Pennsylvania

Stroud Preserve Watershed
Section 319
National Monitoring Program Project

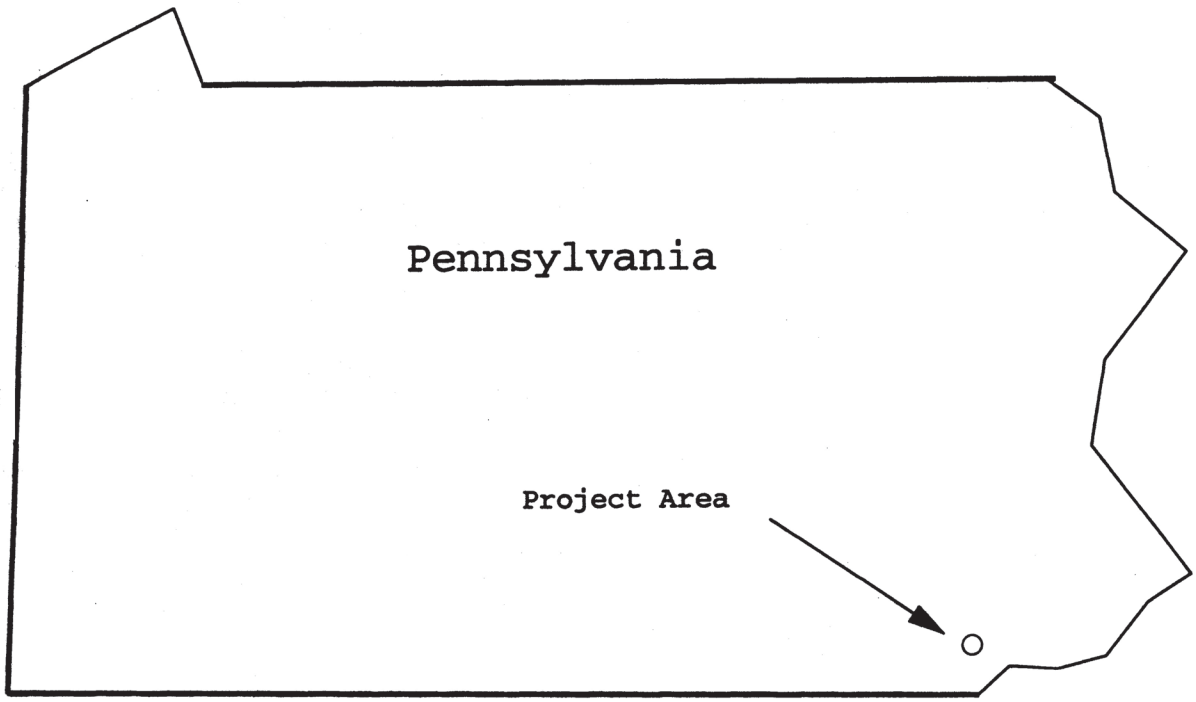

Figure 37: Stroud Preserve (Pennsylvania) Watershed Project Location

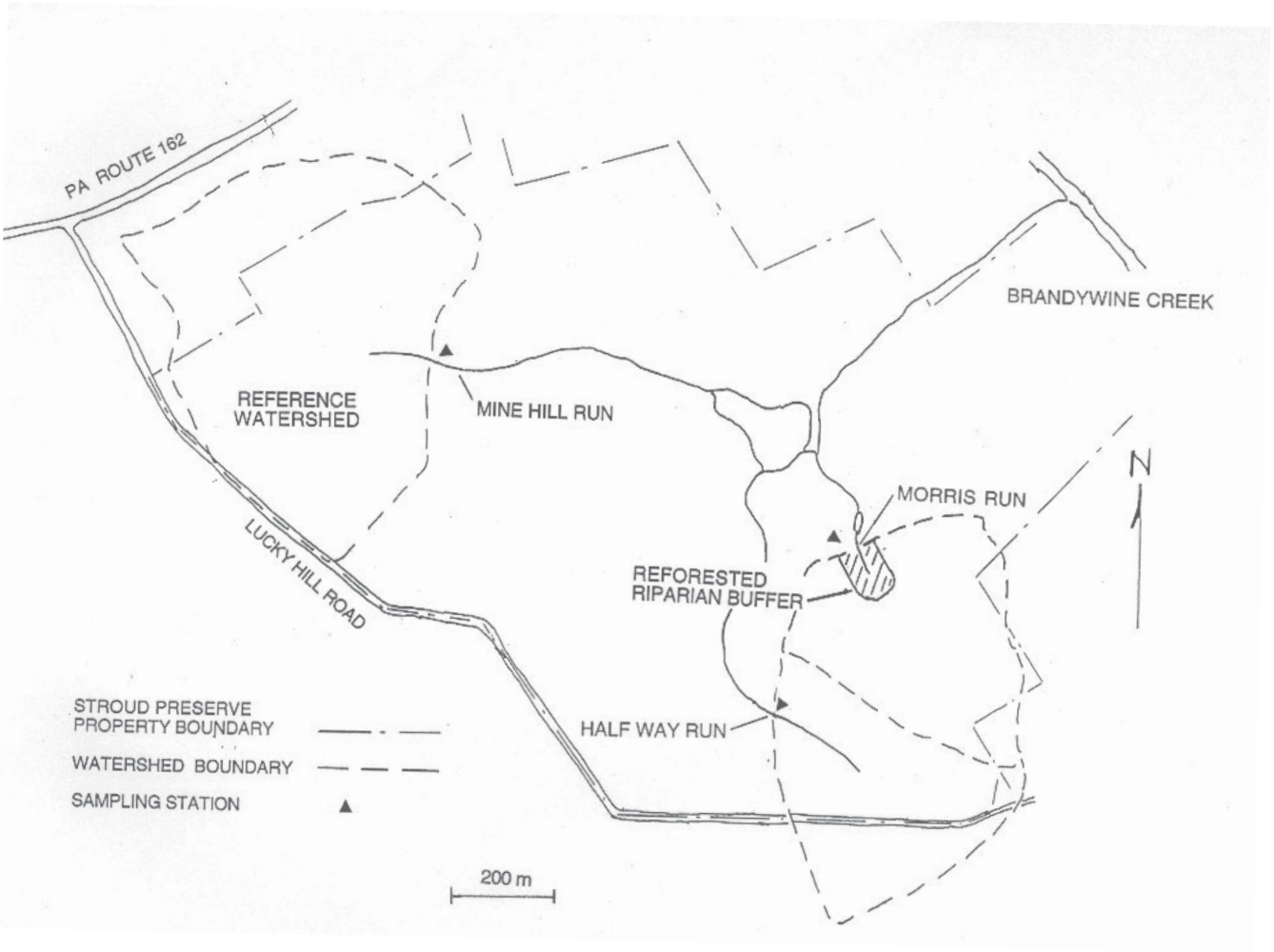

Figure 38: Sampling Stations and Boundaries for Stroud Preserve (Pennsylvania) Watershed

PROJECT OVERVIEW

The Stroud Preserve riparian reforestation project is a demonstration of the three-zone Riparian Forest Buffer System (RFBS) developed by the U.S.D.A. Forest Service. Initiated in 1992, the project involves three experimental agricultural watersheds in the Stroud Preserve, a southeastern Pennsylvania farm protected by conservation easements. The streams are in the drainage of the Brandywine River, which flows into the Delaware Estuary. Prior to 1992, all three watersheds were primarily in crop production (maize, soybeans, hay) under a soil conservation plan including contouring and crop rotation. Water quality was compromised by elevated nutrients and suspended sediments.

The primary objectives of this project are to: (1) evaluate the non-point source reductions of the RFBS in the relatively high-relief terrain of the Mid-Atlantic Piedmont, (2) assess the time required after reforestion to achieve significant mitigation, and (3) establish specific guidelines for planting and managing forest buffers zones in the mid-Atlantic region.

The RFBS consists of: Zone 1, a streamside strip (~5 m) of permanent woody vegetation for stream habitat protection; Zone 2, an 18-20 m strip of managed forest upslope from Zone 2; and Zone 3, a 6-10 m wide grass filter strip. The RFBS was established between 1992 and 1994 in a 16-ha watershed (Morris Run) that is primarily in row crop production. Zone 1 included existing streambank trees; Zone 2 was converted from hay and crops to hardwood seedlings; and a level-lip spreader (to disperse concentrated overland flow) was constructed in Zone 3. A second treatment watershed (Half Way Run) was taken out of agricultural production and reforested in its entirety. The third watershed (Mine Hill Run) is being maintained in agricultural production comparable to that of Morris Run, as a long-term reference watershed.

The monitoring design uses paired watersheds supplemented by mass balance estimates of nutrient removal by the riparian forest buffer**.** Water quality monitoring for nutrients and suspended sediments includes grab samples collected every 14 days from all three streams, intensive sampling storm runoff eight times a year (Morris Run and Mine Hill Run), sampling of overland flow (Morris Run), and quarterly sampling of groundwater (Morris Run).

PROJECT BACKGROUND

Project Area

The project is being carried out within the Stroud Preserve, a 197-hectare tract held in conservation easements that assure control over land-use in perpetuity. The area in riparian reforestation is approximately 1 hectare of the 16.2 ha of the Morris Run watershed. The location of the sampling station at Morris Run is 39º56' 41" N, 75º39’13"W.

Relevant Hydrologic, Geologic, and Meteorological Factors

The average annual precipitation is 115 mm (45 inches). Soils on the Preserve are mainly typic hapludults, but those in the riparian areas are aquic fragiudults. A weathered rock or saprolyte extends to a typical depth of 5-7 m with a bedrock consisting mainly of fractured schist. Slopes average about 10%.

Land Use

All but a few hectares of the Morris Run watershed are maintained in contoured strips under a crop rotation program established by the U.S.D.A. Natural Resources Conservation Service (NRCS). The primary crops are maize, soybeans, and hay (alfalfa). Records are being kept of all fertilizer applications, and of crop yields.

Most of the watershed of Mine Hill Run, the reference watershed, is planted in alfalfa, maize, and soybeans, also under NRCS conservation tillage. A sparsely forested, brushy zone extends 50-200 m from the stream. Land use in this watershed is being maintained without alteration.

The Half Way Run Watershed was in production for row crops and hay prior to 1992 when it was reforested with hardwood seedlings.

Water Resource Type and Size

Morris Run, Mine Hill Run, and Half Way Run are perennial headwater streams in watersheds of 16.2, 36.1, and 15.1 hectares, respectively. They flow into the Brandywine River, which has a 750-km^2 watershed, and is a tributary to the Delaware Estuary.

Water Uses and Impairments

The Brandywine River provides varied water supply and recreational uses and is classified for warm water and migratory fishes in its lower reaches, trout stocking and cold water fishes in various upper reaches. Agricultural sources contribute to elevated nutrient concentrations and sediment loads.

Pollutant Sources

Agricultural fertilizers and atmospheric deposition are the primary sources for elevated exports of nitrogen from the basins. Erosion from tilled fields is the primary source of sediment export. Both erosion and fertilization contribute to elevated phosphorus exports.

Pre-Project Water Quality

Grab samples taken in August 1991 yielded the following:

	Morris Run	**Half Way Run**
Nitrate-N (mg/L)	3.6	2.7
Ammonia-N (mg/L)	0.10	0.05
Dissolved Orthophosphate-P (mg/L)	.029	0.020

Water Quality Objectives

Primary objectives of this project are to: 1) demonstrate the effectiveness of riparian reforestation, when used in conjunction with sound nutrient management and erosion control practices on uplands, in reducing non-point source pollution from agricultural sources and 2) to establish specific guidelines for planting and managing forest buffers zones in the mid-Atlantic region.

Project Time Frame

Initiation of routine water chemistry sampling: Jan 1992
Planting of riparian zone in hardwood seedlings: Apr 1992
Installation of level spreader: May 1994
NMP Monitoring Project: Apr 1997-Mar 2005

PROJECT DESIGN

Nonpoint Source Control Strategy

A riparian forest buffer system was established in Morris Run (the treatment watershed) in April of 1992, in accordance with the specification published by the U.S.D.A. Forest Service (Welsch 1991, Publication NA-PR-07-91). Seedlings of Sugar Maple, Red Oak, Tulip Poplar, White Ash, Black Walnut, and Trembling Aspen were planted in a zone extending 23 meters (75 feet) from the stream bank on either side and upslope from its source. Prior to the planting, the buffer area consisted of mowed grass, some tilled area, and a narrow riparian strip (3-10 m) of hardwood trees and brush. Maintenance of the riparian buffer includes replacement of mortality (drought and deer damage), use of tree-tubes and wire tree protectors, and annual application of glyphosate around each tree.

An additional 6 meters (minimum) beyond the reforested buffer is maintained as grassland, representing "Zone 3" of the Riparian Buffer specification. In accordance with this specification, the grassland zone was contoured in late May 1994 to form a level-lip spreader, designed by the NRCS. The purpose of the spreader is to intercept surface runoff, which is delivered to the buffer via grassed waterways, and to release the runoff to the forested buffer as dispersed sheet flow in order to minimize erosion within the buffer.

Additional nonpoint source control measures applicable to both the treatment and control watersheds include contoured strips, waterways, and crop rotations in accordance with a soil conservation plan.

Water Quality Monitoring

The monitoring program is based on a paired watershed design. Although the riparian forest buffer was established in the first year of monitoring, the first several years (prior to rapid tree growth) serve as a calibration period to establish the pre-implementation comparison between the treatment and reference watersheds. To supplement the paired watershed design, nutrient and sediment retention by the riparian buffer are estimated by mass balance, using data from groundwater monitoring wells and overland flow collectors.

Parameters Measured

Biological
None

Chemical and other
Suspended solids (SS)
Volatile Solids
Dissolved nitrate+nitrite
Dissolved ammonia
Dissolved organic nitrogen, (discontinued 4/02)
Total phosphorus
Total dissolved phosphorus, (discontinued 4/02)
Dissolved orthophosphate
Dissolved organic carbon, (discontinued 4/02)
Chloride
pH
Conductivity

Covariates
Precipitation
Streamflow
Groundwater level
Streamwater temperature
Basal area of woody vegetation within riparian zone

Sampling Scheme

Streamwater samples are collected every 14 days throughout the year from all three streams. Discharge is continuously monitored at all three streams using v-notch weirs. Intensive sampling of streamwater during runoff events is conducted eight times annually from Morris Run and Mine Hill Run. Groundwater is sampled quarterly from 27 monitoring wells. Overland flow in Morris Run watershed is collected from four events annually.

Modifications Since Project Start

The monitoring program described above was implemented 1 April 1997, when the project was accepted for the National Monitoring Program. The only change in the program since then has been in the intensity of event sampling, as described below. The monitoring program prior to 1 April 1997 differed from the current program in the following respects: Between January 1992 and 1 April 1997, regular grab samples from all three streams were taken for nitrate, dissolved ammonium, dissolved orthophosphate, conductivity, and pH, at a frequency of 18-24 times per year. Particulate phosphorus and total dissolved phosphorus were sampled regularly from October 1993 through September 1994. Dissolved organic nitrogen was not sampled regularly prior to April 1997. Sampling for suspended sediments began in late 1993 for Morris Run and Half Way Run, and March 1995 in Mine Hill Run. Seven runoff events were sampled in Morris Run between November 1993 and June 1995 in Morris Run.

Beginning in March 1999, the target rate for sampling runoff during storm events (rainfall > 20 mm) was increased from four per year to eight per year, while the number of samples analyzed from each event was reduced from ten to four.

As of April 2002, monitoring intensity was reduced because tree growth and canopy closure has been slower than expected and further effects of reforestation may not be apparent until substantially more tree growth occurs. Monitoring continues at a level sufficient to detect an impact on baseflow water chemistry when it occurs. Intensive sampling of stormwater exports and overland flow, however, will be suspended until the riparian forest has matured sufficiently to expect measurable effects on these processes. It is anticipated that such maturation will require two to four years and that monitoring of stormflow and overland should resume at that time.

As of April 2002, analyses for the following analytes was discontinued: dissolved organic carbon (DOC), total dissolved phosphorus (TDP), and dissolved organic nitrogen (DON). Ammonium analyses of groundwater samples was also discontinued, but ammonium analyses of surface water samples will continue.

Progress To Date

All planned reforestation and site modifications are complete. As of September 2001, the reforested buffer had a stem density of 433 stems per hectare and a basal area of 0.48 m^2 per hectare.

DATA MANAGEMENT AND ANALYSIS

Data are entered, verified, stored, and analyzed using the SAS Information System. Data will also be entered into the USEPA Storet system and the NonPoint Source Management System.

Data analysis includes:

(1) comparisons of concentrations and annual exports of nitrogen, phosphorus, and suspended solids from each of the three watersheds, testing the hypothesis that these parameters are reduced by riparian reforestation;

(2) mass-balance estimates of nitrogen, phosphorus, and sediment retention within the reforested riparian buffer.

NPSMS Data Summary

	STATION TYPE: Control STATION NAME: Mine Hill Run			STATION TYPE: Treatment STATION NAME: Morris Run		
	Quartile Values					
Parameter Name	_25_	_50_	_75_	_25_	_50_	_75_
Total Suspended Solids (MG/L)	9.98	13.14	15.70	1.28	2.12	4.51
Nitrate + Nitrate (MG/L as N)	3.20	3.40	3.76	4.15	4.30	4.69
Nitrogen, Ammonia (MG/L)	0.01	0.014	0.017	0.007	0.009	0.015
Phosphorus, Total (MG/L)	0.036	0.041	0.051	0.027	0.03	0.047
Phosphorus, Dissolved (MG/L)	0.019	0.022	0.028	0.024	0.027	0.032
Phosphorus, Dissolved Orthophosphate (MG/L)	0.016	0.019	0.026	0.022	0.025	0.032
pH (Standard Units)	7.14	7.24	7.30	6.50	6.56	6.67
Flow, Stream, Instantaneous (L/S)	1.43	2.17	3.86	0.87	1.14	1.65

Quartile Counts								
YEAR: 1992	1	2	3	4	1	2	3	4
Nitrate + Nitrate (MG/L as N)	23	0	0	0	23	0	0	0
Nitrogen, Ammonia (MG/L)	12	1	0	10	15	0	1	7
Phosphorus, Total (MG/L)	1	0	0	0	1	0	0	0
Phosphorus, Dissolved Orthophosphate (MG/L)	1	0	3	18	1	1	5	15
pH (Standard Units)	1	0	0	22	0	0	0	23
Quartile Counts								
YEAR: 1993	1	2	3	4	1	2	3	4
Nitrate + Nitrate (MG/L as N)	16	0	0	0	18	0	0	0
Nitrogen, Ammonia (MG/L)	13	0	0	3	18	0	0	0
Phosphorus, Dissolved Orthophosphate (MG/L)	0	0	3	13	0	2	7	9
pH (Standard Units)	0	0	0	15	0	0	0	18
Quartile Counts								
YEAR: 1994	1	2	3	4	1	2	3	4
Nitrate + Nitrate (MG/L as N)	23	0	0	0	20	0	0	0
Nitrogen, Ammonia (MG/L)	18	0	0	5	18	0	0	2
Phosphorus, Total (MG/L)	0	0	1	0	0	0	10	4
Phosphorus, Dissolved (MG/L)	1	0	1	0	2	1	5	6
Phosphorus, Dissolved Orthophosphate (MG/L)	1	0	6	16	0	0	8	12
pH (Standard Units)	0	0	0	21	0	0	0	19
Quartile Counts								
YEAR: 1995	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	7	2	3	6	5	5	12	1
Nitrate + Nitrate (MG/L as N)	24	0	0	0	23	0	0	0
Nitrogen, Ammonia (MG/L)	23	0	0	1	21	0	0	2
Phosphorus, Dissolved Orthophosphate (MG/L)	0	1	11	12	5	1	5	12
pH (Standard Units)	0	1	0	23	0	0	0	23
Quartile Counts								
YEAR: 1996	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	14	0	2	2	4	1	8	5
Nitrate + Nitrate (MG/L as N)	12	6	0	0	17	0	0	1
Nitrogen, Ammonia (MG/L)	18	0	0	0	17	0	0	1
Phosphorus, Dissolved Orthophosphate (MG/L)	0	1	7	10	0	0	6	12
pH (Standard Units)	0	0	1	16	0	0	0	17
Quartile Counts								
YEAR: 1997	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	6	8	4	5	6	8	7	3
Nitrate + Nitrate (MG/L as N)	3	6	7	8	3	8	5	8
Nitrogen, Ammonia (MG/L)	9	3	5	7	9	4	4	7
Phosphorus, Total (MG/L)	4	5	5	6	6	5	6	3
Phosphorus, Dissolved (MG/L)	5	3	4	8	5	6	5	4
Phosphorus, Dissolved Orthophosphate (MG/L)	5	2	8	9	3	6	9	6

pH (Standard Units)	2	6	4	12	6	6	4	8
Flow, Stream, Instantaneous (L/S)	6	5	4	8	4	6	4	10
Quartile Counts								
YEAR: 1998	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	10	5	2	7	4	1	9	11
Nitrate + Nitrate (MG/L as N)	5	2	8	9	7	0	5	13
Nitrogen, Ammonia (MG/L)	12	8	2	2	11	6	6	2
Phosphorus, Total (MG/L)	6	7	7	4	4	2	13	6
Phosphorus, Dissolved (MG/L)	4	6	7	7	5	9	5	6
Phosphorus, Dissolved Orthophosphate (MG/L)	2	5	9	8	6	2	11	6
pH (Standard Units)	12	3	2	7	7	7	8	3
Flow, Stream, Instantaneous (L/S)	6	4	9	5	10	5	5	5
Quartile Counts								
YEAR: 1999	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	20	2	2	2	3	2	12	9
Nitrate + Nitrate (MG/L as N)	2	5	9	9	7	1	9	8
Nitrogen, Ammonia (MG/L)	9	5	2	9	6	5	10	4
Phosphorus, Total (MG/L)	16	1	4	4	0	3	14	8
Phosphorus, Dissolved (MG/L)	7	5	5	8	3	3	8	11
Phosphorus, Dissolved Orthophosphate (MG/L)	4	6	7	8	0	3	12	10
pH (Standard Units)	14	3	1	8	8	6	6	6
Flow, Stream, Instantaneous (L/S)	8	8	9	1	13	8	2	3
Quartile Counts								
YEAR: 2000	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	19	5	1	1	6	3	8	8
Nitrate + Nitrate (MG/L as N)	1	0	4	21	2	2	12	10
Nitrogen, Ammonia (MG/L)	6	12	1	7	4	5	15	2
Phosphorus, Total (MG/L)	12	5	9	0	6	1	16	3
Phosphorus, Dissolved (MG/L)	0	8	8	10	4	8	9	5
Phosphorus, Dissolved Orthophosphate (MG/L)	1	1	14	10	1	8	13	4
pH (Standard Units)	12	7	2	5	4	3	10	9
Flow, Stream, Instantaneous (L/S)	0	9	10	7	3	10	3	9
Quartile Counts								
YEAR: 2001	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	19	0	2	5	2	7	13	4
Nitrate + Nitrate (MG/L as N)	1	1	7	17	1	0	2	23
Nitrogen, Ammonia (MG/L)	7	8	4	7	4	4	13	5
Phosphorus, Total (MG/L)	15	2	3	6	4	8	13	1
Phosphorus, Dissolved (MG/L)	3	8	4	11	7	6	11	2
Phosphorus, Dissolved Orthophosphate (MG/L)	0	3	12	11	2	7	14	3
pH (Standard Units)	0	1	1	24	0	0	5	21
Flow, Stream, Instantaneous (L/S)	10	4	10	2	13	2	9	2
Quartile Counts								
YEAR: 2002	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	17	0	2	7	9	4	3	4
Nitrate + Nitrate (MG/L as N)	8	9	9	0	1	1	1	19
Nitrogen, Ammonia (MG/L)	2	3	6	15	1	3	6	12
Phosphorus, Total (MG/L)	13	1	4	8	4	3	12	3
Phosphorus, Dissolved (MG/L)	12	3	6	5	12	7	1	2
Phosphorus, Dissolved Orthophosphate (MG/L)	5	0	9	12	4	2	10	6
pH (Standard Units)	0	0	0	26	0	2	8	12
Flow, Stream, Instantaneous (L/S)	17	8	0	1	25	1	0	0
	0							
Quartile Counts								
YEAR: 2003	1	2	3	4	1	2	3	4
Total Suspended Solids (MG/L)	22	4	0	0	8	8	7	3
Nitrate + Nitrate (MG/L as N)	3	2	7	14	7	2	13	4
Nitrogen, Ammonia (MG/L)	10	7	3	6	11	7	5	3
Phosphorus, Total (MG/L)	22	4	0	0	3	3	17	3
Phosphorus, Dissolved (MG/L)	26	0	0	0	26	0	0	0
Phosphorus, Dissolved Orthophosphate (MG/L)	2	4	16	4	1	2	15	8
pH (Standard Units)	12	6	3	5	0	0	2	24
Flow, Stream, Instantaneous (L/S)	2	2	7	15	3	0	2	21

Findings to Date

Tree growth was initially slow but has been rapid since 1999 with a ten-fold increase in basal area between 1999 and 2004. As of early 2004, eleven years after reforestation, the basal area within the reforested Zone 2 was 1.46 m^2 ha^{-1}. However, this remains considerably below typical mature forest densities of 20-60 m^2/ha^{-1}. Canopy cover reached 52% in mid 2004.

Mass balance estimates obtained from concentration gradients in monitoring-well transects and streamwater exports indicate that, since 1994, the RFBS has removed between 18 and 31% annually of upslope inputs of subsurface nitrate. Mass removal rates have varied between 32 and 100 kg y^{-1} per hectare of buffer area. These rates are consistent with denitrification estimates of ~80 kg ha^{-1} y^{-1} made in 1994 and 1995. The temporal trends from both mass balance and the paired-watershed comparison suggest that the nitrate removal began when the buffer area was taken out of agriculture and that the rate of removal did not increase further until 2002. As of 2002 nitrate concentration in the stream draining the reforested buffer began a sharp decline which has continued into 2004. The decline is too recent to evaluate statistically, but appears to be a response to the rapid tree growth.

Sediment export from RFBS-watershed declined relative to that from the reference watershed by about 50% between 1997 and 2001, suggesting that the RFBS is increasingly effective in filtering suspended sediments. An independent estimate of suspended sediment removal was obtained from overland flow collectors arrayed in transects. The spreader (Zone 3) reduced suspended sediment concentration by 42% ($P<0.05$), and the combination of the spreader and the reforested buffer (Zones 2 and 3) reduced suspended sediment by 55% ($P<0.05$).

INFORMATION, EDUCATION, AND PUBLICITY

The project targets both professionals involved in development of nonpoint source control strategies and the public at large. Results will be made available to professionals through scientific papers prepared for refereed publication, presentations and meetings and symposia, and the annual reports. In addition, the project receives considerably exposure through the Stroud Water Research Center's educational program, which reaches thousands of students and adults annually.

Progress Towards Meeting Goals

Two theses have been completed as part of this project:

Watts, S. "Organic matter decomposition, N mineralization and denitrification in organic and mineral soils of two riparian ecosystems," Ph.D. Thesis, Rutgers University, 1997.

Alberts, S. "Reduction of total suspended sediment concentration in agricultural runoff by a vegetative buffer strip in Chester County, Pennsylvania" M.S. Thesis, West Chester University, 2000.

The following manuscript is in preparation:

Watts, S. H., S. S. Seitzinger, and J. D. Newbold. In preparation. Nitrogen removal rates within mixed hardwood riparian ecosystems Manuscript for submission to Journal of Environmental Quality.

A brochure describing the project and results-to-date is in preparation.

TOTAL PROJECT BUDGET

For time period 1 April 1, 1997 to March 31, 2005:

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Personnel	$44,042	$47,475	$48,899	$50,366	$51,877
Travel	1,100	1,133	1,167	1,202	1,238
Equipment	15,370	0	0	0	0
Materials & Supplies	4,000	4,400	4,532	4,668	4,808
Administrative (telephone, copies, postage)	250	258	265	273	281

Contractual Services	28,342	29,192	30,068	30,970	31,899
Water Chemistry Analysis					
TOTAL DIRECT COSTS	$93,104	$82,458	$84,931	$87,479	$90,104

	Year 6	**Year 7**	**Year 8**
Personnel	$30,306	$31,516	$32,777
Travel	1,000	1,040	1,082
Equipment	2,174	2,261	2,351
Contractual Services	7,670	7,977	8,296
(Water Chemistry Analysis)			
Total direct costs	$41,150	$42,794	$44,506
Indirect costs	22,221	23,109	24,033
TOTAL PROJECT COST	63,371	65,903	68,539

IMPACT OF OTHER FEDERAL AND STATE PROGRAMS

The project has received financial support for various periods since 1991 from the USDA Forest Service, the Pennsylvania State Bureau of Forestry, and the Chesapeake Bay Program. Technical assistance has been provided by the U.S.D.A. Forest Service, the Pennsylvania State Bureau of Forestry, and the USDA Natural Resource Conservation Service.

OTHER PERTINENT INFORMATION

None

PROJECT CONTACTS

Administration

Carl Rohr
Nonpoint Source programs
Pennsylvania Department of Environmental Protection
Rachel Carson State Office Building
PO Box 8555
Harrisburg Pa 17105-8555
(717) 772-5653
ROHR.CARL@a1.pader.gov

Land Treatment and Water Quality Monitoring

Denis Newbold
Stroud Water Research Center
970 Spencer Road
Avondale PA 19311
(610)-268-2153 ext. 227
newbold@stroudcenter.org