Hydrologic Disturbance and Response of Aquatic Biota in Big Darby Creek Basin, Ohio

U.S. Geological Survey
Water-Resources Investigations Report 96-4315

Prepared in cooperation with
The City of Columbus, Ohio, and
Franklin, Madison, and Pickaway Counties

COVER: Artistic representation of Big Darby Creek, Ohio

WaterColor - Richard Frehs 1997

ERRATA in APPENDIX 1

Hambrook, J.A., Koltun, G.F., Palcsak, B.B., and Tertuliani, J.S. 1997. Hydrologic Disturbance and Response of Aquatic Biota in Big Darby Creek Basin, Ohio. U.S. Geological Survey, Water-Resources Investigations Report 96-4315, 79 p.

p. 53 Branchiobdellida NOT Branchiobdellia; Elmidae NOT Elmimidae
p. 55 Psephenidae NOT Asephenidae; Coenagrionidae NOT Coenagrioniidae
p. 56 Neoperla clymene (Newman) NOT Neoperla cylmene (Newman)
p. 60 Atrichopogon NOT Atrichipogon; Psychodidae NOT Psychadidae;
Stratiomyidae NOT Stratiomyiidae
p. 61 Antocha is a genus in Tipulidae NOT a Tabanidae;
Rheocricotopus is an Orthocladiinae NOT Tanypodinae
p. 63 Cricotopus vierriensis NOT C. vieriensis
p. 64 Procladius is a Tanypodinae NOT Orthocladiinae; Tvetenia discoloripes NOT T. discoloipes

Changes in family names since Merritt, R.W., and Cummins, K.W., eds., 1984, An introduction to the aquatic insects of North America (2d ed.): Dubuque, Iowa, Kendall Hunt, 722 p.

p. 54 Lutrochus sp. belongs to Lutrochidae NOT Limnichidae
p. 56 Isonychiidae NOT Oligoneuriidae.

Prefered arrangement of the chironomids.

- Chironomidae
  - Tanypodinae
  - Podonominae
  - Diamesinae
  - Orthocladiinae
  - Chironominae
    - Chironomini
    - Pseudochironomini
    - Tanytarsini

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Prepared in cooperation with
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Columbus, Ohio
1997

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
acre	0.4047	square hectometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound-force per square foot	47.87	newtons per square meter
ton	0.9072	megagram

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8(°C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is approximately the same as for concentrations in parts per million.

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

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ABSTRACT

Washout and recolonization of macroinvertebrates and algae associated with a spring and summer storm were measured at three sites in Ohio's Big Darby Creek Basin. Related factors, such as streamflow magnitude, shear stress, and streambed disturbance were considered when interpreting observed changes in densities and community structure of macroinvertebrates and algae.

During the study, 184 macroinvertebrate taxa and 202 algal taxa were identified. The major taxonomic groups for macroinvertebrates were midges and other true flies (Diptera), caddisflies (Trichoptera), beetles (Coleoptera), mayflies (Ephemeroptera), and stoneflies (Plecoptera). Diatoms were the dominant algae (in terms of percentage of total taxa found) followed by green algae, blue-green algae, euglenoids, golden flagellates, and freshwater red algae.

Streamflows associated with the storm events that occurred during April 6–16 and June 23–July 5, 1994, probably had little effect on streambed elevations, but streambed disturbance was documented in the form of shifts in the median particle-size diameters of the subsurface bed materials. The streamflow magnitudes did not correlate well with the magnitude of observed changes in macroinvertebrate and algal-cell densities, but reductions in macroinvertebrate and algal-cell densities generally did occur.

Local minima of macroinvertebrate density did not generally correspond to the first sample after the storms, but instead lagged by about 1 to 3 weeks. Other biotic factors, such as emergence of Diptera, probably affected the observed mid-July depression in macroinvertebrate densities.

Evaluation of pre-event macroinvertebrate community structure in terms of functional feeding groups and flow-exposure groups showed that, on the basis of percentage of total taxa found, gatherers were the dominant feeding group and flow-facultative taxa were the dominant flow-exposure group. Densities of gatherers decreased from pre-event levels following all the storm events at all the sites, whereas flow-facultative and flow-avoiding taxa were significantly reduced only after the summer event at Big and Little Darby Creeks.

Algal-cell densities in the first post-event samples always were lower than pre-event densities; however, the total number of taxa present generally were not statistically different. In four out of five of the first post-event samples, algal-cell densities were only 16 to 26 percent of the pre-event densities. The exception was at Little Darby Creek after the spring event, where only the density of stalked algal cells in the community were significantly reduced. The observed resistance to disturbance of the algal community at Little Darby Creek may have resulted from the relative abundance of the mat-forming blue-green algae *Oscillatoria* spp. The stalked cells were the most consistently reduced in the post-event samples, whereas holdfast types (such as *Audouinella hermannii*) and prostrate epiphytes (such as *Cocconeis* spp.) were the most resistant to washout.

Algal recolonization rates, measured as the change in algal-cell densities over a 7-day period after the summer storm event, ranged from 0.05 to

1.51 billion cells per square meter per day. These recolonization rates are expected to be affected by factors such as nutrients, temperature, amount of canopy, initial post-event algal density, and grazing by macroinvertebrates and fish. On the basis of canopy and nutrient data, one would expect the algal recolonization rates for the three sites in this study to sort in the order observed.

INTRODUCTION

Big Darby Creek (fig. 1), a tributary to the Scioto River in central Ohio, drains 555 mi^2 in the Eastern Corn Belt Plains ecoregion (as delineated by Omernik, 1987). The basin is characterized by smooth plains, predominance of cropland, soil parent material of limestone and glacial drift, and potential natural vegetation of beech-maple forest (Kuchler, 1964). In addition to being among the Nation's most productive agricultural areas for corn and soybeans, the biotic communities of the stream, including more than 86 species of fish and 40 species of freshwater mussels, make Big Darby Creek one of the most biologically diverse streams of its size in the Nation. For this reason, 82 mi of Big and Little Darby Creeks were designated as a "State Scenic River" in 1984 by the Ohio Department of Natural Resources, a "Last Great Place" in 1990 by The Nature Conservancy, and a "National Scenic River" in 1994 by the U.S. Department of the Interior.

The Big Darby Creek Basin is under pressure from residential and commercial development because of its proximity to Columbus. Urban area in the basin increased from 2,146 acres in 1965 to 8,357 acres in 1987 (Gordon and Simpson, 1990, p. 92). Urban nonpoint-source contaminants originate from automobile traffic (heavy metals such as lead, asbestos, acid-making substances, and salt), construction activities (dirt, asphalt, paint, oil, and cleaning solvents), lawns (fertilizer, pesticides, and herbicides), airborne fallout, street debris, and animal and plant refuse. In addition to contaminants associated with urbanization, the increase of impermeable surfaces can produce increased runoff that results in increased peak streamflows. Although urban area in the Big Darby Creek Basin is only a small part of the total drainage area, concern about the potential effects of urban stormwater discharge on such a diverse stream ecosystem prompted a study by the U.S. Geological Survey (USGS), in cooperation with the City of Columbus and Franklin, Madison, and Pickaway Counties. The study objectives were to (1) quantify benthic habitat disturbance by measuring changes in channel morphology and particle-size characteristics of bed material before and after storm runoff, (2) measure the washout and recolonization of the macroinvertebrates and algae, (3) relate the hydrologic and habitat-disturbance factors to the magnitude of washout and rates of recolonization of benthic communities, and (4) document suspended-sediment and water-quality characteristics in the basin.

Data were collected for this study at three stream sites: Hellbranch Run, a second-order stream whose drainage is undergoing urbanization; Little Darby Creek, a third-order stream that drains predominantly agricultural land; and Big Darby Creek, a fourth-order stream whose drainage integrates agricultural land use with increasing urbanization (fig. 1). The site on Big Darby Creek represents drainage from 96 percent of the Big Darby Creek Basin.

Purpose and Scope

This report describes the effects of storm runoff and associated physical disturbances on stream biota in the Big Darby Creek Basin. Hydrologic conditions and habitat disturbances in a stream benthic community were investigated at the three study sites from April 1994 through September 1994. Related factors, such as streambed-sediment particle-size distribution, antecedent streamflow, and biotic interactions are discussed in terms of the washout and recovery of macroinvertebrates and algae.

Acknowledgments

The authors of this report thank The Darby Partnership, the Ohio Chapter of The Nature Conservancy, the City of Columbus, and Franklin, Madison, and Pickaway Counties for their support of this project. Daniel M. Binder and Perry J. Orndorff, City of Columbus Water Quality Assurance Laboratory, are acknowledged for their commitment to helping the project, which included analyzing the water samples and providing perspective on the interpretation of water-quality results. The cooperation and support of Ohio Environmental Protection Agency (OEPA) Division of Surface Water, Monitoring and Assessment Section, is appreciated, especially

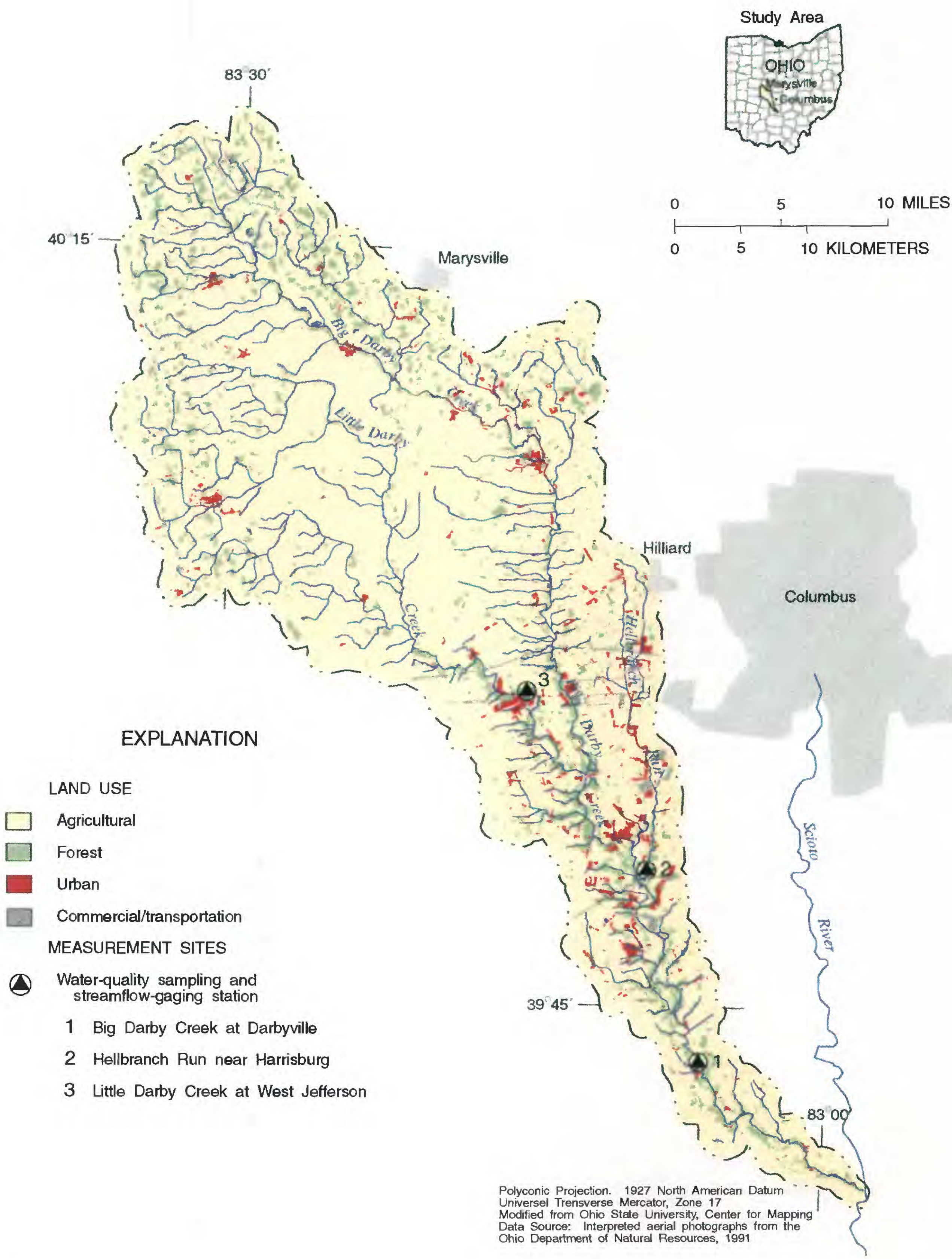

Figure 1. Land use and location of measurement sites, Big Darby Creek Basin.

Michael J. Bolton's analysis of macroinvertebrate taxa and his insight regarding their flow-exposure preference. Dr. Brian J. Armitage, Director of the Ohio Biological Survey, and Dr. Rex L. Lowe and Jennifer Greenwood, Bowling Green State University, are recognized for providing timely results and valuable consultation on the results of the algal community data. John C. Kingston, U. S. Geological Survey National Water Quality Laboratory, Biological/Quality-Assurance Unit, provided valuable expertise and assistance in algal nomenclature that is evolving at this time. We also acknowledge the special efforts of Donna N. Myers and Kevin D. Metzker, U.S. Geological Survey, in coordinating the field and laboratory components of this project,. and Stephen D. Porter, U.S. Geological Survey, for his guidance and commitment to all phases of the project.

STUDY METHODS

Physical and biological data were collected at one riffle site in Hellbranch Run, Little Darby Creek, and Big Darby Creek before and after a spring and summer storm event. A storm event (or simply "event") is defined as the hydrologic conditions associated with a period of time during which rainfall and runoff occurred in the Big Darby Creek Basin. An event was considered to begin on a day in which rainfall was measured at the National Oceanic Atmospheric Administration (NOAA) meteorological station in Marysville, Ohio, and end on the day in which streamflow receded to a value determined as follows:

$$Q_e = Q_p - 0.75\,(Q_p - Q_b),$$

where Q_e is streamflow at the end of the event,
Q_p is runoff-induced peak streamflow, and
Q_b is streamflow at the beginning of the event.

Data related to the spring event (April 6–16, 1994) and the summer event (June 23–July 5, 1994) were collected from April through June 1994 and June through September 1994, respectively. In general, samples were collected before the storms, as soon as streamflow conditions permitted sampling after the storms, and periodically thereafter (totaling six samples per site per event, collected during an 8- to 12-week period). Samples collected immediately before and immediately after the events are referred to as the "pre-event samples" and "first post-event samples," respectively.

Measuring Streamflow and Determining Shear Stress at the Streambed

Streamflow-gaging stations were established for this study on Hellbranch Run near Harrisburg and Little Darby Creek at West Jefferson. A streamflow-gaging station previously had been established in 1922 on Big Darby Creek at Darbyville (fig. 1). Each station was equipped with a pressure transducer and programmable data logger to measure and record stream stage at 15-minute intervals. Standard USGS methods were used to measure and compute streamflow (Rantz and others, 1982).

Shear stress at the streambed was determined for the riffle sites. In an open channel, water is driven downslope by the force of gravity. Friction between the water and the channel boundaries results in a shear stress that is equal to the resisting force over the boundary area. This shear stress, frequently called the boundary shear stress, can be computed as

$$\tau = \gamma R s,$$

where τ is the shear stress,
γ is the specific weight of water,
R is the hydraulic radius, and
s is the energy slope.

Shear stresses were computed on the basis of both the maximum depth and hydraulic radius (which is closer to an average depth in wide channels) for riffle sites on Hellbranch Run, Little Darby Creek, and Big Darby Creek. These shear stresses, which are hereafter referred to as "maximum" and "average" shear stresses, respectively, represent an approximate upper bound for these stresses. It should be noted that the actual shear stress on any particle on the streambed may be considerably different from the maximum or average shear stresses discussed here. Other factors, such as boundary roughness and channel irregularities, tend to increase energy losses and consequently decrease shear. The WSPRO[2] step-backwater model (Shearman, 1990) was used to compute the maximum

[2]WSPRO was developed by the U.S. Geological Survey in cooperation with the Federal Highway Administration. WSPRO is used extensively in the engineering community for the determination of water-surface profiles and hydraulic properties.

depth, hydraulic radius, and energy slope. Step-backwater methods were not appropriate for low flows at these sites; consequently, shear stress values are not reported for the summer pre-event flows.

Streambed Mapping

Cross sections with fixed endpoints were established at each riffle site to establish a grid (composed of 1-m^2 quadrats) for bed-material and biological sampling and to monitor changes in streambed elevation over time. Four cross sections were established at riffle sites on Hellbranch Run and Little Darby Creek to demarcate upper, middle, and lower sampling areas (fig. 2). Three cross sections were established at the riffle site on Big Darby Creek to demarcate upper and lower sampling areas.

The cross sections were surveyed before and after each event by means of conventional differential leveling or by use of an electronic theodolite. A tagline or surveying tape was strung between the fixed endpoints and used as a guide to ensure that streambed elevations were always measured along the same cross sections. All elevations for a given site were referenced to gage datum at the streamflow-gaging station.

Sediment Sampling and Processing

Each streamflow-gaging station was equipped with a refrigerated pumping sampler to collect and store water samples for subsequent suspended-sediment and water-quality analyses. Pumping samplers were programmed to collect water samples at every 1/2-foot increase and 2-foot decrease in stage. In addition to samples collected by means of the pumping samplers, local observers collected daily suspended-sediment samples at the Big Darby Creek and Hellbranch Run stations, and USGS personnel collected

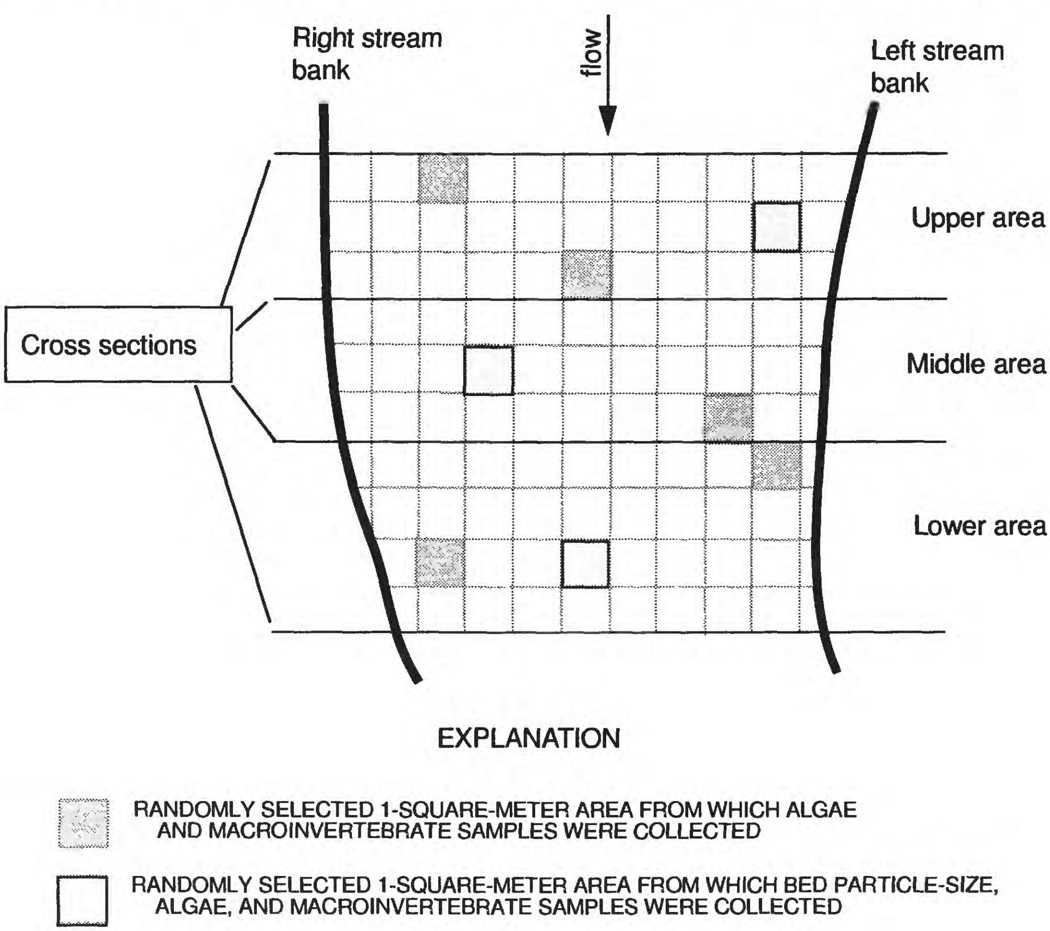

Figure 2. Streambed mapping and sampling design for the collection of macroinvertebrates, algae, and bed particle-size samples.

suspended-sediment samples approximately weekly at the Little Darby Creek station. All suspended-sediment samples were collected by means of methods described by Edwards and Glysson (1988).

Suspended-sediment concentrations were determined by use of standard filtration methods (Guy, 1969) at the Water Quality Laboratory at Heidelberg College, Tiffin, Ohio. Suspended-sediment loads were determined by means of methods described by Porterfield (1972).

The surface bed layer of gravel-bed streams commonly is coarser than the subsurface material. Consequently, two methods were used to characterize the bed sediments. A pebble count (Wolman, 1954) was used to characterize the surface layer, and a freeze-core method (Palcsak, 1996) was used to characterize the subsurface materials.

Pebble counts were done by randomly selecting 100 streambed particles collected along transects spanning the stratified areas (usually the upper, middle, and lower riffle areas). The size of a particle was classified according to the length of its intermediate axis (the axis intermediate in length between the longest and shortest of three mutually perpendicular axes) determined for each particle by means of a template containing a series of square openings with side lengths ranging from 8 to 128 mm at half-phi intervals. (Phi is equal to $-\log_2$ of the length, in millimeters.) The size of the smallest square through which a particle passed was considered to be the upper limit of that particle's size-class range, and the size of the next smaller square was considered to be the lower limit of the size-class range. Thus, a particle passing through the 11.3 mm square but not passing through the 8 mm square would be classified as being in the size-class range extending from 8 to 11.3 mm.

A freeze-core method was used to collect subsurface bed materials from three sampling areas at each riffle site (fig. 2) during each sampling date. The freeze-core method uses a three-tube device, driven approximately 0.2 to 0.4 m (about 0.65 to 1.3 ft) into the streambed, through which a compressed gas is allowed to expand (Everest and others, 1980). The temperature reduction associated with the expanding gas freezes the interstitial water in the bed adjacent to the tubes, allowing the frozen core of relatively undisturbed sediment and organic material to be removed from the streambed. Particle-size distributions of the freeze-core samples, which averaged 7.6 kg per sample, were determined at the USGS office in Columbus by means of dry-sieve analysis (Guy, 1969). The percentage of the particles finer than integer phi values was determined by means of the USGS program SEDSIZE (Stevens and Hubbell, 1986).

Collecting and Processing Biotic Samples

Macroinvertebrates. A stratified random-sampling design was used within each sampling area to select eight 1-m^2 quadrats for collection of macroinvertebrate, algae, and bed particle-size samples (fig. 2). The stratification of areas within each riffle site was based on substrate particle-size characteristics so as to promote consistent representation of macroinvertebrate habitats and reduce sampling variability (Lamberti and Resh, 1979). No quadrat was sampled more than once during the study.

Surber samplers, fitted with 224-µm nylon-mesh nets, metal bases (2.5 cm in depth), and wooden handles were used to sample 929 cm^2 (1 ft^2) of bed material before and after the spring event. The same Surber samplers, equipped instead with 600-µm mesh nets, were used to sample before and after the summer event. (The larger mesh was used during the summer event to alleviate clogging problems with the 224-µm mesh, which were thought to cause organisms to be washed out of the sampler).

Rocks, palm size or larger and lying 50 percent or more within the Surber frame, were scrubbed by hand and examined for attached macroinvertebrates. Scrubbed rocks and native mussels were removed from the frame and returned to the stream. Bed material was then raked with a three-prong garden tool. Smaller rocks and sediment were raked upward into the water column to dislodge the organisms and wash them into the Surber net. Bed material was sampled to a depth of about 10 cm, then the material that accumulated on the net was cleaned of debris, split, and preserved in 95 percent ethanol for further processing.

Each of the eight macroinvertebrate samples from the riffle sites was split into two replicates by means of a Folsom plankton splitter, and one replicate was reserved for archival purposes. Each remaining replicate was combined with another replicate from the same sampling area (where possible), resulting in four composite samples, each representing 929 cm^2 of stream substrate. Median density of organisms and the relative abundance of each group of organisms were computed with reference to the four composite samples from each sampling date. Preserved macroinvertebrate samples were analyzed by the Ohio Biological Survey (through its network of taxonomic specialists) to identify the taxa to the lowest possible taxonomic level and to determine total numbers of organisms per sample. The total number of taxa reported per sample is a minimum estimate because some taxa could not be identified to the species level and consequently were counted as unique only if no other species within the genus were identified.

No mollusks were collected during the event sampling because two species of freshwater mussels — the clubshell (*Pleurobema clava*) inhabiting Little Darby Creek and the Northern riffleshell (*Epioblasma torulosa rangiana*) inhabiting Big Darby Creek — are listed as endangered species by the Federal government.

Snails were collected separately in 1995 to help explain the decline in algal-cell densities that occurred at all three sites in May 1994. The snails were collected by use of the same stratified random sampling design and Surber sampler (600-µm mesh) used to collect macroinvertebrates in 1994.

Algae. Algal samples were collected from rocks found within the same eight quadrats from which the macroinvertebrate samples were collected. Rocks representative of the coarse bed material in the quadrat were gently removed and taken to the streambank for sample processing. Algae harvested from each quadrat represented a total surface area of approximately 200 cm^2, as determined by the perimeter method (Graham and others, 1988).

Algal samples were chilled and transported to the USGS office for additional processing and preservation. Volumes of the samples collected from the eight quadrats were measured in the laboratory, mixed with a biohomogenizer for 30 seconds, and subsampled with a wide-mouth pipette. Four 12-mL composite samples were made up, each formed by combining 5 mL of subsample from each of two quadrats (located within the same sampling area, where possible) and adding 2 mL of 25 percent buffered glutaraldehyde as a preservative. A 0.1-mL aliquot of each composite sample was individually pipetted into a Palmer-Maloney nannoplankton counting chamber. The first 500 algal cells were enumerated and identified to genus and species (where possible); then, algal densities were calculated on the basis of sample volumes, area sampled, and dilution factor used.

Ancillary data on tree canopy and light intensity reaching the stream surface were collected at the three riffle sites on September 9, 1994. The presence or absence of tree canopy was noted at 0.6-m increments along the cross sections used for streambed mapping. The percentage of streambed area where canopy obstructed the sky was determined by superimposing the canopy observations on the sampling grid, interpolating canopy boundaries between cross sections, and counting the numbers of open and obstructed quadrats.

Light intensity, in microeinsteins, was measured at midday by means of a Li-Cor quantum light sensor held at the water surface. Light-intensity measurements were made along the cross sections used for streambed mapping and in open areas near each site in order to estimate the percentage of ambient light reaching the stream surface.

Water-Quality Sampling and Analysis

Water-quality samples were collected during biological sample collections and during periods of runoff to help characterize water quality over a range of streamflow conditions. The water-quality samples were collected at the riffle sites (upstream from the streamflow-gaging stations) during biological sampling periods and at the three streamflow-gaging stations during periods of runoff.

Runoff samples were collected by means of refrigerated pumping samplers and were transported on ice to the USGS office in Columbus for processing. A cone splitter (Ward and Harr, 1990) was used to split the samples into three prelabeled bottles for determination of various constituents. The three subsamples consisted of (1) a 1-L amber glass bottle, for pesticide determinations; (2) a 500-mL polyethylene bottle preserved with 1 mL of sulfuric acid, for nutrient determinations; and (3) a pint glass bottle, for suspended-solids determinations (see "Measurement of Streamflow and Suspended Sediment"). Samples for subsequent nutrient and pesticide determinations were kept cold and transported to the City of Columbus Water Quality Assurance Laboratory. Concentration of each constituent was determined according to standard U.S. Environmental Protection Agency (USEPA) drinking-water methods (U.S. Environmental Protection Agency, 1995). The analyses of nutrients included (1) nitrate plus nitrite, (2) ammonia, (3) total phosphorus, and (4) orthophosphorus. Triazine pesticides (alachlor, atrazine, cyanazine, metolachlor, and simazine) were analyzed by means of gas chromatography (USEPA method 507).

Water-quality samples were collected at the riffle sites by means of the equal-width-increment (EWI) sampling method (Edwards and Glysson, 1988). Samples were collected with depth-integrating isokinetic samplers equipped with either a 1-L or 3-L Teflon collecting bottle, were processed at the riffle site, and were transported on ice to the City of Columbus Water Quality Assurance Laboratory. Specific conductance, water temperature, pH, and dissolved oxygen were measured at each site by use of a four-parameter Hydrolab meter.

Quality Assurance

Quality assurance was an integral part of all water-quality and biological work discussed in this report. Quality-control requirements were written in the macroinvertebrate and periphyton laboratory contracts. The quality of macroinvertebrate-sample identification and quantification was assessed by submitting 2 percent of the sample splits to the OEPA and by consulting with a network of specialists through the Ohio Biological Survey for help with unusual taxa and review of the macroinvertebrate taxonomic list (Appendix 1). Quality-control measures for periphyton analyses included recounting and reidentification of periphyton in 5 percent of the samples analyzed by the contracted laboratory. In addition, replicate samples (totalling 2 percent of samples analyzed) were analyzed by an independent laboratory. Criteria for acceptance of replicates was 85 percent for agreement in estimates of cell density, and 80 percent agreement for taxonomic identification. During May 1994, the macroalga *Cladophora* was present in dense patches, and the agreement in cell densities between replicate samples was below 85 percent. As a result, samples were recounted by use of a Sedgewick Rafter counting cell to provide a more accurate count. The greatest difference between results from the two laboratories was that one laboratory typically identified the blue-green algae (Cyanophyta, Appendix 2) to genera, whereas the other extended the identification to species. Algal frequencies reported in Appendix 2 are aggregated at the genera level unless both laboratories reported a given genus to the species level.

Macroinvertebrate reference samples are available at the Ohio Biological Survey, Columbus, Ohio, and reference collections of the algal taxa identified during this study are being maintained at Bowling Green State University, Bowling Green, Ohio.

The Columbus Water Quality Assurance Laboratory is an Ohio Environmental Protection Agency (OEPA) drinking-water certified lab and, during this project, participated in the USGS National Water Quality Reference Program. In addition, the Columbus Water Quality Assurance Laboratory participated in the USGS Standard Water Reference Sample (SWRS) program by performing semiannual analyses of total phosphorus, nitrate plus nitrite, and ammonia reference samples. Results reported by the laboratory for these SWRS constituents were within the acceptable range. Reference samples and blanks each constituted greater than 5 percent of the streamwater samples analyzed.

The quality of suspended-sediment samples analyzed by the Heildelberg Water Quality Laboratory was assessed by requiring that the laboratory participate in the USGS's standard reference sample program for sediment and by requiring that distilled water blanks be analyzed and reported regularly. In addition, most samples were sent and analyzed in duplicate. Analytical results for blanks and duplicate samples were examined for evidence of laboratory and sampling error. Cross-sectional samples were collected over a range of streamflow to define the relation between mean concentrations in the cross section and concentrations determined for samples collected by the pumping sampler. If necessary, concentrations determined for samples collected by the pumping sampler were adjusted based on the relation just described to better approximate the cross-sectional mean concentrations.

HYDROLOGIC DISTURBANCE

Storms of sufficient magnitude to result in streambed scour are known to cause disruptions of the aquatic community by washing out organisms that do not find refuge in the interstitial environment of the substrate or in the hyporheic (subsurface) zone. Macroinvertebrates and algae often recolonize in a matter of weeks or months when disruption is non-catastrophic. However, increased runoff intensity and frequency due to loss of vegetated land cover, which can occur in watersheds undergoing urban and agricultural development, promotes substrate movement and (or) changes in sediment-deposition patterns that can affect the dynamics of washout and recolonization.

For these reasons, hydrologic and habitat-disturbance factors were measured in the study area before and after the spring event (April 6–16, 1994) and the summer event (June 23 – July 5, 1994).

Streamflow-Related Factors

Evaluating disturbance of the aquatic biota by streamflow involves an understanding of streamflow conditions that the biota were adapted to, and the influence of the streamflow on the streambed habitat.

Trends in Annual Peak Streamflows

Historical hydrologic records were analyzed to add long-term perspective to the interpretation of hydrologic disturbance associated with storm events during this study. Sufficient streamflow data were available for one site, Big Darby Creek at Darbyville (03230500), to test the hypothesis that the magnitude of the annual peak streamflows has changed (either increased or decreased) over time. A total of 71 years (water years 1922–36 and 1938–93) of annual peak streamflow data (fig. 3) were analyzed by means of the nonparametric Mann-Kendall test (Helsel and Hirsch, 1992) to determine whether annual peak streamflows tended to increase or decrease monotonically with time. No statistically significant[3] trend in annual peak streamflows was detected. The absence of a trend indicates that no significant monotonic increase or decrease in the magnitude of peak streamflows occurred during the period 1922–93.

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[3]In this report, the term "significant" refers to the condition in which the p-value associated with an observed value of a test statistic is less than or equal to 0.05, and, consequently, the null hypothesis is rejected.

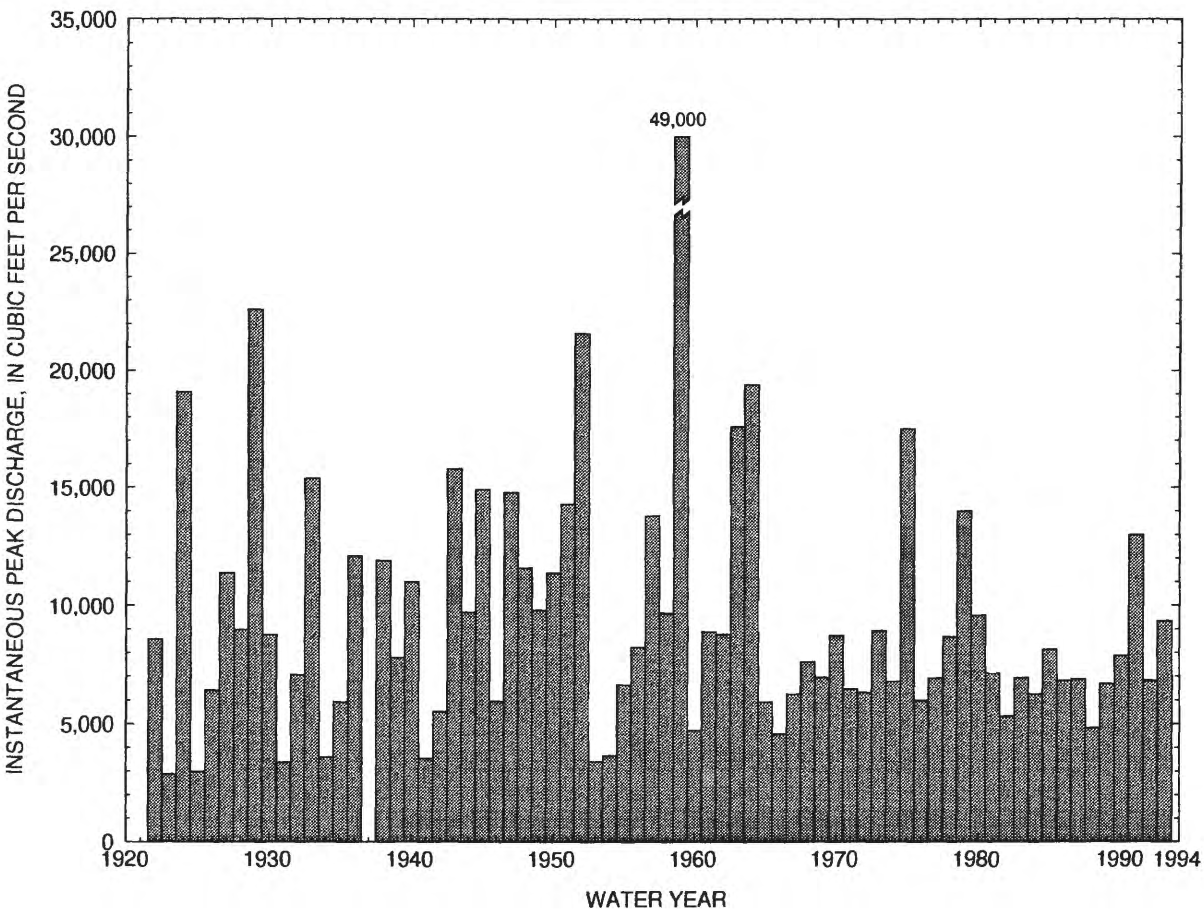


Figure 3. Annual instantaneous peak streamflow for Big Darby Creek at Darbyville, Ohio, water years 1922-94.

Antecedent Conditions

The winter period (January through March 1994) preceding the spring event included prolonged periods of below-freezing temperatures that resulted in freezing of stream surfaces and formation of anchor ice at the Hellbranch Run site. Monthly average temperatures in the NOAA Central Division (a division is an area of fairly uniform climatological characteristics), which includes most of the Big Darby Creek Basin, were 20.1°F for January, 28.7°F for February, and 38.6°F for March, corresponding to departures from normal[4] of -6.0, -0.6, and -1.9°F, respectively (National Oceanic and Atmospheric Administration, 1994a,b).

Cumulative precipitation from January through March 1994 in the NOAA Central Division was 7.23 in., a departure from normal of -0.19 in. Within the NOAA Central Division, April precipitation totals were quite variable and ranged from 2.66 to 6.22 in.; monthly departures from normal ranged from -0.81 to 2.65 in.

Precipitation totaled 0.43 in. for April 1–5, 1994, at the NOAA meteorological site at Marysville, Ohio (on the north-central edge of the Big Darby Basin), with most of the precipitation (0.32 in.) falling on April 4. Precipitation for the spring event (April 6–16, 1994) totaled 2.18 in., the greatest daily precipitation (0.78 in.) falling on April 10.

Precipitation for June 1–22, 1994, was sparse at the Marysville, Ohio, meteorological site; total rainfall was approximately 0.78 in., more than half of which fell on or before June 13. Precipitation for the summer event (June 23–July 5, 1994), totaled approximately 4.74 in., with daily rainfall totals in excess of 1 in. on June 24, June 27, and July 3, 1994.

Information on change in water levels, maximum streamflows and 7-day mean antecedent streamflows for the spring and summer events at the Hellbranch Run, Little Darby Creek, and Big Darby Creek streamflow-gaging stations is listed in table 1. The maximum streamflows at the streamflow-gaging stations during the spring storm event ranged from about 7 to 19 times the mean streamflows for the preceding 7-day period. The magnitude of difference between pre-event streamflows and maximum streamflows at the streamflow-gaging stations during the summer event was higher than that for the spring event, ranging from about 15 times to 30 times the respective mean streamflows for the preceding 7 days. To allow for a comparison between the streamflow events documented during this study with other storm events, flood-frequency data for the three sites are listed in table 2. The maximum steamflows for both storms (table 1, fig. 4) were considerably less than the respective 2-year flood-peak discharges reported for all three streamflow-gaging stations (table 2).

[4]With respect to the meteorological data in this report, normal refers to the average value for the period 1961–90.

Shear Stress at the Streambed

Shear stresses computed for streamflow conditions antecedent to the spring rainfall events and for the spring and summer rainfall events are listed in table 3. The pre-event average shear stress was lowest at Little Darby Creek, followed by those at Hellbranch Run and Big Darby Creek. The ratio of the spring-event average shear stress to the spring pre-event average shear stress ranged from 0.93 to 2.90 (table 3). As compared to pre-event levels, shear stresses increased during the spring event at Little Darby Creek and Hellbranch Run but decreased at Big Darby Creek. Shear stresses can decrease as water depth increases during storms because the energy gradient can be reduced as water fills the channel.

Sediment-Related Factors

The amount and size of sediment particles suspended in the water column and deposited on the streambed can influence the quality of habitat for benthic organisms. Sediments can clog the gills of benthic organisms, cover their homes, or fill interstitial spaces in the streambed where some organisms live and breathe. Bed-sediment analysis provides a description of the available habitat for the aquatic biota, and repeated measurements of streambed cross sections over time provide an indication of the erosion and deposition at the study sites.

Suspended Sediment

Suspended sediment is sediment that is transported in suspension by a stream, in contrast to bedload, which is sediment that moves on or near the streambed and is in almost continuous contact with the bed (Paulson and others, 1993). In the context of this study, suspended-sediment load refers to the dry weight of sediment (measured in tons) that passes a section of a stream. The drainage areas above the three streamflow-gaging stations and the relative percentage of streamflow, and suspended-sediment loads that the three streams contributed in 1993 and 1994 are listed in table 4. The 1994 total annual suspended-sediment loads at the streamflow-gaging stations on Hellbranch Run, Little Darby Creek, and Big Darby Creek were 4,180 tons, 12,100 tons, and 50,200 tons, respectively. Suspended-sediment loads determined for a winter storm event (one during January 25–31 which produced the highest streamflows at the three sites in water year 1994) and the spring and summer events, along with their corresponding percentages of the annual suspended-sediment load, are listed in table 5. The suspended-sediment loads for the two storms measured for this study were not large relative to the 1994 annual suspended-sediment loads, nor were the

Table 1. Change in water levels during selected 1994 storms and maximum event streamflows in the Big Darby Creek Basin, Ohio

[Spring refers to the period April 6-16,1994; summer refers to the period June 23-July 5, 1994; ft, feet; ft^3/s, cubic feet per second]

Station number	Station name	Change in water level during spring and summer events (ft)		Maximum streamflow during spring and summer events (ft^3/s)		Mean streamflow for 7-day period prior to events (ft^3/s)	
		Spring	Summer	Spring	Summer	Spring	Summer
03230450	Hellbranch Run near Harrisburg	2.76	3.4[a]	722	56[a]	38	3.3
03230310	Little Darby Creek at West Jefferson	3.09	3.19	1,170	817	142	27
03230500	Big Darby Creek at Darbyville	5.04	3.48	3,790	1,750	559	112

[a]Due to equipment failure at gage, value was estimated.

Table 2. Flood-frequency data for streamflow-gaging stations in Big Darby Creek Basin, Ohio

Station number	Station name	Flood-peak discharge, in cubic feet per second, for indicated recurrence interval, in years					
		2	5	10	25	50	100
03230450[a]	Hellbranch Run near Harrisburg	1,350	2,140	2,710	3,460	4,020	4,610
03230310[a]	Little Darby Creek at West Jefferson	3,810	5,760	7,130	8,920	10,300	11,700
03230500[b]	Big Darby Creek at Darbyville	8,260	13,100	16,900	22,300	26,700	31,500

[a]Peak discharges determined by means of regional regression equations reported in Koltun and Roberts (1990).

[b]Peak discharges are weighted averages of regional regression equation estimates and log-Pearson Type 3 estimates (Koltun and Roberts, 1990).

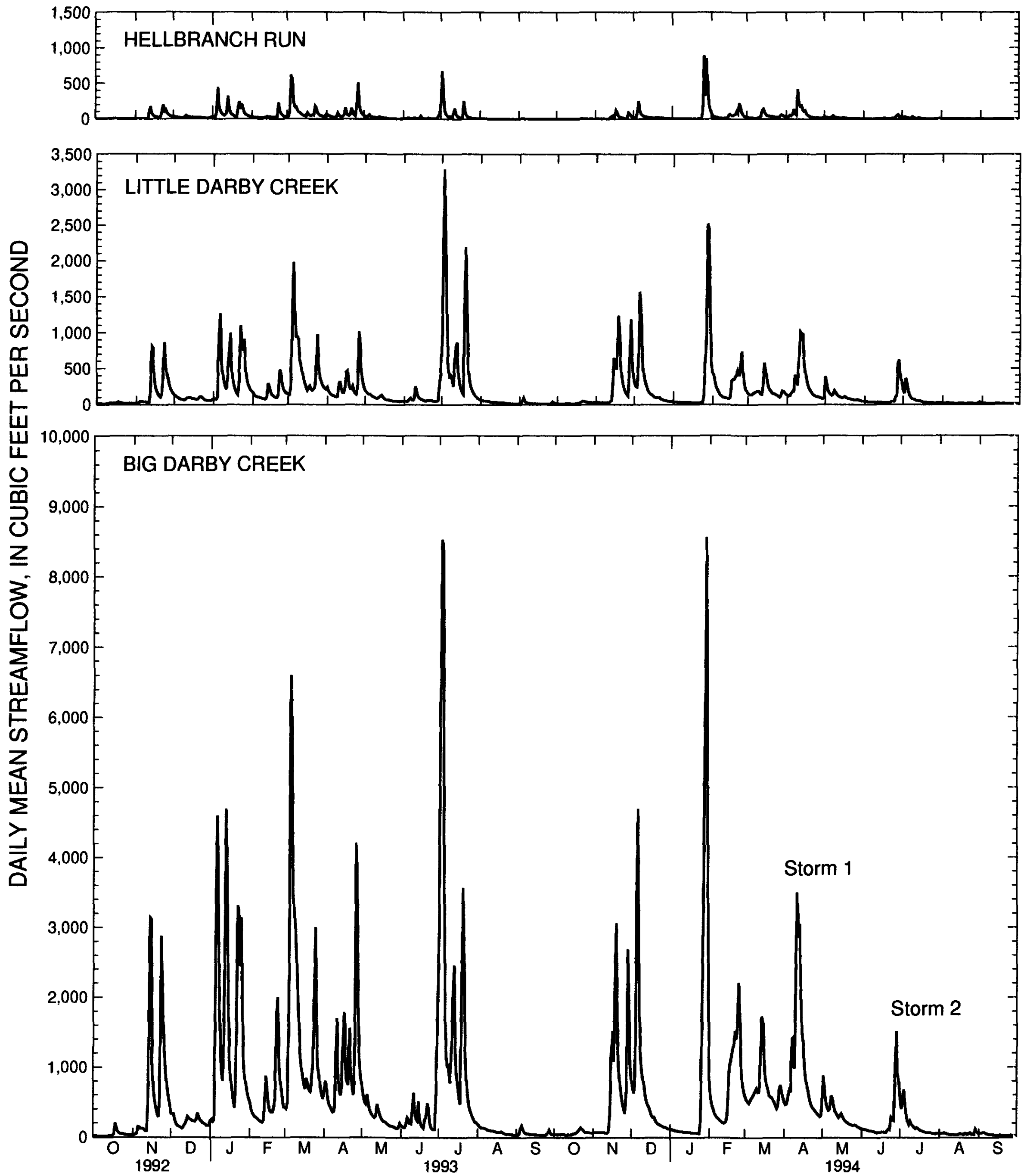


Figure 4. Daily mean streamflow for Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio, October 1992-September 1994, including spring and summer storm events studied for aquatic-biota response.

Table 3. Shear stress for antecedent and event conditions at riffle sites in Big Darby Creek Basin, Ohio

Condition	Date	Gage height, in feet[1]	Streamflow, in cubic feet per second[1]	Average cross-sectional velocity, in feet per second (centimeters per second)	Shear stress,[2] in newtons per square meter		Ratio of the event average shear to pre-event average shear
					Maximum	Average	
Hellbranch Run							
Spring pre-event	04-04-94	5.50	54	1.9 (58)	27.5	12.8	1.53
Spring event	04-10-94	8.12	722	5.0 (152)	36.7	19.6	
Summer pre-event	06-06-94	4.83	2	([3])	([3])	([3])	([3])
Summer event	06-28-94	5.51[4]	56[4]	1.9 (58)[4]	27.5[4]	12.8[4]	
Little Darby Creek							
Spring pre-event	04-05-94	6.08	177	2.6 (79)	16.2	8.9	2.90
Spring event	04-13-94	9.09	1,170	5.3 (162)	48	25.8	
Summer pre-event	06-07-94	4.97	31	([3])	([3])	([3])	([3])
Summer event	06-27-94	8.21	817	4.8 (146)	39	20	
Big Darby Creek							
Spring pre-event	04-05-94	2.96	673	3.1 (94)	20.0	14.3	0.93
Spring event	04-10-94	7.99	3,790	3.8 (116)	17.9	13.3	
Summer pre-event	06-08-94	1.14	132	([3])	([3])	([3])	([3])
Summer event	06-28-94	5.11	1,750	3.4 (104)	19.5	14.0	

[1] Pre-event: gage height and streamflow are daily means. Event: gage height and streamflow are peaks for that event.
[2] Shear stress in pounds per square foot can be calculated by dividing newtons per meter square by 47.87.
[3] Not determined.
4 Estimated.

storm loads large relative to those for the event of January 25–31, 1994.

Sediment-transport plots were developed to display the relation between instantaneous streamflow yield (in cubic feet per second per square mile) and instantaneous sediment yield (in tons per day per square mile) for the streamflow-gaging stations on Hellbranch Run (fig. 5), Little Darby Creek (fig. 6), and Big Darby Creek (fig. 7). Suspended-sediment data from 1993–94 are plotted for each streamflow-gaging station. Historical suspended-sediment data, collected during 1969–74, are available for the Big Darby Creek streamflow-gaging station; consequently, the historical data also are shown (with a different symbol) for that site.

The sediment-transport plots show that the slope of the relation between instantaneous streamflow yield and instantaneous sediment yield is similar for the Little and Big Darby Creek streamflow-gaging stations. This similarity indicates that the sediment yield at both sites increases by about the same amount for a given increase in streamflow yield.

The sediment-transport plot for Hellbranch Run (fig. 5) shows a lower limb corresponding to those data pairs having instantaneous streamflow yields less than about 0.5 $ft^3/s/mi^2$ and an upper limb approximately corresponding to data pairs having

Table 4. Summary of mean daily streamflows and annual suspended-sediment loads, Big Darby Creek Basin, Ohio, 1993 and 1994
[mi^2, square mile; ft^3/s, cubic feet per second]

Gaging station	Drainage area (mi^2)	Percentage of drainage area at Big Darby Creek at Darbyville	Mean daily stream-flow (ft^3/s)	Percentage of stream-flow at Big Darby Creek at Darbyville	Annual suspended-sediment load (tons)	Percentage of annual suspended-sediment load at Big Darby Creek at Darbyville
			1993			
Hellbranch Run near Harrisburg	37	7	42	6	6,940	5
Little Darby Creek at West Jefferson	162	30	220	31	17,400	13
Big Darby Creek at Darbyville	534	100	713	100	139,000	100
			1994			
Hellbranch Run near Harrisburg	37	7	29	6	4,180	8
Little Darby Creek at West Jefferson	162	30	160	34	12,100	24
Big Darby Creek at Darbyville	534	100	476	100	50,200	100

Table 5. Suspended-sediment loads for winter, spring, and summer events, 1994, and their corresponding percentages of the annual suspended-sediment load, Big Darby Creek Basin, Ohio

Gaging station	Suspended-sediment load, Jan. 25-31, 1994 (tons)	Percentage of 1994 annual suspended-sediment load	Suspended-sediment load, Apr. 6-16, 1994 (tons)	Percentage of 1994 annual suspended-sediment load	Suspended-sediment load, June 23-July 5, 1994 (tons)	Percentage of 1994 annual suspended-sediment load
Hellbranch Run near Harrisburg	2,540	61	1,020	24	26	<1
Little Darby Creek at West Jefferson	3,690	30	1,110	9	1,290	11
Big Darby Creek at Darbyville	14,600	29	11,400	23	2,450	5

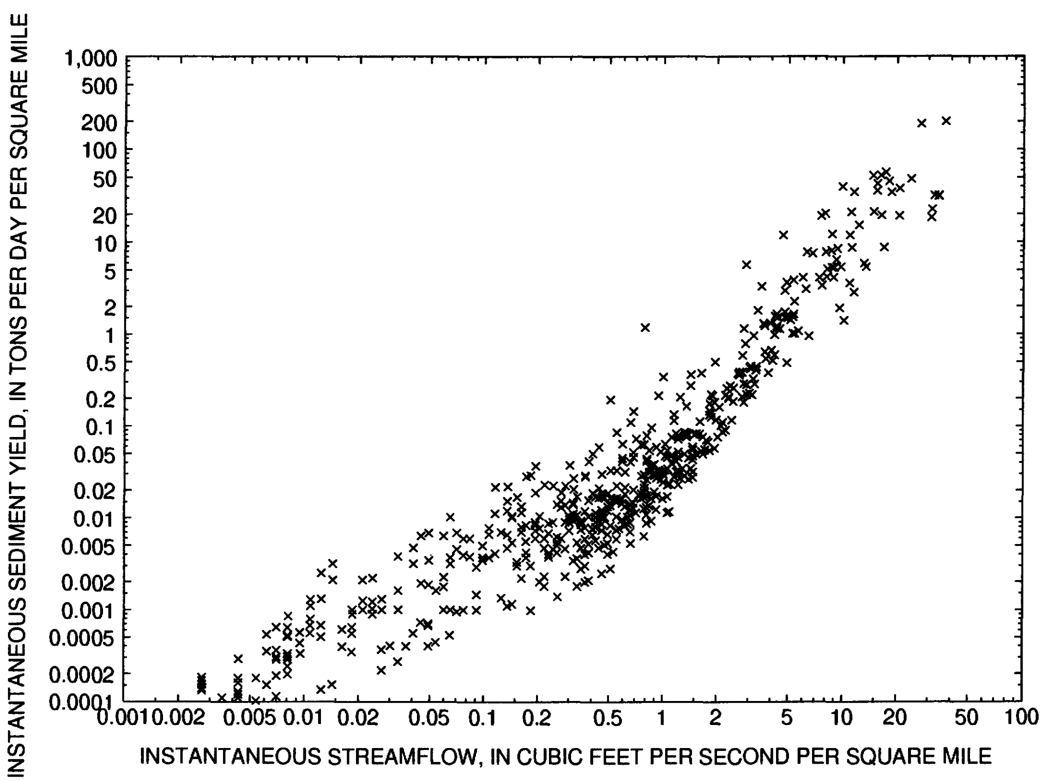


Figure 5. Sediment-transport curve for Hellbranch Run near Harrisburg, Ohio, expressed as instantaneous sediment yield, based on data collected, October 1992-September 1994.

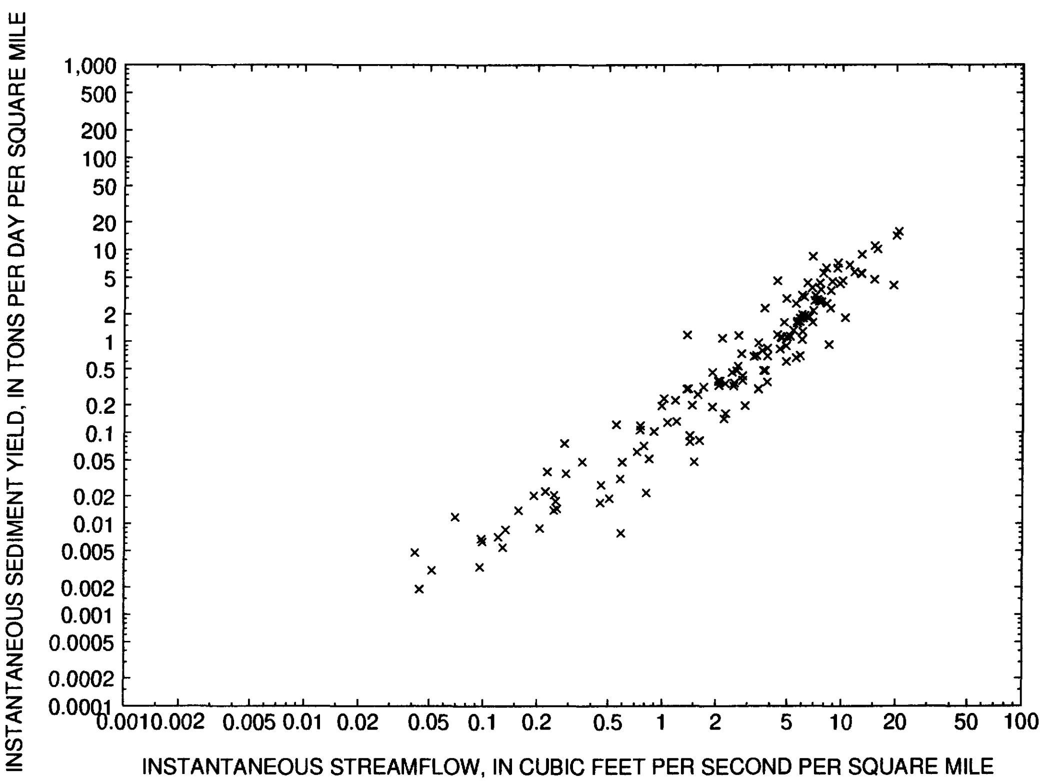


Figure 6. Sediment-transport curve for Little Darby Creek at West Jefferson, Ohio, expressed as instantaneous sediment yied, based on data collected, October 1992-September 1994.

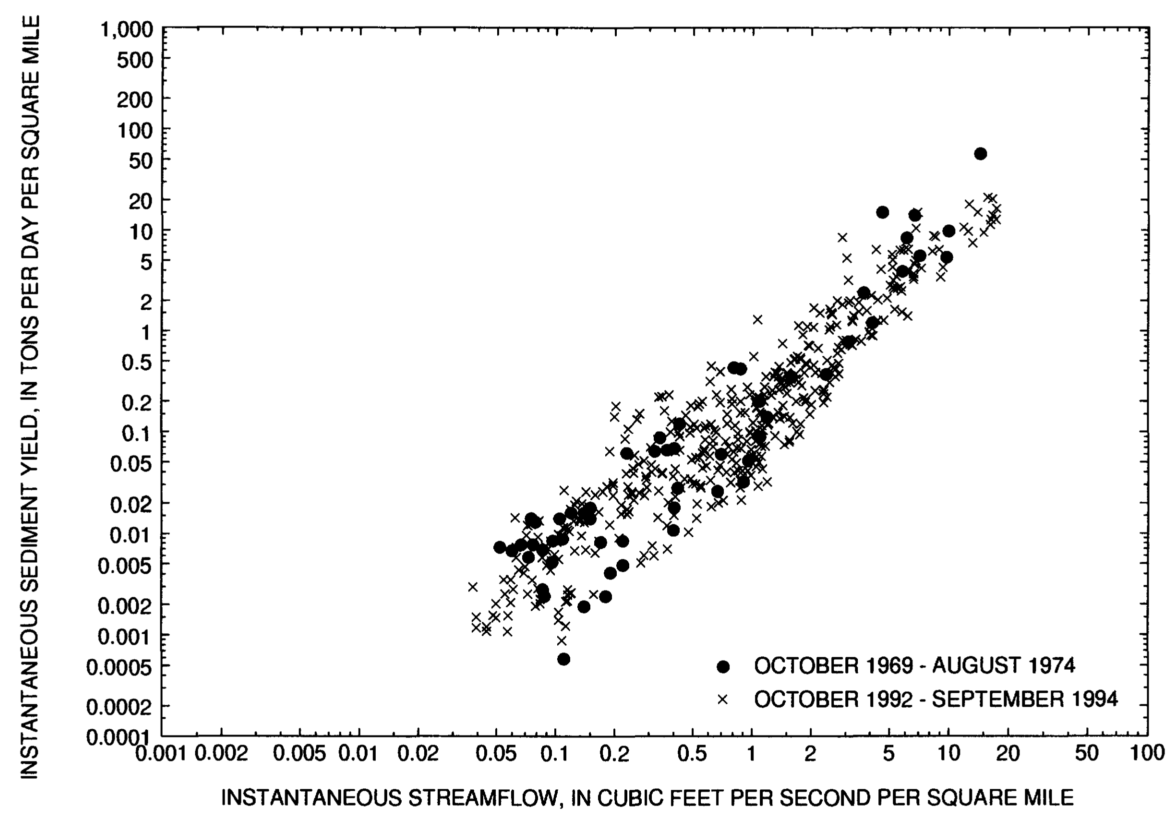


Figure 7. Sediment-transport curve for Big Darby Creek at Darbyville, Ohio, expressed as instantaneous sediment yield.

instantaneous streamflow yields greater than or equal to 0.5 $ft^3/s/mi^2$. A comparison of the transport plots in a range of instantaneous streamflow yields common to all three stations (yields greater than or equal to 0.5 $ft^3/s/mi^2$) indicates that the sediment yield at Hellbranch Run increases by a greater amount for a given increase in streamflow yield than at the Little or Big Darby Creek stations. Many factors can affect the slope of the transport relation; for example, sediment yield tends to increase with decreasing drainage area (Vanoni, 1975).

The historical data shown in the transport plot for Big Darby Creek (fig. 7) generally fall within the scatter of data collected during October 1992 – September 1994. In a qualitative sense, this pattern indicates that the transport relation has not changed greatly in the intervening period. Land-use practices have changed since the 1969–74 data were collected; however, the small amount of historical data (< 5 years) does not permit a more detailed comparison of the relation between instantaneous streamflow yield and land use.

Bed Sediment

Pebble count and freeze-core data were used to describe surface and subsurface bed-material particle-size distributions, respectively. Samples were collected in 1994 before each event and then again as soon as the study sites were accessible after the events. Additional samples were collected periodically thereafter.

Particle-size data obtained for each sample were analyzed to determine particle diameters that correspond to selected percentiles of the size distribution. In particular, particle diameters were determined for which 16, 50, and 84 percent of the sample was finer. These diameters, referred to as the d_{16}, d_{50}, and d_{84}, respectively, are listed in tables 6 and 7 for the surface and subsurface bed materials. The medians of the d_{50} values for surface materials for all sampling dates (table 6) were 51.3 mm (2 in.) for Hellbranch Run, 47.9 mm (1.9 in.) for Little Darby Creek, and 46.6 mm (1.8 in.) for Big Darby Creek. This range of median particle sizes (46.6–51.3 mm) falls within the range commonly classified as very coarse gravel (Lane, 1947). The medians of the d_{50} values for subsurface

Table 6. Selected percentiles of the particle-size distribution of surface bed-material samples collected at riffle sites in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio

[Particle-size diameters are in millimeters]

Date	16% of sample finer than indicated diameter (d_{16})	50% of sample finer than indicated diameter (d_{50})	84% of sample finer than indicated diameter (d_{84})
Hellbranch Run near Harrisburg			
04-04-94	26.4	53.8	90.6
04-15-94	22.5	46.3	90.7
04-22-94	20.0	44.5	95.4
04-29-94	33.9	61.7	95.9
05-18-94	19.2	48.7	86.4
06-06-94	32.1	58.9	103.0
06-30-94	17.1	48.2	75.5
07-21-94	34.4	56.0	84.2
Little Darby Creek at West Jefferson			
04-05-94	22.5	48.9	87.2
04-19-95	20.0	42.7	75.6
04-25-94	20.8	42.9	83.8
05-04-94	26.0	52.2	78.1
05-19-94	18.0	43.1	64.1
06-07-94	18.9	48.7	77.9
07-06-94	18.2	48.4	75.1
07-19-94	21.7	47.3	75.2
Big Darby Creek at Darbyville			
03-04-94	27.6	53.0	110.0
04-21-94	18.1	46.6	98.7
04-27-94	17.5	46.0	120.8
05-06-94	21.6	46.6	101.5
07-13-94	17.8	42.5	90.3
07-20-94	17.8	48.0	83.3

materials for all sampling dates (table 7) were 22.4 mm (0.9 in.) for Hellbranch Run, 28.3 mm (1.1 in.) for Little Darby Creek, and 24.2 mm (nearly 1 in.) for Big Darby Creek. This latter range of median particle sizes (22.4–28.3 mm) falls within the range commonly classified as coarse gravel.

The subsurface bed material of all three study sites can be characterized as predominantly gravel with some sand and very little, if any, silt and clay (table 7). Based on the median percentage of gravel and larger particles in the freeze-core samples, subsurface sediments were generally coarsest at Big Darby Creek. The particle-size distributions of the subsurface bed material at Little Darby Creek and Hellbranch Run were generally similar.

The d_{50} data listed in table 7 suggest that subsurface bed materials tended to become coarser at Big Darby Creek from March to July. In contrast, subsurface bed materials at Hellbranch Run tended to become finer over the period April 4–29 and then remained relatively unchanged. The trend in d_{50} data at Little Darby Creek is less consistent than trends at either Big Darby Creek or Hellbranch Run; however, the data suggest that subsurface bed materials tended to become coarser there as well. No trend in d_{50} values of surface bed materials was apparent for any of the sites.

Erosion and Deposition at the Study Sites

Data gathered from a series of cross sections surveyed at riffle sites on Hellbranch Run, Little Darby Creek, and Big Darby Creek were used to assess short-term temporal changes in streambed elevation associated with streambed erosion or deposition. Cross sections were surveyed at all riffle sites in August 1993, July 1994, and October 1994 (figs. 8–10). In addition, cross sections were surveyed at the Big and Little Darby riffle sites in April 1994. Temporal changes in streambed elevations were assessed visually by reviewing overlaid plots of profile data that were gathered over time at each cross-section location.

Generally, the largest change in streambed elevations occurred between the measurements made in August 1993 and the first measurements made in 1994. A lack of survey data immediately prior to the spring storm makes it impossible to determine how much of the observed changes in streambed elevations were attributable to that storm. However, the changes are presumed to have resulted primarily from the flood that occurred in January 1994, during which peak

Table 7. Selected particle-size characteristics of subsurface bed-material samples collected at riffle sites in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio

[Particle-size diameters are in millimeters (mm)]

Date	16% of sample finer than indicated diameter (d_{16})	50% of sample finer than indicated diameter (d_{50})	84% of sample finer than indicated diameter (d_{84})	Percentage of gravel (2.0-64 mm)	Percentage of sand (0.062-2.0 mm)	Percentage of silt and clay (<0.062mm)
Hellbranch Run near Harrisburg						
04-04-94	5.1	35.6	68.7	89	10	1
04-15-94	3.4	33.1	64.4	89	10	1
04-22-94	2.3	23.2	48.0	85	13	2
04-29-94	2.3	21.2	50.8	85	15	0
05-18-94	4.7	22.4	44.9	90	9	1
06-06-94	2.8	21.8	38.0	87	12	1
06-30-94	1.9	22.3	50.6	83	16	1
07-21-94	1.6	18.6	44.6	83	14	3
Little Darby Creek at West Jefferson						
04-05-94	4.5	26.7	48.9	90	10	0
04-19-95	1.4	16.9	57.7	80	18	2
04-25-94	1.5	20.3	52.9	81	17	2
05-04-94	2.9	22.2	45.4	87	13	0
05-19-94	5.1	32.8	48.6	91	8	1
06-07-94	3.0	32.2	56.8	87	12	1
07-06-94	4.2	39.4	90.1	89	10	1
07-19-94	3.7	29.9	55.4	88	11	1
Big Darby Creek at Darbyville						
03-04-94	4.1	20.2	36.4	91	8	1
04-21-94	3.7	19.5	43.5	89	10	1
04-27-94	2.9	21.2	44.6	88	11	1
05-06-94	6.7	27.2	100.0	93	7	0
07-13-94	6.6	30.0	98.8	95	4	1
07-20-94	19.0	71.0	210.8	96	4	0

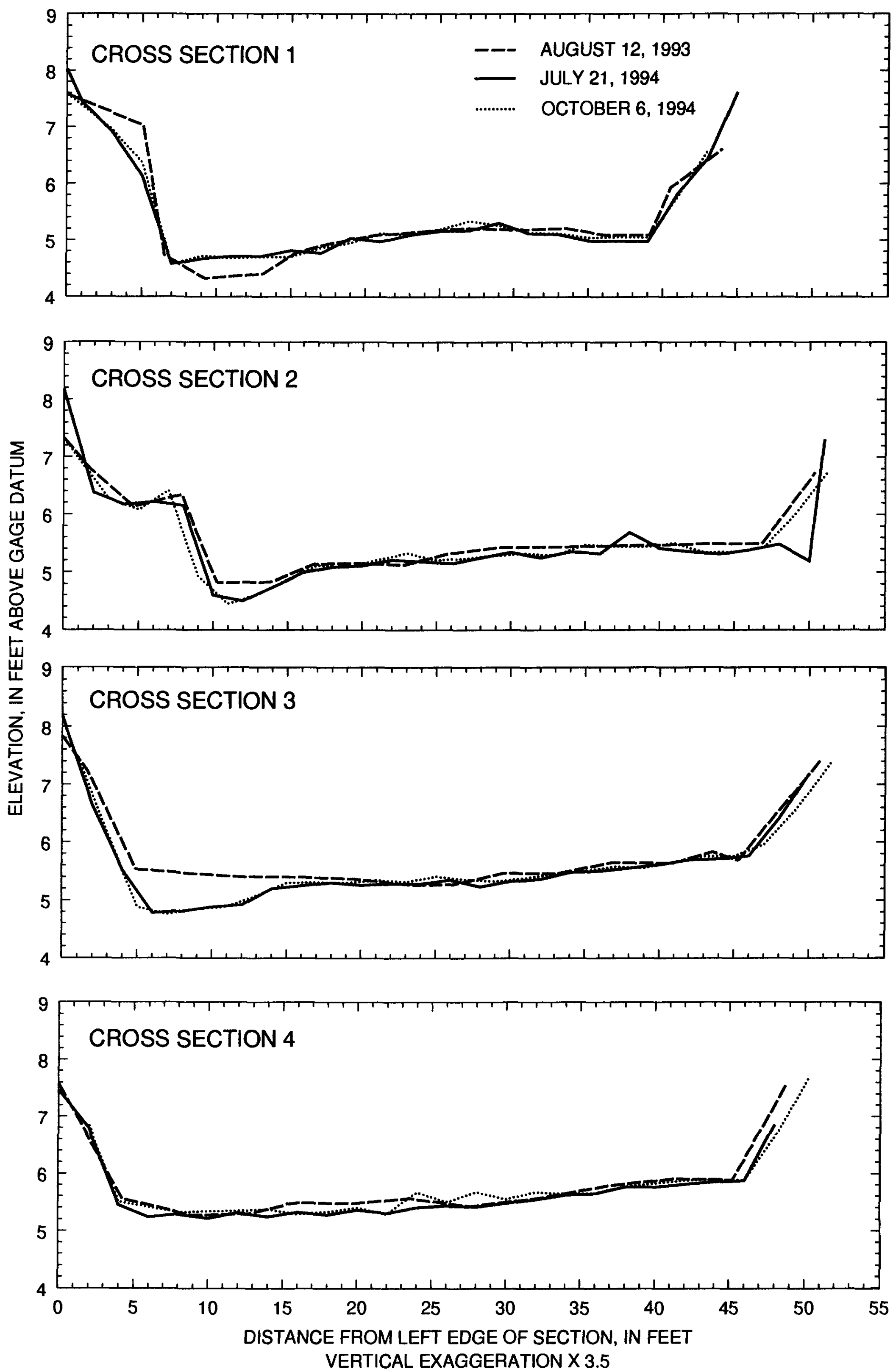


Figure 8. Streambed cross sections at Hellbranch Run near Harrisburg, Ohio, in downstream order from the upstream edge (cross section 1) to the downstream edge (cross section 4) of the study riffle.

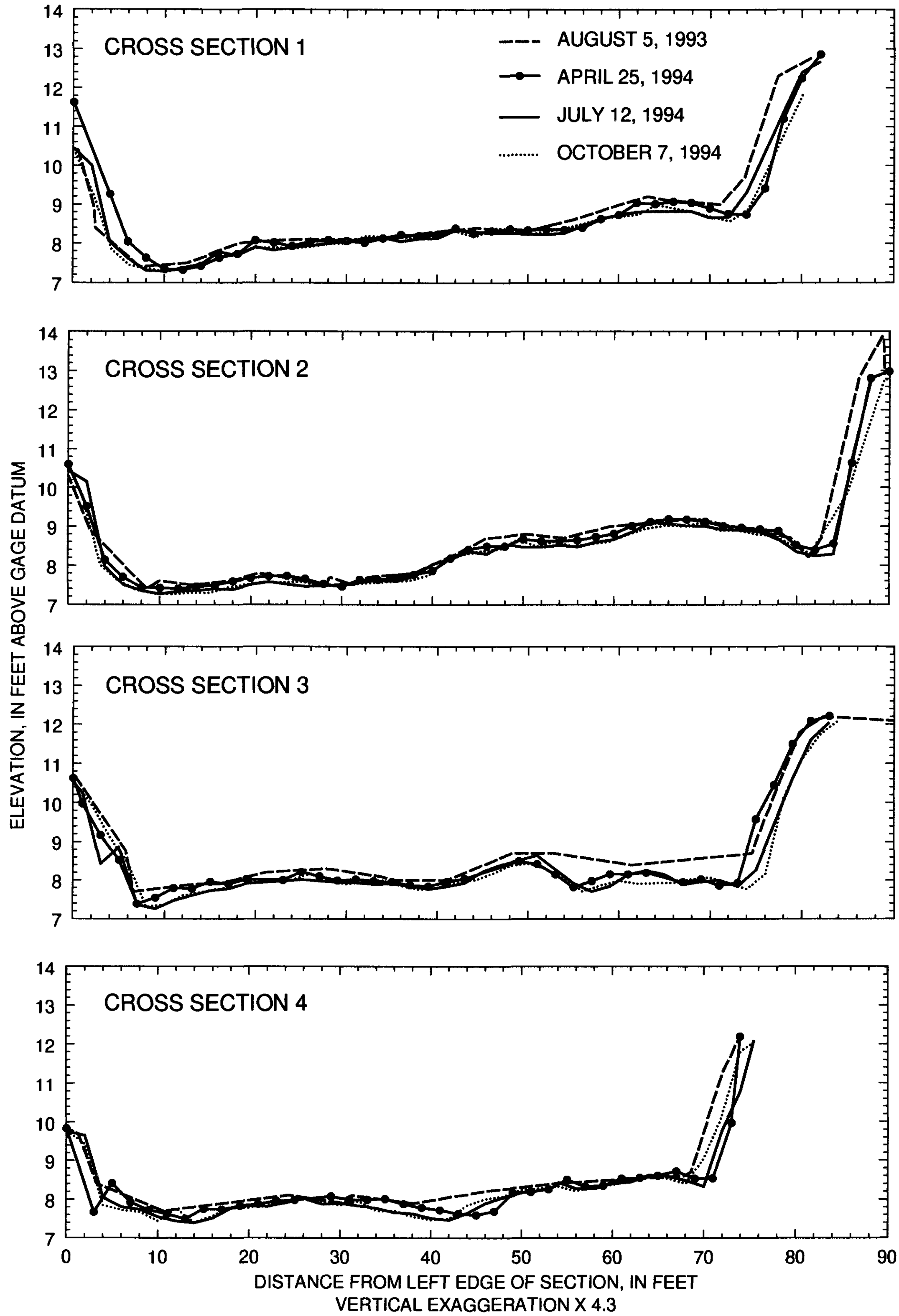


Figure 9. Streambed cross sections at Little Darby Creek at West Jefferson, Ohio, in downstream order from the upstream edge (cross section 1) to the downstream edge (cross section 4) of the study riffle.

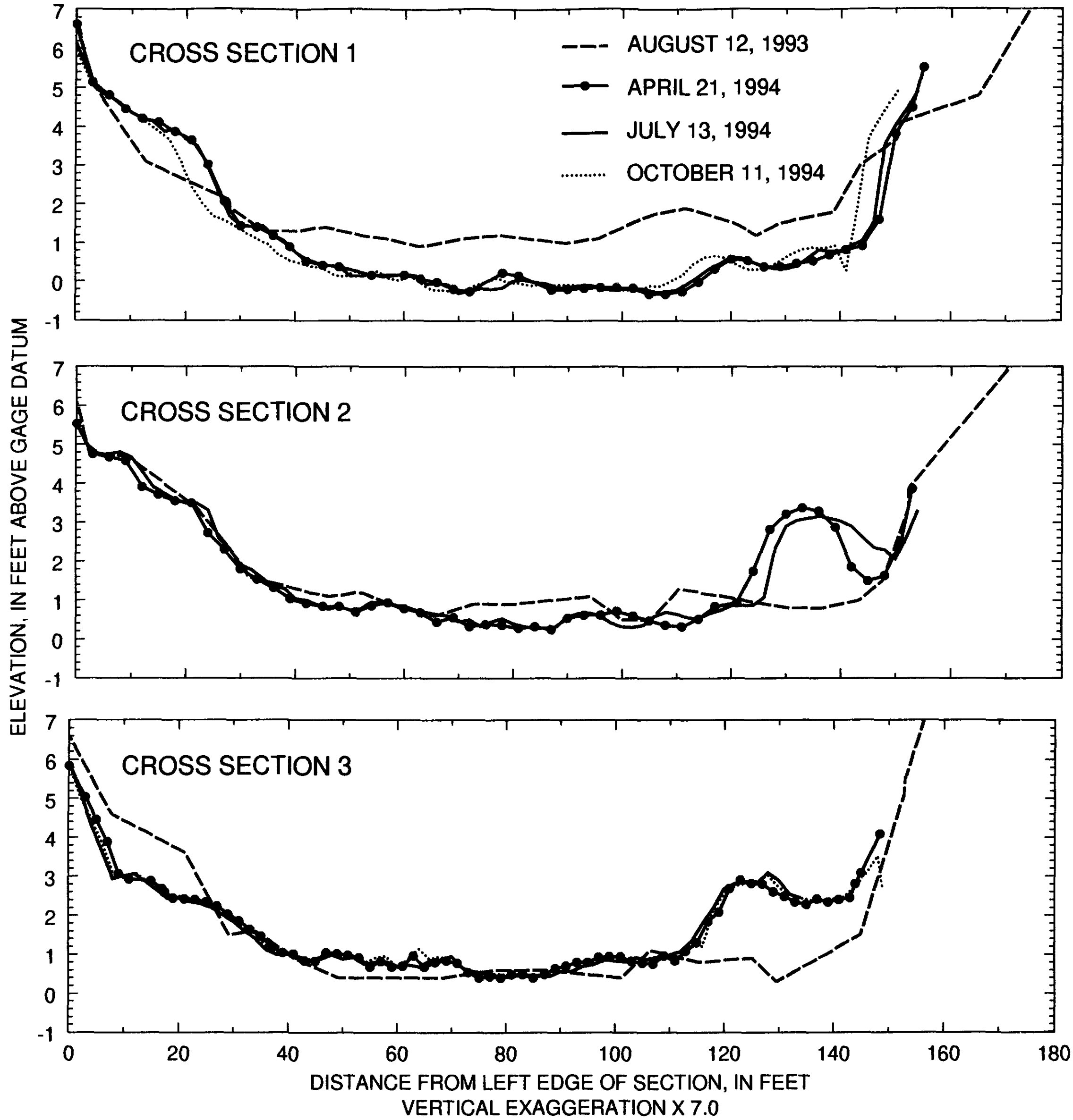


Figure 10. Streambed cross sections at Big Darby Creek at Darbyville, Ohio, in downstream order from the upstream edge (cross section 1) to the downstream edge (cross section 3) of the study riffle.

streamflows at the Hellbranch Run, Little Darby Creek, and Big Darby Creek sites ranged from about 1.3 to 3 times those that occurred during the spring (1994) event.The profiles show that net erosion of the streambed occurred during the August 1993–April 1994 period at most cross sections on Hellbranch Run and Little Darby Creek and at cross section 1 on Big Darby Creek. In addition, cross sections 2 and 3 on Big Darby Creek showed evidence of appreciable reworking of the streambed and formation of a large bar near the right bank. In general, variations in streambed elevations that occurred between sequential measurements at a given location in the cross sections during the remainder of the study (April–October 1994) were small (about 0.2 ft or less). Variations in streambed elevations that were observed in this latter part of the study are as likely to be the result of measurement error (for example, slight differences in the position of the survey rod) as they are to result from actual erosion or deposition.

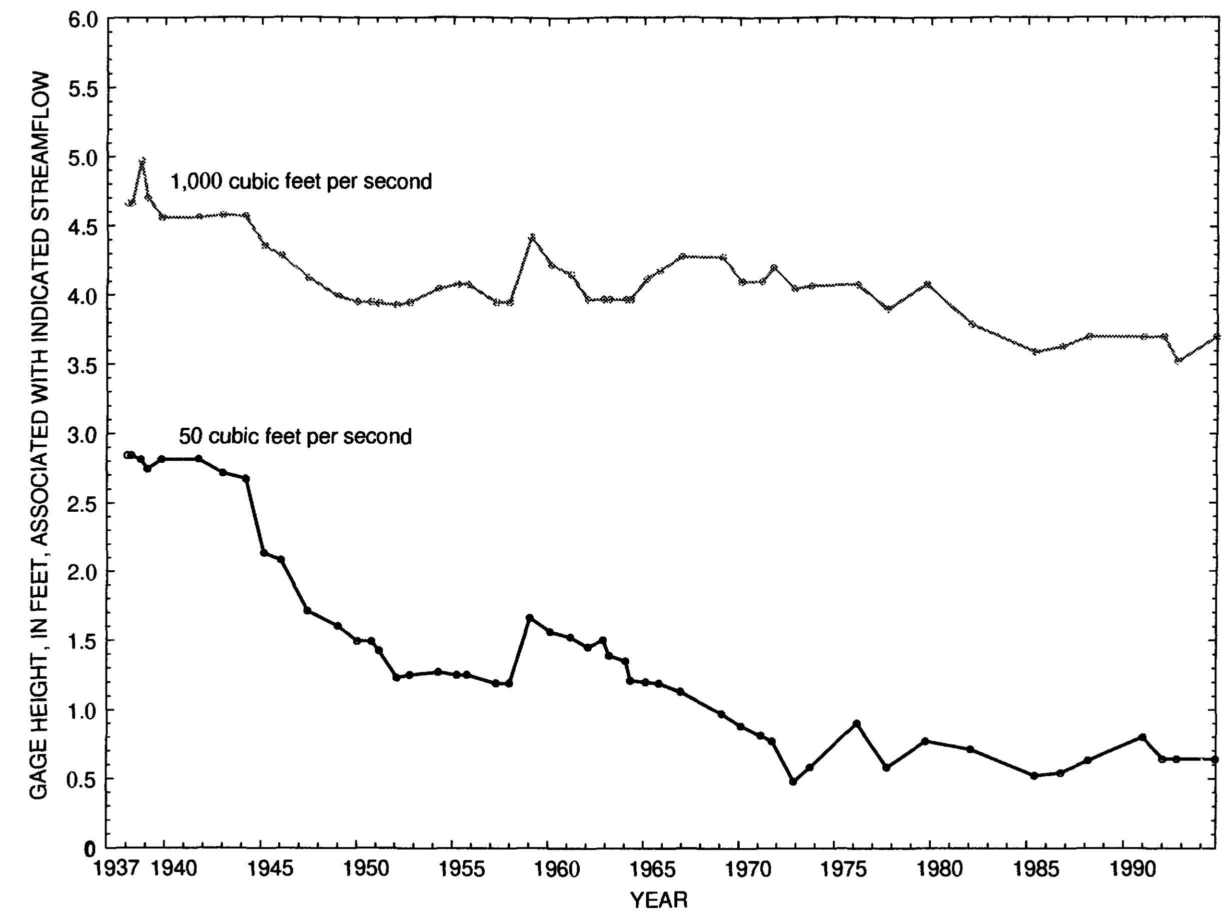


Figure 11. Changes in gage height for selected streamflows, Big Darby Creek at Darbyville, Ohio, 1937-94.

In order to establish a context within which to interpret the short-term changes in streambed elevation, an analysis of long-term trends in streambed elevation was done for the Big Darby Creek streamflow-gaging station. The analysis was based on historical information on the relation between the elevation of the water surface (stage) and streamflow at that station. This relation, called a rating curve, is empirically determined for each streamflow-gaging station by measuring streamflow over a broad range of stages, plotting these values on a graph, and drawing a smooth curve through the points.

The relation of stage to streamflow is usually controlled by a section or segment of channel below the streamflow-gaging station, known as the station control. For stations in the Big Darby Creek Basin, the low-water control is generally a sand-and-gravel or cobble riffle. As physical changes to the channel occur over time (for example, because of channel degradation or widening), the relation between stage and streamflow changes, and the rating curve must be periodically revised. As a result, documented changes to rating curves at a given station over time can provide information on channel erosion and deposition.

A total of 25 rating curves have been used for the Darbyville streamflow-gaging station since 1938. Stages that correspond to streamflows of 50 and 1,000 ft^3/s were plotted against the time that each rating became effective (fig. 11). Stages corresponding to higher flows were not plotted because they could potentially reflect changes to the stream embankments and overbank areas more so than the streambed.

As shown in figure 11, stages corresponding to streamflows of 50 and 1,000 ft^3/s tended to decrease over time at the Darbyville streamflow-gaging station. This decrease indicates that the streambed is degrading or that the stream channel is widening, or both. Historical information on the point of zero flow (PZF), the highest stage at which streamflow ceases, was examined to provide further insight into the cause of the decrease. At Big Darby Creek, the PZF decreased by more than 2 ft from 1938 to 1993. Although the PZF data do not rule out channel widening or other changes as factors, they do indicate that channel degradation has occurred.

Water Quality

Medians of selected constituent concentrations or properties determined for streamwater samples collected at the three study sites during the biological sampling periods are summarized in table 8. Mann-Whitney *U* tests were done to identify statistically significant differences in water quality between spring and summer samplings. Specific conductance, water temperature, and concentrations of dissolved oxygen, nitrogen (as NO_3+NO_2), and total phosphorus were found to differ significantly between spring and summer samples with some exceptions. Concentrations of ammonia (NH_4) and values of pH were not significantly different between spring and summer samples.

The pesticides atrazine, cyanazine, metolachlor, alachlor, and simazine were detected during 1994 (Shindel and others, 1994, 1995). Although atrazine was the most commonly detected pesticide, only one event during this study (July 1993) produced samples with atrazine concentrations in excess of the maximum contaminant level (MCL) of 3.0 µg/L established by the USEPA (1995) for drinking water. The MCL for atrazine was exceeded at all three sites. The MCL level for cyanazine (1.0 µg/L) was exceeded at Big and Little Darby Creeks during the May and June runoff in 1994. The highest concentrations of cyanazine were found in samples collected July 3, 1993 (4.1 µg/L), and June 29, 1994 (3.0 µg/L), at Hellbranch Run. The only detectable pesticide found during the spring event in April 1994 was atrazine (0.12 µg/L) at Big Darby Creek at Darbyville.

Table 8. Median values for selected properties and constituents in water from Big Darby Creek Basin, Ohio, 1994

[Numbers in parentheses are standard deviations. Abbreviations: µS/cm, microsiemens per centimeter; C, Celsius; mg/L, milligrams per liter; n, sample size. Data summarized from Shindel and others, 1994, 1995]

Sampling season	Specific conductance (µS/cm)	pH (standard units)	Temperature (degrees C)	Oxygen, dissolved (mg/L)	Nitrogen, NO_2+NO_3 (mg/L as N)	Nitrogen, ammonia (mg/L as NH_4)	total, Phosphorus (mg/L)	Orthophosphorus (mg/L)
				Hellbranch Run near Harrisburg				
Spring	684 (62) n=6	8.4 (0.26) n=6	14.8 (3.0) n=6	12.4 (1.6) n=6	2.7 (0.5) n=11	0.06 (0.04) n=11	0.13 (0.08) n=11	0.06 (0.06) n=9
Summer	715 (66) n=9	8.3 (0.04) n=9	22.5 (0.8) n=9	9.1 (0.9) n=9	0.9 (2.8) n=7	0.02 (0.01) n=7	0.06 (0.03) n=7	0.04 (0.02) n=7
				Little Darby Creek at West Jefferson				
Spring	626 (15.2) n=5	8.2 (0.25) n=5	14.0 (4.5) n=5	10.1 (1.4) n=6	4.7 (1.1) n=10	0.02 (0.02) n=10	0.06 (0.04) n=10	0.06 (0.02) n=12
Summer	693 (21.2) n=8	8.1 (0.10) n=8	23.2 (1.2) n=8	7.8 (0.3) n=8	1.8 (3.7) n=9	0.03 (0.03) n=9	0.13 (0.03) n=9	0.06 (0.02) n=9
				Big Darby Creek at Darbyville				
Spring	647 (31) n=5	8.3 (0.2) n=5	17.0 (3.0) n=5	11.1 (0.7) n=5	4.0 (0.7) n=12	0.04 (0.01) n=12	0.09 (0.04) n=12	0.05 (0.02) n=12
Summer	726 (50) n=8	8.3 (0.2) n=8	24.5 (1.6) n=8	10.6 (1.3) n=8	4.6 (2.2) n=12	0.02 (0.01) n=11	0.25 (0.05) n=11	0.17 (0.03) n=11

RESPONSE OF AQUATIC BIOTA TO HYDROLOGIC DISTURBANCE

The responses of macroinvertebrate and algal communities at the three sites in the Big Darby Creek Basin are examined from several perspectives including the total numbers of individuals, taxon richness, and community structure before and after the storm events.

Macroinvertebrates

During the study, 184 macroinvertebrate taxa were identified.[2] Of these taxa, 35 had not been previously identified in the principal taxonomic catalogs pertaining to the Big Darby Creek Basin (Olive and Smith, 1975; STORET data base OhioECOS MIDGES files, made available by Ohio Environmental Protection Agency); these newly found taxa are denoted with an asterisk on the macroinvertebrate taxa list in Appendix 1. The major taxonomic groups, listed in order of decreasing number of taxa identified, were Diptera (midges and other true flies), 82 taxa; Trichoptera (caddisflies), 29 taxa; Coleoptera (beetles), 24 taxa; Ephemeroptera (mayflies), 22 taxa; and Plecoptera (stoneflies), 8 taxa. Collectively, they represent about 90 percent of the taxa identified. Mean macroinvertebrate densities at the riffle sites during the summer sampling events were 7,830 organisms/m^2 at the Big Darby Creek riffle site, 3,860 organisms/m^2 at Hellbranch Run, and 2,900 organisms/m^2 at Little Darby Creek.

Density and Taxon Richness

Local minima of macroinvertebrate density did not generally correspond to the first sample after the storm events but instead lagged by about 1 to 3 weeks (figs. 12–14). The depressions in macroinvertebrate densities in mid-July are probably a result of emergence (the transition from aquatic nymph to terrestrial subadult) of midges and other true flies (Diptera) and caddisflies (Trichoptera), which normally occurs in central Ohio from mid-June to mid-July. However, the 1- to 3-week lag for the macroinvertebrate community to reach its minimum density after both the spring and summer storm events could be due, in part, to biotic factors such as reduction in food supply (for example, loss of food resource for filterers).

In only two out of five first post-event samples were significant reductions noted in macroinvertebrate densities, and taxon richness increased in three of these five samples (table 9). This, coupled with the 1- to 3-week lag for the macroinvertebrate community to reach its minimum density, made it impossible to accurately establish a point in time with which to begin measuring recolonization. Consequently, macroinvertebrate recolonization rates were not determined.

Macroinvertebrate Community Structure

Macroinvertebrate community structure was evaluated in terms of functional feeding groups based on criteria from Merritt and Cummins (1984) and flow-exposure groups based on Growns and Davis (1994). In this study, the gatherers were the dominant feeding group in terms of percentage of total taxa found (44 percent), followed by the predators (23 percent), shredders (15 percent), scrapers (10 percent) and filterers (8 percent) (Appendix 1). Gatherers were also the most abundant group throughout the study, whereas predators (a diverse group representing many taxa) were frequently the least abundant (figs. 15–20). Densities of gatherers, with one exception, were statistically less in post-event samples than in pre-event samples (table 9). Gatherers are represented primarily by Diptera, whose density peaked in the spring, declined until mid-July, and then rebounded slightly. One example of a common Diptera at all three sites in the spring was the midge *Orthocladius* sp., which contributed to high densities of gatherers in the pre-event samples at Little Darby Creek (fig. 16) and declined after the event.

An exception to the dominance of the gatherers in the spring was the large proportion of scrapers at Hellbranch Run in April and May. The beetle *Stenelmis* sp., which feeds by scraping substrates for algae and detritus, was found at high densities on April 15 and 22 at Hellbranch Run, where it represented 50 percent and more than 80 percent of the organisms collected, respectively (fig. 15). In addition to contributing to the high beetle densities at Hellbranch Run, the *Stenelmis* sp. beetle was the most commonly occurring invertebrate at all three sites during the spring collecting period, ranging from 83 percent (at Big Darby Creek) to 100 percent (at the other two sites).

[2]Macroinvertebrates identified to the genus level were not included in totals of taxa if organisms of that particular genus were also identified to the species level.

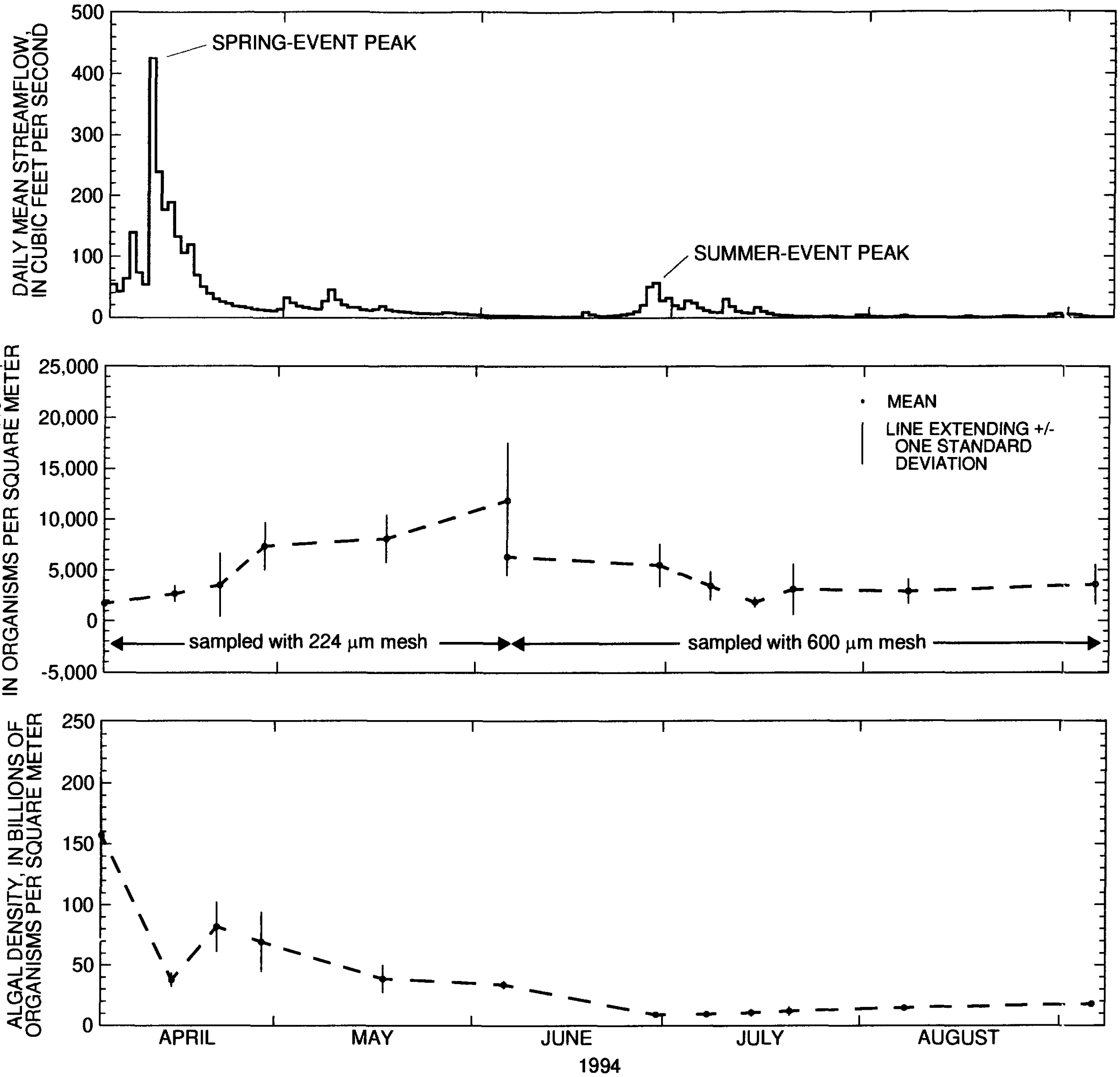


Figure 12. Daily mean streamflow, macroinvertebrate density, and algal-cell density at Hellbrach Run near Harrisburg, Ohio, April 5, 1994-September 8, 1994.

Macroinvertebrate densities remained low at the Big Darby Creek site throughout April and May and then increased abruptly in early June (fig. 17). Diptera (midges and other true flies) had the largest increase in density of the taxonomic groups. Because the emerging Diptera were classified into several of the functional feeding groups, the relative abundance of Diptera increased while the relative abundance of gatherers (the functional feeding group to which most of the Diptera in samples collected in April and May belonged) decreased.

Noted during the summer was a significant reduction in the median density of predators at Hellbranch Run and Big Darby Creek and a reduction in gatherers at Little Darby Creek and Big Darby in the first post-event sample (table 9, figs. 18–20). In general, the filterers, scrapers, and gatherers, all of which rely on algae and detritus for food, were the

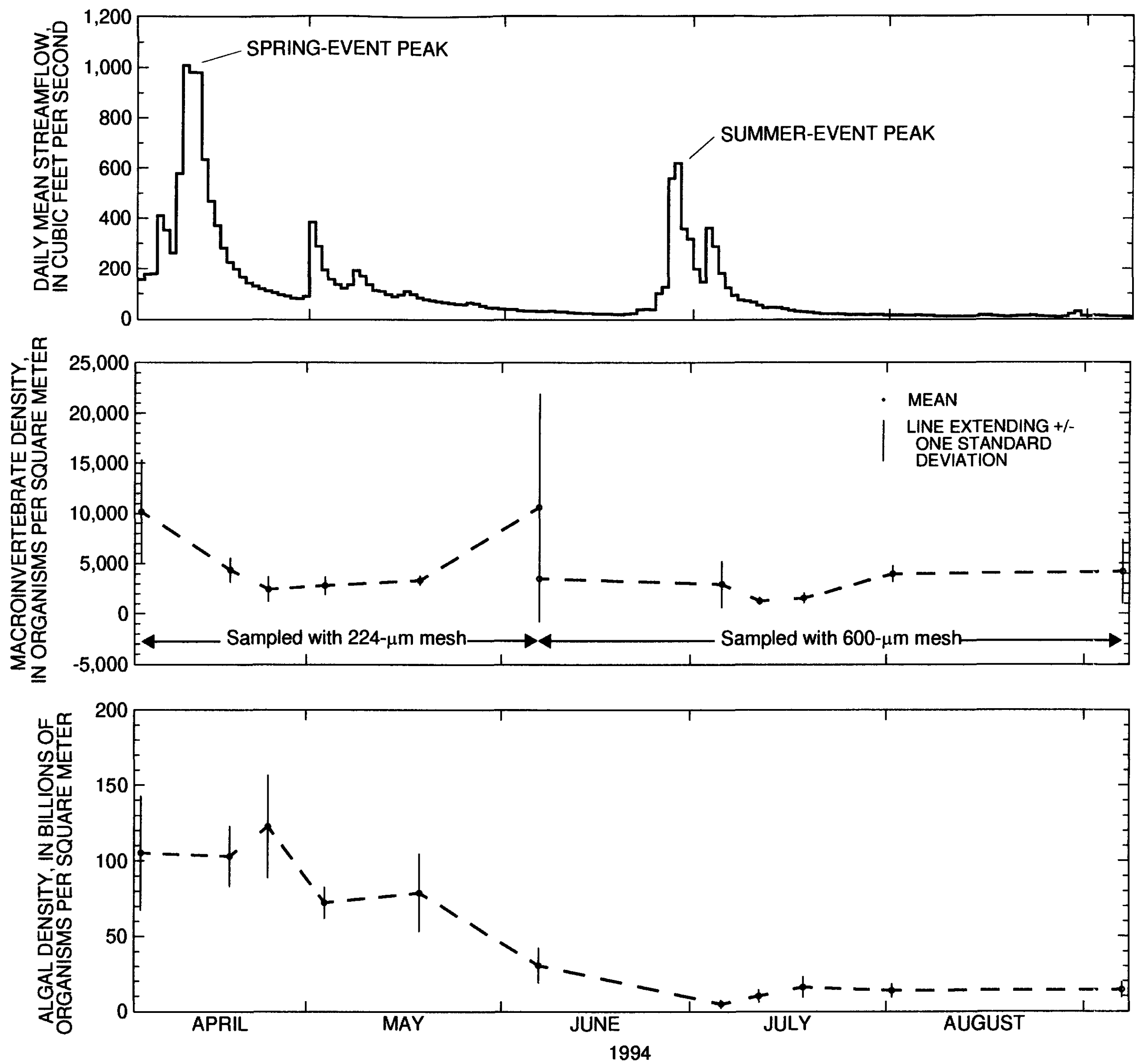


Figure 13. Daily mean streamflow, macroinvertebrate density, and algal-cell density at Little Darby Creek at West Jefferson, Ohio, April 5, 1994-September 8, 1994.

dominant groups in the summer. The predators, which were reduced in density after the storm, did return to constitute approximately 5 percent of the community at all sites by September. The shredders, which feed by breaking down leaf litter, did not represent a large proportion of the community during the summer months; however, this group is expected to represent a greater proportion in the autumn.

Macroinvertebrate taxa were classified into flow-exposure groups by incorporating information on the organisms' behavioral adaptations to flow, including their general morphology and feeding habits (Appendix 1). Macroinvertebrates considered to be flow obligate were fully exposed to the water column on the surface bed material for most of their cycle and generally exhibited behavioral adaptations (for example, fixed retreat constructions, such as that of the

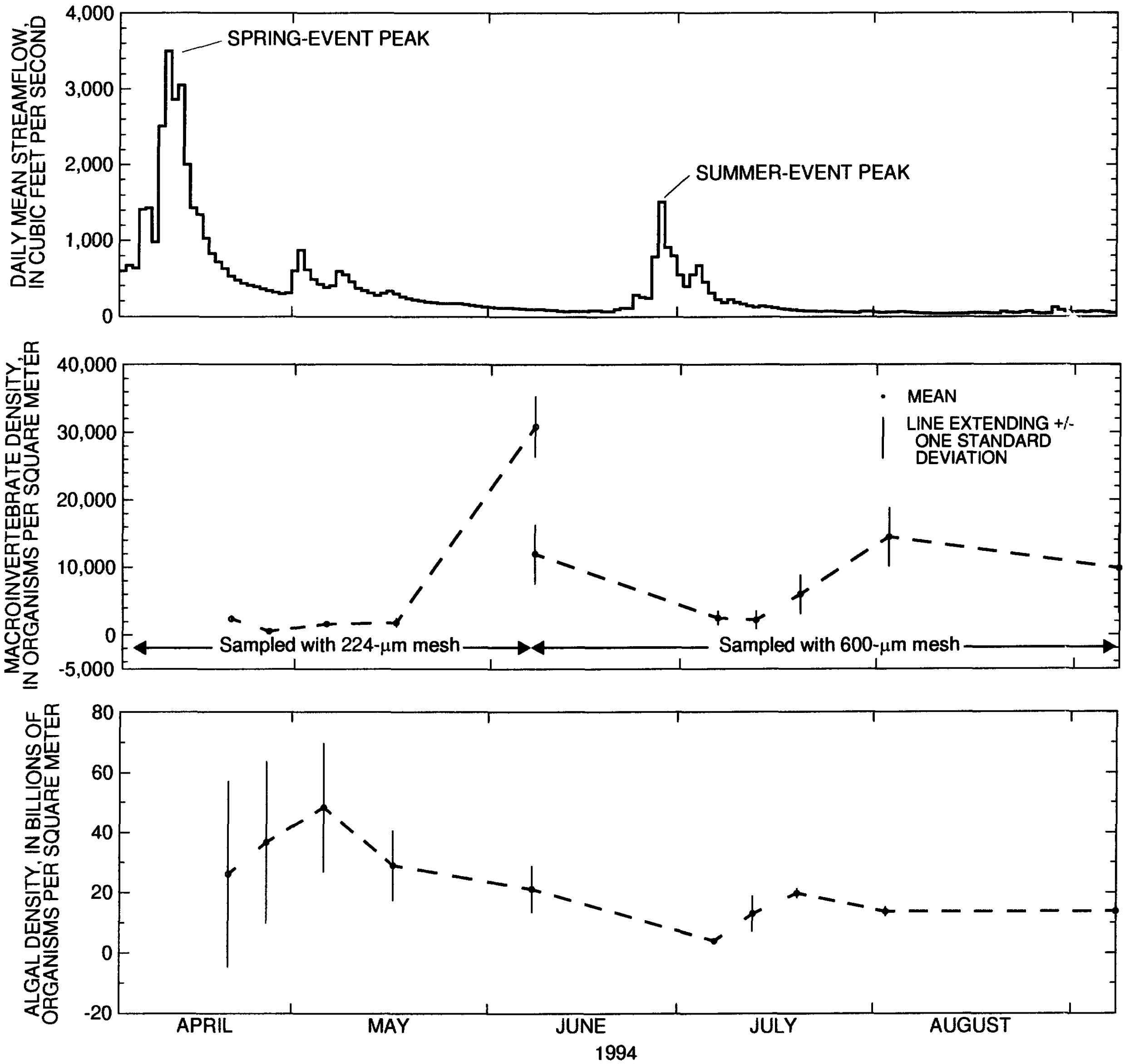


Figure 14. Daily mean streamflow, macroinvertebrate density, and algal-cell density at Big Darby Creek at Darbyville, Ohio, April 4, 1994-September 9, 1994.

caddisfly *Pycnopysche* sp.) or morphological ones (for example, ventral gills arranged to form a sucker, such as that of the black fly larvae *Simulium* sp.) for attachment to the benthic substrate. Flow-facultative taxa are defined as organisms that spend most of their time on the upper surface of the subsurface bed material, usually with morphological adaptations to lessen drag, but have the ability to move into low-flow areas (such as crevices or the lee of large cobbles). Flow avoiders are those organisms that spend most of their life cycle out of contact with direct streamflow or within the substratum. The dominant flow-exposure group in terms of percentage of total taxa found was flow-facultative taxa (46 percent), followed by flow-avoider (34 percent) and flow-obligate taxa (20 percent). Densities of flow-avoider and flow-facultative taxa were significantly reduced after the summer event at Big and Little Darby Creeks (table 9), whereas densities of

Table 9. Macroinvertebrate community response to storm events at three riffle sites in Big Darby Creek Basin, Ohio

[+, density or taxon richness increased; -, density or taxon richness decreased; statistics calculated by means of Mann-Whitney *U* test comparing pre-event and first post-event samples]

Storm event	Macroinvertebrate density	Taxon richness	Density, by functional feeding group					Density, by flow-exposure group		
			Filterer	Gatherer	Predator	Scraper	Shredder	Avoider	Facultative	Obligate
Hellbranch Run near Harrisburg										
Spring	+	+	+	-[1]	+	+	+	+	-	+
Summer	-	+	-	-	-	+	-[1]	-	-	+
Little Darby Creek at West Jefferson										
Spring	-[1]	+	-	-[1]	+	+	+	+	-	-
Summer	-	-[1]	+	-[1]	-	-	-	-[1]	-[1]	+
Big Darby Creek at Darbyville										
Summer	-[1]	-[1]	-	-[1]	-[1]	+	-	-[1]	-[1]	-

[1]Reduction in macroinvertebrate density or taxon richness is statistically significant (one-sided $p < 0.05$).

flow-obligate taxa, which have adapted to living in higher velocities, were not significantly reduced.

This study and a study by Growns and Davis (1994) are the only two that examine responses of community structure to flow using identical flow-exposure groupings. In the Growns and Davis (1994) study, 147 macroinvertebrate taxa were identified and a predominance of flow-avoider taxa were found (42 percent), followed by flow-facultative (38 percent), and flow-obligate taxa (20 percent). In that study, numbers of flow-obligate and flow-avoider taxa were found to be positively correlated with high shear velocities, substrate roughness, and turbulence, which Growns and Davis (1994) suggest may promote higher fluxes of organic matter and oxygen within interstitial sediments. That study also found that numbers of flow-facultative taxa were positively correlated with substrate roughness, possibly because rougher substrates provided better refuge from flow. Although the substrate roughness has not been quantitatively evaluated throughout the Big Darby Creek Basin, the wide diversity of substrates and available instream habitats, ranging from shelves of Silurian or Devonian bedrock to boulders and glacially-derived till, likely contribute to the high diversity of organisms in this watershed.

Macroinvertebrate-Sample Mesh-size Comparison

Surber samplers used during the spring biological sampling period were equipped with a 224-µm mesh net. Field personnel observed clogging of the mesh, prompting a change to a 600-µm mesh net for the summer biological sampling period. Replicate samples were collected with both mesh sizes in June 1994 in order to assess the effects of the mesh size on the resulting macroinvertebrate population composition and numbers.

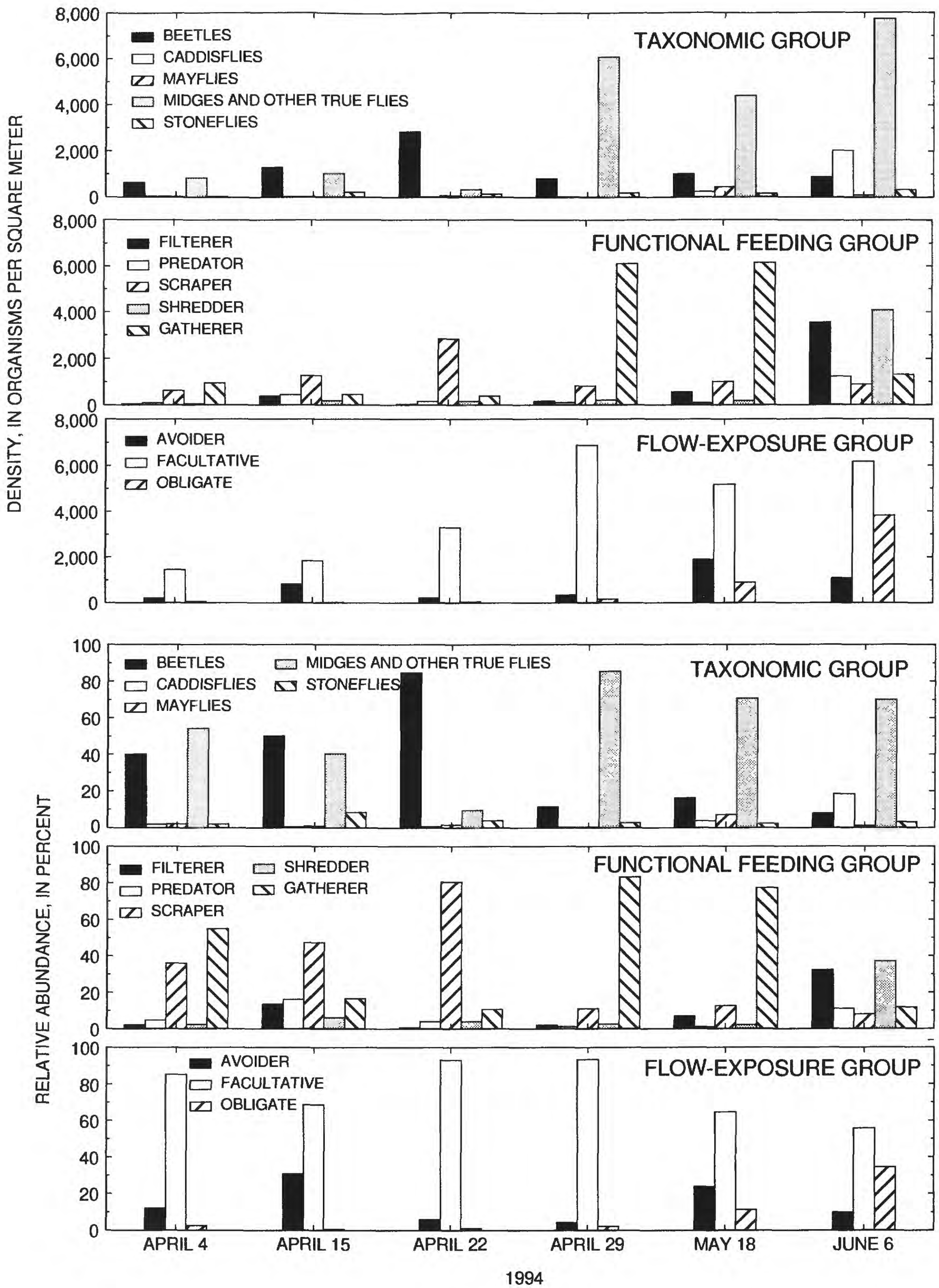


Figure 15. Macroinvertebrate densities and relative abundance by taxonomic groups, functional feeding groups, and flow-exposure groups at the riffle site at Hellbranch Run, Ohio, April-June 1994. (Peak flow for spring event was April 10, 1994.)

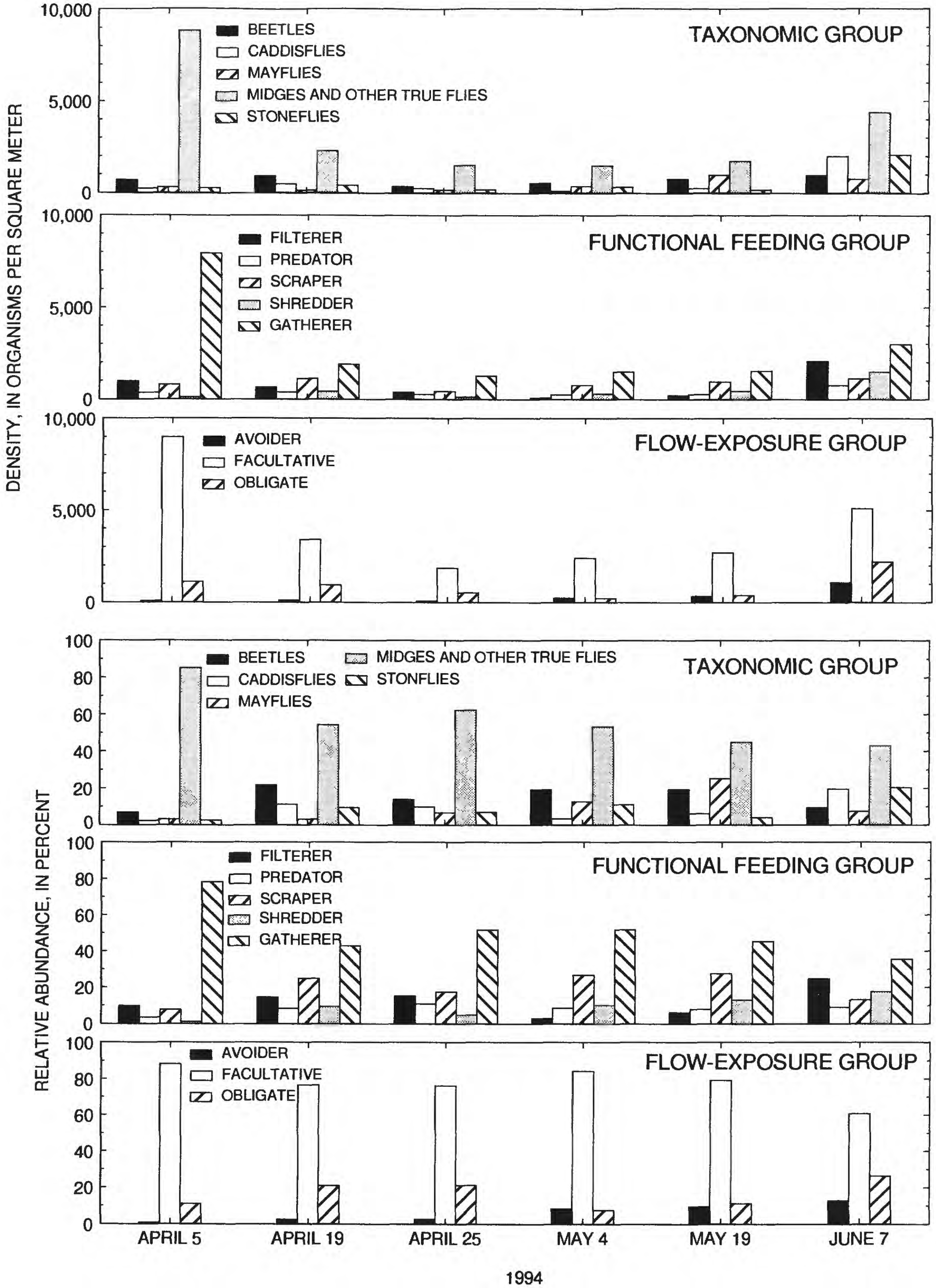


Figure 16. Macroinvertetrate densities and relative abundance by taxonomic groups, functional feeding groups, and flow-exposure groups at the riffle site at Little Darby Creek, Ohio, April-June 1994. (Peak flow for spring events was April 13,1994.)

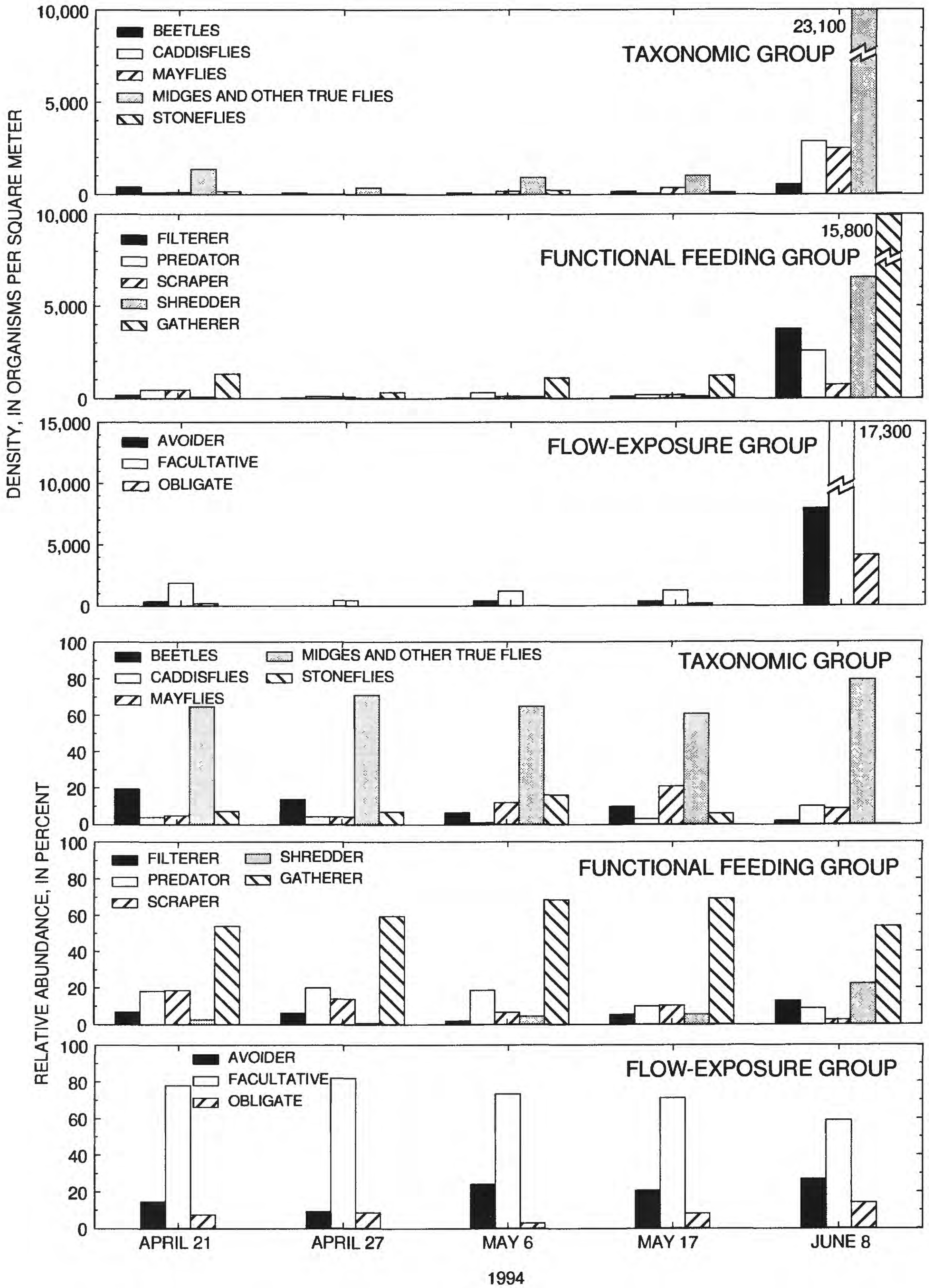


Figure 17. Macroinvertebrate densities and relative abundance by taxonomic groups, functional feeding groups, and flow-exposure groups at the riffle site at Big Darby Creek, Ohio, April-June 1994. (Peak flow for spring event was April 10, 1994.)

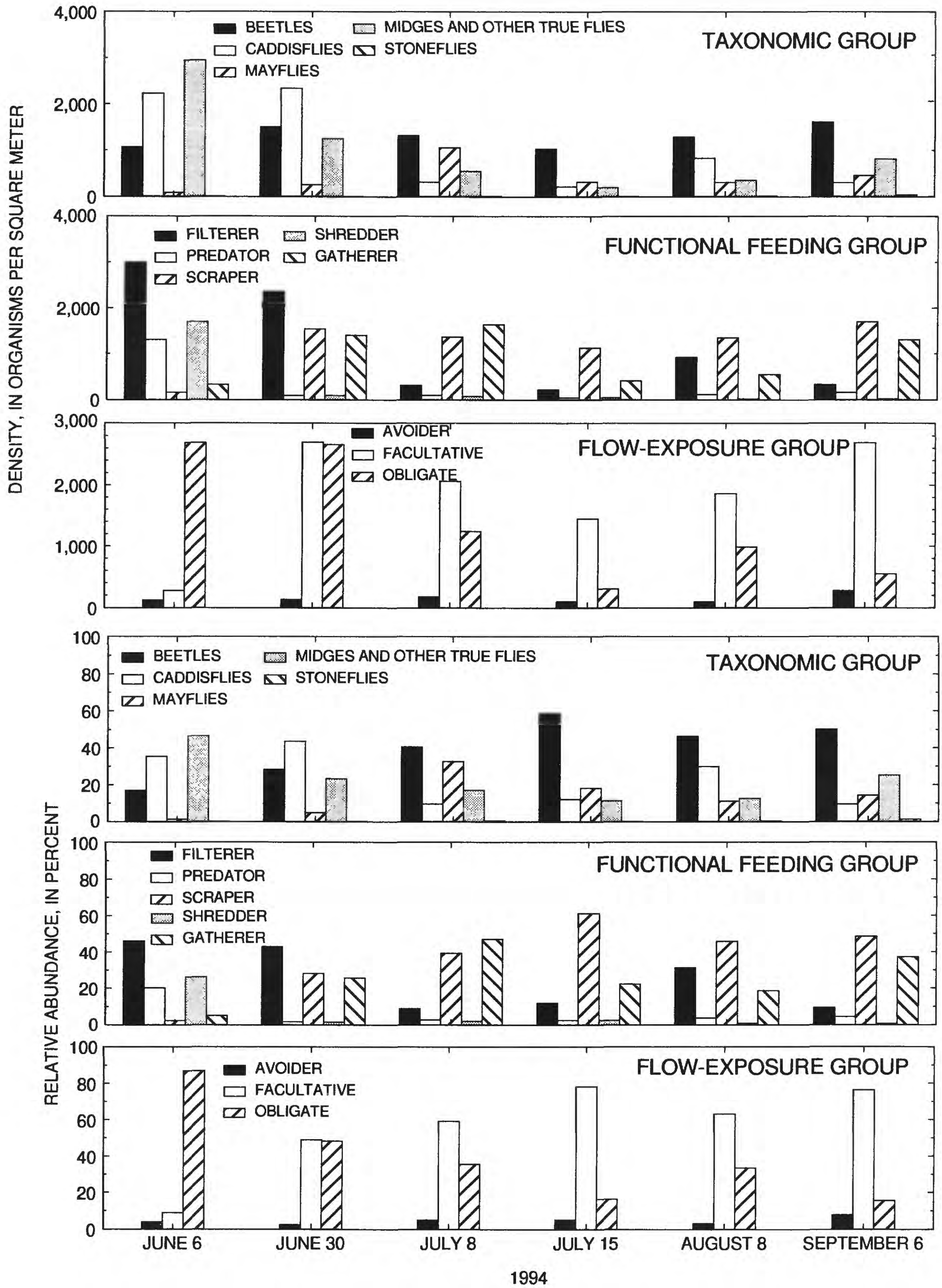


Figure 18. Macroinvertebrate densities and relative abundance by taxonomic groups, functional feeding groups, and flow-exposure groups at the riffle site at Hellbranch Run, Ohio, June-September 1994. (Peak flow for summer event was June 27, 1994.)

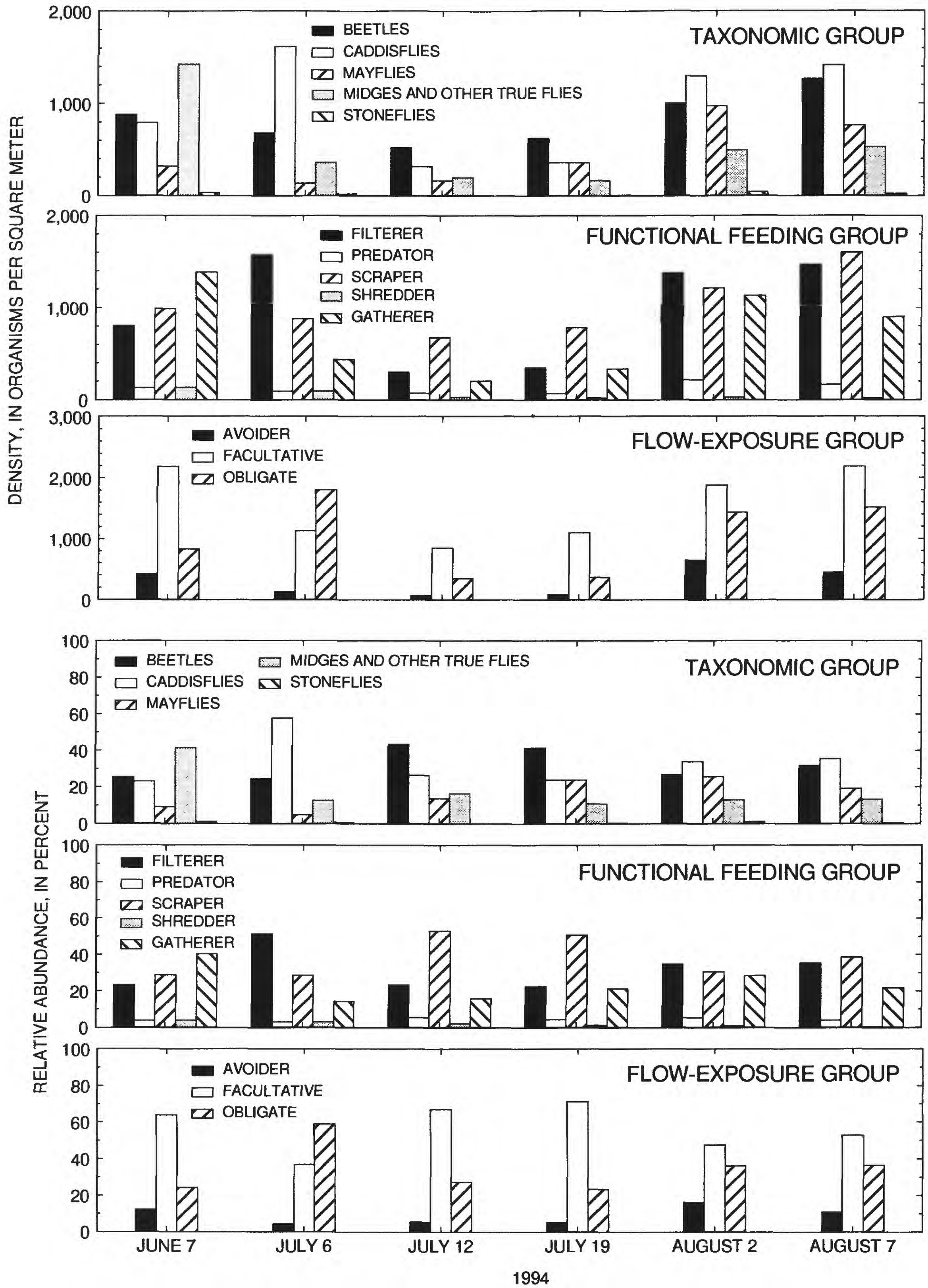


Figure 19. Macroinvertebrate densities and relative abundance by taxonomic groups, functional feeding groups, and flow-exposure groups at the riffle site at Little Darby Creek, Ohio, June-September 1994. (Peak flow for summer event was June 27, 1994.)

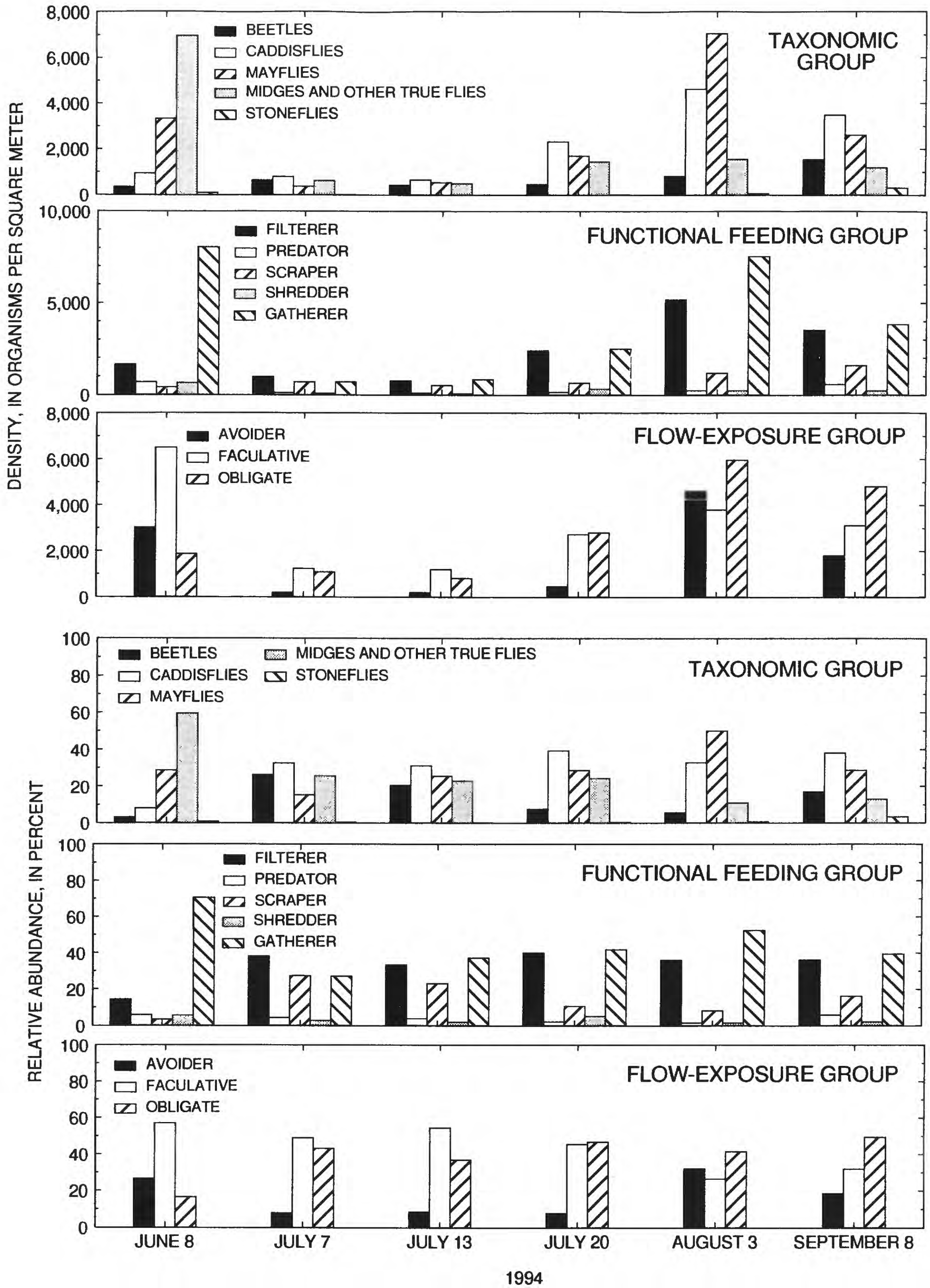


Figure 20. Macroinvertebrate densities and relative abundance by taxonomic groups, functional feeding groups, and flow-exposure groups at the riffle site at Big Darby Creek, Ohio, June-September 1994. (Peak flow for summer event was June 28, 1994.)

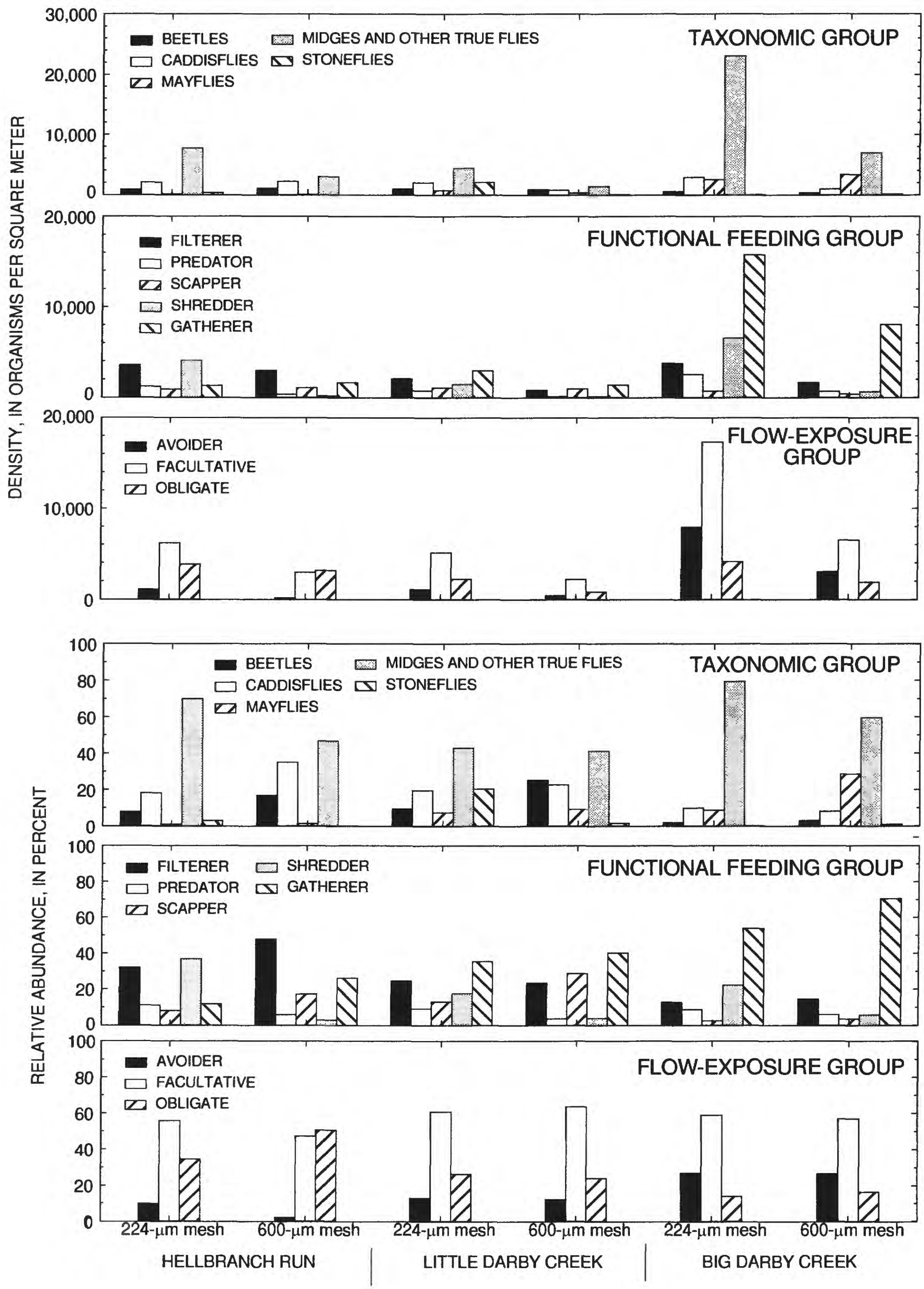


Figure 21. Macroinvertebrate sample mesh-size comparison, corresponding to the last of the spring-event samples and the first of the summer-event samples, Big Darby Creek Basin, Ohio.

Wilcoxon signed ranks test (Helsel and Hirsch, 1992) indicated that aggregate median macroinvertebrate densities were significantly lower in samples collected with the 600-μm mesh than with the 224-μm mesh. Although median densities of macroinvertebrates in all taxonomic groups were frequently lower in samples collected with the 600-μm mesh, Diptera was the only major taxonomic group for which a statistically significant reduction in median densities was found with the increase in mesh size.

Changes in median macroinvertebrate densities associated with changes in the Surber sampler mesh size were also assessed with respect to functional feeding groups and flow-exposure groups (fig. 21). Wilcoxon signed ranks tests indicated that median densities of macroinvertebrates classified as filterers, gatherers, and shredders were significantly lower in samples collected with the 600-μm mesh net than in samples collected with the 224-μm mesh net. In addition, median densities of macroinvertebrates classified as flow avoiders and flow obligates were also significantly lower in samples collected with the 600-μm mesh net than in samples collected with the 224-μm mesh net. Qualitatively, the change in mesh size appears to have had the least effect on results for the flow-exposure group, where the densities changed with mesh size but the relative abundance of each group generally remained about the same.

Algae

Over the period 1992–94, 202 algal taxa were identified[2] (Appendix 2). The diatoms (Bacilliariophyta) were the dominant group (161 taxa), followed by green algae (Chlorophyta, 18 taxa), blue-green algae (Cyanophyta, 16 taxa), euglenoids (Euglenophyta, 3 taxa), golden flagellates (Chrysophyta, 2 taxa), and freshwater red algae

[2]Algae identified to the genus level were not included in totals of taxa if organisms of that particular genus were also identified to the species level.

Table 10. Algae collected during the spring and summer events, 1994, Big Darby Creek Basin, Ohio, by algal division, form, attachment, and size
[μm, micrometers]

Algal division	Taxa	Relative abundance, in percent	Form			Attachment						Size		
			Single	Colonies	Filaments	Unattached cells	Stalked	Apical pad	Mats	Holdfast	Prostrate	Small (<50 μm)	Medium (50-100 μm)	Large (>100 μm)
Cyanophyta (blue-green algae)	8	6	2	2	4	3	0	0	2	3	0	3	4	5
Chlorophyta (green algae)	12	8	5	3	4	9	0	0	0	3	0	4	2	6
Euglenophyta (euglenoids)	2	1	2	0	0	2	0	0	0	0	0	2	0	0
Bacillariophyta (diatoms)	120	83	101	6	13	83	23	6	0	0	8	61	41	14
Rhodophyta (red algae)	2	1	0	0	2	0	0	0		2	0	0	0	2
Total	144	100	110	11	23	97	23	6	2	8	8	70	47	27
Percentage of grouping			84	5	11	67	16	4	1	6	6	49	33	19

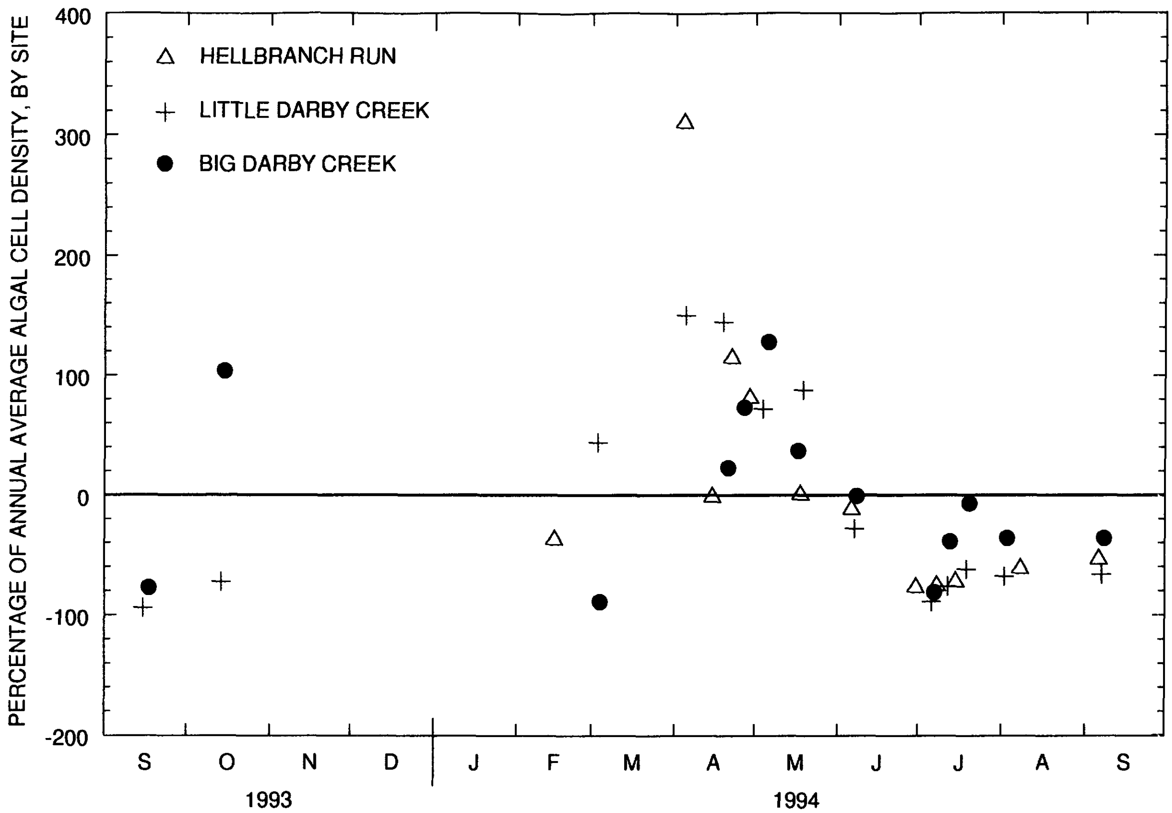


Figure 22. Seasonal differences in algal-cell density, Big Darby Creek Basin, Ohio, plotted as percentage of annual average algal-cell density.

(Rhodophyta, 2 taxa). The diatoms, particularly those classified as single celled, unattached, or small, were the most numerous in the algal community (table 10). Of the 202 algal taxa found in the Big Darby Creek Basin, the 144 taxa that were found during the 1994 spring and summer event samplings were studied for their response to storms at the three riffle sites on Hellbranch Run, Little Darby Creek, and Big Darby Creek. The algal taxa and their forms, attachment, and size are listed in Appendix 3 and are summarized in table 10. The most common form of attachment was by stalks.

Density and Taxon Richness

Algal-cell densities varied seasonally and were greater in the spring than in the summer during 1994 (fig. 22). The largest range in algal-cell densities was found at Hellbranch Run (table 11). The largest average algal-cell density was found at Little Darby Creek, followed by Hellbranch Run and Big Darby Creek (table 11).

Based on the Mann-Whitney *U* test, algal-cell densities were significantly lower in four out of five post-event samples compared to pre-event densities (table 12, figs. 12–14). However, only one associated significant change in taxon richness occurred (table 12); this was an increase in algal taxa after the summer storm at Big Darby Creek. About 30 taxa were found in each sample, although the combinations of taxa differed among samples.

Algal Community Structure

Periphyton communities are analogous to communities of higher plants in terms of three-

Table 11. Annual average and event-related algal-cell density characteristics in Big Darby Creek Basin, Ohio

[Data (except percentages) are billions of cells per square meter. NC, not used for calculations because too much time had lapsed to make a valid pre-event comparison]

Riffle site	Annual average[1]	Annual range	Spring pre-event	Spring post-event	Percent change	Summer pre-event	Summer post-event	Percent change
Hellbranch Run, upstream of gage	38.3	5.59-227	157	37.7	-76	33.8	8.95	-74
Little Darby Creek, 0.7 mi upstream of gage	42.0	0.82-160	105	103	- 2	30.5	4.80	-84
Big Darby Creek, upstream of gage	21.2	4.72-79.5	NC	26.2	NC	21.1	3.94	-81

[1]Annual average algal-cell density is based on all samples collected from September 15, 1993, through September 8, 1994.

Table 12. Algal community response to storm events at three riffle sites in Big Darby Creek Basin, Ohio

[+, density or taxon richness increased; -, density or taxon richness decreased; statistics calculated by means of Mann-Whitney *U* test comparing pre-event and first post-event samples; µm, micrometers]

Storm event	Cell density	Taxon richness	Density, by form			Density, by attachment							Density, by size		
			Single cells	Colonies	Filaments	Unattached cells	Stalked	Apical pad	Mat	Epiphytic	Holdfast	Biofilm	Small (<50 µm)	Medium (50-100 µm)	Large (>100 µm)
Hellbranch Run near Harrisburg															
Spring	-[1]	-	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	-	-	-	-[1]	-[1]	-[1]	-[1]
Summer	-[1]	-	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	-[1]	-	-	-	-[1]	-[1]	-
Little Darby Creekat West Jefferson															
Spring	-	-	-	-	-	-	-[1]	-	-	-	-	-	-	-	-
Summer	-[1]	-	-[1]	-	-[1]	-[1]	-[1]	-[1]	-[1]	-	-	-[1]	-[1]	-[1]	-
Big Darby Creek at Darbyville															
Summer	-[1]	+[1]	-[1]	-	-[1]	-[1]	-[1]	-[1]	-	-	-	-[1]	-[1]	-[1]	-

[1]Reduction in algal density or taxon richness is statistically significant (one-sided $p < 0.05$).

dimensional structure and succession (Hoagland and others 1982). Algae on rocks in streams colonize bare substratum and can develop into a miniature forest with an upperstory (canopy) of filaments or long-stalked cells, an understory of cells with short stalks or apical pads, and a forest floor of prostrate cells that may be surrounded by a biofilm (fig. 23). A mat forms when algal filaments become interwoven and when mucilage is produced, causing the matrix to become smooth. The thickness of algal mats has been found to increase with increasing current velocity as progressively more mucilage is produced (Biggs and Hickey, 1994). In considering the response that the algal community would have to increases in flow, it is hypothesized that the unattached cells and the long-stalked upperstory would be the least resistant to hydrologic disturbance, whereas the cells that lie prostrate on the substrate would be the most resistant (fig. 24).

Changes in algal-cell density from pre-event to first post-event samples were evaluated on the basis of form (single cells, colonies, or filaments), attachment (unattached, stalked, apical pad, biofilm, epiphytic, mat, or holdfast), and size (small, <50 μm; medium, 50–100 μm; or large, >100 μm). Algal-cell densities in first post-event samples were reduced from pre-event levels for all categories of form, attachment, and size (table 12); however, only densities of cells with stalked attachment (such as *Gomphoneis olivacea*) were in all cases significantly reduced. In contrast, no significant reductions in cell densities were found for holdfast types (such as *Audouinella hermannii*) or epiphytes (such as *Cocconeis* spp.). Densities of single cells and filaments (which include diatom chains) were significantly reduced in all but one case, the spring event at Little Darby Creek, whereas densities of cells that form colonies (such as the blue-green alga *Chroococcus* sp.) were relatively low at all times and were significantly reduced only at Hellbranch Run. Fewer significant reductions in algal-cell densities were found for large cells than for either small or medium-sized cells; however, nearly half the taxa composing the large-cell category had holdfasts, and many of the large diatoms were not very abundant (with the exception of *Synedra ulna* at Hellbranch Run in the spring).

Throughout February–September 1994, density and relative abundance of the mat-forming blue-green algae *Oscillatoria* spp. tended to be greater at the Little Darby Creek site than at the other two sites. During that same period, the highest densities of *Oscillatoria* spp. were found around the time of the spring event (April 1994) at Little Darby Creek. Peterson and others (1994) found that filamentous blue-green algae, which develop an interwoven, mucilaginous matrix, are more resistant to disturbance than algae that do not develop a similar matrix.

Recolonization Rates

Algal recolonization rates were determined for a period following the summer event by computing the average daily change in algal-cell densities based on samples collected on two dates spaced 7 days apart. The computed algal recolonization rates were 0.05, 0.88, and 1.51 billion cells/m^2/d for Hellbranch Run, Little Darby Creek, and Big Darby Creek, respectively. These recolonization rates are expected to be affected by factors such as nutrient availability, temperature, amount of tree canopy overlying the riffle site (and consequently the amount of light incident on and penetrating the water), initial post-event algal density; and grazing by macroinvertebrates, snails, and fish.

Median temperatures and nitrogen concentrations, in the form of ammonia, were not appreciably different at the three sites for the summer event. However, there was a gradient in median nitrate concentrations, from 0.9 mg/L at Hellbranch Run, to 1.8 mg/L at Little Darby Creek, to 4.6 mg/L at Big Darby Creek (table 8). A similar gradient in median concentrations of total phosphorus and orthophosphorus was found in summer-event samples, where median concentrations were smallest at Hellbranch Run and largest at Big Darby Creek. The riffle site at Big Darby Creek had the least amount of canopy shading the riffle area (30 percent canopy), followed by Little Darby Creek (42 percent canopy) and Hellbranch Run (53 percent canopy). Consequently, on the basis of canopy and nutrient data, one might expect the algal recolonization rates for the three sites in this study to sort in the order observed.

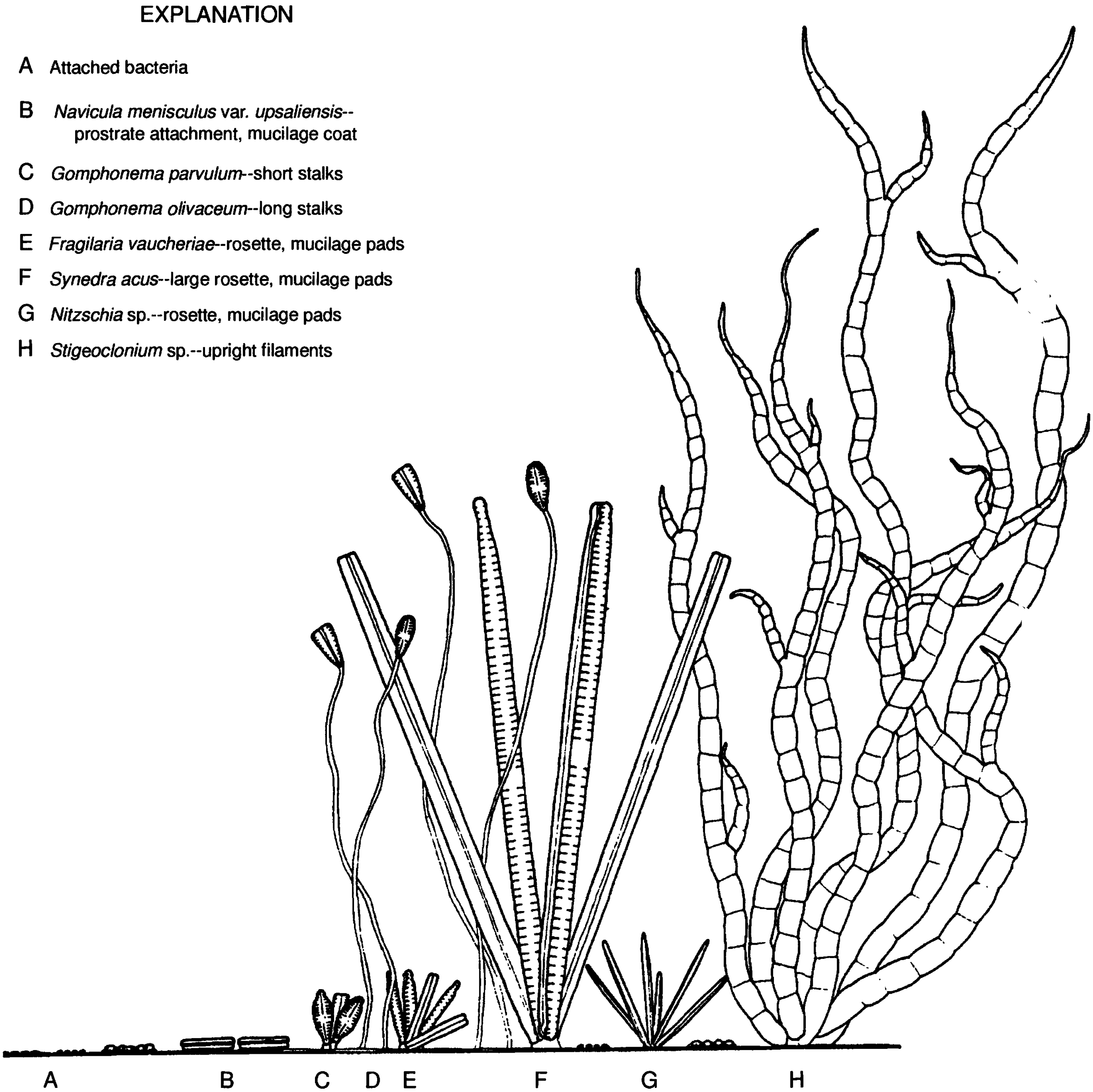


Figure 23. Range of vertical stature in the periphyton community, from attached bacteria to upright filaments (from Hoagland and others, 1982).

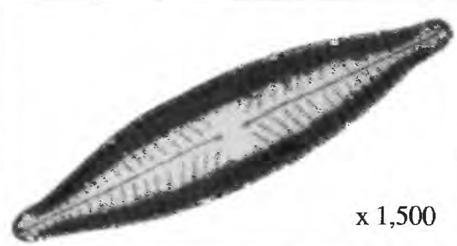
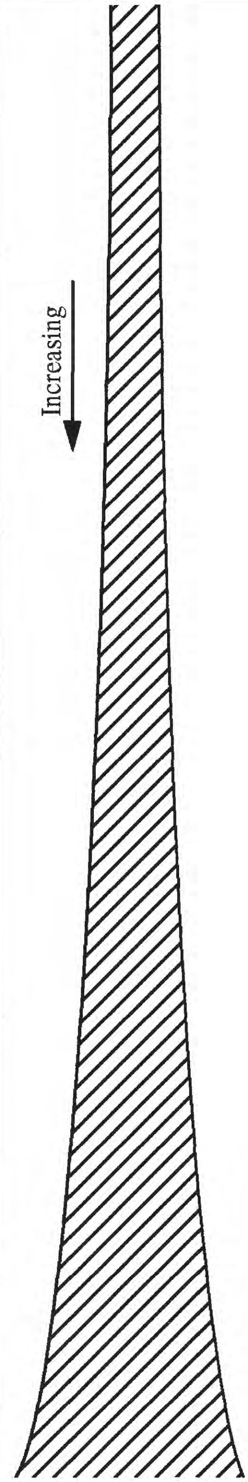
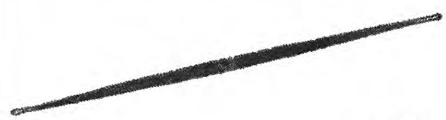
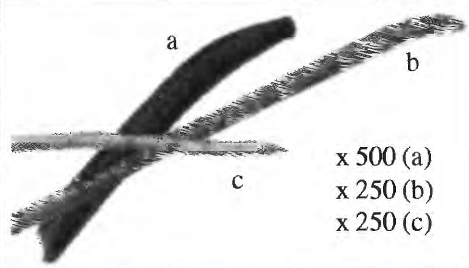
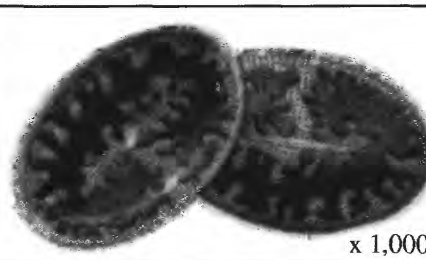
Form of attachment	Representative taxa	Morphology	Hydrologic resistance
Unattached single cells	*Navicula*	 x 1,500	
Long stalks	*Gomphonema*	 x 175	
Apical pads	*Synedra*	 x 250	
Mat-forming	*Oscillatoria*	 x 500 (a) x 250 (b) x 250 (c)	
Holdfasts	*Audouinella*	 x 175	
Prostrate Biofilm	*Cocconeis*	 x 1,000	

Figure 24. Gradient of hydrologic resistance of stream benthic algae by form of attachment.

INTEGRATION OF HYDROLOGIC DISTURBANCE AND THE RESPONSE OF AQUATIC BIOTA

Macroinvertebrate and algal communities in streams can be physically disturbed by the shear force of water, by sediment movement, or by grazer/predator actions. Water-quality degradation associated with storm runoff also can result in a hydrologic disturbance; however, this report focuses on the direct influence of physical disturbance.

Streamflow and Community Adaptations

Bed forms and turbulence cause stream velocities to vary near the substrate where the benthic organisms live. Gore and Judy (1981) found that the velocity preference range for 19 macroinvertebrates studied was 26 to 107 cm/s. Nelson and Roline (1995), in a review of macroinvertebrate communities and probable impacts of discharge, found that the highest taxon richness was in the upper end of this range (75 to 125 cm/s (Gore, 1978); 80 to 100 cm/s (Gore and Judy, 1981)). Nelson and Roline concluded that macroinvertebrate communities generally would not be deleteriously affected by velocities less than or equal to 100 cm/s. The broad range of velocity preference and tolerance by aquatic invertebrates may be related to Statzner's suggestion (1981) that stream velocity has little direct effect on the microdistribution of aquatic invertebrates because they are sheltered from the effects of fast-flowing water by stones, branches, leaves, and other debris.

The average spring pre-event velocities at the three sites in the Big Darby Creek Basin ranged from 58 cm/s at Hellbranch Run to 94 cm/s at Big Darby Creek (table 3) and are within the preferred range. However, the peak flows at Hellbranch Run during the spring event (152 cm/s) and at Little Darby Creek during the spring and summer events (162 cm/s and 146 cm/s, respectively) result in velocities that exceed the general velocity preference range for macroinvertebrates reported in the literature. The reduction in density of flow-avoider and flow-facultative taxa without a significant reduction in densities of flow-obligate taxa at Little Darby Creek after the summer event could be expected, but similar results at Big Darby Creek, where the velocity preference range was not exceeded, require another explanation. Possible explanations include the effects of particle movement and the seasonal emergence of caddisflies, and midges and other true flies.

A broad range of shear stresses has been found to remove aquatic organisms under various conditions, from nanonewtons per square meter (to move stationary individual diatom cells) to tens of newtons per square meter (to reduce certain attached algal communities)(Silvester and Sleigh, 1985). Previous studies that measured the shear stress necessary to remove organisms are summarized in table 13. Biggs and Thomsen (1995), using a laminar-flow flume to control shear stress of the water, found that events without bedload movement can potentially have widely differing disturbance effects on reductions of algae among streams depending on the initial taxonomic composition of resident communities. In this study, algal-cell density at Little Darby Creek was not significantly reduced after the spring event, whereas the community at Hellbranch Run, with a similar cross-sectional velocity and a smaller magnitude of change in shear stress, was reduced by 76 percent. One of the differences between the two sites was the higher relative abundance of mat-forming blue-green algal filaments *Oscillatoria* spp. at Little Darby Creek in pre-event and post-event samples. Biggs and Thomsen (1995) also found biomass of some taxa potentially persisting through event peaks. These results emphasize the need for better understanding of the dynamics of community structure before predictions can be made regarding the response of the biotic community to changes in hydrology.

Bed-Material Particle Movement

The movement of small bed-material particles can be abrasive to the benthic community, and movement of larger particles can disrupt or even remove streambed habitat. The estimated maximum shear stresses calculated for the spring event at the three sites were 49 N/m^2 at Hellbranch Run, 48 N/m^2 at Little Darby Creek, and 18 N/m^2 at Big Darby Creek (table 3). Table 14 lists the critical shear stresses for incipient motion of noncohesive particles with diameters from 15 mm (<1/16 in.) to 50 mm (2 in.). A comparison of surface bed-material d_{50} particle sizes (table 6) with the critical shear stresses (table 14) and estimated maximum shear stresses reported earlier indicates that estimated maximum shear stresses associated with spring-event streamflow may have been sufficient to cause movement of median-sized surface

Table 13. Critical shear stress found to remove organisms from substrates
[N, newtons; nN, nanonewtons; µN, micronewtons]

Reference	Organism(s)	Criteria for removal	Critical surface shear stress per square meter
Harper and Harper (1967)	*Navicula* or *Nitzschia*	Detachment of stationary motile diatom individuals	Tens of nN
Harper and Harper (1967)	*Amphora ovalis*	Detachment of stationary motile diatom individuals	A few µN
Harper and Harper (1967)	Diatoms	Detachment of attached diatoms in glass capilary	0.1 to 10 N
Powell and Slater (1982)	*Bacillus cereus*	Remove 98% of bacteria on walls of glass capillary	24 N
Powell and Slater (1982)	*Bacillus cereus*	Removal of all bacteria on walls of glass capillary	32 N
Powell and Slater (1982)	*Escherichia coli* or *Salmonella typhimurium*	Removal of all bacteria on walls of glass capillary	50 N
Biggs and Thomsen (1995)	*Melosira varians/ Gomphonema parvulum*	50% reduction in community chlorophyll *a*	3.6 N
Biggs and Thomsen (1995)	*Spirogyra* sp./ *Gomphoneis herculeana/ Ulothrix zonata*	50% reduction in community chlorophyll *a*	10 N
Biggs and Thomsen (1995)	*Fragilaria construns/ Cymbella minuta*	50% reduction in community chlorophyll *a*	50.6 N
Biggs and Thomsen (1995)	*Fragilaria vaucheria/ Cymbella minuta*	50% reduction in community chlorophyll *a*	> 90 N

bed-material particles at the Hellbranch Run and Little Darby Creek sites, but not at the Big Darby Creek site. An analogous comparison suggests that median-sized surface bed-material particles were not moved during the summer event.

Although estimated maximum shear stresses for the spring event exceeded Shields' critical shear stresses at Hellbranch Run and Little Darby Creek, the potential for movement of a given bed-material particle is a function of a complex set of factors in addition to flow-field parameters. These factors include the particle's position within the channel, the presence or absence of an armoring layer, the presence of cohesive sediments, anchoring by aquatic plants, and the effect of biofilms. In addition, research has shown that bedload transport can occur in gravel-bed streams even when tractive forces are less than critical values needed to move the armor layer (Klingeman and Emmett, 1982). Consequently, considerable uncertainty remains as to the extent to which bed materials were in transport. However, ancillary channel geometry data (figures 8–10) and bed-material particle-size data (tables 6–7) collected over the duration of study indicate that any disturbances of the bed materials that may have been associated with the events were probably minor.

Post-event macroinvertebrate and algal densities generally were lower than pre-event densities; however, the magnitudes of the decrease generally did not correlate well with either the magnitude of the peak streamflow or the magnitude of the estimated maximum shear stress. The reasons for the lack of correlation are not entirely clear. Factors such as seasonality of the macroinvertebrate and algal populations, changing rates of regrowth and recolonization, and timing issues associated with the logistics of sampling streams of various stream orders may have influenced the observed results.

Table 14. Critical shear stress for given particle size based on Shield's criteria

[mm, millimeters; τ_c, tau critical or critical shear stress; lb/ft^2, pounds per square foot; N/m^2, newtons per square meter. Data derived from Vanoni, 1975]

Particle size (mm)	τ_c (lb/ft^2)	τ_c (N/m^2)	Particle size (mm)	τ_c (lb/ft^2)	τ_c (N/m^2)
15	0.32	15.4	33	0.67	32.0
16	.34	16.3	34	.69	32.9
17	.36	17.3	35	.71	33.8
18	.38	18.2	36	.72	34.7
19	.40	19.1	37	.74	35.6
20	.42	20.1	38	.76	36.5
21	.44	21.0	39	.78	37.4
22	.46	21.9	40	.80	38.3
23	.48	22.9	41	.82	39.2
24	.50	23.8	42	.84	40.0
25	.52	24.7	43	.86	40.9
26	.54	25.6	44	.87	41.8
27	.55	26.5	45	.89	42.7
28	.57	27.5	46	.91	43.6
29	.59	28.4	47	.93	44.5
30	.61	29.3	48	.95	45.4
31	.63	30.2	49	.97	46.2
32	.65	31.1	50	.98	47.1

Biotic Interactions

Late spring declines in algal-cell densities were observed at the Hellbranch Run, Little Darby, and Big Darby Creek sites. At Hellbranch Run, algal-cell density declined in late spring as macroinvertebrate densities increased (fig. 12), resulting in a weak but significant inverse correlation (as determined by Kendall's tau-b; τ=-0.40, p=0.006). No comparable significant relation was found between algal-cell and macroinvertebrate densities at the other two sites.

As primary producers, the benthic algae serve as a food source for many macroinvertebrate scrapers and gatherers. Grazers have been observed to significantly reduce the periphyton community in several grazing experiments (Colletti and others 1987; Lowe and Hunter, 1988; Steinman and others 1987; Swamikannu and Hoagland, 1989).The physiognomic types of algal structure considered by Lowe and Hunter (1988) are similar to those tested in this study for hydraulic resistance (table 12; Appendix 3). In addition to significant reductions in algal-cell density, Lowe and Hunter (1988) found that the snail, *Physa integra,* reduced species richness, species diversity, and physiognomic complexity, and its presence led to a community dominated by grazer-resistant taxa that were largely prostrate diatoms. Swamikannu and Hoagland (1989) examined low, intermediate, and high densities of the freshwater snail, *Physella*, (12, 30, and 70 snails/m^2) and found that periphyton diversity was highest at low to intermediate levels of grazing. Morphology and method of attachment were found to be the primary factors mediating periphyton community response to various levels of grazing disturbance: filamentous algae and upright cells with apical pads were suppressed at moderate to high levels of grazing, densities of low-profile algae were enhanced at moderate grazing, and densities of prostrately attached taxa were enhanced at moderate and high grazing levels. Results from these grazing experiments indicate that, if snails are present, interpretations of hydrologic disturbance should include consideration of snail grazing rates.

Snails were not collected during the normal biological sampling periods (in 1994); however, field observation of what appeared to be increasing snail populations, coupled with the observed late-spring decline in algal-cell densities, prompted an additional study (in 1995) on the seasonal variation of snail population densities. Snail densities were found to increase appreciably between the March and April 1995 samplings (table 15), possibly explaining in part the earlier observed late-spring decline in algal-cell densities. The snail, *Elimia* sp., was the most abundant taxon. In the Piedmont region of Alabama, losses of *Elimia* snails during winter (temperature 10°C or less) resulted in the net reduction of biomass, because snail production was extremely low during that period (Huryn and others, 1995). Low temperatures in central Ohio (such as occurred during the winter of 1994, when average temperatures were below freezing) may have reduced the grazing pressure of the *Elimia* snails on the periphyton community during winter, possibly contributing to the high algal-cell densities found in early spring.

Changes in food supplies after storm events also can affect macroinvertebrates and algal communities. The density of gatherers decreased at each study site after storm events (table 9). Grimm and Fisher (1989) found steep declines in gatherers during the later stages of flash-flood-induced succession. The declines were attributed to limited food quality rather than synchronous emergence. Earlier work by Rabeni and Minshall (1977) and Minshall (1988) supports the proposal by Grimm and Fisher that food may limit macroinvertebrate distribution. Rabeni and Minshall found insects colonizing in response to amounts of detritus and concluded that detritus is primarily important; however, it is the physical factor of substratum particle size that determines the distribution of detritus. Although trends in subsurface streambed-particle size were found at all three sites during this study, understanding how the observed trends might influence the macroinvertebrate communities in the Big Darby Creek Basin would require additional investigation.

Temperature and Other Environmental Factors

Temperature plays an important role in many biological processes by affecting such factors as the availability of gases (oxygen and carbon dioxide) and metabolic rates; these factors, in turn, affect emergence of many macroinvertebrates and nutrient uptake by algae. Data on the physical properties and chemical

Table 15. Summary statistics of snail densities at riffle sites in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio

[Data based on 27 samples per site, collected in 1995. Mean is mean density of snails per square meter; SD is standard deviation]

Riffle site	March 17		April 19		May 8	
	Mean	SD	Mean	SD	Mean	SD
Hellbranch Run	32	32	1,130	355	560	678
Little Darby Creek	43	32	1,151	51	786	323
Big Darby Creek	172	247	377	441	667	882

constituents (table 8) indicate significant seasonal differences that may affect the study sites to varying degrees. Gordon and others (1992) mention that, as a general rule, a rise of 1°C increases the rate of metabolism in cold-blooded animals by about 10 percent. The relatively low density of macroinvertebrates at Hellbranch Run (1,722 ± 269 organisms/m^2) compared with Little Darby Creek (10,147 ± 5,197 organisms/m^2) in early April (April 4–5, 1994) may have been a result of the lower water temperature. The water temperature was 5.5°C at Hellbranch Run on April 4th and 9.0°C at Little Darby Creek on April 5, 1994. Freezing of the substrate by anchor ice in February 1994 may also have contributed to the low pre-event macroinvertebrate densities in April 1994.

As figure 25 illustrates, many interacting factors contribute to the community structure of the algae and macroinvertebrates. The combined effects of these factors influence the macroinvertebrate and algal-cell densities that were found during this study. Although physical disturbance has been documented in the form of shifts in particle sizes at all three sites, the initial densities and recolonization rates will also be influenced by a combination of these factors.

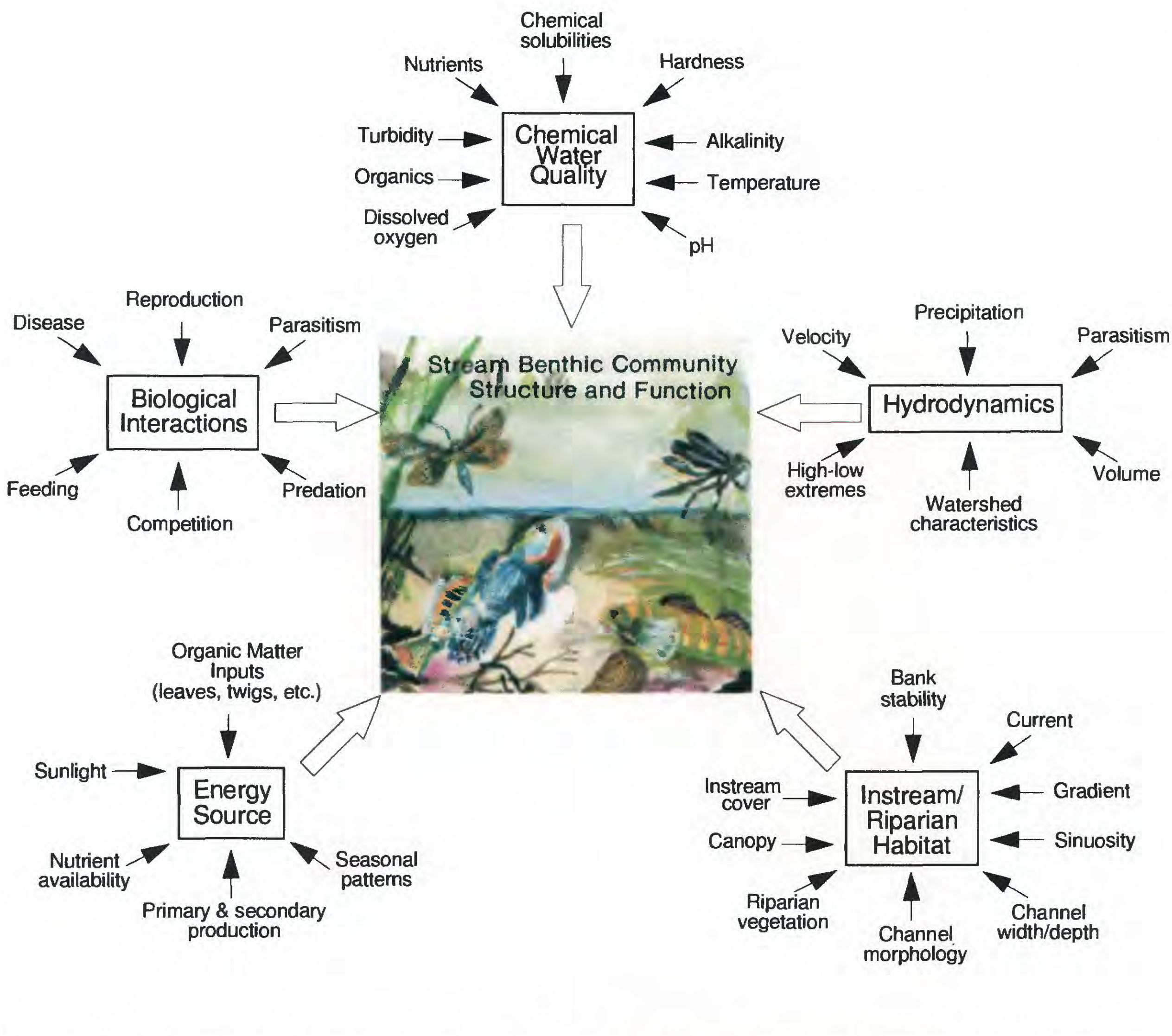


Figure 25. Five classes of environmental factors that affect the structure and function of the stream benthic community (modified from Karr, 1986, and Ohio Environmental Protection Agency, 1987).

SUMMARY

Floods of sufficient magnitude to result in streambed scour are known to cause disruptions of the aquatic community by washing out organisms that do not find refuge in the interstitial environment of the substrate or subsurface zone. Macroinvertebrates and algae often recolonize in a matter of weeks or months when disruption is noncatastrophic. However, increases in the amount and frequency of runoff due to loss of vegetated land cover, which can occur in watersheds like the Darby Creek Basin in central Ohio that are undergoing urban and agricultural development, can affect flood characteristics and promote substrate movement and (or) changes in sediment deposition patterns that can affect the dynamics of washout and recolonization. To document and enhance the understanding of such effects, aquatic communities and their associated hydrologic and habitat-disturbance factors were characterized for three riffle sites in the Big Darby Creek Basin before and after two storm events (April 6–16, 1994, and June 23–July 5, 1994).

During the study, 184 macroinvertebrate taxa were identified. The major taxonomic groups (representing 90 percent of the taxa identified) were midges and other true flies (Diptera), caddisflies (Trichoptera), beetles (Coleoptera), mayflies (Ephemeroptera), and stoneflies (Plecoptera). Macroinvertebrate densities at the riffle sites during the summer averaged 7,830 organisms/m^2 at the Big Darby Creek riffle site, 3,860 organisms/m^2 at Hellbranch Run, and 2,900 organisms/m^2 at Little Darby Creek.

The macroinvertebrate community was evaluated as a function of the feeding and flow-exposure characteristics of the taxa. Evaluation of the macroinvertebrate community structure in terms of functional feeding groups showed that, on the basis of percentage of total taxa found, gatherers were the dominant feeding group, followed by predators, shredders, scrapers, and filterers. Gatherers were also the most abundant group throughout the study, and predators were frequently the least abundant. Evaluation of the macroinvertebrate community structure in terms of flow-exposure groups showed that, on the basis of percentage of total taxa found, flow-facultative taxa were the dominant flow-exposure group, followed by flow-avoider and flow-obligate taxa.

During the study, 202 algal taxa were identified. Diatoms were the dominant group (in terms of percentage of total taxa found) followed by green algae, blue-green algae, euglenoids, golden flagellates, and freshwater red algae. The diatoms (particularly those that are single celled, unattached, or small) also were the most abundant in the algal community.

Macroinvertebrate and algal-cell densities were determined from samples collected before and after the storm events. Densities of organisms in pre-event samples and in the first set of post-event samples were compared statistically to assess whether significant changes had occurred. Densities were said to be reduced when densities in the pre-event samples were greater than densities in the first post-event samples. Densities were said to have increased when the opposite was true.

Densities of gatherers always decreased from pre-event levels following the storm events and were significantly reduced in most cases. Densities of flow-avoider and flow-facultative taxa were significantly reduced after the summer event at Big and Little Darby Creeks, whereas densities of flow-obligate taxa were not significantly reduced.

Algal-cell densities varied seasonally and were greater in the spring than in the summer. Algal-cell densities in the first post-event samples always were lower than pre-event densities; however, the total number of taxa present generally were not statistically different. In four out of five of the first post-event samples, algal-cell densities were only 16 to 26 percent of the pre-event densities. The exception was at Little Darby Creek after the spring event, where only the density of stalked algal-cells in the community was significantly reduced.

Algal recolonization rates computed for the period following the summer event were 0.05, 0.88, and 1.51 billion cells/m^2/d for Hellbranch Run, Little Darby Creek, and Big Darby Creek, respectively.

Although post-event macroinvertebrate and algal densities generally were lower than pre-event densities, the magnitudes of the decrease generally did not correlate well with either the magnitude of the peak streamflow or the magnitude of the estimated maximum shear stress. Several factors such as seasonality of the macroinvertebrate and algal populations, changing rates of regrowth and recolonization, and timing issues associated with the logistics of sampling streams of different stream order may have influenced the observed results.

Streamflow, stream velocity, and shear stress. During the spring storm event (April 6–16, 1994), maximum streamflows ranged from about 7 to 24 times the mean streamflows for the preceding 7-day period. Differences between pre-event streamflows and maximum streamflows at the streamflow-gaging stations during the summer event were greater than those for the spring event, ranging from about 15 to 30 times the respective mean streamflows for the preceding 7 days. The maximum streamflows for both storms were considerably less than the respective 2-year flood-peak discharges reported for all three streamflow-gaging stations. Although average pre-event velocities at the three sites are within the general velocity preference range (26-107 cm/s) reported in literature for selected macroinvertebrate species, peak flows at Hellbranch Run during the spring event and at Little Darby Creek during the spring and summer events resulted in velocities that exceeded the preference range. The reduction in density of flow-avoider and flow-facultative taxa without a significant reduction in densities of flow-obligate taxa at Little Darby Creek after the summer event could be expected, but similar results at Big Darby Creek, where flows did not exceed velocity preference ranges, may reflect the influence of other factors such as the effects of particle movement and (or) the seasonal emergence of midges and other true flies.

Algal-cell density at Little Darby Creek was not significantly reduced after the spring event, whereas the community at Hellbranch Run, with similar cross-sectional velocity and a smaller magnitude of change in shear stress, was reduced by 76 percent. The observed resistance to disturbance of the algal community at Little Darby Creek may have resulted from the relative abundance of the mat-forming blue-green algae, *Oscillatoria* spp. (The thickness of algal mats has been found to increase with increasing stream velocity as progressively more mucilage is produced that surrounds the interwoven filaments with a smooth biofilm). As would be expected, the stalked cells, the least resistant of the attached cells to hydrologic disturbance, were found to be the most consistently reduced in the post-event samples, whereas algae that lie flat or have a holdfast were the most resistant to washout.

Bed-material movement. The movement of small bed-material particles can be abrasive to the benthic community, and movement of larger particles can disrupt or even remove streambed habitat. Estimated maximum shear stresses associated with the spring event may have been sufficient to cause movement of median-sized surface bed-material particles at the Hellbranch Run and Little Darby Creek sites, but not at the Big Darby Creek site. An analogous comparison indicates that median-sized surface bed-material particles were likely not moved during the summer event.

Although estimated maximum shear stresses for the spring event exceeded Shields' critical shear stresses for median-sized surface bed-material particles at Hellbranch Run and Little Darby Creek, the potential for movement of a given bed-material particle is a function of a complex set of factors in addition to flow-field parameters. Considerable uncertainty remains as to the extent to which bed materials were in transport; however, ancillary channel geometry and bed-material particle-size data collected over the duration of study indicate that any disturbances of the bed materials that may have been associated with the events were probably minor.

Nevertheless, subsurface bed materials tended to become coarser at Big Darby Creek from March to July. In contrast, subsurface bed materials at Hellbranch Run tended to become finer over the period April 4-29 and then remained relatively unchanged. The trend in d_{50} data at Little Darby Creek is less consistent than trends at either Big Darby or Hellbranch Run; however, the data suggest that subsurface bed materials tended to become coarser there as well. No trend in d_{50} values of surface bed materials was apparent for any of the sites.

Temporal changes in streambed elevations were assessed visually by reviewing overlaid plots of profile data that were gathered over time at each cross-section location. Generally, the largest change in streambed elevations occurred between the measurement made in August 1993 and the first measurements made in 1994. The changes observed for this time period are presumed to have resulted primarily from a flood that occurred in January 1994. In general, variations in streambed elevations that occurred between sequential measurements at a given location in the cross sections during the remainder of the study (April–October 1994) were small (about 0.2 ft or less).

Biotic and water-quality factors. Local minima of macroinvertebrate density did not generally correspond to the first sample after the storm events but instead lagged by about 1 to 3 weeks. Depressions in macroinvertebrate densities in mid-July are probably a result of the emergence of midges and other true flies and caddisflies, which normally occurs in central Ohio from mid-June to mid-July. However, the 1- to 3-week lag for the macroinvertebrate community to reach its minimum density after both the spring and summer storm events could be due, in part, to biotic factors such reduction in food supply (for example, loss of food resource for filterers).

In general, the filterers, scrapers, and gatherers, all of which rely on algae and detritus for food, were the dominant groups during the summer. Predators, which were reduced in density after the storm, constituted approximately 5 percent of the community by September. Shredders did not represent a large proportion of the community during the summer months; however, this group is expected to represent a greater proportion in the autumn as leaves fall into the water.

Late spring declines in algal-cell densities were observed at the Hellbranch Run, Little Darby, and Big Darby Creek sites. At Hellbranch Run, the late spring decline in algal-cell density occurred as macroinvertebrate densities increased, resulting in a weak but statistically significant inverse correlation. No comparable statistically significant relation was found between algal-cell and macroinvertebrate densities at the other two sites.

There are significant seasonal differences in physical and chemical water-quality characteristics that may affect the study sites to varying degrees. The relatively low early-April (1994) density of macroinvertebrates at Hellbranch Run (1,722 $\pm$269 organisms/m^2) compared with Little Darby Creek (10,147 $\pm$ 5,197 organisms/m^2) may have been influenced by the lower water temperature at Hellbranch Run. Freezing of the substrate by anchor ice in February 1994 may also have contributed to the low early-April macroinvertebrate densities.

Many interacting factors contribute to the community structure of the algae and macroinvertebrates. Although physical disturbance was documented in the form of shifts in the median particle-size of the subsurface bed materials and reductions in macroinvertebrate and algal densities were observed, factors not directly related to peak streamflows, such as seasonal patterns of the benthic community and the preconditioning of the benthic community to flow may have strongly influenced the measured washout and recolonization of stream biota.

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APPENDIXES

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
PLATYHELMINTHES			
TURBELLARIA			
Dugesia tigrina	Ga	F	19
ANNELIDA			
HIRUDINEA (leeches)	Pr	A	6
BRANCHIOBDELLIA (commensals)	n.c.	n.c.	14
OLIGOCHAETA (aquatic worms)	Ga	A	72
ARTHROPODA			
CRUSTACEA			
Isopoda (aquatic sow bugs)	Sh	F	19
Amphipoda (scuds)	Sh	F	5
Decapoda (crayfish)	Ga	F	11
Orconectes rusticus	Ga	F	6
HYDRACARINA (water mites)	Pr	F	27
INSECTA			
Collembola (springtails)	n.c.	n.c.	15
Coleoptera (beetles)			
Dryopidae			
Helichus sp.	Sc	F	1
Dytiscidae			
Agabus sp.	Pr	A	1*
Elimidae			
Ancyronyx variegatus (German)	Ga	A	1
Dubiraphia sp.	Ga	A	19
Dubiraphia brevipennis Hilsenhoff	Ga	A	1

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Coleoptera (beetles) - continued			
Dubiraphia minima Hilsenhoff	Ga	A	4
Dubiraphia vittata (Melcheimer)	Ga	A	1
Macronychus sp.	Ga	A	1
Stenelmis sp.	Sc	F	100
Stenelmis bicarinata Le Conte	Sc	F	5
Stenelmis crenata (Say)	Sc	F	36
Stenelmis decorata Sanderson	Sc	F	2
Stenelmis markeli Motschulsky	Sc	F	6
Stenelmis quadrimaculata Horn	Sc	F	1
Stenelmis sexlineata Sanderson	Sc	F	74
Gyrinidae			
Dineutus sp.	Pr	A	4
Halipidae			
Peltodytes sp.	Sh	A	5
Peltodytes lengi Roberts	Sh	A	1
Hydrophilidae	Sh	A	2
Berosus sp.	Sh	A	1
Berosus peregrinus (Herbst)	Sh	A	1
Enochrus perplexus (Le Conte)	Ga	A	1
Helophorus orientalis Motschulsky	Sh	A	1
Paracymus subcupreus (Say)	Ga	A	1
Limnichidae			
Limnichus sp.	Ga	F	1
Lutrochus sp.	Ga	F	1

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Coleoptera (beetles) - continued			
Asephenidae			
Ectopria sp.	Sc	F	1
Psephenus herricki (De Kay)	Sc	F	64
Scirtidae			
Cyphon sp.	Sc	A	1
Hemiptera (true bugs)			
Gerridae	Pr	F	8
Corixidae	Pr	A	1
Lepidoptera (aquatic moths)			
Petrophila sp.	Sh	F	1
Megaloptera (alderflies)			
Sialis sp.	Pr	F	24
Corydalus cornutus (L.)	Pr	O	5
Odonata			
Zygoptera (damselflies)	Pr	A	3
Calopterygidae	Pr	A	1
Calopteryx sp.	Pr	A	1
Coenagrioniidae	Pr	A	11
Ischnura sp.	Pr	A	1
Argia sp.	Pr	F	1
Anisoptera (dragonflies)	Pr	F	1
Macromia sp.	Pr	A	1
Ophiogomphus sp.	Pr	F	1

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Ephemeroptera (mayflies)			
Baetidae	Ga	F	25
Baetis sp.	Ga	F	16
Baetis flavistriga McDunnough	Ga	O	13
Baetis intercalaris McDunnough	Ga	O	24
Baetis virile (McDunnough)	Ga	O	10
Centroptilum sp.	Ga	A	2
Caenidae			
Caenis sp.	Ga	A	75
Ephemerellidae	Ga	F	8
Ephemerella sp.	Ga	F	1
Ephemerella needhami McDunnough	Ga	F	1*
Serratella sp.	Ga	F	2
Serratella deficiens Morgan	Ga	F	7
Ephemeridae	Ga	A	1
Ephemera sp.	Ga	A	6
Hexagenia sp.	Ga	A	1
Heptageniidae	Sc	F	42
Leucrocuta sp.	Sc	F	14
Stenacron sp.	Ga	F	42
Stenonema sp.	Sc	F	42
Stenonema exiguum Traver	Sc	F	1
Stenonema femoratum (Say)	Sc	F	28
Stenonema terminatum (Walsh)	Sc	F	10

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Ephemeroptera (mayflies) - continued			
Stenonema mediopunctatum (McDunnough)	Sc	F	22
Stenonema pulchellum (Walsh)	Sc	F	17
Leptophlebiidae	Ga	F	3
Oligoneuriidae			
Isonychia sp.	Fi	O	42
Polymitarcyidae			
Ephoron sp.	Ga	F	14
Potamanthidae			
Anthopotamus sp.	Ga	F	5
Siphlonuridae	Ga	F	1*
Tricorythidae			
Tricorythodes sp.	Ga	F	29
Plecoptera (stoneflies)			
Capniidae	Sh	F	24
Allocapnia sp.	Sh	F	7
Chloroperlidae	Pr	F	5*
Nemouridae	Sh	F	1
Amphinemura sp.	Sh	F	9*
Perlidae	Pr	F	24
Agnetina flavescens Frison	Pr	F	18
Neoperla sp.	Pr	F	24
Neoperla cylmene (Newman)	Pr	F	4
Perlesta sp.	Pr	F	10
Perlodidae	Pr	F	1

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Plecoptera (stoneflies) - continued			
Isoperla sp.	Pr	F	1
Isoperla nana Frison	Pr	F	1*
Taeniopterygidae	Sh	F	1*
Trichoptera (caddisflies)			
Glossosomatidae			
Protoptila sp. (Hagen)	Sc	O	15
Protoptila maculata (Hagen)	Sc	O	2
Helicopsychidae			
Helicopsyche borealis	Sc	F	3
Hydropsychidae	Fi	O	28
Ceratopysche sp.	Fi	O	10
Ceratopysche bronta (Ross)	Fi	O	30
Ceratopsyche cheilonis (Ross)	Fi	O	34
Ceratopsyche morosa group	Fi	O	35
Cheumatopsyche sp.	Fi	O	81
Cheumatopsyche campyla Ross	Fi	O	5
Cheumatopsyche pasella Ross	Fi	O	1
Cheumatopsyche pettiti (Banks)	Fi	O	4
Hydropsyche sp.	Fi	O	6
Hydropsyche betteni Ross	Fi	O	9
Hydropsyche dicantha Ross	Fi	O	12
Potamyia flava (Hagen)	Fi	O	1
Hydroptilidae	Sh	O	6
Agraylea multipunctata Curtis	Sh	A	1*

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Trichoptera (caddisflies) - continued			
Hydroptila sp.	Sh	O	35
Hydroptila consimilis Morton	Sh	O	2
Hydroptila grandiosa Ross	Sh	O	3
Hydroptila perdita Morton	Sh	O	1
Ochrotrichia tarsalis (Hagen)	Ga	O	4
Oxyethira sp.	Sh	F	1*
Stactobiella sp.	Sh	O	8*
Leptoceridae			
Ceraclea sp.	Ga	F	1
Oecetis sp.	Sh	F	9
Mystacides sp.	Ga	F	1*
Limnephilidae			
Pycnopysche sp.	Sh	F	14
Pycnopsyche lepida group	Sh	F	1
Philopotamidae			
Chimarra sp.	Fi	O	28
Psychomyiidae			
Psychomyia flavida Hagen	Fi	O	6
Rhyacophilidae	Pr	O	1
Rhyacophila fenestra/ledra (Ross/Ross)	Pr	O	2*
Rhyacophila invaria (Walker)	Pr	O	1*
Rhyacophila lobifera Betten	Pr	O	1*
Uenoidae			
Neophylax sp.	Sc	F	8

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Trichoptera (caddisflies) - continued			
Polycentropodidae			
Polycentropus sp.	Pr	F	1
Diptera (true flies)			
Athericidae			
Atherix sp.	Pr	O	1*
Ceratopogonidae	Pr	A	22
Atrichipogon sp.	Ga	F	1
Chaoboridae			
Chaoborus sp.	Pr	A	2*
Culicidae	Fi	A	4
Psorophora sp.	Pr	A	1*
Dolichopodidae	Pr	A	2*
Empididae	Pr	O	1
Clinocera sp.	Pr	O	6
Hemerodromia sp.	Pr	O	38
Ephydridae	Sh	A	1
Ephydra sp.	Sh	A	3
Psychadidae			
Pericoma sp.	Ga	A	4*
Psychoda sp.	Ga	A	2
Simuliidae	Fi	O	4
Prosimulium sp.	Fi	O	3*
Simulium sp.	Fi	O	42
Stratiomyiidae	Ga	A	1

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Diptera (true flies) - continued			
Tabanidae			
Chrysops sp.	Pr	A	2
Antocha sp.	Ga	O	25
Tipulidae	Sh	A	4
Erioptera sp.	Ga	A	1*
Hexatoma sp.	Pr	F	39
Molophilus sp.	Sh	A	1*
Ormosia sp.	Ga	A	1*
Pedicia sp.	Pr	A	1*
Pilaria sp.	Pr	A	1
Tipula sp.	Sh	A	7
Chironomidae	Ga	F	44
Chironomidae-Tanypodinae	Pr	F	1
Ablabesmyia sp.	Pr	A	1
Ablabesmyia mallochi (Walleyi)	Pr	A	17
Conchapelopia sp.	Pr	F	56
Labrundinia sp.	Pr	F	2
Meropelopia sp.	Pr	F	1
Natarsia sp.	Pr	A	1
Nilotanypus sp.	Pr	F	38
Paramerina sp.	Pr	A	1
Rheocricotopus sp.	Ga	F	25
Rheocricotopus robacki (Beck and Beck)	Ga	F	6
Thienemannimyia group	Pr	F	31

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Diptera (true flies) - continued			
Chironomidae-Chironomini	Ga	F	15
Chironomus sp.	Ga	F	10
Cryptotendipes sp.	Ga	A	1
Cryptochironomus sp.	Ga	A	31
Demicryptochironomus sp.	Ga	F	1*
Dicrotendipes sp.	Ga	F	15
Dicrotendipes neomodestus group	Ga	F	8
Glyptotendipes sp.	Ga	A	1
Microtendipes sp.	Ga	F	26
Microtendipes pedellus group	Ga	F	42
Parachironomus sp.	Ga	A	1
Paratendipes sp.	Ga	A	8
Phaenopsectra sp.	Ga	A	18
Phaenopsectra flavipes group	Ga	A	1*
Polypedilum sp.	Ga	F	44
Polypedilum convictum group	Ga	F	37
Polypedilum fallax (Johannsen)	Ga	A	3
Polypedilum halterale (Coquillett)	Ga	A	2
Polypedilum illinoense group	Ga	A	8
Polypedilum scalaenum group	Ga	A	25
Polypedilum tritum (Walker)	Ga	A	3*
Pseudochironomus sp.	Ga	A	5
Saetheria sp.	Ga	F	1*
Stictochironomous sp.	Ga	A	12

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Diptera (true flies) - continued			
Tribelos sp.	Ga	A	1
Chironomidae-Orthocladiinae	Ga	F	7
Acricotopus sp.	Ga	A	1*
Brillia sp.	Sh	A	4
Cardiocladius sp.	Ga	O	24
Chaetocladius sp.	Ga	A	1*
Corynoneura sp.	Ga	F	32
Cricotopus sp.	Sh	F	8
Cricotopus bicinctus group	Sh	F	22
Cricotopus infuscatus (Malloch)	Sh	A	1
Cricotopus infuscatus group	Sh	A	14
Cricotopus sylvestris (Fabricius)	Sh	A	5*
Cricotopus trifascia Edwards	Sh	F	15
Cricotopus varipes group	Sh	F	7
Cricotopus vieriensis Goetghebuer	Sh	F	1
Eukiefferiella sp.	Ga	F	23
Eukiefferiella brehmi group	Ga	O	1
Eukiefferiella brevicalcar group	Ga	F	10*
Limnophyes sp.	Ga	F	1
Nanocladius sp.	Ga	F	22
Orthocladius sp.	Ga	F	62
Orthocladius (*Euorthocladius*) sp.	Ga	F	1*
Paracricotopus sp.	Ga	O	1*
Parakiefferiella sp.	Ga	F	10

Appendix 1. Macroinvertebrate taxa, functional feeding groups, flow-exposure groups, and frequency in Hellbranch Run, Little Darby Creek, and Big Darby Creek, Ohio—*Continued*

[Data based on 144 samples per site, collected in 1994 by use of both 224- and 600-micrometer mesh nets. Functional feeding group (based on Merritt and Cummins, 1984): Fi, filterer; Ga, gatherer; Pr, predator; Sc, scraper; Sh, shredder. Flow-exposure group (based on Growns and Davis, 1994): A, avoider; F, facultative; O, obligate; n.c., not categorized. An asterisk after the frequency indicates taxa not previously listed as found in the Big Darby Creek Basin]

Taxa	Functional feeding group	Flow-exposure group	Frequency
ARTHROPODA - continued			
INSECTA - continued			
Diptera (true flies) - continued			
Parametriocnemis sp.	Ga	F	15
Parametriocnemis lundbecki (Johannsen)	Ga	F	1
Procladius sp.	Pr	A	4
Thienemanniella sp.	Pr	F	51
Tvetenia sp.	Ga	F	15
Tvetenia bavarica group	Ga	F	1
Tvetenia discoloipes group	Ga	F	6
Chironomidae-Tanytarsini	Ga	F	8
Cladotanytarsus sp.	Ga	A	32
Micropsectra sp.	Ga	F	1
Paratanytarsus sp.	Ga	A	1
Rheotanytarsus sp.	Fi	O	51
Stempellinella sp.	Ga	F	74
Sublettea sp.	Ga	O	11
Tanytarsus sp.	Ga	F	67
Tanytarsus curticornis group	Ga	F	4
Diamesinae			
Diamesa sp.	Ga	F	1*

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frecuency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Cyanophyta		
Agmenellum quadruplicatum (Meneghini) Brébisson		7
Aphanocapsa delicatissima West & West	15	
Aphanothece sp.	3	
Chroococcus sp.		21
Chroococcus minutus (Kützing) Nägeli	69	
Desmococcus sp.	8	45
Entophysalis lemaniae (Agardh) Drouet & Dailey		13
Gloeocapsa sp.	7	
Gloeocystis sp.	80	
Lyngbya sp.		37
Microcystis sp.	37	
Nostoc sp.	5	
Oscillatoria sp.		66
O. angustissima West & West	37	
O. hamelii Frémy	85	
Spirulina sp.		3
Calothrix sp.		<1
Stigonema sp.		<1
Chlorophyta		
Ankistrodesmus sp.		7
Chlamydomonas sp.	2	29
Cladophora sp.	34	18
Closterium sp.		5
Coelastrum sp.		<1
Cosmarium sp.		5
Euastrum sp.	2	
Mougeotia sp.	2	

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Chlorophyta—continued		
Oedogonium sp.		2
Oocystis sp.		2
Pediastrum sp.		<1
Rhizoclonium sp.	14	
Spirogyra sp.		3
Scenedesmus sp.		15
Sphaerellopsis sp.	2	
Stigeoclonium sp.		6
Tetraspora sp.	8	
Ulothrix sp.	7	
Euglenophyta		
Euglena sp.	56	<1
Lepocinclis sp.		3
Trachelomonas sp.	34	
Chrysophyta		
Mallomonas acaroides Perty emend. Iwanoff	29	
Synura sp.	17	
Bacillariophyta		
Achnanthes conspicua Mayer		20
A. linearis (W. Smith) Grunow		8
A. trinodis (W. Smith) Grunow		5
Achnanthidium sp.		4
A. clevei (Grunow in Cleve & Grunow) Czarnecki & Edlund		4
A. exiguum (Grunow in Cleve & Grunow) Czarnecki & Edlund		8
A. hungaricum Grunow	2	
A. lanceolata[a] Brébisson in Kützing	66	37
A. lanceolata var. *dubia* (Grunow in Cleve & Grunow) Meist.	14	
A. minutissimum[a] (Kützing) Czarnecki	73	68

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
Amphora sp.		<1
A. ovalis (Kützing) Kützing		31
A. ovalis var. *affinis* (Kützing) Van Heurck in De Toni	61	
A. ovalis var. *pediculus*[a] (Kützing) Van Heurck	98	69
A. perpusilla Grunow		99
A. submontana Kützing	2	11
A. veneta Kützing		3
Aulacoseira sp.		<1
Aulacoseira alpigena (Grunow) Krammer	3	
Aulacoseira granulata (Ehrenberg) Simonsen		3
Biddulphia laevis[a] Ehrenberg [*Pleurosira laevis* (Ehrenberg) Compere]	5	15
Caloneis bacillum (Grunow) Cleve	5	
C. hyalina Hustedt		56
C. lewisii Patrick	2	
Cocconeis pediculus[a] Ehrenberg	86	64
C. placentula[a] Ehrenberg	20	52
Cyclotella atomus[a] Hustedt	10	
C. comensis Grunow		9
C. meneghiniana Kützing[a]	3	55
C. pseudostelligera Hustedt[a]		
C. stelligera[a] Cleve in Grunow	5	
C. striata var. *ambigua*[a] Grunow	47	
Cymatopleura solea (Brébisson) W. Smith		3
Cymbella sp.		5
C. affinis Kützing	24	5
C. amphicephala Nägeli in Kützing	3	
C. cistula (Ehrenberg) Kirchner	8	
C. microcephala Grunow		<1

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
C. minuta[a] Hilse in Rabenhorst [*Encyonema minutum* (Hilse in Rabenhorst) D.G. Mann]	37	17
C. prostrata (Berkley) Cleve [*Encyonema prostratum* (Berkley) Kützing]		4
C. sinuata[a] Gregory [*Reimeria sinuata* (Gregory) Kociolek & Stoermer]	37	38
C. tumida Grunow	25	10
C. turgida Grunow	10	
Diatoma tenue Agardh	3	
D. vulgare Bory	34	39
D. vulgare var. *breve* Bory	7	
Diploneis elliptica (Kützing) Cleve		3
D. oblongella (Nägeli in Kützing) Ross	2	
Eunotia sp.		5
Fragilaria sp.		2
F. construens (Ehrenberg) Grunow [*Staurosira construens* Ehrenberg]	7	1
F. lanceolata (Kützing) Reichart	25	
F. pinnata Ehrenberg [*Fragilariforma virescens* (Ralfs) Williams & Round]		3
F. pinnata v. *lancettula* (Schuman) Hustedt		<1
F. vaucheriae (Kützing) Peters	20	48
F. virescens (Ralfs) Williams & Round	12	
Frustulia rhomboides (Ehrenberg) De Toni		3
F. vulgaris Thwaites	2	
Gomphoneis olivacae[a] (Lyngbye) Dawson	68	50
Gomphonema sp.		2
G. acuminatum Ehrenberg	25	<1
G. affine Kützing	19	6
G. angustatum[a] Kützing	15	41

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94 —*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
G. brasiliense Grunow		17
G. cf. *clevei* Fricke		3
G. dichotomum Kützing	5	3
G. gracile Ehrenberg	29	2
G. intricatum Kützing		1
G. parvulum[a] Kützing	37	36
G. sphaerophorum Ehrenberg	14	3
G. subclavatum (Grunow) Grunow		5
G. tenellum Kützing		2
G. truncatum Ehrenberg	8	<1
G. truncatum var. *capitata* (Ehrenberg) Patrick nom. nov.		5
Gyrosigma acuminatum (Kützing) Rabenhorst		15
G. attenuatum (Kützing) Cleve		2
G. scalproides (Rabenhorst) Cleve		5
G. sciotense (Sullivan & Wormley) Cleve		39
G. spencerii var. *curvula*[a] (Grunow) Reimer	29	
Hantzschia amphioxys (Ehrenberg) Grunow	8	3
Melosira varians[a] Agardh	63	8
Meridion circulare (Greville) Agardh	5	10
Navicula sp. *Sellophora* sp.		7 <1
N. accomoda Hustedt [*Craticula accomoda* (Hustedt) D.G. Mann]		<1
N. anglica Ralfs	5	
N. biconica[a] Patrick		
N. capitata[a] Ehrenberg	17	11
N. cincta[a] (Ehrenberg) Rabenhorst	34	
N. citrus Krasske		<1
N. confervacea (Kützing) Grunow		3

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
N. cryptocephala[a] Kützing	85	64
N. cryptocephala var. *exilis* (Kützing) Grunow		<1
N. cryptocephala var. *veneta*[a] (Kützing) Rabenhorst	100	83
N. cuspidata var. *ambigua* Cleve [*Craticula cuspidata* (Kützing) D.G. Mann]		<1
N. decussis Oestrup		2
N. gregaria Donkin		5
N. halophila (Grunow) Cleve		3
N. hustedtii Krasske		<1
N. menisculus Schumann		31
N. menisculus var. *upsaliensis*[a] (Grunow) Grunow	54	
N. minima[a] Grunow	59	71
N. muraliformis Hustedt		25
N. mutica Kützing [*Luticola mutica* (Kützing) D. G. Mann]		<1
N. mutica var. *goeppertiana* Bleisch [*Luticola goeppertiana* (Bleisch) H. L. Smith]		6
N. pupula Kützing [*Sellophora pupula* (Kützing) Mereschkowsky]		5
N. pygmaea Kützing [*Fallacia pygmaea* (Kützing) Stickle & Mann]		4
N. radiosa var. *parva* Wallace		44
N. radiosa var. *tenella* (Brébisson) Cleve		100
N. rhychocephala Kützing		18
N. salinarum Grunow		9
N. salinarum var. *intermedia* Grunow		77
N. secura[a] Patrick	10	
N. seminulum Grunow [*Sellaphora seminulum* (Grunow) D.G.Mann]		23
N. symmetrica[a] Patrick	46	38
N. tenera Hustedt		2

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
N. tenneloides Hustedt		20
N. tripunctata[a] (O.F. Mueller) Bory	85	98
N. tripunctata var. *schizonemoides* (Van Heurck) Patrick		21
N. viridula Kützing	68	46
N. viridula var. *avenaceae* (Brébisson) Van Heurck		6
N. viridula var. *linearis* Hustedt		<1
N. viridula var. *rostellata* (Kützing) Cleve	15	
Nedium binode (Ehrenberg) Hustedt	2	2
Nitzschia acicularis[a] W. Smith	3	19
N. amphibia[a] Grunow	68	36
N. angustata (W. Smith) Grunow		3
N. capitellata[a] Hustedt	30	
N. compressa (Bailey) Boyer	30	
N. constricta[a] (Kützing) Ralfs	32	
N. debilis[a] Arnott [*Tryblionella debilis* Arnott in O'Meara]	3	
N. dissipata[a] (Kützing) Grunow	78	98
N. dubia W. Smith		4
N. epiphytica[a] O. F. Mueller	71	
N. filiformis (W. Smith) Grunow	63	3
N. flexa Schumann	19	
N. fonticola Grunow	88	7
N. gracilis Hantzsch	25	
N. hungarica[a] Grunow [*Tryblionella hungarica* (Grunow) D.G. Mann]	15	35
N. inconspicua Grunow		92
N. levidensis (W. Smith) Grunow [*Tryblionella levidensis* W. Smith]		28
N. linearis[a] (Agardh in W. Smith) W. Smith	59	23

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
N. microcephala[a] Grunow	8	
N. palea (Kützing) W. Smith	39	89
N. recta Hantzsch		14
N. reversa W. Smith		5
N. sigmoidea (Ehrenberg) W. Smith	7	7
N. sociabilis Hustedt		48
N. sublinearis Hustedt		2
N. tryblionella Hantzsch	3	
N. tryblionella var. *subsalina* Hantzsch [*Tryblionella gracilis* W. Smith]		<1
N. vexans Grunow		<1
Pleurosigma salinarum var. *boyeri* (Keeley) Reimer		8
Rhoicosphenia curvata[a] (Kützing) Grunow [*Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot]	86	98
Stauroneis anceps Ehrenberg	3	
Stephanodiscus astraea var. *minutula*[a] (Kützing) Grunow [*Stephanodiscus medius* Håkansson]	3	
S. hantzschii Grunow in Cleve & Grunow		9
Surirella sp.		2
S. angusta Kützing	5	2
S. linearis W. Smith		<1
S. ovata[a] Kützing	47	49
S. ovata var. *pinnata*[a] W. Smith	5	
Synedra sp.		6
S. delicatissima[a] W. Smith	19	
S. fasciculata (Agardh) Kützing		1
S. rumpens Kützing		1
S. tabulata Hopkins		6
S. ulna[a] (Nitzsch) Ehrenberg		61

Appendix 2. Algae taxa found in the Big Darby Creek Basin, Ohio, and frequency of occurrence, 1992–94—*Continued*

[Frequency 1992, the percentage of times the taxon was found among 59 samples during May and August from 30 sites; frequency 1993-94, the percentage of times the taxon was found among 195 samples from 3 sites. Recent reclassifications (in brackets) follow listings under the historically used names]

Taxa	Frequency 1992	Frequency 1993–94
Bacillariophyta—continued		
S. ulna var. *danica* (Kützing) Van Heurck	54	
Thalassiosira fluviatilis[a] Hustedt [*T. weissflogii* (Grunow) Fryxell & Hasle]		6
Rhodophyta		
Audouinella hermannii (Roth) Duby	37	55
Batrachospermum sp.		3

[a]Diatom taxa identified as being present during 1968–69 (Collins and Kalinsky, 1977).

Appendix 3. Taxa, form, physiognomy, attachment, size, and frequency of occurrence of algae during the washout and recolonization study (1993–94) in the Big Darby Creek Basin, Ohio

[Form: S, single cells; C, colonies; F, filaments. Size: S, small (< 50 millimeters); M, medium (50-100 millimeters); L, large (> 100 millimeters); -, unknown. Frequency: the percentage of times (out of 195 samples analyzed) that the taxon was found]

Taxa	Form	Physiognomy	Attachment	Size	Frequency
Cyanophyta					
Chroococcus sp.	C	Tychoplanktonic	Unattached	L	21
Agmenellum quadruplicatum	C	Tychoplanktonic	Unattached	L	7
Entophysalis lemaniae	S	Upright	Holdfast	M	13
Lyngbya #1	F	Mat	Mat	S	21
Lyngbya #2	F	Mat	Mat	M	33
Lyngbya #3	F	Mat	Mat	L	37
Oscillatoria #1	F	Mat	Mat	S	66
Oscillatoria #2	F	Mat	Mat	M	49
Oscillatoria #3	F	Mat	Mat	L	45
Spirulina sp.	S	Tychoplanktonic	Unattached	M	3
Calothrix sp.	F	Upright	Holdfast	S	<1
Stigonema sp.	F	Upright	Holdfast	L	<1
Chlorophyta					
Ankistrodesmus sp.	S	Tychoplanktonic	Unattached	S	7
Chlamydomonas sp.	S	Motile	Unattached	S	29
Cladophora sp.	F	Upright	Holdfast	L	18
Closterium sp.	S	Tychoplanktonic	Unattached	L	5
Coelastrum sp.	C	Tychoplanktonic	Unattached	M	<1
Cosmarium spp.	S	Tychoplanktonic	Unattached	M	5
Oedogonium sp	F	Upright	Holdfast	L	2
Oocystis sp.	S	Tychoplanktonic	Unattached	S	2
Pediastrum sp.	C	Tychoplanktonic	Unattached	L	<1
Spirogyra sp.	F	Loose	Unattached	L	3
Scenedesmus sp.	C	Tychoplanktonic	Unattached	S	15
Stigeoclonium sp.	F	Upright	Holdfast	L	6
Euglenophyta					
Euglena sp	S	Motile	Unattached	L	<1
Lepocinclis sp.	S	Motile	Unattached	M	3

Appendix 3. Taxa, form, physiognomy, attachment, size, and frequency of occurrence of algae during the washout and recolonization study (1993–94) in the Big Darby Creek Basin, Ohio—*Continued*

[Form: S, single cells; C, colonies; F, filaments. Size: S, small (< 50 millimeters); M, medium (50-100 millimeters); L, large (> 100 millimeters); -, unknown. Frequency: the percentage of times (out of 195 samples analyzed) that the taxon was found]

Taxa	Form	Physiognomy	Attachment	Size	Frequency
		Bacillariophyta			
Achnanthes conspicua	S	Prostrate	Biofilm	S	20
A. linearis	S	Upright	Stalked	S	8
A. trinodis	S	Prostrate	Biofilm	S	5
Achnanthidium sp.	S	Prostrate	Biofilm	S	4
A. clevei	S	Prostrate	Biofilm	S	4
A. exigua	S	Prostrate	Biofilm	S	8
A. lanceolata	S	Upright	Stalked	S	37
A. minutissimum	S	Upright	Stalked	S	68
Amphora sp.	S	Motile	Unattached	S	<1
A. ovalis	S	Motile	Unattached	M	31
A. ovalis v. *pediculus*	S	Motile	Unattached	S	69
A. perpusilla	S	Motile	Unattached	S	99
A. submontana	S	Motile	Unattached	S	11
A. veneta	S	Motile	Unattached	S	3
Aulacoseira sp.	F	Loose	Unattached	-	<1
A. granulata	F	Loose	Unattached	M	3
Caloneis hyalina	S	Motile	Unattached	S	56
Cocconeis pediculus	S	Prostrate	Epiphytic	S	64
C. placentula	S	Prostrate	Epiphytic	M	52
Cyclotella comensis	S	Tychoplanktonic	Unattached	S	9
C. meneghiniana	F	Tychoplanktonic	Unattached	S	55
Cymatopleura solea	S	Motile	Unattached	L	3
Cymbella sp.	S	Upright	Stalked	S	5
C. affinis	S	Upright	Stalked	S	5
C. microcephala	S	Upright	Stalked	S	<1
C. minuta	S	Upright	Stalked	S	17
C. prostrata	F	Loose	Unattached	M	4
C. sinuata	S	Upright	Stalked	S	38
C. tumida	S	Upright	Stalked	M	10

Appendix 3. Taxa, form, physiognomy, attachment, size, and frequency of occurrence of algae during the washout and recolonization study (1993–94) in the Big Darby Creek Basin, Ohio—*Continued*

[Form: S, single cells; C, colonies; F, filaments. Size: S, small (< 50 millimeters); M, medium (50-100 millimeters); L, large (> 100 millimeters); -, unknown. Frequency: the percentage of times (out of 195 samples analyzed) that the taxon was found]

Taxa	Form	Physiognomy	Attachment	Size	Frequency
Bacillariophyta—continued					
Diatoma vulgare	S	Loose	Unattached	M	39
Diploneis elliptica	S	Motile	Unattached	M	3
Eunotia sp.	F	Loose	Unattached	L	5
Fragilaria sp.	F	Loose	Unattached	-	2
F. construens	F	Loose	Unattached	M	1
F. pinnata	F	Loose	Unattached	M	3
F. pinnata v. *lancettula*	F	Loose	Unattached	M	<1
F. vaucheriae	C	Upright	Apical pad	M	48
Frustulia rhomboides	S	Motile	Unattached	L	3
Gomphoneis olivaceae	S	Upright	Stalked	S	50
Gomphonema sp.	S	Upright	Stalked	-	2
G. acuminatum	S	Upright	Stalked	S	<1
G. affine	S	Upright	Stalked	M	6
G. angustatum	S	Upright	Stalked	S	41
G. brasiliense	S	Upright	Stalked	S	17
G. cf. *clevei*	S	Upright	Stalked	S	2
G. dichotomum	S	Upright	Stalked	S	3
G. gracile	S	Upright	Stalked	M	2
G. intricatum	S	Upright	Stalked	S	1
G. parvulum	S	Upright	Stalked	M	36
G. sphaerophorum	S	Upright	Stalked	S	3
G. subclavatum	S	Upright	Stalked	M	5
G. tenellum	S	Upright	Stalked	S	2
G. truncatum	S	Upright	Stalked	S	<1
G. truncatum v. *capitata*	S	Upright	Stalked	S	5
Gyrosigma acuminatum	S	Motile	Unattached	L	15
G. attenuatum	S	Motile	Unattached	L	2
G. scalproides	S	Motile	Unattached	M	5
G. sciotense	S	Motile	Unattached	L	39

Appendix 3. Taxa, form, physiognomy, attachment, size, and frequency of occurrence of algae during the washout and recolonization study (1993–94) in the Big Darby Creek Basin, Ohio—*Continued*

[Form: S, single cells; C, colonies; F, filaments. Size: S, small (< 50 millimeters); M, medium (50-100 millimeters); L, large (> 100 millimeters); -, unknown. Frequency: the percentage of times (out of 195 samples analyzed) that the taxon was found]

Taxa	Form	Physiognomy	Attachment	Size	Frequency
Bacillariophyta—continued					
Hantzschia amphioxys	S	Motile	Unattached	M	3
Melosira varians	F	Loose	Unattached	M	8
Meridion circulare	C	Tychoplanktonic	Unattached	M	10
Navicula sp.	S	Motile	Unattached	-	7
N. accomoda	S	Motile	Unattached	S	<1
N. capitata	S	Motile	Unattached	S	11
N. citrus	S	Motile	Unattached	M	<1
N. confervacea	F	Loose	Unattached	S	3
N. crytocephala	S	Motile	Unattached	S	64
N. crytocephala var. *exilis*	S	Motile	Unattached	S	<1
N. crytocephala var. *veneta*	S	Motile	Unattached	S	83
N. cuspidata v. *ambigua*	S	Motile	Unattached	L	<1
N. decussis	S	Motile	Unattached	S	2
N. gregaria	S	Motile	Unattached	S	5
N. halophila	S	Motile	Unattached	S	3
N. hustedtii	S	Motile	Unattached	S	<1
N. menisculus	S	Prostrate	Biofilm	S	31
N. minima	S	Prostrate	Biofilm	S	71
N. muraliformis	S	Motile	Unattached	S	25
N. mutica	S	Motile	Unattached	S	<1
N. mutica var. *goeppertiana*	S	Motile	Unattached	S	6
N. pygmaea	S	Motile	Unattached	S	4
N. radiosa var. *parva*	S	Motile	Unattached	S	44
N. radiosa var. *tenella*	S	Motile	Unattached	M	100
N. rhychocephala	S	Motile	Unattached	M	18
N. salinarum	S	Motile	Unattached	S	9
N. salinarum var. *intermedia*	S	Motile	Unattached	S	77
N. seminulum	S	Motile	Unattached	S	23
N. symmetrica	S	Motile	Unattached	S	38

Appendix 3. Taxa, form, physiognomy, attachment, size, and frequency of occurrence of algae during the washout and recolonization study (1993–94) in the Big Darby Creek Basin, Ohio—*Continued*

[Form: S, single cells; C, colonies; F, filaments. Size: S, small (< 50 millimeters); M, medium (50-100 millimeters); L, large (> 100 millimeters); -, unknown. Frequency: the percentage of times (out of 195 samples analyzed) that the taxon was found]

Taxa	Form	Physiognomy	Attachment	Size	Frequency
Bacillariophyta—continued					
N. tenera	S	Motile	Unattached	S	2
N. tenneloides	S	Motile	Unattached	S	20
N. tripunctata	F	Motile	Unattached	M	98
N. tripunctata var. *schizonemoides*	F	Motile	Unattached	M	21
N. viridula	S	Motile	Unattached	M	46
N. viridula var. *avenaceae*	S	Motile	Unattached	M	6
N. viridula var. *linearis*	S	Motile	Unattached	M	<1
Nedium binodis	S	Motile	Unattached	S	2
Nitzschia acicularis	S	Tychoplanktonic	Unattached	L	19
N. amphibia	S	Motile	Unattached	S	36
N. angusta	S	Motile	Unattached	M	3
N. dissipata	S	Motile	Unattached	S	98
N. dubia	S	Motile	Unattached	L	4
N. filiformis	S	Motile	Unattached	M	3
N. fonticola	S	Motile	Unattached	S	7
N. hungarica	S	Motile	Unattached	M	35
N. inconspicua	S	Motile	Unattached	M	92
N. levidensis	S	Motile	Unattached	S	28
N. linearis	S	Motile	Unattached	M	23
N. palea	S	Motile	Unattached	S	89
N. recta	S	Motile	Unattached	M	14
N. reversa	S	Tychoplanktonic	Unattached	L	5
N. sigmoidea	S	Motile	Unattached	L	7
N. sociabilis	S	Motile	Unattached	S	48
N. sublinearis	S	Motile	Unattached	M	2
N. tryblionella var. *subsalina*	S	Motile	Unattached	M	<1
N. vexans	S	Motile	Unattached	S	<1
Pleurosigma salinarum var. *boyeri*	S	Motile	Unattached	M	8
Pleurosira laevis	F	Loose	Unattached	M	15

Appendix 3. Taxa, form, physiognomy, attachment, size, and frequency of occurrence of algae during the washout and recolonization study (1993–94) in the Big Darby Creek Basin, Ohio—*Continued*
[Form: S, single cells; C, colonies; F, filaments. Size: S, small (< 50 millimeters); M, medium (50-100 millimeters); L, large (> 100 millimeters); -, unknown. Frequency: the percentage of times (out of 195 samples analyzed) that the taxon was found]

Taxa	Form	Physiognomy	Attachment	Size	Frequency
Bacillariophyta—continued					
Rhoicosphenia curvata	S	Upright	Stalked	S	98
Sellophora sp.	S	Motile	Unattached	-	<1
S. pupula	S	Motile	Unattached	S	5
Stephanodiscus hantzschii	S	Tychoplanktonic	Unattached	S	9
Surirella sp.	S	Motile	Unattached	M	2
S. angusta	S	Motile	Unattached	M	2
S. linearis	S	Motile	Unattached	M	<1
S. ovata	S	Motile	Unattached	M	49
Synedra sp.	S	Motile	Unattached	-	6
S. fasciculata	C	Upright	Apical pad	L	1
S. rumpens	C	Upright	Apical pad	M	1
S. tabulata	C	Upright	Apical pad	L	6
S. ulna	C	Upright	Apical pad	L	61
Thalassiosira fluviatilis	S	Tychoplanktonic	Unattached	S	6
		Rhodophyta			
Audouinella hermannii	F	Upright	Holdfast	L	55
Batrachospermum sp.	F	Upright	Holdfast	L	3

Darby Notes:

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