Physical and Vegetative Characteristics of a Relocated Stream Reach, Constructed Wetland, and Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04

In cooperation with the Pennsylvania Department of Transportation
Engineering District 5–0

Scientific Investigations Report 2006-5042

U.S. Department of the Interior
U.S. Geological Survey

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By Jeffrey J. Chaplin, Kirk E. White, and Connie A. Loper

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U.S. Geological Survey

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Contents

Abstract........1
Introduction........2
Purpose and Scope........2
Description of the Study Area........2
Monitoring Methods........5
Relocated Stream Reach........5
Constructed Wetland........8
Riparian Buffer........10
Physical and Vegetative Characteristics........12
Relocated Stream Reach........12
Hydrologic Conditions........12
Changes to the Channel........12
Constructed Wetland........26
Riparian Buffer........30
Herbaceous Plant Community........30
Trees and Shrubs........32
Summary........35
References Cited........36
Appendix 1—Photo-Documentation of the Relocated Stream Reach, Upper Saucon Township, Lehigh County, Pennsylvania........37
Appendix 2—Photo-Documentation of the Constructed Wetland, Upper Saucon Township, Lehigh County, Pennsylvania........44
Appendix 3—Photo-Documentation of the Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania........53
Appendix 4—Vegetation in the Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04........62

Figures

1. Topographic setting and physical features in the vicinity of the relocated stream reach, constructed wetland, and riparian buffer in Upper Saucon Township, Lehigh County, Pennsylvania........3
2. Relative locations of the relocated stream reach, constructed wetland, and riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania........4
3. Locations of cross-section surveys of the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania........6
4. Monitoring grid used to collect vegetation, soil, and hydrologic data within the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania........9
5. Monitoring grid used to collect vegetation data in the riparian buffer adjacent to the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania........11
6. Longitudinal profile of the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania........14

7. Cross-sectional channel surveys in the relocated stream reach, 97 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 16
8. Cross-sectional channel surveys in the relocated stream reach, 134 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 17
9. Cross-sectional channel surveys in the relocated stream reach, 174 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 18
10. Cross-sectional channel surveys in the relocated stream reach, 214 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 19
11. Cross-sectional channel surveys in the relocated stream reach, 261 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 20
12. Cross-sectional channel surveys in the relocated stream reach, 315 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 21
13. Cross-sectional channel surveys in the relocated stream reach, 357 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 22
14. Cross-sectional channel surveys in the relocated stream reach, 390 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 23
15. Cross-sectional channel surveys in the relocated stream reach, 425 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 24
16. Cross-sectional channel surveys in the relocated stream reach, 506 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 25
17. Water levels within the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04 28
18. View of trees and shrubs planted in the riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania....30
19. Areal cover of herbaceous species growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania....31

Tables

1. Summary of dates associated with data collection in the relocated stream reach, constructed wetland, and riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania 7
2. Longitudinal profile characteristics of the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania....12
3. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 97 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 16
4. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 134 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 17

5. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 174 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 18
6. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 214 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 19
7. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 261 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 20
8. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 315 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 21
9. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 357 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 22
10. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 390 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 23
11. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 425 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 24
12. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 506 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 25
13. Areal cover of vegetation in the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04 26
14. Cumulative precipitation measured at Allentown International Airport for water years 2000–04, Lehigh County, Pennsylvania 27
15. Presence or absence of hydric indicators in soils within the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04 29
16. Dominant herbaceous species growing in the riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04. 31
17. Density and browsing of trees and shrubs in the riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04 33
20. Areal cover of trees and shrubs growing in the riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04 34

Appendix 1—Photo-Documentation of the Relocated Stream Reach, Upper Saucon Township, Lehigh County, Pennsylvania

1-1. Photo-documentation stations and locations of cross-sectional surveys in the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania 38
1-2. Looking upstream at relocated stream reach at cross section surveyed 97 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. 39
1-3. Looking upstream at relocated stream reach at cross section surveyed 134 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 39

1-4. Looking downstream at relocated stream reach at cross section surveyed 174 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 40
1-5. Looking downstream at relocated stream reach at cross section surveyed 214 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 40
1-6. Looking upstream at relocated stream reach at cross section surveyed 261 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 41
1-7. Looking upstream at relocated stream reach at cross section surveyed 315 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 41
1-8. Looking upstream at relocated stream reach at cross section surveyed 357 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 42
1-9. Looking downstream at relocated stream reach at cross section surveyed 390 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 42
1-10. Looking downstream at relocated stream reach at cross section surveyed 425 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 43
1-11. Looking upstream at relocated stream reach at cross section surveyed 506 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania 43

Appendix 2—Photo-Documentation of the Constructed Wetland, Upper Saucon Township, Lehigh County, Pennsylvania

2-1. Photo-documentation stations and monitoring grid in a constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania 45
2-2. Looking west to east from photo-documentation station 1 at the constructed wetland, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania 46
2-3. Looking west to east from photo-documentation station 2 at the constructed wetland, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania 46
2-4. Looking west to east from photo-documentation station 1 at the constructed wetland, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania 47
2-5. Looking west to east from photo-documentation station 2 at the constructed wetland, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania 47
2-6. Looking west to east from photo-documentation station 1 at the constructed wetland, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania 48
2-7. Looking west to east from photo-documentation station 2 at the constructed wetland, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania 48
2-8. Looking west to east from photo-documentation station 1 at the constructed wetland, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania 49
2-9. Looking west to east from photo-documentation station 2 at the constructed wetland, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania 49
2-10. Looking west to east from photo-documentation station 1 at the constructed wetland, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania 50

2-11. Looking west to east from photo-documentation station 2 at the constructed wetland, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania 50
2-12. Looking west to east from photo-documentation station 1 at the constructed wetland, October 2003, Upper Saucon Township, Lehigh County, Pennsylvania 51
2-13. Looking west to east from photo-documentation station 2 at the constructed wetland, October 2003, Upper Saucon Township, Lehigh County, Pennsylvania 51
2-14. Looking west to east from photo-documentation station 1 at the constructed wetland, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania 52
2-15. Looking west to east from photo-documentation station 2 at the constructed wetland, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania 52

Appendix 3—Photo-Documentation of the Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania

3-1. Photo-documentation stations and monitoring grid in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania 54
3-2. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania 55
3-3. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania 55
3-4. Looking north to south from photo-documentation station 1 at the riparian buffer, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania. 56
3-5. Looking south to north from photo-documentation station 2 at the riparian buffer, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania. 56
3-6. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania 57
3-7. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania 57
3-8. Looking north to south from photo-documentation station 1 at the riparian buffer, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania. 58
3-9. Looking south to north from photo-documentation station 2 at the riparian buffer, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania. 58
3-10. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania 59
3-11. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania 59
3-12. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2003, Upper Saucon Township, Lehigh County, Pennsylvania 60
3-13. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2003, Upper Saucon Township, Lehigh County, Pennsylvania 60
3-14. Looking north to south from photo-documentation station 1 at the riparian buffer, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania 61
3-15. Looking south to north from photo-documentation station 2 at the riparian buffer, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania 61

Appendix 4—Vegetation in the Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04

4-1. Herbaceous and woody species growing in the riparian buffer, Lehigh County, Pennsylvania, 2000–04 62

Conversion Factors

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
Flow rate		
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Physical and Vegetative Characteristics of a Relocated Stream Reach, Constructed Wetland, and Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04

By Jeffrey J. Chaplin, Kirk E. White, and Connie A. Loper

Abstract

The U.S. Geological Survey, in cooperation with the Pennsylvania Department of Transportation, Engineering District 5-0, investigated physical and vegetative changes within a relocated stream reach, constructed wetland, and riparian buffer from September 2000 to October 2004. This report presents an evaluation of data collected using methods from multiple sources that have been adapted into a consistent approach. This approach is intended to satisfy a need for consistent collection of different types of data with the goal of transferring technology and findings to similar projects.

Survey data indicate that adjustment of the upstream part of the relocated stream reach slowed over the monitoring period, but the downstream channel remains unstable as evidenced by excessive deposition. Upstream migration of a nick point has slowed or stopped altogether as of the 2003 assessment when this feature came in contact with the upstream-most part of the channel that is lined with riprap. Documented streambed erosion in the upstream cross sections, along with deposition downstream, has resulted in an overall decrease in slope of the stream channel over the monitoring period. Most streambed erosion took place prior to the 2002 assessment when annual mean streamflows were less than those in the final 2 years of monitoring. An abundance of fine sediment dominates the substrate of the relocated channel. Annual fluctuations of large particles within each cross section demonstrates the capacity of the relocated channel to transport the entire range of sediment.

The substrate within the 0.28-acre constructed wetland (a mixture of soil from an off-site naturally occurring wetland and woodchips) supported a hydrophytic-vegetation community throughout the investigation. *Eleocharis obtusa* (spike rush), an obligate-wetland herb, was the most prevalent species, having a maximum areal cover of 90 percent in fall 2001 and a minimum of 23 percent in fall 2004. Drought-like conditions in water year[1] 2002 (cumulative precipitation was 28.11 inches) allowed species like *Panicum dichotomiflorum* (witch grass), *Salix* sp. (willow), *Leersia oryzoides* (rice cutgrass), and *Echinocloa crusgalli* (barnyard grass) to become established by fall 2002. Above-average precipitation in water years 2003 and 2004 (58.55 and 53.17 inches, respectively) coincided with increased areal cover by *E. obtusa* in fall 2003 (56 percent) and decreased areal cover in fall 2004 (23 percent). Pond-like conditions that probably persisted throughout the 2004 growing season favored aquatic species like *Alisma subcordatum* (water plantain) to the detriment of many emergent species, including *E. obtusa*. Despite the pond-like conditions, *L. oryzoides*, an obligate-wetland grass, increased in areal cover (from 12 to 34 percent) between the 2003 and 2004 growing seasons because it was established in the higher elevations and the peripheral areas of the constructed wetland that were less prone to persistent inundation.

Canopy development by trees and shrubs in the riparian buffer was initially (fall 2000) poor (39.7 percent), resulting in more available sunlight for the herbaceous understory than in any other growing season. As a result, areal cover of herbaceous species and trees and shrubs less than 1-meter tall was 108 percent in fall 2000 with *Lolium perenne* (perennial rye), *Polygonum persicaria* (lady's thumb), and *Setaria faberi* (foxtail) collectively contributing nearly half the cover (59.2 percent). Because of increases in canopy cover by trees and shrubs (39.7 percent in fall 2000 to 127 percent in fall 2004), herbaceous cover decreased to 76 percent by the fall of 2001 and varied between 72 and 77 percent for the rest of the study period.

Tree density in the riparian buffer ranged from 3,078 and 4,130 plants per acre (fall 2000 and 2003, respectively) over the study period but essentially remained constant after fall 2001; computations reported each fall between fall 2001 and fall 2004 are within 10 percent of one another. When the study ended in fall 2004, *Acer negundo* (box elder) and *Fraxinus pennsylvanica* (green ash) were the most populous tree species (1,526 and 1,084 plants per acre, respectively) followed by *Quercus bicolor* (swamp white oak; 720 plants per acre). *A. negundo*, *F. pennsylvanica*, and *Q. bicolor* also contributed the greatest areal cover in fall 2004 (31.2, 24.0, and 18.5 percent, respectively).

[1]Water year is the 12-month period October 1 through September 30 and is designated by the calendar year in which it ends.

Introduction

Authorized modification of existing stream channels and naturally occurring wetlands commonly is necessary to complete roadway improvements. Compensatory mitigation generally is required by Federal and State regulatory agencies and may include monitoring of modified stream channels and construction and monitoring of wetlands and (or) riparian buffers. In the spring of 2000, the Pennsylvania Department of Transportation (PennDOT) completed construction of Center Valley Parkway, which connects State Route (SR) 2036 to SR 378 in Upper Saucon Township, Lehigh County, Pa (fig. 1). Construction of Center Valley Parkway resulted in the relocation of an unnamed tributary to Saucon Creek and destruction of 0.22 acre of naturally occurring wetland. To compensate for these actions, 0.28 acre of wetland was constructed in a different but nearby location, and a riparian buffer adjacent to the relocated stream reach was planted with native trees and shrubs (fig. 2).

In accordance with project permits issued by the U.S. Army Corps of Engineers (ACOE) and the Pennsylvania Department of Environmental Protection (PaDEP), monitoring of the relocated stream reach, constructed wetland, and riparian buffer was required over five consecutive growing seasons. The U.S. Geological Survey (USGS), in cooperation with PennDOT, collected data from 2000 through 2004 to quantify changes in the profile, dimension, and substrate of the relocated stream reach; the vegetation, soils, and areal extent of the constructed wetland; and the vegetation within the riparian buffer. The evaluation of these data is provided in this report and gives PennDOT and ACOE the information needed for them to assess the success of the relocated stream reach, constructed wetland, and riparian buffer.

Monitoring of mitigation activities commonly is qualitative in nature. Quantitative data potentially provide more definitive documentation; however, differing methods of collection can make comparison among similar projects difficult. By adapting monitoring methods from multiple sources and evaluating data collected using a consistent approach, this investigation can serve as a basis for transferring technology and findings among similar projects. The methods adapted for this investigation include those described by Rosgen (1996), Dunne and Leopold (1978), Wolman (1954), U.S. Army Corps of Engineers Environmental Laboratory (1987), Fitzpatrick and others (1998), and Bauer (1943). Adaptation of these monitoring methods into a consistent approach for data collection and storage allows for comparison of results from multiple projects with similar objectives. Additional methods that may be considered for future investigations include, but are not limited to, protocols for documentation of benthic-invertebrate communities, habitat, and (or) water quality as dictated by project objectives.

Purpose and Scope

This report presents an evaluation of data collected within a relocated stream reach, constructed wetland, and riparian buffer during seven post-construction monitoring events from September 2000 through October 2004. The evaluation provides PennDOT and ACOE with the information needed for them to determine the success of the relocated stream reach, constructed wetland, and riparian buffer.

Changes to the profile, dimension, and substrate of the relocated stream reach were quantified by longitudinal and cross-section surveys and pebble-count data. Photographs of the relocated stream reach document the conditions at the beginning (fall 2000) and end (fall 2004) of the study period. Areal cover of vegetation, hydric-soils indicators, water levels, and the areal extent of the constructed wetland are presented. The vegetation community growing in the riparian buffer was characterized on the basis of areal-cover computations and computation of tree and shrub density. Tabulated results and photographs document changes in the relocated stream reach, constructed wetland, and riparian buffer over the monitoring period.

Description of the Study Area

The study area is in Upper Saucon Township, Lehigh County, Pa., approximately 80 mi northeast of Harrisburg and 60 mi north of Philadelphia (fig. 1). The relocated stream reach and riparian buffer are approximately 0.25 mi (1,320 ft) from the 0.28 acre constructed wetland. All three components of the study area are within the Reading Prong Section of the New England Physiographic Province and have underlying geology characterized by laminated dolomite and bands of quartz sand and quartz grains (Geyer and Wilshusen, 1982). Bedrock is weathered to a shallow depth (Pennsylvania Department of Conservation and Natural Resources, 1995). Soils in the vicinity of the study area generally are well drained with a dark-brown silty surface layer characteristic of Washington silt loam (WgB2) (Carey and Yaworski, 1963). However, the constructed wetland is underlain by an inclusion of Bedford silt loam (BdA), which, in its unaltered state, is moderately well drained with a surficial layer of dark brown silt loam overlying subsoils that are yellow brown and have more clay. Hydric-soil indicators usually associated with wetlands are not common in BdA soils (Carey and Yarworski, 1963; Iowa State University of Science and Technology, 1993). However, native BdA soils were removed and replaced with a mixture of soil and woodchips. Thus, the upper 12 to 20 in. of the new soil profile no longer resembles BdA.

The constructed wetland is bounded on the north by an agricultural field that was planted annually with corn by no-till methods during the study period. Water is provided to the wetland by an intermittent tributary that originates on the forested south-facing slope of South Mountain (fig. 1) and flows through a sparsely wooded riparian buffer that bisects the agri-

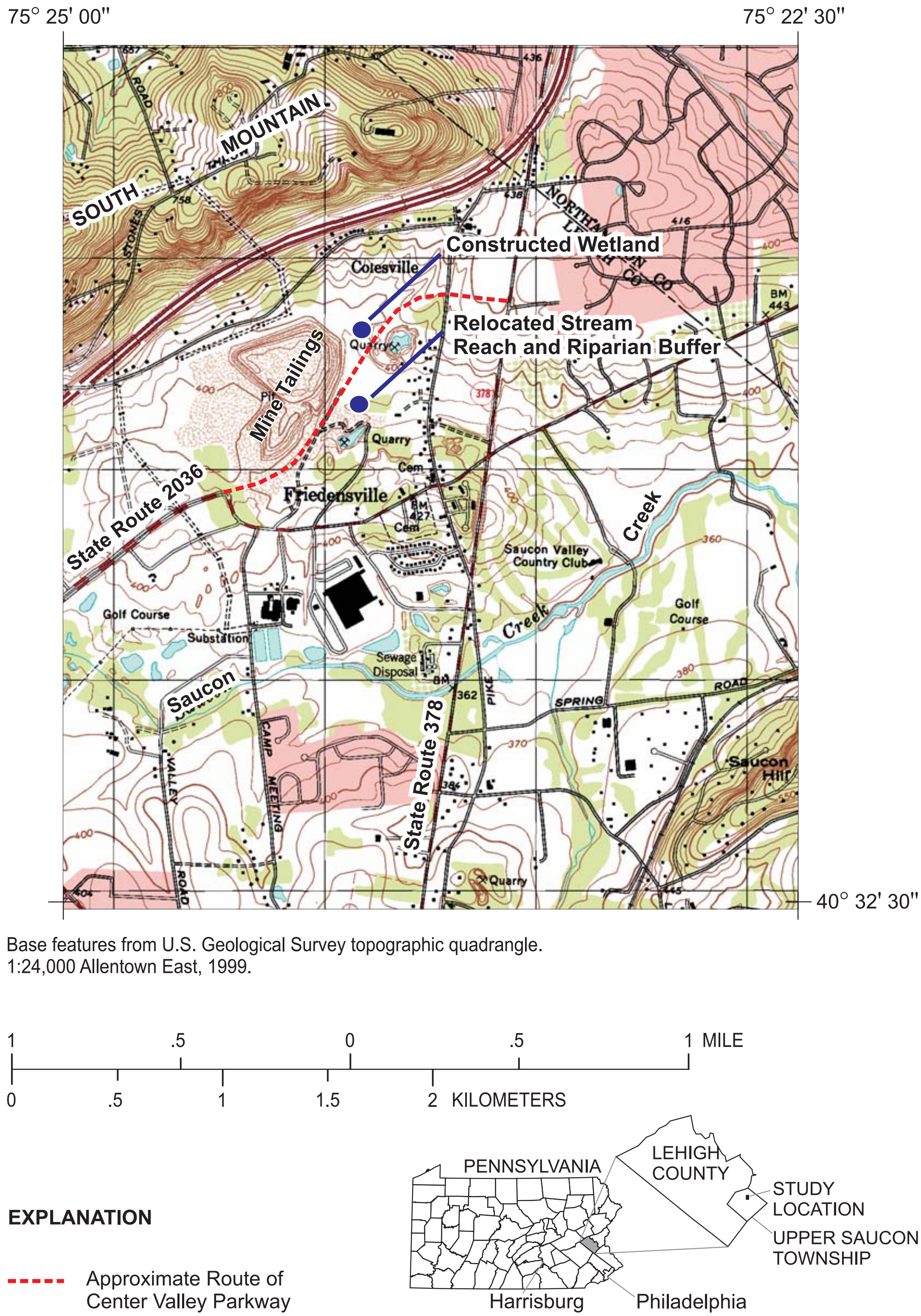

Figure 1. Topographic setting and physical features in the vicinity of the relocated stream reach, constructed wetland, and riparian buffer in Upper Saucon Township, Lehigh County, Pennsylvania.

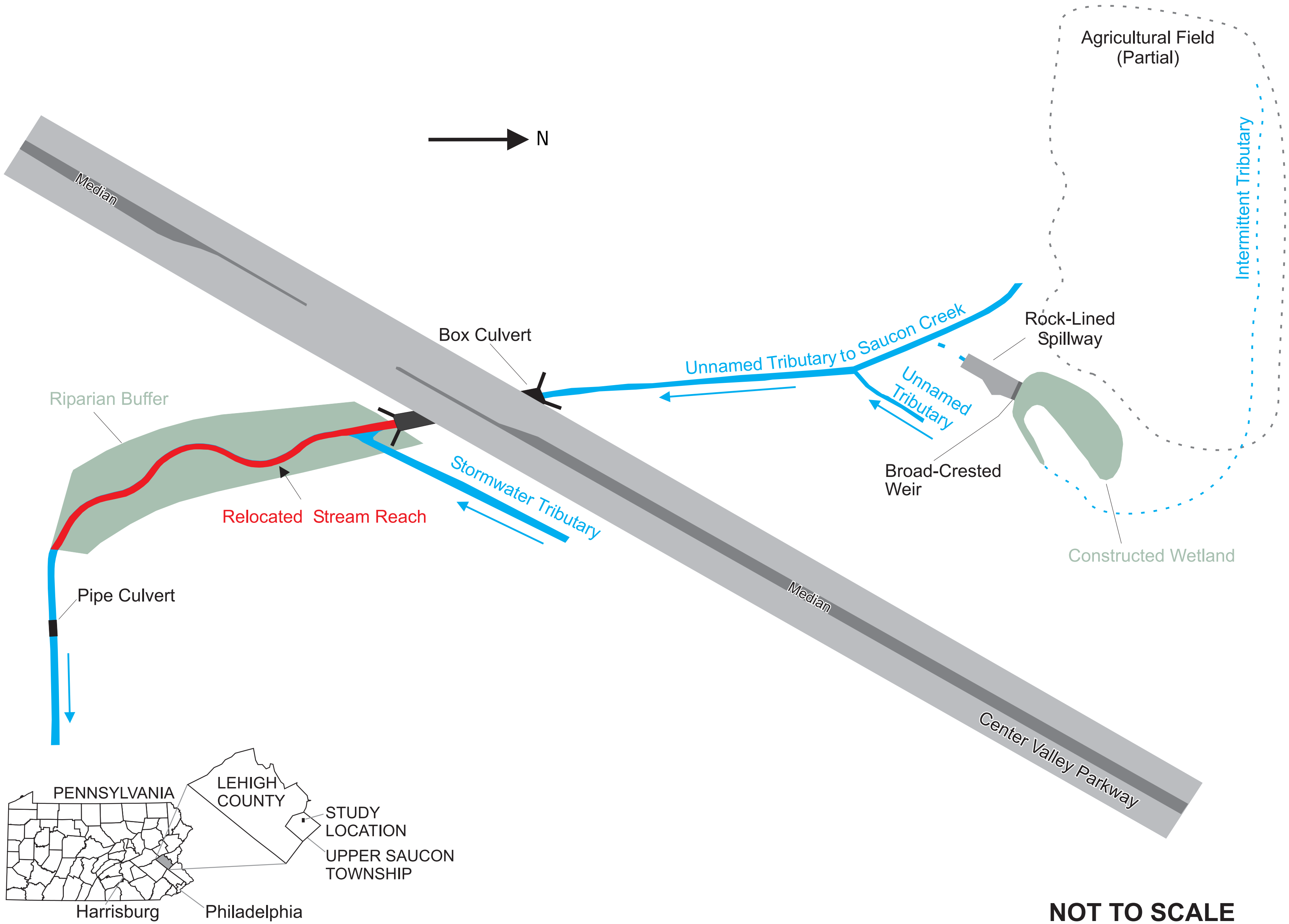

Figure 2. Relative locations of the relocated stream reach, constructed wetland, and riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

cultural field. Water is detained by a concrete broad-crested weir within a shallow basin excavated for wetland construction (fig. 2). When the water level in the constructed wetland is higher than the weir, water flows through a rock-lined spillway and enters the unnamed tributary to Saucon Creek upstream of the relocated stream reach (fig. 2).

The relocated stream reach and associated riparian buffer extend from a box culvert on the downstream side of Center Valley Parkway for approximately 570 ft downstream (fig. 2). Tailings piles from an abandoned mine extend parallel to Center Valley Parkway on the upstream side of the box culvert (fig. 1). Grey sediment from these piles is readily mobilized and deposited within the riparian buffer and relocated stream reach. The riparian buffer ranges from about 75 ft wide at the northern end to 100 ft wide at the southern end.

After seeding the riparian buffer with *Lolium perenne* (perennial rye grass) in the spring of 2000, four species of 2-4 ft tall shrubs and four species of 8-12 ft tall trees were planted at extremely high densities compared to planting guidelines described in Palone and Todd (1997). Shrub species including *Sambucus canadensis* (common elderberry), *Viburnum acerifolium* (maple-leaf viburnum), *Cornus* sp. (dogwood; includes *Cornus racemosa (*gray dogwood) and *Cornus amomum* (silky dogwood)) were planted 2 ft on center between tree species of *Quercus bicolor* (swamp white oak), *Fraxinus pennsylvanica* (green ash), *Acer negundo* (box elder), and *Acer rubrum* (red maple), which also were planted 2 ft on center. The riparian buffer is surrounded by sparsely forested land to the east and west, a small field to the south, and Center Valley Parkway to the north. The forested land is dominated by *Robinea psuedo-acacia* (black locust) and a host of non-native vines and shrubs including *Lonicera japonica* (japanese honeysuckle) and *Lonicera tatarica* and *Lonicera morrowi* (collectively referred to as *Lonicera* sp., bush honeysuckle). Common herbaceous species growing in the field include *Solidago canadensis* (canada goldenrod), *Solidago (Euthamia) graminifolia* (grass-leaved goldenrod), and *Oenothera biennis* (evening primrose).

Monitoring Methods

In response to the project permit requirements, the USGS developed and implemented monitoring plans intended to quantify changes in 1) the profile, dimension, and substrate of the relocated stream reach; 2) the vegetation community, soils, and areal extent of the constructed wetland; and 3) the vegetation community growing within the riparian buffer. The data needed to accomplish these objectives are varied and their collection required adapting methods from multiple sources into a consistent approach. The relocated stream reach was monitored following methods adapted from Rosgen (1996), Dunne and Leopold (1978), and Wolman (1954). Methods for monitoring the wetland are largely from the wetland-delineation manual published by the U.S. Army Corps of Engineers Environmental Laboratory (1987) and vegetation sampling protocols described by Fitzpatrick and others (1998). Vegetation sampling methods from Fitzpatrick and others (1998), U.S. Army Corps of Engineers Environmental Laboratory (1987), and Bauer (1943) were adapted for herbaceous and woody vegetation in the riparian buffer. The approaches used to monitor each project component are described below.

Monitoring of the relocated stream reach, constructed wetland, and riparian buffer was conducted each fall from 2000 through 2004 (table 1). Plants generally are easier to identify at the end of the growing season (fall) because leaves, stems, and, most importantly, reproductive parts are mature. However, some plants flower in the spring and are difficult to identify in the fall because few or no reproductive parts are present (those species of the genus *Carex* that flower in the spring are particularly difficult to identify in the fall). Therefore, additional monitoring of the wetland and riparian buffer in the spring of 2001 and 2002 (table 1) provided the opportunity to better identify some plants that flower in spring.

Relocated Stream Reach

Construction of the Center Valley Parkway in Upper Saucon Township, Lehigh County, Pa., required relocation of a 450-ft reach of an unnamed tributary to Saucon Creek into a constructed channel of about 570 ft in length (herein referred to as relocated stream reach). Monitoring of the relocated stream reach quantified annual changes (from September 2000 through October 2004) to the profile, dimension, and substrate of the stream by surveying the longitudinal profile and channel cross sections and sampling the bed substrate. Conditions of the permits required “channel characteristics be compared to those found in the existing stream to be impacted.” However, the destruction of the existing stream and construction of the new stream channel were completed prior to monitoring, thus eliminating the possibility of this comparison. All surveyed elevations are referenced to a stable point on the upstream box culvert, which was assigned an arbitrary elevation of 100 ft.

The longitudinal profile extends from the outlet of a box culvert, station 0, to the mouth of a small pipe culvert beyond the end of the relocated stream channel, at about station 570 (fig. 3). The longitudinal profile is limited to surveyed elevations of the thalweg and, during times of streamflow, the water surface. A definitive bankfull feature, indicating a flood plain bounding an active channel, has not been formed since the channel was constructed. Distances along the longitudinal profile, referred to as stations, are measured along the main flowpath of the stream (thalweg). Annual discrepancies in stationing along the longitudinal profile are because of changes in the thalweg and the resulting inability to place the measuring tape along the exact same path.

Cross-section locations shown in figure 3 were selected immediately upon completion of the channel construction to provide representative samples of pool-and-riffle cross sections. Cross sections were oriented perpendicular to the centerline of the channel at the time of selection. Because the stream

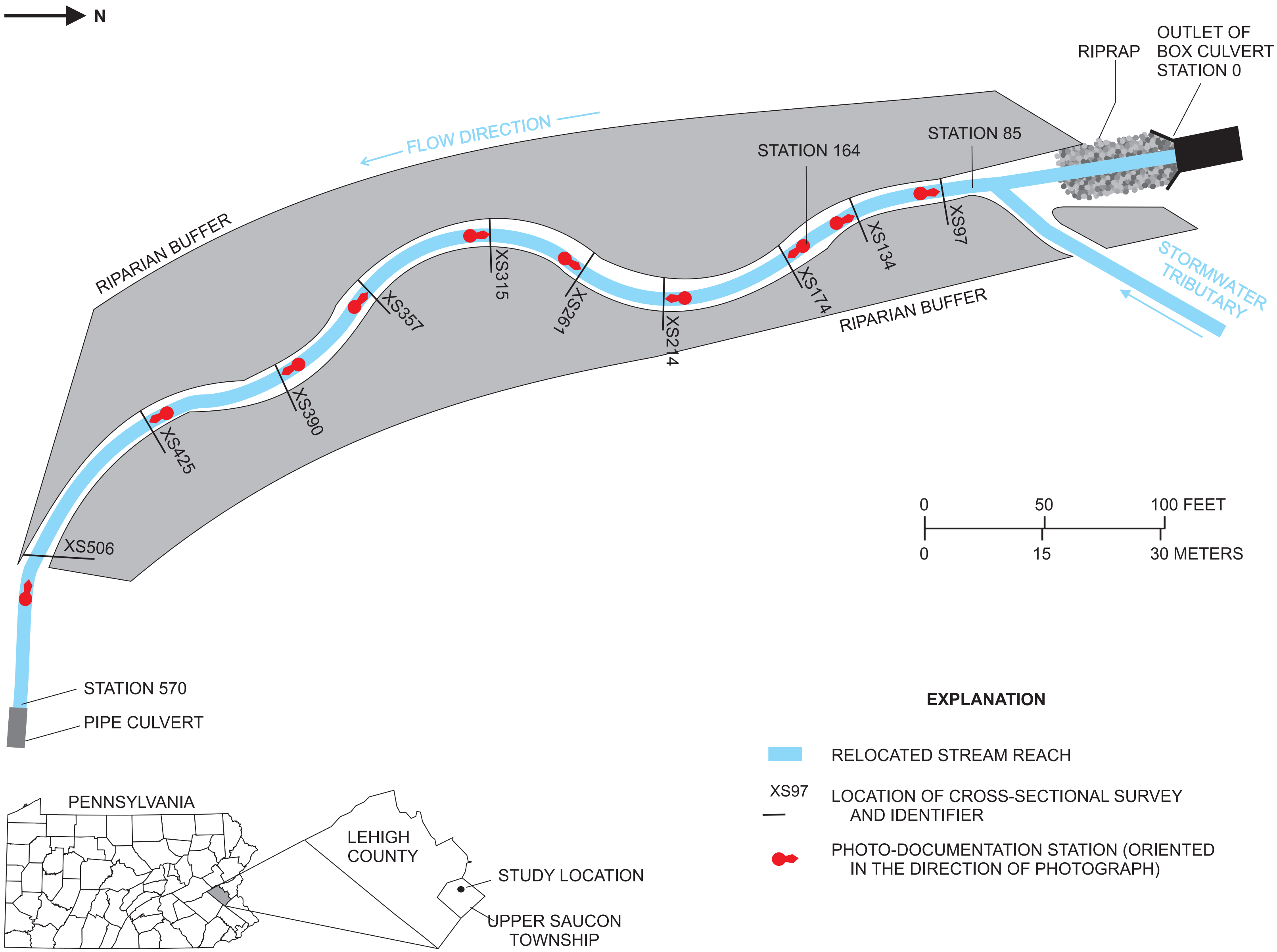

Figure 3. Locations of cross-section surveys of the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 1. Summary of dates associated with data collection in the relocated stream reach, constructed wetland, and riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania.

[—, no monitoring; Sept., September; Aug., August; Oct., October]

Feature	Fall 2000[1]	Spring 2001[2]	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
Relocated stream reach	Sept. 11-13	—	Sept. 17-19	—	Sept. 16-18	Oct. 10, Oct. 14, 16	Sept. 21, Oct. 1, 5
Constructed wetland	Sept. 27-28	May 22-23	Sept. 11-13	May 30	Sept. 25	Oct. 10	Aug. 31
Riparian buffer	Aug. 29-Oct. 19	May 24-June 1	Sept. 20-26	May 28-31	Sept. 23-Oct. 2	Oct. 10-14	Aug. 30-Sept. 1

[1]For the purposes of this report, monitoring in August, September, and October is referred to as "fall."

[2]For the purposes of this report, monitoring in May and June is referred to as "spring."

channel shifted, some cross sections became slightly skewed from the original orientation relative to the thalweg. Despite fixed cross-section endpoints, measurements of width varied between assessments because riparian vegetation prevented extending the measuring tape along the exact same line between monumented endpoints. Left and right banks are oriented with the observer looking downstream.

Cross-sectional channel geometries were determined from surveys of the areas bounded by the fixed monuments marking the ends of each cross section. Monuments were established beyond the active channel, onto the flood plain, to ensure the presence of cross-section endpoints throughout the monitoring period despite anticipated, but unpredictable, channel change. Changes in cross-section geometry were computed from the baselines originally established in 2000. Because cross-section surveys include parts of the flood plain, stream widths, mean stream depths, and the cross-section areas determined from the survey data are not indicative of the active channel. Photographs taken at each cross section in September 2000 and October 2004 are provided in appendix 1 to document stream-channel conditions shortly after relocation and at the end of monitoring.

Component parts of the longitudinal profile survey were analyzed to provide more detail on the response of riffles and pools to channel construction. Data used to characterize the longitudinal profile, such as sinuosity, riffle and pool characteristics, and others, were collected and analyzed according to the definitions and methods described by Rosgen (1996).

Pebble counts adapted from Wolman (1954), conducted to quantify the bed-particle distribution of the cross sections throughout the stream reach, did not clearly distinguish between the particle sizes in the silt/clay to medium-sand range. Despite that much of the bed substrate was in this range, the particle distributions will effectively characterize any changes should the channel evolve to a coarser bed material. Subsequent pebble counts yielding bed-particle distributions within the present size range would suggest continued transport of similar-sized sediment. Pebble counts did not extend the full distance between monuments but were conducted at established stationing within each cross section. Bed-particle distributions are extracted from a cumulative frequency curve and reported in a “D#” format where # is the percentage of particles with a medium axis less than or equal to the reported value.

Constructed Wetland

For the purposes of this report, a wetland is defined as an area inundated or saturated by water at a frequency and duration sufficient to support a prevalence of vegetation adapted for life in saturated-soil conditions (U.S. Army Corps of Engineers Environmental Laboratory, 1987). Frequent and (or) extended periods of saturation lead to a reducing environment that causes chemical reduction of some soil components (like iron and manganese oxides). Reducing conditions result in soil colors and other physical characteristics indicative of wetland or hydric soils. Hydric soils limit the growth of many plants but favor hydrophytic species adapted to grow in wetlands. Thus, vegetation and soil characteristics, along with hydrologic characteristics, were used to delineate 0.28 acre of constructed wetland. The constructed wetland boundary was surveyed by standard land-survey techniques using a Nikon DTM 750 Total Station. The extent of the constructed wetland was computed as the area surrounded by the delineated boundary (fig. 4), which did not change throughout the monitoring period.

The wetland-monitoring grid consists of a baseline parallel to the long axis of the constructed wetland and four transects perpendicular to the baseline. Seven 1-m^2 sampling plots were established along the transects in September 2000. One additional sampling plot on transect 2 (plot 1A; fig. 4) was established in spring 2002 to provide better representation of volunteer *Salix* sp. (willow). Individual sampling-plot locations referenced in this report are identified by a combination of the transect and plot number. For example, transect 2 plot 1A is referred to as sampling plot 0201A.

The sampling plots were, among other things, used to compute the percentage of ground that was covered by vegetation (areal cover) growing in the constructed wetland. The areal cover of each species within the plots was estimated visually. Estimates of areal cover from each species were then totaled and averaged to derive vegetative cover within the constructed wetland. In some cases, areal cover was greater than 100 percent because of overlapping layers of vegetation.

By definition, the plant community growing within the constructed wetland is hydrophytic. A vegetation community is considered hydrophytic when greater than 50 percent of the dominant species have an indicator status of Obligate-wetland (OBL), Facultative-wetland (FACW), or Facultative (FAC) (U.S. Army Corps of Engineers Environmental Laboratory, 1987). The indicator status of each species in the constructed wetland was obtained from the National List of Plant Species that Occur in Wetlands Region I–Northeast (Reed, 1988). Reed (1988) categorizes plants according to the probability that a given species grows in a wetland. OBL species almost always grow solely in wetlands (estimated probability greater than 99 percent). FACW species usually grow in wetlands (estimated probability 67–99 percent) but occasionally grow in non-wetlands. FAC species grow in wetlands roughly half of the time (estimated probability 34–66 percent). Facultative-upland species (FACU) occasionally grow in wetlands (estimated probability 1–33 percent) but usually grow in non-wetlands, and Upland species (UPL) grow in non-wetlands. A plus after the category (such as FAC+) indicates a frequency of occurrence in the upper end of the probability range, whereas a minus indicates a frequency of occurrence in the lower end of the range (Tiner, 1999).

Dominant species were determined by the 50/20 rule described by U.S. Army Corps of Engineers Environmental Laboratory (1987). Under this rule, a species can be considered dominant at two levels. At the first level, areal cover for individual species is compared to 50 percent of the total cover. Areal cover percentages for individual species are added, start-

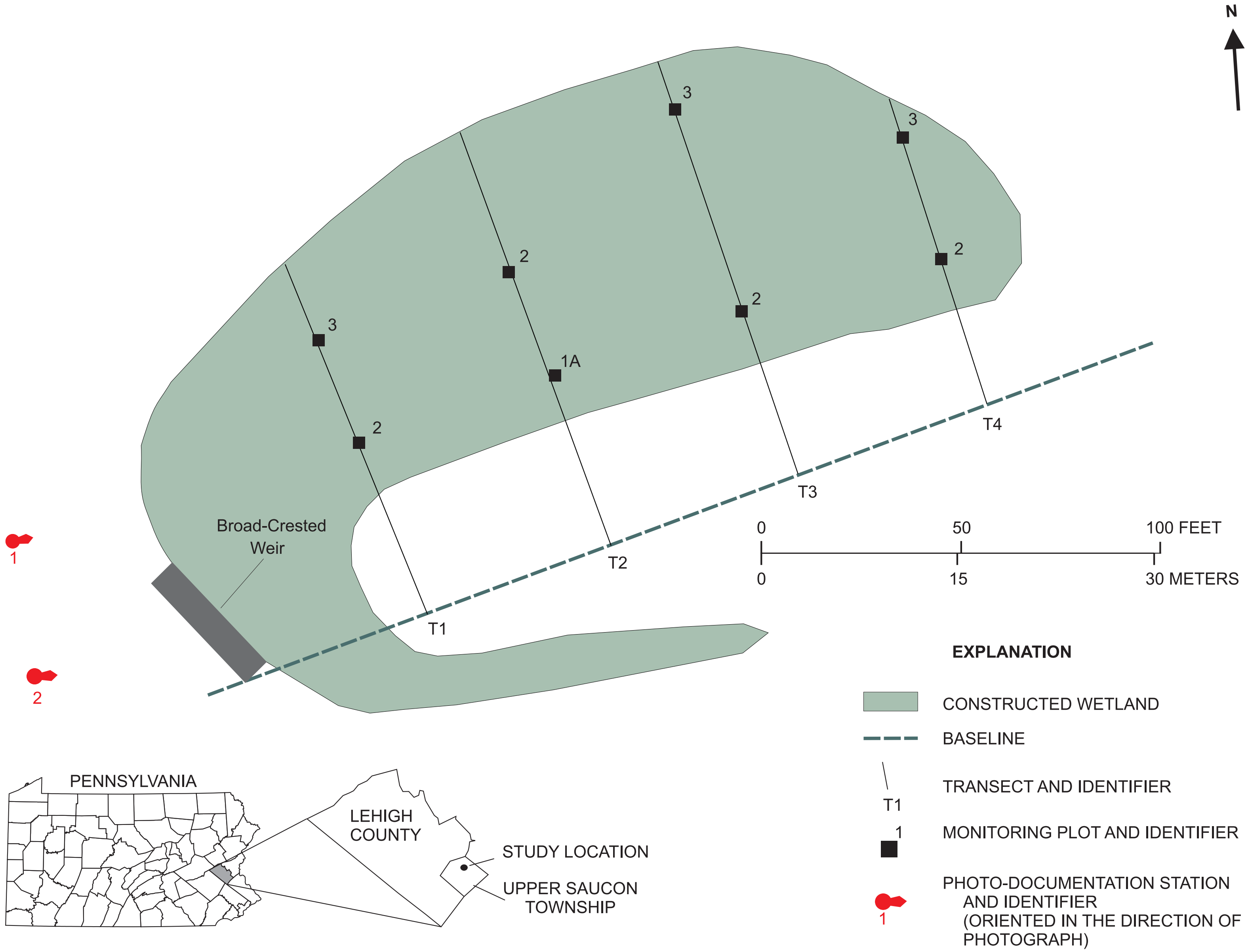

Figure 4. Monitoring grid used to collect vegetation, soil, and hydrologic data within the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania.

ing with the species providing the most cover and working down, until 50 percent of the total cover is equaled or exceeded. Those species necessary to exceed 50 percent of the total areal cover are considered dominant. At the second level, species that did not already qualify as dominant but exceed 20 percent of the total areal cover also are considered dominant.

Pits, dug to a depth of at least 12 in., were used to measure water elevations in the constructed wetland. Depth of, or depth to, water was measured relative to ground surface with a measuring tape. The pits were located in 1-m^2 plots.

The top 12 to 20 in. of soil in the constructed wetland consisted of a mixture of soil from a natural wetland that was filled during roadway construction and woodchips. This mixture was examined to a depth of at least 12 in. in a soil pit within each sampling plot. The exact location of the soil pit was different for each monitoring event so that soil previously disturbed was not resampled. For the purpose of describing the soils, the mixture was divided into horizons characterized by homogeneous color and texture. The top horizon was defined as the “A” horizon and subsequent horizons were “B,” “C,” and so on.

Each horizon was evaluated for hydric-soil indicators, which include evidence of histosol (organic) or histic epipedon soils, sulfidic odor, aquic moisture regime, gleyed or low-chroma colors, concretions, high organic content in surface layer in sandy soils, and organic streaking in sandy soils (U.S. Army Corps of Engineers Environmental Laboratory, 1987). Chroma refers to the strength of the soil color (Munsell Color, 2000) and low-chroma colors within the “B” horizon are indicative of a fluctuating water table that causes periodic chemical reduction.

Riparian Buffer

In spring 2000, PennDOT planted four species of trees (*Q. bicolor*, *F. pennsylvanica*, *A. negundo*, and *A. rubrum*) and four species of shrubs (*S. canadensis*, *V. acerifolium*, *C. racemosa*, and *C. amomum*) in the riparian buffer after seeding with *L. perenne*. Trees were from 8 to 12 ft tall and were planted 2 ft on center. Shrubs were from 2 to 4 ft tall and also were planted 2 ft on center between the trees. The areal cover of herbaceous and woody species along with the density of woody species was determined on seven occasions between August 2000 and September 2004 to provide a record of changes in planted and volunteer vegetation over the monitoring period.

Two different methods were used to determine vegetative cover in the riparian buffer. The areal cover of herbaceous plants and trees and shrubs less than 1 m tall was determined by visually estimating the percentage of ground each species covered within thirty-two 1-m^2 (10.8-ft^2) plots. Areal cover of trees and shrubs greater than 1 m tall was estimated using the line-intercept method described by Bauer (1943). Values of areal cover for trees and shrubs presented in this report represent the sum of areal cover determined with the two methods. Each method is described in more detail below, along with a description of how the density of trees and shrubs was determined.

The thirty-two 1-m^2 plots used to determine areal cover of herbaceous plants and trees and shrubs less than 1 m tall were systematically spaced along nine transects. The transects extended across the riparian buffer at fixed 50-ft intervals beginning near the upstream end of the relocated stream reach and ending near the downstream terminus (fig. 5). Each transect had four plots, except for transects 1 and 9, which had two plots each. For transects 2 through 8, the four plots were spaced such that one plot was at the east and west boundaries of the riparian buffer and the other two plots were situated alternately along the stream or midway between the stream and the boundary of the buffer (fig. 5). Plots along transects 1 and 9 were established between the left streambank and the boundary of the riparian buffer (fig. 5).

The percentage of ground area covered by each species within each of the 32 plots was estimated visually. Estimates of areal cover from each species were totaled and then averaged to derive vegetative cover within the riparian buffer. Areal cover may exceed 100 percent because of overlapping layers of vegetation. Dominant herbaceous and woody species were determined by the 50/20 rule (U.S. Army Corps of Engineers Environmental Laboratory, 1987).

For determining areal cover of trees and shrubs greater than 1 m tall, a measuring tape was strung along each transect between the east and west riparian-buffer boundaries. Beginning at one boundary and working toward the other, all woody plant canopies projecting through the imaginary vertical plane of the tape were tallied. The decimal fraction of the total length of all transects intercepted by a woody species, multiplied by 100, is equal to the areal cover for that species.

The density of trees and shrubs, expressed as plants per acre, was determined by dividing the number of individuals growing in 16 circular plots by the total area of the plots. Plants having multiple trunks were counted as one individual. The plots were established midway between the stream and the riparian buffer (fig. 5). All plots had a radius of 10 ft and were 29 m^2 (314-ft^2) except for some plots in fall 2003 that had a radius of 12 ft and an area of 42 m^2 (452 ft^2). The total area of the plots used to compute density equates to approximately 11 percent of the area of the riparian buffer. Each plot was redefined each year by measuring a 10-ft radius from a fixed monument.

Browsing by deer and other herbivores may affect the cover and density of planted and volunteer trees and shrubs. Each tree and shrub growing within the density plots was assessed for missing leaves, twigs, or other plant parts. The extent of browsing (expressed as a percentage) was determined by dividing the number of browsed individuals by the total number of individuals.

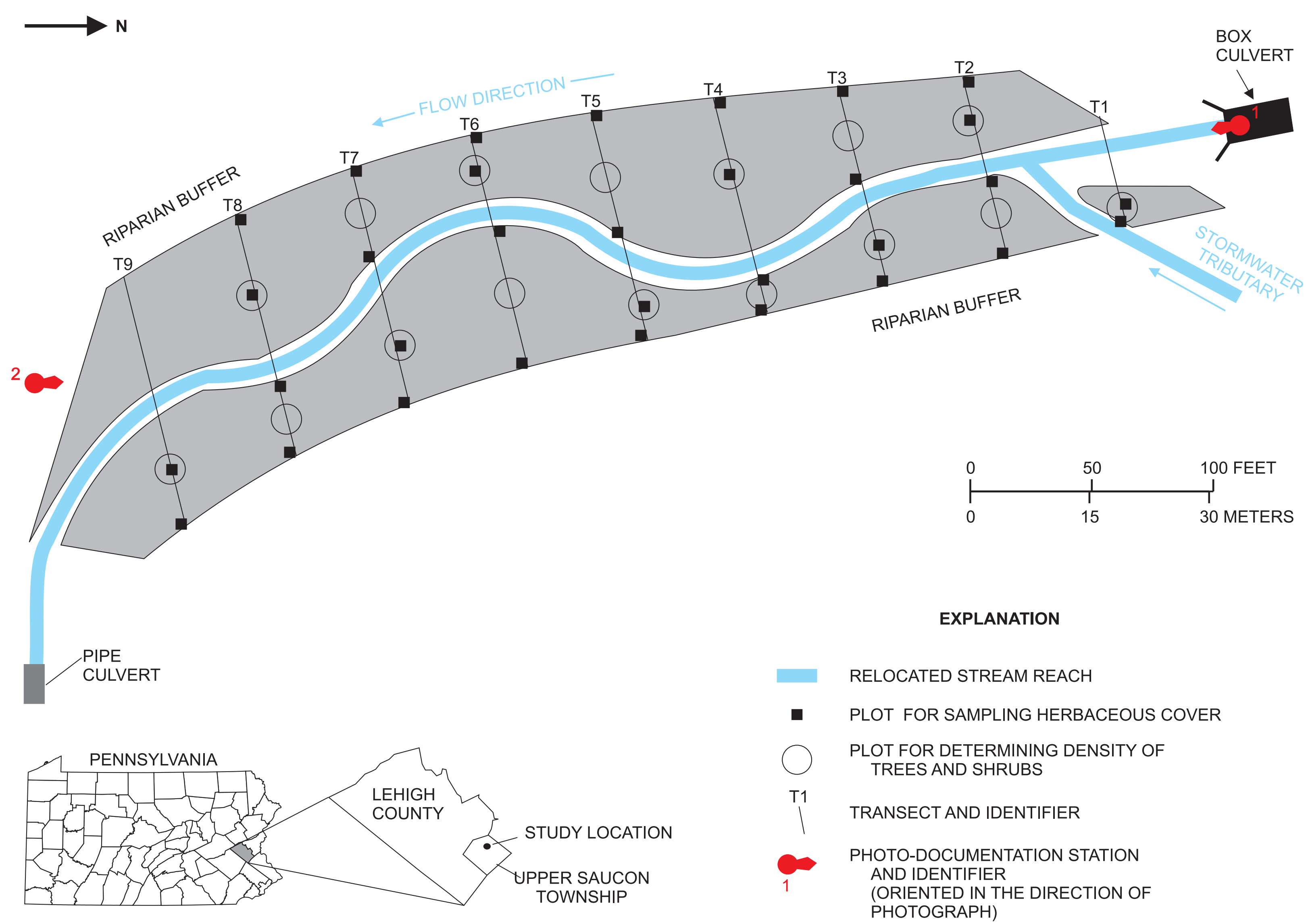

Figure 5. Monitoring grid used to collect vegetation data in the riparian buffer adjacent to the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania.

Physical and Vegetative Characteristics

Relocated Stream Reach

Changes to constructed stream channels usually are anticipated following construction. The extent of change is a direct function of constructed channel morphology and hydrologic conditions to which the new channel is subjected. In the spring of 2000, PennDOT relocated a tributary to Saucon Creek into a constructed, meandering stream channel. Changes to this channel were documented over the 2000 to 2004 time period (see table 1 for dates of monitoring).

Hydrologic Conditions

The streamflow-gaging station at Little Lehigh Creek near Allentown, Pa. (USGS station number 01451500), has been in operation since 1946 and is about 5 mi west of the study site. Instead of streamflow data from the relocated stream reach, data from Little Lehigh Creek were used for characterizing the hydrologic conditions that probably occurred in the relocated stream reach.

Data used for the hydrologic characterization were collected during the 2000-04 monitoring period (Durlin and Schaffstall, 2001, 2002, 2003, 2004, 2005). The annual mean streamflow for the period of record (1946 to 2004) was 101 ft^3/s. Annual mean streamflow during the period the relocated stream reach was monitored ranged from 52.6 ft^3/s in the 2002 water year to 178 ft^3/s in water year 2004 (from 48 percent lower to 76 percent higher than the annual mean for the period of record). Storm peaks during the monitoring period ranged from 711 to 9,670 ft^3/s; 16 peaks had probabilities of exceedance of 67 percent or less (1.5-year recurrence interval or greater). Streamflows with recurrence intervals of 1-2 years (1.5 years on average) commonly are considered to be the most effective or dominant channel-forming flows (Dunne and Leopold, 1978). The highest storm peak for the period of record at the Little Lehigh Creek streamflow-gaging station is 11,800 ft^3/s.

Changes to the Channel

The slope of a stream channel is a key factor in determining its capacity to transport sediment. An increasing channel slope may increase the bed-particle size the channel can transport during a given flow; conversely, a decreasing slope may reduce transport capacity.

Elevations surveyed as close as possible to stations 85 and 570 were used to compute channel slope for the reach of relocated stream bounded upstream by the confluence with a stormwater tributary and downstream by a pipe culvert (fig. 3). The slope calculations presented in table 2 use this upstream endpoint to avoid the expected effect of the riprap-lined part of the channel immediately upstream (fig. 3). It should be noted that the presence of riprap may effect the extent of scour between stations 55 and 80 and the steepening of the channel slope between stations 80 to 100. During the monitoring period, channel slopes ranged from a maximum of 0.008 ft/ft in the 2001 and 2002 assessments to a minimum of 0.005 ft/ft in 2003 (table 2).

Table 2. Longitudinal profile characteristics of the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania.

{ft/ft, feet per foot; ft, feet]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Stream channel slope (ft/ft)	0.007	0.008	0.008	0.005	0.006	14	14	-28	-14
Sinuosity (ft/ft)	1.08	1.08	1.08	1.09	1.09	0	0	1	1
Average riffle slope (ft/ft)	.016	.016	.028	.021	.013	0	75	31	-19
Average pool slope (ft/ft)	.002	.002	.001	.001	.001	0	-50	-50	-50
Average riffle length (ft)	14.1	28.3	24.2	21.1	33.3	100	-14	50	140
Average pool length (ft)	20.7	42.3	57.3	74.9	98.2	100	35	260	370
Average riffle-to-riffle spacing (ft)	35.5	73.6	65.4	109	179	110	-11	200	400
Average pool-to-pool spacing (ft)	35.5	75.8	23.4	107	151	110	-69	200	320

Using stations 85 and 570 to compute channel slope can be misleading because appreciable changes in the channel between the endpoints will have no effect on the slope computation. Conversely, changes specific to endpoint elevations will be associated with the entire reach. On the basis of the established endpoints, the data indicate that, as of the 2002 assessment and throughout the remainder of the monitoring period, the upstream part of the channel has slowed in its adjustment of slope, but the amount of deposition downstream is evidence of continued instability and active channel evolution at a rate dictated by the streamflow and sediment introduced into the stream system.

One factor contributing to the decreasing channel slope is the upstream migration of a “nick point,” a localized appreciable change in bed elevation, in the vicinity of station 85, an endpoint used in the slope computation. The initial thalweg elevation at station 85 during the 2000 assessment was 98.73 ft; during the 2003 assessment, the thalweg elevation at station 85 was 97.42 ft, indicating 1.31 ft of streambed erosion. The bed elevation at station 85 during the 2004 assessment was within 0.04 ft of the 2003 assessment, approaching at least a temporary cessation of streambed erosion. The thalweg elevation of 97.42 ft migrated from station 164 during the 2000 assessment to station 85 during the 2003/2004 assessments indicating headward erosion over a 79-ft reach during the monitoring period. Despite the similarity in the upper two-thirds of the channel between the 2003 and 2004 assessments, some evidence of erosion was noted between stations 55 and 70 that, if continued, could provide a mechanism for the resumption of upstream migration of the nick point until the stream attains a stable base level similar to the rest of the channel, though the rate would be expected to slow as a result of the riprap-lined part of the channel.

During the monitoring period, reach sinuosity increased slightly, which may have been the result of a slightly different placement of the measuring tape. However, reductions in channel slope frequently are accompanied by increased sinuosity as the stream channel continues to evolve toward equilibrium.

Sequences of deeper pools with slow-flowing water and shallow riffles with higher-velocity flow provide a range of habitat necessary to support a diverse biological community. Over the monitoring period, the number of pools and riffles decreased by about 75 percent. The average pool length increased by about 370 percent since the 2000 assessment, and pools in 2004 composed about 80 percent of the reach compared to 60 percent in 2000. The average riffle length has increased by 140 percent over the entire monitoring period, and the average riffle slope has decreased by 19 percent (table 2).

Changes in maximum depth and cross-section area are indicators of the degree to which a channel is stabilizing. The stream channel will continue to adjust until it reaches dynamic equilibrium. This equilibrium takes place when streamflow is capable of conveying the sediment load being supplied without excessive erosion or deposition.

As is apparent in the longitudinal profile (fig. 6) and cross-section surveys, downcutting of the thalweg was appreciable in the early evolution of cross-sections 97 through 357 (figs. 7-13; tables 3-9); increasing bed elevation was observed in the reach from cross-sections 390 to 506 (figs. 14-16; tables 10-12). Increases in maximum depth over the monitoring period ranged from 1.37 ft (cross-section 97; table 3) to 0.16 ft (cross-section 506; table 12). A transition from increasing to decreasing maximum depths, resulting from deposition, occurred downstream from cross-section 390, where streambed elevation increased (maximum depth decreased) by as much as 1.10 ft at cross-section 425 (table 11). Overall, the most appreciable increase in maximum depth was within the first 2 years of monitoring; an average decrease in streambed elevation of 0.63 ft was measured.

Changes in cross-section area are further evidence of the degree of channel adjustment to be expected in the future. Increases in cross-section area of as much as 36 percent over the monitoring period are noted for cross-section 97 (table 3) and to a much lesser degree at cross-sections 134 (6 percent), 174 (2 percent), and 214 (1 percent) (tables 4-6), most of which are attributed to the downcutting and widening (cross-section 97) of the active channel. One factor likely adding to the widening of cross-section 97 (fig. 7) may be its proximity to the confluence with a stormwater tributary and the necessary adjustment to accommodate the combined flows in this area. Cross-section areas for stations 134 to 214 have changed little since the 2001 assessment, indicating the approach to a stable form. Despite that data from cross-section 261 indicate decreasing cross-section area (table 7) because of isolated pockets of deposition beyond the active channel (fig. 11), the cross section continues to maintain similar geometry to previous assessments. Cross-section 315 (fig. 12) had a 12-percent decrease in cross-section area over the monitoring period (table 8), resulting from increasing deposition on the left bank of the stream channel. Beginning with cross-section 357 (fig. 13) and continuing downstream to cross-sections 390, 425, and 506 (figs. 14, 15, and 16, respectively), streambank and flood-plain deposition are more apparent. The resulting decreases in cross-section areas range in magnitude from 37 percent for cross-section 357 (table 9) to 54 and 91 percent at cross-sections 390 (table 10) and 425 (table 11), respectively. Cross-section 506 had a 37-percent decrease in cross-section area (table 12). One cause for the deposition in the lower part of the channel is most likely the decreasing capacity of the stream to transport the sediment load from upstream because of the decreased slope. An additional cause could be an undersized culvert at the bottom of the reach (fig. 3) that is prone to debris blockage and resulting backwater (pooled water) upstream from the culvert. The extremely low velocities result in the sediment load being deposited on the channel sides and the flood plain.

Beginning with cross-section 357 (table 9) and continuing downstream to cross-sections 390, 425, and 506 (tables 10-12 and figs. 13-16), calculation of changes to maximum depth and cross-section area over the monitoring period may be misleading. Deposition on the flood plain, including at cross-section endpoints, has elevated the ground level beyond the elevation of

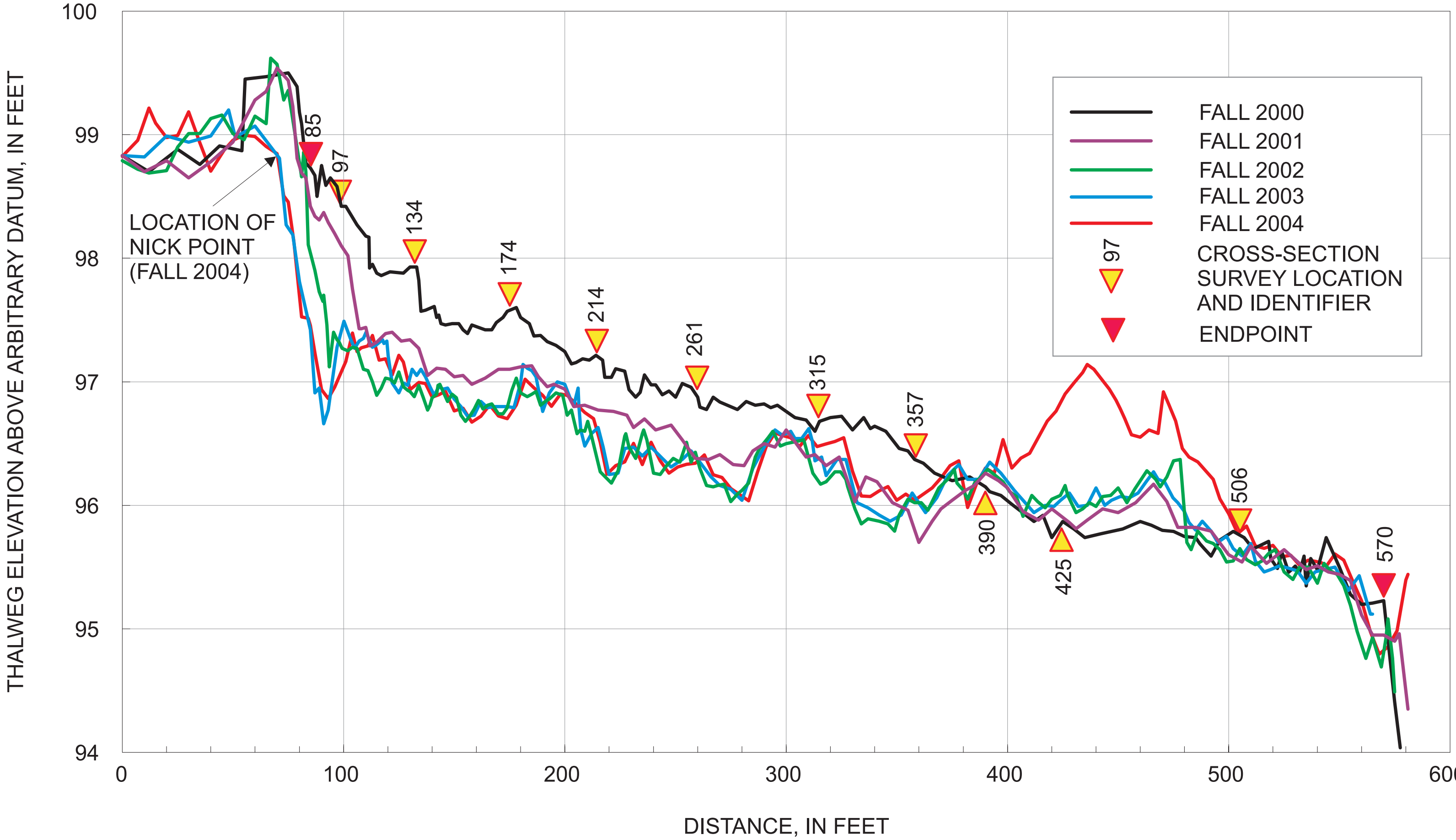

Figure 6. Longitudinal profile of the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania.

[Annual discrepancies in stationing along the longitudinal profile are due to changes in the thalweg and the resulting inability to place the measuring tape along the exact same path.

the established baseline used to compute channel geometry; thus, effectively decreasing the apparent extent of deposition.

The bed-particle distribution of a stream is indicative of the sediment load being supplied to the stream system as well as the capacity of the stream to transport it. Tailings piles from an abandoned mine (fig. 1) extend parallel to Center Valley Parkway on the upstream side of the box culvert. Grey, extremely fine sediment from these piles is readily mobilized and introduced into the constructed channel. The resulting excessive fine sediment within the channel is an indication of this abundant source of fine material and an indication the stream has insufficient energy, over the range of flow conditions, to move the entire load of fine material being supplied to the system.

Bed-particle distributions of the substrate within the relocated stream reach are dominated by extremely fine sediment in the silt/clay to very-fine sand range that is easily mobilized and redistributed. Bed-particle sizes occurring at selected frequencies within each cross section are shown in tables 3-12. Median bed-particle sizes (D50) for 8 of the 10 cross sections sampled over the monitoring period were no greater than 0.1 mm (tables 3-12). Particles in this size range are not measurable but are determined in the field using visual and tactile comparison to a calibrated sample card. The particle size equal to or greater than 84 percent of the bed substrate within each cross section (D84) ranged in size from 0.1 to 32.0 mm (table 3-12). The particle size equal to or greater than 95 percent of the bed substrate within each cross section (D95) ranged in size from 0.2 to 73.3 mm.

The averages of the D84 and D95 particle categories in tables 3-12, computed annually and including all previous years, display alternating increases and decreases in bed-particle size. Bed-particle distributions in 8 of the 10 cross sections have included at least 1 particle in the 128-180 mm range or greater. The distributions in bed-particle size emphasize the dominance of the fine-grained material throughout the reach as well as the erratic presence of isolated larger particles. The consistency with which fined-grained sediment dominates the substrate within each cross section indicates the supply of fine material exceeds the capacity of the stream channel to move it through the reach. The annual fluctuations in the larger particle categories within each cross section demonstrate the capacity of the stream to periodically move the range of sediment introduced to the stream system.

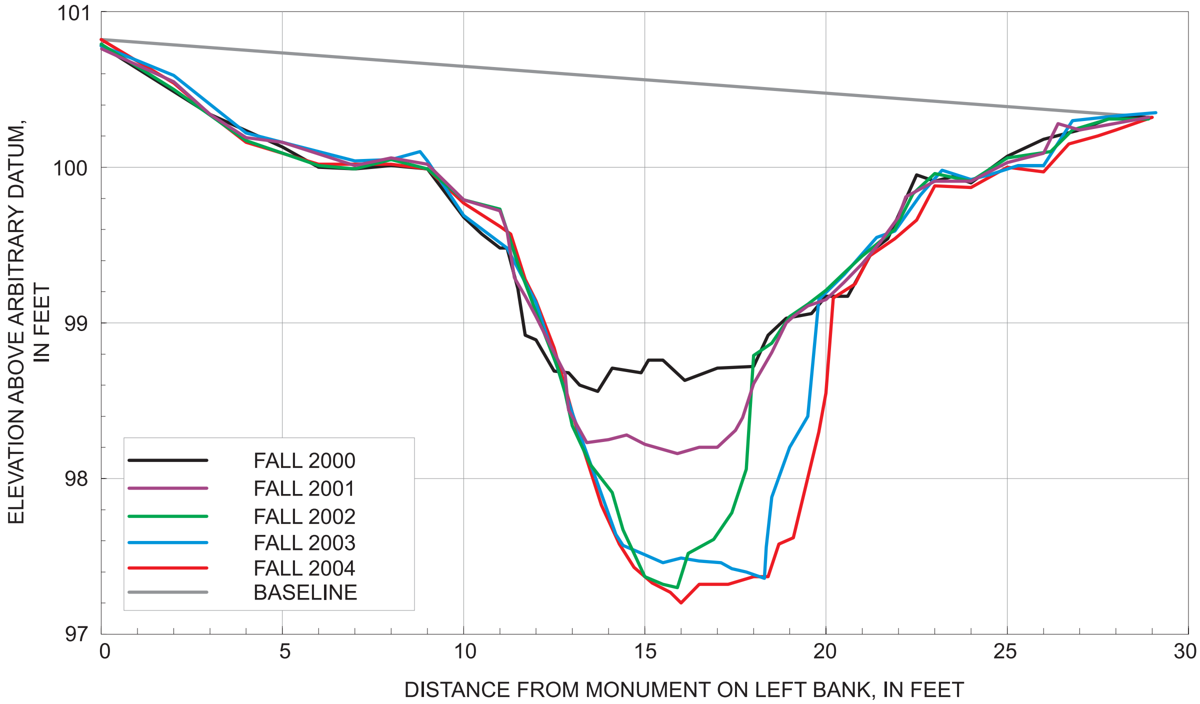

Figure 7. Cross-sectional channel surveys in the relocated stream reach, 97 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 3. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 97 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Riffle	Riffle	Riffle	Pool	Pool				
Cross-section area, in square feet	25.5	26.9	29.9	32.3	34.8	5	17	27	36
Baseline width, in feet	28.8	28.9	28.9	29.1	29.0	<1	<1	1	1
Mean cross-section depth, in feet	.88	.93	1.04	1.11	1.20	6	18	26	36
Maximum cross-section depth, in feet	2.00	2.38	3.22	3.21	3.37	19	61	60	68
Pebble count, in millimeters:									
D15	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D50	.1	.1	<.1	.1	.1	0	—	0	0
D84	3.5	6.0	6.0	32.0	13.9	71	71	810	300
D95	10.5	26.4	13.2	73.3	54.2	150	25	600	420

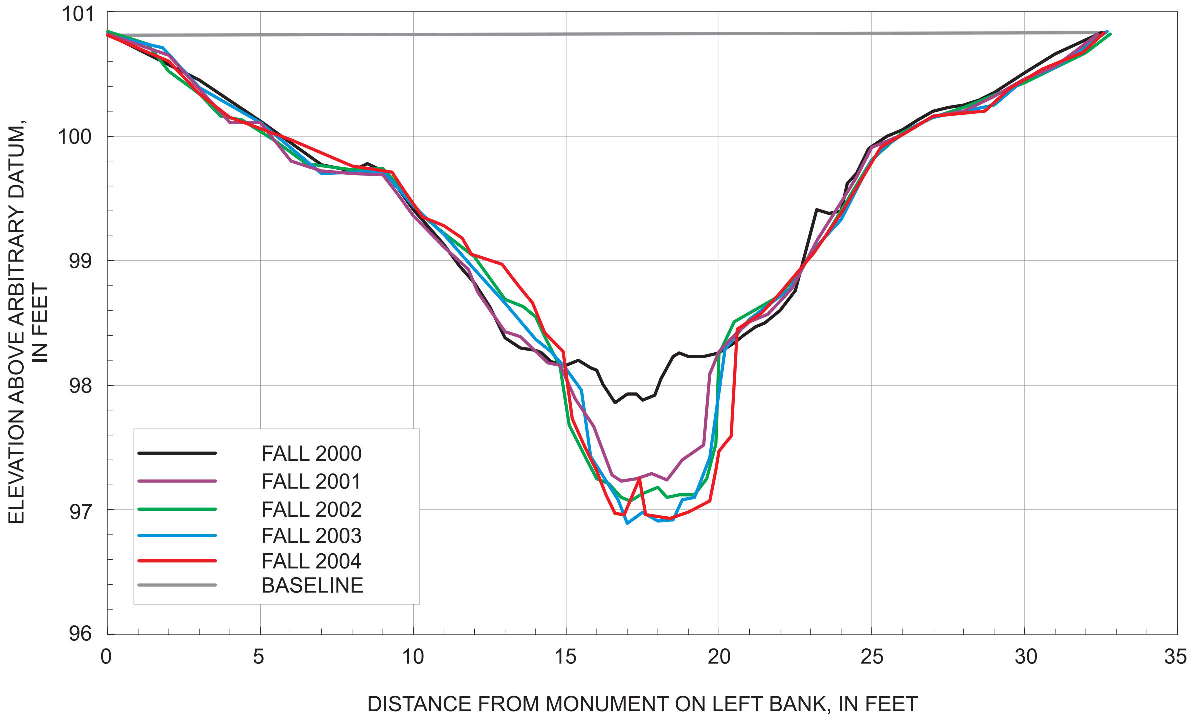

Figure 8. Cross-sectional channel surveys in the relocated stream reach, 134 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 4. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 134 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Riffle	Riffle	Riffle	Pool	Pool				
Cross-section area, in square feet	45.5	47.6	48.4	48.4	48.3	5	6	6	6
Baseline width, in feet	32.5	32.4	32.7	32.8	32.6	<1	1	1	0
Mean cross-section depth, in feet	1.40	1.47	1.48	1.47	1.48	5	6	5	6
Maximum cross-section depth, in feet	3.01	3.59	3.94	3.76	3.89	19	31	25	29
Pebble count, in millimeters:									
D15	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D50	.1	.1	<.1	.1	<.1	0	—	0	—
D84	6.0	3.4	.4	11.6	.2	-43	-93	93	-97
D95	27.7	13.9	11.3	38.8	24.7	-50	-59	40	-11

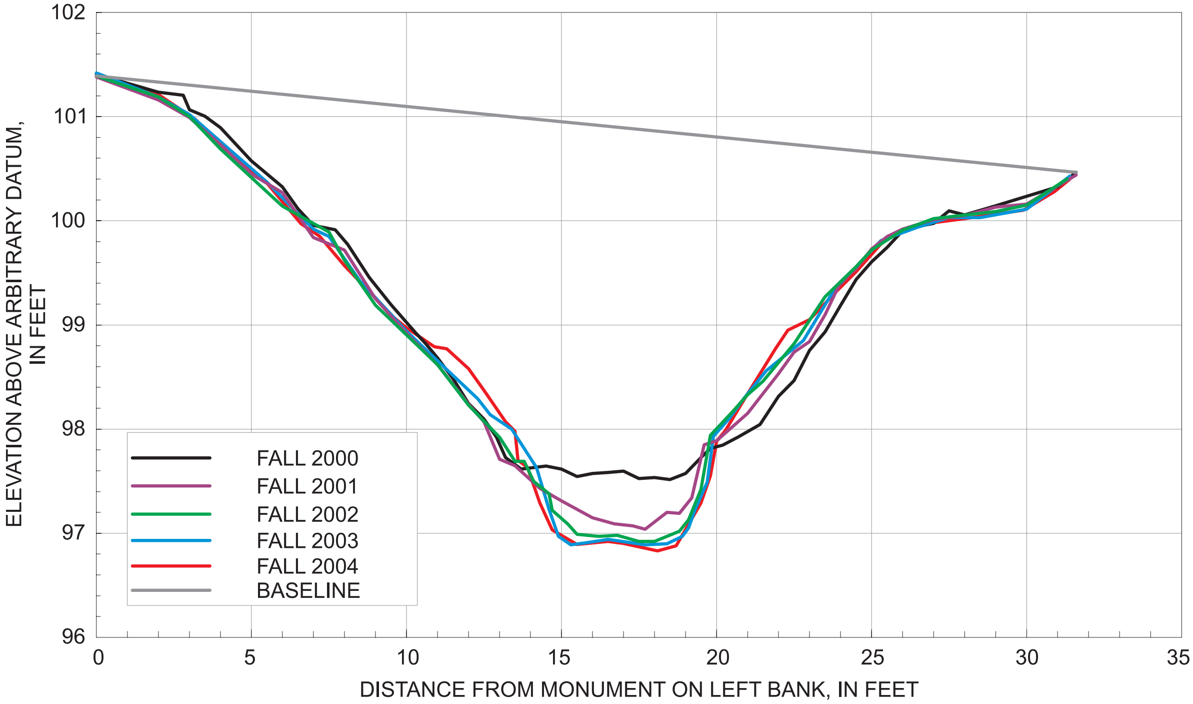

Figure 9. Cross-sectional channel surveys in the relocated stream reach, 174 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 5. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 174 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Pool	Pool	Pool	Pool	Pool				
Cross-section area, in square feet	52.5	54.2	53.9	54.7	53.8	3	3	4	2
Baseline width, in feet	31.6	31.6	31.3	31.4	31.4	0	-1	-1	-1
Mean cross-section depth, in feet	1.66	1.71	1.72	1.74	1.71	3	4	5	3
Maximum cross-section depth, in feet	3.40	3.87	3.91	4.04	4.07	14	15	19	20
Pebble count, in millimeters:									
D15	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D50	.1	<.1	.1	.1	<.1	—	0	0	—
D84	10.2	4.0	.7	9.3	.5	-61	-93	-9	-95
D95	29.1	32.0	14.8	32.5	20.8	10	-49	12	-28

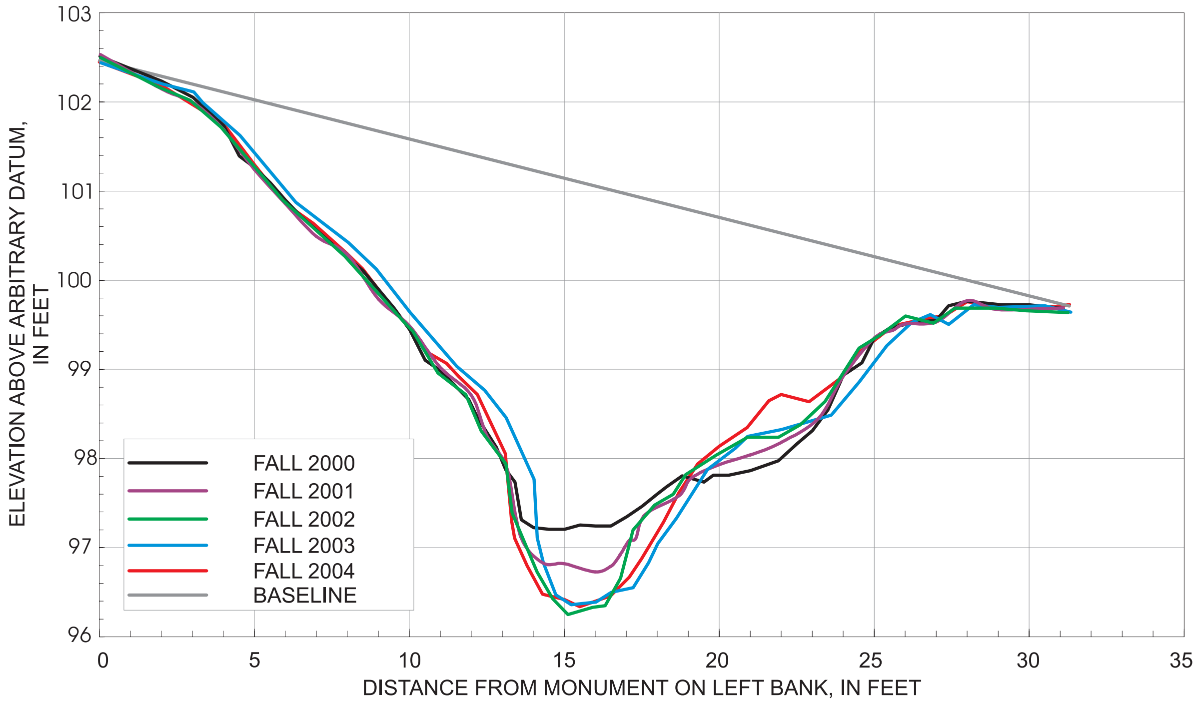

Figure 10. Cross-sectional channel surveys in the relocated stream reach, 214 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 6. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 214 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Riffle	Riffle	Riffle	Pool	Pool				
Cross-section area, in square feet	54.5	56.1	55.6	53.3	55.2	3	2	-2	1
Baseline width, in feet	31.1	31.1	31.2	31.7	31.3	0	<1	2	1
Mean cross-section depth, in feet	1.75	1.80	1.78	1.68	1.76	3	2	-4	1
Maximum cross-section depth, in feet	4.03	4.38	4.87	4.67	4.75	9	21	16	18
Pebble count, in millimeters:									
D15	.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	.1	<.1	.1	<.1	<.1	—	0	—	—
D50	.2	.1	.2	.1	<.1	-50	0	-50	—
D84	12.0	3.4	.9	6.1	.5	-72	-92	-49	-96
D95	16.0	13.9	10.7	19.3	21.0	-13	-33	21	31

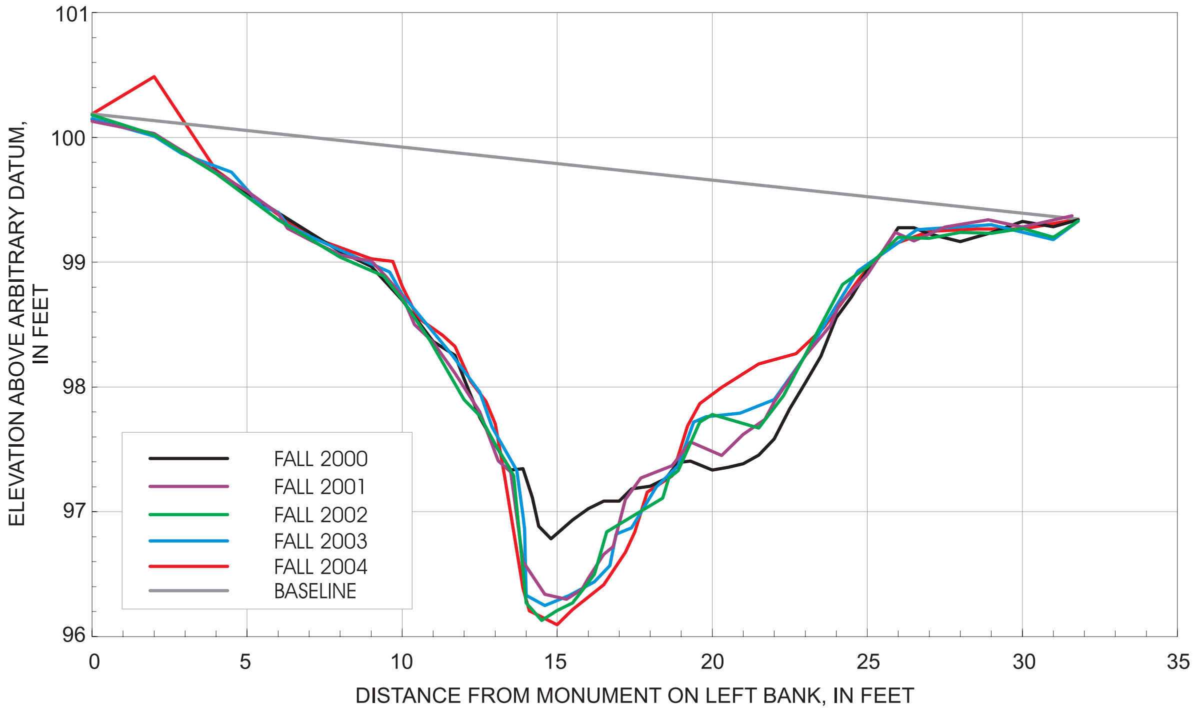

Figure 11. Cross-sectional channel surveys in the relocated stream reach, 261 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 7. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 261 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Pool	Pool	Pool	Pool	Pool				
Cross-section area, in square feet	39.9	38.2	39.0	37.3	37.3	-4	-2	-7	-7
Baseline width, in feet	31.8	31.6	31.8	31.8	31.8	<-1	0	0	0
Mean cross-section depth, in feet	1.26	1.21	1.23	1.17	1.17	-4	-2	-7	-7
Maximum cross-section depth, in feet	3.06	3.45	3.66	3.49	3.67	13	20	14	20
Pebble count, in millimeters:									
D15	.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	.1	<.1	.1	<.1	<.1	—	0	—	—
D50	.1	.1	.2	<.1	<.1	0	100	—	—
D84	12.0	.5	1.0	1.1	.1	-96	-92	-91	-99
D95	22.8	13.9	32.0	18.4	11.8	-39	40	-19	-48

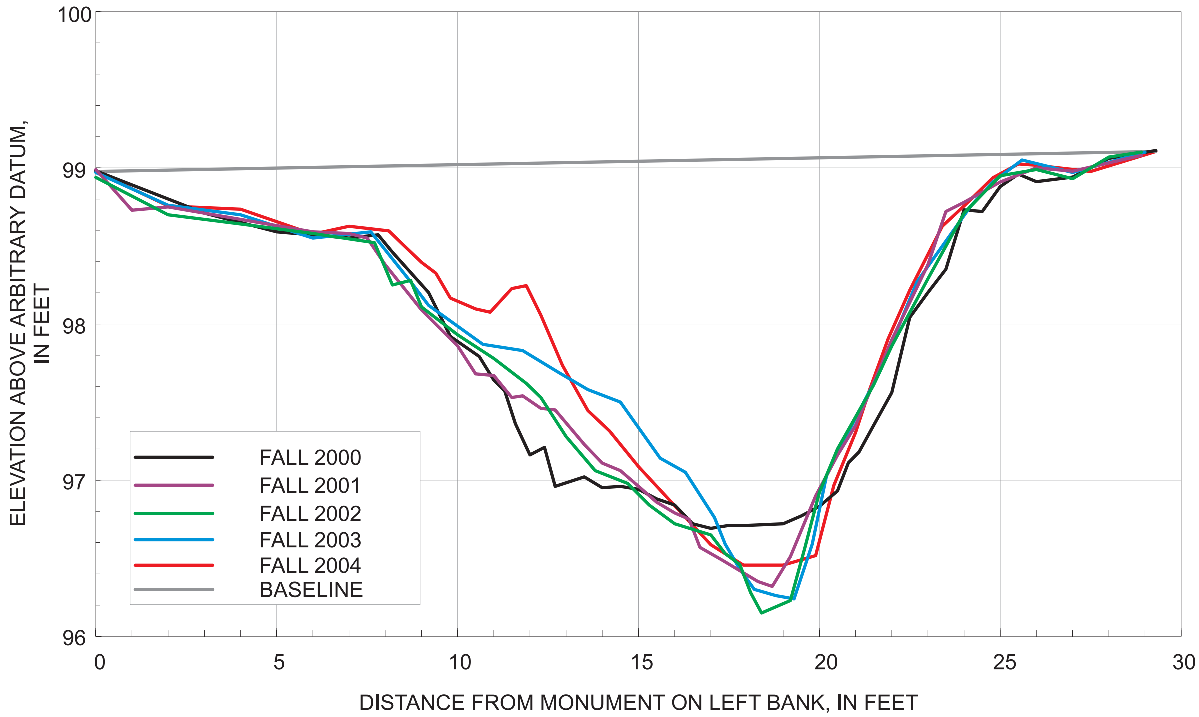

Figure 12. Cross-sectional channel surveys in the relocated stream reach, 315 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 8. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 315 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Pool	Riffle	Riffle	Pool	Pool				
Cross-section area, in square feet	30.7	30.0	30.0	27.7	27.1	-2	-2	-10	-12
Baseline width, in feet	29.3	28.9	28.9	29.0	29.3	-1	-1	-1	0
Mean cross-section depth, in feet	1.05	1.04	1.04	.96	.93	-1	-1	-9	-11
Maximum cross-section depth, in feet	2.36	2.72	2.90	2.80	2.59	15	23	19	10
Pebble count, in millimeters:									
D15	.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	.1	.1	.1	<.1	<.1	0	0	—	—
D50	.5	.1	.2	.1	<.1	-80	-60	-80	—
D84	8.0	32.0	15.9	3.1	13.2	300	-99	-61	65
D95	24.0	69.4	43.0	29.1	55.4	190	79	21	130

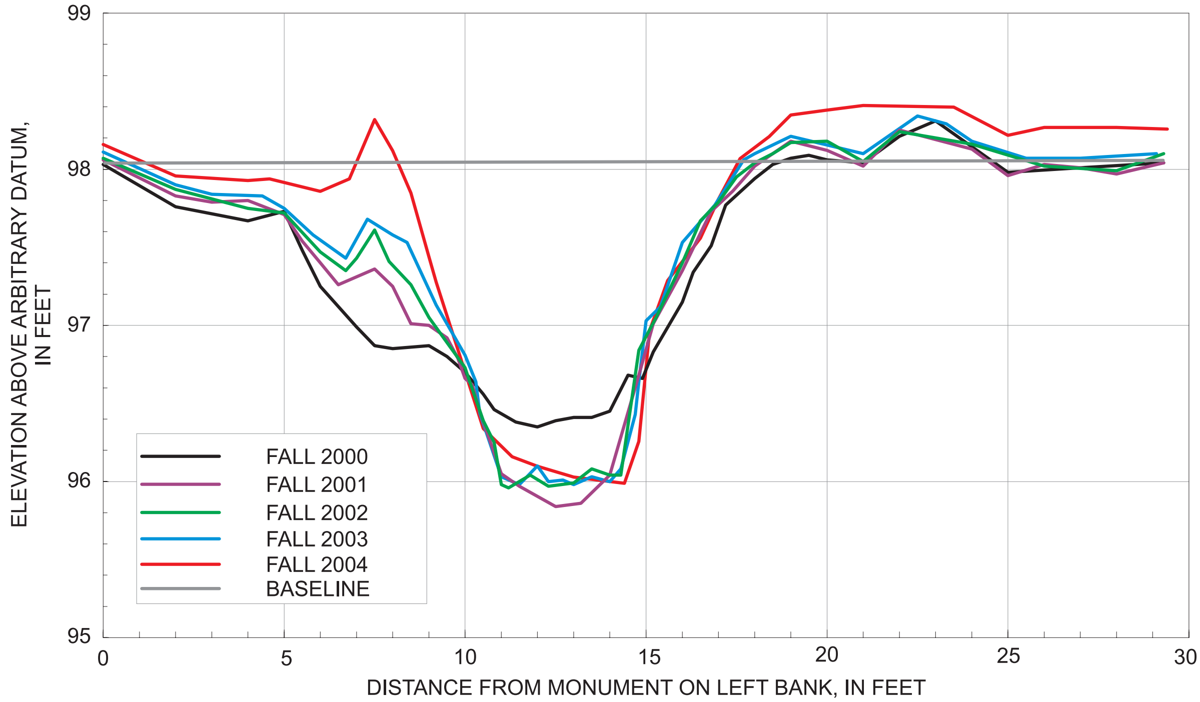

Figure 13. Cross-sectional channel surveys in the relocated stream reach, 357 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 9. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 357 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Riffle	Pool	Pool	Pool	Pool				
Cross-section area, in square feet	19.8	16.2	15.2	14.3	12.4	-18	-23	-28	-37
Pin-to-pin width, in feet	29.3	29.3	29.3	29.1	29.4	0	0	-1	<1
Mean cross-section depth, in feet	.72	.55	.52	.49	.42	-24	-28	-32	-42
Maximum cross-section depth, in feet	1.80	2.19	2.07	2.05	2.05	22	15	14	14
Pebble count, in millimeters:									
D15	.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	.2	<.1	.1	<.1	<.1	—	-50	—	—
D50	1.8	.1	.2	<.1	<.1	-94	-89	—	—
D84	13.9	6.0	5.6	5.3	.8	-57	-60	-62	-94
D95	30.7	39.2	38.4	40.5	27.9	28	25	32	-9

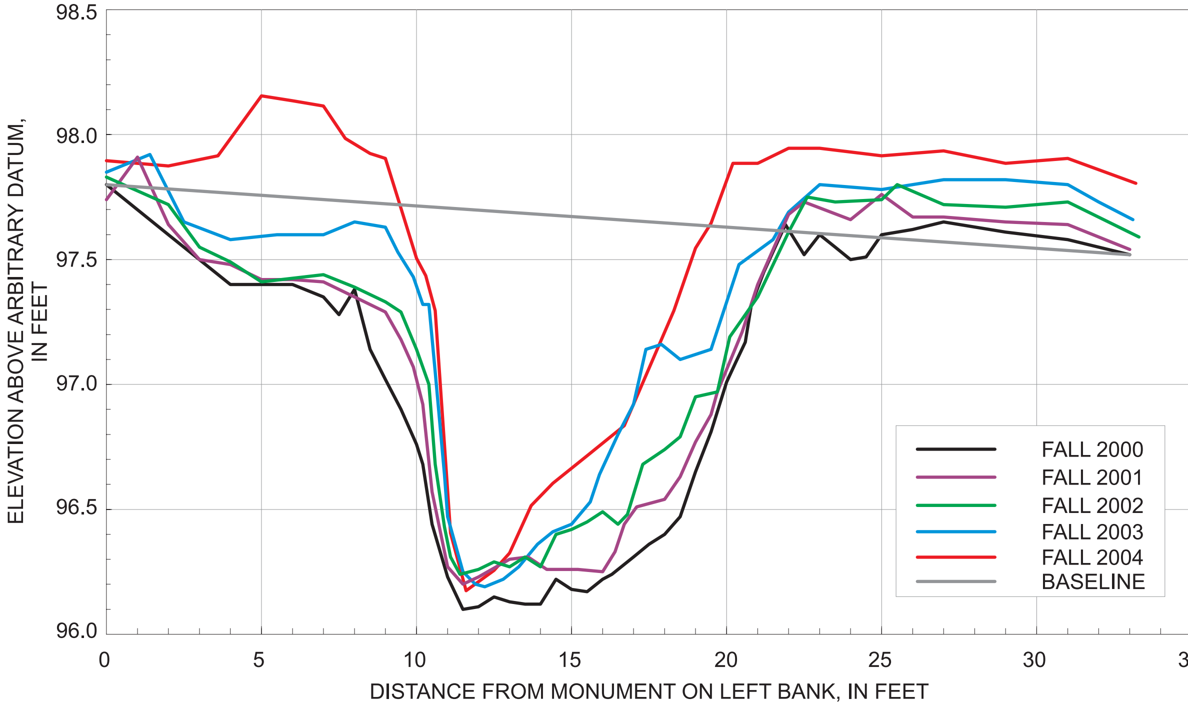

Figure 14. Cross-sectional channel surveys in the relocated stream reach, 390 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 10. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 390 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Riffle	Riffle/ Pool	Riffle/ Pool	Pool	Pool				
Cross-section area, in square feet	18.2	15.6	14.4	11.0	8.4	-14	-21	-40	-54
Baseline width, in feet	33.0	33.0	33.3	33.1	33.2	0	1	<1	1
Mean cross-section depth, in feet	.55	.47	.43	.33	.25	-14	-22	-40	-54
Maximum cross-section depth, in feet	[1]1.56	1.46	1.42	1.47	1.49	-6	-9	-6	-4
Pebble count, in millimeters:									
D15	<.1	<.1	.1	<.1	<.1	—	—	—	—
D35	.1	<.1	.2	<.1	<.1	—	100	—	—
D50	.5	.1	.2	<.1	.1	-80	-60	—	-80
D84	7.4	28.3	14.3	2.8	10.8	280	93	-62	46
D95	14.3	60.4	43.2	22.9	32.0	320	200	60	120

[1]2000 maximum depth revised from previously reported values based on recalculation of channel geometry.

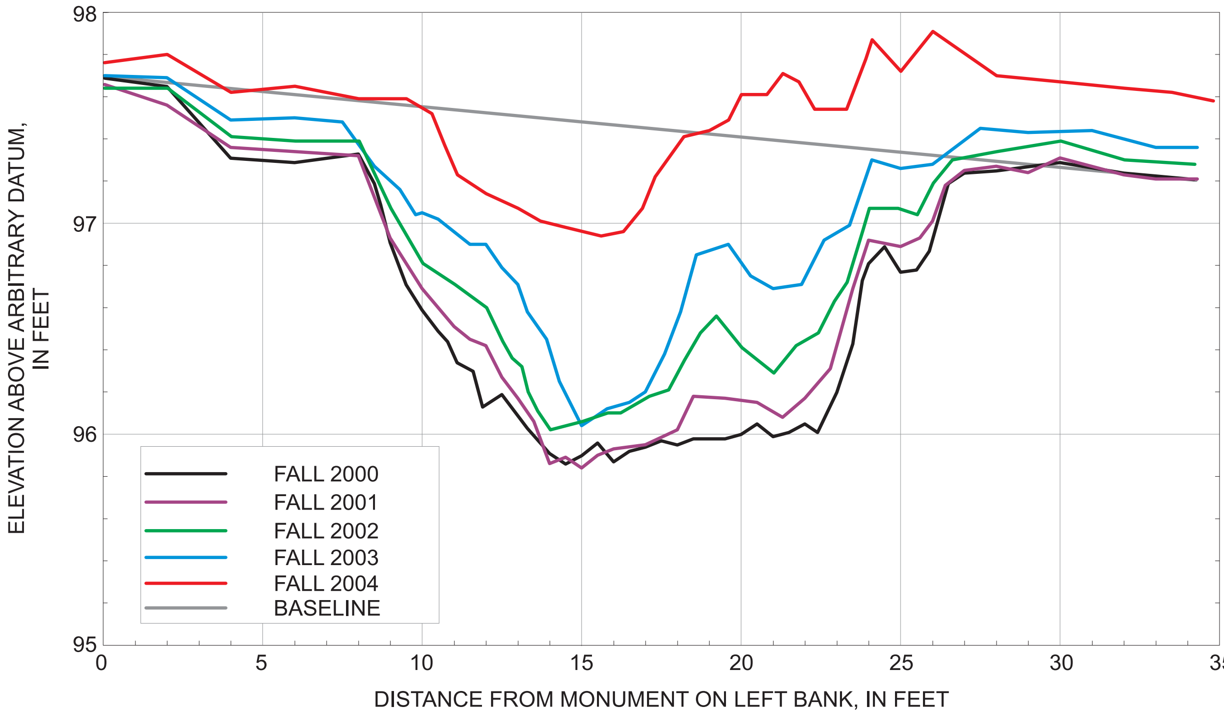

Figure 15. Cross-sectional channel surveys in the relocated stream reach, 425 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 11. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 425 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Pool	Pool	Pool	Pool	Pool				
Cross-section area, in square feet	31.3	21.1	17.0	12.3	2.9	-32	-46	-61	-91
Baseline width, in feet	34.2	34.3	34.2	34.3	34.8	<1	0	<1	2
Mean cross-section depth, in feet	.92	.62	.50	.36	.08	-33	-46	-61	-91
Maximum cross-section depth, in feet	[1]1.59	1.60	1.42	1.40	.49	1	-11	-12	-69
Pebble count, in millimeters:									
D15	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	<.1	<.1	.1	<.1	.1	—	—	—	—
D50	.1	.1	.2	<.1	.1	0	100	—	0
D84	2.2	9.0	6.3	.1	7.7	310	190	-95	250
D95	9.8	29.1	24.0	9.5	15.3	200	-60	81	56

[1]2000 maximum depth revised from previously reported values based on recalculation of channel geometry.

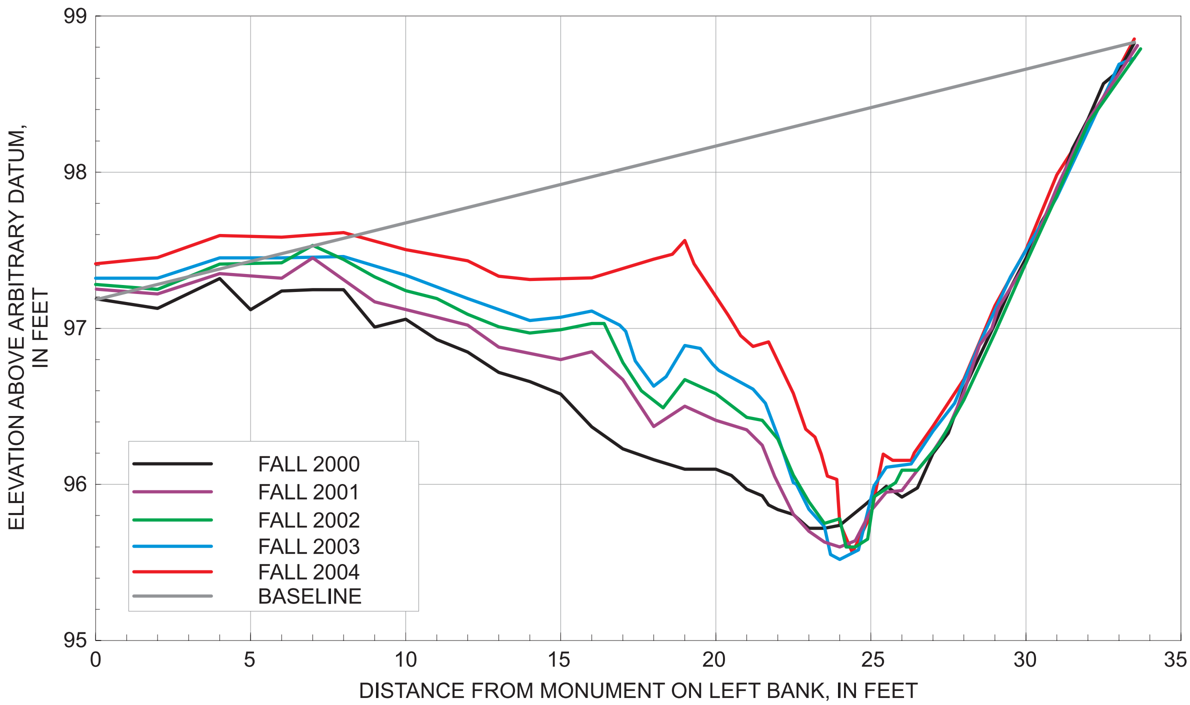

Figure 16. Cross-sectional channel surveys in the relocated stream reach, 506 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

Table 12. Cross-section dimensions and bed-particle-size distribution in the relocated stream reach, 506 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania.

[D15, 15th percentile bed-particle size; D35, 35th percentile bed-particle size; D50, 50th percentile bed-particle size; D84, 84th percentile bed-particle size; D95, 95th percentile bed-particle size; —, unable to quantify change; <, less than]

Profile characteristics	2000	2001	2002	2003	2004	Change, in percent			
						2000-01	2000-02	2000-03	2000-04
Flow regime	Pool	Pool	Pool	Pool	Riffle				
Cross-section area, in square feet	41.0	35.7	34.1	32.2	25.8	-13	-17	-21	-37
Baseline width, in feet	33.5	33.6	33.7	33.5	33.5	<1	1	0	0
Mean cross-section depth, in feet	1.22	1.03	1.01	.96	.77	-16	-17	-21	-37
Maximum cross-section depth, in feet	[1]2.29	2.41	2.41	2.49	2.45	5	5	9	7
Pebble count, in millimeters:									
D15	<.1	<.1	<.1	<.1	<.1	—	—	—	—
D35	.1	<.1	.1	<.1	<.1	—	0	—	—
D50	.1	.1	.1	<.1	<.1	0	0	—	—
D84	6.0	.2	.2	.1	.1	-97	-97	-98	-98
D95	22.6	4.0	.7	.2	.2	-82	-97	-99	-99

[1]2000 maximum depth revised from previously reported values based on recalculation of channel geometry.

Constructed Wetland

The constructed wetland supported a hydrophytic-vegetation community throughout the study period (table 13). Most observed species commonly are found in or near wetlands. Non-native species common to some wetlands [such as *Lythrum salicaria* (purple loosestrife)] do not pose a threat to the vegetation community at this time (2005).

Eleocharis obtusa (spike rush), a perennial OBL herb, was the most prevalent species each fall despite variation in areal cover from growing season to growing season (table 13). Drought-like conditions throughout the 2002 water year (cumulative precipitation was 28.11 in.; table 14) coincided with a decrease in areal cover of *E. obtusa* from 90 percent in fall 2001 to 34 percent by fall 2002. Less competition by *E. obtusa* allowed other species, most notably *Panicum dichotomiflorum* (witch grass), *Salix* sp. (willow), *Leersia oryzoides* (rice cutgrass), *Echinocloa crusgalli* (barnyard grass), and various sedges and rushes, to become established, even if temporarily (table 13).

Table 13. Areal cover of vegetation in the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.

[NE, Northeast; OBL, obligate-wetland species; FACW, facultative-wetland species; FAC, facultative species; FACU, facultative-upland species; +, indicates a frequency of occurrence in the upper end of the probability range for that category; -, indicates a frequency of occurrence in the lower end of the probability range for that category; --, not observed]

Latin name	Common name	NE regional indicator	Areal cover, in percent						
			Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
Alisma subcordatum	water plantain	OBL	--	--	--	--	--	2	14
Carex lurida	shallow sedge	OBL	--	--	--	--	3	--	2
Carex vulpinoidea	foxtail sedge	OBL	--	--	--	--	--	4	1
Cyperus strigosus	sedge grass	FACW	--	--	--	2	5	--	--
Echinocloa crusgalli	barnyard grass	FACU	5	--	3	--	6	--	--
Eleocharis obtusa	spike rush	OBL	46	24	90	45	34	56	23
Eleocharis tenuis	slender spikerush	FACW+	--	--	--	--	--	--	3
Festuca rubra	red fescue	FACU	--	1	4	4	2	--	--
Juncus effusus	soft rush	FACW+	--	4	2	5	6	1	7
Juncus tenuis	yard rush	FAC-	--	--	--	--	1	2	--
Leersia oryzoides	rice cutgrass	OBL	--	--	--	--	6	12	34
Lysimachia nummularia	moneywort	OBL	6	3	--	--	4	4	--
Nasturtium officinale	watercress	OBL	--	--	--	--	--	--	3
Panicum dichotomiflorum	witch grass	FACW-	--	--	--	1	21	--	--
Rorippa islandica	marsh yellow grass	OBL	8	--	4	--	1	--	--
Salix sp.	willow	FACW+	1	--	--	--	7	4	8
Scirpus validus	great bulrush	OBL	--	--	--	4	5	11	6
Typha latifolia	broadleaf cattail	OBL	--	--	--	--	--	1	1
Total			66	32	103	61	101	97	102

Table 14. Cumulative precipitation measured at Allentown International Airport for water years 2000–04, Lehigh County, Pennsylvania.

Water year	[1]Cumulative precipitation (inches)	[2]Departure from 30-year mean (1971-2000) (inches)
2000	44.05	-1.12
2001	39.79	-5.38
2002	28.11	-17.06
2003	58.55	10.38
2004	53.17	8.00

[1]Computed from data published by Northeast Regional Climate Center (2005).

[2]30-year mean equals 45.17 inches and is considered normal precipitation (Northeast Regional Climate Center, 2005).

Above-average precipitation in water year 2003 (58.55 in.; table 14) resulted in a higher water table than in water year 2002 (fig. 17). These conditions were favorable for growth of perennial OBL species and probably were responsible for the rebound of *E. obtusa* and increases in cover by *L. oryzoides* and *Scirpus validus* (great bulrush) during the 2003 growing season. *L. oryzoides* and *S. validus* provided greater cover in fall 2003 than in fall 2002, but neither *P. dichotomiflorum* or *E. crusgalli* (FACW- and FACU species, respectively) were observed after fall 2002.

A consecutive period of above-average precipitation in water year 2004 (53.17 in.; table 14) probably resulted in pond-like habitat in most of the wetland through much of the 2004 growing season. Despite the OBL status of *E. obtusa*, it does not thrive in persistently inundated habitats. Because *E. obtusa* occupied parts of the constructed wetland that were most prone to inundation, it decreased in cover from 56 percent in 2003 to 23 percent in 2004. In contrast, *L. oryzoides* increased in cover from 12 to 34 percent between fall 2003 and 2004 because it was established in the higher elevations and the peripheral areas of the constructed wetland that were less prone to persistent inundation but still supported a hydrophytic-vegetation community. *Alisma subcordatum* (water plantain), an aquatic species that grows in shallow water and mud (Strausbaugh and Core, 1978), provided 14 percent cover in fall 2004. This species was most common near the outlet of the constructed wetland (fig. 4).

Temporal variation of water levels within the wetland (fig. 17) generally followed the yearly fluctuation of precipitation (table 14). At most plots, water levels in years with below-normal precipitation (shown as fall 2000, 2001, and 2002 in figure 17) were lower (farther below ground surface) than years with above-normal precipitation (shown as fall 2003 and fall 2004 in figure 17). Exceptions to these patterns occurred at plots 0303, 0402, and 0403 in fall 2004, where water levels remained well below ground surface (10 in. or greater) despite above-average precipitation and inundation at other plots throughout the constructed wetland. These plots are at topographically high locations, which may explain the exceptions.

The unique characteristics of hydric soils result from periodic or permanent soil saturation for a duration long enough to create anaerobic conditions in the soil. Water-level data presented in figure 17 and photographs in appendix 2 represent the hydrologic characteristics at a point in time and do not capture the duration and frequency of saturation necessary to directly determine if anaerobic conditions persisted for long periods of time. However, the presence of prolonged anaerobic soil conditions may be determined indirectly through observation of physical characteristics of the soil.

Anaerobic conditions lead to a chemically reducing environment that causes reduction of iron and manganese oxides in the soil. Reduction of these metals commonly results in soils with a matrix (the portion of the soil that has the predominant color) characterized by a chroma of less than 2 units, mottles having a chroma less than 1 unit, and (or) gleying if greatly reduced (U.S. Army Corps of Engineers Environmental Laboratory, 1987). These characteristics were the most common indicators of hydric soils present within the constructed wetland.

In addition to reducing conditions caused by prolonged soil saturation, the presence (or absence) of hydric indicators was a function of the mixture of soil and woodchips originally spread throughout the wetland when it was constructed. Because part of the mixture was soil from a naturally occurring wetland, hydric indicators were common as early as in fall 2000. Hydric indicators observed in fall 2000 were probably already present before the mixture of soil and woodchips were brought in and were probably not the result of chemical alterations in the soil. Hydric indicators were present at most plots throughout the investigation and were most consistently observed at plots 0102, 0103, 0202, 0303, and 0403 (table 15). Distinct soil-horizon development generally was poor.

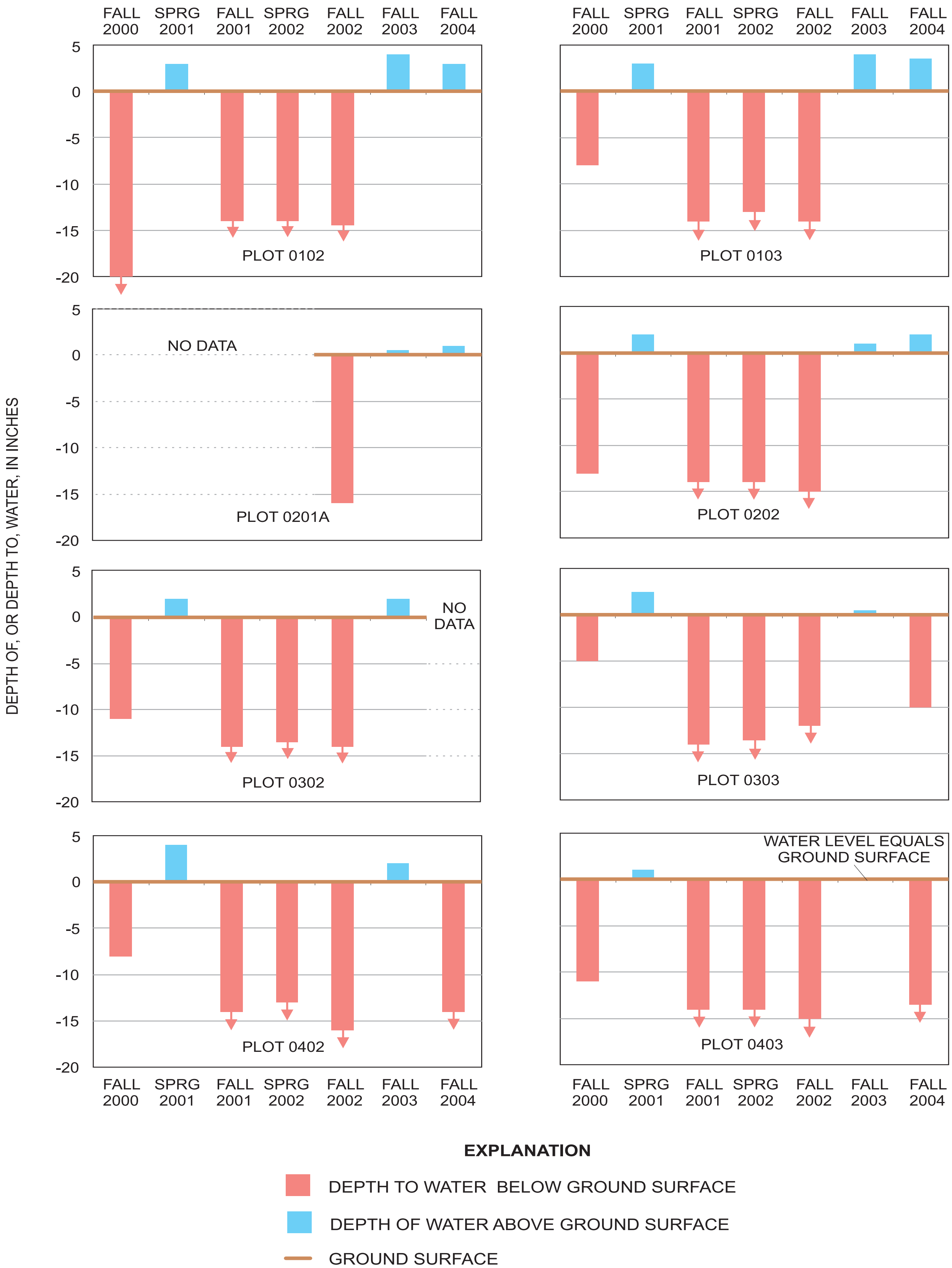

Figure 17. Water levels within the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04. Sampling plots are identified by a four-digit code consisting of transect number and plot number. For example, “0301” refers to transect 03, plot 01. See figure 4 for sampling plot locations. [SPRG, Spring; Arrow indicates water level is deeper below ground surface.]

Table 15. Presence or absence of hydric indicators in soils within the constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.

[Shading, presence of hydric-soil indicators; no shading, absence of hydric-soil indicators; ND, no data collected]

<table>
<tr><th>Plot Identifier[1]</th><th>Fall 2000</th><th>Spring 2001</th><th>Fall 2001</th><th>Spring 2002</th><th>Fall 2002</th><th>Fall 2003</th><th>Fall 2004</th></tr>
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<tr><td>0201A</td><td>ND</td><td>ND</td><td>ND</td><td>ND</td><td></td><td bgcolor="#b3b3b3"></td><td bgcolor="#b3b3b3"></td></tr>
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</table>

[1]Sampling plots are identified by a four-digit code consisting of transect number and plot number. For example, “0301” refers to transect 03, plot 01. See figure 4 for sampling plot locations.

Riparian Buffer

The composition of the plant community growing in the riparian buffer in fall 2004 is related directly to the species planted. Initially, *L. perenne* was planted by broadcasting seed throughout the buffer to provide stabilization of the bare ground that existed after construction. In the spring of 2000, bare-root shrubs of *S. canadensis*, *V. acerifolium*, and *Cornus sp.* were planted 2 ft on center between tree species of *Q. bicolor*, *F. pennsylvanica*, *A. negundo*, and *A. rubrum*, which also were planted 2 ft on center. The roots of the planted trees and shrubs were pruned prior to planting. Although this pruning allowed for efficient planting, it affected survival because nutrient and water uptake was hindered by removal of small roots and root hairs. Despite a relatively wet spring compared to other years, many of the trees and shrubs did not leaf out and appeared dead during a site visit on July 14, 2000 (fig. 18). On closer inspection, the main trunks of many trees and shrubs were in fact dead, but multiple stump sprouts were growing from the base, an indication that nutrient and water intake by the root system was not sufficient to support the entire plant. The stump sprouts provided a mechanism to keep the plant alive at the expense of the main trunk and generally were less than 1 ft tall by the first monitoring event (fall 2000).

Herbaceous Plant Community

Areal cover by herbaceous plants in fall 2000 (108 percent) reflects the poor canopy cover by woody riparian plantings (fig. 19). Lack of canopy development during the 2000 growing season resulted in more sunlight in the herbaceous understory than in any other growing season of the study period. This additional sunlight promoted growth by *L. perenne* (41.3 percent cover), *Polygonum persicaria (*lady's thumb; 8.8 percent cover), *Setaria faberi* (foxtail; 9.1 percent cover), and a host of other species characteristic of disturbed conditions (see appendix 4 for the list of species found in the riparian buffer during each monitoring event).

Herbaceous cover decreased to 76 percent by the fall of 2001 and varied between 72 and 77 percent for the rest of the study period (fig. 19). Although the cover provided by herbaceous species remained relatively constant after 2000, the dominant species varied substantially from year to year (table 16). This variability suggests the herbaceous community was, and may still be, in a state of transition. By fall 2004, species such as *Eupatorium rugosum* (white snakeroot) dominated the shaded areas where tree and shrub growth was rigorous. In contrast, *S. canadensis*, which thrives in full sun, dominated those areas where tree and shrub mortality were high. Most herbaceous species and grasses within the riparian buffer also were growing in the adjacent woods and open areas.

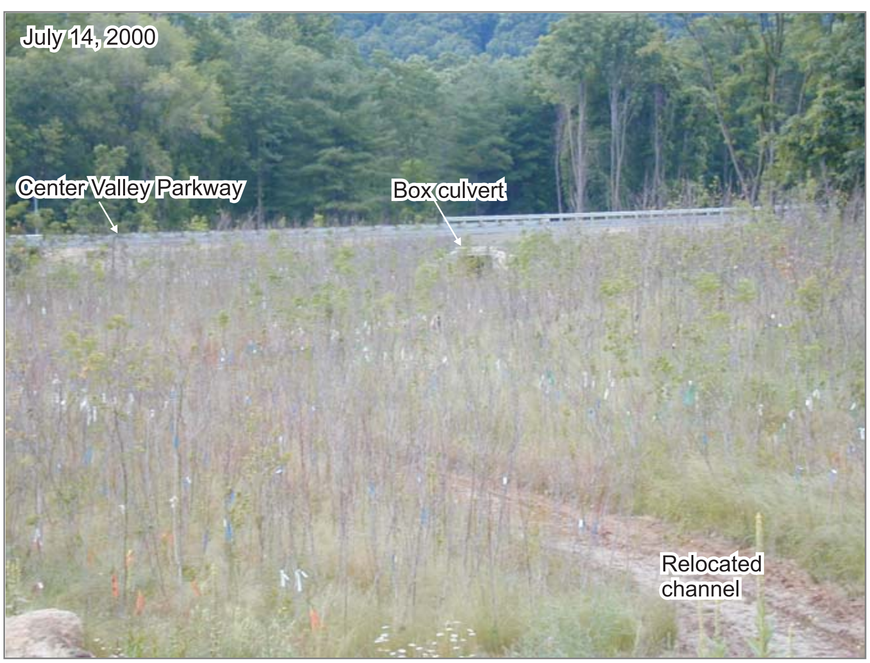

Figure 18. View of trees and shrubs planted in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed from the southern end of the riparian buffer facing north (upstream). Photographed by Jeffrey J. Chaplin, U.S. Geological Survey, on July 14, 2000.

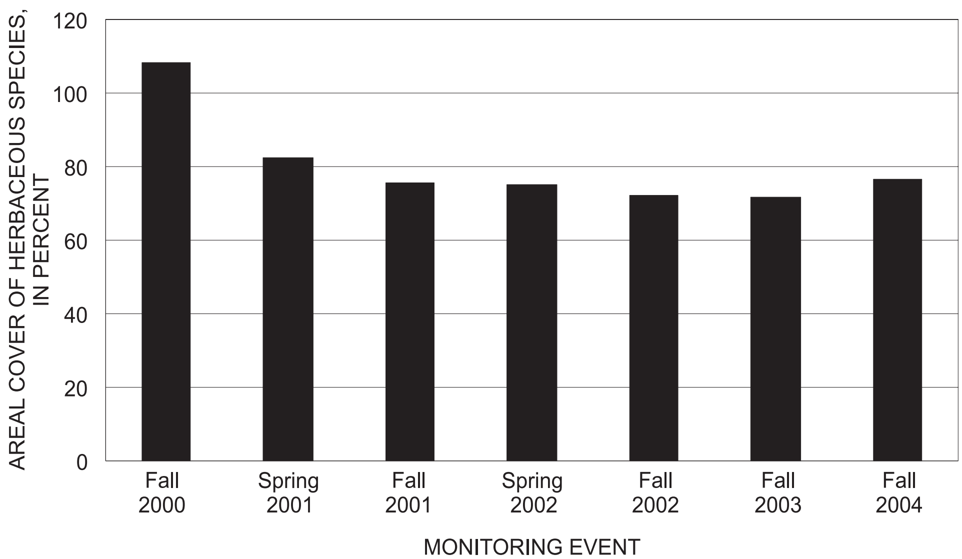

Figure 19. Areal cover of herbaceous species growing in a riparian buffer associated with construction of Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Note that areal cover may be greater than 100 percent because of overlapping layers of vegetation.

Table 16. Dominant herbaceous species growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.

[Bold-face type indicates dominance in given year. Dominance determined by 50/20 rule. —, not observed]

Species		Areal cover, in percent						
Scientific name	Common name	Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
Cirsium arvense	canada thistle	—	2.7	1.9	**8.8**	4.5	—	—
Cirsium discolor	field thistle	—	—	**3.7**	—	.3	**6.4**	1.9
Eupatorium rugosum	white snakeroot	—	—	—	—	1.2	**10.9**	**11.4**
Festuca rubra	red fescue	—	—	**6.3**	.3	**7.5**	**6.6**	—
Lolium perenne	perennial rye	**41.3**	**25.5**	1.3	**16.0**	**11.4**	3.3	**5.2**
Microstegium vimineum	stiltgrass	—	—	.1	.2	—	—	**6.6**
Oxalis europaea	european yellow woodsorel	3	**6.3**	**10.9**	**7.7**	**4.8**	—	.2
Plantago lanceolata	lanceleaf plantain	1.3	2.6	**3.8**	5	**10.6**	**7.7**	3.4
Polygonum persicaria	lady's thumb	**8.8**	.5	.6	.3	—	—	—
Rumex crispus	curly dock	1.7	**6.9**	**3.8**	—	.5	.2	.6
Rumex obtusifolius	bitter dock	5.3	**11.7**	2.7	3.6	.2	2.5	—
Setaria faberi	foxtail	**9.1**	—	**5.3**	—	**5.5**	.5	.3
Solidago canadensis	canada goldenrod	.2	1.4	2.6	3.3	2.2	**11.6**	**18.8**
Trifolium repens	white clover	1.9	6.2	**3.8**	**6.7**	.2	.9	—
Unidentified grass[1]	unidentified grass	**5.9**	—	2.5	.2	—	1.4	—

[1]Some species could not be identified because of small size or undeveloped features.

Trees and Shrubs

The close spacing of tree and shrub stock planted in the riparian buffer resulted in extraordinarily dense woody vegetation (table 17). Riparian trees typically are planted 8-12 ft on center, and shrubs are planted 6-8 ft on center (Palone and Todd, 1997), which would correspond to about 436 trees per acre and 889 shrubs per acre. In fall 2000, one growing season after the initial planting, tree density was 3,078 plants per acre, and shrub density was 2,410 plants per acre. These computed densities represent minimum estimates of the actual densities because some plants are inevitably missed during the counting process. The ability to obtain an accurate visual count of individual plants, especially in fall 2000, was hindered by the small size of stump sprouts and thick herbaceous cover.

Tree density ranged from 3,078 to 4,130 plants per acre over the study period (minimum in fall 2000 and maximum in 2003). Tree density increased substantially from fall 2000 to 2001 (3,078 to 3,745 plants per acre) probably because of growth of stump sprouts that were not detected in fall 2000. Note that individual stump sprouts were not counted as separate plants. Instead, all stump sprouts originating from a single trunk were counted as one plant. Increases in tree density essentially plateaued as of fall 2001; computations reported between fall 2001 and fall 2004 are within 10 percent of one another. *A. negundo* and *F. pennsylvanica* followed by *Q. bicolor* were the most populous planted tree species (1,526; 1,084; and 720 plants per acre, respectively, in fall 2004). The least populous planted species in fall 2004 was *A. rubrum* (477 plants per acre). Decreases in density of *A. rubrum* over the study period may have been from mortality brought on from browsing by deer (mean browsing rate of *A. rubrum* was 59 percent for the study period; table 17).

Overall, shrub density decreased over the study period, but some species maintained higher densities than others. Density computations indicate *Cornus* sp. was more heavily planted and fared better than the other planted shrubs despite heavy browsing (87 percent in 2004). Density of *Cornus* sp. essentially remained flat (1,622 plants per acre in fall 2004; table 17) whereas densities of other planted species including *S. canadensis* and *V. acerifolium* decreased over the study period. Volunteer shrubs including *Lonicera* sp. (bush honeysuckle), *Buddleja davidi* (butterfly bush), *Alnus serrulata* (smooth alder), and *Ligustrum vulgare* (european privet) collectively have a density of 312 plants per acre. Because *A. serrulata* typically grows on streambanks and streambank locations were poorly represented in plots established for measuring density, the density of *A. serrulata* (9 plants per acre) may be higher than table 17 indicates.

As a result of poor leaf-out and mortality prior to the initial assessment, areal cover of planted trees and shrubs was only 28.8 and 10.9 percent, respectively, in fall 2000 (table 18). Stump sprouts were underdeveloped at this time and provided little in the way of cover. As they matured, many tree plantings that originally had a solitary trunk began to resemble shrubs as stump sprouts provided increasingly more cover with each year. This shrub-like habit was particularly evident in *A. negundo*.

Areal cover of trees and shrubs combined increased from 39.7 percent in fall 2000 to 127 percent in fall 2004, but the proportion of cover provided by trees was much greater than that of shrubs (table 17), largely because the spacing and placement of shrubs relative to the trees left the shrubs at a competitive disadvantage from the start. As canopy development of trees increased over time (table 18), the sunlight available to the shrub layer decreased, resulting in slower growth and increased mortality among planted shrub species. For example, *V. acerifolium* and *S. canadensis* collectively provided less than 5-percent areal cover at the end of any growing season (table 18). *Cornus* sp. provided the most cover of any planted shrubs (12.6 percent in fall 2004; table 18), mainly because it was planted more densely in areas of the riparian buffer where tree mortality was high and more sunlight was available.

Tree cover increased from 28.8 percent in fall 2000 to 99.1 percent in 2004 (table 18) because of growth of stump sprouts and canopy development in trees. The largest increase took place between fall 2002 and 2003 (from 44.4 to 75.4 percent; table 18). Precipitation over this period was well above average (table 14), creating conditions favorable for rapid growth. Among the planted tree species, *A. negundo*, *F. pennsylvanica*, and *Q. bicolor* seemed to grow faster and provided more cover (31.2, 24.0, and 18.5 percent in fall 2004; table 18) than *A. rubrum* (13.9 percent in fall 2004). Volunteer species including *Platanus occidentalis* (sycamore), *Robinea pseudo-acacia* (black locust), and *Ulmus* sp. (elm) provided varying and relatively small amounts of cover throughout the study period (12.0 percent by fall 2004). Note that another volunteer species, *B. davidi*, was not growing in any plot or along any transect established for determining areal cover but was observed in various plots established for determining the density of trees and shrubs. Although not directly measured, the areal cover provided by this species is negligible.

Table 17. Density and browsing of trees and shrubs in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.

[—, not observed]

Species	Fall 2000			Spring 2001			Fall 2001			Spring 2002			Fall 2002			Fall 2003			Fall 2004		
	Count	Density (plants/acre)[1]	Browsed (percent)[2]	Count	Density (plants/acre)	Browsed (percent)	Count	Density (plants/acre)	Browsed (percent)	Count	Density (plants/acre)	Browsed (percent)	Count	Density (plants/acre)	Browsed (percent)	Count	Density (plants/acre)	Browsed (percent)	Count	Density (plants/acre)	Browsed (percent)
Trees																					
Acer negundo	123	1,066	25	140	1,213	29	153	1,327	29	149	1,292	30	157	1,361	31	184	1,402	32	176	1,526	57
Acer rubrum	76	659	8	91	789	63	107	928	34	86	746	83	87	754	85	97	739	72	55	477	69
Cercis canadensis[3]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	9	—
Corylus americana[3]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	8	—	—	—	—
Fraxinus pennsylvanica	85	737	1	121	1,049	28	123	1,066	17	112	971	29	123	1,066	21	163	1,242	37	125	1,084	52
Platanus occidentalis[3]	1	9	—	1	9	—	1	9	—	1	9	—	2	17	—	2	15	—	2	17	50
Quercus bicolor	70	607	—	77	667	9	48	416	10	72	624	13	76	659	4	93	709	9	83	720	1
Robinea pseudo-acacia[3]	—	—	—	1	9	100	4	35	100	3	26	100	4	35	75	2	15	—	1	9	—
Ulmus sp.[3,4]	—	—	—	1	9	—	—	—	—	—	—	—	1	9	—		—	—	—	—	—
Subtotal	355	3,078	11	432	3,745	32	436	3,781	25	423	3,668	38	450	3,901	34	542	4,130	36	443	3,842	46
Shrubs																					
Alnus serrulata[3]	—	—	—	—	—	—	2	17	—	—	—	—	1	9	—	1	8	—	1	9	—
Buddleja davidi[3]	—	—	—	—	—	—	—	—	—	—	—	—	9	78	—	7	53	0	3	26	—
Cornus sp.[5]	184	1,595	21	204	1,768	62	220	1,907	58	197	1,708	84	181	1,569	81	208	1,585	76	187	1,622	87
Ligustrum vulgare[3]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	8	—	1	9	100
Lonicera sp.[3,6]	—	—	—	—	—	—	2	17	50	—	—	—	4	35	—	—	—	—	30	260	3
Sambucus canadesis	39	338	8	43	373	42	37	321	78	31	269	29	6	52	33	2	15	—	5	17	—
Vibernum acerifolium	55	477	5	36	312	53	36	312	33	16	139	63	22	191	82	3	23	100	—	—	—
Subtotal	278	2,410	16	283	2,453	58	297	2,574	57	244	2,116	76	223	1,934	75	222	1,692	73	227	1,943	72
Trees and Shrubs																					
Total	633	5,488	13	715	6,198	42	733	6,355	38	667	5,784	52	673	5,835	48	764	5,822	47	670	5,785	55

[1]For purposes of determining density, only alive and stressed individuals were counted.

[2]Each individual was assessed for evidence of browsing by deer or other herbivores. Subtotal and total percentages are computed as the ratio of browsed individuals to the number of individuals counted. For example, the percentage of trees that were browsed in fall 2000 is computed as follows: 100 x [(0.25x123) + (0.08x76) + (0.01x85)] / 355.

[3]Non-planted species.

[4]Includes *Ulmus americana* and *U. rubra*.

[5]Includes *Cornus racemosa* (*foemina*) and *C. amomum*.

[6]Includes *Lonicera tatarica* and *L. morrowi*.

Table 18. Areal cover of trees and shrubs growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.

[Bold-face type indicates trees and shrubs that were dominant in given year. Dominance was determined by the 50/20 rule. Trees and shrubs were combined into one cover class for the purpose of determining dominance. —, not observed; sp., species]

Species		Areal cover, in percent[1]						
Scientific name	Common name	Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
		Trees						
Acer negundo	box elder	6.1	**6.2**	**11.1**	**12.9**	**13.5**	**23.1**	**31.2**
Acer rubrum	red maple	**8**	**5.6**	**9.5**	5.1	6.6	10.2	13.9
Fraxinus pennsylvanica	green ash	**6.2**	4.4	8.8	**8.2**	**15.3**	**21.1**	**24.0**
Platanus occidentalis[2]	sycamore	.1	—	1.6	.7	1.1	3.4	2.9
Quercus bicolor	swamp white oak	3.1	4.4	4.8	4.2	6.2	**10.6**	**18.5**
Robinea pseudo-acacia[2]	black locust	4.1	**8.7**	5.6	2.0	1.5	3.6	4.9
Salix sp.[2]	willow	—	—	.3	—	—	—	—
Ulmus sp.[2,3]	elm	1.2	4.4	3.2	—	.2	3.4	3.7
Subtotal		28.8	33.7	44.9	33.1	44.4	75.4	99.1
		Shrubs						
Alnus serrulata[2]	smooth alder	.5	2	2.7	6.0	4.5	6.8	12.0
Cornus sp.[4]	dogwood	**9.2**	**6.8**	**10.3**	**8.0**	**8.2**	6.6	12.6
Ligustrum vulgare[2]	european privet	—	—	—	—	.2	.3	.3
Lonicera sp.[2,5]	honeysuckle	.1	.7	—	1.0	—	.5	2.2
Sambucus canadensis	common elderberry	.3	.7	1.1	.6	3.3	—	.8
Vibernum acerifolium	mapleleaf vibernum	.8	.4	.2	.2	.2	.2	—
Subtotal		10.9	10.6	14.3	15.8	16.4	14.4	27.9
		Trees and Shrubs						
Total		39.7	44.3	59.2	48.9	60.8	89.8	[6]127

[1]For plants less than 1 meter tall, areal cover was determined by visual estimation in 32 1-square-meter plots. For plants greater than 1 meter tall areal cover was determined using the line-intercept method described by Bauer (1943). Values in this table represent the sum of areal cover determined by both methods. See the Monitoring-Methods section for a more detailed description of each method.

[2]Non-planted species

[3]Includes *Ulmus americana* and *Ulmus rubra.*

[4]Includes *Cornus amomum* and *Cornus racemosa* (*foemina*).

[5]Includes *Lonicera morrowi* and *Lonicera tatarica.*

[6]Areal cover is greater than 100 percent because of overlapping layers of vegetation.

Summary

Authorized modifications of stream channels and naturally occurring wetlands commonly is necessary to complete roadway improvements. Construction of Center Valley Parkway resulted in the relocation of an unnamed tributary to Saucon Creek. The U.S. Geological Survey, in cooperation with the Pennsylvania Department of Transportation, Engineering District 5-0, evaluated physical and vegetative changes within the relocated stream reach, constructed wetland, and riparian buffer from September 2000 through October 2004. The data for this investigation were collected using an approach that can serve as a basis for transferring technology and findings among other similar projects. The investigation documents changes in the profile, dimension, and substrate of the relocated stream reach; vegetation, soils, and areal extent of the constructed wetland; and vegetation within the riparian buffer. The findings provide the Pennsylvania Department of Transportation and the Army Corp of Engineers with the information needed for them to assess the success of the relocated stream reach, constructed wetland, and riparian buffer.

The slope of the relocated stream reach decreased over the monitoring period as a result of streambed erosion in the upstream part of the channel and deposition in the downstream part of the channel. Most streambed erosion took place prior to the 2002 assessment when mean annual streamflows were less than those in the final 2 years of monitoring. Survey data suggest the upstream part of the channel has slowed in its adjustment of slope, but the amount of deposition downstream is evidence of continued instability and active channel evolution. Upstream migration of the nick point has slowed or stopped altogether as of the 2003 assessment when this feature came in contact with the upstream-most part of the channel that is lined with riprap. The consistency with which fined-grained sediment dominates the substrate within each cross section indicates the supply of fine material exceeds the ability of the stream channel to move it through the reach. The annual fluctuations in the larger particle categories within each cross section demonstrate the capacity of the stream to periodically move the range of sediment introduced to the system.

The substrate within the constructed wetland (a mixture of woodchips and soil from a naturally occurring wetland) supported a hydrophytic-vegetation community throughout the investigation. *Eleocharis obtusa* (spike rush), an obligate-wetland herb, was the most prevalent species, having a maximum areal cover of 90 percent in fall 2001 and a minimum of 23 percent in fall 2004. Drought-like conditions throughout water year 2002 (cumulative precipitation was 28.11 in.) coincided with a decrease in areal cover of *E. obtusa* to 34 percent by fall 2002. This gave other species a competitive advantage, allowing *Panicum dichotomiflorum* (witch grass), *Salix* sp. (willow), *Leersia oryzoides* (rice cutgrass), *Echinocloa crus-galli* (barnyard grass), and various sedges and rushes to become established by fall 2002, even if temporarily. Above-average precipitation in water year 2003 (58.55 in.) resulted in a higher water table compared to 2002, conditions that were favorable for and resulted in a rebound in areal cover of *E. obtusa*. *L. oryzoides* and *Scirpus validus* (great bulrush) also increased in areal cover during the 2003 growing season. A consecutive period of above-average precipitation in water year 2004 (53.17 in.) probably resulted in pond-like habitat in most of the wetland throughout much of the 2004 growing season. Despite the OBL status of *E. obtusa,* it does not thrive in persistently inundated habitats, and because it had occupied parts of the constructed wetland that are most prone to inundation, *E. obtusa* decreased in cover from 56 percent in 2003 to 23 percent in 2004. In contrast, *L. oryzoides* increased in areal cover from 12 to 34 percent during the 2004 growing season because it was established in the higher elevations and the peripheral areas of the constructed wetland that were less prone to persistent inundation but still supported a hydrophytic-vegetation community.

Canopy development by trees and shrubs in the riparian buffer was initially (fall 2000) poor (areal cover was 39.7 percent), resulting in more available sunlight for the herbaceous understory than in any other growing season. This sunlight promoted growth of *Lolium perenne* (perennial rye), *Polygonum persicaria* (lady's thumb), and *Setaria faberi* (foxtail), which collectively provided nearly half (59.2 percent) the areal cover in fall 2000 (108 percent). These species and most of the other herbaceous species growing in the riparian buffer thrive in disturbed settings. Herbaceous cover decreased to 76 percent by the fall of 2001 and varied between 72 and 77 percent for the rest of the study period. By fall 2004, species such as *Eupatorium rugosum* (white snakeroot) dominated parts of the buffer where tree and shrub growth shaded the understory and *Solidago canadensis* (canada goldenrod) dominated those areas where tree and shrub mortality was high. Most herbs and grasses within the buffer boundary also were growing in the adjacent woods and open areas.

Close spacing of planted tree and shrub stock in the riparian buffer resulted in extraordinarily dense woody vegetation that provided greater areal cover with each growing season. Areal cover increased from 39.7 percent in fall 2000 to 127 percent in fall 2004. Planted trees were responsible for the majority of the increases because canopy development each year progressively deprived the underlying shrubs of sunlight. As a result, planted shrubs generally experienced high rates of mortality (except *Cornus* sp.) and collectively provided only 27.9 percent of the areal cover in fall 2004.

Tree density ranged from 3,078 to 4,130 plants per acre (fall 2000 and 2003, respectively) over the study period but essentially remained constant after fall 2001; computations reported each fall between fall 2001 and fall 2004 are within 10 percent of one another. When the study ended in fall 2004, *Acer negundo* (box elder) and *Fraxinus pennsylvanica* (green ash) were the most populous tree species (1,526 and 1,084 plants per acre, respectively) followed by *Quercus bicolor* (swamp white oak; 720 plants per acre) and provided the greatest areal cover (31.2, 24.0, and 18.5 percent, respectively).

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Appendix 1—Photo-Documentation of the Relocated Stream Reach, Upper Saucon Township, Lehigh County, Pennsylvania

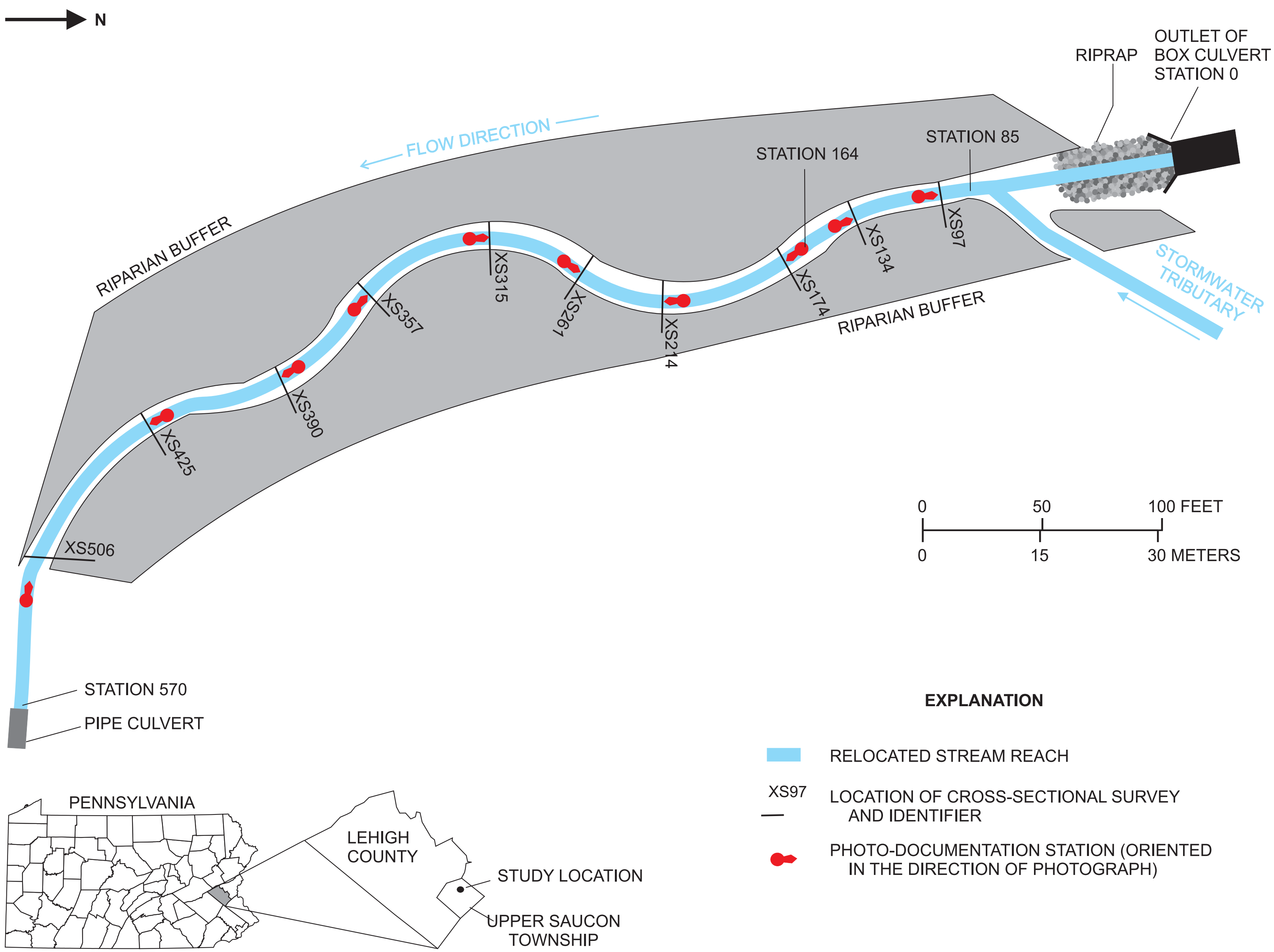

Figure 1-1. Photo-documentation stations and locations of cross-sectional surveys in the relocated stream reach, Upper Saucon Township, Lehigh County, Pennsylvania.

Figure 1-2. Looking upstream at relocated stream reach at cross section surveyed 97 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-3. Looking upstream at relocated stream reach at cross section surveyed 134 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-4. Looking downstream at relocated stream reach at cross section surveyed 174 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-5. Looking downstream at relocated stream reach at cross section surveyed 214 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-6. Looking upstream at relocated stream reach at cross section surveyed 261 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-7. Looking upstream at relocated stream reach at cross section surveyed 315 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-8. Looking upstream at relocated stream reach at cross section surveyed 357 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-9. Looking downstream at relocated stream reach at cross section surveyed 390 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-10. Looking downstream at relocated stream reach at cross section surveyed 425 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Figure 1-11. Looking upstream at relocated stream reach at cross section surveyed 506 feet downstream of a box culvert under Center Valley Parkway, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Kirk E. White, U.S. Geological Survey.

Appendix 2—Photo-Documentation of the Constructed Wetland, Upper Saucon Township, Lehigh County, Pennsylvania

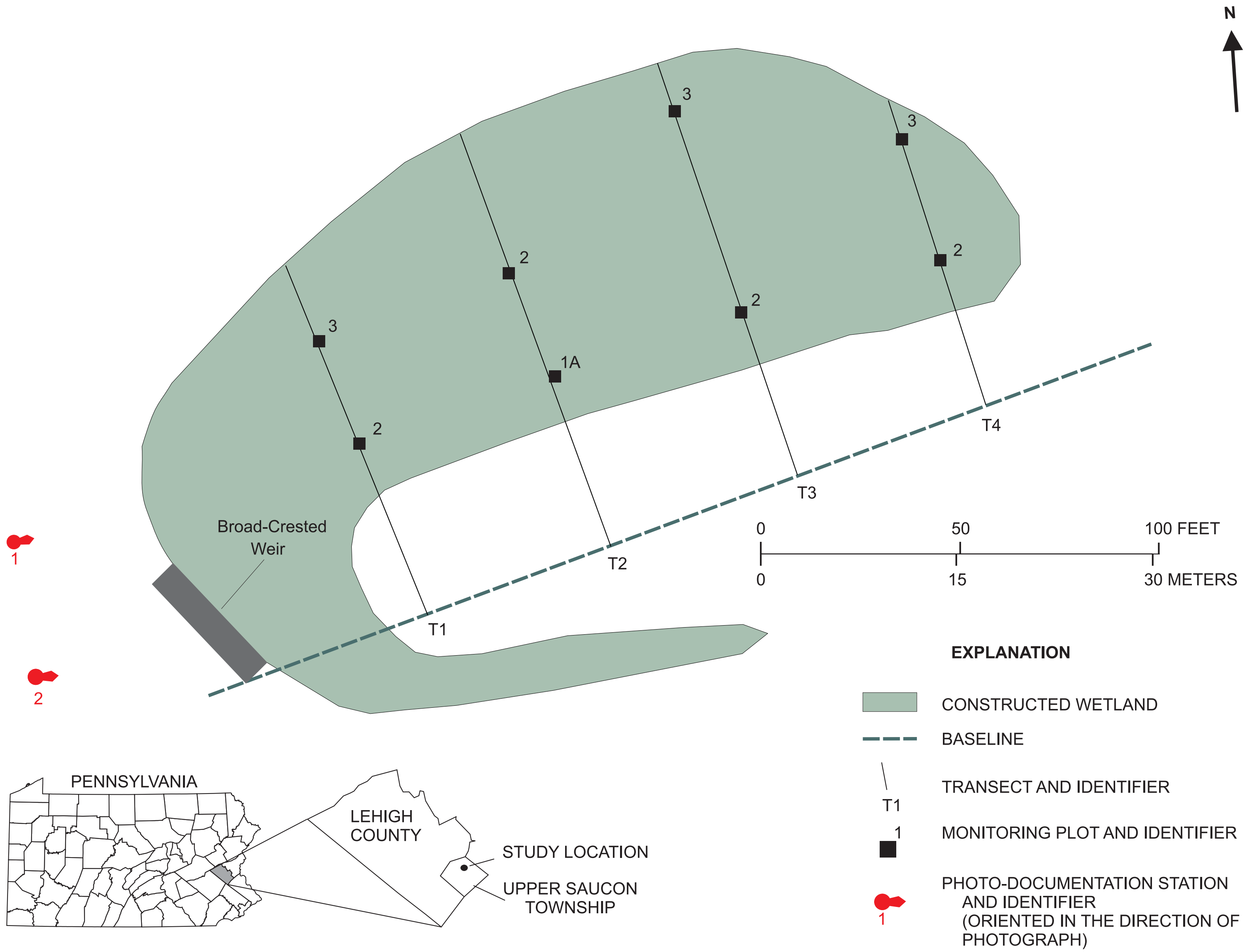

Figure 2-1. Photo-documentation stations and monitoring grid in a constructed wetland, Upper Saucon Township, Lehigh County, Pennsylvania.

Figure 2-2. Looking west to east from photo-documentation station 1 at the constructed wetland, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

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Figure 2-3. Looking west to east from photo-documentation station 2 at the constructed wetland, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-4. Looking west to east from photo-documentation station 1 at the constructed wetland, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-5. Looking west to east from photo-documentation station 2 at the constructed wetland, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-6. Looking west to east from photo-documentation station 1 at the constructed wetland, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-7. Looking west to east from photo-documentation station 2 at the constructed wetland, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-8. Looking west to east from photo-documentation station 1 at the constructed wetland, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-9. Looking west to east from photo-documentation station 2 at the constructed wetland, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-10. Looking west to east from photo-documentation station 1 at the constructed wetland, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-11. Looking west to east from photo-documentation station 2 at the constructed wetland, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-12. Looking west to east from photo-documentation station 1 at the constructed wetland, October 2003, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-13. Looking west to east from photo-documentation station 2 at the constructed wetland, October 2003, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-14. Looking west to east from photo-documentation station 1 at the constructed wetland, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Figure 2-15. Looking west to east from photo-documentation station 2 at the constructed wetland, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 2-1 for location and orientation of photo-documentation stations.

Appendix 3—Photo-Documentation of the Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania

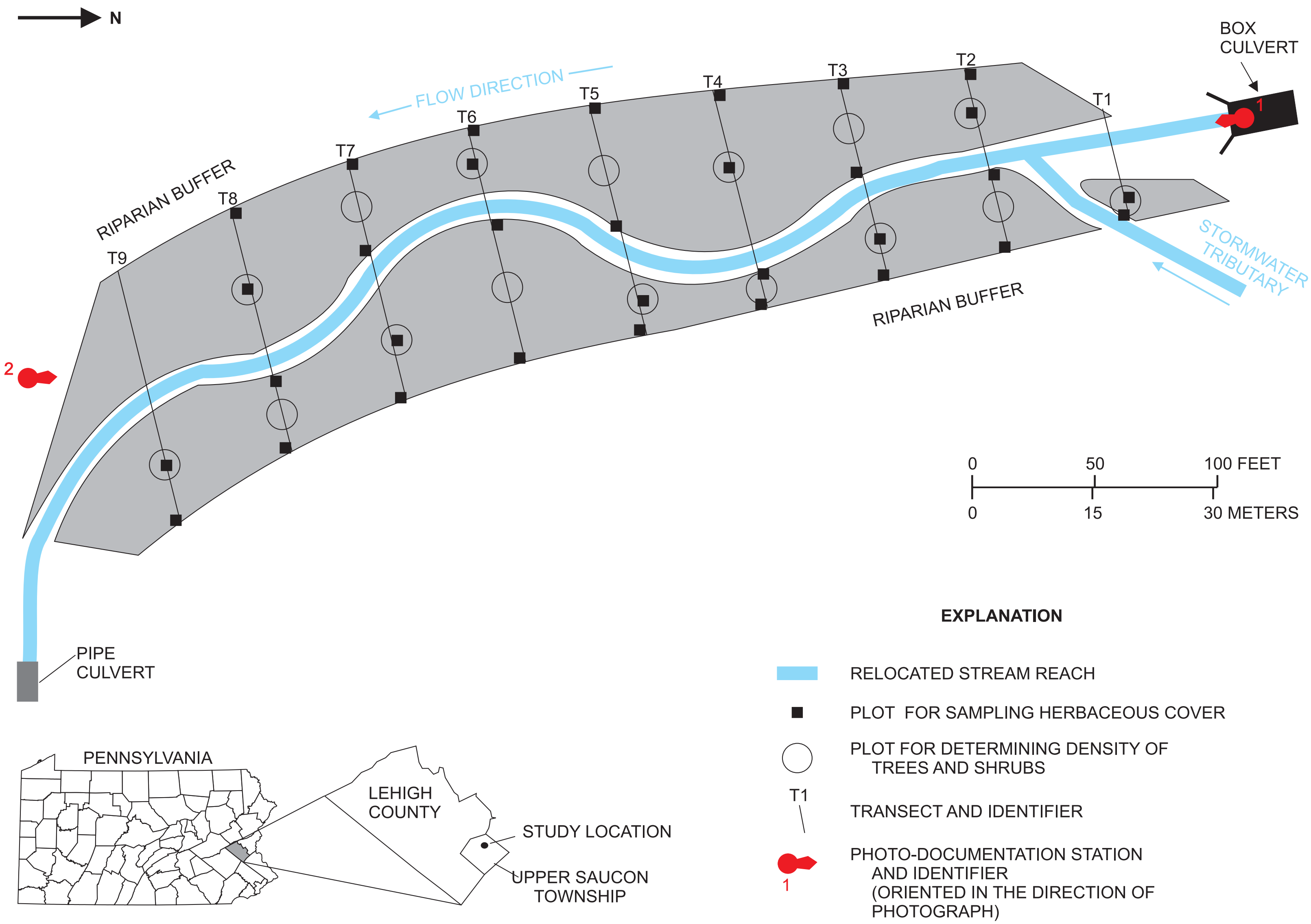

Figure 3-1. Photo-documentation stations and monitoring grid in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania.

Figure 3-2. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-3. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2000, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-4. Looking north to south from photo-documentation station 1 at the riparian buffer, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-5. Looking south to north from photo-documentation station 2 at the riparian buffer, May 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-6. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-7. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2001, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-8. Looking north to south from photo-documentation station 1 at the riparian buffer, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-9. Looking south to north from photo-documentation station 2 at the riparian buffer, May 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-10. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-11. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2002, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-12. Looking north to south from photo-documentation station 1 at the riparian buffer, September 2003, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-13. Looking south to north from photo-documentation station 2 at the riparian buffer, September 2003, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-14. Looking north to south from photo-documentation station 1 at the riparian buffer, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Figure 3-15. Looking south to north from photo-documentation station 2 at the riparian buffer, August 2004, Upper Saucon Township, Lehigh County, Pennsylvania. Photographed by Jeffrey J. Chaplin, U.S. Geological Survey. See figure 3-1 for location and orientation of photo-documentation stations.

Appendix 4—Vegetation in the Riparian Buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04

Table 4-1. Herbaceous and woody species growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.

[—, not observed; sp., species]

Species		Areal cover, in percent						
Scientific Name	Common Name	Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
Acalypha rhomboidea	Three-seeded mercury	—	—	0.8	—	0.3	0.5	0.2
Acer negundo[1]	Box elder	6.1	6.2	11.1	12.9	13.5	23.1	31.2
Acer rubrum[1]	Red maple	8	5.6	9.5	5.1	6.6	10.2	13.9
Achillea millefolium	Common yarrow	.2	.2	.2	.2	—	—	—
Agrostis alba	Redtop	—	—	—	—	—	1.7	—
Agrostis stolonifera	Spreading bentgrass	—	—	—	—	.2	—	—
Alliaria officinalis (petiolata)	Garlic mustard	—	1.3	.3	1.4	.8	.8	2.7
Alnus serrulata[1]	Smooth alder	.5	2	2.7	6	4.5	6.8	12
Ambrosia artemisiifolia	Common ragweed	.2	—	—	—	—	—	—
Anagallis arvensis	Common pimpernel	4.4	.9	1	—	.2	—	—
Anthoxanthum odoratum	Sweet vernal grass	—	.9	—	—	—	—	—
Apocynum cannabinum	Hemp dogbane	.5	.3	—	.2	—	—	—
Barbarea vulgaris	Yellow rocket	—	1	—	—	—	—	—
Bidens frondosa	Leafy beggar-ticks	—	—	—	—	.6	.2	—
Boehmeria cylindrica	False nettle	.3	1.6	.2	.3	.3	.5	.9
Brassica rapa	Bird's rape	—	—	—	.5	—	—	—
Brassica sp.	Mustard	.3	.2	—	—	—	—	.2
Carex sp.	Sedge	—	—	.5	1.1	.7	—	—
Carex vulpinoidea	Foxtail sedge	—	—	—	.9	—	—	—
Celastrus orbiculata	Oriental bittersweet	—	—	.3	—	—	1.1	—
Celastrus scandens	Climbing bittersweet	.3	—	—	.8	.4	.3	1.7
Chenopodium album	Lambsquarter	2.8	—	—	—	—	—	—
Chrysanthemum leucanthemum	Ox-eye daisy	.3	1.7	.7	.4	1.8	1.6	.2
Cirsium altissimum	Tall thistle	—	—	—	.6	—	—	—
Cirsium arvense	Canada thistle	—	2.7	1.9	8.8	4.5	—	—
Cirsium discolor	Field thistle	—	—	3.7	—	.3	6.4	1.9
Cirsium vulgare	Bull thistle	—	—	.2	—	—	—	—
Convolvulus arvensis	Field bindweed	—	—	.1	—	—	—	.5
Convolvulus sepium	Hedge bindweed	.3	—	.5	1.3	.5	.3	—
Cornus sp.[1,2]	Dogwood	9.2	6.8	10.3	8	8.2	6.6	12.6
Coronilla varia	Crown vetch	—	.2	.2	.8	.9	.9	.8
Cyperus strigosus	Sedge grass	.9	.5	.8	.3	.6	—	1.1
Daucus carota	Queen ann's lace	.9	1.1	.5	—	.3	.2	.2
Digitaria filiformis	Finger grass	.2	—	—	—	—	—	—

Table 4-1. Herbaceous and woody species growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.—Continued

[—, not observed; sp., species]

Species		Areal cover, in percent						
Scientific Name	Common Name	Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
Echinocloa crusgalli	Barnyard grass	1.4	—	0.5	—	—	—	—
Eleocharis obtusa	Spike rush	.2	—	.2	0.2	0.1	—	—
Eragrostis capillaris	Lacegrass	.2	—	—	—	—	—	—
Erigeron annuus	White-top fleabane	—	—	—	—	—	—	0.5
Eupatorium album	White thoroughwort	—	—	—	—	—	—	.3
Eupatorium perfoliatum	Common boneset	.2	—	.2	.1	.1	0.9	.9
Eupatorium rugosum	White snakeroot	—	—	—	—	1.2	10.9	11.4
Eupatorium serotinum	Late-flowering thoroughwort	—	—	.6	—	—	—	—
Festuca rubra	Red fescue	—	—	6.3	.3	7.5	6.6	—
Fragaria sp.	Wild strawberry	—	0.2	.2	.9	—	—	.2
Fraxinus pennsylvanica[1]	Green ash	6.2	4.4	8.8	8.2	15.3	21.1	24.0
Galium asprellum	Rough bedstraw	—	—	—	—	—	—	.2
Galium mollugo	Wild madder	—	.2	—	—	—	—	—
Galium sp.	Bedstraw	—	—	—	.5	—	—	—
Glechoma hederacea	Ground ivy	—	—	—	—	—	.2	—
Hibiscus moscheutos	Swamp rosemallow	—	—	—	—	—	—	.5
Hypericum perforatum	Common st.johnswort	—	—	.3	—	—	—	—
Impatiens capensis	Jewelweed	—	.3	1.3	.4	—	.8	3
Ipomoea coccinea	Red morning glory	—	—	.1	—	—	—	—
Ipomoea sp.	Morning glory	—	—	.2	—	—	—	—
Juncus effusus	Soft rush	—	—	.4	1.1	1.3	—	—
Juncus tenuis	Yard rush	—	—	.1	.4	—	—	—
Leersia oryzoides	Rice cutgrass	—	—	—	—	.6	.8	—
Lepidium campestre	Field pepper grass	—	.4	.2	.3	—	—	—
Ligustrum vulgare	European privet	—	—	—	—	.2	.3	.3
Lolium perenne	Perennial rye	41.3	25.5	1.3	16.0	11.4	3.3	5.2
Lonicera japonica	Japanese honeysuckle	—	—	.5	—	1	.3	—
Lonicera sp.[1,3]	Honeysuckle	.1	.7	—	1.0	—	.5	2.2
Lychnis alba	White campion	—	—	.5	—	—	—	—
Lycopus uniflorus	Northern bungleweed	—	—	.2	—	—	—	—
Lysimachia nummularia	Moneywort	—	—	—	.6	.5	—	.3
Malva neglecta	Common mallow	.5	—	—	—	—	—	—
Melilotus alba	White sweet clover	1.9	—	—	—	—	.6	—
Melilotus officinalis	Sweet yellow clover	.3	—	—	—	—	—	—
Melilotus sp.	Sweet clover	.6	.7	.2	.3	1.3	.5	.2
Mentha arvensis	Field mint	—	—	—	.6	—	.9	—
Microstegium vimineum	Stiltgrass	—	—	.1	.2	—	—	6.6
Monarda fistulosa	Wild bergamot	—	—	.5	—	—	—	—

Table 4-1. Herbaceous and woody species growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.—Continued

[—, not observed; sp., species]

Species		Areal cover, in percent						
Scientific Name	Common Name	Fall 2000	Spring 2001	Fall 2001	Spring 2002	Fall 2002	Fall 2003	Fall 2004
Nepeta cataria	Catnip	—	—	0.3	—	—	—	0.3
Oenothera biennis	Common evening primrose	0.3	0.8	.6	—	—	—	.5
Oxalis europaea	European yellow woodsorel	3.0	6.3	10.9	7.7	4.8	—	.2
Panicum capillare	Old witchgrass	—	—	.2	—	—	—	—
Panicum dichotomiflorum	Witch grass	3.8	—	2.8	—	.3	—	—
Panicum philadelphicum	Wood witch grass	.3	—	—	—	—	—	—
Parthenocissus quinquefolia	Virginia creeper	—	—	—	.2	.2	—	—
Phragmites australis	Common reed	—	—	.2	—	—	0.2	.5
Phytolacca americana	Pokeweed	—	—	1.1	.2	.2	—	.8
Pilea pumila	Clearweed	1.1	.1	.3	—	.3	.5	1.3
Plantago lanceolata	Lanceleaf plantain	1.3	2.6	3.8	5	10.6	7.7	3.4
Plantago major	Great plantain	.9	.2	.2	.3	.2	—	—
Platanus occidentalis[1]	Sycamore	.1	—	1.6	.7	1.1	3.4	2.9
Polygonum aviculare	Doorweed	.5	.8	.1	.5	.3	—	—
Polygonum cristatum	Hedge buckwheat	.2	—	—	—	—	—	—
Polygonum persicaria	Lady's thumb	8.8	.5	.6	.3	—	—	—
Polygonum sp.	Smartweed	—	—	.2	—	—	—	—
Quercus bicolor[1]	Swamp white oak	3.1	4.4	4.8	4.2	6.2	10.6	18.5
Ranunculus sp.	Buttercup	—	—	—	.2	—	.3	1.9
Rhus radicans	Poison ivy	—	—	—	.1	—	—	.2
Robinea pseudo-acacia[1]	Black locust	4.1	8.7	5.6	2	1.5	3.6	4.9
Rubus occidentalis	Black raspberry	—	—	.2	—	—	—	—
Rubus pensilvanicus (alumnus)	Blackberry	.3	.5	—	—	1	.5	—
Rubus phoenicolasius	Wineberry	—	—	—	—	—	.2	—
Rubus sp.	Blackberry	—	—	.1	.2	.2	—	.5
Rumex crispus	Curly dock	1.7	6.9	3.8	—	.5	.2	.6
Rumex obtusifolius	Bitter dock	5.3	11.7	2.7	3.6	.2	2.5	—
Salix sp.	Willow	—	—	.3	—	—	—	—
Sambucus canadensis[1]	Common elderberry	.3	.7	1.1	.6	3.3	—	.8
Setaria faberi	Foxtail	9.1	—	5.3	—	5.5	.5	.3
Solanum carolinense	Canada goldenrod	.2	—	—	—	—	—	—
Solanum nigrum	Black nightshade	.6	—	2	.5	1.1	.6	.3
Solidago canadensis	Canada goldenrod	.2	1.4	2.6	3.3	2.2	11.6	18.8
Solidago (Euthamia) graminifolia	Flat-top goldenrod	—	.2	—	.2	.5	1.1	3
Solidago rugosa	Wrinkled-leaf goldenrod	—	—	.1	.4	.2	—	.3
Solidago sp.	Golden rod	.2	.1	—	—	—	—	—
Sonchus oleraceus	Common sow thistle	—	—	—	—	—	—	.3

Table 4-1. Herbaceous and woody species growing in the riparian buffer, Upper Saucon Township, Lehigh County, Pennsylvania, 2000–04.—Continued

[—, not observed; sp., species]

Species		Areal cover, in percent						
Scientific Name	**Common Name**	**Fall 2000**	**Spring 2001**	**Fall 2001**	**Spring 2002**	**Fall 2002**	**Fall 2003**	**Fall 2004**
Stellaria media	Common chickweed	0.2	—	—	—	—	—	—
Taraxacum officinale	Common dandelion	.2	—	—	0.5	—	—	—
Taraxacum sp.	Dandelion	.2	—	—	—	0.2	—	—
Thymus serpyllum	Wild thyme	—	—	—	—	—	—	0.5
Trifolium pratense	Red clover	1.1	—	—	—	—	—	—
Trifolium repens	White clover	1.9	6.2	3.8	6.7	.2	0.9	—
Trifolium sp.	Clover	.2	—	—	—	—	—	—
Ulmus sp.[1,4]	Elm	1.2	4.4	3.2	—	.2	3.4	3.7
Unidentified grass[5]	Unidentified grass	5.9	—	2.5	.2	—	1.4	—
Unidentified herb[2]	Unidentified herb	1.7	1.8	.4	.6	1.3	1.3	—
Urtica dioica	Stinging nettle	—	—	—	—	—	.2	—
Verbascum thapsus	Common mullein	.3	.6	2.1	1.6	.5	—	—
Verbina urticifolia	White vervain	—	—	1.3	.9	1	1.4	—
Veronica arvensis	Corn speedwell	—	—	—	.8	—	—	—
Veronica polita	Field speedwell	—	.2	—	—	—	—	—
Vibernum acerifolium	Mapleleaf vibernum	.8	.4	.2	.2	.2	.2	—
Vitis sp.	Grape	—	.1	.1	—	—	—	.3
Total[6]		147.4	125.2	133.3	122.4	129.7	161.2	200.7

[1] For plants less than 1 meter tall, areal cover was determined by visual estimation in 32 1-square-meter plots. For plants greater than 1 meter tall areal cover was determined using the line-intercept method described by Bauer (1943). Values in this table represent the sum of areal cover determined by both methods. See the Monitoring-Methods section for a more detailed description of each method.

[2] Includes *Cornus amomum* and *C. racemosa* (*foemina*).

[3] Includes *Lonicera morrowi* and *L. tatarica*.

[4] Includes *Ulmus americana* and *U. rubra*.

[5] Some species could not be identified because of small size or undeveloped features.

[6] Areal cover is greater than 100 percent because of overlapping canopy layers.