Effects of Removing Good Hope Mill Dam on Selected Physical, Chemical, and Biological Characteristics of Conodoguinet Creek, Cumberland County, Pennsylvania

In cooperation with Conodoguinet Creek Watershed Association

Scientific Investigations Report 2005-5226

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

Cover photograph:
View looking upstream at the initial breach of Good Hope Mill Dam on November 2, 2001.
Photographed by J. Chaplin, U.S. Geological Survey.

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With a Section on Response of the Fish Assemblage by Paola Ferreri, Pennsylvania State University

By Jeffrey J. Chaplin, Robin A. Brightbill, and Michael D. Bilger

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Conversion Factors and Datum

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	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Acronyms Used in This Report

CCWA	Conodoguinet Creek Watershed Association
EPT	Ephemeroptera, Plecoptera, and Trichoptera
EST	Eastern Standard Time
HFBI	Hilsenhoff's Family-Level Index of Biotic Integrity
MS-222	Tricaine methane sulfonate (Finquel ®)
NTU	Nephelometric Turbidity Units
NWQL	U.S. Geological Survey National Water-Quality Laboratory
PADEP	Pennsylvania Department of Environmental Protection
PFBC	Pennsylvania Fish and Boat Commission
PSU	Pennsylvania State University
RBP	Rapid Bioassessment Protocols
USGS	U.S. Geological Survey

Temperature in degrees Celsius (˚C) may be converted to degrees Fahrenheit (˚F) as follows:

$$^{\circ}F = (1.8 \times {}^{\circ}C) + 32$$

Vertical coordinate information is referenced to the *National Geodetic Vertical Datum of 1929 (NGVD 29)* unless otherwise indicated.

Horizontal coordinate information is referenced to the *North American Datum of 1983 (NAD 83).*

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25˚C).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Abbreviations used in report:

µm - micrometer

mL - milliliter

mm - millimeter

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By Jeffrey J. Chaplin, Robin A. Brightbill, and Michael D. Bilger

Abstract

The implications of dam removal on channel characteristics, water quality, benthic invertebrates, and fish are not well understood because of the small number of removals that have been studied. Comprehensive studies that document the effects of dam removal are just beginning to be published, but most research has focused on larger dams or on the response of a single variable (such as benthic invertebrates). This report, prepared in cooperation with the Conodoguinet Creek Watershed Association, provides an evaluation of how channel morphology, bed-particle-size distribution, water quality, benthic invertebrates, fish, and aquatic habitat responded after removal of Good Hope Mill Dam (a small "run of the river" dam) from Conodoguinet Creek in Cumberland County, Pa.

Good Hope Mill Dam was a 6-foot high, 220-foot wide concrete structure demolished and removed over a 3-day period beginning with the initial breach on November 2, 2001, at 10:00 a.m. eastern standard time. To isolate the effects of dam removal, data were collected before and after dam removal at five monitoring stations and over selected reaches upstream, within, and downstream of the impoundment. Stations 1, 2, and 5 were at free-flowing control locations 4.9 miles upstream, 2.5 miles upstream, and 5 miles downstream of the dam, respectively. Stations 3 and 4 were located where the largest responses were anticipated, 115 feet upstream and 126 feet downstream of the dam, respectively.

Good Hope Mill Dam was not an effective barrier to sediment transport. Less than 3 inches of sediment in the silt/clay-size range (less than 0.062 millimeters) coated bedrock within the 7,160-foot (1.4-mile) impoundment. The bedrock within the impoundment was not incised during or after dam removal, and the limited sediment supply resulted in no measurable change in the thalweg elevation downstream of the dam. The cross-sectional areas at stations 3 and 4, measured 17 days and 23 months after dam removal, were within 3 percent of the area measured before removal.

Some of the impounded silt/clay at station 3 and other sediment in the work area downstream of the dam were initially entrained over the 3-day removal period and deposited on substrate at station 4. Remaining silt/clay at station 3 and deposits at station 4 were transported downstream by the flows measured over the 23 months after removal (daily mean flow ranged from 38 to 5,180 cubic feet per second). The median bed-particle size at station 3 increased by approximately 32 millimeters in the 23-month period after removal. Bed-particle-size distribution at station 4 became finer when silt/clay was initially deposited but coarsened as high flows flushed it downstream; median bed-particle size was 77.7 millimeters before removal compared to 31.3 millimeters 17 days after removal and 99 millimeters 23 months after removal.

Good Hope Mill Dam had either no effect on water-quality characteristics or the effect was so small it was masked by seasonal and periodic variability. Measurements of daily mean temperature, dissolved-oxygen concentration, pH, and specific conductance on a short time scale (every 15 minutes) indicate the daily range of temperature was suppressed under impounded conditions and daily extremes of temperature, dissolved-oxygen concentration, pH, and specific conductance at station 2 were out of phase by approximately 12 hours with station 3. Once the dam was removed, the pattern at station 3 shifted and converged with the pattern at station 2. The offset before removal may be related to a lag time resulting from a decrease in velocity through the impoundment.

Total nitrogen and suspended-sediment concentrations increased upon the initial dam breach but were within the range of concentrations measured from March 2001 through April 2002 over varying flow conditions at station 1. Total nitrogen concentration at station 4 was 4.66 milligrams per liter upon the initial breach of the dam, an increase of approximately 0.5 milligram per liter compared to concentrations measured within 24 hours before removal (range before removal was 3.92 to 4.19 milligrams per liter). Suspended-sediment concentrations at station 4 ranged from 22 to 98 milligrams per liter during dam removal compared to a range of 2.8–3.0 milligrams per liter in the preceding 24 hours. Mobilization of reduced forms of nitrogen, mainly NH_4^+, did not cause an appreciable decrease in dissolved-oxygen concentration in the reach downstream of the dam. Correlation between flow and sediment data indicates that the flow events re-occurring from less than 1 to 1.5 years (1,100-5,900 cubic feet per second) are likely to have suspended-sediment concentrations similar to the maximum concentration measured during dam removal.

Dam removal did not appreciably alter the downstream benthic-invertebrate community in the vicinity of stations 4 or 5. In contrast, there was a short-term shift at station 3 from predominantly *Gammarus* amphipods and *Tanytarsus* midges before removal to more Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa 2 weeks after removal. This shift may be the result of different sampling methods used before and after removal. Alternatively, *Caenis* and other EPT taxa may have exploited newly established riffle habitat created by dam removal. Approximately 1 year after dam removal, the invertebrate community at station 2 was comparable to the other free-flowing reaches; dominance switched from *Caenis* to *Gammarus* and the midge composition was characterized by more nutrient intolerant species.

The changes observed in the fish assemblage are not beyond the scope of natural fluctuations related to climate and water levels. Because each station was sampled only once before and after dam removal and because fish assemblages can vary naturally, this study was unable to discern any changes in the fish assemblage related to the removal of Good Hope Mill Dam.

Introduction

Small dams with impoundments restricted to the channel are common features of Pennsylvania's river systems. These structures commonly are referred to as “run of the river” dams and were built to provide water supply, irrigation, power generation, and recreation. Many of Pennsylvania's run of the river dams, including Good Hope Mill Dam, have become obsolete, turning attention from the benefits they once provided to ecological and safety concerns they now pose. The primary ecological factor for removal of Good Hope Mill Dam was to provide passage for anadromous alosines (including American shad) so they might once again inhabit over 25 mi of historical spawning and rearing habitat rendered inaccessible when the dam was constructed. In addition, the dam had no identifiable owner (considered “orphaned”) and was located on submerged waters of the Commonwealth of Pennsylvania, which essentially shifted ownership responsibilities to the State (written commun., R. Scott Carney, Pennsylvania Fish and Boat Commission, 2005). After considering various alternatives, the State determined that removal was a cheaper option to mitigate safety and ecological concerns than rebuilding or retrofitting the structure to meet current safety and environmental regulations. As a result, the dam was removed over a 3-day period beginning November 2, 2001, at 10:00 a.m. eastern standard time (EST).

Dam removal alters the longitudinal profile of a stream and changes the upstream impoundment from a lentic system to a higher velocity lotic system in a short timeframe. The implications of removal on channel characteristics, water quality, benthic invertebrates, and fish are not well understood because of the small number of dam removals that have been studied. Comprehensive studies that document the effects of dam removal are just beginning to be published, and most available dam-removal research has focused on larger dams or on the response of a single variable (such as benthic invertebrates). This limited knowledge base underscores the need for additional empirical study to develop understanding of stream response to dam removal.

The Pennsylvania Fish and Boat Commission (PFBC), Conodoguinet Creek Watershed Association (CCWA), Pennsylvania Department of Environmental Protection (PADEP), American Rivers, and Land Studies, Inc., coordinated efforts to remove Good Hope Mill Dam from Conodoguinet Creek and to provide riparian plantings, streambank stabilization, and other property improvements after removal. The U.S. Geological Survey (USGS) and the Pennsylvania State University (PSU), in cooperation with the CCWA, studied the effects of removing Good Hope Mill Dam. Data characterizing channel geometry and substrate, water quality, benthic invertebrates, fish, and aquatic habitat were collected before and after removal between July 2001 to October 2003.

Purpose and Scope

This report provides an evaluation of how channel morphology, bed-particle-size distribution, water quality, benthic invertebrates, fish, and aquatic habitat responded after removal of Good Hope Mill Dam from Conodoguinet Creek in Cumberland County, Pa. The dam was demolished and removed over a 3-day period beginning with the initial breach on November 2, 2001, at 10:00 a.m. EST. Data for the evaluation of channel morphology, bed-particle-size distribution, benthic invertebrates, and habitat were collected once before dam removal and twice after removal between July 2001 and October 2003. The fish assemblage was sampled by PSU in August 2001 and July-August 2002. Water temperature, dissolved-oxygen concentration, pH, specific conductance, and turbidity were monitored continuously (15-minute intervals) from August 30, 2001, to January 8, 2002. Samples for nitrogen, phosphorus, and suspended sediment were collected periodically before, during, and after dam removal from July 20, 2001, through January 25, 2002.

Description of Study Area

Conodoguinet Creek flows eastward through the Cumberland Valley and joins the Susquehanna River across from Harrisburg, Pa. (fig. 1). The watershed is predominantly underlain by the Great Valley Section of the Ridge and Valley Physiographic Province (Pennsylvania Department of Conservation and Natural Resources, 1995) and carbonate bedrock is common throughout the watershed (Pennsylvania Department of Conservation and Natural Resources, 2000). Ground-water discharge from carbonate settings provides a large proportion of base flow to the creek (Becher and Root, 1981). As a result, base flow is well buffered by dissolved-carbonate minerals and has near-neutral pH. Although limestone outcrops are common

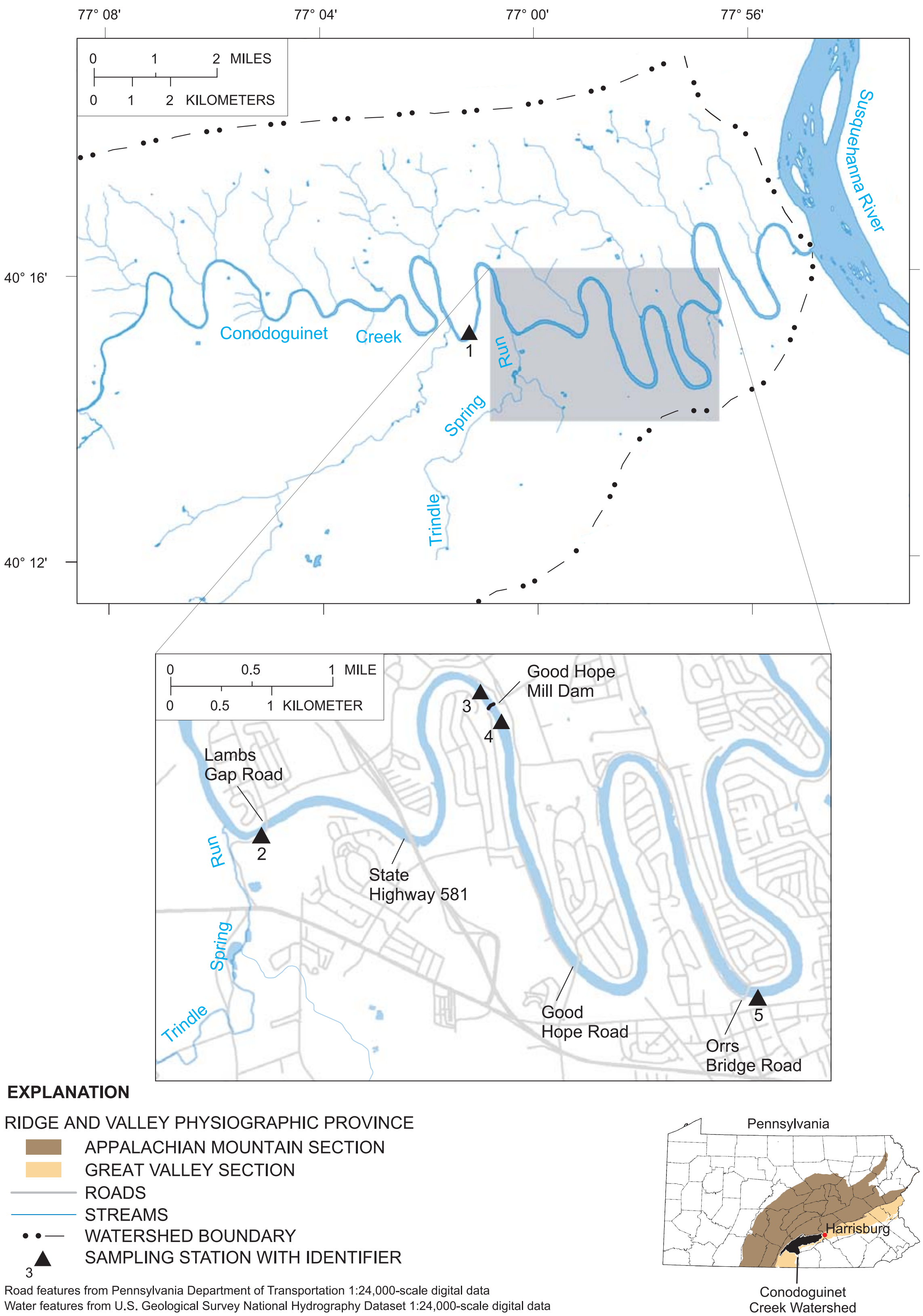

Figure 1. Sampling stations upstream and downstream of Good Hope Mill Dam, Cumberland County, Pennsylvania (adapted from Chaplin, 2003). [See table 1 for station descriptions.]

on terraces between stations 1 and 5 (fig. 1), most of the streambed throughout the study reach is composed of erosion-resistant, dark-gray shale and interbeds of siltstone, metabentonite, and graywacke (Geyer and Wilshusen, 1982). Bedrock is exposed in parts of the study reach that have sufficient streamflow velocity to transport bedload downstream. In parts of the reach having slower streamflow velocities, bedrock commonly is overlain by alluvium in the gravel/cobble size range (from 2 to 256 mm).

Good Hope Mill Dam was constructed on a bedrock riffle at the former Good Hope Mill, approximately 13.5 mi upstream of the confluence with the Susquehanna River (fig. 1). The dam was a 6-ft high, 220-ft wide concrete structure (fig. 2) built over 100 years ago to provide waterpower to the mill. Drainage area at the dam site is 488 mi^2, and the mean annual flow is estimated at 608 ft^3/s based on 70 years of daily streamflow recorded at station 1 (USGS streamflow-gaging station 01570000), 4.9 mi upstream of the dam (fig. 1). Under the flow conditions encountered during this study, the dam impounded a 7,160-ft (1.4-mi) reach and stored approximately 52 acre-ft (64,141 m^3) of water, all of which was contained within the channel.

The upstream and downstream channel substrate in the immediate vicinity of the dam was characterized by exposed gray shale in high-energy reaches overlain by alluvial beds of gravel, cobble, and silt in low-energy reaches. Within the impoundment, fine sediment in the silt/clay fraction covered the bedrock surface at a depth of 1-3 in., except for a solitary depositional feature that was removed with the dam (fig. 2). This feature was on the north side of the channel (left bank), was approximately 240 ft^2, and had a maximum depth of 1.5 ft. Channel composition was a mix of coarse woody debris, gravel, and fine sediment. Concern over downstream sediment loading prompted removal of this feature with the dam. It was not considered a source of contamination because metal and pesticide concentrations measured immediately upstream of the dam (Durlin and Schaffstall, 2003, p. 455–459) were less than concentration guidelines for contaminated sediment established by MacDonald and others (2000).

Figure 2. Conodoguinet Creek flowing over Good Hope Mill Dam, a 6-foot high, 220-foot wide concrete structure constructed on bedrock over 100 years ago to power a former mill, Cumberland County, Pennsylvania. (Photographed by J. Kent Crawford, U.S. Geological Survey, on May 21, 2001).

Study Design and Methods

The study design is based on the premise that removal of Good Hope Mill Dam will cause the largest response immediately upstream and downstream of the dam and no response far upstream or far downstream of the dam. To isolate the effects of dam removal, data were collected before, during, and after removal at five monitoring locations (stations) and over selected reaches upstream, within, and downstream of the impoundment. Stations 1, 2, and 5 are free-flowing control sites where no response to dam removal was anticipated (4.9 mi upstream, 2.5 mi upstream, and 5 mi downstream of the dam, respectively; table 1); the largest responses were anticipated at stations 3 and 4 (115 ft upstream and 126 ft downstream of the dam, respectively; table 1).

The longitudinal profile of the thalweg (deepest location in the channel) and water-surface elevation were determined following standard surveying procedures in the reach between stations 2 and 5 on three occasions: approximately 3 months before, 1 month after, and 21 months after dam removal (table 2). Cross-sectional elevations of the channel and bed-particle-size distribution (Wolman, 1954) at stations 2 through 5 were determined 2 to 3 months before removal, 1 month after removal, and 23 months after dam removal (table 2). For the sake of uniform comparison between each monitoring event, cross-sectional area and mean depth were computed for the areas delineated by monuments (rebar pins) established on the right and left bank at each station.

In-situ water-quality characteristics were measured at 15-minute intervals (referred to as continuous) and at selected times (referred to as discrete). Temperature (°C), dissolved-oxygen concentration ($O_{2(aq)}$) (mg/L), pH (standard units), specific conductance (µS/cm), and turbidity (NTU) were measured at stations 2, 3, and 4 on a continuous basis between August 30, 2001, and January 8, 2002, with Yellow Springs Instruments (YSI) multi-parameter sondes following Wilde and others (1998, chapter A6). Sondes were situated as close to the thalweg as possible and were fastened to a chain lead that was anchored to bedrock with a bolt. Water-quality characteristics measured continuously were periodically compared to measurements made at 10- to 20-ft increments across the channel (channel width ranged from about 160 ft at station 2 to 290 ft at station 5) to determine if water-quality characteristics measured near the thalweg were representative of the creek.

In most cases, water-quality characteristics measured at the thalweg were within 10 percent of measurements made across the channel (Durlin and Schaffstall, 2003, p. 416, 427, 439, and 449). Exceptions were at station 2, where water from Trindle Spring Run is poorly mixed with Conodoguinet Creek, and at station 4, where sediment mobilized by machinery during dam removal was not uniformly mixed across the channel. Trindle Spring Run contributes relatively dilute water (lower specific conductance) to Conodoguinet Creek about 150 ft upstream of station 2 (fig. 1). The sonde (and thalweg) at station 2 was near the left bank and did not capture this influence. The sonde at station 4 was near the right bank and did not capture increases in turbidity caused by mobilization of sediment from machinery operation except when the machines were working immediately upstream of the sonde.

Table 1. Sampling stations used to determine the effects of removing Good Hope Mill Dam from Conodoguinet Creek, Cumberland County, Pennsylvania.

[mi^2, square miles; ft, feet; Cr, Creek; Rd, Road; mi, miles; us, upstream; ds, downstream]

U.S. Geological Survey station identification number[1]	Description	Name (shown on Fig. 1)	Drainage area (mi^2)	Altitude[2] (ft)	Latitude[3]	Longitude[3]
01570000	Conodoguinet Cr near Sample Bridge Rd, 4.9 mi us of Good Hope Mill Dam	station 1	470	351	40°15′08″	77°01′16″
01570064	Conodoguinet Cr near Lambs Gap Rd, 2.5 mi us of Good Hope Mill Dam	station 2	486	345	40°15′11″	77°00′14″
01570076	Conodoguinet Cr 115 ft us of Good Hope Mill Dam	station 3	488	340	40°15′46″	76°58′46″
01570078	Conodoguinet Cr 126 ft ds of Good Hope Mill Dam	station 4	488	340	40°15′45″	76°58′44″
01570150	Conodoguinet Cr near Orrs Bridge Rd Bridge, 5.0 mi ds of Good Hope Mill Dam	station 5	495	325	40°14′23″	76°57′04″

[1]U.S. Geological Survey station identification number is assigned based on watershed position. Data collected at each station are available on the World Wide Web at *http://pa.waterdata.usgs.gov/nwis/*.

[2]Altitude was determined from 7.5-minute topographic quadrangles published by the U.S. Geological Survey. Vertical datum is National Geodetic Vertical Datum of 1929. Accuracy is ±10 ft.

[3]Horizontal datum is North American Datum of 1983.

Table 2. Summary of dates associated with data collected to determine the effects of removing Good Hope Mill Dam from Conodoguinet Creek, Cumberland County, Pennsylvania.

	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Jul-02	Aug-02	Nov-02	Jul-03	Aug-03	Sep-03	Oct-03
Longitudinal profile of thalweg and water-surface elevation														
Reach between stations 2 and 5	Jul. 30 - Aug. 14				Nov. 28 - Dec. 10						Jul. 22 - Aug 29			
Bed-particle-size distribution														
Station 2			18		20									8
Station 3			19		19									9
Station 4			18		19									9
Station 5			18		19									9
Cross-Sectional surveys of the channel														
Station 2		7				4								8
Station 3		15				3								9
Station 4		17				3								9
Station 5		17				4								9
Continuous measurement (15-minute interval) of water characteristics														
Station 2		30-31	1-30	1-31	1-30	1-31	1-8							
Station 3		30-31	1-30	1-31	1-30	1-31	1-7							
Station 4		30-31	1-30	1-31	1-30	1-31	1-8							
Sampling of nutrients and suspended sediment														
Station 1	20	16	19,25	23	23	18	23,25							
Station 2				25										
Station 3				25	2,5									
Station 4				25	1,2,5									
Station 5				25	2									
Benthic-invertebrate community and aquatic habitat														
Station 2			18		20					25				
Station 3			19		19					25				
Station 4			18		19					25				
Station 5			18		19					25				
Fish assemblage														
Station 2		13-18						29-31	1-2					
Station 3		13-18						29-31	1-2					
Station 4		13-18						29-31	1-2					
Station 5		13-18						29-31	1-2					

Nutrients (nitrogen and phosphorus) and suspended sediment were analyzed in samples collected at stations 2 through 5 at various times before, during, and after dam removal (see table 2 for a summary of sampling dates). Data for nutrients and suspended sediment collected at station 1 between March 2001 and April 2002 were used to provide a longer-term dataset of concentrations that occur in a free-flowing control reach over a range of hydrologic conditions. These concentrations were compared to those measured downstream of the dam during removal.

Samples for nutrients and suspended sediment were collected with a DH-81 sampler and teflon bottle using the equal-width increment and depth-integrated method described by Wilde and others (1998, chapter A4). In this method, depth-integrated samples collected at equal-width increments across the creek are mixed. The composite sample approximates a streamflow-weighted concentration at the cross section being sampled (Wilde and others, 1998, chapter A4, p. 25). A teflon cone splitter was used to split the composite sample into subsamples processed according to the constituent of interest. The cone splitter was rinsed with native water before each use. Approximately 20 percent of the nutrient samples were collected for quality control and quality assurance. Nutrient concentrations from field and trip blanks collected during routine sampling of stations 2 through 5 on October 25, 2001, were below laboratory reporting limits. This result indicates the equipment was clean when sampling began and was not cross contaminated as sampling progressed from station to station. Nutrient concentrations in duplicate samples were within 10 percent of each other indicating laboratory results were precise.

Water sampled for determination of nutrient concentrations was analyzed by the USGS National Water-Quality Laboratory (NWQL) in Denver, Colo. Water analyzed for dissolved constituents, including ammonia (NH_4^+), nitrite ($NO_2^-{}_{(aq)}$), nitrate ($NO_3^-{}_{(aq)}$), and orthophosphate ($PO_4^{3-}{}_{(aq)}$) concentration, was filtered through a capsule filter with 0.45 µm pores, stored in 125-mL brown polyethylene bottles, and shipped on ice to the NWQL. Water samples for analysis of total ammonia and organic nitrogen (NH_4^+ + organic N) and total phosphorus (P) concentrations were stored in 125-mL clear polyethylene bottles, acidified with 1 mL of sulfuric acid ($H_2SO_4^-$), and shipped on ice. NH_4^+, $NO_2^-{}_{(aq)}$, and $NO_3^-{}_{(aq)}$ concentrations were determined colorimetrically following methods described by Fishman (1993, p. 125-166). Dissolved NH_4^+ + organic N and total NH_4^+ + organic N concentrations were determined following methods described by Patton and Truitt (2000). Total and dissolved phosphorus concentrations were determined colorimetrically following U.S. Environmental Protection Agency (1983) and dissolved orthophosphate concentration was determined by methods described in Fishman (1993, p. 197-202).

Water collected for determination of suspended-sediment concentration was analyzed by the USGS sediment laboratory in Louisville, Ky. Approximately 400 mL (0.11 gal) of composite water sample was portioned into 0.12-gal (450-cm^3) glass bottles with a cone splitter and sealed to minimize evaporation during shipment to the lab. Suspended-sediment concentration (in parts per million) was determined as the ratio of the weight of the sediment to the weight of the water-sediment mixture (Sholar and Shreve, 1998; Potterfield, 1972). Sediment concentrations were converted to milligrams per liter at the Kentucky sediment lab by applying a conversion factor to the parts per million concentrations (Sholar and Shreve, 1998, p. 10).

Benthic invertebrates were sampled at stations 2 through 5. Stations 2, 4, and 5 are at free-flowing natural riffles and were conducive to kick sampling following methods described by Barbour and others (1999) during all sampling events (table 2). Impoundment of water at station 3 precluded using kick samples prior to dam removal. Alternative methods describing the capture of benthos in bed sediment also were not applicable because the substrate was dominated by bedrock. Thus, prior to dam removal, benthic invertebrates at station 3 were captured by jab sampling habitat, such as downed trees and rocks near the dam and periphery of the channel (Barbour and others, 1999). After dam removal, station 3 converted to a free-flowing riffle and was kick sampled in the same manner as stations 2, 4, and 5. Benthic invertebrates were identified to the lowest possible taxon (distinct taxonomic group) at the USGS biology lab in New Cumberland, Pa. Benthic invertebrate and fish identifications were checked by the New York Department of Environmental Conservation and USGS, respectively, to ensure proper identification of taxa.

The response of the benthic-invertebrate community to dam removal was evaluated on the basis of the number, density, and taxa of individuals collected and Hilsenhoff's Family Level Index of Biotic Integrity (HFBI). Insects in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) generally are considered to be intolerant of contamination and fine sediment. The number of EPT taxa (EPT index) in a reach generally decreases as organic enrichment increases. There is no set criteria of how many taxa present are good or bad, but a decreasing EPT index is indicative of lower water and habitat quality of a reach. The HFBI summarizes the overall pollution tolerances of the taxa collected and commonly is used to indicate nutrient enrichment, high sediment loads, and (or) low dissolved oxygen, although it originally was developed to detect organic contamination (Hilsenhoff, 1988). HFBI values range from 0 to 10 and can be used to characterize water quality as excellent (0.00-3.75), very good (3.76-4.25), good (4.26-5.00), fair (5.01-5.75), fairly poor (5.76-6.50), poor (6.51-7.25), or very poor (7.26-10.00) (Klemm and others, 1990).

The fish assemblage was sampled by a crew from the PSU at stations 2, 3, 4, and 5 in August 2001 and July-August 2002 (table 2). Stations 2, 4, and 5 were sampled using a towboat-electrofishing unit during sampling events (Reynolds, 1996). To characterize the fish assemblage, three 200-m (656-ft) segments were sampled; each segment was separated by a distance of 500 m (1,640 ft). The width of Conodoguinet Creek at stations 4 and 5 was greater than 250 ft, making it impractical to sample the entire channel from bank to bank. Instead, half of the channel width was sampled in each segment. A single pass, using a zig-zag path from bank to bank (or bank to mid-channel in stations 4 and 5) was made with the towboat to cover all present habitat types starting at the downstream end of the segment and working upstream. The fish assemblage at station 3 was sampled using night boat electrofishing before dam removal and made a single pass along the shoreline of the impoundment. After the dam was removed, two 656-ft (200-m) segments, separated by 1,312 ft (500 m), were delineated in the channel that was formerly impounded. These segments were sampled using towboat electrofishing in the same manner as stations 4 and 5. Fishes were identified, measured (total length in millimeters), and released. Fishes that were too small or difficult to accurately identify in the field (such as darters and minnows) were euthanized using an overdose of MS-222 and preserved in 10 percent formalin. Preserved fishes were identified in the lab. Taxa lists (including number of individuals) were created for each station by combining the data across the stream segments sampled at each station.

Habitat surveys were completed at stations 2 through 5 before and after dam removal (table 2) following Rapid Bioassessment Protocols (RBP) described in Barbour and others (1999). The riffle-and-run prevalence data form was used to characterize habitat on the basis of 13 criteria. Criteria pertaining to the channel substrate, morphology, and flow characteristics are rated using scores that range from 0 to 20. A score of 0-5 is considered poor, 6-10 is marginal, 11-15 is suboptimal, and 16-20 is optimal (Barbour and others 1999; Lazorchak and others, 1998). For criteria that pertain to the banks, the left and right banks are rated independently using scores that range from 0 to 10. For either bank, a score of 0-2 is considered poor, 3-5 is marginal, 6-8 is suboptimal, and 9-10 is optimal. To evaluate the habitat quality for the reach, scores for each criterion are added together. A reach with a higher habitat score should, theoretically, support a healthier benthic-invertebrate community than a reach with a lower score (Barbour and others, 1999).

Effects of Removing Good Hope Mill Dam on Characteristics of Conodoguinet Creek

Channel adjustment after dam removal—in terms of bed-sediment redistribution and bank erosion—is a common response to the increase in slope, streamflow velocity, and shear stress that results from removal. The channel may respond immediately if sediment accumulated behind the dam is in the silt- or clay-size range (Stanley and others, 2002) or over a longer period of time if accumulated sediment is more coarse. Removal of a 6.6 ft (2 m) high dam on Manatawny Creek in southeastern Pennsylvania resulted in redistribution of accumulated sediment from the impounded reach to downstream channel bars and a coarsening of impounded sediments following high-flow events. The thalweg elevation within the impoundment decreased approximately 6 ft over a 9-month period after removal (Bushaw-Newton and others, 2002). In contrast to the Manatawny Dam and others (Stanley and others, 2002), the impoundment behind Good Hope Mill Dam had little sediment accumulation. In general, sediment depths on bedrock immediately upstream of the dam were less than 3 in.

Response of the Channel Bed and Banks

Surveyed elevations of the thalweg through the impoundment (fig. 3) indicate Good Hope Mill Dam was not an effective barrier to sediment transport. Dams that are effective barriers cause aggradation of the impounded reach through entrapment of bedload and (or) deposition of suspended sediment resulting in a thalweg slope that approximates the water-surface slope of the impoundment. The slope of the thalweg within the impoundment of Good Hope Mill Dam is an order of magnitude greater than the water-surface slope (5.5×10^{-4} ft/ft compared to 5.1×10^{-5} ft/ft) and is similar to the slope of the entire surveyed reach (6.4×10^{-4} ft/ft) as illustrated in figure 3. These observations indicate the majority of bedload and suspended sediment carried by Conodoguinet Creek was transported over the dam.

The thalweg within the impoundment and in the downstream reach was unchanged as a result of dam removal, other than demolition of the dam structure itself (fig. 4). Erosion-resistant bedrock throughout the impoundment was not subject to degradation during or after removal. Large-scale aggradation in the reach downstream of Good Hope Mill Dam, a commonly reported result of other dam removals (Bushaw-Newton and others, 2002), did not occur because little sediment was available for transport (fig. 4).

Pebble-count data collected after the dam removal indicate silt/clay bed particles were initially entrained and deposited on the substrate at station 4 (fig. 5; table 3), the first riffle downstream of the dam. The source of fine material was a combination of silt/clay that coated bedrock within the impoundment and sediment mobilized by heavy equipment operating between the dam and station 4. The range of flows between November 19, 2000, and October 3, 2003 (daily mean ranged from 38 to 5,810 ft^3/s), transported the silt/clay at stations 3 (fig. 6) and 4 (fig. 5) downstream. As a result, the particle distribution at station 3 became coarser (median bed-particle size 17 days after removal was 2.9 mm, compared to 35 mm 23 months after removal; table 3), and the distribution at station 4 reverted to pre-removal conditions (fig. 5). Pebble-count data collected at station 5 indicate sediment mobilized from within the impoundment was most likely transported downstream of the study reach or deposited in a location that was not sampled. The distribution at station 5 was coarser 23 months after removal than before removal (table 3).

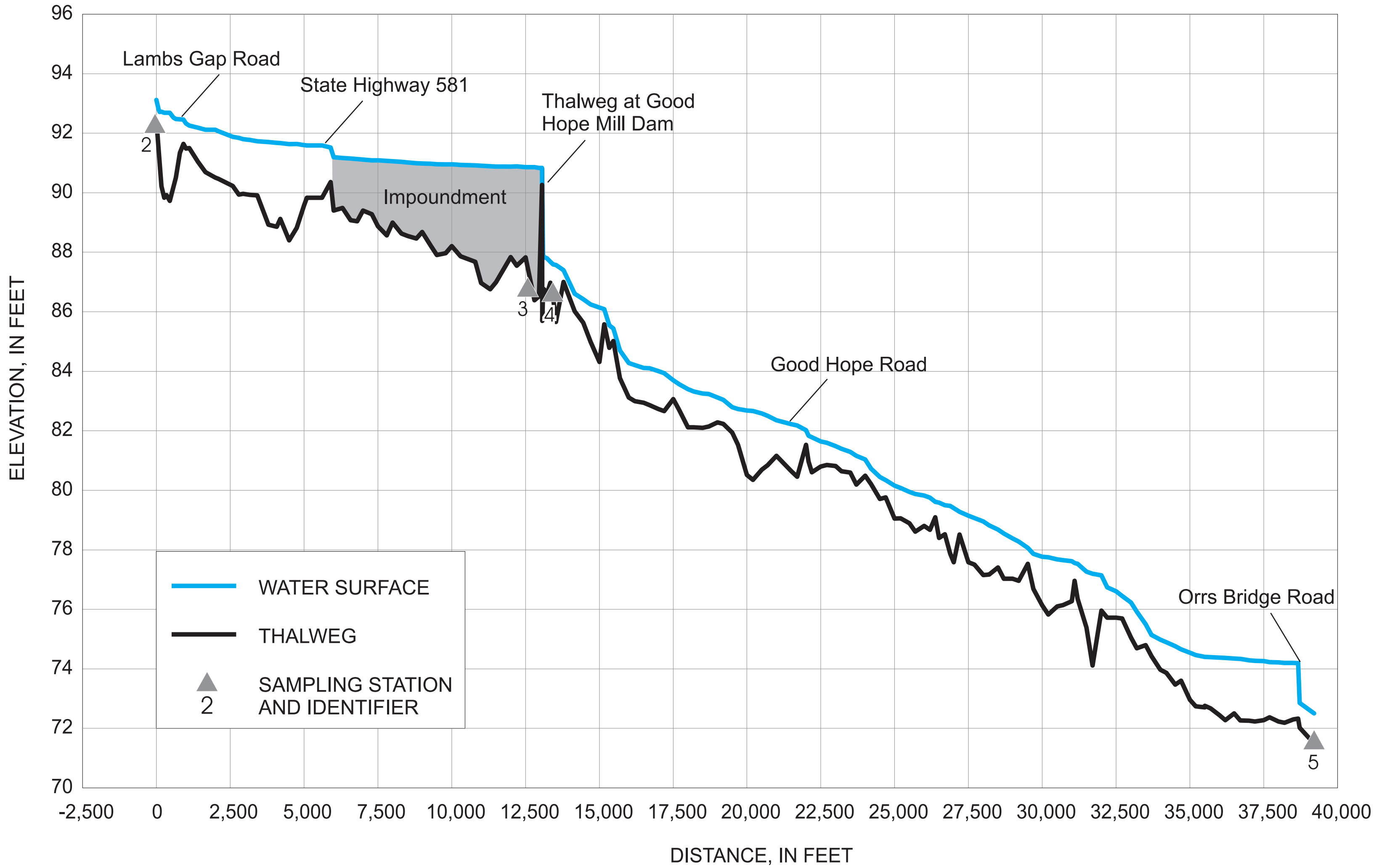

Figure 3. Longitudinal profile of the water surface and thalweg of Conodoguinet Creek as measured July–August 2001 before removal of Good Hope Mill Dam, Cumberland County, Pennsylvania.

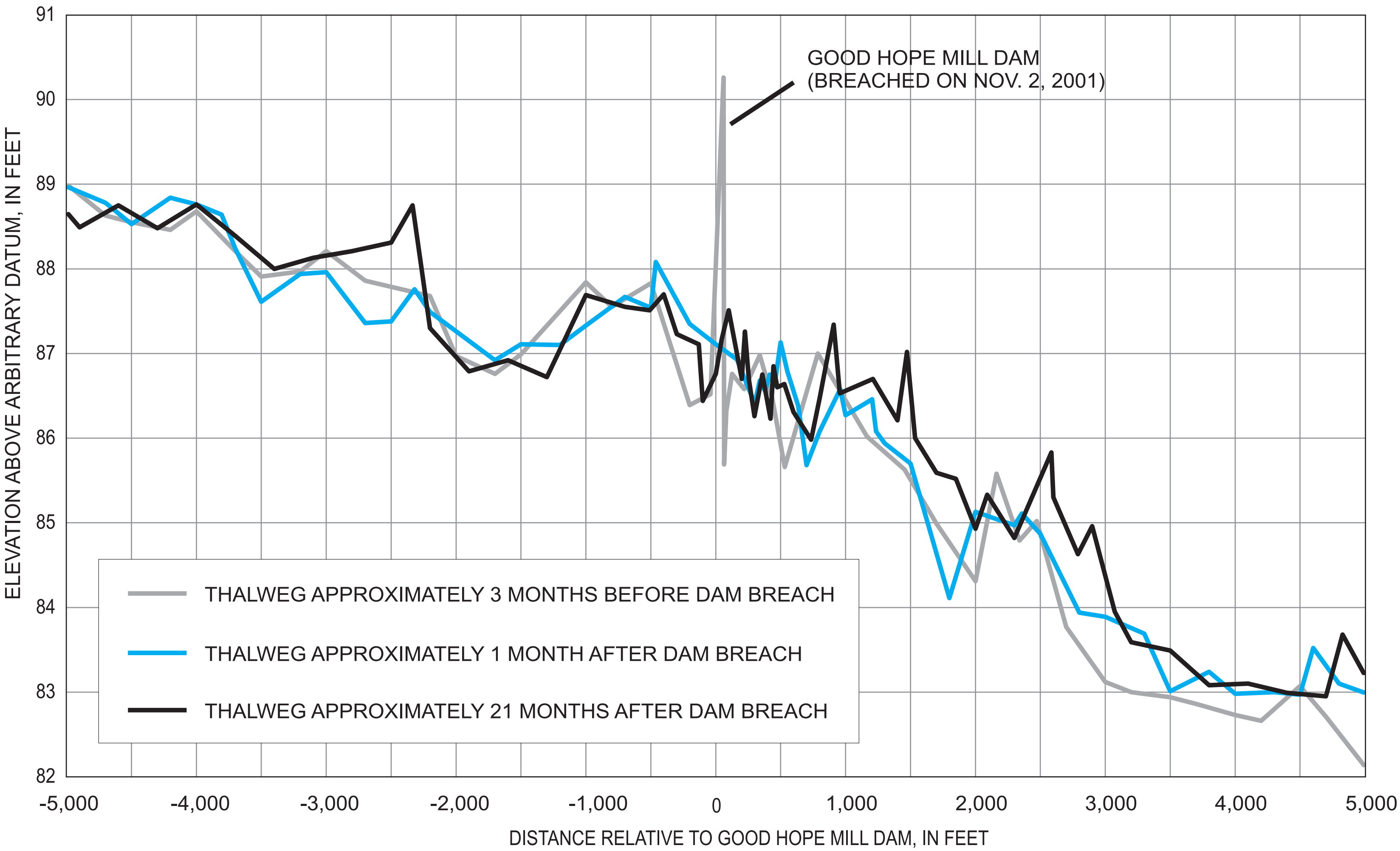

Figure 4. Longitudinal profile of the thalweg of Conodoguinet Creek in the vicinity of Good Hope Mill Dam, Cumberland County, Pennsylvania.

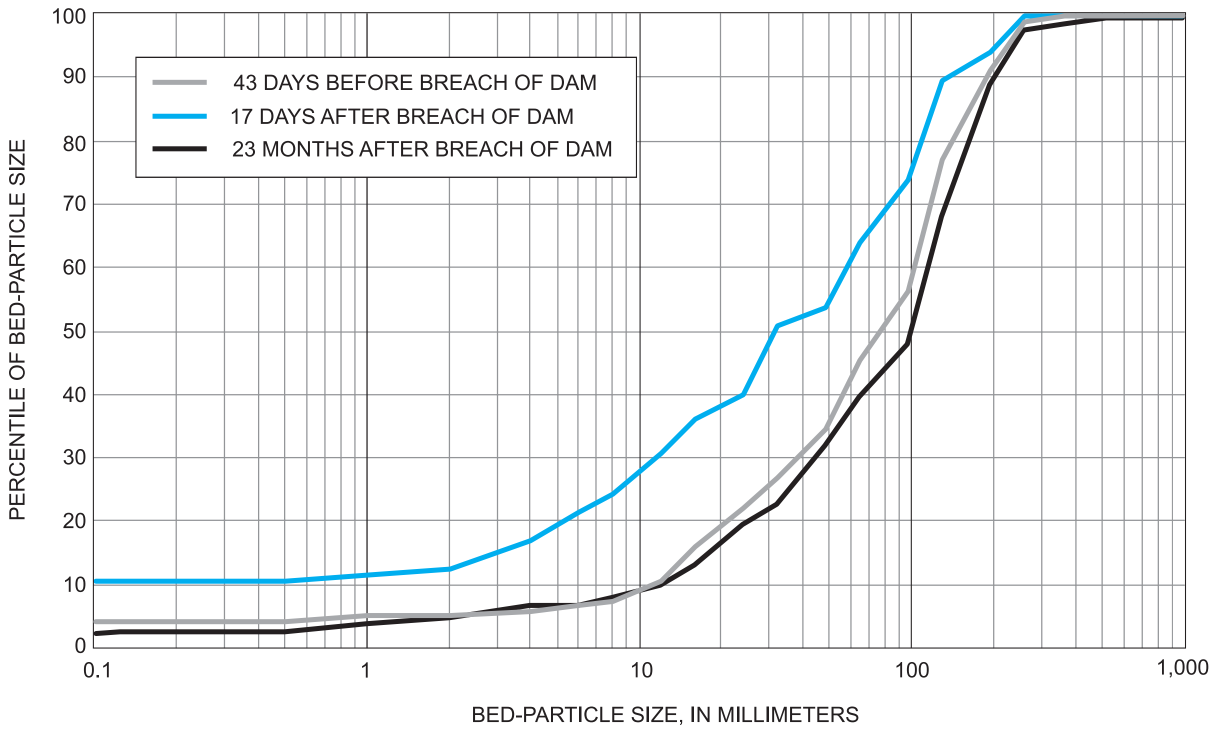

Figure 5. Bed-particle-size distribution in Conodoguinet Creek at station 4, 126 feet downstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

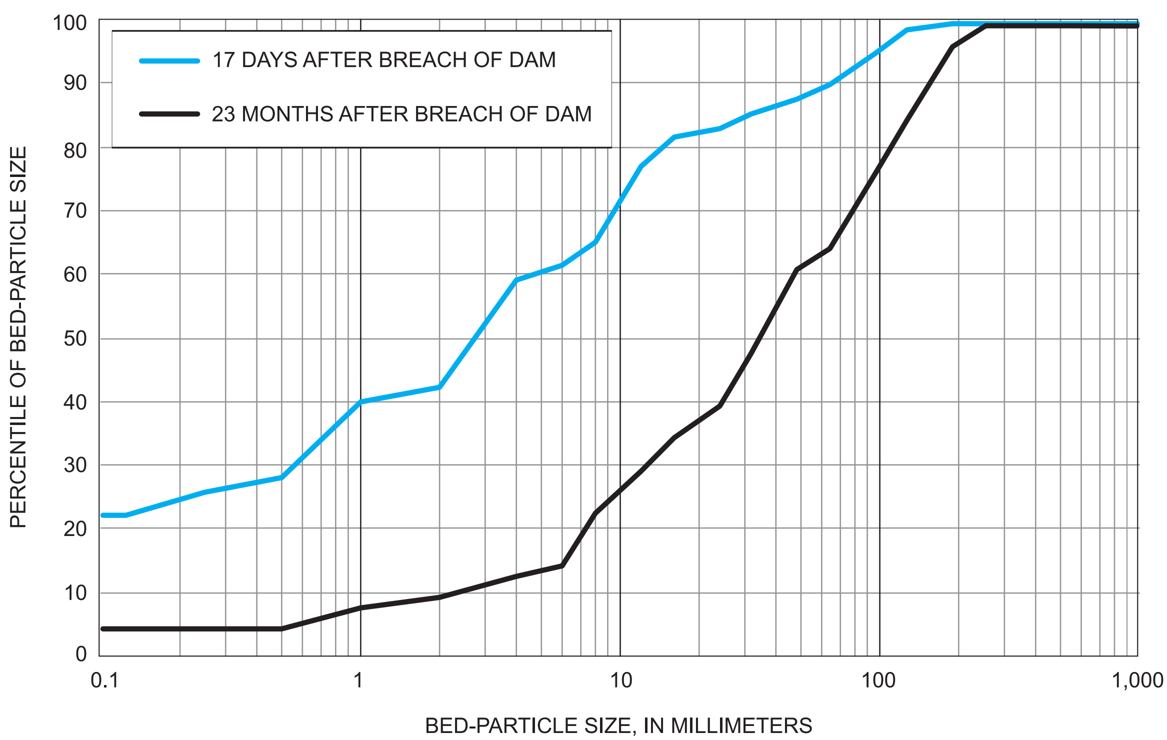

Figure 6. Bed-particle-size distribution in Conodoguinet Creek at station 3, 115 feet upstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

Table 3. Cross-sectional dimensions and bed-particle-size distribution before and after removal of Good Hope Mill Dam from Conodoguinet Creek, Cumberland County, Pennsylvania.

[ft, feet; ft^2, square feet; mm, millimeters; %, percent; diff, difference; xs, cross sectional; dpt, depth; --, no data; 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]

Cross-sectional dimensions and bed-particle-size distribution	Station 2 2.5 miles upstream of dam					Station 3 115 feet upstream of dam				
	44 days before	18 days after	% diff	23 months after	% diff[1]	43 days before	17 days after	% diff	23 months after	% diff[2]
xs area (ft^2)	540	537	-0.5	538	-0.3	2,229	2,248	0.9	2,296	3.0
mean xs dpt (ft)	3.34	3.30	-1.2	3.79	13.5	7.7	7.5	-2.6	7.8	1.3
D15 (mm)	15.8	13.0	-17.7	24.1	52.5	--	.1	--	6.2	6,100
D35 (mm)	33.5	34.6	3.3	44.7	33.4	--	.8	--	17.3	2,063
D50 (mm)	59.2	59.2	.0	59.8	1.0	--	2.9	--	35	1,107
D84 (mm)	188	147	-21.8	172	-8.7	--	28.2	--	127	350
D95 (mm)	248	225	-9.3	250	1.0	--	99.2	--	187	88.5

Cross-sectional dimensions and bed-particle-size distribution	Station 4 126 feet downstream of dam					Station 5 5 miles downstream of dam				
	44 days before	17 days after	% diff	23 months after	% diff[1]	44 days before	17 days after	% diff	23 months after	% diff[1]
xs area (ft^2)	1,279	1,274	-0.4	1277	-0.2	1,238	1,237	-0.1	1,235	-0.2
mean xs dpt (ft)	4.38	4.40	.5	4.16	-5.0	3.94	3.99	1.3	3.61	-8.4
D15(mm)	15.3	3.1	-79.7	18	17.6	7.0	7.8	11.4	6.8	-2.9
D35 (mm)	48.7	15.1	-69.0	54	10.9	15.3	13.2	-13.7	13.7	-10.5
D50 (mm)	77.7	31.3	-59.7	99	27.4	21.4	19.4	-9.3	22.4	4.7
D84 (mm)	160	117	-26.9	177	10.6	59.1	52.1	-11.8	98	65.8
D95 (mm)	224	875	291	238	6.3	138	119	-13.8	161	16.7

[1]Refers to the percent difference between 44 days before and 23 months after dam removal.

[2]For xs area and mean xs dpt, refers to the percent difference between 43 days before and 23 months after dam removal. For D15, D35, D50, D84, and D95, refers to the percent difference between 17 days after and 23 months after dam removal.

Cross-sectional dimensions at stations 3 and 4 remained similar throughout the study (figs. 7 and 8). The difference in cross-sectional area before removal and 17 days after removal was only 0.9 percent at station 3 and -0.4 percent at station 4 (table 3). Streamflows occurring within 23 months of dam removal transported silt/clay from the impoundment (fig. 6), resulting in a 3.0-percent increase in cross-sectional area at station 3 and essentially no change at station 4. Cross-sectional area at control stations 2 (fig. 9) and 5 (fig. 10) changed less than 1 percent between the initial and final surveys (table 3).

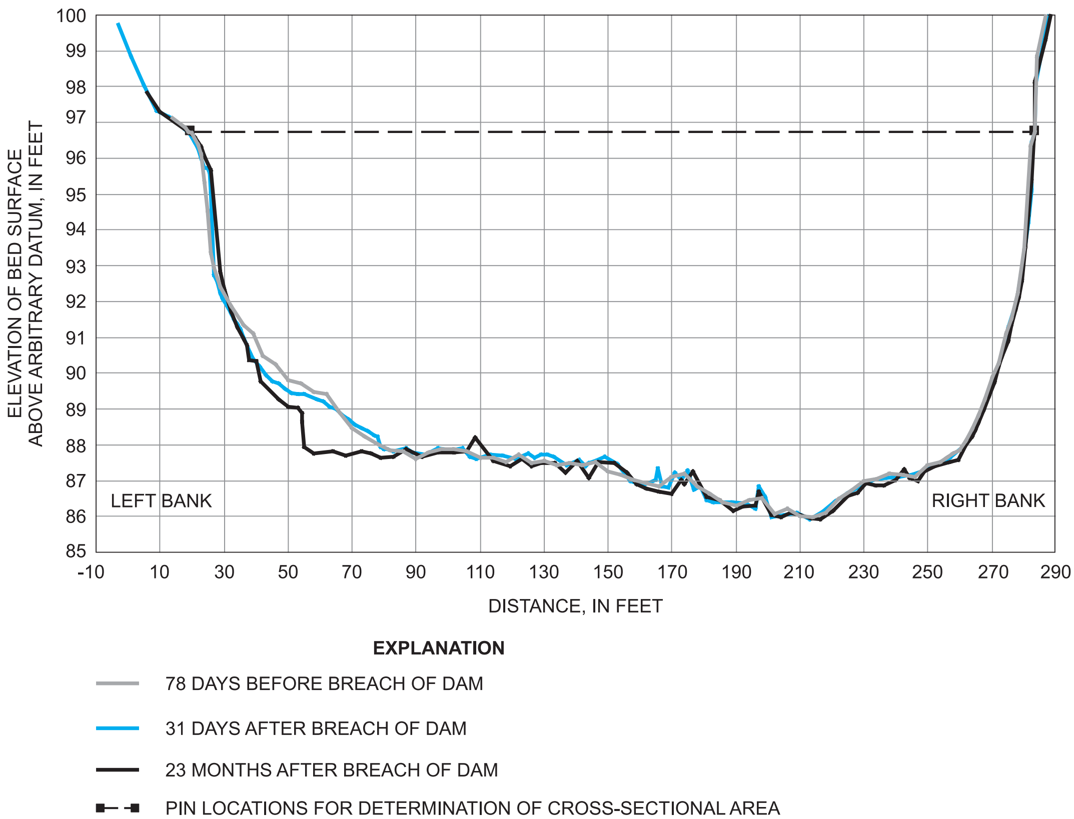

Figure 7. Cross-sectional channel surveys of Conodoguinet Creek at station 3, 115 feet upstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

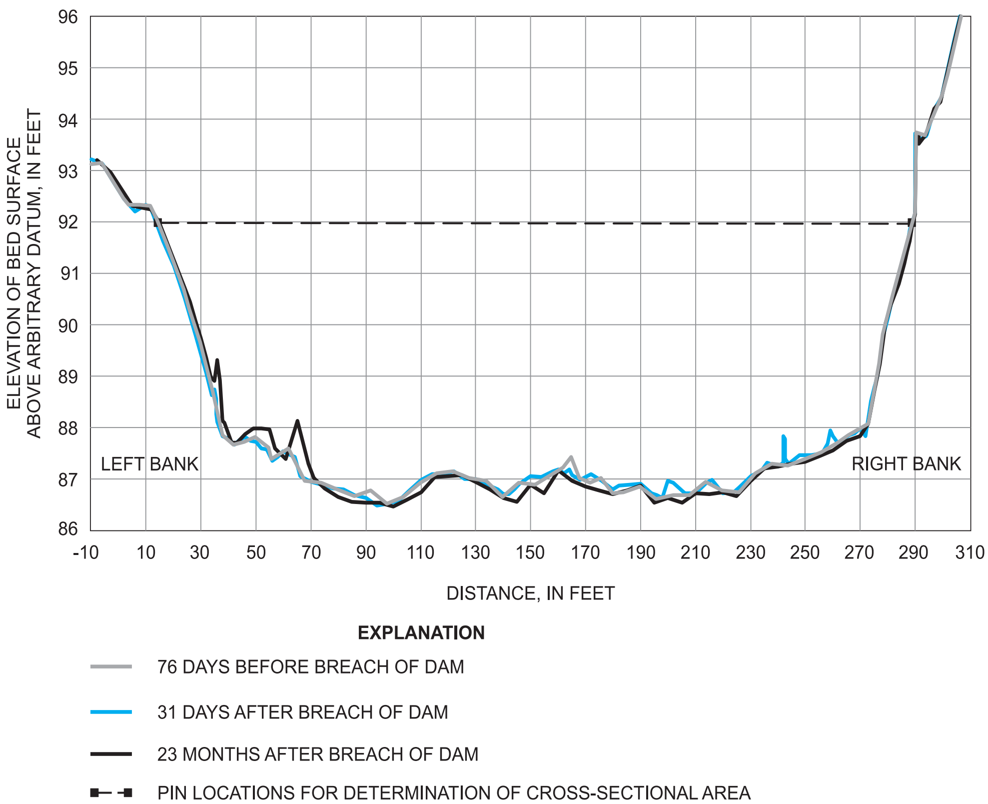

Figure 8. Cross-sectional channel surveys of Conodoguinet Creek at station 4, 126 feet downstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

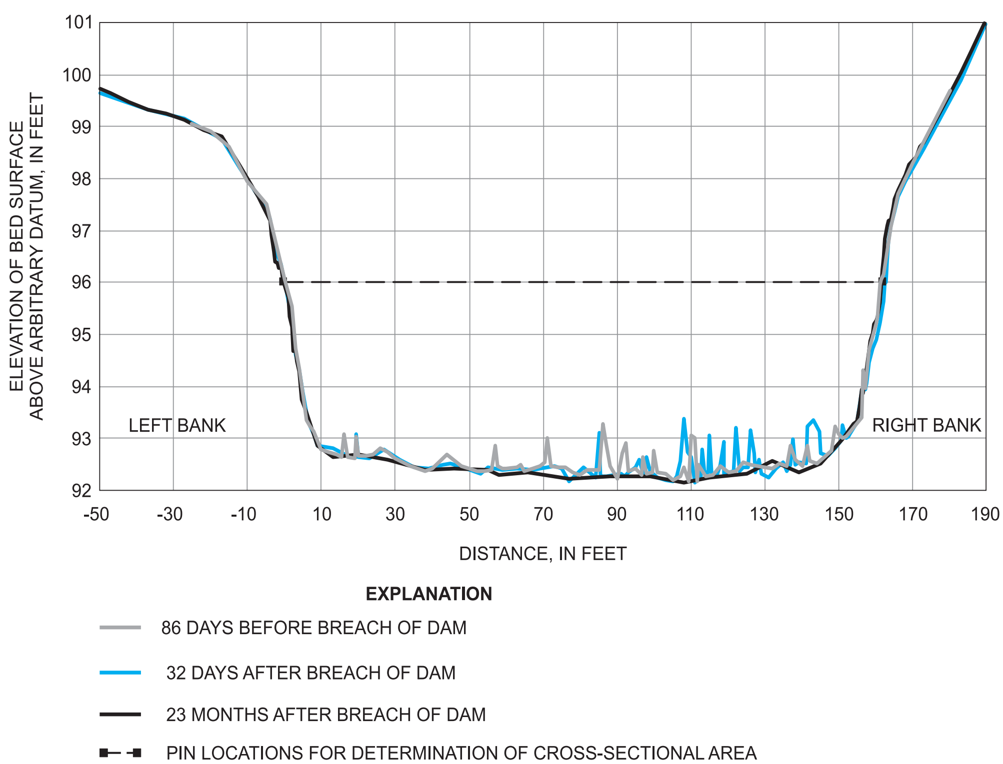

Figure 9. Cross-sectional channel surveys of Conodoguinet Creek at station 2, 2.5 miles upstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

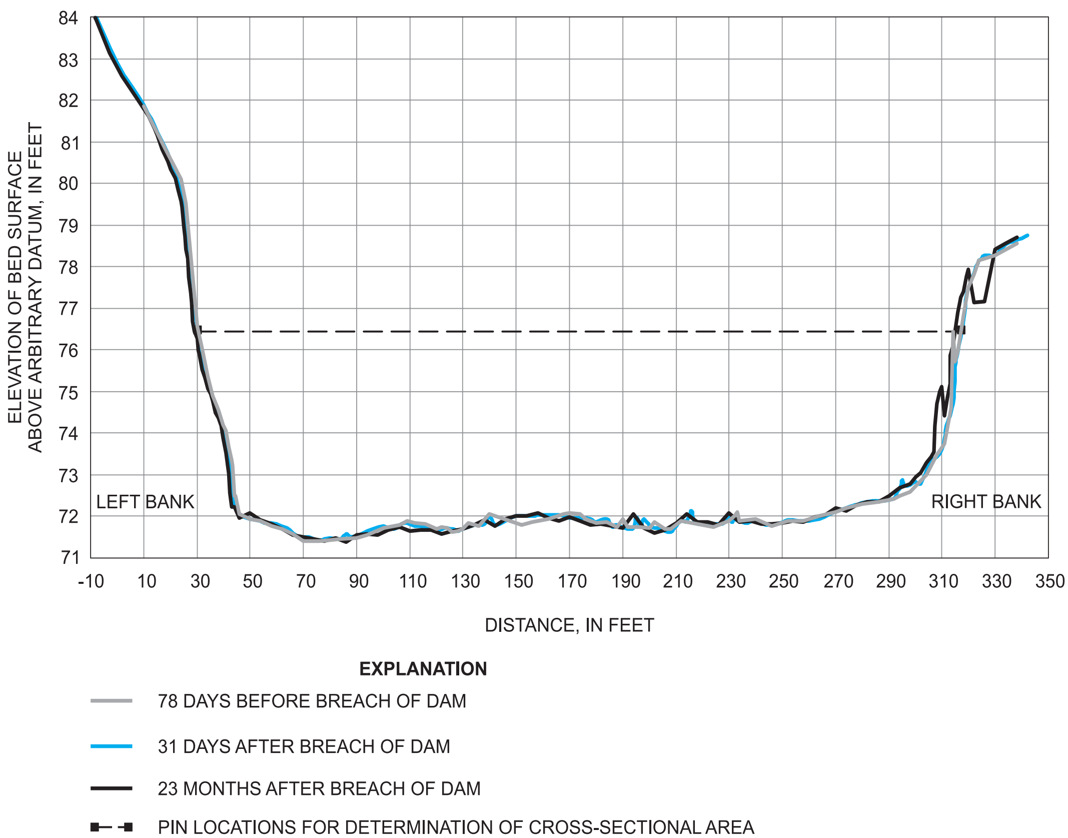

Figure 10. Cross-sectional channel surveys of Conodoguinet Creek at station 5, approximately 5 miles downstream of Good Hope Mill Dam, Cumberland County, Pennsylvania.

Water-Quality Variations

The evaluation of effects from Good Hope Mill Dam removal on water characteristics in Conodoguinet Creek has two primary objectives: 1) determine how temperature, dissolved oxygen, pH, specific conductance, and turbidity varied before, during, and after removal; and 2) determine how nitrogen, phosphorus, and suspended sediment released during dam removal compared to concentrations measured over a range of hydrologic conditions at station 1.

The retention time of water upstream of Good Hope Mill Dam was relatively short (hours) because the dam stored only about 52 acre-ft (64,141 m^3; 2.3 million ft^3) of water. The daily mean streamflow during the period of water-quality-data collection (September 1–December 31, 2001) was 81.33 ft^3/s (Durlin and Schaffstall, 2002, p. 178; Durlin and Schaffstall, 2003, p. 205). On the basis of this storage and flow rate, it took, on average, about 7.7 hours for inflowing water to replace all the water in the impoundment. Hence, similar to many other small impoundments (Baxter, 1977, p. 261), the chemistry of water impounded upstream of Good Hope Mill Dam was dominated by the chemistry of inflow from free-flowing reaches rather than the chemical and physical processes common to larger impoundments and reservoirs.

Continuously Measured Water-Quality Characteristics

Water quality in rivers and creeks can be affected by numerous processes, including seasonal changes in temperature, photosynthesis and respiration, diel cycles of light and dark, and stormwater runoff. These processes caused fluctuations in water characteristics of Conodoguinet Creek that were observed over four different time scales:

1) Seasonal patterns from September to December 2001;
2) Periodic patterns lasting for days;
3) Diel patterns associated with 24-hour light and dark cycles; and
4) Random variations resulting from stormwater runoff.

Seasonal patterns were most evident in temperature and dissolved-oxygen concentrations ($O_{2(aq)}$) (fig. 11). Daily mean temperature decreased at stations 2 and 3 from about 25°C in early September 2001 to 0°C by late December 2001. Superimposed on the seasonal temperature decrease is a periodic pattern characterized by temperature peaks and troughs with periods ranging from 6 to 13 days. Because the solubility of oxygen is inversely proportional to temperature, daily mean $O_{2(aq)}$ increased at stations 2 and 3 from September to December 2001. Maximum daily mean $O_{2(aq)}$ in September 2001 was 11.1 and 10.6 mg/L at stations 2 and 3, respectively, compared to 13.2 and 12.9 mg/L in December 2001 (fig. 11; Durlin and Schaffstall, 2003, p. 415-459). The maximum of periodic

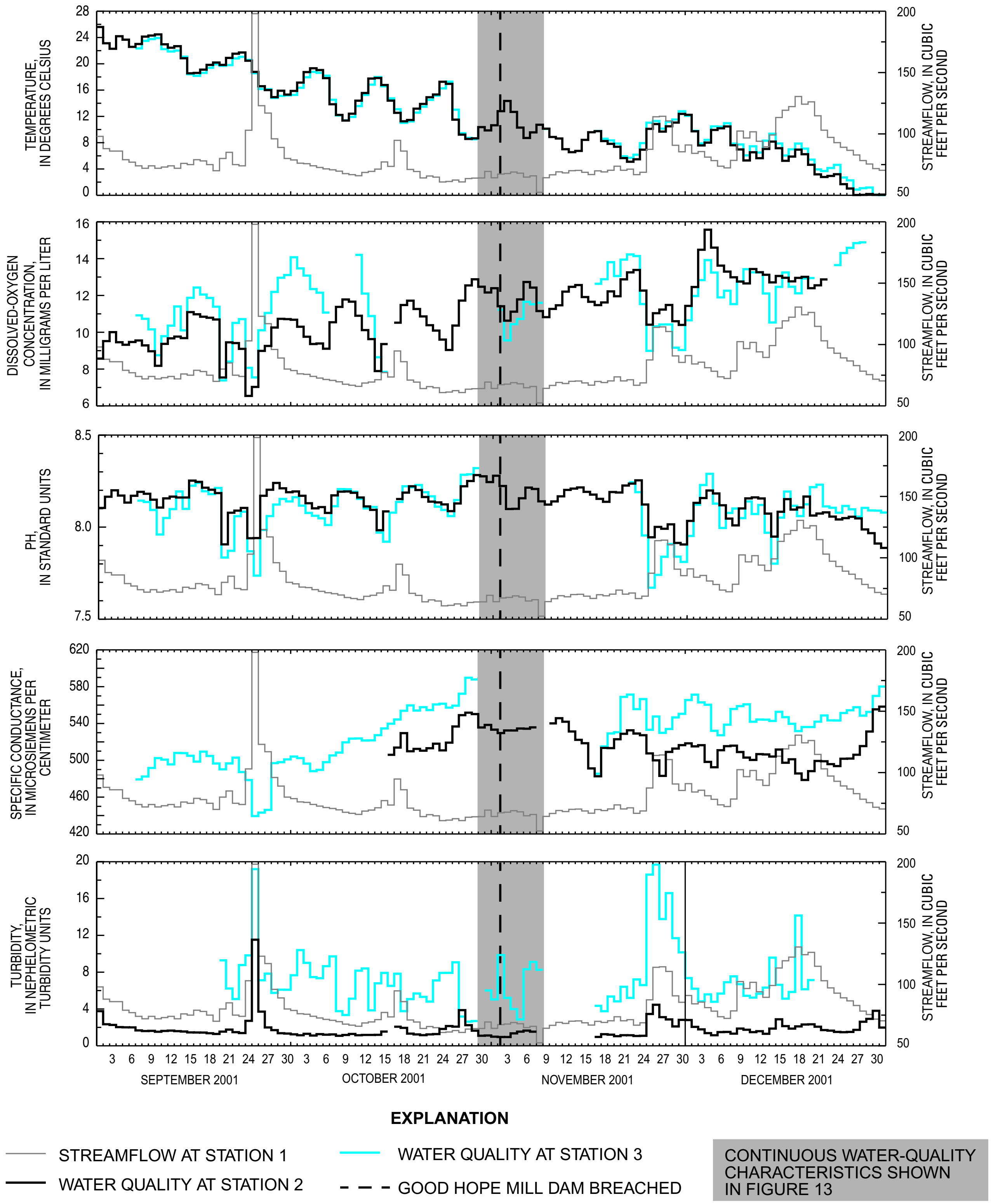

Figure 11. Relations among daily mean water-quality characteristics in Conodoguinet Creek, 4.9 miles, 2.5 miles, and 115 feet upstream of Good Hope Mill Dam (stations 1, 2, and 3, respectively), Cumberland County, Pennsylvania.

increases in $O_{2(aq)}$ generally occurred near the minimum of temperature periods. For example, daily mean $O_{2(aq)}$ at station 2 increased from 9.0 mg/L on October 25 to 12.9 mg/L on October 29. Over the same timeframe, the daily mean water temperature decreased from 17 to 8.5°C (fig. 11).

Seasonal patterns are not apparent in daily mean pH at stations 2 and 3, but a periodic pattern in daily mean pH similar to that of $O_{2(aq)}$ was observed (fig. 11). The interaction between temperature and photosynthesis controls the variability of $O_{2(aq)}$, but photosynthesis seems to be the primary process that affects the variability of pH. During daylight hours, photosynthesis by macrophytic vegetation, periphyton (attached algae), and (or) phytoplankton produces oxygen and consumes CO_2 by the following generalized relation:

$$CO_2 + H_2O \rightarrow \text{organic carbon} + O_2 \text{ (photosynthesis)} \qquad (1)$$

At night, respiration by plants and benthos consumes O_2 and produces CO_2 by

$$O_2 + \text{organic carbon} \rightarrow CO_2 + H_2O \text{ (respiration).} \qquad (2)$$

During periods of elevated photosynthetic activity, pH increases as the result of CO_2 consumption and $O_{2(aq)}$ increases from oxygen production (eqn. 1). This effect is most evident in summer when water temperature and solar radiation are higher than other parts of the year.

The range (fig. 12) and variability (fig. 11) of daily mean temperature, $O_{2(aq)}$, and pH were similar between stations 2 and 3. In contrast, median-daily mean specific conductance and turbidity were 7 and 230 percent greater, respectively, at station 3 compared to station 2 (fig. 12). This difference is apparently not a result of Good Hope Mill Dam because both constituents were consistently greater at station 3 before and after dam removal (fig. 11). Markedly higher turbidity and specific conductance at station 3 may have been caused by unmeasured inputs or use of the reach between stations 2 and 3 by waterfowl, recreational boaters, and fisherman.

Streamflow data collected at station 1 and water-quality data collected at stations 2 and 3 indicate short-term decreases in $O_{2(aq)}$, pH, and specific conductance occur during storm events (fig. 11). Decreases in $O_{2(aq)}$ are most likely a result of disruption and depression of photosynthetic oxygen production by eqn. 1, but the decrease in pH and specific conductance was primarily caused by mixing of weakly acidic and relatively dilute runoff (Hem, 1985, p. 35-36) with base flow in Conodoguinet Creek.

The effect of removing Good Hope Mill Dam on water characteristics in Conodoguinet Creek depends on the time scale and values that are considered. Daily mean values reported from September to December 2001 (fig. 11) indicate removal of the dam had either no effect on water characteristics or the effect was so small it was masked by seasonal and periodic variability. At the time scale of days and hours, Good Hope Mill Dam affected the range and variability of most water characteristics (fig. 13).

Before dam removal, daily extremes of temperature, dissolved oxygen, pH, and specific conductance at station 2 were out of phase by approximately 12 hours with station 3 (fig. 13). Once the dam was removed, the pattern at station 3 shifted and converged with the pattern at station 2. The offset before removal may be related to a lag time resulting from a decrease in velocity through the impoundment. Continuous measurements indicate impounded conditions did not affect the magnitude of daily $O_{2(aq)}$ or pH extremes but did suppress daily extremes of temperature and specific conductance (fig. 13).

Nutrients and Suspended Sediment

Dams modify streamflow patterns and may increase the retention of nutrients (nitrogen and phosphorus) within the impounded reach (Baxter, 1977). Nitrogen occurs in water as nitrite or nitrate ions (NO_2^- and NO_3^-), ammonium (NH_4^+), and at intermediate oxidation states as part of organic solutes (Hem, 1985). The sum of these three nitrogen forms is the total nitrogen concentration. The predominant form of nitrogen in near-neutral, oxygenated water characteristic of Conodoguinet Creek is NO_3^-, but reduced forms like NH_4^+ are commonly associated with bed sediments because they may be strongly adsorbed onto mineral surfaces (Hem, 1985). Retention of nitrogen in general, and NH_4^+ specifically, is of concern because oxygen depletion may take place upon mobilization and conversion of NH_4^+ to NO_3^- through nitrification (eqns. 3 and 4; Stumm and Morgan, 1996):

$$NH_4^+ + 1.5\ O_2 \rightarrow NO_2^- + H_20 + 2\ H^+ \qquad (3)$$

$$NO_2^- + 0.5\ O_2 \rightarrow NO_3^- \qquad (4)$$

Severe depletion of oxygen (to concentrations less than 5 mg/L) can have detrimental effects on fish (U.S. Environmental Protection Agency, 1986). Nitrogen concentrations measured downstream of the impoundment were used in conjunction with continuously measured $O_{2(aq)}$ at station 4 to 1) determine how the total nitrogen concentrations measured during release compare to concentrations measured at station 1 over a range of hydrologic conditions, and 2) determine if oxygen depletion occurred downstream of the dam.

Total nitrogen concentrations at station 4 between October 25, 2001, and November 2, 2001, at 10:00 a.m. EST ranged from 3.92 to 4.19 mg/L (fig. 14). Greater than 90 percent of total nitrogen before the breach was in the form of NO_2^- or NO_3^-; less than 10 percent was NH_4^+ + organic form. When the dam was breached, the initial release of water contained a total nitrogen concentration of 4.66 mg/L (fig. 14). Total nitrogen in two samples collected approximately 1 hour and 3 hours after the initial breach decreased to 4.35 and 4.29 mg/L, respectively. These concentrations are comparable to the concentrations at station 1, which ranged from 2.39 to 4.92 mg/L (fig. 14).

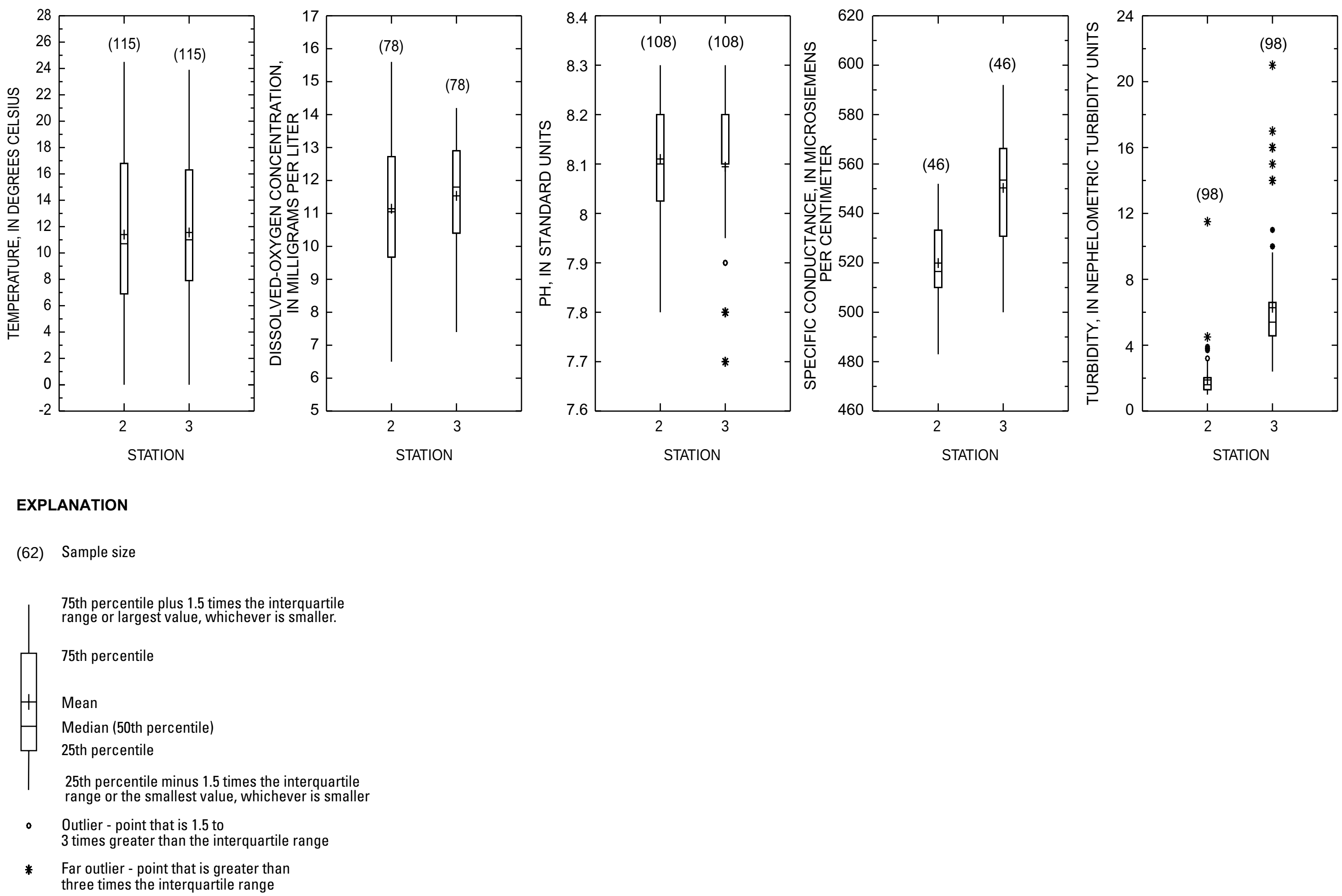

Figure 12. Range of daily mean water-quality characteristics in Conodoguinet Creek at stations 2 and 3, 2.5 miles and 115 feet upstream of Good Hope Mill Dam, respectively, Cumberland County, Pennsylvania, August 2001–January 2002. Daily means are computed from *in-situ* measurements made at 15-minute intervals. When *in-situ* measurements were missing for a continuous period of 240 minutes or greater within a day, daily means were not computed.

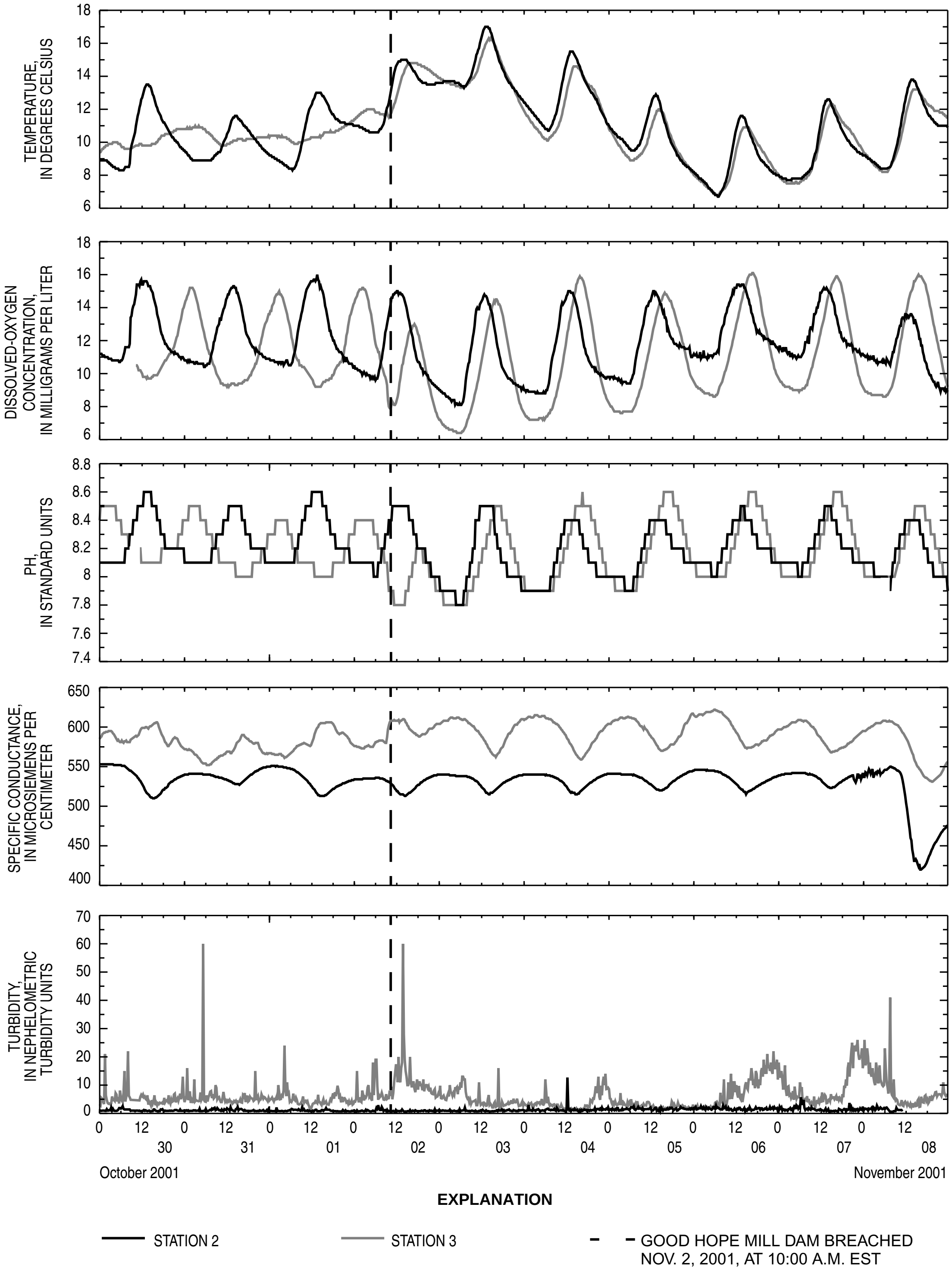

Figure 13. Relations among water-quality characteristics measured at 15-minute intervals in Conodoguinet Creek, 2.5 miles and 115 feet upstream of Good Hope Mill Dam (stations 2 and 3, respectively), Cumberland County, Pennsylvania (adapted from Chaplin, 2003). (EST, Eastern Standard Time)

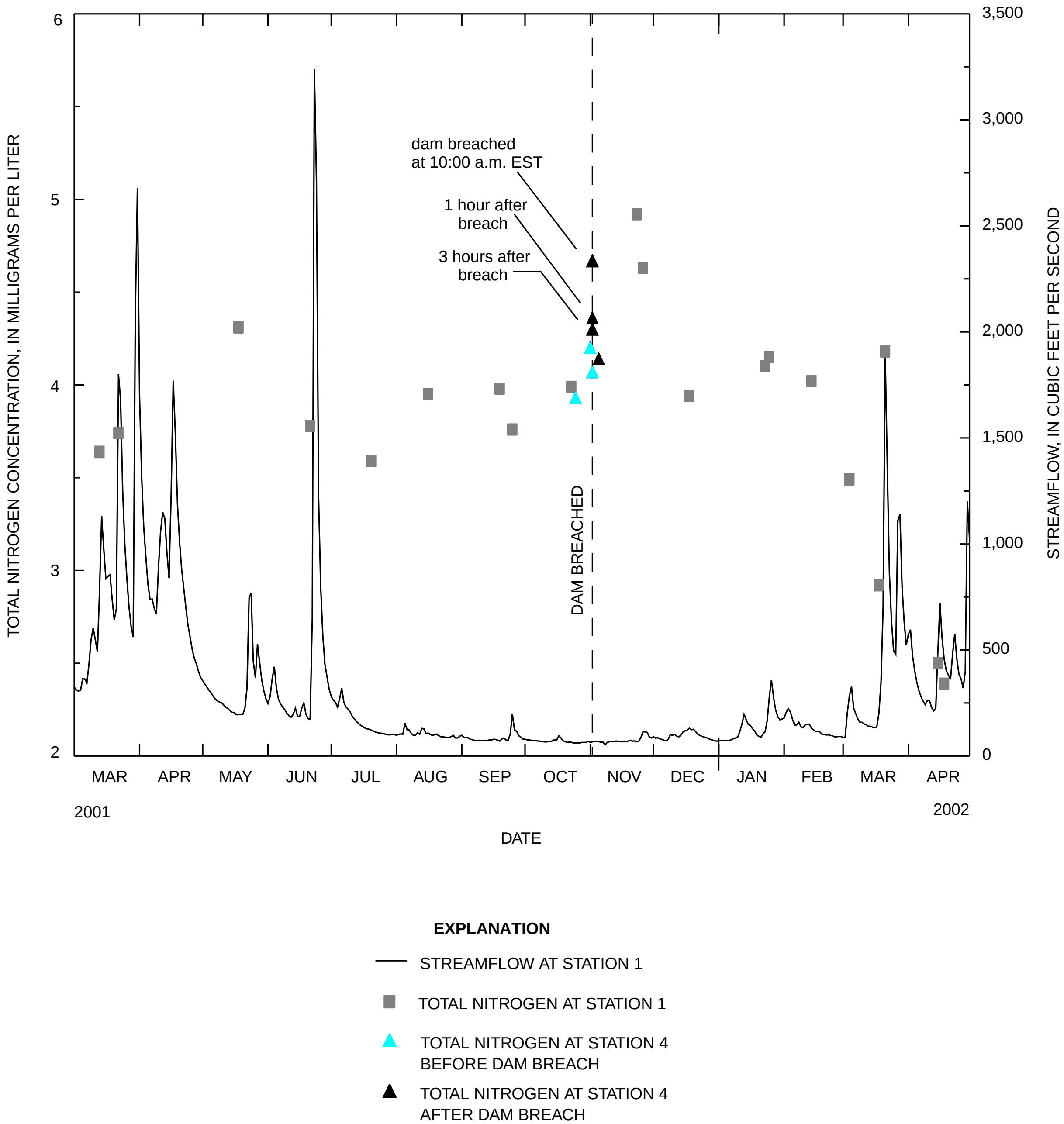

Figure 14. Concentrations of total nitrogen measured in Conodoguinet Creek at station 4, 115 feet downstream of Good Hope Mill Dam, compared to those measured at station 1, 4.9 miles upstream of the dam, over a range of streamflows, Cumberland County, Pennsylvania. (EST, Eastern Standard Time)

Concentration of NH_4^+ + organic N in the sample collected upon the initial dam breach indicates some NH_4^+ was present within the impoundment and was released upon the initial breach of the dam. In the sample, NH_4^+ + organic N was 20 percent of the total nitrogen concentration, an increase of 10 percent compared to samples collected before the breach. This increase did not cause appreciable depletion of oxygen (fig. 15) nor did it result in unusually high total nitrogen concentrations compared to measurements made between March 2001 and April 2002 at station 1. Further, the 20 percent of total nitrogen concentration that was in the NH_4^+ + organic N form upon the initial dam breach was comparable to concentrations measured at station 1. NH_4^+ + organic N accounted for 5 to 62 percent of total nitrogen at station 1 and was greater than 20 percent in 4 of the 20 samples shown in figure 14.

Phosphorus may be present in dissolved, colloidal, or particulate form and commonly is concentrated in lake and reservoir sediments (Hem, 1985, p. 126; Allen and Kramer, 1972). Eutrophication is a concern in reservoirs that accumulate phosphorus because it is a critical element for zooplankton, phytoplankton, and algal growth. Release of phosphorus accumulated in sediment may accelerate algal growth, which in turn would increase demand for oxygen during respiration (eqn. 2). Thus, phosphorus concentrations measured downstream of the impoundment were used to determine if there was a release as a result of removing Good Hope Mill Dam.

Total phosphorus concentrations in two samples collected at station 4 in the 24 hours preceding the dam breach were 0.021 and 0.023 mg/L. Upon the initial breach of the dam, total phosphorus concentrations increased to 0.116 mg/L but then decreased to less than 0.100 mg/L in samples collected 1 and 3 hours after the breach (Durlin and Schaffstall, 2003, p. 437). After the dam removal was complete, total phosphorus concentration returned to pre-removal levels (0.023 mg/L). The short-term (hours) increase in phosphorus concentration during dam removal was unlikely to effect algal growth downstream.

Mobilization and deposition of fine sediment during and after dam removal can fill interstitial voids between coarse bed material and may cause suffocation or abrasion of benthos. Suspended-sediment concentrations measured at station 1 are representative of concentrations that commonly occur in Conodoguinet Creek over a range of flow events. These data were compared with suspended-sediment concentrations measured during the removal of Good Hope Mill Dam.

Suspended-sediment concentrations measured during removal of the dam were not extreme when considered in the context of longer-term data collected between March and December 2001 at station 1 (fig. 16). Suspended-sediment concentration measured over a range of hydrologic conditions at station 1 ranged from 1.0 to 490 mg/L between March 1, 2001, and April 31, 2002. Suspended-sediment concentrations at station 4 ranged from 22 to 98 mg/L during dam removal. Correlation between flow and sediment data indicates that flow events re-occurring from less than 1 to 1.5 years (1,100-5,900 ft^3/s) are likely to have suspended-sediment concentrations similar to the maximum concentration measured during dam removal.

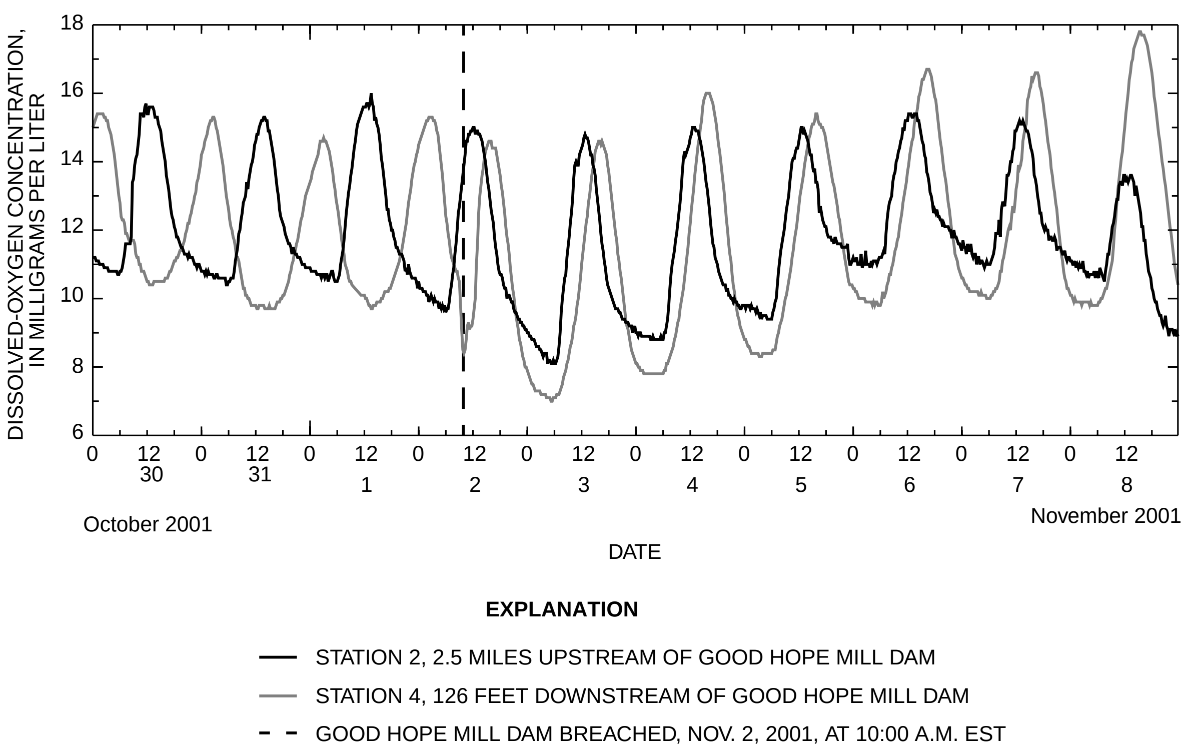

Figure 15. Dissolved-oxygen concentration in Conodoguinet Creek at station 2, 2.5 miles upstream of Good Hope Mill Dam, and station 3, 126 feet downstream of the dam, Cumberland County, Pennsylvania. (EST, Eastern Standard Time)

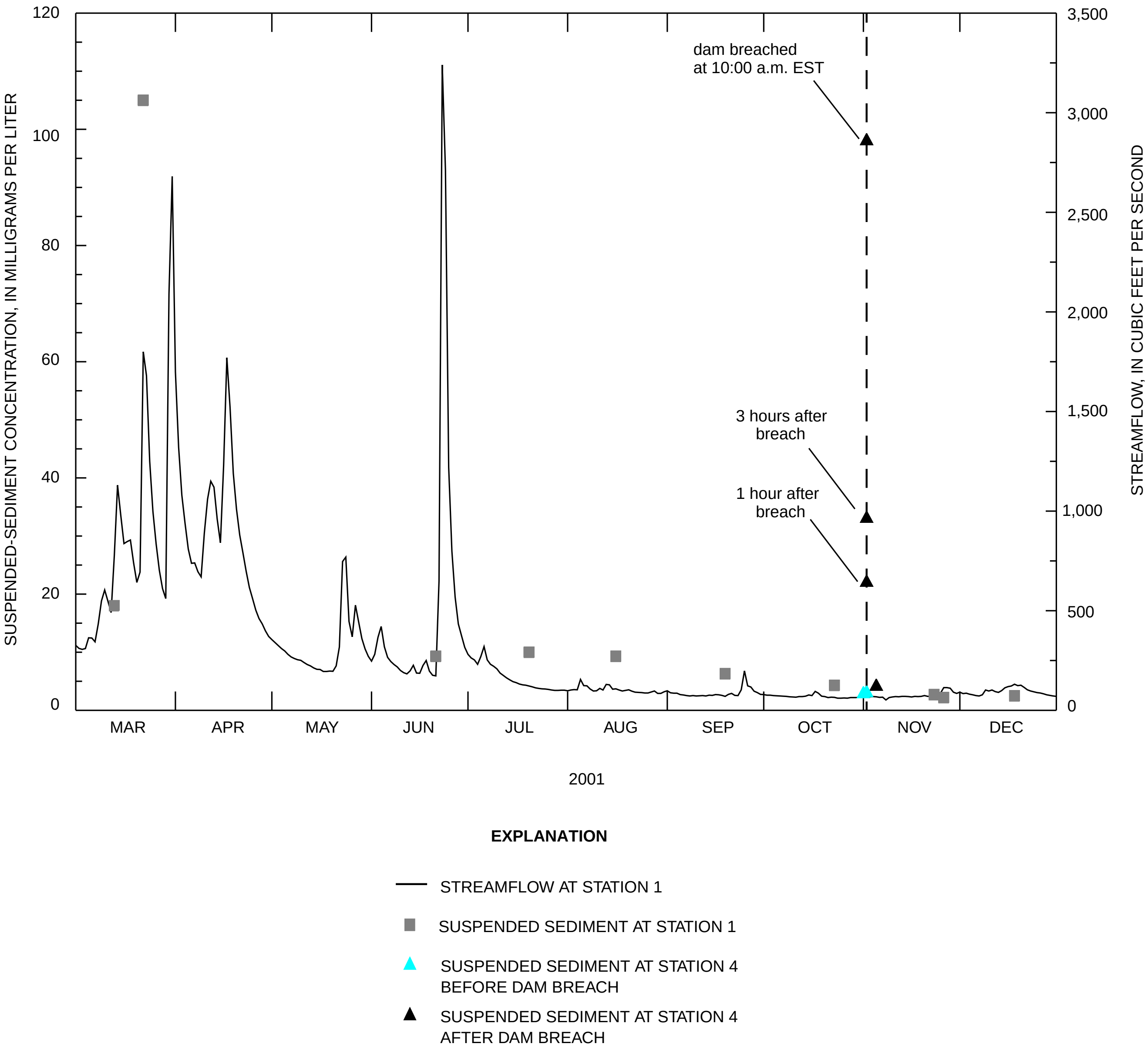

Figure 16. Concentrations of suspended sediment measured in Conodoguinet Creek at station 4, 115 feet downstream of Good Hope Mill Dam, compared to those measured at station 1, 4.9 miles upstream of the dam, over a range of streamflows, Cumberland County, Pennsylvania. (EST, Eastern Standard Time)

Response of the Benthic-Invertebrate Community

The sampling design used to determine the response of the benthic-invertebrate community to removal of Good Hope Mill Dam consisted of a spatial and temporal component. Benthic invertebrates were collected at stations 2 through 5 approximately 1.5 months before dam removal, 2 weeks after removal, and 12 months after removal (table 2). By following this sampling regimen, it was possible to record short-term (weeks and months) and long-term (up to 12 months) responses of the benthic-invertebrate community to dam removal and to document the stability of the upstream and downstream invertebrate-community composition.

In September and November 2001, the stream reach in the vicinity of station 2 supported an invertebrate community representative of a riffle habitat in a suburbanized area as evidenced by the dominance of filter-feeding hydropsychid caddisfly larvae (table 4). These animals usually are found in areas of good water quality with low to moderate nutrient concentrations (<1 to 3 mg/L NO_2^- + NO_3^- and <0.005 to 0.01 mg/L PO_4^{3-}; Frink, 1991). Other biological measures of water quality, including total EPT taxa, percent EPT, and HFBI values, provide further affirmation of a good water-quality condition during the September and November 2001 samples. The sample collected in November 2002, however, was greatly affected by a high-water condition that prohibited sampling of the left edge of water (looking downstream). As a result, the invertebrate-community composition consisted of large numbers of the isopod *Lirceus* that originated from Trindle Spring Run, about 50 m (165 ft) upstream on the right edge of water. An examination of the metric scores shows this high water and sampling anomaly (table 4).

The macroinvertebrate community in the wider, more shallow reach near station 5 was indicative of a limestone-influenced stream with moderate to high nutrient concentrations (1 to 5 mg/L NO_2^- + NO_3^- and 0.005 to 0.015 mg/L PO_4^{3-}; Frink, 1991) associated with suburban land use. The invertebrate-community composition was dominated by the amphipod *Gammarus* in both 2001 collections along with a diverse fauna of mayflies (Ephemeroptera), caddisflies (hydropsychids), and elmid beetles (table 4). In November 2002, high-water conditions made it difficult to locate riffles and deploy the 1-m^2 kick net. An examination of the metric values showed a decrease in EPT taxa numbers by 50 percent, a higher HFBI score, and the dominance shift from *Gammarus* to *Caenis*. This is an appreciable change in EPT taxa (toward a less-desirable community composition) but may have been caused by the high water and the inability to collect samples in riffles where they were collected previously.

The riffle sampled in the vicinity of station 4 had moderate depth and represented ideal habitat for a range of benthic-invertebrate taxa. This reach had the greatest total taxa and EPT scores and the lowest HFBI scores (table 4) in 2001. The dominant animals were the elmid beetles *Stenelmis* and *Optioservus*. In November 2002, high water hindered collection as indicated by the decrease in the number of EPT taxa to less than 50 percent of the 2001 values. The number of flatworms, *Gammarus*, and the Asiatic clam *Corbicula fluminea* increased, which resulted in a corresponding increase in HFBI scores (table 4). The increase in *Corbicula* might have happened when the dam was removed and these animals were physically relocated downstream.

Invertebrate taxa and metrics shown in table 4 indicate the largest response to dam removal took place in the reach upstream of the dam. However, some changes may be caused by the use of different collection methods rather than dam removal. In September 2001, impounded conditions in the vicinity of station 3 restricted access to mid-channel locations and limited the habitat that could be jab sampled to downed trees and rocks near the dam and periphery of the channel (fig. 2). The taxa collected within the impoundment are characteristic of a lentic community. Dominant taxa were the amphipod *Gammarus* and 13 taxa of midges (predominantly *Tanytarsus;* table 4). After the dam was removed, the habitat near station 3 changed to a free-flowing lotic reach that was kick sampled in the same manner as stations 2, 4, and 5. An influx of the mayfly *Caenis* collected about 2 weeks after the dam removal and habitat shift is reflected in the taxa and metrics shown in table 4. About 66 percent of the invertebrate community was made up of *Caenis*, which caused a corresponding increase in HFBI scores. Perhaps the newly created riffle habitat opened a previously unoccupied niche. A more likely explanation is that these mayfly larvae, which favor slow-moving velocities, were always present but were more difficult to collect before the dam was removed than after. In November 2002, it appeared, even with a high-water condition, that the lentic to lotic habitat conversion had caused the EPT taxa to progressively increase, the midge composition to shift from nutrient tolerant to more intolerant taxa, and dominance to revert from *Caenis* back to *Gammarus* (table 4).

In summary, the dam-removal process has not dramatically altered the benthic-invertebrate community in the vicinity of station 4 or station 5. If the dam removal had been detrimental, the downstream invertebrate community would have experienced a shift in dominance and diversity characterized by fewer EPT taxa and more oligochaetes and chironomids. The expected change from a lentic to lotic condition has occurred upstream of the former dam and with time it is likely the invertebrate-community composition will not greatly differ from other reaches of Conodoguinet Creek with similar habitat.

Table 4. Taxa list, number of individuals, and associated metrics characterizing the benthic-invertebrate community before and after removal of Good Hope Mill Dam from Conodoguinet Creek, Cumberland County, Pennsylvania.

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Taxa and metrics	Number of individuals											
	Station 2			Station 3			Station 4			Station 5		
	Sep. 18, 2001	Nov. 20, 2001	Nov. 25, 2002	[1]Sep. 19, 2001	Nov. 19, 2001	Nov. 25, 2002	Sep. 18, 2001	Nov. 19, 2001	Nov. 25, 2002	Sep. 18, 2001	Nov. 19, 2001	Nov. 25, 2002
PLATYHELMINTHES												
TURBELLARIA												
TRICLADIDA												
Planariidae	--	--	12	--	--	3	--	--	18	--	--	4
ANNELIDA												
OLIGOCHAETA (aquatic earthworms)												
TUBIFICIDA												
Enchytraeidae	--	--	--	--	2	--	--	--	--	--	--	--
Tubificidae												
Aulodrilus pleuriseta	--	--	2	--	--	7	--	--	--	--	--	2
Spirosperma nikolskyi	--	--	--	--	2	--	--	--	2	--	--	--
Tubificidae w/o capilliform setae	--	--	15	--	--	10	--	--	--	--	--	28
LUMBRICINA	--	--	--	--	--	--	--	--	--	--	--	1
MOLLUSCA												
GASTROPODA (snails)												
MESOGASTROPODA												
Hydrobiidae	--	--	2	--	--	--	--	--	--	--	--	--
Amnicola	--	--	--	--	--	2	--	--	--	--	--	3
Pleuroceridae												
Elimia	--	--	--	--	--	--	--	--	2	--	--	--
Leptoxis carinata	--	--	2	--	1	--	--	--	--	--	1	1
BASOMMATOPHORA												
Ancylidae (limpets)												
Ferrissia	2	--	7	--	1	8	--	--	7	--	--	3
Planorbidae												
Gyraulus	--	--	1	--	1	--	--	--	--	--	--	--
Planorbella	--	--	--	--	--	1	--	--	1	--	--	10
Lymnaeidae												
Fossaria	--	--	--	--	--	2	--	--	--	--	--	--
Physidae												
Physella	--	--	--	--	--	--	--	--	1	--	--	4

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Taxa and metrics	Number of individuals											
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BIVALVIA (clams and mussels)												
VENEROIDA												
Corbiculidae												
Corbicula fluminea	1	1	2	--	6	14	2	--	39	--	--	23
Pisidiidae (fingernail clams)	--	--	1	--	--	--	--	--	1	--	--	--
Pisidium	--	--	2	--	1	1	--	--	--	--	--	--
CHELICERATA												
ARACHNIDA												
HYDRACHNIDIA (water mites)	--	--	2	--	--	3	--	1	1	--	1	1
ARTHROPODA												
CRUSTACEA												
OSTRACODA	--	--	--	--	--	1	--	--	2	--	1	--
MALACOSTRACA												
ISOPODA (sow bugs)												
Asellidae												
Lirceus	--	--	105	--	--	--	--	--	1	--	--	--
AMPHIPODA (scuds)												
Crangonyctidae												
Crangonyx	--	--	--	2	--	--	--	--	--	--	--	--
Gammaridae												
Gammarus	--	5	34	34	9	58	--	6	28	91	54	27
Hyalellidae												
Hyalella azteca	--	--	--	6	--	--	--	--	--	--	--	--
INSECTA												
EPHEMEROPTERA (mayflies)												
PISCIFORMA												
Baetidae	--	--	--	1	--	--	3	4	--	--	--	--
Acentrella	5	1	--	--	--	--	4	--	--	--	--	--
Acerpenna	5	--	--	--	--	--	15	15	--	--	--	--
Baetis	14	20	1	--	--	--	6	--	1	29	2	--
Baetis (2-tailed)	--	--	--	--	--	--	--	--	--	1	--	--

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SETISURA												
Heptageniidae	2	--	1	1	--	--	4	--	--	--	--	--
Heptagenia	1	--	--	--	--	--	1	--	--	--	--	--
Leucrocuta	--	--	--	--	--	--	3	--	--	1	--	--
Stenacron	1	--	--	--	--	1	4	--	1	2	1	--
Stenonema	6	14	2	--	--	9	14	16	7	6	15	6
Isonychiidae												
Isonychia	7	12	1	--	--	--	9	5	--	--	2	1
FUCATERGALIA												
Leptophlebiidae												
Leptophlebia	--	--	--	--	--	--	--	1	--	--	--	--
Paraleptophlebia	--	--	--	--	--	--	--	1	--	--	--	--
Ephemeridae												
Hexagenia	--	--	--	--	2	--	--	--	--	--	--	--
Potamanthidae												
Anthopotamus	1	8	--	--	--	3	6	5	4	2	11	1
Caenidae												
Caenis	1	--	--	1	146	36	1	1	10	14	3	77
Ephemerellidae												
Ephemerella	--	6	--	--	--	--	--	1	--	--	--	--
Serratella	--	6	--	--	--	1	1	1	--	--	2	--
Leptohyphidae												
Tricorythodes	--	--	--	--	--	--	--	--	--	3	--	--
ODONATA (dragonflies and damselflies)												
ZYGOPTERA												
Coenagrionidae												
Argia	2	3	1	1	--	1	3	2	5	1	2	2
Enallagma	--	--	--	7	--	--	--	--	--	--	--	--

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HEMIPTERA (true bugs)												
Corixidae	--	--	--	1	--	--	--	--	--	--	--	--
PLECOPTERA (stoneflies)												
EUHOLOGNATHA												
Taeniopterygidae												
Taeniopteryx	--	4	1	--	--	--	--	5	3	--	3	--
SYSTELLAGNATHA												
Perlidae												
Agnetina	--	1	--	--	--	--	1	--	--	--	--	--
Paragnetina	1	--	--	--	--	--	--	--	--	--	--	--
COLEOPTERA (beetles)												
POLYPHAGA												
Hydrophilidae (water scavenger beetles)												
Berosus	--	--	--	1	--	1	--	--	1	--	--	1
Psephenidae (water pennies)												
Psephenus	1	--	--	--	--	--	4	1	13	5	2	20
Elmidae (riffle beetles)												
Dubiraphia	--	1	--	5	30	27	--	--	3	--	2	4
Macronychus	--	--	--	2	1	--	--	--	--	--	--	--
Optioservus	9	17	2	--	2	2	30	47	32	13	37	11
Promoresia	--	--	--	4	--	2	--	1	--	--	--	--
Stenelmis	19	9	--	1	1	8	42	11	26	49	10	27
Scirtidae	--	1	--	--	--	--	--	--	--	--	--	--
MEGALOPTERA (dobsonflies and fishflies)												
Corydalidae												
Corydalus	--	--	--	--	1	--	2	--	--	--	--	--
Sialidae												
Sialis	--	--	--	--	--	--	1	--	--	--	--	--

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TRICHOPTERA (caddisflies)												
SPICIPALPIA												
Hydroptilidae												
Hydroptila	--	--	--	--	--	--	1	2	--	1	1	1
Leucotrichia	--	--	--	--	--	--	3	--	--	--	--	--
Glossosomatidae	2	--	--	--	--	--	--	--	--	--	--	--
Glossosoma	--	1	--	--	--	--	1	--	--	--	--	--
ANNULIPALPIA												
Philopotamidae												
Chimarra	22	2	--	--	--	--	5	3	--	--	--	--
Hydropsychidae	--	--	--	--	--	--	1	1	--	2	--	--
Cheumatopsyche	35	41	1	--	--	5	35	32	3	2	8	--
Hydropsyche	51	42	4	3	--	14	11	7	7	6	12	--
Hydropsyche morosa gr.	12	4	--	--	--	1	1	9	--	--	--	--
INTEGRIPALPIA												
Leptoceridae												
Oecetis	--	--	--	--	--	2	--	--	--	--	--	--
Helicopsychidae												
Helicopsyche	--	--	1	--	--	1	1	--	2	--	--	3
LEPIDOPTERA (aquatic moths)												
Pyralidae												
Petrophila	6	--	--	--	--	3	4	1	1	--	--	--
DIPTERA (true flies)												
Ceratopogonidae (biting midges)	--	--	--	1	--	--	--	1	--	--	--	--
Probezzia	--	--	--	--	--	--	--	--	1	--	--	--
Chironomidae (non-biting midges)												
Tanypodinae	1	--	--	--	--	--	--	--	--	--	--	--

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Pentaneurini												
Ablabesmyia	--	--	--	1	--	--	--	--	--	--	--	--
Ablabesmyia mallochi	--	--	--	7	--	--	--	--	--	--	--	--
Conchapelopia	--	--	1	--	--	--	1	6	--	--	8	1
Pentaneura	--	1	--	--	--	--	1	1	--	1	1	--
Thiennemannimyia gr.	--	--	--	--	--	--	1	--	--	--	1	--
Procladiini												
Procladius	--	--	--	4	1	--	--	--	--	--	--	--
Tanypodini												
Tanypus	--	--	--	1	--	--	--	--	--	--	--	--
Orthocladiinae												
Corynoneurini												
Corynoneura	--	--	--	2	--	--	--	--	--	--	--	--
Orthocladiini												
Cricotopus/Orthocladius	--	--	--	1	--	1	--	3	2	--	--	--
Cricotopus										2		
Cricotopus bicinctus	--	2	--	2	--	--	3	6	--	1	3	--
Cricotopus trifascia	--	--	1	--	--	--	--	1	--	--	--	--
Eukiefferiella	--	1	3	--	--	--	--	--	--	--	1	4
Eukiefferiella brevicalcar gr.	--	--	--	--	--	--	--	--	5	--	--	--
Nanocladius	--	--	--	1	--	--	--	--	--	1	--	--
Orthocladius	--	--	3	--	--	6	--	3	2	--	1	9
Thiennemaniella	--	1	--	--	--	--	3	--	--	1	--	--
Tvetenia												
Tvetenia bavarica gr.	--	--	--	--	--	--	1	--	--	--	--	--
Tvetenia vitracies gr.	--	1	--	--	--	--	--	--	--	--	1	--
Chironominae	--	--	--	--	--	--	1	--	--	1	1	--

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Chironomini												
Chironomus	--	--	--	1	1	--	--	--	--	--	--	--
Cryptochironomus	--	--	--	--	--	--	--	--	--	--	1	--
Dicrotendipes	--	--	1	9	5	1	--	2	--	--	3	--
Microtendipes pedellus gr.	--	--	--	--	--	1	--	4	--	4	8	1
Paratendipes	--	--	--	--	--	1	--	--	--	--	--	--
Phaenopsectra	--	--	1	--	--	--	--	--	--	--	--	--
Polypedilum	1	--	--	9	--	--	--	--	--	--	2	--
Polypedilum flavum	--	3	--	--	--	--	6	1	1	--	3	--
Polypedilum scalaenum gr.	--	--	--	--	--	2	--	--	--	--	--	13
Pseudochironomini												
Pseudochironomus	--	--	--	--	--	--	--	--	--	--	2	--
Tanytarsini												
Cladotanytarsus	--	--	--	--	6	2	--	3	--	--	7	--
Rheotanytarsus	--	2	--	1	--	--	6	12	1	2	30	1
Tanytarsus	1	1	--	22	2	--	6	7	--	12	14	--
Simuliidae (black flies)												
Simulium	--	1	--	--	--	--	--	--	1	--	--	--
Total taxa	26	30	29	29	20	36	41	38	35	26	37	30
Total number of animals	209	212	212	132	221	241	248	229	235	253	257	290
Density, as animals/m^2	3,414	1,484	6,925	462	773	3,374	4,861	7,481	7,677	8,265	6,296	9,473
Total EPT taxa	16	14	8	4	2	10	22	17	9	12	11	6
EPT taxa, as % of total taxa	61	47	27	14	10	28	54	45	26	46	30	20
Number of midge taxa	3	8	6	13	5	7	10	12	5	9	17	6
Midge taxa, as % of total taxa	1	6	5	46	7	6	12	21	5	10	34	10
HFBI	3.92	3.92	7.15	5.46	6.36	5.18	3.86	4.4	5.49	4.42	4.76	5.03
Dominant taxon, as % of total taxa	47	41	50	26	66	24	29	25	17	36	20	27

[1]Based on a 20 jab composite sample. All other stations sampled by compositing two 1-m^2 kick net samples.

Response of the Fish Assemblage

In general, the species composition and relative number of individuals in the fish assemblage in Conodoguinet Creek did not change dramatically in response to the removal of Good Hope Mill Dam. The greatest change in species composition and number was expected at station 3, where the habitat changed from a lentic pool habitat before the removal to a lotic condition after the dam removal. At station 3, 531 individuals representing 18 species were collected before the dam removal, and 601 individuals representing 19 species were collected after the dam removal (table 5). Unfortunately, the fishes brought back to the lab from the pre-removal sample at station 3 were not preserved correctly and began to decay before a count could be made; however, species could be identified and are indicated by a "+" in table 5. It is likely that the number of individuals captured in each year was similar. The dominant species in the catch were rock bass and redbreast sunfish in both years.

Less change in the fish assemblages was expected below the dam (station 4) and above the impoundment (station 2). At station 4, 678 individuals (19 species) were collected before the dam was removed, and 532 individuals (18 species) were collected after the dam was removed (table 5). The dominant fish in this reach was rock bass in both years. The fish assemblage at station 2 changed more than the assemblage at either of the other stations; however, the changes were not related to the dam removal because station 2 is 2.5 mi upstream of the former dam. At station 2, 880 individuals (20 species) were collected before the dam was removed, and 1,111 individuals (25 species) were collected after the dam was removed (table 5). The number of rock bass at this station increased during the second year, and the number of darters decreased. The relative numbers of smallmouth bass and white suckers also changed during the 2 years of the study. Both species decreased at stations 3 and 4 but increased at station 2.

Fishes were sampled in the vicinity of station 5, which is 5.0 mi downstream from Good Hope Mill Dam (table 5). No changes in the fish assemblage were expected at this station related to the dam removal. The fish assemblage in this section was markedly different, both in number of species and relative densities, than in the other stations sampled. Only 7 species (61 individuals) were collected before the dam was removed, and 11 species (158 individuals) were collected after the dam was removed. Rock bass was the dominant species in the sample for both years, and the changes in the sample composition are within the scope of natural fluctuations.

The changes observed in the fish assemblage between the two sample periods are not beyond the scope of natural fluctuations in fish assemblages in rivers related to climate and water levels. Because only one sample was collected before the removal of the dam and one sample collected after the dam removal and because fish assemblages can vary quite a bit naturally, there are no discernible changes in the fish assemblage related to the removal of Good Hope Mill Dam.

Aquatic Habitat

Aquatic habitat (habitat) as used in this report refers to the instream and riparian features that affect the structure and function of the aquatic community (Barbour and others, 1999). Habitat quality is assessed on the basis of 13 criteria that include physical, vegetative, and channel-morphology characteristics. Each criterion is scored separately, and the sum of all the scores represents a measure of the overall habitat quality at a given site. Because the scoring of each criterion is subjective, minor changes in the habitat-criteria scores (two or three points) from one sampling event to another are common and may not be indicative of any change. Larger differences (5 to 10 points) may result from a change in habitat and may be accompanied by a response in the benthic-invertebrate community. Response to habitat change is generally more detectable in benthic invertebrates than in fish, because invertebrates are relatively sessile compared to fish, which tend to be mobile.

Habitat at stations 2 and 5 had few changes, and those that did occur were related to site-specific conditions rather than dam removal. For example, the landowner at station 2 cleared some small trees and herbaceous plants on the banks that caused the vegetative-protection criteria to decrease between the November 2001 and November 2002 sampling events (table 6). Conversely, the riparian vegetative zone widths increased at station 5 because bank-protecting vegetation was allowed to grow (table 6). This vegetation growth, along with improvement in velocity/depth regime, channel-flow status, and frequency of riffles caused the total habitat score at station 5 to increase by 12 percent between November 2001 and November 2002. Epifaunal substrate decreased from optimal to sub-optimal and embeddedness ranged between sub-optimal and optimal.

Habitat changes related to dam removal occurred at station 3 and, to a lessor extent, station 4. Before dam removal, epifaunal substrate/available cover at station 3 consisted of woody debris that had piled up behind the dam and along the periphery of the channel (fig. 2). Benthic invertebrates typically favor woody debris over bedrock that was exposed in many locations behind the dam. Because much of the woody debris was removed with the dam, the score for epifaunal substrate/available cover dropped from optimal to poor (table 6). In contrast, the velocity/depth regime and riffle frequency scores improved from poor to suboptimal as the creek changed from a lentic to a lotic condition. Increasing velocities generally are associated with mobilization of fine sediment that would normally decrease embeddedness (increase the embeddedness score) and make more surface area available to invertebrates. However, the embeddedness score increased between November 2001 and 2002. This increase may be the result of difficulty in determining embeddedness when the reach was impounded (November 2001) rather than an actual change. Regardless, by November 2002 both riffle and pool habitat types existed within the former impoundment providing conditions preferable to a wider range of benthic invertebrate taxa.

Table 5. Fish taxa list and number of individuals in Conodoguinet Creek before and after removal of Good Hope Mill Dam, Cumberland County, Pennsylvania.

[Locations of stations are shown on figure 1; +, indicates additional individuals were present but could not be counted due to decay. Numbers preceding the + represent a partial count]

Scientific name	Common name	Number of individuals							
		Station 2 2.5 miles upstream of dam		Station 3 115 feet upstream of dam		Station 4 126 feet downstream of dam		Station 5 4.5 miles downstream of dam	
		Aug. 1, 2001	July 30, 2002	July 30, 2001	July 31, 2002	July 31, 2001	July 29, 2002	Aug. 2, 2001	July 29, 2002
Campostoma anomalum	central stoneroller	0	1	0	0	0	0	0	0
Cyprinella spiloptera	spotfin shiner	12	15	1+	6	8	7	0	0
Cyprinus carpio	common carp	0	0	4	8	1	0	0	0
Exoglossum maxillingua	cutlilps minnow	71	54	0	4	9	22	0	1
Luxilus cornutus	common shiner	15	29	4+	5	0	8	0	0
Nocomis micropogon	river chub	1	25	0	0	2	1	0	0
Notropis hudsonius	spottail shiner	21	80	1+	75	36	36	0	3
Notropis rubellus	rosyface shiner	0	13	1+	1	0	0	0	0
Pimephales notatus	bluntnose minnow	5	25	0	23	19	26	0	0
Rhinichthys cataractae	longnose dace	8	3	0	0	3	0	0	0
Semotilus atromaculatus	creek chub	0	0	0	0	1	0	0	0
Semotilus corporalis	fallfish	0	0	0	0	0	1	0	0
Catostomus commersoni	white sucker	2	22	88	15	29	1	1	0
Hypentelium nigricans	northern hog sucker	6	4	0	0	0	0	0	0
Ameiurus natalis	yellow bullhead	13	16	4	16	12	9	18	6
Ameiurus nebulosus	brown bullhead	0	0	4	0	0	0	4	0
Ictalurus punctatus	channel catfish	0	0	0	1	0	1	0	3
Noturus insignis	margined madtom	18	11	0	0	2	0	0	0
Oncorhynchus mykiss	rainbow trout	0	2	0	0	0	0	0	0
Fundulus diaphanus	banded killifish	3	12	1+	29	2	8	0	5
Cottus bairdi	mottled sculpin	0	1	0	0	0	0	0	0
Cottus cognatus	slimy sculpin	29	28	0	0	0	0	0	0
Ambloplites rupestris	rock bass	93	486	208	254	243	237	26	77
Lepomis auritus	redbreast sunfish	28	90	136	94	9	28	2	2
Lepomis cyanellus	green sunfish	0	0	2	0	0	0	0	0
Lepomis gibbosus	pumpkinseed	0	0	4	1	0	0	0	0
Lepomis macrochirus	bluegill	0	0	1	6	0	1	1	0
Micropterus dolomieu	smallmouth bass	17	31	70+	17	65	11	9	7
Micropterus salmoides	largemouth bass	0	1	6	0	0	0	0	0
Etheostoma blennioides	greenside darter	13	55	1+	15	47	70	0	11
Etheostoma olmstedi	tesselated darter	352	56	1+	24	87	55	0	32
Etheostoma zonale	banded darter	172	39	0	7	99	10	0	11
Percina peltata	shield darter	1	12	0	0	4	0	0	0
Total		880	1,111	531+	601	678	532	61	158

Table 6. Rapid bioassessment habitat scores characterizing the quality of aquatic habitat before and after removal of Good Hope Mill Dam from Conodoguinet Creek, Cumberland County, Pennsylvania.

[Good Hope Mill Dam removed over a 3-day period beginning November 2, 2001, at 10:00 a.m. eastern standard time; Locations of stations are shown on figure 1]

Site name and date	Rapid Bioassessment Habitat Criteria and Scores													
	Epifaunal substrate/ available cover	Embedded-ness	Velocity/ depth regime	Sediment deposition	Channel-flow status	Channel alteration	Frequency of riffles	Bank stability left bank	Bank stability right bank	Vegetative protection left bank	Vegetative protection right bank	Riparian vegetative zone width left bank	Riparian vegetative zone width right bank	Total site score
Station 2														
Sep. 18, 2001	16	18	18	19	18	15	10	9	7	3	1	1	1	136
Nov. 20, 2001	19	18	15	19	18	15	13	8	6	8	6	1	1	147
Nov. 25, 2002	15	15	19	18	19	19	13	9	9	0	1	0	1	138
Station 3														
Sep. 19, 2001	18	13	0	17	19	1	0	8	6	5	5	3	1	96
Nov. 19, 2001	7	1	8	18	15	18	7	9	9	2	2	2	1	99
Nov. 25, 2002	3	2	12	10	19	15	5	9	9	8	5	7	2	106
Station 4														
Sep. 18, 2001	17	15	10	18	19	6	5	9	8	6	6	1	1	121
Nov. 19, 2001	13	17	10	18	15	17	11	9	8	5	5	1	1	130
Nov. 25, 2002	12	8	19	12	20	16	13	9	9	1	1	1	2	125
Station 5														
Sep. 18, 2001	18	8	10	18	18	15	5	9	10	9	9	2	7	138
Nov. 19, 2001	12	17	10	18	15	15	9	8	9	7	7	1	7	135
Nov. 25, 2002	13	10	18	15	19	15	10	9	9	8	10	6	10	152

The density of benthic invertebrates sampled at station 3 successively increased in samples collected 17 days and about 12 months after dam removal (773 and 3,374 animals/m^2, respectively) compared to density before removal (462 animals/m^2; table 4). This increase may have occurred because, after dam removal, invertebrates that preferentially colonize riffle habitat, such as many of the EPT taxa, could co-occur with taxa that prefer nearby pools. The increase in EPT taxa and HFBI about 12 months after removal (table 4) is indicative of the higher velocity/depth regime at station 3 in November 2002.

The response of the fish assemblage to changes in habitat at station 3 is difficult to determine because of the mobility of fish. However, the number of darter species, which prefer relatively high velocity/depth regimes, increased after dam removal. Sucker and smallmouth bass, species with a tolerance for impounded conditions, decreased. The dominance of red-breast sunfish and rock bass did not change.

The reach of Conodoguinet Creek in the vicinity of station 4 had fewer dam-related changes in habitat. The epifaunal substrate/available cover habitat scores decreased slightly from optimal to suboptimal and embeddedness increased slightly within a year of the dam being removed (table 6). The velocity/depth regime score probably increased because of higher flows in November 2002 than during previous sampling events not because the dam was removed. During the first sampling event after the dam was removed, no change in embeddedness or sediment deposition at station 4 could be determined; however, the following year embeddedness and sediment deposition increased (reflected by a decrease in the embeddedness and sediment-deposition scores). Both scores went from optimal to suboptimal/marginal. Channel-flow status was optimal except for November 2001 where it dipped to suboptimal. The channel alteration and frequency of riffle scores increased from marginal to optimal right after the dam was removed. The vegetative bank-protection score decreased from sub-optimal/high marginal to poor between November 2001 and November 2002. The other scores stayed within the same scoring criteria of poor or marginal.

Limitations of the Study

The primary limitations of this study fall into three general categories: 1) limitations of a short-term timeframe; 2) limitations associated with the reach of Conodoguinet Creek that was studied; and 3) limitations associated with atypical hydrologic conditions. This study examined the short-term effects of removing Good Hope Mill Dam from Conodoguinet Creek. It may not be appropriate to extrapolate the findings presented in this report to a longer timeframe. The spatial extent of this study is approximately 10 mi of Conodoguinet Creek extending from station 1 to station 5 with the most concentration on the 7.5-mi reach between stations 2 and 5 (fig. 1). Sampling stations located where the greatest effects of dam removal were anticipated may not have captured all of the effects; changes to the channel banks, water quality, benthic-invertebrate community, fish assemblage, and (or) aquatic habitat may have taken place between or beyond the sampling stations. If so, these changes were not captured by the data collected for this study.

Below-average precipitation during much of the study period resulted in streamflows that were much lower than historical means during most, but not all, data-collection activities. For example, streamflow during dam removal, the timeframe when the most dramatic response was anticipated, was less than 20 percent of mean annual flow. Redistribution of sediment within and downstream of the impoundment and streambank erosion may have been more severe under normal or high-flow conditions.

The first two benthic-invertebrate samples were collected under similar low-flow conditions (streamflow ranged from 70 to 75 ft^3/s) allowing access to all substrate. During the third and final collection, streamflow was approximately 10 times greater, rendering some of the substrate that was previously sampled inaccessible. Consequently, the third sample may not be entirely representative of the number of individuals or taxa that were present.

Summary and Conclusions

The U.S. Geological Survey (USGS) and the Pennsylvania Sate University (PSU), in cooperation with the Conodoguinet Creek Watershed Association, led an investigation from July 2001 to October 2003 to evaluate the effects of removing Good Hope Mill Dam on channel characteristics, water quality, benthic invertebrates, fish, and aquatic habitat in Conodoguinet Creek, Cumberland County, Pa. The 6-ft high, 220-ft wide dam was demolished and removed over a period of 3 days beginning with an initial breach on November 2, 2001, at 10:00 a.m. eastern standard time. Data were collected before and after dam removal at five specific locations (stations) and over selected reaches upstream, within, and downstream of the impoundment. Stations 1, 2, and 5 were free-flowing control sites where no response to dam removal was anticipated (4.9 mi upstream, 2.5 mi upstream, and 5 mi downstream of the dam, respectively). Stations 3 and 4 were located where the largest responses were anticipated (115 ft upstream and 126 ft downstream of the dam, respectively).

Data for evaluation of channel morphology, bed-particle-size distribution, benthic invertebrates, and aquatic habitat were collected once before dam removal and twice after removal between July 2001 and October 2003. Fish-assemblage surveys were conducted by PSU in August 2001 and July-August 2002. Water temperature, dissolved-oxygen concentration, pH, specific conductance, and turbidity were measured continuously (15-minute intervals) from August 30, 2001, to January 8, 2002. Samples for nitrogen, phosphorus, and suspended sediment were collected before, during, and after dam removal between July 20, 2001, and January 25, 2002.

Surveyed elevations of the thalweg and water surface through the impoundment indicate Good Hope Mill Dam was not an effective barrier to sediment transport. Thus, the majority of bedload and suspended sediment carried by Conodoguinet Creek before dam removal was transported over the dam. A thin coating (2-3 in.) of sediment in the silt/clay size range (<0.062 millimeters) was mobilized from the impoundment in the 23 months after dam removal, but this did not change the elevation of the thalweg within the impoundment or in the reach downstream of the dam. Erosion-resistant bedrock in the impoundment was not subject to degradation during or after removal, and large-scale aggradation downstream of the dam, a commonly reported result of other dam removals, did not take place because the impoundment did not have a large sediment supply. Cross-sectional dimensions at stations 2 through 5 changed little throughout the study. Cross-sectional area at stations 3 and 4 measured 17 days and 23 months after dam removal was within 3 percent of the area measured before removal.

Pebble-count data indicate that some silt/clay was initially entrained from station 3 during dam removal and deposited at station 4, the first riffle downstream of the dam. This deposition merely coated the substrate. Remaining sediment at station 3 and deposition at station 4 were transported downstream by subsequent streamflows (daily mean ranged from 38 to 5,810 ft^3/s between November 19, 2000, and October 3, 2003). As a result, the particle distribution at station 3 was coarser 23 months after removal, and the distribution at station 4 reverted to pre-removal conditions.

Water chemistry within the impoundment upstream of the dam was dominated by the chemistry of inflow from upstream rather than by chemical and physical processes common to larger impoundments and reservoirs. Daily mean values reported from September to December 2001 indicate removal of the dam had either no effect on temperature, dissolved oxygen, pH, and specific conductance, or the effect was so small it was masked by seasonal and periodic variability. Measurements of these constituents on a shorter time scale (every 15 minutes) indicate that although diel cycles of light and dark control temperature, dissolved-oxygen concentration, pH, and specific conductance, Good Hope Mill Dam affected the range and variability of some water characteristics.

Impounded conditions did not affect daily dissolved-oxygen concentration and pH extremes but suppressed the daily range of temperature and fluctuations of specific conductance. Before dam removal, daily extremes of temperature, dissolved oxygen, pH, and specific conductance at station 2 were out of phase by approximately 12 hours with station 3. Once the dam was removed, the pattern of constituents at station 3 shifted and converged with the pattern at station 2. The offset before removal may be related to a lag time resulting from a decrease in velocity through the impoundment.

Total nitrogen and suspended-sediment concentrations increased upon the initial dam breach but were well within the range of concentrations measured over a range of flow events at station 1. Concentrations of total nitrogen measured at station 1 between March 2001 and April 2002 ranged from 2.39 to 4.92 mg/L (number of samples (n) = 20). Concentration of total nitrogen at station 4 was 4.66 mg/L upon the initial breach of the dam; an increase of approximately 0.5 mg/L compared to concentrations measured shortly before removal (range before removal = from 3.92 to 4.19 mg/L; n=2). Mobilization of reduced forms of nitrogen, mainly NH_4^+, did not cause an appreciable decrease in dissolved-oxygen concentration in the reach downstream of the dam.

Suspended-sediment concentrations during removal were not extreme when considered in the context of longer-term data collected over 12 months at station 1. Suspended sediment at the Hogestown streamflow-gaging station (01570000) ranged from 1.0 to 490 mg/L between March 1, 2001, and April 31, 2002, compared to a range of 2.8 to 98 mg/L during dam removal. Correlation between flow and sediment data indicates the flow events re-occurring from less than 1 to 1.5 years (1,100-5,900 ft^3/s) are likely to have suspended-sediment concentrations similar to the maximum concentration measured during dam removal.

Dam removal did not appreciably alter the downstream benthic-invertebrate community in the vicinity of stations 4 or 5. In contrast, there was a short-term shift at station 3 from predominantly *Gammarus* amphipods and *Tanytarsus* midges before removal to more Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa 2 weeks after removal. This shift may be the result of differing sampling methods used before and after dam removal. Alternatively, *Caenis* and other EPT taxa may have exploited previously unoccupied riffle habitat that was created by dam removal. Approximately 12 months after dam removal, the benthic invertebrate community at station 2 was comparable to the other free-flowing reaches; dominance switched from *Caenis* to *Gammarus*, and the midge composition was characterized by more nutrient intolerant species.

The changes observed in the fish assemblage between the two sample periods are not beyond the scope of natural fluctuations in fish assemblages in rivers related to climate and water levels. Because only one sample was collected before dam removal and one sample after dam removal and because fish assemblages vary naturally, the fish assemblage showed no discernible changes related to the removal of Good Hope Mill Dam.

The nature and magnitude of physical, chemical, and biological effects related to dam removal are likely to depend on dam size, geologic setting, sediment accumulation, hydrologic conditions during removal, and other stream and watershed characteristics. The findings presented in this report are transferable to other dam removals to the extent that dam and stream characteristics are similar to those encountered in this study. Futures studies of dam removals over a range of settings and sizes could document effects that help guide management decisions and maximize the effectiveness of stream restoration projects.

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