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RELATION OF ALGAL BIOMASS TO CHARACTERISTICS OF SELECTED STREAMS IN THE LOWER SUSQUEHANNA RIVER BASIN

by Robin A. Brightbill and Michael D. Bilger

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CONVERSION FACTORS AND ABBREVIATIONS

MULTIPLY	BY	TO OBTAIN
	AREA	
square miles (mi^2)	2.590	square kilometers
	FLOW	
cubic feet per second (ft^3/s)	0.02832	cubic meter per second
	TEMPERATURE	
degree Celsius (°C)	°F=1.8 °C+32	degree Fahrenheit (°F)

Abbreviated water-quality units used in report:

cm/s, centimeters per second
μS/cm, microsiemens per centimeter at 25 degrees Celsius
mg/L, milligrams per liter
mg/m^2, milligrams per square meter

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ABSTRACT

Seven small tributary streams with drainage areas ranging from 12.6 to 71.9 square miles, representative of both limestone and freestone settings, in the Lower Susquehanna River Basin were sampled for algae, nutrients, water quality, habitat, land use, hydrology, fish, and invertebrates. Nutrients, site characteristics, and selected characteristics of the invertebrate and fish communities known to influence algal growth were compared to chlorophyll *a* concentrations. Nitrogen was not found limiting in these streams; however, phosphorus may have been limiting in five of the seven streams. Concentrations of chlorophyll *a* in riffles increased with the degree of open canopy and as bottom substrate reached the gravel/cobble size fraction. These increased chlorophyll *a* concentrations and the substrate size in turn raised the levels of dissolved oxygen in the streams. Freestone streams had increased chlorophyll *a* concentrations associated with increases in percentage of omnivorous fish and in pH and decreases in percentage of collector/gatherer invertebrates. Concentrations of chlorophyll *a* in limestone riffles decreased as the percentage of omnivorous fish increased. Depositional chlorophyll *a* concentrations increased as the Bank Stability Index decreased and as the riffle velocity increased. Depositional chlorophyll *a* concentrations increased in limestone streams as collector/gatherer invertebrates increased and as phosphorus concentrations decreased. No relations were seen between chlorophyll *a* concentrations and land-use characteristics of the basin.

In this study, there were too few sampling sites to establish statistically based relations between algal biomass and nutrient concentrations. Further study is needed to generate data suitable for statistical interpretation.

INTRODUCTION

The Chesapeake Bay Program re-evaluation project is a 5-year effort to provide relevant information on nutrient and sediment concentrations, trends, and loads in Bay tributary streams that can be used to assess progress in 1997 toward meeting the nutrient-reduction goal for the tributaries by the year 2000. A non-tidal component is being added to the current tidal focus of the Chesapeake Bay Program. The effort is to link non-tidal and tidal nutrient loads and show the effects of non-tidal water interactions on the Bay. A 40-percent reduction of controllable nutrient input into the Bay is the nutrient-reduction goal of the Chesapeake Bay Program. Restoration of the natural ecosystem of the Bay is the hopeful result of the nutrient input reduction process. Additional information is available from Pennsylvania's Chesapeake Bay Nutrient Reduction Strategy (Ridge and Seif, 1996).

Nutrients affect algal growth, and algae are present in both tidal and non-tidal waters. Are nutrients the controlling factor, or are there other environmental factors that control algal growth? Can algal biomass be used as an indicator of whether nutrient reduction strategies are working?

PURPOSE AND SCOPE

This report evaluates the influence of nutrient concentrations and other selected environmental characteristics on algal concentrations in streams representing seven environmental settings in the Lower Susquehanna River Basin. Data on chlorophyll *a*, nutrients and other water-quality characteristics, habitat, invertebrate community, and fish community were collected from seven long-term monitoring sites, according to the National Water-Quality Assessment (NAWQA) Program guidelines and used for the analysis. These data were collected from mid-May 1993 through early-July 1995.

The NAWQA Program and Ecological Studies

The U.S. Geological Survey's (USGS) NAWQA Program is a long-term effort to describe the status of, and trends in, the quality of the Nation's surface- and ground-water resources and to provide an understanding of the natural and human factors that affect the quality of these resources (Hirsch and others, 1988; Leahy and others, 1990). A national team was established by NAWQA for nutrient synthesis and has published several reports on nutrients in waters across the United States. These reports deal with nutrients and sediment. Representative examples are Puckett (1994), Mueller and others (1995), and Mueller and Helsel (1996). One report from the study units, the Kentucky River Basin NAWQA, included relations between algal concentrations and nutrients (Haag and Porter, 1994). Two abstracts discussing algae and nutrients in the Yakima River Basin have been published (Leland, 1994; Leland and Stallard, 1995).

NAWQA ecological studies include surveys that focus on community structure and function and habitat characteristics to assess water quality. Three taxonomic groups—algae, invertebrates, and fish—are investigated because each aquatic community responds differently to natural or anthropogenic disturbances caused by differences in habitat, food, mobility, physiology, and life history. The use of a multiple-community approach adds additional power to the design of the study; agreement, or lack thereof, between these sets of community data can be very instructive. A multiple-community approach is especially valuable in broad-scope water-quality programs. It represents a compromise between the greater sensitivity of species indicators or physiological responses to individual stresses and the lower variability, but broader response, of ecosystem processes (Gurtz, 1994).

Acknowledgments

Many colleagues have contributed to the collection and presentation of data in this paper. Steven Bogush, Harry Campbell, Andrew Gavin, Naomi Weisbeker, and Tammy Bickford (Lower Susquehanna River Basin NAWQA, U.S. Geological Survey) provided field expertise. J. Kent Crawford and Robert Hainly (U.S. Geological Survey) provided field and water-quality expertise. Guidance for data exploration was provided by Stephen Porter and Edward Koerkle (U.S. Geological Survey). The authors also recognize the guidance provided by the Lower Susquehanna River Basin Liaison Committee and the report team of Kevin Breen, James Coles, and Scott Phillips. Technical support was provided by Kim Wetzel and Steven Siwiec (U.S. Geological Survey). Finally, the authors wish to recognize the many land owners that provided access and other private citizens that assisted in various ways at the collection sites.

THE LOWER SUSQUEHANNA RIVER BASIN STUDY

The Lower Susquehanna River Basin NAWQA study collected information between 1993 and 1995 on ground water, surface water, ecology, and multiple communities (algae, invertebrates, and fish). Reports from the NAWQA Program describing the water-quality condition of the Lower Susquehanna River Basin that have been published are Lindsey and others (1997), Risser and Siwiec (1996), Hainly and Kahn (1996), Daly and Lindsey (1996), Lindsey and Ator (1996), Breen and others (1994), and Bilger and Brightbill (1998).

Description of Study Area

The Lower Susquehanna River Basin study unit includes the drainage beginning at the confluence of the West Branch and mainstem Susquehanna River at Sunbury, Pa., downstream to the Chesapeake Bay at Havre de Grace, Md. The study unit (fig. 1) consists of approximately 9,350 mi^2 of the 27,100 mi^2 that comprise the Susquehanna River watershed. A detailed description of the environmental settings that comprise the study unit are given in Risser and Siwiec (1996).

Physiography and Land Use

The Lower Susquehanna River Basin study unit contains parts of five distinct physiographic provinces: the Appalachian Plateaus, Ridge and Valley, Blue Ridge, New England, and Piedmont (Berg and others, 1989); the majority of the basin area is represented by the Ridge and Valley (68 percent) and Piedmont (29 percent) Provinces (Risser and Siwiec, 1996). These physiographic provinces have distinctive characteristics that are derived from their particular geologic framework. These characteristics give rise to distinctive landforms that result in particular types of vegetation, soils, water, and climate (Hunt, 1967). Water quality is greatly affected by these landforms because they control the distribution of precipitation and the physical pathway that surface runoff and ground water follow to the Susquehanna River. Basin relief, hillslope morphology, and stream-drainage pattern influence the residence time of runoff from soil, rocks, and vegetative cover—all factors that affect the sediment and natural chemical composition of surface and ground waters in the basin.

Ecoregions are areas of relative homogeneity in the components of their ecological systems and are defined in part by the associated physiography. Factors associated with spatial differences in the quality and quantity of ecosystem components include soils, vege-

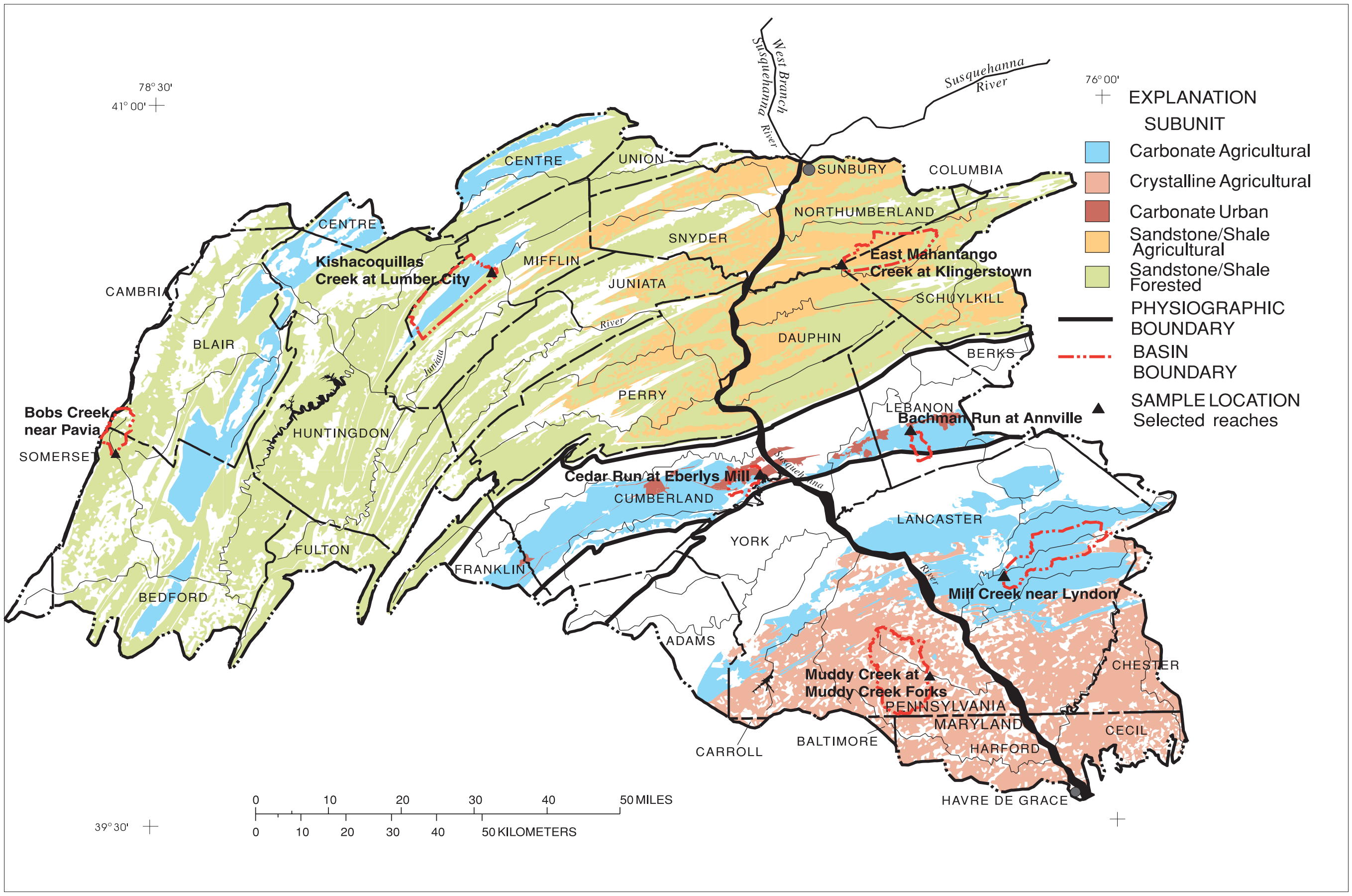

Figure 1. The Lower Susquehanna River Basin, counties, major environmental subunits, and location of the seven sites surveyed for algal biomass from 1993 to 1995.

tation, climate, geology, and physiography. Ecoregions also separate different patterns of human stresses on the environment and different patterns in the existing and attainable quality of environmental resources. Furthermore, they have proven to be an effective aid for inventorying and assessing national and regional environmental resources, for setting resource-management goals, and for developing biological criteria and water-quality standards (Woods and others, 1996).

Land use within the Lower Susquehanna Basin area is evenly divided between agriculture (47 percent) and forested (47 percent). Urban and built-up areas cover about 4 percent of the basin; the remaining 2 percent consists of waterbodies and barren lands. Overall, patterns of land use are reflective of the differences in the physical characteristics of the basin.

STUDY METHODS

Site Selection

Prior to the selection of sites, the study unit was subdivided into 12 relatively homogeneous subunits by use of a geographic information system (GIS) (Risser and Siwiec, 1996). These subunits were based on physiography and lithology and in some cases land use and land cover. Each subunit was considered for site selection. The NAWQA Program and the liaison committee, consisting of representatives from Federal, State, and various local agencies, were primarily concerned with water-quality influences associated with agricultural land use in the Lower Susquehanna River Basin. The most intense agricultural areas are underlain by carbonate bedrock. Therefore, areas of agricultural land use and carbonate bedrock were given principal consideration in choosing monitoring sites. A secondary consideration in site selection was areas of land-use conversion from agricultural to commercial, industrial, and residential and the resulting effect on water quality (Siwiec and others, 1997). On the basis of these water-quality issues, basins in 7 of the 12 subunits were chosen for the monitoring program. Within each of the seven basins, a site was selected (table 1) so that the most apparent factors influencing the water quality were bedrock type and land use. These streams were classified as either freestone (noncarbonate) or limestone (carbonate) type streams.

The seven sites selected for the algal study encompassed two level III ecoregions—the Ridge and Valley and the Northern Piedmont (table 2). Within the Ridge and Valley ecoregion, three level IV ecoregions were represented by five sampling sites. The Cedar Run and Bachman Run locations fell within the Northern Limestone / Dolomite Valleys, which are characterized by broad, level to undulating fertile valleys that are farmed extensively. Drainage density is low, and streams tend toward gentle gradients with plentiful year around streamflow and distinctive fish assemblages. Local relief typically ranges from 15 to 152 m. Vegetation is classified as mostly Appalachian oak forest in the north and oak / hickory / pine forest in the south. The East Mahantango Creek site is on the border between the Northern Shale Valleys and the Northern Sandstone Ridges. The Northern Shale Valleys ecoregion is characterized by rolling valleys and low hills. Local relief varies from 15 to 152 m. Surface streams tend to be larger and drainage density higher than in limestone areas. Streams also tend to exhibit more turbidity and impaired stream habitat. Vegetation resembles that of the Northern Limestone Valleys. In addition to the East Mahantango Creek, the Northern Sandstone Ridges also include the sites at Bobs Creek and Kishacoquillas Creek and are characterized by high, steep, forested ridges with narrow crests. Local relief ranges from 305 to 1,311 m; the high-gradient, poorly buffered streams flow into the valleys. The vegetation is similar to the other ecoregions; however, the area remains heavily forested.

Within the Level III Northern Piedmont ecoregion, two level IV ecoregions were represented by two sampling sites. The Muddy Creek site lies in the Piedmont Uplands, which is underlain by metamorphic rock and characterized by rolling hills and low ridges. This is an area of irregular plains and narrow valleys; the local relief can be as much as 180 m. Remnants of the Appalachian oak forests persist in the deep gorges. Specialized habitats exist here, such as the serpentine barrens that can support many vegetative species rare to Pennsylvania. The Piedmont Limestone / Dolomite Lowlands, which includes the Mill Creek site, is underlain by limestone and dolomite and presents very fertile farming conditions. Many sinkholes, caverns, and disappearing streams can be found in this region. Local relief typically is only 9 to 38 m. Appalachian oak forests originally grew here but have been mostly replaced by some of the most productive agricultural uses in the state.

Collection and Laboratory Determination of Algal Biomass

Periphyton samples were collected from riffles in 1993 according to the NAWQA protocols (Porter and others, 1993). In 1994 and 1995, a circular wire brush was used to scrape the periphyton from the rocks instead of the recommended nylon periphyton brush. Periphyton samples were collected from depositional areas according to the NAWQA protocols for all 3 years of sampling (Porter and others, 1993). Samples were sent to the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., and analyzed for chlorophyll *a*, chlorophyll *b*, and ash free dry mass (Britton and Greeson, 1989). Chlorophyll *a* and chlorophyll *b* were analyzed by use of high-pressure liquid chromatography (Britton and Greeson, 1989). Ash free dry mass was calculated by subtracting the ash weight from the total dry weight of a periphyton sample. A gravimetric method was used to measure ash weight and total dry weight (Britton and Greeson, 1989).

Collection of Nutrients and Other Selected Water-Quality Characteristics

Water samples for analysis of nutrients were collected as part of the surface-water procedures. Field measurements of water temperature, dissolved oxygen, pH, and specific conductance also were recorded at the seven sites each time ecological samples were collected and when water samples were collected for chemical analysis. Methods of field and nutrient data collection are described in Siwiec and others (1997). Nitrate availability is detailed in Lindsey and others (1997). Average nutrient concentrations and field measurements for the month of May during the 3 years of study were used in data analysis. May data were used because those nutrients and water-quality characteristics were the most influential to the algal crops of late May, June, and early July.

Water-quality characteristics at the seven study sites were monitored from 1993 to 1995. The mean water temperature, pH, dissolved oxygen, and specific conductance for the 3 water years are shown in table 1. The mean values for each study site are similar except for specific conductance. Limestone streams exhibit a higher specific conductance than do freestone streams. Water-quality characteristics not shown in table 1—suspended sediments, total phosphorus, and nitrates—exhibit the same pattern between the two stream types as is seen with specific conductance.

Environmental characteristics such as canopy cover, vegetative bank stability, stream-channel embeddedness, suspended sediments, and width-to-depth ratio differed with bedrock type and land use within the drainage area of the stream. Bobs Creek (freestone), which is mostly forested, had boulder / cobble substrate, greater than 80 percent of the stream shaded by canopy cover, greater than 50 percent of the banks covered with vegetation and other stable substrate, and suspended sediments of less than 1 mg / L on average per year. Bachman Run (limestone), which

Table 1. *Locations and selected water-quality characteristics of streams studied for assessments of algal concentrations in the Lower Susquehanna River Basin study, Pennsylvania and Maryland*

[°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; the minimum, maximum, and mean are given for the 3-year period 1993-95; Min, minimum; Max, maximum; n, number of data points]

Station name	Latitude/ longitude	Stream type	Water temperature (°C)				pH				Dissolved oxygen (mg/L)				Specific conductance (µS/cm)			
			Min	Max	Mean	n	Min	Max	Mean	n	Min	Max	Mean	n	Min	Max	Mean	n
Bobs Creek near Pavia, Pa.	40°16'21"/ 78°35'55"	Freestone	0.0	26	16	42	6.6	7.7	7.1	31	5.9	14	9.4	30	51	94	68	497
Cedar Run at Eberlys Mill, Pa.	40°13'30"/ 76°54'24"	Limestone	5.8	23	15	98	6.8	8.4	8.0	94	5.3	14	10	78	119	970	645	740
Mill Creek at Eshelman Mill Road near Lyndon, Pa.	40°00'36"/ 76°16'39"	Limestone	.1	26	17	110	7.1	8.6	7.9	154	5.9	14	8.5	59	213	861	662	500
Bachman Run at Annville, Pa.	40°18'59"/ 76°30'58"	Limestone	6.4	21	13	65	6.5	8.4	8.0	59	5.1	14	11	47	359	810	592	248
Kishacoquillas Creek at Lumber City, Pa.	40°39'42"/ 77°36'01"	Freestone	1.3	24	15	40	8.0	9.0	8.4	34	7.0	15	11	28	179	757	437	420
East Mahantango Creek at Klingerstown, Pa.	40°39'48"/ 76°41'30"	Freestone	0	27	16	80	6.5	8.7	7.5	70	7.1	14	9.6	67	50	206	145	532
Muddy Creek at Muddy Creek Forks, Pa.	39°48'27"/ 76°28'34"	Freestone	0	26	16	35	6.2	8.5	7.6	30	8.1	14	9.9	27	60	260	127	279

Table 2. *Seven selected sites and the physiographic province and ecoregion associated with each site*

Site name	Physiographic province	Level III ecoregions	Level IV subecoregions	Environmental subunits	Land-use designation at study sites
Bobs Creek near Pavia, Pa.	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Sandstone Ridges	Appalachian Mountain Sandstone and Shale Forested	Forested
Cedar Run at Eberlys Mill, Pa.	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Limestone/ Dolomite Valleys	Great Valley Urban	Urban
Mill Creek near Lyndon, Pa.	Piedmont	Northern Piedmont	Piedmont Limestone/ Dolomite Lowlands	Piedmont Carbonate Agricultural	Agricultural
Bachman Run at Annville, Pa.	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Limestone/ Dolomite Valleys	Great Valley Carbonate Agricultural	Agricultural
Kishacoquillas Creek at Lumber City, Pa.	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Sandstone Ridges	Appalachian Mountain Carbonate Agricultural	Agricultural
East Mahantango Creek at Klingerstown, Pa.	Ridge and Valley	Central Appalachian Ridges and Valleys	Northern Shale Valleys/ Northern Sandstone Ridges	Appalachian Mountain Sandstone and Shale Agricultural	Agricultural
Muddy Creek at Muddy Creek Forks, Pa.	Piedmont	Northern Piedmont	Piedmont Uplands	Piedmont Crystalline Agricultural	Agricultural

is mostly agricultural, had sand / silt substrate, less than 35 percent of the stream shaded by canopy cover, less than 25 percent of the banks covered with vegetation and other stable substrate, and suspended sediments greater than 1.5 mg / L on average per year. These are the two extremes for the seven sites.

QUANTIFICATION OF HABITAT AND LAND USE

A set of habitat parameters was quantified at the sites in 1993 according to NAWQA habitat protocols (Meador and others, 1993b). These protocols are based on four spatial scales—basin, segment, stream reach, and microhabitat. Biological investigations included examining a USGS 7.5-minute topographic quadrangle map. Of the characteristics determined from the map, only stream order was used in this analysis. Land use also was determined at this time. Procedures used for land-use determination are described in Risser and Siwiec (1996).

Habitat parameters (Meador and others, 1993b) consisted of 35 reach features, some of which were direct measurements and others subjective observations. Those used in this analysis were canopy cover, embeddedness, stream order, vegetative bank stability, and Wolman pebble ranked size. Wolman pebble counts (Wolman, 1954) were conducted at three transects—top, middle, and bottom—within each reach to determine bed material particle-size distribution. Particle sizes were categorized into classes ranked from 0 to 5 according to the habitat protocols for substrate size by Meador and others (1993b). The particle size ranked scores were used in the analysis. Two variables were calculated from the raw habitat data: a Bank Stability Index (BSI) (Simon and Downs, 1995) using bank angle, bank cover, bank height, and bank material; and a width-to-depth ratio.

DETERMINATION OF HYDROLOGIC VARIABLES

Hydrologic variables were generated through use of USGS 7.5-minute topographic quadrangle maps and through field collections as described in the NAWQA protocols for stream habitat characterization (Meador and others, 1993b). Instantaneous velocity and the width-to-depth ratio were used in the analysis.

Hydrologic data were examined during the 3-year intensive collection period and over a longer period of record to check on the variability of streamflows and any deviations from the average. Algal growth can be affected by antecedent hydrologic events and by hydrologic conditions during the period of data collection. The period of streamflow record collected at the seven streams studied (2-3 years) is too short to develop any meaningful streamflow statistics for a comparative analysis to previous years. For this reason, surrogate streamflow-measurement stations with longer periods of record were chosen to represent each of the sites where algae data were collected (table 3). The surrogate sites were selected because they were in the same or an adjacent basin and had similar basin and streamflow characteristics.

Two types of hydrologic information are included in table 3. The range and mean of daily mean streamflows for each of the 5 years preceding data collection (1988-92) are provided to document any extreme hydrologic events that may have significantly altered the stream habitat and, subsequently, the amount of algal growth immediately prior to data collection. The maximum daily mean streamflow for five of the seven sites during the 1988-92 period was in the 1989 water year—4 years prior to the data-collection period. The remaining two maximums were in 1988 and 1991. Duration tables based on daily streamflows were generated for each of the long-term sites. The streamflows recorded during the 1988-92 period did not exceed those that would normally be expected. Annual mean streamflows computed at the sites for each of the 5 years ranged between the 25th to 75th percentiles of all daily mean streamflows measured. On the basis of this evidence, it is believed that no extreme hydrologic events occurred prior to the data-collection period that would have significantly altered the stream habitat.

Mean daily streamflows for the long-term surrogate (1940-94) and study streams (1992-94) are provided to compare the hydrologic conditions that existed during the data-collection period (table 3). The 1992-94 means were higher than the long-term means at all seven sites. However, the differences in the two means were small—ranging from 6 to 32 percent. On the basis of an analysis of the streamflow alone, the sampled stream conditions are considered representative of long-term hydrologic conditions.

COLLECTION OF FISH AND INVERTEBRATES

Collections of fish were completed from June 1993 to June 1995 on an annual basis at the seven study sites (table 1). All sites were wadable and sampled with either of two types of electrofishing gear—a pulsed direct current (DC) backpack unit or a tow barge also using pulsed DC. A minnow seine was used for a follow-up collection in the riffle habitats. These collections were completed according to the NAWQA protocols by Meador and others (1993a).

Invertebrates were collected according to NAWQA protocols (Cuffney and others, 1993). The samples were sent to the Biological Unit of the USGS NWQL for taxonomic identification and enumeration. The invertebrate data used for analysis in this report are from the 1995 riffle collection and are not mean abundance values for the 3 years. These 1995 data were the only data available at the time of analysis.

Table 3. *Streamflow statistics for streamflow-measurement stations with long-term record comparable to streams studied in the Lower Susquehanna River Basin study, Pennsylvania and Maryland*

[ft^3/s, cubic feet per second; Max, maximum; Min, minimum]

Streamflow-gaging site with long-term record (surrogate station) number and name	Streams studied for algal concentrations number and name	Surrogate period of record	Mean daily streamflow statistics, in ft^3/s															Surrogate long term mean (ft^3/s)	1992-1994 mean (ft^3/s) at algal sites
			1988 water year			1989 water year			1990 water year			1991 water year			1992 water year				
			Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean		
01560000 - Dunning Creek at Belden	01559795 - Bobs Creek near Pavia	1940-94	2,060	12	167	3,300	18	294	1,440	16	186	2,200	11	252	1,100	11	135	230	264
01569800 - Letort Spring Run near Carlisle	01571490 - Cedar Run at Eberlys Mill	1979-94	87	22	35.7	126	20	35.5	114	26	40.8	135	21	42.8	92	17	28.3	43.1	45.6
01576500 - Conestoga River at Lancaster	01576540 - Mill Creek near Lyndon	1928-94	5,400	101	455	9,400	103	520	4,050	129	424	1,880	52	344	3,200	70	263	396	469
01573160 - Quittapahilla Creek near Bellgrove	01573095 - Bachman Run at Annville	1976-94	646	55	88.8	600	39	102	418	36	101	297	19	73.6	316	44	77.3	106	121
01564500 - Aughwick Creek near Three Springs	01564997 - Kishacoquillas Creek at Lumber City	1939-94	4,330	10	185	4,820	12	295	1,600	7.7	150	2,340	5.2	250	1,940	8.7	105	244	269
01555500 - East Mahantango Creek near Dalmatia	01555400 - East Mahantango Creek at Klingerstown	1939-94	2,070	14	171	4,310	15	252	2,300	33	209	2,530	7.8	222	3,350	9.3	155	226	267
01575000 - South Branch Codorus Creek near York	01577300 - Muddy Creek at Muddy Creek Forks	1928-94	2,010	.86	97.2	2,880	1.2	99.2	1,290	12	110	856	6.6	94.1	1,330	7.0	64.4	113	149

DATA ANALYSIS

Linear regressions were initially used to compare the influence of certain environmental characteristics, nutrients, and water-quality characteristics to chlorophyll *a* and ash free dry mass (biomass indicators). Regression analysis was not able to separate the freestone from the limestone streams and generate conclusive results because of too few data points. Instead, scatter plots are used to show possible relations between chlorophyll *a* concentrations at sites and the environmental variables. Chlorophyll *a* was chosen for the algal biomass indicator because not all algae contains chlorophyll *b* (Sze, 1993) and ash free dry mass could be biased by inorganic matter and non-algal organic matter (Stevenson and others, 1996). The method for sampling depositional algae introduced a silt and inorganic bias to the depositional ash free dry mass, but this bias is not seen with the chlorophyll *a* concentrations. The 3-year averages of chlorophyll *a* concentrations were used in the analysis (table 4). For each site, depositional and riffle chlorophyll *a* are examined separately.

QUALITY ASSURANCE AND QUALITY CONTROL

Quality-assurance and quality-control procedures for nutrients and other selected water-quality characteristics are described in Siwiec and others (1997). Quality-assurance results for nitrates are described in Lindsey and others (1997). Fish species identifications were confirmed by Charles Dix of Normandeau Associates in Spring City, Pa., and at the USGS NWQL. Invertebrate identifications, quality assurance, and quality control were performed at the NWQL. In addition, duplicate samples of chlorophyll *a* (table 5) were analyzed. The percentage differences in concentration range from 4 percent at Bobs Creek to 250 percent at Kishacoquillas Creek. No precision data are available for this analysis from the NWQL (Britton and Greeson, 1989).

RELATION OF ALGAL BIOMASS TO STREAM CHARACTERISTICS

Algal growth has been linked to many variables including, but not limited to, light, total suspended sediments, temperature, streamflow, particle size, and nutrient concentrations. Thus, algal biomass may be used as a measure of water quality. Algal biomass indicators commonly measured are chlorophyll *a*, chlorophyll *b*, and ash free dry mass. These measurements assist in establishing baseline conditions and relations between algae and nutrients in non-tidal tributary streams. These baselines may then be used in a long-term monitoring program to determine the effects of the nutrient-reduction goals.

Table 4. *Periphyton chlorophyll a concentrations for the seven sites in the Lower Susquehanna River Basin for 1993-95*

Site name	Site number	Chlorophyll *a* concentration, in milligrams per square meter					
		1993		1994		1995	
		Riffle	Depositional	Riffle	Depositional	Riffle	Depositional
Bobs Creek near Pavia, Pa.	1	17	18	2.3	3.9	15	12
Cedar Run at Eberlys Mill, Pa.	2	23	4	44	61	49	19
Mill Creek at Eshelman Mill Road near Lyndon, Pa.	3	44	16	6.6	17	22	8.8
Bachman Run at Annville, Pa.	4	42	3	38	44	71	29
Kishacoquillas Creek at Lumber City, Pa.	5	49	32	49	24	90	23
East Mahantango Creek at Klingerstown, Pa.	6	30	2	8.8	3.3	20	14
Muddy Creek at Muddy Creek Forks, Pa.	7	21	62	6.2	26	17	11

Table 5. *Concentrations of periphyton chlorophyll a in split samples for quality assurance at three selected sites in the Lower Susquehanna River Basin*

[QA, quality assurance duplicate sample; mg/m^2, milligrams per square meter]

Site name	Year	Chlorophyll *a* (milligrams per square meter)	Chlorophyll *a* (QA) (milligrams per square meter)	Percentage difference[1]
Bobs Creek near Pavia, Pa.	1993	2.3	2.2	4.3
	1994	3.9	6.1	56
Kishacoquillas Creek at Lumber City, Pa.	1994	24	84	250
East Mahantango Creek at Klingerstown, Pa.	1994	8.8	13	48
	1995	20	28	40
	1995	14	16	14

[1] $\left(\frac{\text{concentration of environmental sample} - \text{concentration of QA sample}}{\text{concentration of environmental sample}}\right) \times 100 = \text{Percentage difference.}$

Chlorophyll *a* concentrations in riffle areas can be influenced by different factors than in depositional areas (S.D. Porter, U.S. Geological Survey, oral commun., 1997). Relations between chlorophyll *a* concentrations and environmental characteristics were different between the riffle and depositional samples for each environmental characteristic described. Also, relations between chlorophyll *a* concentrations and environmental characteristics were different between streams classified as freestone and limestone. Therefore, two chlorophyll *a* concentrations (riffle and depositional) were evaluated for every environmental characteristic. These concentrations are the 3-year means for each site. Four sites are freestone streams and three are limestone streams.

Nutrient Concentrations and Other Selected Water-Quality Characteristics

No consistent relations were noted between concentrations of chlorophyll *a* and nitrogen. Depositional chlorophyll *a* concentrations increased as phosphorus concentrations decreased in the limestone streams (fig. 2).

Other water-quality characteristics measured were pH, specific conductance, and percentage of dissolved oxygen. As riffle chlorophyll *a* concentrations increased in freestone streams, the pH increased (fig. 3). Riffle chlorophyll *a* concentrations increased in freestone streams with increased specific conductance (fig. 4) but decreased in limestone streams as conduc-

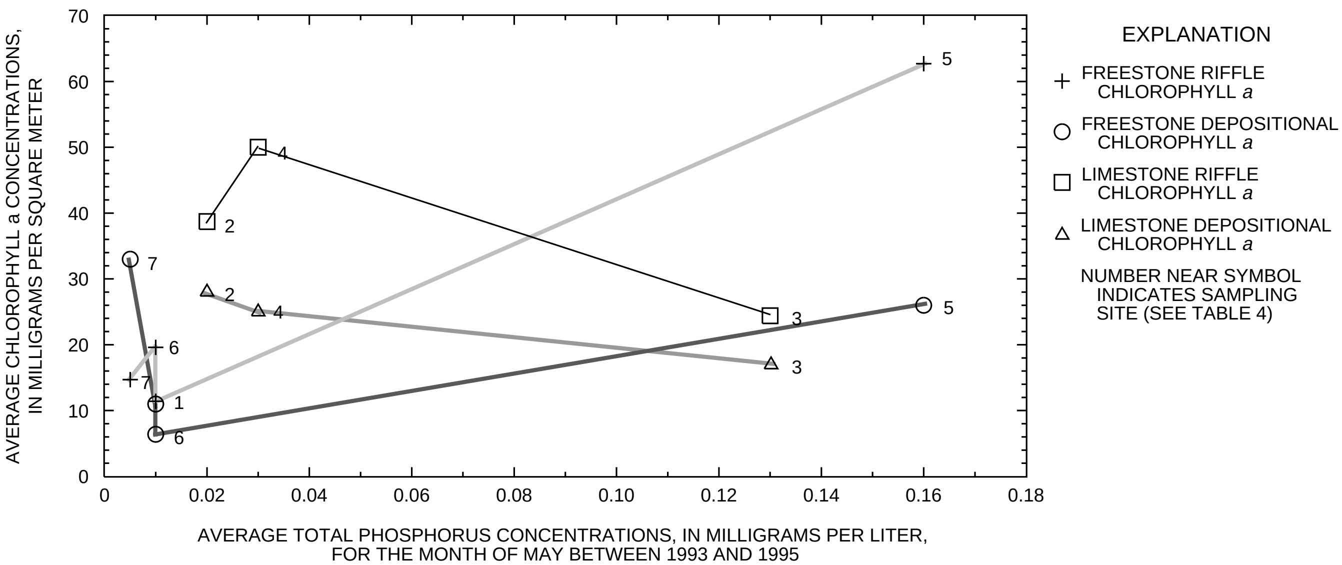

Figure 2. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to the average May total phosphorus concentrations.

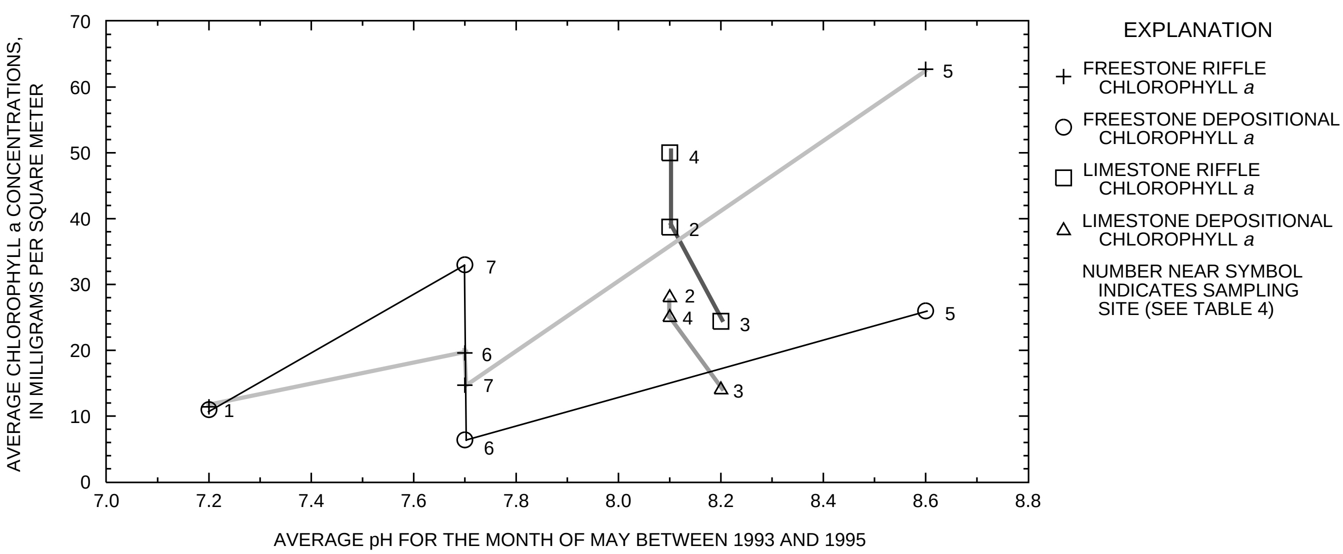

Figure 3. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to average May pH.

tance increased. Riffle chlorophyll *a* concentrations increased in both stream types as percentage of dissolved oxygen increased (fig. 5).

HABITAT AND LAND USE

The relation between chlorophyll *a* concentrations and six habitat variables—BSI, canopy cover, embeddedness, stream order, vegetative bank stability, and ranked Wolman pebble sizes—were examined. No relation was observed between chlorophyll *a* and embeddedness, stream order, or vegetative bank stability. Relations were evident for BSI (fig. 6), canopy cover (fig. 7), and Wolman pebble sizes (fig. 8). Chlorophyll *a* concentrations in limestone depositional areas decreased as bank stability decreased (fig. 6). Riffle chlorophyll *a* concentrations increased as the degree of open canopy increased and more light was able to reach the stream (fig. 7). Freestone riffle chlorophyll *a* concentrations decreased as the stream bottom changed from gravel to boulder (ranks 4 through 6), except for Kishacoquillas Creek, which had a chlorophyll *a* concentration of 63 mg / m^2 (fig. 8).

Land use as percentage of agriculture, urban, forest, and corn crops per agricultural area showed no relation to chlorophyll *a* concentrations.

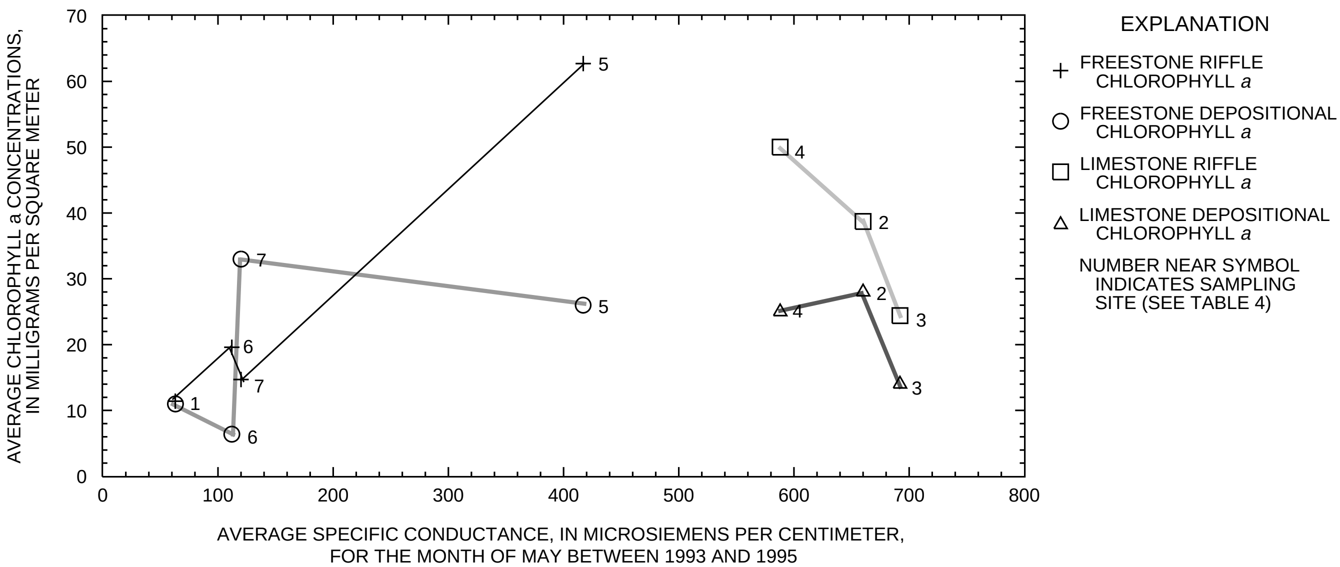

Figure 4. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to average May specific conductance.

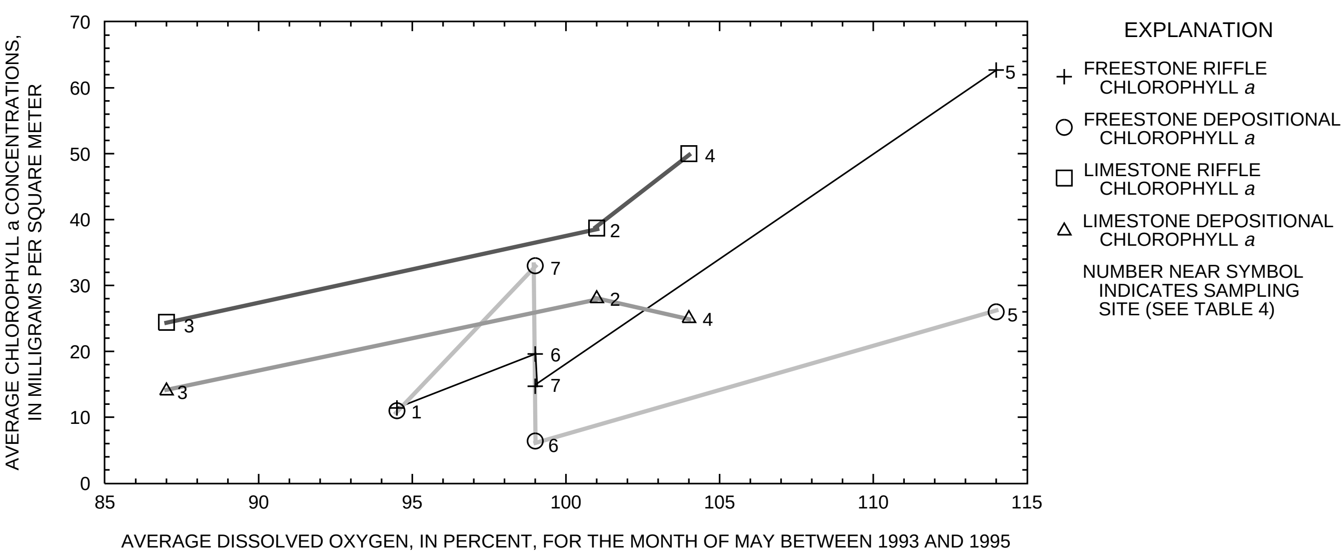

Figure 5. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to percent dissolved oxygen.

Hydrology

The relations between chlorophyll *a* concentration and depositional instantaneous velocity, riffle instantaneous velocity, and width-to-depth ratio were examined. No relations were noted between chlorophyll *a* concentrations and depositional instantaneous velocity. Depositional chlorophyll *a* concentrations increased as riffle velocity increased (fig. 9). Depositional chlorophyll *a* concentrations in limestone streams decreased with increased width-to-depth ratio (fig. 10).

Fish and Invertebrates

Chlorophyll *a* concentrations were compared to percentage of stonerollers (*Campostoma anomalum*) and percentage of omnivorous fish because of their possible effects on algal biomass. Stonerollers were present in only two of the seven streams, and no relations were seen. Riffle chlorophyll *a* concentrations increased in freestone streams as the percentage of omnivorous fish increased (fig. 11). Riffle chlorophyll *a* concentrations in limestone streams decreased as percentage of omnivorous fish increased (fig. 11).

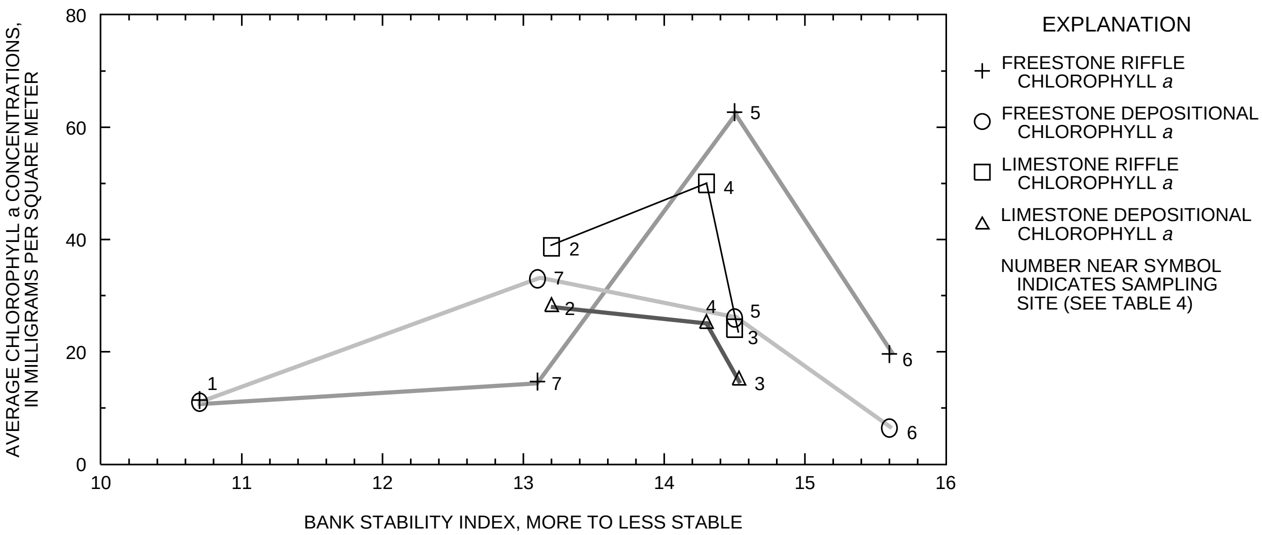

Figure 6. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to Bank Stability Index.

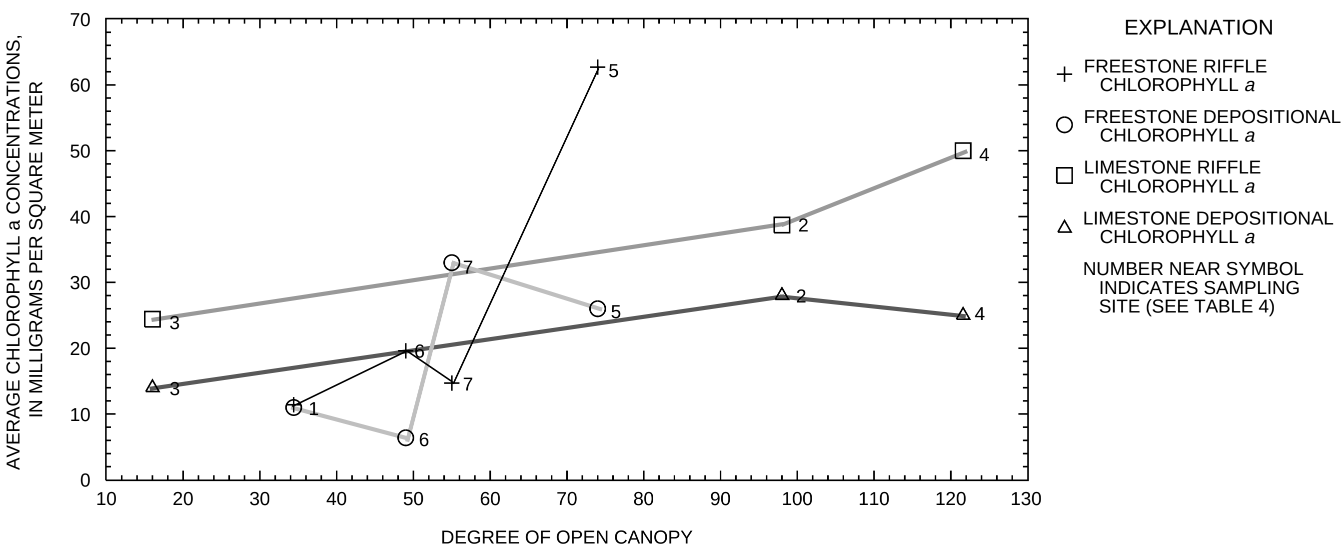

Figure 7. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to degree of open canopy.

Chlorophyll *a* concentrations were compared to percentage of baetid mayflies, percentage of collector / gatherer invertebrates, and percentage of scraper invertebrates. No relation was seen between the chlorophyll *a* concentrations and percentage of mayflies. The collector / gatherer invertebrates (fig. 12) had a negative influence on riffle chlorophyll *a* concentrations in freestone streams. Kishacoquillas Creek—chlorophyll *a* concentration of 63 mg / m^2 —was the exception. Depositional chlorophyll *a* concentrations in limestone streams increased as the percentage of collector / gatherer invertebrates increased (fig. 12). Depositional chlorophyll *a* concentrations in limestone streams decreased as the percentage of scraper invertebrates increased (fig. 13).

FACTORS INFLUENCING ALGAL BIOMASS

In this study, freestone streams were shown to have, on average, lower chlorophyll *a* concentrations than limestone streams of the same stream order. Lithology has been determined to have an effect on algal biomass (Biggs, 1990; Leland, 1995). Hard sedimentary (freestone) rocks are low in enriching nutrients; other rock types (limestone) result in more enriching conditions (Biggs, 1990). The weathering of bedrock and dissolution of chemical constituents show a strong relation with algal communities (Leland, 1995). The chlorophyll *a* concentrations from the Lower Susquehanna River Basin show limestone streams as being more productive than freestone streams.

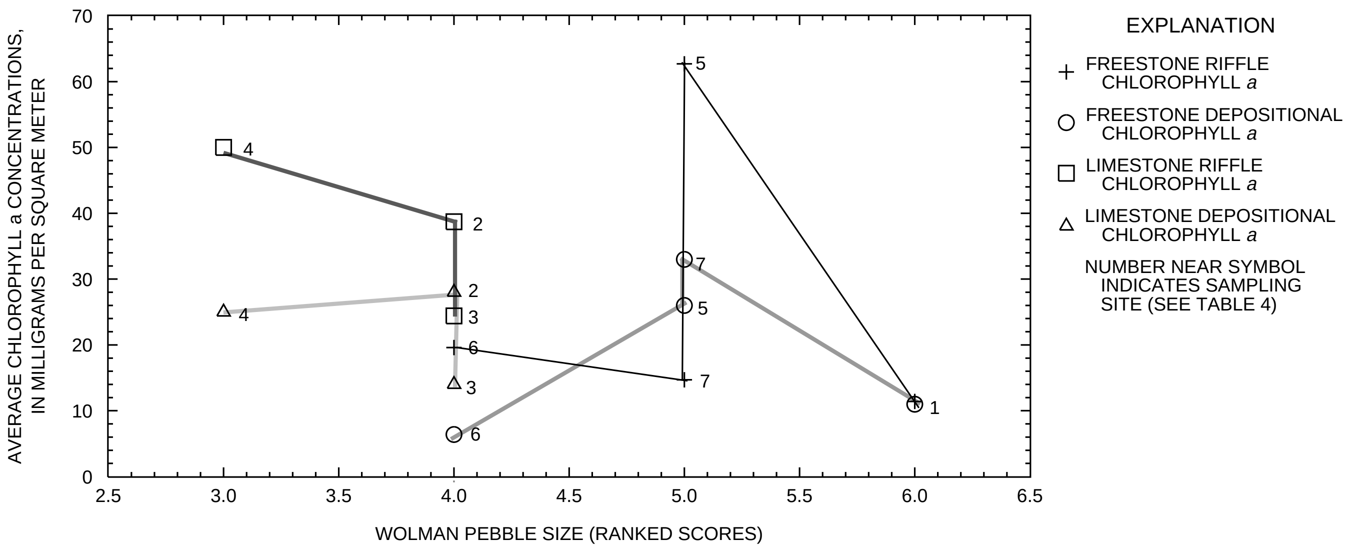

Figure 8. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to Wolman pebble size.

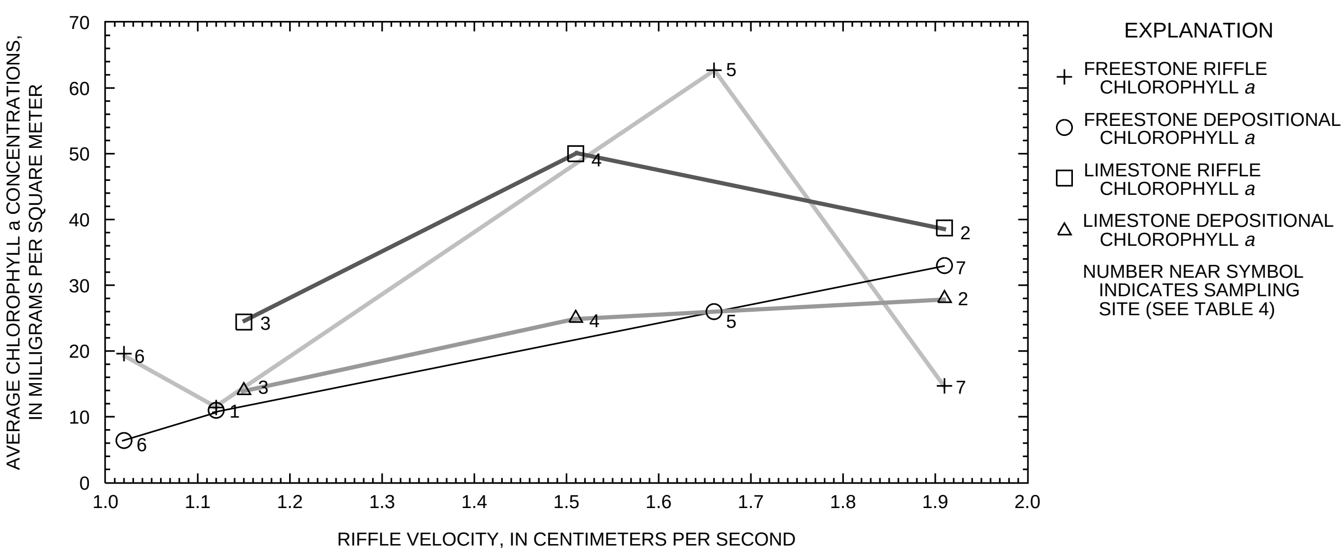

Figure 9. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to riffle velocity.

Algal biomass increases with stream size until the waters become too deep for light to penetrate to the substratum (Stevenson and others, 1996). Kishacoquillas Creek, the only fourth-order stream studied, had the highest chlorophyll *a* concentrations of the seven streams. This creek is greater than 15 m wide and has an average depth of 0.5 m. Light is able to reach the stream bottom over the entire width of the stream. Kishacoquillas Creek also has a limestone influence that may contribute to its higher chlorophyll *a* concentrations. The other six streams studied were second- and third-order streams. These streams also had adequate light penetration but were narrower and could not carry as much biomass. Muddy Creek is wide and shallow but is a freestone stream without a limestone influence, and Muddy Creek does not have high algal concentrations when compared to Kishacoquillas Creek.

Nutrient limitation in streams is difficult to assess because even low concentrations of nutrients may support algal growth. This growth is caused by constant renewal of water supply around the algae and the pulses of nutrient input during storms or seasonally (with leaf fall) (Hauer and Lamberti, 1996). Nitrogen, however, did not appear limiting in these seven streams. High concentrations of nitrogen are probably a result of the high percentage of agriculture in the basin. Results of other studies suggest that 0.3 mg/L of inorganic nitrogen and 0.01 mg/L of phosphorus are

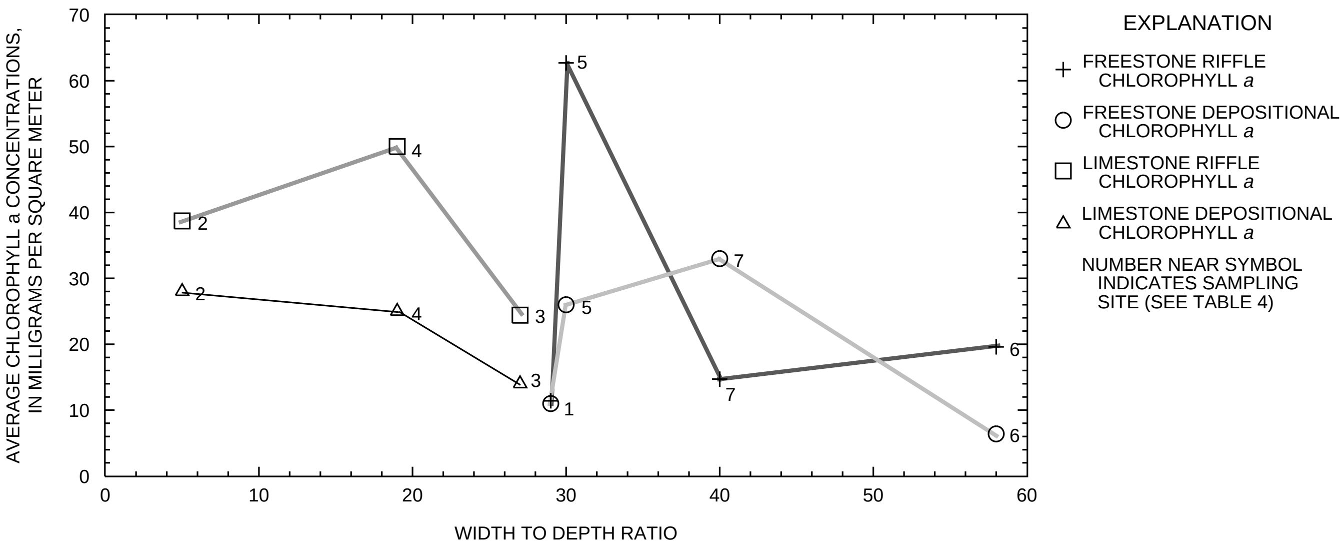

Figure 10. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to the width-to-depth ratio.

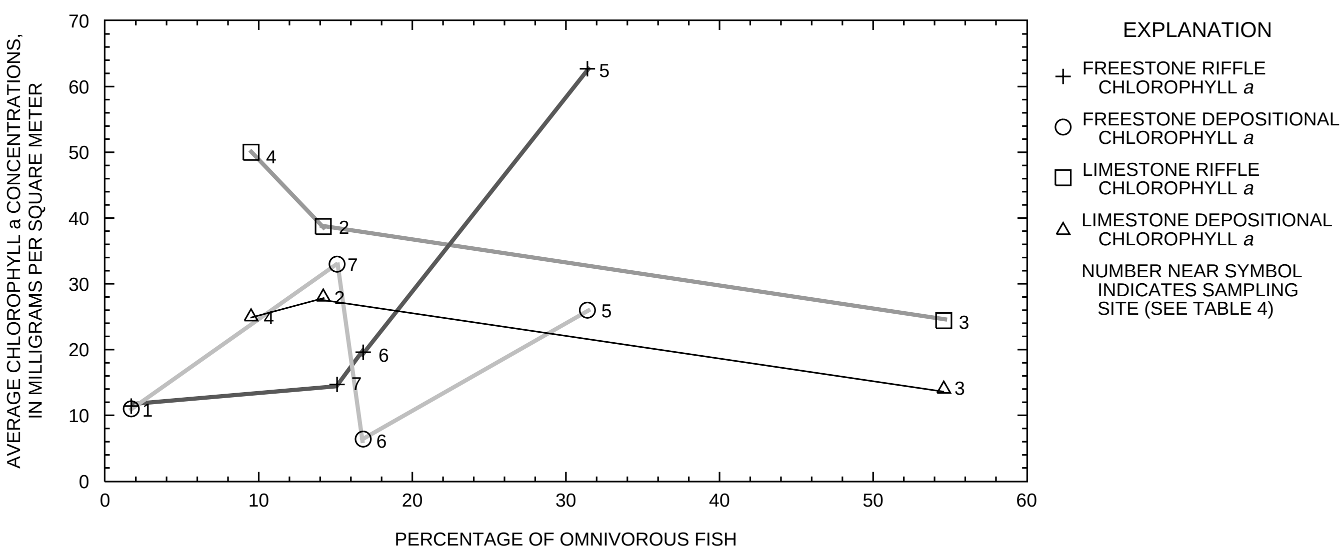

Figure 11. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to the percentage of omnivorous fish.

critical lows for algal growth for lentic systems (Fishel, 1983) and 0.35 mg/L of total nitrogen and 0.03 mg/L of total phosphorus in lotic systems (Dodd and others, 1997). Nitrogen concentrations in the Lower Susquehanna River Basin exceeded this critical value for lotic systems.

The nutrient most limiting to algal growth in freshwater systems in the northern half of the United States is usually phosphorus (Stevenson and others, 1996; Hauer and Lamberti, 1996). Phosphorus may have been limiting in five of the streams. Kishacoquillas Creek and Mill Creek had phosphorus concentrations greater than 0.03 mg/L. Factors such as canopy cover or bank instability may have been more influential to the decreased algal concentrations seen in Mill Creek as compared to the other limestone streams.

Riffle chlorophyll *a* concentrations in both freestone and limestone streams increased as canopy cover decreased. Shading by terrestrial vegetation can intercept 95 percent of the available light that could potentially reach the stream (Stevenson and others, 1996). As canopy decreases, more light is able to reach the stream and be used by algae for photosynthesis.

Riffle chlorophyll *a* concentrations in both freestone and limestone streams increased when bottom substrate reached the gravel/cobble size range. As riffle chlorophyll *a* concentrations increased, so did

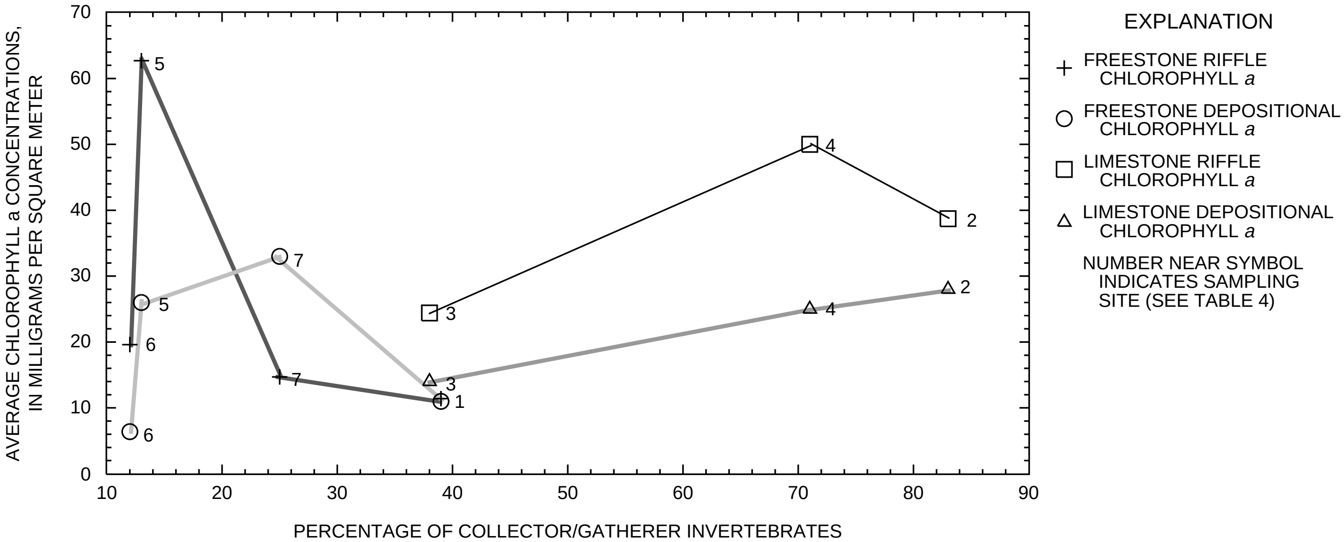

Figure 12. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to percentage of collector/gatherer invertebrates.

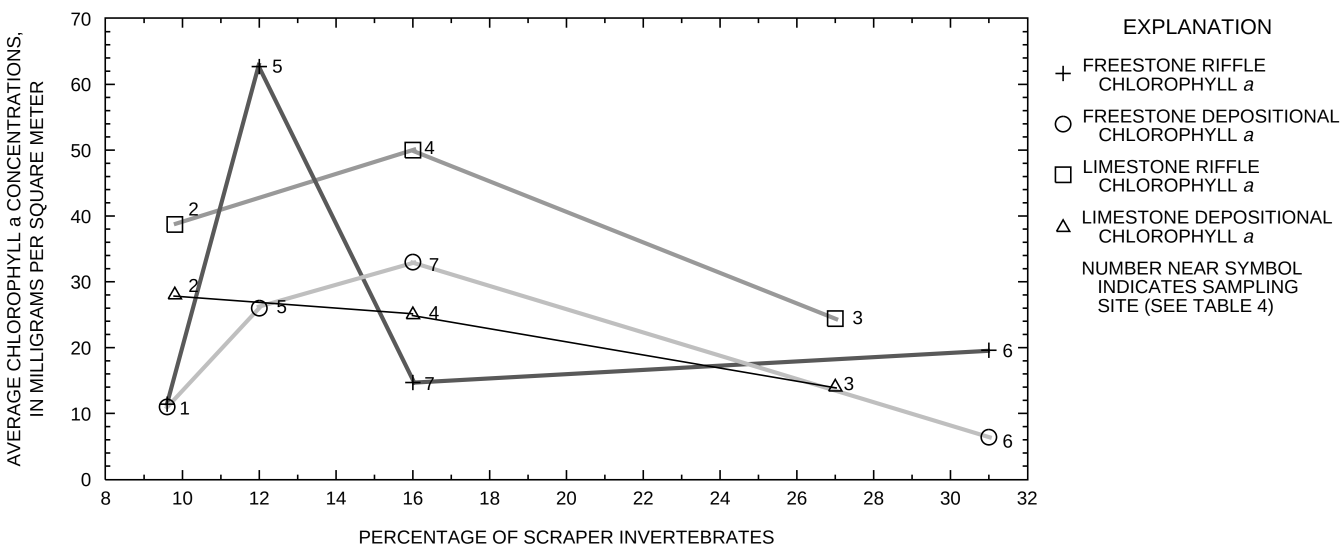

Figure 13. Riffle and depositional chlorophyll *a* concentrations in freestone and limestone streams in relation to percentage of scraper invertebrates.

dissolved oxygen concentrations. The gravel / cobble substrate size supplies algae with an adequate place to anchor and grow. These heaver particles are less likely to roll downstream during normal conditions than smaller, lighter sized substrate. The ability of the substrate to stay in place gives the algae a more stable environment on which to grow. As the algae grow, they photosynthesize and release oxygen to the water, sometimes causing the water to become supersaturated with oxygen (Hynes, 1970; Hauer and Lamberti, 1996). The gravel / cobble substrate also causes turbulence in flowing water, which raises the dissolved-oxygen levels. Algal growth and substrate size both may be influential on the amount of dissolved oxygen in the water.

Freestone streams had increased riffle chlorophyll *a* concentrations along with increased pH and percentage of omnivorous fish but decreased concentrations as collector / gatherer invertebrates increased. Measurements of pH may reflect the acidity of the stream waters. Less algae grow in the more acidic streams until acidity becomes low enough to cause a change in community structure (Hynes, 1970; Stevenson and others, 1996). Higher order streams have the capacity to carry more diverse fish species than do lower order streams, allowing for a greater percentage of omnivorous fish. Bobs Creek is a second order stream, Muddy and East Mahantango Creeks are third order streams, and Kishacoquillas Creek is a fourth order stream. These stream order differences could negate the effects the fish are having on the algal population. Invertebrates can have a strong influence on the algal crops seen in streams (Stevenson and others, 1996). Collector / gatherer species graze on fine particulate organic matter (Merritt and Cummins, 1984). Some fine particulate matter may be small algal cells.

Concentrations of chlorophyll *a* in limestone stream riffles were unaffected by changes in pH or percentage of collector / gatherer invertebrates but decreased as percentage of omnivorous fish increased. In limestone streams, the water is buffered by the carbonate lithology, and pH is relatively constant and should not affect the algal biomass. These streams also have a tendency to be higher in fine particulate matter than freestone streams, and collector / gatherer invertebrates do not seem to be as influential to the algal biomass as in the freestone streams. However, the higher concentration of algae in these streams can be a food source for the omnivorous fish. Many species of minnows are omnivores that readily eat algae as part of their diet and have been shown to have a negative effect on algal growth (Stevenson and others, 1996).

Concentrations of chlorophyll *a* in depositional areas reacted to different environmental factors than riffle concentrations. Depositional chlorophyll *a* concentrations in limestone streams decreased as the BSI decreased and as the riffle velocity increased. BSI and riffle velocity may work together for this relation. As the riffle velocity increases, the BSI decreases. A lower BSI and higher velocities allow for sediments to be deposited in depositional areas. These clean areas are commonly inhabited by immigrating algal colonies (Stevenson and others, 1996). Also, the increased riffle velocity may aid in scouring some algal cells from the riffle areas that are deposited on the fresh sediments of the depositional areas.

Limestone streams had an increase in depositional chlorophyll *a* concentrations as collector / gatherer invertebrates increased, as phosphorus concentrations decreased, and as width-to-depth ratios decreased. The collector / gatherer invertebrates consume fine particulate matter and may remove senescent cells resulting in more external resources reaching the viable cells or as a result of nutrient regeneration from within the periphyton matrix as cells are removed from the periphyton community (Stevenson and others, 1996). Generally, the limestone streams that had more macrophytes had less algae. Macrophytes growing in the water compete with algae for phosphorus (Stevenson and others, 1996). The more shallow streams (smaller width-to-depth ratio) have higher chlorophyll *a* concentrations than the deeper streams (larger width-to-depth ratio). Depositional areas in the more shallow streams are limited to slow water along the edges of the stream where sunlight can penetrate to the stream bottom. The deeper streams, like Mill Creek, have deep pools where sunlight cannot reach the stream bottom.

Algal growth is highly dependent on temperature (Hynes, 1970; Stevenson and others, 1996). However, the water temperature in May for the seven sites in the Lower Susquehanna River Basin ranged from 12°C to 13.8°C and did not affect concentrations of chlorophyll *a* at these sites. Other factors conducive to growth are light, current, pH, bottom substrate, and nutrients (Hynes, 1970; Goldman and Horne, 1983; Sze, 1993; Hauer and Lamberti, 1996; Stevenson and others, 1996). These environmental characteristics were influential to chlorophyll *a* concentrations seen in the Lower Susquehanna River Basin. Nitrogen did not appear limiting in the streams selected in the Lower Susquehanna River Basin study. Phosphorus did appear limiting in two of the limestone streams and three of the freestone streams where concentrations were 0.03 mg / L or less. Kishacoquillas Creek and Mill Creek had phosphorus concentrations over 0.03 mg / L.

In 1980 and 1981, work was conducted on the Lower Susquehanna River to assess the nutrients entering the Chesapeake Bay by utilizing chlorophyll *a* and *b* concentrations (Fishel, 1983). Nitrogen and phosphorus were not limiting factors in algal growth at that time (Fishel, 1983). This small sampling between 1993 and 1995 showed similar results as the 1980-81 sampling for nitrogen; however, phosphorus may now be limiting in some of the tributary streams to the Lower Susquehanna River.

Use of Algal Biomass in Describing Nutrient Cycling in Streams

Algae are primary producers in streams and utilize two pathways for nutrient cycling in periphyton-dominated streams. The first pathway is spiraling, displacement of nutrients downstream, and the second is internal cycling, a diffusion-controlled process within the benthic algae group (Mulholland and others, 1991). Stevenson and others (1996) state three direct effects of benthic algae on nutrient cycling in streams: 1) increase the total supply of nutrients through fixation of atmospheric and substratum nutrients; 2) uptake and use of nutrients from the stream water; and 3) transformation and remineralization of nutrients. It has been observed that as biomass increases, internal cycling of nutrients increases and less nutrients are taken from the stream water for growth (Mulholland and others, 1994).

To understand the role of algae in the tributaries to the Susquehanna River and their role in nutrient cycling, further study must be done. This study shows that bedrock plays a role in algal production. Nitrogen was not limiting in the agricultural streams, but phosphorus may have been limiting at five of the seven sites. Bobs Creek, which had the lowest concentrations of chlorophyll *a* and nitrogen of the seven sites, is forest dominated with little agriculture in the basin.

This study had a small sample size and thus, the conclusions cannot be rigorously supported statistically. For a better understanding of this complex system, at least 40 representative streams from each bedrock type would need to be studied—20 samples from agricultural land use and 20 samples from urban land use. Analyses would be run on each group of sites, which would negate bedrock type and allow nutrients and other environmental characteristics and their relation to algae to be the focus of the research.

An understanding of the principles of nutrient cycling into the Chesapeake Bay also is needed. Nitrogen tends to be dissolved in waters that flow into the Bay; most phosphorus is in the suspended state and can be retained in the Conowingo Reservoir (Fishel, 1983). The application of this knowledge and a more comprehensive sampling design will aid in determining if benthic algae are good indicators of nutrient reduction into the Chesapeake Bay.

SUMMARY

The Chesapeake Bay Program is trying to restore the Chesapeake Bay ecosystem to its natural condition by reducing nutrient inputs. The goal of a 40-percent reduction of controllable inputs of nutrients into the Bay by the year 2000 has been set. These reductions must take place in the non-tidal portion of the Bay's system. The intent of this report was to determine if algae in the non-tidal streams of the Lower Susquehanna River Basin can be used to monitor this reduction or if other factors influential to algal growth are more limiting than nutrients.

Algal, invertebrate, and fish communities were sampled at seven sites in the Lower Susquehanna River Basin. Four of these sites were classified as freestone streams and three as limestone streams. The algal community was sampled separately in riffle and depositional areas. Nutrient concentrations, water-quality measurements, habitat characteristics, land use, and hydrologic conditions were recorded for each site. These site conditions and select portions of the invertebrate and fish communities were compared to chlorophyll *a* concentrations.

Relations were identified between concentrations of chlorophyll *a* and Bank Stability Index, canopy cover, bottom substrate size, riffle velocity, width to depth ratio, phosphorus, pH, conductance, dissolved oxygen, omnivorous fish, collector/gatherer invertebrates, and scraper invertebrates. Relations were different between the freestone and limestone streams and between riffle and depositional chlorophyll *a* concentrations. Chlorophyll *a* was not related to land use. Concentrations of nitrogen in the seven streams were higher than the critical lows needed for excessive algal growth. A similar conclusion was reached in a 1980-81 study of the Susquehanna River. In this study, phosphorus concentrations were below the critical low needed for excessive algal growth at five of the seven sites. This differs from that of the earlier study.

To better understand the role of algae and its influence on nutrients into the Chesapeake Bay, further study is required. A larger sample size in both freestone and limestone stream types is needed. A greater number of samples from different land uses may show that land-use activities affect nutrients and other habitat features and thus affect algal growth. Findings from this study could be used to design future data-collection efforts in the Lower Susquehanna River Basin.

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