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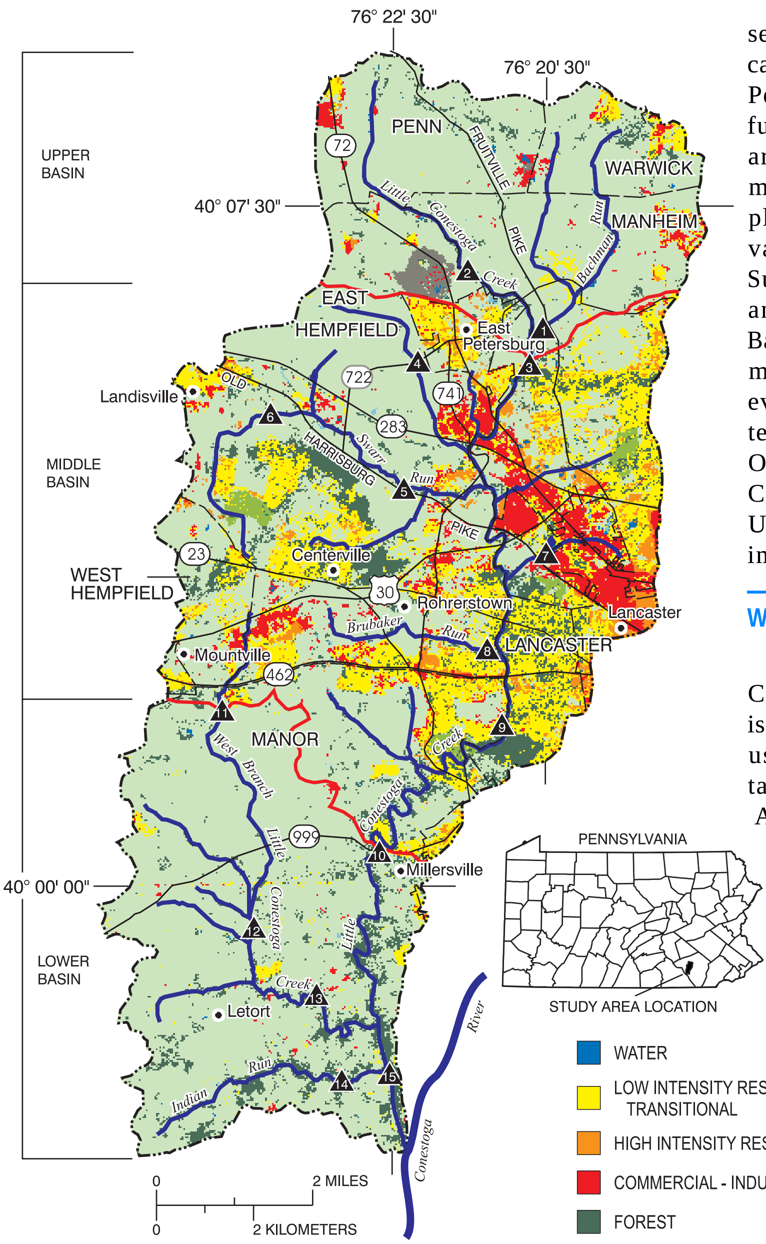
A Snapshot Evaluation of Stream Environmental Quality in the Little Conestoga Creek Basin, Lancaster County, Pennsylvania

A Cooperative Project Between the Residents of Lancaster County, the Alliance for the Chesapeake Bay, and the U.S. Geological Survey

WHY STUDY THE LITTLE CONESTOGA CREEK?

Many Lancaster County residents are interested in stream monitoring and habitat restoration to maintain or improve stream water quality and to keep contaminants from reaching ground water used to supply drinking water. To promote resident involvement and environmental stewardship, the Alliance for the Chesapeake Bay (ACB) and the U.S. Geological Survey (USGS) designed this “snapshot” study of water quality and aquatic-insect communities in the Little Conestoga Creek Basin. Citizen-based restoration programs can improve water quality at a local level; such efforts will ultimately improve the ecological integrity of the Lower Susquehanna River and the Chesapeake Bay.

The Little Conestoga Creek Basin (fig. 1) was studied for several reasons. It was felt the project should benefit Lancaster County residents because funding was provided by Pennsylvania Department of Environmental Protection funds generated in Lancaster County. The small drainage area size, 65.5 mi^2 (square miles), allowed resident involvement in the necessary training and the snapshot sampling plan. Also, a previous study within south-central Pennsylvania reported the highest nutrient yields entering the Susquehanna River are contributed by the Conestoga River and its tributary subbasins (Ott and others, 1991), and the Basin’s location within the Conestoga River watershed made it a potential contributor of high nutrient loads. However, few data had been collected in this Basin to characterize the water quality and aquatic-insect populations. Ongoing studies by a “stream team” from Lancaster County Academy and by students and staff at Millersville University did not fully document the level of stream impairment throughout the Basin.



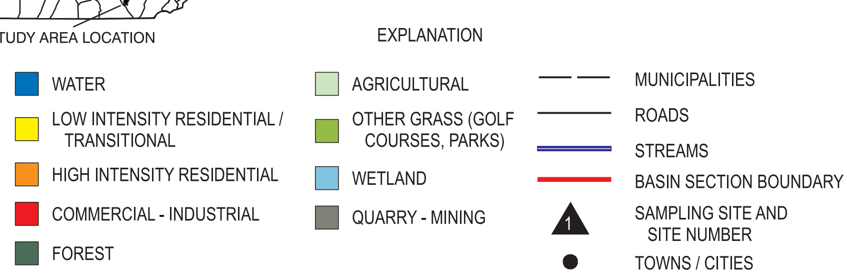


Figure 1. Location of Little Conestoga Creek Basin, major streams, sampling sites, urban areas, land use, major roads, and municipal boundaries.

WHAT ARE THE BASIN’S KNOWN CHARACTERISTICS?

The Little Conestoga Creek Basin is in Lancaster County, south-central Pennsylvania. Agricultural intensity is fairly uniform in the upper and lower basins, where land use is usually greater than 80 percent agriculture (fig. 1, table 1) (U.S. Environmental Protection Agency, 1994). About 90 percent of the Basin is underlain by fractured carbonate bedrock. Carbonate rock weathers easily to create rich topsoil for agriculture and maintains excellent filtration capacities. Contaminants and ground water move quickly through the carbonate bedrock, especially in fractures enlarged by dissolving rock.

Stream water in the Basin is used for irrigation, livestock, and commercial operations; Little Conestoga Creek is not used for public supply. Municipal water systems, which use water from wells and from the Conestoga and Susquehanna Rivers, serve approximately 83 percent of the residents in the Basin; the remaining 17 percent relies on private wells for drinking water.

Streams in the Basin receive discharges from several sources, including industries with National Pollution Discharge Elimination System (NPDES) permits, stormwater, and filtration-unit backwash from public water supply treatment plants. Discharges from these sources probably have little effect on the total nutrient load to the Basin because of their low nutrient content or the sporadic timing of the discharge.

Table 1. Total area and percentages of land use and carbonate bedrock in the sampled subbasins and the entire Little Conestoga Creek Basin, Lancaster County, Pa.

[mi^2, square miles; upper basin - yellow, middle basin - green, lower basin - blue]

Site number on figure 1	Stream	Drainage area, in mi^2	Land use classifications[1] (percentage of subbasin)			Percentage of carbonate bedrock
			Agriculture	Urban	Forest	
1	Bachman Run	6.2	85	10	4	83
2	Little Conestoga Creek	6.5	87	5	3	83
3	Little Conestoga Creek	14.0	86	8	4	86
4	Unnamed tributary to Little Conestoga Creek	1.0	86	12	1	100
5	Swarr Run	7.2	68	19	12	71
6	Unnamed tributary to Swarr Run	3.6	63	27	10	75
7	Unnamed tributary to Little Conestoga Creek	2.0	9	82	7	100
8	Brubaker Run	2.7	58	34	8	100
9	Little Conestoga Creek	41.2	61	30	9	88
10	Little Conestoga Creek	46.2	61	29	9	89
11	West Branch Little Conestoga Creek	2.0	61	32	7	50
12	West Branch Little Conestoga Creek	7.3	86	9	4	86
13	West Branch Little Conestoga Creek	11.6	89	7	4	92
14	Indian Run	2.9	84	1	14	67
15	Little Conestoga Creek	64.9	68	22	9	89
--	Little Conestoga Creek (at mouth)	65.5	68	22	10	89

[1] Sums of percentages of land use in subbasins may not equal 100 percent because water, quarries, mines, and wetlands were not included in these categories. Data from U.S.Environmental Protection Agency Landsat Thematic Mapper mosaic (created from flight-line images taken in 1990 and 1993). Urban percentages are a sum of percentages for low intensity and high intensity residential, commercial-industrial, transitional, and other grass.

Little Conestoga Creek Basin between sampling sites 9 and 10, showing agricultural and suburban land uses (1997 photograph, courtesy of Lancaster Inter-Municipal Committee).

HOW WAS THE STUDY CONDUCTED?

Water samples for nutrient analysis and samples of aquatic insects were collected at 15 sites on Sept. 13, 1997, by two teams of three or more volunteers with assistance from ACB and USGS staff. The USGS measured streamflow immediately after water-quality samples were collected. The aquatic insects were collected at each site following USEPA Rapid Bioassessment Protocols II (Plafkin and others, 1989). Because of the inadvertent use of different sampling equipment by the two teams, Sites 1-7 were resampled for aquatic insects on Sept. 17-18 to ensure consistency in the data set.

One hundred organisms were randomly selected from each aquatic-insect sample and sorted to order level by use of invertebrate flashcards (Stroud Water Research Center of the Academy of Natural Sciences of Philadelphia, 1994) and an invertebrate key (Bode and others, 1997) by Lancaster County Academy and Millersville University students. Taxonomic identification to family level was completed by a USGS biologist.

Water samples for analyses of dissolved nutrients [ammonia-nitrogen (N), nitrite-N, nitrite plus nitrate-N, ammonia plus organic-N, phosphorus (P), and orthophosphate] and total nutrients (ammonia plus organic-N and phosphorus) were chilled and sent by overnight mail to the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo. NWQL analytical methods for nutrient determinations followed procedures in Fishman and Friedman (1989). References to concentrations or loads of nitrate and ammonia will actually be the weight of nitrogen in those compounds. Hereafter, ammonia-N will be called “ammonia,” and dissolved nitrite plus nitrate-N will be referred to as “nitrate” because all samples contained less than 0.05 mg/L (milligrams per liter) nitrite and are, therefore, predominantly nitrate. Concentrations or loads of total phosphorus will be referred to as “phosphorus” for brevity.

All sites except Site 15 in the Basin were probably near or at base-flow conditions (no recent precipitation) when sam-

What are Nutrients?

Nutrients are chemical elements and compounds in the environment that living things use to create new cells for growth and reproduction. Nutrients analyzed for this study include several forms of nitrogen (N) and phosphorus (P) in water.

Sampling team [USGS biologist (left) and volunteers] removing aquatic-insect specimens from a kick net at agricultural site.

What are Aquatic Insects?

Aquatic insects are insects that spend part or all of their life in aquatic environments and are important links in the aquatic food chain. Some species of aquatic insects that spend only their immature stage in streams, such as mayflies, stoneflies, or caddisflies, are extremely sensitive to pollution; others, such as midges, are pollution-tolerant.

(Clip art from the University of Illinois at Urbana-Champaign, Department of Entomology Archive)

Mayfly

Stonefly

ples were collected on Sept. 13. Approximately 1.5 inches of precipitation, recorded at USGS precipitation gages near the Basin, fell on Sept. 10-11. Streamflow conditions were evaluated by reviewing the record of flow at the nearest USGS streamflow-measurement site, Mill Creek near Lyndon, Pa., and by using hydrologic calculations (Viessman and others, 1977). These tools indicated that streamflow at Mill Creek (drainage area = 54.2 mi^2) was approximately 20-30 percent above base-flow levels on Sept. 13. All sites except Site 15, however, have smaller drainage areas than Mill Creek, which would result in a quicker return to base flow at these sites. Samples were collected at base flow because (1) lower flows create a safer stream environment for sampling, (2) during base-flow conditions, ground water (which is used for human and livestock consumption) is the primary component of streamflow, and (3) comparison of water chemistry between sites is more reliable if variability in stream chemistry caused by stormflow is removed.

WHAT QUALITY-ASSURANCE MEASURES WERE USED?

Each team collected an additional stream sample (replicate) to evaluate repeatability and prepared a sample of laboratory deionized water to evaluate effectiveness of the sampling equipment cleaning procedure between sites. This quality-assurance data indicated that the cleaning procedure was highly effective, and there was excellent precision between replicates.

Volunteer decontaminating sampling equipment after water-quality sample processing at Site 8.

Teams also collected a replicate aquatic-insect sample at Sites 3 and 11 to evaluate the sampling consistency. The replicate samples at Site 3 revealed little difference; eight of nine different kinds of organisms collected in the original sample were present in the replicate. The aquatic-insect impairment assessment of the site was the same using either data set. Organisms in the samples from Site 11 were more variable. Only 5 of the 12 kinds of organisms collected in the original sample were present in the replicate. The sites assessed as severely impaired (Sites 2, 7, and 12) would have been assessed as moderately impaired if the replicate sample was used in the data analysis.

The USGS biologist rechecked taxonomic identifications on a second 100-organism subsample from Sites 5 and 8 to compare with the initial identifications. The comparison showed discrepancies between samples processed by volunteers and samples processed by the USGS biologist. Five more kinds of organisms were identified in both samples processed by the USGS biologist. The aquatic insects missed by the volunteers were generally small and difficult to see without magnification, but few were pollution sensitive.

HOW WERE THE DATA ANALYZED?

The concentrations of total N [(ammonia plus organic, total) + (nitrate)] and total P in water samples were used to determine the relative degree of nutrient impairment at each sampling site by use of the following formulas:

$$\frac{\text{total N concentration}}{\text{highest sampled total N concentration in basin}} + \frac{\text{total P concentration}}{\text{highest sampled total P concentration in basin}} = \text{site nutrient impairment value}$$

$$\frac{\text{site nutrient impairment value}}{\text{highest site nutrient impairment value for all sites sampled}} \times 100 = \text{relative degree of nutrient impairment}$$

(where N is nitrogen and P is phosphorus)

Aquatic-insect communities are useful indicators of the environmental quality of streams because many species have limited migration patterns or sedentary life styles, and, therefore, integrate the environmental conditions that are present in the stream over time (Plafkin and others, 1989). Seven aquatic-insect community measurements were calculated and combined by use of formulas in Plafkin and others (1989) to compute a “bioassessment,” a single number that quantifies the degree of impairment of the aquatic-insect community for each site. Relative degree of impairment of aquatic-insect communities was calculated as (1.0 – Bioassessment) × 100. Site 11 was used as the reference site for the aquatic-insect analyses because it was the least-impaired site based on water-quality and aquatic-insect data.

What Constitutes Impaired Water Quality?

Impaired water quality means the water chemistry or surrounding habitat is not ideal for the health of aquatic life, animals, or humans consuming the water. Streams flowing through undisturbed forested areas can have “zero” degree of impairment; dissolved nutrient concentrations are low, grasses or trees line stream banks (buffer strips), and aquatic-insect diversity is high. Impairment can be visible (excessive algae growth, muddy water, lack of shade and buffer strips) or not as obvious (high concentrations of dissolved nutrients and low aquatic diversity).

Nutrient standards and recommendations are set to ensure good public health and thriving aquatic life. Pennsylvania has a drinking water standard of 10 mg/L (milligrams per liter) nitrate-nitrogen after filtration and treatment (Commonwealth of Pennsylvania, 1994). However, McKee and Wolf (1963) report that excessive algae can grow in ponds or lakes when nitrate concentrations exceed 0.3 mg/L provided the phosphorus concentration is at least 0.01 mg/L. The U.S. Environmental Protection Agency (USEPA) (1986) recommends that total phosphorus should not exceed 0.1 mg/L in streams not discharging directly to lakes or impoundments to prevent plant nuisances; and ammonia, the only nutrient with an established aquatic-life criterion, should not exceed 0.07 to 2.1 mg/L ammonia-nitrogen depending on water temperature and pH.

WAS POOR WATER QUALITY FOUND IN ANY PART OF THE BASIN?

The first step in determining the degree of nutrient impairment was to evaluate nitrate concentration. Nitrate concentration ranged from 2.56 to 13.2 mg/L (fig. 2) (Durlin and Schaffstall, 1998). This range is directly related to the predominant land use in the Little Conestoga Creek Basin and the associated underlying bedrock. Sites in the lower basin having greater than 80 percent agricultural land use had the highest nitrate concentrations (11.7-13.2 mg/L). Elevated nitrate concentrations, in relation to the other sites, were also measured at all the remaining predominantly agricultural (greater than 80 percent) subbasins (fig. 2). Nitrate concentration at these sites ranged from 7.31 to 9.61 mg/L. Sites 1, 12, 13, and 14 had nitrate concentrations that approximated or exceeded the nitrate drinking water standard. Nitrate in drinking water at levels in excess of 10 mg/L can result in methemoglobinemia (blue-baby syndrome) in bottle-fed infants up to 6 months old. Probably because of the predominantly agricultural land use in the Basin, nitrate concentrations were sufficiently elevated (significantly above 0.3 mg/L) to cause increased plant productivity that could lead to reduced levels of oxygen in ponds or lakes. Levels of oxygen that are too low can adversely affect or be fatal to aquatic organisms.

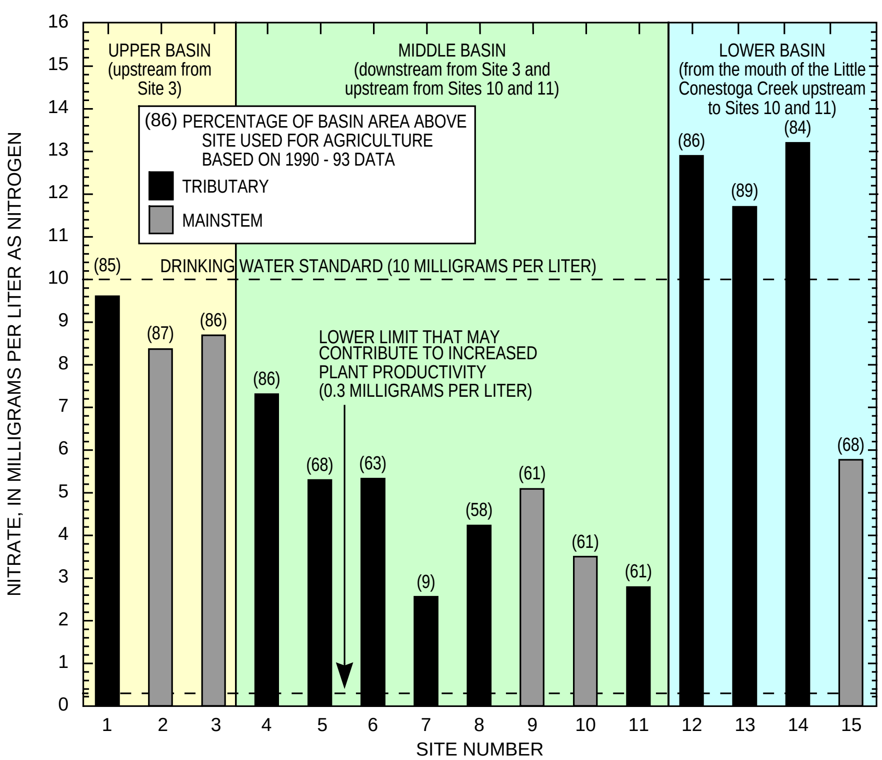


Figure 2. Nitrate concentration and percentage of basin area used for agriculture (above site) at sites sampled in the Little Conestoga Creek Basin, Lancaster County, Pa., on Sept. 13, 1997.

A comparison between nitrate data from Site 15 (5.77 mg/L) and data from a similarly located site in a 1976 base-flow study (3.96 mg/L) indicates a small positive difference in nitrate concentration (Brezina and others, 1980). Another study in 1985 measured an 8.57 mg/L nitrate concentration in the Little Conestoga Creek north of the confluence with the West Branch Little Conestoga Creek (McMorran, 1986). Other south-central Pennsylvania snapshot studies in areas of agricultural land use and carbonate rock report median nitrate concentrations of 5.7 and 7.9 mg/L (Hainly and Loper, 1997; Lindsey and others, 1997)—similar to the 5.77 mg/L median nitrate concentration from this study.

Calculations of daily loads provide information about the total amount of a constituent (nitrate, phosphorus, etc.)

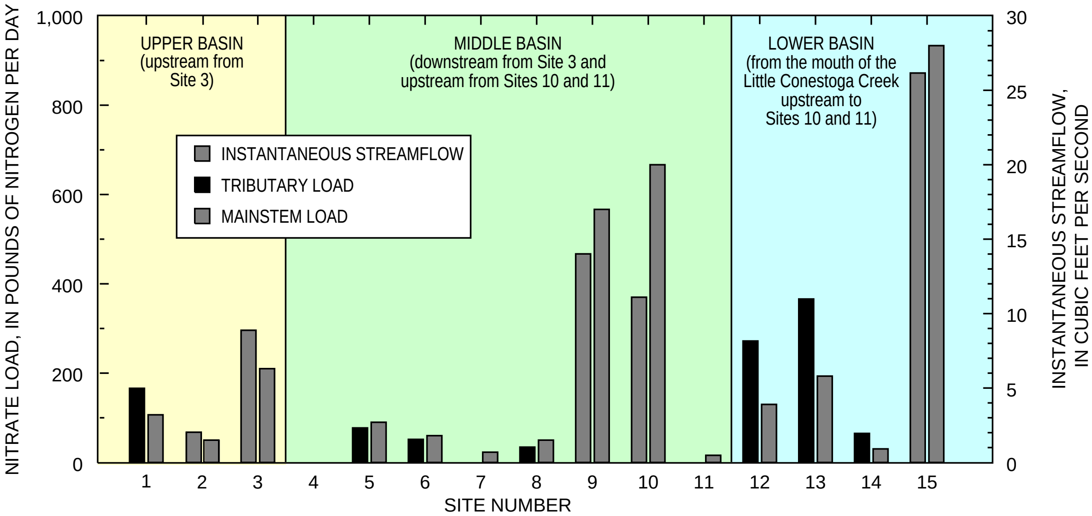


Figure 3. Nitrate loads and instantaneous streamflow at sites sampled in the Little Conestoga Creek Basin, Lancaster County, Pa., on Sept. 13, 1997.

leaving a basin in 1 day. If the concentration of a particular constituent is identical in two streams, a large stream that has a high flow will carry a larger load of that constituent than a smaller stream with a lower flow, because the larger volume of streamflow increases the load carried by that stream. Daily nitrate loads calculated from concentrations of nitrate and flow at sites in the Little Conestoga Creek Basin are shown in figure 3. Nitrate loads at mainstem sites generally increase in a downstream direction because of added streamflow and nitrate contributions from tributaries. An exception was noted between Sites 9 and 10, however, where the streamflow in the mainstem increased because of flow from an unnamed tributary, but the nitrate concentration and resulting nitrate load decreased. Data collected for this study could not explain this decrease. The highest nitrate loads from tributaries entering the Little Conestoga Creek were at Site 1 [166 lb / d (pounds per day)], Site 12 (272 lb / d), and Site 13 (366 lb / d). Even though Site 14 (Indian Run) had the highest nitrate concentration, the nitrate load was not excessive because of the relatively small streamflow.

To further characterize the degree of nutrient impairment in the Little Conestoga Creek Basin, phosphorus concentrations were evaluated. Phosphorus concentrations measured at sites in the Basin were consistently below the 0.1 mg / L recommended upper limit for total phosphorus established by USEPA (fig. 4). More than 50 percent of the total (dissolved plus suspended) phosphorus at all sites was comprised of dissolved phosphorus. This indicates that the phosphorus originated from ground-water base flow or from the flushing of dissolved phosphorus from the soil rather than from suspended phosphorus, which is bound to stream sediment.

Daily phosphorus loads (fig. 5) leaving the tributaries and mainstem of the Little Conestoga Creek Basin are small in comparison to the respective nitrate loads. The cumulative phosphorus load from Site 15, at the mouth of the Basin, was 11 lb / d. The phosphorus load nearly doubled between mainstem Sites 9 and 10 because of a rise in phosphorus concentration. The cause of this rise was not determined and may be related to several factors, such as leaking sewer pipes, fertilizer application, or stormwater runoff.

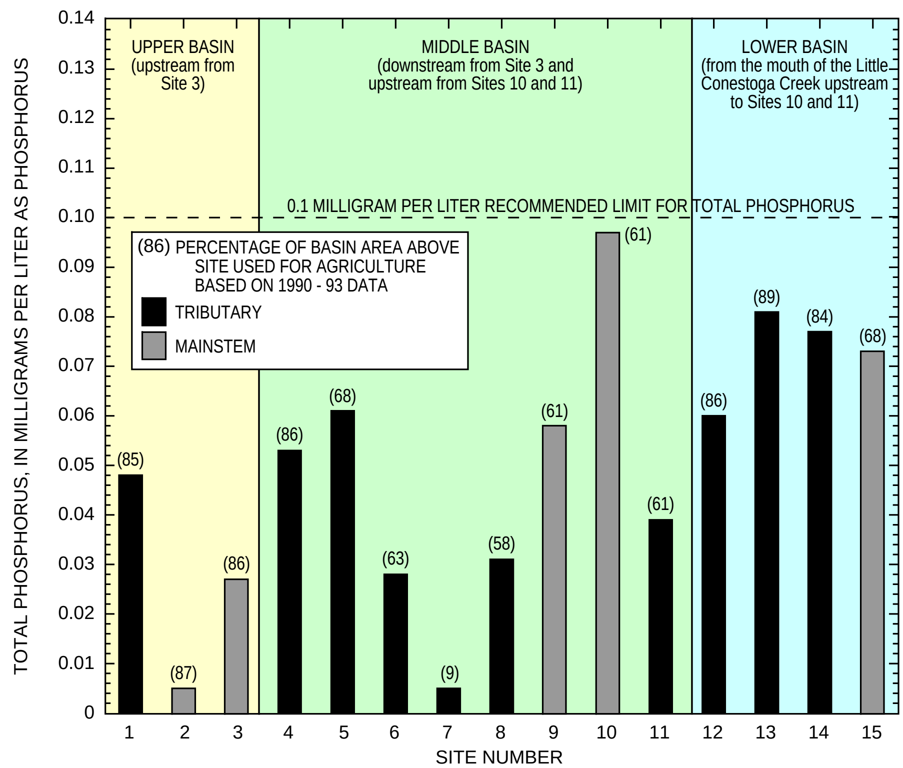


Figure 4. Total phosphorus concentration and percentage of basin area used for agriculture (above site) at sites sampled in the Little Conestoga Creek Basin, Lancaster County, Pa., on Sept. 13, 1997.

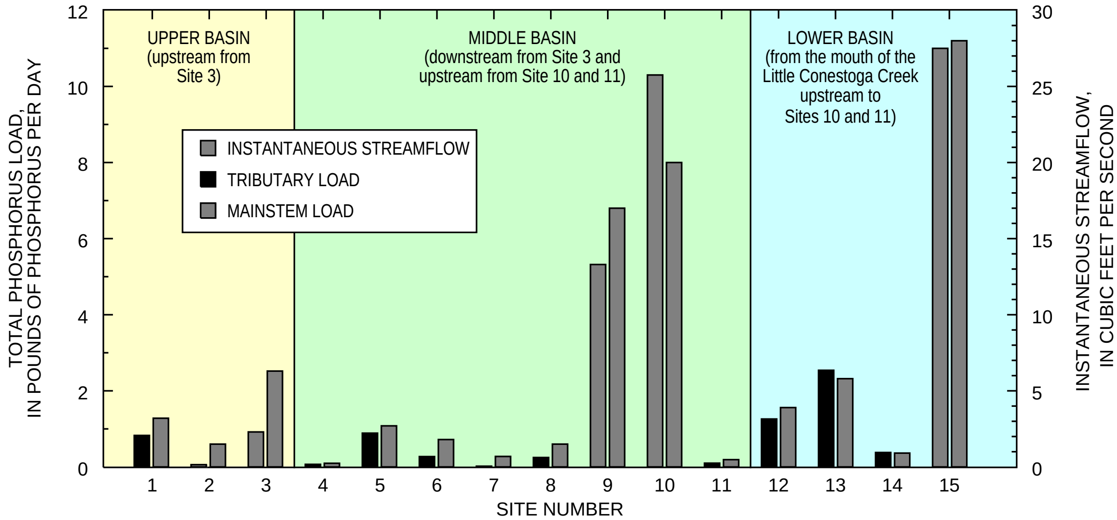


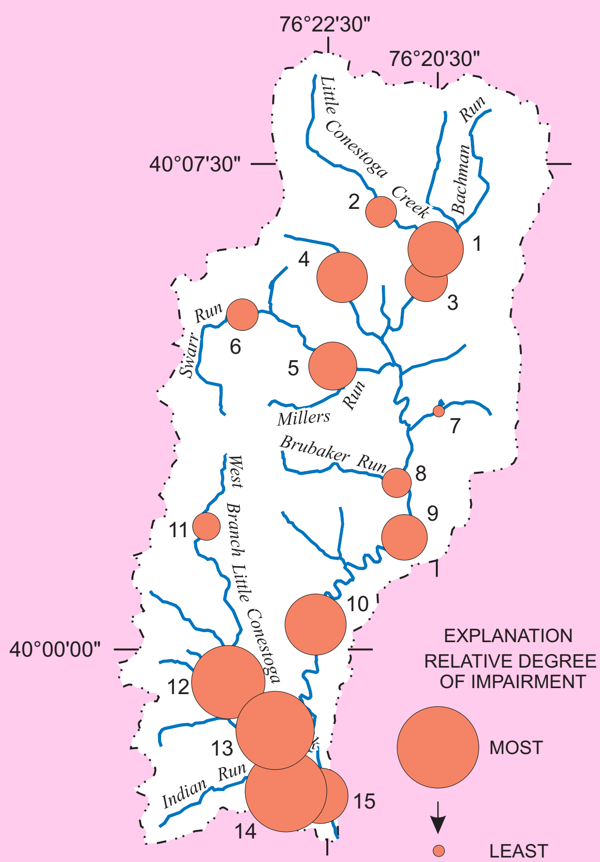
Figure 5. Total phosphorus loads and instantaneous streamflow at sites sampled in the Little Conestoga Creek Basin, Lancaster County, Pa., on Sept. 13, 1997.

Concentrations of dissolved ammonia ranged from less than 0.015 to 0.079 mg/L. Evaluation for ammonia toxicity to aquatic life at Sites 8-15 determined that ammonia concentrations were not sufficiently high to be harmful to fish.

Combining the nitrogen and phosphorus data is the final step in determining the degree of nutrient impairment. The sites having the highest relative degrees of impairment were Sites 12, 13, and 14 (fig. 6).

WHAT DO AQUATIC INSECT COMMUNITIES TELL US ABOUT STREAM ENVIRONMENTAL QUALITY?

To further evaluate stream impairment in the Basin, the "bioassessment" values determined from numbers and types of aquatic insects were used to compute the relative impairment of aquatic-insect communities (fig. 7). On the

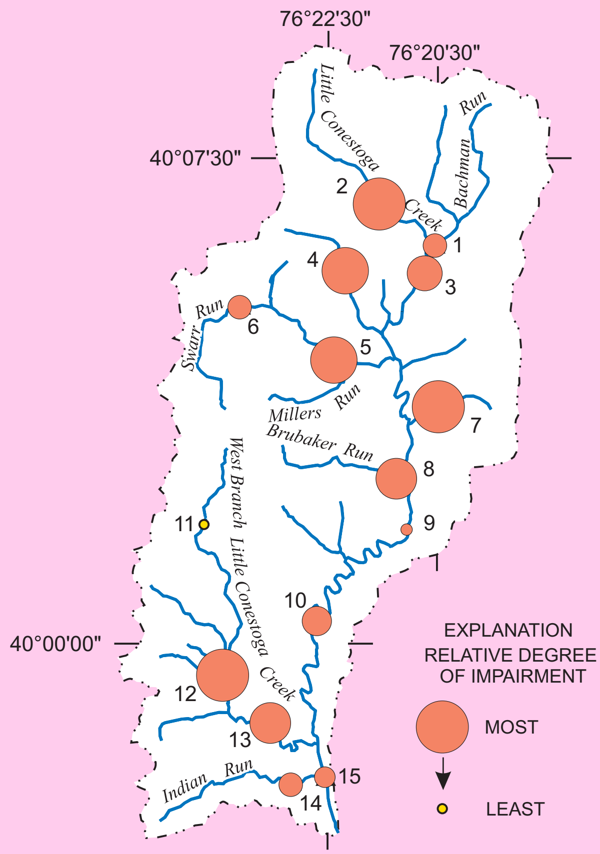


Site number on figure 1	Total nitrogen, in milligrams per liter as nitrogen	Total phosphorus, in milligrams per liter as phosphorus	Relative degree of nutrient impairment, as a percentage of most impaired nutrient water quality
1	9.88	0.048	68
2	8.60	[1]<.01	38
3	8.90	.027	52
4	7.60	.053	62
5	5.85	.061	59
6	5.58	.028	39
7	2.66	[1]<.01	14
8	4.50	.031	36
9	5.42	.058	56
10	4.04	.097	72
11	2.89	.039	34
12	13.30	.060	90
13	12.06	.081	96
14	13.46	.077	100
15	6.21	.073	68

[1] Set to 0.005 for use in calculations.

Figure 6. Relative degree of nutrient impairment, as percentage of most impaired nutrient water quality, at sites sampled in the Little Conestoga Creek Basin, Lancaster County, Pa., on Sept. 13, 1997.

basis of the results, Sites 2, 7, and 12 have the most impaired aquatic-insect communities. It is important to note, however, that even the least-impaired site (Site 11) showed some signs of environmental stress. Previous studies in south-central Pennsylvania showed as many as 27 kinds of organisms present at sites with good water quality (Brezina and others, 1980; McMorran, 1986). At the least-impaired site, only 12 kinds of organisms were present. Additionally, only 2 of the 12 kinds of organisms were sensitive to pollution. In fact, no site had more than three pollution-sensitive varieties, indicating that relatively impaired aquatic-insect communities exist throughout the Little Conestoga Creek Basin.



Site number on figure 1	Bioassessment	Relative degree of impairment of aquatic-insect community, in percent[1]
1	0.714	29
2	.357	64
3	.571	43
4	.429	57
5	.429	57
6	.714	29
7	.357	64
8	.500	50
9	.857	14
10	.643	36
11	1.000	0
12	.357	64
13	.500	50
14	.714	29
15	.785	22

[1] Relative to the least-impaired aquatic-insect community (Site 11), the smaller the percentage, the better the condition of the aquatic-insect community.

Figure 7. Relative degree of impairment of aquatic-insect community, in percent, at sites sampled in the Little Conestoga Creek Basin, Lancaster County, Pa., on Sept. 13, 1997.

WHAT WERE THE CONCLUSIONS FROM THE STUDY?

✥ *An important goal of this project was to involve local community groups in the data-collection process to facilitate communication between these groups and foster an understanding of the importance of water quality and aquatic insects for assessing stream health. From this perspective, the project was a great success.*

✥ *Phosphorus concentrations measured in the Little Conestoga Creek Basin were consistently below the 0.1 mg/L recommended upper limit for total phosphorus established by USEPA, and 80 percent of all sites sampled had nitrate concentrations below the 10 mg/L nitrate drinking water standard. Nitrate concentrations were sufficiently elevated (significantly above 0.3 mg/L) to cause increased plant productivity.*

✥ *Nitrate concentrations were the highest in basins with greater than 80 percent of the land area used for agriculture. Phosphorus concentrations did not show the same relation to percentage of agricultural land use as nitrate concentration.*

✥ *On the basis of the degree of nutrient impairment, Sites 12, 13, and 14, all in areas of predominantly agricultural land use, were the MOST impaired and had nitrate concentrations exceeding 10 mg/L. Site 7, the urban sampling site, was the LEAST impaired. However, the aquatic-insect data at Site 7 indicated high levels of impairment. The cause is unknown but may be related to water chemistry changes caused by urban runoff and industry.*

✥ *On the basis of the relative impairment of aquatic-insect communities, Sites 2 and 12, both in areas of predominantly agricultural land use, and Site 7, the urban site, were the MOST impaired. Site 11 was the LEAST impaired, even though more than half the drainage area above the site is agricultural land.*

✥ *Volunteers for any similar future snapshot evaluations need to receive more training in aquatic-insect sorting and identification. Smaller varieties of aquatic insects could easily be overlooked by inexperienced volunteers; thus, some bias in this data set may be inherent. Additional training is important to eliminate bias in determining impairment based on aquatic-insect communities.*

✥ *Combining the results of both nutrient water-quality and aquatic-insect analyses, the West Branch Little Conestoga Creek at Site 12 is the MOST impaired of the sites in the Little Conestoga Creek Basin sampled for this study. Stream impairment at this site is most likely due to nonpoint pollution from agricultural land, but this has not been quantified.*

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