
Diversion ditches to improve field drainage
Subsurface drainage to reduce field saturation
Contour strip cropping to reduce erosion
Crop rotation to reduce erosion

Post-implementation monitoring began in November 1996 and continued for 10 years. Comparison of before and after water quality from the farm, with reference to the control site to account for natural inter-annual variability, was used to document effectiveness of WFP practices. Detailed records of farm activities, such as location and amount of manure spreading and fertilizer used, were kept in order to relate changes in water quality to changes in farm practices.

Water Quality Monitoring

Sampling Scheme

Automated monitoring stations were installed on the tributaries of the farm and control sites. Streamflow and precipitation were continuously recorded by data-loggers which trigger automatic sample collection during runoff events upon rise in stream stage and/or onset of precipitation. Frequency of sample collection over the course of the event varied, depending on rate of stream rise or fall, up to a maximum of one every 10 minutes. Samples were also collected on a routine basis during base-flow periods at least one per week. All were analyzed for nutrients (3 forms each of phosphorus and nitrogen), organic carbon and suspended sediment. Streamflow volumes and nutrient and sediment loads were calculated. Sampling for macroinvertebrates was first conducted at both sites in July 1996 prior to completion of BMP implementation. Post-implementation bioassessment monitoring was performed once a year during the summer season through 2001.

Variables Measured

Biological

Macroinvertebrates

Chemical and Other

Particulate phosphorus (PP)
Total dissolved phosphorus (TDP)
Soluble reactive phosphorus (SRP)
Nitrate + nitrite (NO_X)
Total ammonia (T-NH_3)
Total Kjeldahl nitrogen (TKN)
Total organic carbon (TOC)
Total suspended solids (TSS)

Alkalinity
pH

Covariates

Runoff
Precipitation

Monitoring Scheme for the New York City Watershed 319 National Monitoring Program Project

Design	Sites or Activities	Primary Parameters	Covariates	Frequency of WQ Sampling	Frequency of Biological/Habitat Assessment	Duration
Paired	BMP farm Site Control non-ag Site	PP TDP SRP NOx T-NH3 TKN TOC TSS pH Alkalinity	Rainfall Runoff	Once/wk at low flow Storm event up to once every 10 min.	Once a year in July	2yr pre-BMP 1 ½ yr BMP installation 9yr post-BMP

Land Treatment Monitoring

The farm operator at the treatment site kept daily records of manure placement and quantity by field before and after BMP implementation. Manure analysis was performed several times. Soil test P has been compared by field before and after as well. Other record keeping included usage of commercial fertilizer and pesticides, and herd rotation in grazing paddocks.

Modifications Since Project Start

Original plans called for all BMPs to be installed within one year. However, due to the extent of treatment on this farm, startup of post-implementation monitoring was delayed by about 5 months until November 1996 when the practices listed in Table 1 were completed. After several years of monitoring, a former machine shed used as a shelter area for dry cows and heifers was identified as a high contributing source area. Located just upstream of the monitoring station, a cattle path led from it down a steep, eroded slope through the stream and up the opposite bank to a pasture area. In late summer of 2001, a stream crossing was constructed to exclude the cows, and the banks were repaired and revegetated.

In January 2001, this farm was selected for participation in a pilot program of precision feeding to reduce phosphorus importation on dairy farms from purchased feed. Feeds and homegrown forages were analyzed for their protein, carbohydrate and mineral contents and the nutritional needs of the herd were determined using the *cu*NMPS (Cornell University Nutrient Management Planning System) software. Diets were adjusted and as a result, phosphorus imported onto the farm in purchased feed was reduced by 30%. This directly translated into a 30% reduction in phosphorus excreted by the cow (Cerosaletti et.al, 2004).

Installation of a spring development and remote watering system was performed in 2001 on the farm, resulting in less cattle traffic in and around the stream.

It was expected that additional improvements to water quality would result from the new management practices described above. Thus, post-implementation sampling was extended from 5 to 10 years in order to observe the effects of these more recent farm management improvements. To differentiate between the two treatment phases, the post-implementation period was split into Phase 1: initial round of BMPs, and Phase 2: initial round plus BMPs since 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. Analysis of data, therefore, focuses on changes in water quality between the Pre-BMP period and Phase 1, and changes between Phase 1 and Phase 2.

In summer of 2002 (Post-6), there was a failure of the manure storage system and a portion of the lagoon contents back-flowed through the barn eventually reaching the stream. The spill was largely cleaned up within a few days, but enough manure remained in the stream bed and near-stream areas to produce elevated nutrient concentrations during the next several runoff events.

Progress to Date

The study is completed. Data have been analyzed for the two-year pre-implementation phase and ten-year post-implementation phase.

DATA MANAGEMENT AND ANALYSIS

Data Management and Storage

Water quality data were stored in Microsoft Excel workbooks. Data analysis was conducted using Excel, Statistica and S-Plus statistical software.

NPSMS Data Summary

Not available

Findings to Date

Water Quality Results

Table 2 shows the dates corresponding to each monitoring year and the number of samples collected during these periods. Over 1,300 samples were collected during the two Pre years and about 5,900 during the ten Post years. The bulk of samples each year were collected during runoff events. The number of samples collected in a year generally varied directly with amount of runoff produced (also see Table 4a).

Stream water nutrient and sediment concentrations at the farm were typically three to twenty times higher than at the control site during events (Table 3), reflecting the more intensive land use and presence of livestock. As one of the objectives of the study was to determine if farm runoff quality could be improved enough to approach background water quality, given the amount of BMP implementation that occurred, it is apparent from the comparison in Table 3 that concentrations of pollutants in farm runoff were still elevated considerably after treatment compared to control levels.

Annual runoff and loads of nutrients and sediment were substantially greater at the farm site than at the control site (Tables 4a and 4b). The more intensive land use and somewhat greater watershed area of the farm site are obvious factors that contribute to this result. Source track-down studies revealed that much of the load leaving the farm was generated on the most intensively utilized portion of the farm consisting of the farmstead area and fields spread with manure.

Runoff varied somewhat over the twelve years due to variations in precipitation amounts and timing (Table 4a). Annual loads were variable at the farm, less so at the control, and tended to be smaller in years with less runoff. 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. 3). 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.

Table 2. **Study periods and number of samples collected during study.**

	Period	Farm	Control	Total
Pre-1	6/1/93 – 5/31/94	468 331 79		9
Pre-2	6/1/94 – 5/31/95	315 212 52		7
Post-1	11/1/96 – 10/31/97	416	232	648
Post-2	11/1/97 – 10/31/98	483	262	745
Post-3	11/1/98 – 10/31/99	273	191	464
Post-4	11/1/99 – 10/31/00	403	275	678
Post-5	11/1/00 – 10/31/01	206	137	343
Post-6	11/1/01 – 10/31/02	305	162	467
Post-7	11/1/02 – 10/31/03	299	209	508
Post-8	11/1/03 – 10/31/04	475	291	766
Post-9	11/1/04 – 10/31/05	387	204	591
Post-10	11/1/05 – 10/31/06	443	282	725
Total		4,475	2,788	7,263

Table 3. Average event concentrations computed as event load divided by event flow volume for each of the three study phases at the farm (F) and control (C) sites. Concentrations in ug/L except for TSS, which is in mg/L.

	PP		TDP		T-NH_3		NOX		TSS	
	F	**C**	**F**	**C**	**F**	**C**	**F**	**C**	**F**	**C**
Pre-BMP	202	35	94	12	197	10 607	147		85.2	23.3
Phase 1	234 5	1	81	13 122		11	795	132	97.2	30.9
Phase 2	219 6	5	79	13	102	16	530	65	105.6	44.3

Analysis of Events

Throughout the study, runoff events accounted for a substantial portion of the annual loading of most analytes. Typically, 75 – 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 – 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.

Table 4a. **Annual runoff (cm) and loads (kg·ha^{-1}) of phosphorus and sediment at farm and control sites.**

	Runoff		PP		TDP		TSS	
	Farm	**Control**	**Farm**	**Control**	**Farm**	**Control**	**Farm**	**Control**
Pre-1	70.4	59.9	0.57	0.08	0.47	0.05	217	45
Pre-2	52.7	49.4	0.61	0.10	0.49	0.04	231	61
Post-1	60.1	55.1	0.79	0.14	0.20	0.05	343	76
Post-2	60.7	54.2	0.70	0.13	0.27	0.05	298	75
Post-3	36.3	36.2	0.29	0.12	0.22	0.04	108	74
Post-4	70.2	53.9	1.04	0.12	0.42	0.05	384	70
Post-5	38.4	32.1	0.33	0.08	0.29	0.03	135	37
Post-6[a]	39.2	35.4	0.58	0.05	0.20	0.03	253	30
Post-7	74.1	51.0	0.54	0.07	0.42	0.05	211	47
Post-8	66.5	71.4	0.93	0.24	0.38	0.08	453	154
Post-9	59.1	62.0	0.61	0.27	0.33	0.06	314	166
Post-10								

[a] Farm values calculated with manure spill load removed from the analysis.

Table 4b. **Annual runoff (cm) and loads of nitrogen and organic carbon (kg·ha^{-1}) at farm and control sites*.**

	NH_3-N		NOX-N		TKN-N		TOC	
	Farm	**Control**	**Farm**	**Control**	**Farm**	**Control**	**Farm**	**Control**
Pre-1	1.04	0.04	3.77	0.76	2.72	0.77	29.1	14.8
Pre-2	0.50	0.05	2.23	0.48	1.99	0.91	30.0	14.9
Post-1	0.36	0.05	3.47	0.62	2.63	1.09	25.2	17.3
Post-2	0.44	0.03	4.87	0.55	3.16	1.47	29.0	18.6
Post-3	0.25	0.04	2.43	0.60	1.69	0.93	16.5	13.2
Post-4	0.64	0.05	3.76	0.47	4.51	1.18	33.3	16.6
Post-5	0.48	0.03	3.77	0.33	2.38	0.74	15.1	8.7
Post-6[a]	0.28	0.05	1.88	0.29	2.93	0.88	20.3	10.8
Post-7	0.72	0.11	4.27	0.35	4.62	1.26	35.3	16.0

* Sampling for nitrogen and carbon was discontinued after Post-7.

[a] Farm values calculated with manure spill load removed from the analysis.

Table 5. 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.

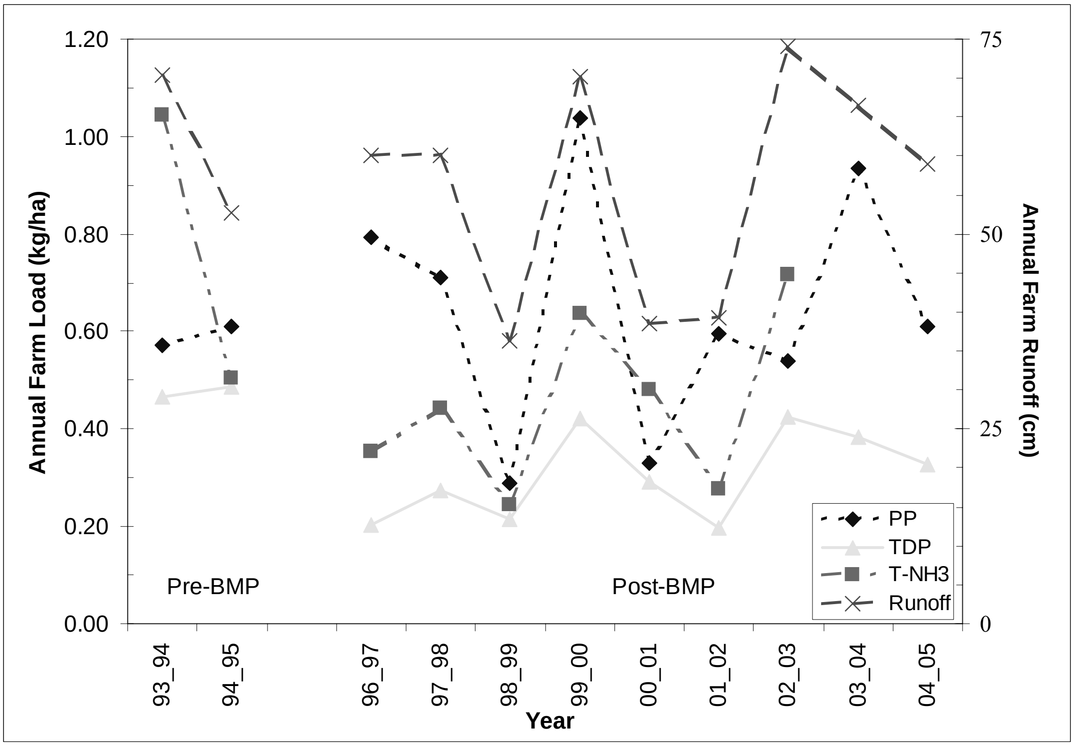
	Number of Matched Events			
Season	Pre-BMP†	Phase 1‡	Phase 2§	Total
Winter (16 December–13 April)	33	70	33	136
Spring (14 April–15 June)	12	33	27	72
Summer (16 June–30 September)	17	35	48	100
Fall (1 October–15 December)	12	29	28	69
Full year	74	167	136	377

† June 1993 – May 1995

‡ November 1996 – April 2001

§ May 2001 – October 2005

Figure 3. Annual farm loads of selected analytes during the eleven study years. PP = particulate phosphorus, TDP = total dissolved phosphorus, T-NH_3 = total ammonia.



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 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.

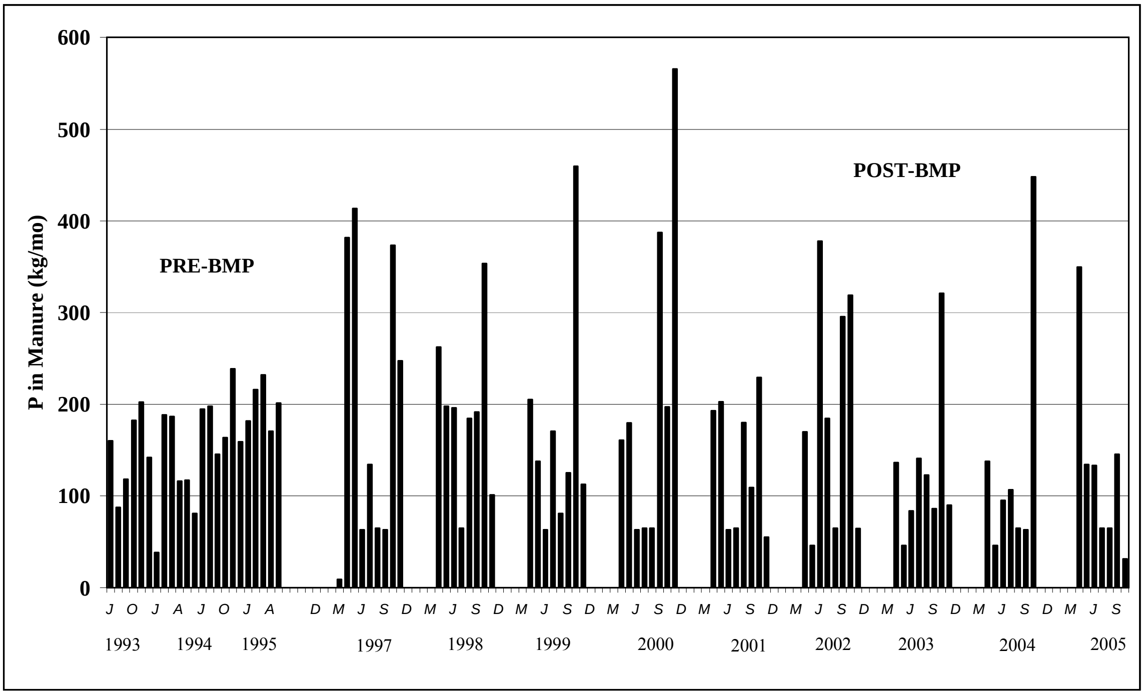
Over the course of the study, 486 runoff events were observed and sampled. One hundred and eight of these events were removed from the analysis because they were unmatched (event at farm but not at control: n=87; or vice-versa: n=21). Unmatched events occurred mainly when event size was small, so analysis of seasonal loading trends for the farm watershed was not affected by their removal. One additional event (28 Jan. 1994) 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 (Table 5). Data were grouped (Table 5) to reflect seasonal variation in both land application of manure, (considered a primary source of nutrients on the farm) following BMP implementation and hydrologic runoff processes (wet versus dry periods). Manure in the PRE-BMP period was daily spread, while in the POST-BMP period, manure was stored from mid-December to about mid-April and then spread heavily in spring and fall and less heavily in summer. Figure 4, which shows the monthly P contained in both land-applied manure and manure deposited by pastured cows, illustrates this change in spreading pattern. Approximate begin and end dates for the dry period and timing of manure spreading were used to define seasonal date ranges.

Statistical Model to Evaluate Event Loads

The following discussion of the statistical analysis is based on Bishop et al. (2005). A complete discussion of the development of the statistical model may be found there.

USEPA recommends an analysis of covariance (ANCOVA) model for paired watershed data analysis, using matched event loads from control and treatment watersheds to determine effects of

Figure 4. Monthly P in manure applied on the farm watershed from spreading and pastured cows. One load manure = 4.6 kg P.



BMPs (USEPA 1993, 1997a, 1997b). In addition to event load at the control site, several available covariates were employed during this study 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. The control event load reflects 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 pollutant loading processes associated with the farm landscape. All of these variables can be considered for use as covariates in an ANCOVA model evaluating post-treatment changes in farm event pollutant loads, as long as they did not change in response to the BMP treatments. Variation in farm event pollutant loads that is not explained by the combined covariates can be attributed to pre-treatment versus post-treatment effects, represented by an indicator variable, k, or to unexplained error, ε.

The natural log transformation was employed to normalize the distribution of event magnitude, as is common practice (Cohn et al., 1989; USEPA, 1997b). The complete multivariate regression model, which was applied to both the seasonal and full-year dataset, is written as:

$$\ln(Pf_i) = a + b\ln(Pnf_i) + c\ln(Qf_i/Qnf_i) + d\ln(peak\ Qf_i) + e\ln(QRf_i) + fk_i + gk_i[\ln(Pnf_i) - m] + \varepsilon_i \qquad [1]$$

where ln is the natural logarithm, i is the event index, Pf_i is the farm event load for the pollutant of interest for event i, Pnf_i is the matched nonfarm event load for the pollutant of interest for event i, Qf_i is the farm event flow volume for event i, Qnf_i is the matched nonfarm event flow volume for event i, peak Qf_i is the farm instantaneous peak flow rate for event i, QRf_i is the average farm flow rate (volume/duration) for event i, k_i is the BMP treatment index variable, m is the average of $\ln(Pnf_i)$ during the post-BMP period, and ε_i is the residual error, assumed to be independently distributed. For simplicity in the following text, the interaction term $k_i[\ln(Pnf_i) - m]$ is denoted as $k\ln Pnf$. Interpretation and discussion of these model terms are given below.

1. *a*: The intercept accounts for differences in watershed area and land use, as well as the greater magnitude of pollutant losses from the farm site. The farm watershed (160 ha) is 1.9 times the size of the nonfarm watershed (86 ha).

2. $\ln(Pnf_i)$: Event loads from the nonfarm watershed reflect background environmental factors, including event magnitude, antecedent soil moisture, rainfall intensity, and seasonal variation in watershed hydrological processes.
3. $\ln(Qf_i/Qnf_i)$: This flow ratio term accounts for imbalances in matched-event precipitation between the two study watersheds (amount and intensity, and subsequent variation in runoff volume) that make $\ln(Pnf_i)$ a less than perfect predictor of $\ln(Pf_i)$. Because event loads and flows are highly correlated (load is the product of flow and concentration), and it is the imbalance that is likely to be important, the farm and nonfarm flow variables were combined into a single covariate (Qf/Qnf), thereby reducing multi-collinearity.
4. $\ln(peak\ Qf_i)$: This term represents environmental processes affecting farm load that vary with event magnitude, yet are not captured by the control watershed variables because of differences between the farm and nonfarm landscape. For example, sediment loading from impermeable near-stream areas, which are more prevalent on the farm, is expected to correlate with event peak flow
5. $\ln(QRf_i)$: The average farm event flow rate is an indicator of event intensity. Again, particulate detachment and transport processes at the farm and control watersheds should respond differently under differing runoff intensities, due to the greater percentage of impermeable and unvegetated areas in the farm landscape.
6. k_i: The coefficient f associated with this BMP treatment index variable describes the log-change in farm event loads between the pre- and post-treatment periods ($k = 0$ for the pre-BMP period; $k = 1$ for the post-BMP period).

$k\ln Pnf$: This interaction term allows for a change in regression slope between the pre- and post-BMP periods. The term was made orthogonal to the BMP treatment index variable by subtracting m from $\ln(Pnf)$, where m is the average value of $\ln(Pnf)$ over the post-BMP period. Consequently, addition of this interaction term to the model had relatively little effect on the coefficient of k. Significance of the $k\ln Pnf$ term would indicate that the BMPs performed differently under high- versus low-flow events, in which case analysis of treatment effects becomes more complex as load reductions would then vary with event magnitude.

The treatment period interaction covariate $k\ln Pnf$, which was included in the model to allow for PRE- vs. POST-BMP changes in the regression slope, was not significant in most of the seasonal and full-year analyses. In those cases it was dropped from the model prior to calculation of treatment effects. Significance of the $k \cdot \ln P_{nf}$ term may point to seasons or situations where the BMPs are performing differently under high- versus low-flow events.

The use of the flow ratio term $\ln(Qf/Qnf)$ as an explanatory covariate is only valid if the BMPs are assumed to have no effect on the relationship between precipitation and runoff production at the farm site. This assumption was tested using the model:

$$\ln(Qf_i) = a + b\ \ln(Qnf_i) + f\ k_i + \varepsilon_i \qquad [2]$$

The analysis found no significant pre- vs. post-treatment differences in the matched watershed flow relationship for any season, nor for the full-year (f not significant at a = 5%). Overall, adoption of BMPs did not seem to produce significant changes in the relationship of farm runoff volume and precipitation characteristics, and $\ln(Qf/Qnf)$ could therefore be safely used as a predictor variable.

For each seasonal and full-year dataset, the full multivariate model was fit and non-significant terms were subsequently dropped. Confidence intervals (CI_{95}) for reductions in event loads were calculated. For most cases where $k\ln Pnf$ was not significant, the analysis was based upon the multivariate model:

$$\ln(Pf_i) = a + b\ \ln(Pnf_i) + c\ \ln(Qf_i/Qnf_i) + d\ \ln(peakQf_i) + e\ \ln(QRf_i) + f\ k_i + \varepsilon_i \qquad [3]$$

Differences in pre- vs. post-BMP event P loading were based on a one-sided t test on the f coefficient in Eq. [2] using a 5% significance level.

Model Results

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 6). When data from the full-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.

Table 6. Percent reductions event loads between pre-BMP and Phase 1 post-BMP, and between Phase 1 with Phase 2 post-BMP *. 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	[‡]
T-NH$_3$					
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[‡] -2	1[‡]	**-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[‡] -1	2[‡] -9	[‡] 18	[‡] -4	8[‡]
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) and 95% confidence interval (CI_L / CI_U).

[‡] Indicates non-significant ($p > 0.05$) change.

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

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

By comparing event loading in Phase 1 to Phase 2, it was determined that additional reductions occurred after the second round of practices were installed on the farm for some analytes (Table 6). In Phase 2 TDP and T-NH3 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, T-NH3 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. 4). 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 6). Total 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. 4).

Fall (1 October–14 December)

Significant event load reductions after Phase 1 were not observed during the fall season for any analytes (Table 6). Increased fall manure spreading in the post-BMP period (Fig. 4) 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. 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, T-NH_3 and TOC event loads showed nonsignificant ($p > 0.05$) reductions ranging from 15 – 24%. Manure was heavily surface-applied in the spring months (Fig. 4) 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 trafic 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 $T\text{-}NH_3$ 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, due to the confounding effects of interannual variability it made more sense to examine baseflow sample concentrations for any significant changes during the study period.

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 $T\text{-}NH_3$ 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 7). 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 $T\text{-}NH_3$ and TKN, winter SRP and TKN, and spring T-NH3 were also observed between Phase 1 and Phase 2 baseflow concentrations.

Table 7. 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-BMP 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)
$T\text{-}NH_3$	**68** (61/74)	-
TKN	**-15** (-2/-28)	**-28** (-15/-42)
TOC	-	**-16** (-7/-26)

[†] Percent reduction (bold) and 95% confidence interval (CI_L / CI_U.

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.

Although the farm baseflow concentrations were reduced over the course of the study they still remain quite elevated when compared to those measured at the control site. Average annual baseflow concentrations computed as baseflow load divided by baseflow volume are shown in Table 8. As observed with event periods, it appears that BMPs may be able to reduce farm losses to varying degrees, but for most pollutants they are unlikely to ever control these losses to the point where the quality of water from intensively used agricultural land begins to approach that from forested, non-farm areas. Baseflow concentrations of TDP, T-NH_3 and NOX were all still considerably higher in Phase 1 and 2, although PP and TSS did approach the magnitude of those observed at the control site after practice implementation (Table 8).

Table 8. Average baseflow concentrations computed as baseflow load divided by baseflow flow volume for each of the three study phases at the farm (F) and control (C) sites. Concentrations in ug/L except for TSS, which is in mg/L.

	PP		TDP		T-NH_3		NOX		TSS	
	F	**C**	**F**	**C**	**F**	**C**	**F**	**C**	**F**	**C**
Pre-BMP	37	8	68	7	86	7	420	99	9.4	4.1
Phase 1	21	10	27	7	42	6	568	96	6.0	4.9
Phase 2	18	10	35	8	66	14	503	55	4.6	4.6

Total Farm Reductions

The overall effect of BMPs on the farm may be estimated by adding the event reductions to the baseflow reductions. Table 8 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, 64% and 53% respectively, 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 60-70% 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 6) 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 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 program 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.

INFORMATION, EDUCATION AND PUBLICITY

Tours conducted by the Watershed Agricultural Council have included stops at the R. farm to view the WFP practices and monitoring station. Numerous publications, including newsletters, have been prepared to disseminate information on the WAP. Workshops on WFP plan preparation and in-service training sessions have been held and a printed WFP guide and environmental audit procedure have been developed. The website for the WAP and its activities can be accessed at http://www.nycwatershed.org/.

TOTAL PROJECT BUDGET

NRCS provided consulting and design services for the BMPs. NYSDEC project personnel are funded through the state. The majority of funds to pay for both the BMPs and the monitoring comes from NYC Department of Environmental Protection. There was also local input in the form of the farmers' time in helping to prepare the Whole Farm Plans and those that serve on the Watershed Agricultural Council. Approximate costs are as follows:

Monitoring	
Installation of stations:	~$85,000
Operation of stations:	$5,000/year
Analytical services:	$60,000/year
Personnel:	~$150,000/year
Misc.:	$8,000/year
BMPs:	~$350,000+

IMPACT OF OTHER FEDERAL AND STATE PROGRAMS

Unknown

OTHER PERTINENT INFORMATION

None.

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