Benthic Invertebrate Assemblages and Their Relation to Physical and Chemical Characteristics of Streams in the Eastern Iowa Basins, 1996–98

By Allison R. Brigham and Eric M. Sadorf

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation, and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity and quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. (http://water.usgs.gov/nawqa/nawqamap.html). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings (http://water.usgs.gov/nawqa/natsyn.html).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply inch-pound units	By	To obtain metric units
centimeter (cm)	0.3937	inch
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (m)
square kilometer (km^2)	0.3861	square mile (mi^2)
kilogram (kg)	0.4536	pound (lb)
liter (L)	0.2642	gallon (gal)

Temperature in degrees Celsius (° C) can be converted to degrees Fahrenheit (° F) as follows:

$$°F = [1.8(°C)] + 32$$

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 the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units: Chemical concentrations are given in metric units of milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter and micrograms per liter are units expressing the concentration of chemical constituents in solution as mass (milligrams or micrograms) of solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value of milligrams per liter is the same as for concentrations in parts per million. The numerical value of micrograms per liter is the same as for concentrations in parts per billion.

These additional abbreviations and symbols are used in this report:

Abbreviation	Description
ANOVA	Analysis of variance
DCA	Detrended correspondence analysis
EIWA	Eastern Iowa Basins
EPT	Ephemeroptera, Plecoptera, Trichoptera
GIS	Geographic Information System
NAWQA	National Water-Quality Assessment Program
NWQL	National Water Quality Laboratory
TWINSPAN	Two-Way Indicator Species Analysis
USGS	U.S. Geological Survey
±	plus or minus
>	greater than
<	less than
≥	greater than or equal to
≤	less than or equal to
%	percent
µm	micrometer
$g\ O_2/m^3/hr$	grams of oxygen per cubic meter per hour

Benthic Invertebrate Assemblages and Their Relation to Physical and Chemical Characteristics of Streams in the Eastern Iowa Basins, 1996–98

By Allison R. Brigham *and* Eric M. Sadorf

Abstract

Over 250 benthic invertebrate taxa were identified from snags and woody debris in streams and rivers of the Wapsipinicon, Cedar, Iowa, and Skunk River Basins in the Eastern Iowa Basins (EIWA) study unit of the U.S. Geological Survey National Water-Quality Assessment Program. The composition, distribution, and abundance of 74 predominant taxa were related to environmental conditions in the study unit, using habitat, hydrologic, and water-quality data. Four groups of sites were defined, based on the distribution and relative abundance of taxa. Detrended correspondence analysis was used to identify relations in the structure of the invertebrate assemblages, and the correspondence of taxa and sites in the groups was related to habitat, hydrologic, and water-quality information. Responses of invertebrate assemblages were explained by natural factors, such as surficial geology or physical habitat conditions, as well as human influences, such as agriculture or high-density hog-feeding operations.

Mayflies, caddisflies, and true flies were well represented in streams and rivers of the EIWA study unit. The mayflies *Tricorythodes* and *Baetis intercalaris*, the net-spinning caddisflies *Hydropsyche bidens* and *H. simulans*, and the Chironomidae *Glyptotendipes*, *Polypedilum*, and *Rheotanytarsus* predominated. Spatial variation in benthic invertebrate assemblages within a site was less than that observed among sites. Assemblages from 3 years of sampling generally were grouped by site, with exceptions related to differences in discharge among years.

The benthic invertebrate assemblages associated with the four groups of sites reflected the cumulative effects of agricultural and urban land use, sources of nutrient and organic enrichment, and longitudinal stream succession—the natural sequence of communities in streams from headwaters to large rivers. These factors, especially the natural changes from upstream to downstream, were influential in characterizing the benthic invertebrate assemblages of the site groups.

Stream size, a reflection of basin area, was a principal influence in categorizing the benthic invertebrate assemblages, with sites that have the largest basin areas forming a separate group. Although it is difficult to distinguish among the contributions of large basin area, increased concentrations of nutrients and pesticides, and decreasing instream habitat diversity, the resulting invertebrate assemblage described was distinct. The remaining sites were headwater or tributary streams that reflected conditions more common to smaller streams, such as higher gradients and the potential for more diverse or extensive riparian habitat, but were distinguished by landform. Following basin area in importance, landform contributed to the differences observed among the benthic invertebrate communities at the remaining sites.

INTRODUCTION

The Eastern Iowa Basins (EIWA) study unit (fig. 1) drains about 50,500 km^2 (19,500 mi^2),

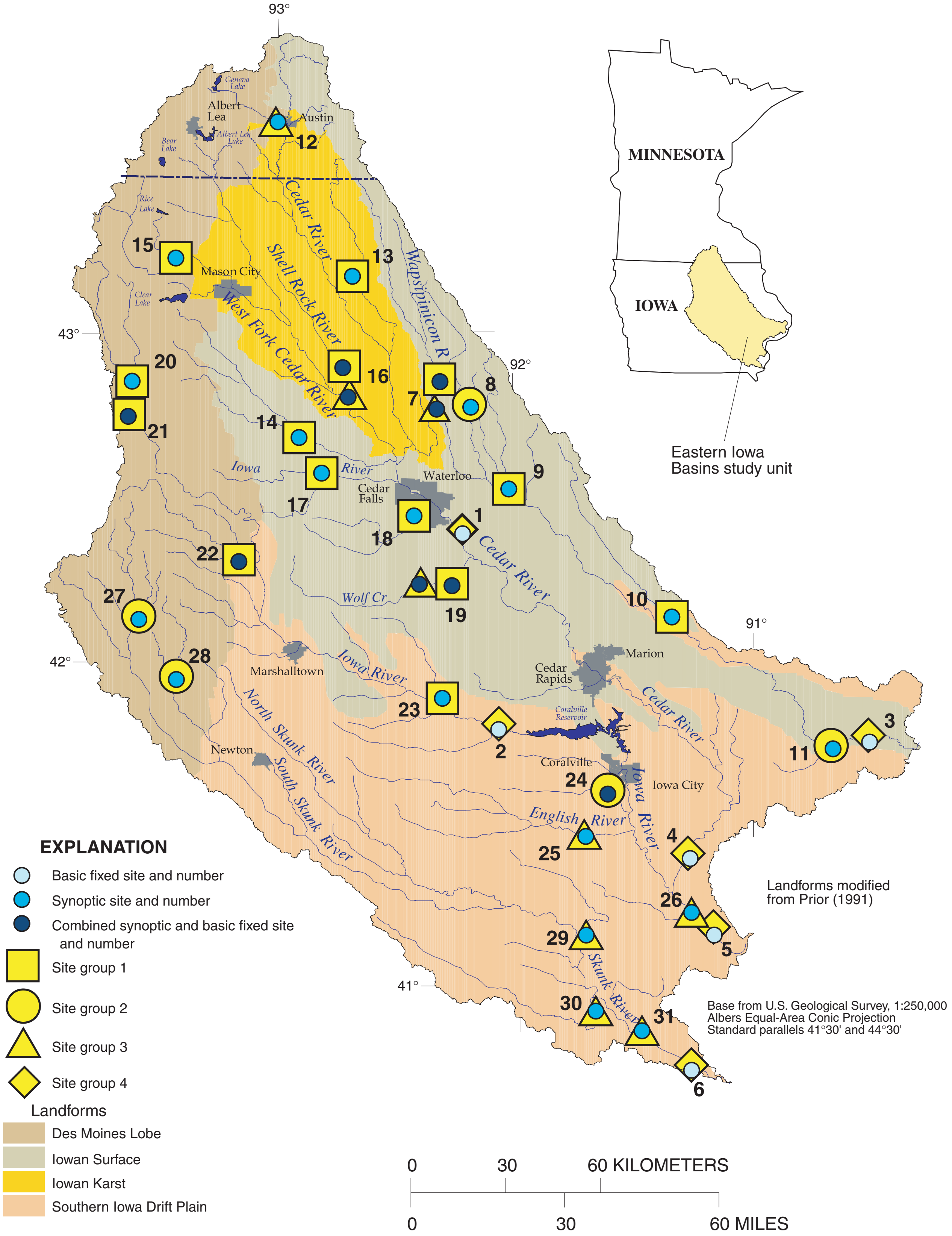

Figure 1. Location of benthic invertebrate sampling sites and landforms in the Eastern Iowa Basins, Iowa and Minnesota.

including the Wapsipinicon, Cedar, Iowa, and Skunk River Basins. Presettlement, the area was primarily tall grass prairie with wooded stream valleys (Prior, 1991); now more than 90 percent of the area is in intensive agricultural production (Schnoebelen and others, 1999). Nutrients and pesticides used to produce row crops, such as corn and soybeans, enter streams by surface runoff and discharges from ground-water flow and tile drains. The effects of these chemicals on benthic invertebrates and how assemblages respond to differences in surficial geology, riparian cover, and streamflow characteristics are poorly known.

The National Water-Quality Assessment (NAWQA) Program was established to describe water-quality conditions for a large part of the Nation's streams, rivers, and aquifers; to describe how water quality is changing over time; and to improve understanding of natural and human factors that affect water-quality conditions (Hirsch and others, 1988; Leahy and others, 1990; Gilliom and others, 1995). One of 59 water-quality investigations in large river basins or aquifer systems (study units) throughout the United States, the EIWA study unit represents a hydrologic system in an intensive agricultural area (Akers and others, 1999). The integrated assessment objectives of the program incorporated physical, chemical, and biological components (Gurtz, 1994; Meador and Gurtz, 1994) that used basic data-collection activities to determine the status and trends in water quality. In addition, sites in the EIWA study unit were included in a regional, low-flow synoptic study that assessed the condition of wooded riparian zones and the influence of basin soil-drainage characteristics on water quality and biological-community responses (Sorenson and others, 1999).

Purpose and Scope

This report describes the benthic invertebrates present in the streams and rivers of the Wapsipinicon, Cedar, Iowa, and Skunk River Basins during 1996–98. The composition, distribution, and abundance of benthic invertebrates were related to physical and chemical characteristics of streams, using habitat, hydrologic, and water-quality data. The quality of the aquatic resources was assessed by evaluating the influence of natural factors, such as differences in surficial geology or physical habitat conditions, and human influences, including row-crop agriculture and confined, high-density hog-feeding operations, on the benthic invertebrate assemblages.

Description of the Eastern Iowa Basins

The major landforms present in the study unit are the Des Moines Lobe, Iowan Karst, Iowan Surface, and Southern Iowa Drift Plain (fig. 1). The Des Moines Lobe is a region of the most recent glaciation in Iowa and is characterized by knob and kettle terrain with areas of low relief. This area contains natural wetlands caused by poor surface drainage. The Iowan Surface is characterized by a gently rolling terrain, and consists of thin loess or loam over glacial drift, with bedrock near the land surface. The Iowan Karst is a subunit of the Iowan Surface defined for this study and not described by Prior (1991). It is an area with a thin layer of unconsolidated material overlying limestone and dolomite that contains karst features, recognized by sinkholes on the land surface. The Southern Iowa Drift Plain is similar to the Iowan Surface except it has relatively thick glacial drift with a thick loess cover. Streams have eroded deeply into the glacial drift to produce steeply rolling hills.

Agriculture, the dominant land use, is present across about 93 percent of the study unit. Forests cover about 5 percent of the study unit, and urban land accounts for about 2 percent. Water, wetland, and barren land each account for less than 1 percent.

Average annual precipitation from 1961 through 1990 ranged from 76 cm in the northwestern part of the study unit to 91 cm in the southeastern part (Wendland and others, 1992), with most of the precipitation occurring during spring and summer. Snowfall has been recorded from September to May, with accumulations rarely exceeding 25 cm in 1 day.

Streamflow in eastern Iowa generally increases from snowmelt or rain in spring, often as early as February, and may remain high into early summer (fig. 2). In a typical year, streamflow during late summer is fed primarily through ground-water discharge. This low-flow condition persists through autumn and into winter.

Acknowledgments

The authors acknowledge the contributions and assistance of the EIWA NAWQA team and the many

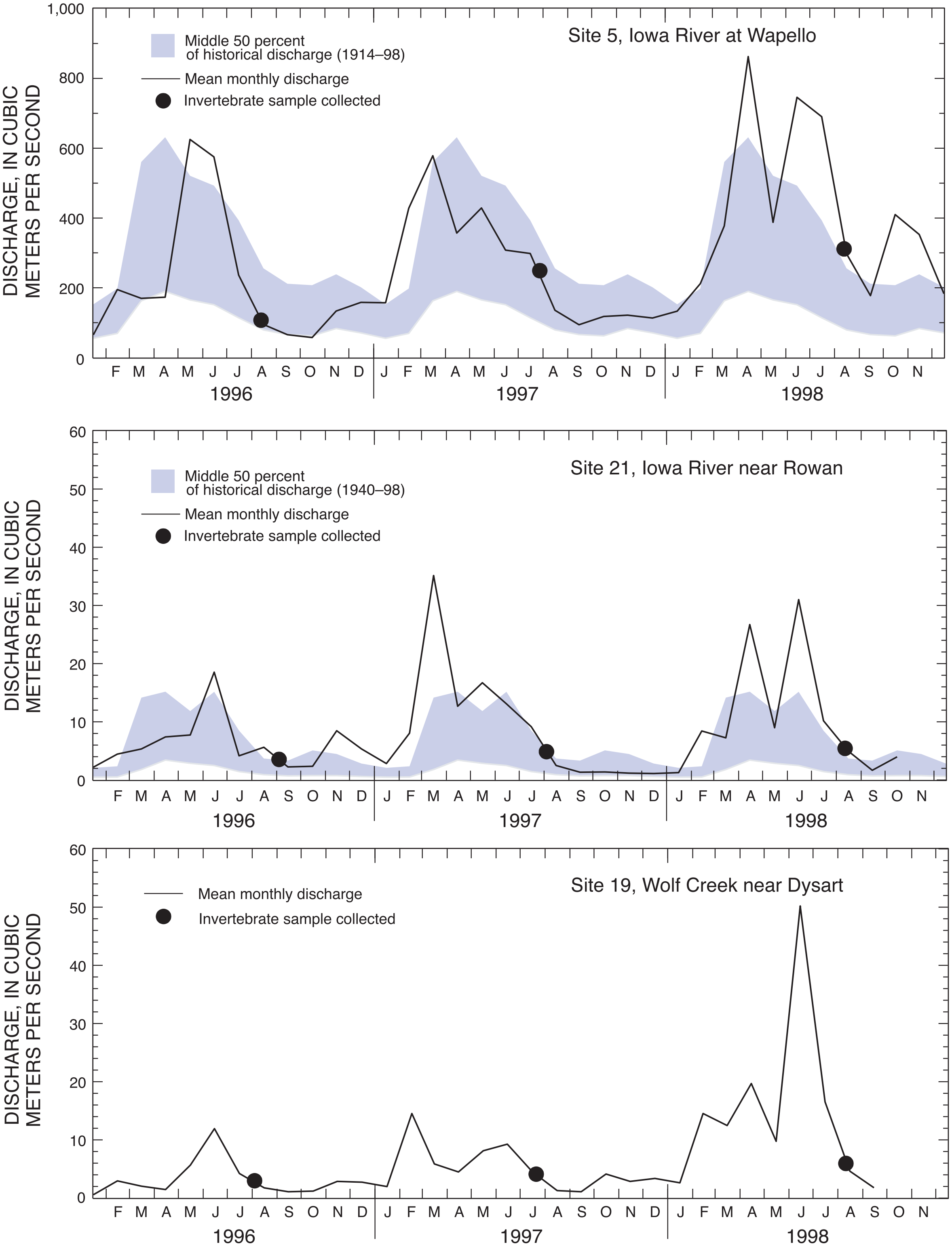

Figure 2. Discharge at the three multiple-reach, multiple-year sampling sites in the Eastern Iowa Basins, Iowa and Minnesota. Discharge during sampling years is shown with historical discharge for two of the three sites.

U.S. Geological Survey (USGS) staff members who participated in field collection and analyses, including Kymm Akers, Kent Becher, James Cerveny, David Connell, Jeff Copa, Joshua Eash, Debra Sneck-Fahrer, Demarius George, Jeffery Harms, Sienna Hill, Sandy Kautz, James Klaus, Patrick Lustgraaf, Denise Montgomery, Julie Noe, Stephen Porter, Nancy Reilly, Pamela Smith, Anna Sojka, Angie Stortz, Patrick Sweeney, Scott Thul, Jennifer Tobias, and Scott Yess. Linda Roberts, the former study-unit biologist for the EIWA study unit, planned, organized, and participated in the sampling. Stephen Porter, Jonathan Kennen, Jeffrey Pritt (USGS), and John Kingston (University of Minnesota–Duluth, Natural Resources Research Institute) provided guidance and assistance with statistical analyses and interpretation of data. Robin Brightbill, Stephen Kalkhoff, Stephen Porter, and Jon Raese (USGS) provided technical review of the manuscript and valuable insight.

METHODS

Site Selection and Description

Thirty-one sites within the EIWA study unit were sampled for benthic invertebrates. Twelve of these were basic fixed sites, chosen for the NAWQA network of surface-water-quality sampling. These sites represented either large basins, where the stream or river might be affected by a combination of land-use types, point sources of chemical contributions, and natural factors that affect water quality or small basins that reflected a specific combination of land use and physiographic condition (table 1, fig. 1) (Gilliom and others, 1995; Akers and others, 1999). Twenty-five sites within the study unit, including six of the basic fixed sites, were chosen as part of a low-flow synoptic water-quality study in the upper Midwest that was conducted during August 1997 (Sorenson and others, 1999).

Environmental variables used to describe the basic fixed sites at which benthic invertebrate data were collected are listed in table 2. Variables associated with site characterization include agricultural-chemical use, crop data, geology and land-use/land-cover information, and population data. Various geographic information system (GIS) coverages were used to quantify the variables used for describing the synoptic (Sorenson and others, 1999) and basic fixed sites. Data for population density, land use/land cover, and landform are listed in table 11. Application rates for pesticides, nitrogen (inorganic, organic, and atmospheric sources) and phosphorus (inorganic and organic sources), and results of field measurements are listed in table 12. Tables 11 and 12 are in the "Supplemental Data" section of this report. Data derived from the synoptic study are tabulated in Sorenson and others (1999).

Water-Quality Variables

Surface water was sampled monthly, with extra high- or low-flow samples collected as needed. Standard protocols were used to ensure consistency (Edwards and Glysson, 1988; Ward and Harr, 1990; Shelton, 1994; Capel and Larson, 1996). General water-quality variables monitored and used for this study include field measurements of water temperature, dissolved oxygen, pH, and specific conductance and concentrations of nutrients, major ions, organic carbon, and dissolved pesticides (tables 2 and 12). Field data and data from water-quality sampling closest to the time of biological sampling were used in the analyses. Estimates of algal stream productivity were calculated using the method described in Sorenson and others (1999).

The design of the surface-water-quality sampling program, and the methods used for surface-water sample collection and analyses are summarized in Akers and others (1999, 2000). These comprehensive reports include descriptions, analytical techniques, and minimum reporting limits for data collected from September 1995 through September 1998. Schnoebelen and others (1999) reported historical nutrient and pesticide concentrations.

Habitat

Reach selection and characterization at a site followed the NAWQA Level-1 habitat-assessment protocol (Meador and others, 1993). Habitat variables (table 2) were measured at each of the main stream reaches. Habitat features were quantified at multiple spatial scales—basin, stream segment, and stream reach. Segment and basin features included sinuosity, gradient, drainage area, and land use/land cover.

Table 1. Location and basin characteristics of 31 stream sites in the Eastern Iowa Basins, Iowa and Minnesota

[km^2, square kilometers; IA, Iowa; MN, Minnesota; 42° 24' 57", location in degrees, minutes, seconds; X, basic fixed or synoptic site; –, not applicable]

Site number (fig. 1)	Site name	U.S. Geological Survey station identification	Location		Basin area (km^2)	Basin	Site type	
			Latitude	Longitude			Basic fixed	Syn-optic
1	Cedar River at Gilbertville, IA	05464020	42° 24' 57"	92° 13' 07"	13,564	Cedar (large-river site)	X	–
2	Iowa River at Marengo, IA	05453100	41° 48' 48"	92° 03' 51"	7,239	Iowa (large-river site)	X	–
3	Wapsipinicon River near DeWitt, IA	05422000	41° 46' 01"	90° 32' 05"	6,050	Wapsipinicon (large-river site)	X	–
4	Cedar River near Conesville, IA	05465000	41° 24' 36"	91° 17' 06"	20,153	Cedar (large-river site)	X	–
5	Iowa River at Wapello, IA	05465500	41° 10' 48"	91° 10' 57"	32,365	Iowa (large-river site)	X	–
6	Skunk River at Augusta, IA	05474000	40° 45' 13"	91° 16' 40"	11,163	Skunk (large-river site)	X	–
7	Wapsipinicon River near Tripoli, IA	05420680	42° 50' 10"	92° 15' 26"	896	Wapsipinicon	X	X
8	East Fork Wapsipinicon River near Tripoli, IA	05420720	42° 50' 51"	92° 13' 48"	373	Wapsipinicon	–	X
9	Little Wapsipinicon River at Littleton, IA	05420900	42° 32' 27"	92° 01' 30"	544	Wapsipinicon	–	X
10	Buffalo Creek near Stone City, IA	05421700	42° 08' 33"	91° 20' 44"	603	Wapsipinicon	–	X
11	Mud Creek near Donahue, IA	05421870	41° 44' 18"	90° 41' 27"	308	Wapsipinicon	–	X
12	Turtle Creek at Austin, MN	05456510	43° 40' 25"	93° 01' 11"	396	Cedar	–	X
13	Little Cedar River near Floyd, IA	05457950	43° 11' 54"	92° 41' 15"	648	Cedar	–	X
14	Maynes Creek near Kesley, IA	05458870	42° 41' 47"	92° 54' 27"	352	Cedar	–	X
15	Winnebago River near Fertile, IA	05459300	43° 14' 49"	93° 26' 16"	761	Cedar	–	X
16	Flood Creek near Powersville, IA	05461390	42° 54' 26"	92° 43' 14"	389	Cedar	X	X
17	Beaver Creek near Parkersburg, IA	05462770	42° 35' 15"	92° 48' 37"	376	Cedar	–	X
18	Black Hawk Creek at Waterloo, IA	05463510	42° 27' 24"	92° 25' 22"	847	Cedar	–	X
19	Wolf Creek near Dysart, IA	05464220	42° 15' 06"	92° 17' 55"	847	Cedar	X	X
20	East Branch Iowa River at Belmond, IA	05449200	42° 51' 48"	93° 36' 47"	505	Iowa	–	X
21	Iowa River near Rowan, IA	05449500	42° 45' 36"	93° 37' 23"	1,083	Iowa	X	X
22	South Fork Iowa River near New Providence, IA	05451210	42° 18' 54"	93° 09' 08"	580	Iowa	X	X
23	Salt Creek at Belle Plaine, IA	05452020	41° 53' 31"	92° 18' 00"	518	Iowa	–	X
24	Old Mans Creek near Iowa City, IA	05455100	41° 36' 23"	91° 36' 56"	521	Iowa	X	X
25	English River near Kalona, IA	05455500	41° 28' 11"	91° 42' 52"	1,487	Iowa	–	X
26	Long Creek near Columbus Junction, IA	05465310	41° 13' 36"	91° 16' 31"	399	Iowa	–	X
27	South Skunk River near Story City, IA	05469980	42° 08' 14"	93° 34' 01"	554	Skunk	–	X
28	East Branch Indian Creek near Iowa Center, IA	05471120	41° 57' 08"	93° 24' 21"	332	Skunk	–	X
29	Crooked Creek near Coppock, IA	05473060	41° 09' 31"	91° 42' 30"	736	Skunk	–	X
30	Cedar Creek near Oakland Mills, IA	05473400	40° 55' 20"	91° 40' 10"	1,380	Skunk	–	X
31	Big Creek near Lowell, IA	05473550	40° 51' 37"	91° 28' 51"	433	Skunk	–	X

Table 2. Environmental variables used to describe 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996–98

[km^2, square kilometer; %, percent; population data, see Sorenson and others, 1999; kg/km^2, kilogram per square kilometer; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; S, sulfur; µg/L, micrograms per liter; ESA, ethanesulfonic acid; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; m, meter; m/km, meters per kilometer; m/s, meters per second; g $O_2/m^3/hr$, grams of oxygen per cubic meter per hour]

Site Characterization
- *General*
  - Basin area (km^2)
- *Geology and Land Use/Land Cover (% of basin area)*
  - Des Moines Lobe
  - Iowan Surface
  - Iowan Karst
  - Southern Iowa Drift Plain
  - Agriculture
  - Barren
  - Grassland
  - Row crop
  - Urban
  - Wetland
  - Wooded
- *Population Data (1990)*
  - Human population density (number/km^2)
  - Human population of basin
- *Agricultural Use of Nitrogen, Phosphorus, and Pesticides (kg/km^2 in basin)*
  - Pesticides applied per basin, total
  - Nitrogen from:
    - atmosphere
    - inorganic fertilizer
    - manure
  - Phosphorus from:
    - inorganic fertilizer
    - manure

Water-Column Chemistry
- *Water Quality (mg/L)*
  - Alkalinity (as $CaCO_3$)
  - Bicarbonate (as $CaCO_3$)
  - Carbonate (as $CaCO_3$)
  - Calcium, dissolved
  - Carbon, organic
    - dissolved
    - suspended
  - Chloride, dissolved
  - Fluoride, dissolved
  - Hardness, total (as $CaCO_3$)
  - Iron, dissolved
  - Magnesium, dissolved
  - Manganese, dissolved
  - Nitrogen (as N):
    - ammonia + organic, dissolved
    - ammonia + organic, total
    - ammonia, dissolved
    - nitrite + nitrate, dissolved
    - nitrite, dissolved
  - Phosphorus (as P):
    - dissolved
    - ortho, dissolved
    - total
  - Potassium, dissolved
  - Silicon, dissolved
  - Sodium, dissolved
  - Sulfate, dissolved (as S)
- *Herbicides and Degradation Products (µg/L)*
  - Fonofos
  - Chlorpyrifos
  - Diazinon
  - Carbofuran
  - *Triazine*
    - Atrazine
    - Deethylatrazine
    - Deisopropylatrazine
    - Atrazine + metabolites
    - Cyanazine
    - Cyanazine amide
    - Hydroxylatrazine
    - Prometon
    - Simazine
  - *Chloroacetamide*
    - Acetochlor
    - Acetochlor ESA
    - Acetochlor oxanilic acid
    - Acetochlor + metabolites
    - Alachlor
    - Alachlor ESA
    - Alachlor oxanilic acid
    - Alachlor + metabolites
    - Metolachlor
    - Metolachlor ESA
    - Metolachlor oxanilic acid
    - Metolachlor + metabolites
    - Total acetanilide herbicides
- *Single Measurements and Continuous-Monitoring Data*
  - Water temperature (°C):
    - time of sampling
    - 4-month low
  - Specific conductance (µS/cm):
    - time of sampling
    - 4-month low
  - pH:
    - time of sampling
    - 4-month low
  - Dissolved oxygen:
    - time of sampling (mg/L)
    - 4-month low (mg/L)
    - saturation, 4-month low (%)

Habitat
- Bank height (m):
  - mean
  - maximum
- Bank vegetation stability
  - mean
  - maximum
- Bank width (m):
  - mean
  - maximum
- Bottom material (lab analysis):
  - % clay
  - % sand
  - % silt
- Canopy angle (degrees):
  - mean (sum both sides)
  - maximum
- Gradient, stream segment (m/km)
- Sinuosity, stream segment
- Stream depth (m):
  - mean
  - maximum
- Stream width (m):
  - wetted channel
  - maximum
- Velocity (m/s):
  - mean
  - maximum

Stream Productivity
- g $O_2/m^3/hr$ by calculation

Stream-reach information was gathered from multiple transects at a site as described in Meador and others (1993). Data were collected to quantify the riparian and instream habitats. Stream depth, velocity, and particle size of the bed material were measured at the stream-reach level.

Streambank characteristics and canopy shading at basic fixed sites in the EIWA study unit are listed in table 13, streambed material and stream characteristics in table 14. These tables are in the "Supplemental Data" section of this report.

Benthic Invertebrate Collection and Data Preparation

Field Sampling

Samples of benthic invertebrates were collected as part of basic ecological studies to meet occurrence and distribution objectives of the NAWQA Program (1996–98) (Meador and Gurtz, 1994; Gilliom and others, 1995), and as part of a low-flow, synoptic water-quality study in the upper Midwest (Sorenson and others, 1999). Cuffney and others (1993) describe the benthic invertebrate sampling protocol used.

Quantitative and qualitative samples of benthic invertebrates were collected during the seasonal low-flow period between July and September 1996 in the main reach of each of the 12 basic fixed sites (fig. 1, table 1). Three of these sites (Iowa River near Rowan, Iowa River at Wapello, and Wolf Creek near Dysart) were selected for more intensive quantitative and qualitative sampling in July and August 1997 when samples were collected at multiple reaches (the main reach and two additional reaches located upstream and downstream from the main reach). Only the main reach was sampled in August 1998 (fig. 2). These data were used to assess the degree of spatial (reach-to-reach) and temporal (year-to-year) variability. Quantitative samples were collected in August 1997 from 25 sites on medium-sized streams throughout the study unit (synoptic sites in fig. 1 and table 1) as part of the upper Midwest low-flow synoptic study (Sorenson and others, 1999).

In 1996, quantitative samples were taken from woody snags that appeared to have been submerged in flowing water and available for colonization by benthic invertebrates for an extended period. Organisms were gently dislodged with a brush from five separate areas of submerged woody debris within each stream reach, caught, and composited into a single sample using a Slack sampler equipped with a 425-µm-mesh sieve. The sample was transferred to a labeled jar and preserved with 10-percent buffered formalin. In 1997 and 1998, 30- to 50-cm sections of snags were cut under water and caught in the Slack sampler before removing the organisms. The total area of the woody snags associated with each sample was measured.

A D-frame net fitted with a 210-µm-mesh net was used to collect invertebrates for a qualitative sample during a 1-hour period at basic fixed sites from all accessible instream habitats, supplemented by hand-picking from large rocks, woody debris, and leaves. Specimens were composited into a single sample container, labeled, and preserved with 10-percent buffered formalin.

Laboratory Processing

All invertebrate samples were sent to the USGS National Water Quality Laboratory's (NWQL) Biological Group in Lakewood, Colo., for processing. Identification to the lowest reasonable taxonomic level and quantification of organisms followed the standard NWQL protocol that included a fixed-count method for quantitative samples (no more than 500 organisms sorted and identified for a sample) and a visual-sort method for qualitative samples. The visual-sort method only records a taxon as present (Moulton and others, 2000). A voucher collection of invertebrates is kept at the NWQL. Taxonomic nomenclature and hierarchy follow the recommendations of the Biological Group (S.R. Moulton and J.P. Slusark, U.S. Geological Survey, written commun., 2000;[1] Moulton and others, 2000).

Data Preparation

Invertebrate taxa found at 31 sites sampled in the EIWA study unit are listed in table 3. All available

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[1] Moulton, S.R., II, and Slusark, J.P., 2000, Taxonomic identification of benthic macroinvertebrates: unpublished U.S. Geological Survey document, National Water Quality Laboratory Standard Operating Procedure—Laboratory Analytical Method or Procedure BS0335.0, 7 April 2000, 20 p.

Table 3. Distribution of benthic invertebrates collected at 31 sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996–98, and the number of sites where each taxon was found

[All invertebrate data available for a site (quantitative, qualitative, multiple-reach and multiple-year samples) were included in the summary. Data are unedited and uncensored. The number of sites sampled in each watershed or group is in parentheses under the name of the site group]

Taxon	Number of sites with taxon					
	Headwater or tributary sites					
	Wapsipinicon (5)	Cedar (8)	Iowa (7)	Skunk (5)	Large river (6)	All sites (31)
Platyhelminthes						
Turbellaria	0	4	1	0	0	5
Nematoda	4	1	0	0	2	7
Bryozoa	2	1	2	1	2	8
Mollusca						
Gastropoda						
Ancylidae	2	0	0	0	0	2
Ferrissia	1	0	0	0	0	1
Lymnaeidae	1	0	1	1	0	3
Physidae	0	0	3	0	0	3
Physella	1	2	2	1	2	8
Planorbidae	0	0	1	0	0	1
Pleuroceridae	0	1	0	0	0	1
Bivalvia						
Sphaeriidae	0	0	1	1	0	2
Annelida						
Oligochaeta						
Naididae	5	8	6	5	4	28
Tubificidae	1	4	4	0	3	12
Hirudinea						
Glossiphoniidae	1	1	2	0	2	6
Arthropoda						
Chelicerata						
Acari						
Hydrachnidia	5	6	7	5	3	26
Malacostraca						
Amphipoda						
Gammaridae						
Gammarus	0	0	0	0	1	1
Hyalellidae						
Hyalella azteca (Saussure)	0	1	2	0	1	4
Decapoda						
Cambaridae	1	1	2	0	1	5
Cambarus	0	0	1	0	0	1
Orconectes	1	2	2	1	3	9
Isopoda						
Asellidae						
Caecidotea	0	0	0	1	0	1
Insecta						
Ephemeroptera	1	1	5	0	3	10
Baetidae	5	8	7	5	5	30
Acentrella turbida (McDunnough)	0	0	1	0	0	1
Acentrella	3	5	3	4	0	15
Baetis intercalaris McDunnough	4	7	5	4	3	23
Baetis	0	0	3	0	2	5
Centroptilum/Procloeon	3	2	3	2	1	11
Fallceon quilleri (Dodds)	2	3	5	4	4	18
Paracloeodes minutus (Daggy)	0	1	0	0	1	2
Plauditus parvulus (McDunnough)	0	1	1	0	0	2
Plauditus punctiventris (McDunnough)	0	0	1	0	0	1
Plauditus	1	1	1	0	0	3
Pseudocloeon dardanum (McDunnough)	0	2	2	0	1	5
Pseudocloeon ephippiatum (Traver)	0	0	1	0	0	1
Pseudocloeon longipalpus (Morihara and McCafferty)	0	0	0	0	3	3
Pseudocloeon propinquum (Walsh)	0	1	1	0	0	2
Pseudocloeon	1	3	3	2	1	10
Baetiscidae						
Baetisca	0	0	2	1	0	3
Caenidae	0	0	1	0	1	2
Amercaenis ridens (McDunnough)	0	1	1	0	4	6
Brachycercus	0	0	1	0	1	2
Caenis hilaris (Say)	0	1	1	0	1	3
Caenis	4	5	5	4	5	23
Cercobrachys	0	1	1	0	0	2
Ephemeridae	0	1	0	0	1	2
Ephemera simulans Walker	0	0	0	0	2	2
Ephemera	0	0	0	0	1	1

Table 3. Distribution of benthic invertebrates collected at 31 sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996–98, and the number of sites where each taxon was found—Continued

Taxon	Number of sites with taxon					
	Headwater or tributary sites					
	Wapsi-pinicon (5)	Cedar (8)	Iowa (7)	Skunk (5)	Large river (6)	All sites (31)
Hexagenia atrocaudata McDunnough	0	0	1	0	0	1
Hexagenia limbata (Serville)	0	1	1	0	0	2
Hexagenia	2	0	2	1	0	5
Pentagenia vittigera (Walsh)	0	0	0	0	1	1
Heptageniidae	4	7	6	5	3	25
Heptagenia diabasia Burks	2	6	5	2	6	21
Heptagenia flavescens (Walsh)	2	5	3	3	6	19
Heptagenia	2	2	3	0	4	11
Leucrocuta	0	2	2	0	0	4
Stenacron candidum (Traver)	0	1	0	0	0	1
Stenacron interpunctatum (Say)	0	1	1	0	0	2
Stenacron	2	1	6	2	1	12
Stenonema exiguum Traver	5	5	5	2	4	21
Stenonema mexicanum (Ulmer)	1	4	2	2	6	15
Stenonema pulchellum (Walsh)	0	1	0	1	0	2
Stenonema terminatum (Walsh)	3	5	5	3	1	17
Stenonema	5	7	6	4	4	26
Isonychiidae						
Isonychia	4	4	5	3	5	21
Leptohyphidae						
Tricorythodes	5	8	7	5	6	31
Oligoneuriidae	2	1	0	1	0	4
Homoeoneuria ammophila (Spieth)	0	0	0	0	1	1
Polymitarcyidae						
Ephoron album (Say)	0	1	2	0	2	5
Ephoron	1	0	0	0	0	1
Tortopus primus (McDunnough)	0	0	0	0	1	1
Potamanthidae						
Anthopotamus	0	0	1	0	0	1
Odonata						
Aeshnidae	0	1	0	0	1	2
Aeshna	0	1	0	0	0	1
Anax	0	0	1	0	0	1
Boyeria vinosa (Say)	1	2	1	0	0	4
Boyeria	0	2	0	0	0	2
Calopterygidae	0	0	1	0	0	1
Hetaerina americana (Fabricius)	0	1	2	0	2	5
Hetaerina titia (Drury)	0	1	0	0	0	1
Hetaerina	1	1	0	0	0	2
Coenagrionidae	3	1	4	4	0	12
Argia	0	1	0	1	2	4
Corduliidae						
Neurocordulia molesta (Walsh)	0	1	0	0	1	2
Gomphidae	1	1	2	3	2	9
Arigomphus	0	0	1	0	0	1
Gomphus	0	1	0	0	2	3
Progomphus obscurus (Rambur)	0	1	0	1	0	2
Progomphus	0	0	0	1	0	1
Stylurus	0	1	0	0	3	4
Macromiidae						
Didymops transversa (Say)	0	0	0	0	1	1
Macromia illinoiensis Walsh	0	0	0	1	0	1
Macromia	0	0	0	0	1	1
Plecoptera						
Perlidae	0	1	1	0	1	3
Acroneuria	1	4	3	2	2	12
Agnetina	0	0	1	0	0	1
Neoperla	0	0	0	0	1	1
Paragnetina	2	0	0	0	0	2
Perlesta placida complex	0	2	0	0	0	2
Perlesta	0	2	0	0	0	2
Pteronarcyidae						
Pteronarcys	3	5	3	2	3	16
Heteroptera						
Belostomatidae						
Belostoma	1	0	1	0	0	2
Corixidae	1	3	4	3	5	16
Palmacorixa gillettei Abbott	1	1	2	0	0	4
Palmacorixa	1	1	2	0	0	4
Sigara	0	2	0	0	0	2
Trichocorixa	0	1	4	0	6	11
Gerridae	0	1	2	0	0	3
Metrobates hesperius Uhler	0	1	0	0	1	2
Metrobates	3	1	1	0	3	8
Rheumatobates	1	1	3	2	3	10

Table 3. Distribution of benthic invertebrates collected at 31 sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996–98, and the number of sites where each taxon was found—Continued

Taxon	Number of sites with taxon					
	Headwater or tributary sites					
	Wapsi-pinicon (5)	Cedar (8)	Iowa (7)	Skunk (5)	Large river (6)	All sites (31)
Mesoveliidae						
Mesovelia	0	0	0	1	0	1
Naucoridae						
Pelocoris	0	0	0	0	1	1
Nepidae						
Ranatra	0	1	0	0	0	1
Pleidae						
Neoplea striola (Fieber)	0	1	1	0	0	2
Neoplea	1	0	2	0	0	3
Saldidae						
Saldula	0	0	0	0	1	1
Veliidae	0	0	1	2	1	4
Rhagovelia oriander Parshley	0	1	1	0	0	2
Rhagovelia	3	1	3	1	5	13
Megaloptera						
Corydalidae	0	0	1	1	0	2
Chauliodes rastricornis Rambur	0	0	0	0	1	1
Corydalus cornutus (Linnaeus)	0	1	1	1	3	6
Corydalus	0	0	1	0	0	1
Sialidae						
Sialis	2	0	0	0	0	2
Trichoptera	0	2	1	0	0	3
Brachycentridae						
Brachycentrus numerosus (Say)	2	5	1	0	1	9
Hydropsychidae	4	7	7	5	6	29
Ceratopsyche morosa (Hagen)	0	1	0	0	0	1
Ceratopsyche slossonae (Banks)	0	1	0	0	0	1
Ceratopsyche	3	5	5	4	1	18
Cheumatopsyche aphanta Ross	0	0	0	1	0	1
Cheumatopsyche	5	5	5	4	2	21
Hydropsyche betteni Ross	0	0	0	1	0	1
Hydropsyche bidens Ross	3	5	6	5	6	25
Hydropsyche bidens Ross/*orris* Ross	0	1	0	0	0	1
Hydropsyche orris Ross	0	2	0	0	4	6
Hydropsyche rossi Flint, Voshell, and Parker/*simulans* Ross	0	1	1	0	1	3
Hydropsyche simulans Ross	4	6	7	5	6	28
Hydropsyche	3	8	6	5	5	27
Potamyia flava (Hagen)	0	3	2	1	5	11
Hydroptilidae	1	6	2	1	1	11
Hydroptila ajax Ross	0	1	0	0	0	1
Hydroptila	2	5	2	2	0	11
Mayatrichia ayama Mosely	0	4	0	1	1	6
Mayatrichia	0	0	1	2	0	3
Leptoceridae	0	1	2	0	0	3
Ceraclea maculata (Banks)	0	0	0	1	0	1
Ceraclea	2	0	0	1	0	3
Nectopsyche candida (Hagen)	0	1	4	4	6	15
Nectopsyche candida (Hagen)/ *spiloma* (Ross)	0	1	1	0	1	3
Nectopsyche diarina (Ross)	2	2	2	2	0	8
Nectopsyche exquisita (Walker)	0	1	2	0	0	3
Nectopsyche	1	2	5	0	2	10
Oecetis	0	0	0	1	0	1
Limnephilidae	1	0	0	0	0	1
Pycnopsyche	2	0	3	1	0	6
Polycentropodidae						
Neureclipsis	1	0	1	0	1	3
Paranyctiophylax	0	3	2	2	0	7
Lepidoptera	1	0	0	0	1	2
Pyralidae						
Crambus	0	1	0	0	0	1
Coleoptera	0	1	1	0	1	3
Dryopidae						
Helichus lithophilus (Germar)	0	4	4	2	4	14
Helichus striatus LeConte	1	1	1	0	1	4
Helichus	0	1	0	1	0	2
Dytiscidae						
Laccophilus maculosus Say	0	0	2	0	5	7
Laccophilus	0	0	0	0	1	1
Liodessus	0	0	1	0	0	1
Elmidae	5	4	4	2	0	15
Ancyronyx variegata (Germar)	2	3	1	0	0	6
Dubiraphia minima Hilsenhoff	0	1	0	0	1	2
Dubiraphia vittata (Melsheimer)	0	0	1	0	0	1
Dubiraphia	2	3	6	4	2	17

Table 3. Distribution of benthic invertebrates collected at 31 sites in the Eastern Iowa Basins,, Iowa and Minnesota, 1996–98, and the number of sites where each taxon was found—Continued

Taxon	Number of sites with taxon					
	Headwater or tributary sites					
	Wapsi-pinicon (5)	Cedar (8)	Iowa (7)	Skunk (5)	Large river (6)	All sites (31)
Macronychus glabratus Say	5	6	7	4	4	26
Stenelmis crenata (Say)	0	1	1	0	0	2
Stenelmis decorata Sanderson	0	2	0	0	2	4
Stenelmis grossa Sanderson	2	3	4	4	3	16
Stenelmis	2	2	3	4	4	15
Gyrinidae						
Dineutus assimilis (Kirby)	0	0	0	0	2	2
Dineutus discolor Aubè	1	0	0	0	0	1
Dineutus	1	0	0	0	2	3
Gyrinus analis Say	0	0	0	0	1	1
Gyrinus fraternus Couper	0	1	0	0	0	1
Haliplidae						
Haliplus	0	0	1	0	0	1
Peltodytes	0	1	0	0	1	2
Helophoridae						
Helophorus	0	1	0	0	0	1
Hydrochidae						
Hydrochus	0	0	1	0	0	1
Hydrophilidae	0	0	2	1	1	4
Berosus	0	0	1	0	1	2
Crenitis	0	0	1	0	0	1
Cymbiodyta	0	1	0	0	0	1
Enochrus	0	0	0	0	1	1
Paracymus	0	1	0	0	0	1
Sperchopsis tessellata (Ziegler)	0	1	1	0	0	2
Tropisternus lateralis (Fabricius)	0	0	0	0	1	1
Tropisternus	0	0	2	0	3	5
Scirtidae	0	2	2	1	1	6
Diptera						
Nematocera						
Ceratopogonidae	1	0	2	0	0	3
Atrichopogon	0	2	2	2	1	7
Bezzia/Palpomyia	1	0	1	0	0	2
Culicoides	1	0	1	0	0	2
Chironomidae	3	4	5	1	5	18
Chironominae	5	8	7	5	6	31
Chironomini	4	2	4	0	1	11
Axarus	0	0	1	2	2	5
Chernovskiia	0	0	1	0	1	2
Chironomus	1	4	4	2	4	15
Cryptochironomus	1	3	4	1	1	10
Cryptotendipes	0	2	1	2	0	5
Dicrotendipes	3	6	4	4	1	18
Endochironomus	0	1	1	0	0	2
Endotribelos	0	0	1	0	0	1
Glyptotendipes	2	5	3	4	6	20
Harnischia	0	1	1	0	0	2
Lipiniella	0	0	0	0	1	1
Microtendipes	1	1	1	0	0	3
Parachironomus	3	1	2	1	5	12
Paracladopelma	1	2	1	0	1	5
Paralauterborniella	0	1	1	0	0	2
Phaenopsectra	0	3	1	2	1	7
Polypedilum	5	7	7	5	6	30
Robackia	1	0	1	1	1	4
Saetheria	2	1	3	1	0	7
Stelechomyia perpulchra (Mitchell)	0	0	0	2	0	2
Stenochironomus/Xestochironomus	0	0	1	0	0	1
Stenochironomus	4	7	7	4	6	28
Stictochironomus	0	1	0	0	0	1
Tribelos	0	1	1	0	1	3
Pseudochironomini						
Pseudochironomus	0	1	0	0	0	1
Tanytarsini	4	4	3	3	2	16
Cladotanytarsus	1	3	3	2	2	11
Micropsectra	0	2	1	0	0	3
Micropsectra/Tanytarsus	0	1	0	0	0	1
Paratanytarsus	2	3	0	0	0	5
Rheotanytarsus	5	8	7	5	6	31
Stempellinella	1	2	0	0	0	3
Sublettea	0	1	0	0	0	1
Tanytarsus	4	7	6	5	3	25
Orthocladiinae	5	6	5	3	3	22
Corynoneurini						
Corynoneura	2	1	1	0	3	7
Thienemanniella	5	4	4	3	1	17

Table 3. Distribution of benthic invertebrates collected at 31 sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996–98, and the number of sites where each taxon was found—Continued

Taxon	Number of sites with taxon					
	Headwater or tributary sites					
	Wapsi-pinicon (5)	Cedar (8)	Iowa (7)	Skunk (5)	Large river (6)	All sites (31)
Orthocladiini/Metriocnemini						
Brillia	1	5	3	0	0	9
Cricotopus bicinctus group	3	4	6	2	2	17
Cricotopus trifascia group	0	1	2	0	0	3
Cricotopus/Orthocladius	5	8	5	2	3	23
Cricotopus	1	3	2	0	3	9
Eukiefferiella	1	1	0	0	0	2
Lopescladius	0	0	0	0	1	1
Nanocladius	3	3	2	1	4	13
Parakiefferiella	4	6	4	2	1	17
Parametriocnemus	0	1	1	0	0	2
Rheocricotopus	4	5	4	1	0	14
Tvetenia	1	1	0	0	0	2
Tanypodinae	3	2	6	3	4	18
Pentaneurini	0	2	1	0	3	6
Ablabesmyia	1	4	3	1	4	13
Labrundinia	2	3	1	2	1	9
Larsia	1	2	2	0	1	6
Nilotanypus	4	4	3	2	0	13
Paramerina	0	1	0	0	0	1
Thienemannimyia group	5	7	7	5	6	30
Procladiini						
Procladius	1	2	3	0	1	7
Culicidae	0	1	0	0	0	1
Aedes	0	1	0	0	0	1
Anopheles	0	0	1	0	0	1
Simuliidae	3	6	5	4	4	22
Simulium	1	4	5	1	5	16
Tipulidae	0	0	1	0	2	3
Hexatoma	1	0	0	0	0	1
Limonia	0	1	0	0	1	2
Brachycera	3	2	0	0	2	7
Athericidae						
Atherix variegata Walker	4	6	3	0	0	13
Dolichopodidae	0	0	2	1	1	4
Empididae	1	1	0	0	1	3
Chelifera	0	0	0	0	2	2
Chelifera/Hemerodromia	2	2	4	2	3	13
Hemerodromia	4	5	4	5	4	22
Tabanidae	2	0	0	0	0	2

quantitative, qualitative, multiple-reach, and multiple-year data were used to prepare the composite list of taxa and their distribution within the study unit. Entries in table 3 reflect the number of headwater or tributary streams within a watershed (Wapsipinicon, Cedar, Iowa, Skunk) or large river sites (basic fixed sites with a basin area greater than 6,000 km^2) within the study unit where a taxon was found. Invertebrate taxa in table 3 were later edited and censured as described below.

Qualitative and quantitative benthic invertebrate data were formatted into a species-by-sample data matrix and ambiguous taxa were removed. This step avoids an overestimation of taxa richness and diversity that might result from problems associated with benthic invertebrate identification (Cuffney and others, 1997). There are many reasons why benthic invertebrates cannot be identified to consistent and low taxonomic levels. The most commonly cited reasons include specimens too immature or damaged for identification and the absence of appropriate keys or descriptions for the life stage of the specimens or a particular region of the country. Subsets of the edited data matrix were used in subsequent analyses.

Three techniques were applied to the data matrix to minimize the presence of ambiguous taxa. The commonly used technique was proportioning the abundances of higher level (parental) taxa among lower level (child) taxa in accordance with the abundances of the children. In some situations child taxa were combined with the parent taxon if the child abundances were low or about equal to that of the parent, or the parent taxon was eliminated if its abundance were low compared to that of the child taxa. Cuffney and others (1997) concluded that such data-editing techniques ensured consistency in the level of identification for all sites and increased the validity of intersite comparisons.

Benthic invertebrate data are often censured by eliminating rare taxa to emphasize more common or abundant taxa. Rare species are eliminated for the following reasons: (1) frequency or abundance did not meet a predetermined level or value [for example, all taxa whose combined abundance does not exceed 0.02 percent of the total (Leland, 1995)]; (2) taxa were not present at a minimum number of sites [for example, taxa found at less than 5 of 25 sites (Cuffney and others, 1997)]; or (3) taxa did not meet a combination of criteria [for example, taxa present at only one site and not comprising at least 0.5 percent of the total abundance (Tate and Heiny, 1995)]. Terrestrial taxa were removed. No additional taxa were eliminated from the basic-fixed-site data set initially, but species whose combined abundance was less than 0.05 percent were eliminated from the synoptic-site data set. Prior to detrended correspondence analysis (DCA), taxa found in fewer than five samples were eliminated to create data sets of a more manageable and interpretable size. Organism abundances in the edited data set were converted to relative abundance by sample and octave-transformed prior to data analysis (Gauch, 1982; Mohler, 1987).

Statistical Analyses and Other Calculations

The data distribution of each environmental variable was examined and transformed (log or square-root transformation), if necessary, to achieve approximate normal distribution prior to analysis.

Species composition among instream reaches, collection years, and all sites was examined using the two-way indicator species analysis (TWINSPAN), a divisive classification method based on correspondence analysis (Hill, 1979). TWINSPAN was used to identify four groups of sites based on the affinities of the benthic invertebrate assemblages identified from quantitative samples collected at the 12 basic fixed sites in 1996 and the 25 synoptic sites in 1997 (table 4).

Taxa represented in the final species-by-sample data matrix were assigned to one of five functional feeding groups on the basis of available trophic information in Merritt and Cummins (1996). These groups describe how invertebrates obtain food. The groups include shredders (that feed on live or dead plant material, including leaves and wood), scrapers (that graze on periphyton and associated material on organic and mineral substrates), collector-filterers (that feed on suspended fine particulate organic material), collector-gatherers (that feed on sediment or loose surface films), and predators (that feed on living animal tissues, including carnivores as well as those that pierce tissues and cells to suck body fluids). The relative abundance of each functional feeding group in each of the four TWINSPAN site groups and all samples combined is listed in table 5.

Metrics (data summaries) based on functional feeding groups and other aspects of the benthic inver-

Table 4. Distribution of samples among site groups, and mean and cumulative relative abundance of benthic invertebrates in the Eastern Iowa Basins, Iowa and Minnesota, 1996–97

[Taxa ranked by mean relative abundance among all samples. Site groups identified using TWINSPAN analysis (Hill, 1979). The number of sites sampled in each indicated site group is in parentheses under the number of the site group; %, percent; *p*-value, attained level of significance determined from one-way ANOVA (SAS Institute, Inc., 1999a, 1999b) with site group as independent variable; –, not significantly different among site groups (*p*-value greater than 0.05); <, less than]

Variable	Number of samples in indicated site group					Mean relative abundance by indicated site group or total (%)					Cumulative relative abundance (%)	*p*-value
	1 (16)	2 (6)	3 (9)	4 (6)	All (37)	1	2	3	4	All samples		
Tricorythodes	16	6	9	4	35	12.8	13.2	13.3	0.6	11.0	11.0	–
Polypedilum	15	6	9	6	36	5.9	6.2	10.4	17.7	8.9	19.9	<0.01
Hydropsyche bidens	14	3	8	6	31	12.1	1.6	1.5	18.7	8.9	28.8	.01
Rheotanytarsus	15	6	9	6	36	8.0	2.0	5.0	21.6	8.5	37.3	.01
Baetis intercalaris	16	4	7	2	29	6.3	9.1	2.6	2.9	5.3	42.6	–
Hydropsyche simulans	14	5	8	6	33	4.9	5.9	2.2	2.3	4.0	46.6	–
Glyptotendipes	4	2	7	6	19	.1	.5	12.2	5.1	3.9	50.5	–
Naididae	13	6	8	4	31	6.0	1.9	3.2	1.6	3.9	54.4	–
Macronychus glabratus	14	5	6	3	28	4.0	3.1	1.2	.2	2.6	57.0	–
Cricotopus/Orthocladius	15	4	6	4	29	3.8	1.2	.9	1.5	2.3	59.3	–
Stenonema terminatum	11	6	5	1	23	3.2	4.5	.6	.1	2.3	61.6	.05
Fallceon quilleri	8	4	5	2	19	1.6	7.8	.7	.6	2.2	63.8	–
Stenonema	15	5	2	0	22	3.7	3.0	<.1	.0	2.1	65.9	.02
Thienemannimyia group	13	6	9	5	33	1.1	3.6	1.9	.8	1.6	67.6	<.01
Acentrella	11	2	3	0	16	3.3	.9	.2	.0	1.6	69.1	–
Tanytarsus	11	5	9	2	27	1.0	1.6	3.0	.5	1.5	70.7	.05
Ceratopsyche	13	4	4	1	22	3.0	.6	.2	<.1	1.5	72.1	–
Stenochironomus	13	6	7	6	32	.8	2.9	.9	2.4	1.4	73.5	.02
Cricotopus bicinctus group	10	2	6	1	19	.8	4.1	1.0	<.1	1.2	74.8	–
Caenis	10	4	8	5	27	.8	.3	1.9	1.7	1.1	75.9	–
Corixidae	1	2	6	2	11	<.1	.1	4.3	.2	1.1	77.0	.05
Dicrotendipes	8	3	7	1	19	.2	.8	3.7	.1	1.1	78.1	<.01
Simuliidae	13	4	5	4	26	1.3	.8	.6	1.0	1.0	79.1	–
Hydrachnidia	11	5	6	2	24	.9	1.7	1.2	.1	1.0	80.1	–
Hemerodromia	9	6	7	4	26	.6	1.1	.7	2.2	1.0	81.1	.02
Stenelmis grossa	8	3	4	0	15	1.8	.4	.5	.0	1.0	82.0	–
Atherix variegata	13	1	3	0	17	2.0	.1	.1	.0	.9	82.9	.04
Cheumatopsyche	10	4	5	2	21	1.2	1.3	.3	.2	.8	83.8	–
Cladotanytarsus	3	0	6	2	11	.1	.0	3.1	.3	.8	84.6	.03
Centroptilum/Procloeon	5	2	3	1	11	.4	.7	1.7	.2	.7	85.3	–
Parakiefferiella	10	4	3	1	18	.7	1.7	.4	.1	.7	86.0	–
Pseudocloeon	4	3	3	1	11	.3	.8	.7	1.3	.7	86.7	–
Chironomus	1	0	7	3	11	<.1	.0	2.1	.8	.7	87.4	–
Heptagenia diabasia	9	6	2	1	18	.8	1.1	.5	<.1	.6	88.0	–
Stenacron	2	3	5	0	10	.1	2.3	.8	.0	.6	88.6	–
Potamyia flava	3	0	2	4	9	.1	.0	.2	3.2	.6	89.2	<.01
Coenagrionidae	2	4	6	1	13	<.1	2.0	.7	<.1	.5	89.7	<.01
Rheocricotopus	9	5	1	0	15	.5	1.1	.4	.0	.5	90.2	–
Phaenopsectra	1	1	4	1	7	<.1	.1	1.6	.1	.4	90.6	–
Stenonema mexicanum	5	3	3	2	13	.3	.3	.6	.6	.4	91.1	–
Hydropsyche orris	1	0	1	4	6	<0.1	0.0	<0.1	2.3	0.4	91.5	<.01
Hydroptila	10	5	2	0	17	.5	.8	.1	.0	.4	91.9	.02
Thienemanniella	9	3	5	0	17	.5	.6	.2	.0	.4	92.2	–
Heptagenia flavescens	7	4	5	4	20	.3	.6	.4	.2	.4	92.6	–
Isonychia	9	3	4	2	18	.3	.2	.3	.7	.3	92.9	–
Amercaenis ridens	0	1	1	4	6	.0	.2	.1	1.6	.3	93.3	.01
Tubificidae	4	1	3	2	10	.2	<.1	.6	.1	.3	93.5	–
Saetheria	0	2	3	0	5	.0	.5	.7	.0	.3	93.8	–
Parachironomus	4	2	1	3	10	.2	.1	<.1	.9	.2	94.0	.05
Nanocladius	4	2	4	4	14	.1	.2	.4	.3	.2	94.3	–

Table 4. Distribution of samples among site groups, and mean and cumulative relative abundance of benthic invertebrates in the Eastern Iowa Basins, Iowa and Minnesota, 1996–97—Continued

Variable	Number of samples in indicated site group					Mean relative abundance by indicated site group or total (%)					Cumulative relative abundance (%)	*p*-value
	1 (16)	2 (6)	3 (9)	4 (6)	All (37)	1	2	3	4	All samples		
Paratanytarsus	0	2	3	0	5	.0	.4	.6	.0	.2	94.5	–
Dubiraphia	3	3	7	0	13	<.1	.2	.6	.0	.2	94.7	<0.01
Nilotanypus	9	3	1	0	13	.3	.3	<.1	.0	.2	94.9	.04
Brillia	3	1	3	0	7	.1	.3	.4	.0	.2	95.1	–
Brachycentrus numerosus	7	0	0	0	7	.4	.0	.0	.0	.2	95.2	–
Mayatrichia ayama	7	2	2	1	12	.2	.3	.1	.1	.2	95.4	–
Hexagenia	3	2	2	0	7	.1	.4	.2	.0	.1	95.5	–
Ablabesmyia	1	1	5	0	7	<.1	<.1	.5	.0	.1	95.7	<.01
Nectopsyche candida	3	3	4	1	11	.1	.2	.3	<.1	.1	95.8	–
Corynoneura	1	1	1	2	5	<.1	.1	.1	.5	.1	95.9	.03
Nematoda	2	2	1	2	7	<.1	.1	<.1	.5	.1	96.0	–
Veliidae	1	4	2	0	7	<.1	.4	.1	.0	.1	96.1	.01
Paranyctiophylax	3	1	3	0	7	<.1	.1	.3	.0	.1	96.2	–
Labrundinia	2	2	4	0	8	<.1	.1	.2	.0	.1	96.3	–
Ancyronyx variegata	5	0	0	0	5	.2	.0	.0	.0	.1	96.4	–
Atrichopogon	3	2	1	1	7	.1	.1	<.1	.1	.1	96.5	–
Cryptochironomus	1	2	3	0	6	<.1	.1	.2	.0	.1	96.5	–
Helichus lithophilus	3	1	4	2	10	<.1	<.1	.2	<.1	.1	96.6	–
Gomphidae	1	1	4	1	7	<.1	<.1	.2	<.1	.1	96.7	<.01
Nectopsyche diarina	3	4	3	0	10	<.1	.1	.1	.0	.1	96.7	–
Acroneuria	7	2	1	0	10	.1	.1	<.1	.0	.1	96.8	–
Pteronarcys	11	2	2	1	16	.1	<.1	<.1	<.1	.1	96.8	–
Bryozoa	3	0	2	0	5	<.1	.0	<.1	.0	<.1	96.9	–
Pycnopsyche	3	2	0	0	5	<.1	.1	.0	.0	<.1	96.9	–

each of the four TWINSPAN site groups and all samples combined is listed in table 5.

Metrics (data summaries) based on functional feeding groups and other aspects of the benthic invertebrate assemblage are used in assessments of biological impairment as part of the rapid bioassessment protocol of the U.S. Environmental Protection Agency (USEPA) (Plafkin and others, 1989). Seven of the USEPA's invertebrate assemblage metrics were calculated, including taxa richness (the number of distinct taxa in a sample); EPT taxa richness [the number of taxa in the orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies)]; the ratio of shredders to the total abundance of organisms in a sample; the ratio of scrapers to collector-filterers; the percent contribution of the dominant three taxa in a sample; the percent contribution of EPT taxa; and the percent contribution of Chironomidae (midges) (table 5). These metrics and their application to interpretations of benthic invertebrate data are discussed by Resh and Jackson (1993) and Plafkin and others (1989).

Differences in quantitative taxonomic and derived assemblage metric and functional-feeding-group data among the four TWINSPAN site groups defined by the 37 samples in the combined basic-fixed- and synoptic-site data set were examined for significance ($p \leq 0.05$) using one-way analysis of variance (ANOVA) in StatView version 5 (SAS Institute, Inc., 1999a, 1999b). Results are included in tables 4 and 5.

Jaccard coefficients of community were calculated to assess the degree of similarity in taxonomic composition between pairs of data by using presence or absence of taxa to differentiate between collections (Jaccard, 1912) from multiple reaches (table 6) or multiple years (table 7) at three basic fixed sites (1996–98). This is a conventional method used to assess community similarity (Plafkin and others, 1989;

Table 5. Values of metrics and functional-feeding-group data associated with benthic invertebrates in site groups identified in the Eastern Iowa Basins, Iowa and Minnesota, 1996–97

[Site groups identified using TWINSPAN analysis. *p*-value, attained level of significance determined from one-way ANOVA with site group as independent variable; –, not significantly different among site groups (*p*-value greater than 0.05); %, percent; <, less than; EPT, Ephemeroptera, Plecoptera, and Trichoptera taxa. The sum of the five invertebrate functional feeding groups by site group is not 100 percent because some taxa could not be classified.]

Variable	Mean value of metric by indicated site group or all samples					*p*-value
	1	2	3	4	All samples	
Invertebrate assemblage metrics						
Taxa richness	45.4	50.8	52.0	36.3	46.4	0.02
EPT taxa richness	0.4	22.7	17.3	15.2	19.2	–
Shredders/total abundance	.1	.1	.2	.2	.2	.05
Scrapers/collector-filterers	.4	1.0	.5	.0	.4	–
Dominant taxa abundance (%)	47.3	40.1	45.2	55.9	47.0	–
EPT abundance (%)	50.0	57.8	30.8	39.8	48.0	<.01
Chironomidae abundance (%)	25.2	29.7	52.9	53.6	37.3	<.01
Invertebrate functional feeding groups (% total abundance)						
Shredder	10.3	12.0	25.0	21.7	16.0	.05
Scraper	6.7	8.2	4.2	.8	5.4	.01
Collector-filterer	31.9	14.2	13.4	50.5	27.5	<.01
Collector-gatherer	45.1	54.4	44.5	22.0	42.7	<.01
Predator	5.6	10.3	11.5	4.8	7.7	.03

The analysis of data from all sites (ordination of 74 taxa and 12 derived metrics from 37 samples from 31 stream sites) was used to illustrate the four site groups (fig. 3) associated with the differences in benthic invertebrate assemblages identified in the TWINSPAN analysis. Ordination by DCA displays sites in a biplot whereby sites with similarities in taxonomic composition, assemblage metrics, and functional feeding groups tend to cluster.

Axis or site scores for ordination axes 1 and 2 derived from the DCA were correlated to the taxa in the original data set to identify those that contributed significantly to grouping of the sites in the biplot (fig. 3). Paired comparisons for this and other subsequent analyses were performed using the *z*-test with a significance level of 0.05 in StatView version 5 (SAS Institute, Inc., 1999a, 1999b). The *z*-test uses Fisher's *R* to *z* transformation to test the hypothesis that the correlation between two variables is equal to a specified value.

A linear regression was performed to assess the significance of the relation between two invertebrate measures (fig. 4) because the relative abundances of EPT taxa and Chironomidae were important in interpreting the gradient along DCA axis 1 (the x axis).

Quantitative taxonomic data from basic fixed sites in 1996 were examined using DCA (ordination of 33 taxa and 12 sites). Correlation coefficients between DCA site scores and environmental data (table 8) were used to identify significant physical, chemical, and land-use variables in the study unit that influenced the grouping of sites in the biplot (fig. 5) from the benthic invertebrate data.

Environmental variables from the basic fixed sites were assigned to the appropriate TWINSPAN site group and analyzed by using the Kruskal-Wallis ANOVA in Systat version 8.0 (SPSS, Inc., 1998). Basic-fixed-site data were used to represent environmental conditions among the four site groups (table 9).

The relative abundances of 74 benthic invertebrate taxa were correlated with the concentrations of forms of organic carbon, nitrogen, and phosphorus measured at basic fixed and synoptic sites when the benthic invertebrates were collected. This was done to

Table 6. Jaccard coefficient of community between reaches in percent similarity of taxonomic composition and the number of taxa at sites 5, 19, and 21 in the Eastern Iowa Basins, Iowa and Minnesota, 1997

[QT, quantitative; QT + QL; combined quantitative and qualitative; –, no comparison made; main, stream reach sampled 1996–98; upper, stream reach located upstream main reach; lower, stream reach located downstream main reach; QA, an additional sample for quality assurance from the lower reach]

Variable	Site 5		Site 19		Site 21	
	QT	QT+QL	QT	QT+QL	QT	QT+QL
Pairs of reaches	**Percent similarity**					
main and upper	75	48	46	53	65	45
main and lower	62	53	62	70	50	43
upper and lower	67	65	41	51	43	47
main and QA	–	–	53	55	–	–
upper and QA	–	–	38	42	–	–
lower and QA	–	–	77	56	–	–
Reach	**Number of taxa**					
main	17	29	23	39	11	33
upper	18	30	31	48	17	38
lower	17	26	24	41	16	37
QA	–	–	26	37	–	–

The relative abundances of 74 benthic invertebrate taxa were correlated with the concentrations of forms of organic carbon, nitrogen, and phosphorus measured at basic fixed and synoptic sites when the benthic invertebrates were collected. This was done to identify taxa that might be tolerant or intolerant of organic enrichment or exhibit no response to ambient concentrations. A taxon with a significant ($p \leq 0.05$) positive correlation to any of the forms of carbon, nitrogen, or phosphorus measured was listed as positive for that variable in table 10. A taxon with a significant negative correlation was listed as negative.

DISTRIBUTION OF BENTHIC INVERTEBRATES

Over 250 benthic invertebrate taxa were identified from snags and woody debris in streams and rivers of the Wapsipinicon, Cedar, Iowa, and Skunk River Basins. After data editing and censuring, 74 taxa remained to represent the more widely distributed and abundant taxa. Mayflies, caddisflies, and true flies were well represented in streams and rivers of the EIWA study unit. The mayflies *Tricorythodes* and *Baetis intercalaris*; the net-spinning caddisflies *Hydropsyche bidens* and *H. simulans*; and the Chironomidae *Glyptotendipes*, *Polypedilum*, and *Rheotanytarsus* accounted for about 50 percent of the cumulative mean relative abundance of organisms in collections from 1996 and 1997 (table 4). The distribution of individuals followed the recognizable pattern of a few taxa represented at many sites by many individuals, with most taxa collected infrequently and represented by only a few individuals (Johnson and others, 1993).

Spatial and Temporal Variability

Data used to describe the benthic invertebrate assemblages of the EIWA study unit were collected on single visits to each of 12 basic fixed sites in 1996 and 25 synoptic sites in 1997. Additional samples were taken from three basic fixed sites (sites 5, 19, and 21) (table 1, fig. 1) to assess the amount of spatial (reach-

Table 7. Jaccard coefficient of community between years in percent similarity of taxonomic composition and the number of taxa at sites 5, 19, and 21 in the Eastern Iowa Basins, Iowa and Minnesota, 1996–98

[QT, quantitative; QT + QL; combined quantitative and qualitative]

Variable	Site 5		Site 19		Site 21	
	QT	**QT+QL**	**QT**	**QT+QL**	**QT**	**QT+QL**
Pairs of years	**Percent similarity**					
1996 and 1997	38	45	33	37	22	29
1996 and 1998	36	35	16	33	32	36
1997 and 1998	43	33	23	33	28	37
Year	**Number of taxa**					
1996	25	38	50	64	33	48
1997	17	30	22	36	11	32
1998	13	27	15	44	21	58

River. Six sites among the 25 chosen for the 1997 low-flow, synoptic water quality in the upper Midwest duplicated basic fixed sites, thus providing an additional opportunity to evaluate temporal variability. These included sites 7, 16, 19, 21, 22, and 24. These six duplicated sites are distinguished in figure 3 by the suffix “A” or “B,” which represent basic-fixed-site sampling and synoptic-site sampling, respectively.

TWINSPAN and Jaccard’s coefficient of community were used to assess spatial variability among the reaches sampled at the three basic fixed sites in 1997 and temporal variability among the sites

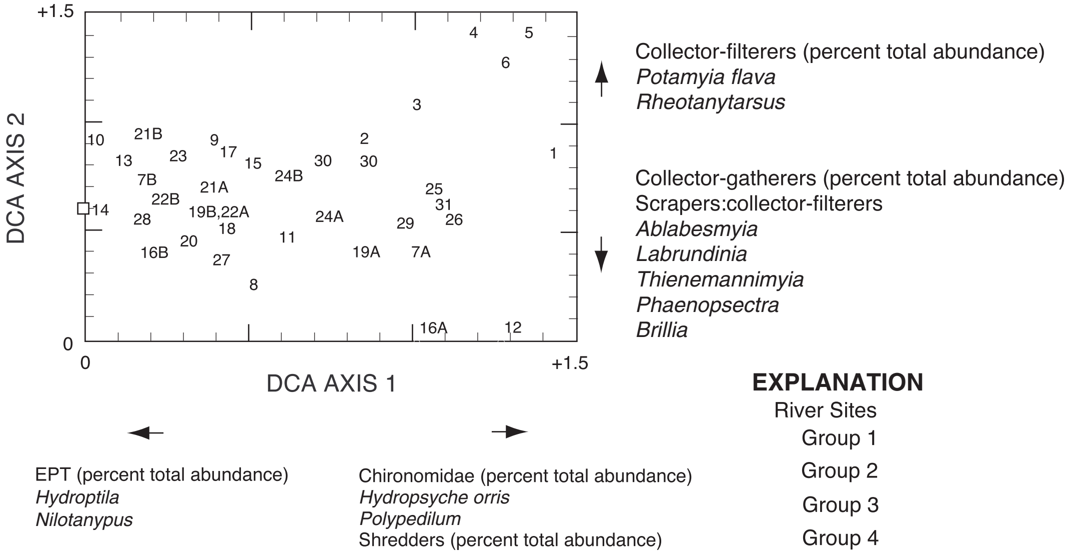

Figure 3. Detrended correspondence analysis (DCA) biplot of benthic invertebrate taxa in relation to 31 basic fixed and synoptic sites in the Eastern Iowa Basins, Iowa and Minnesota, 1966–97.

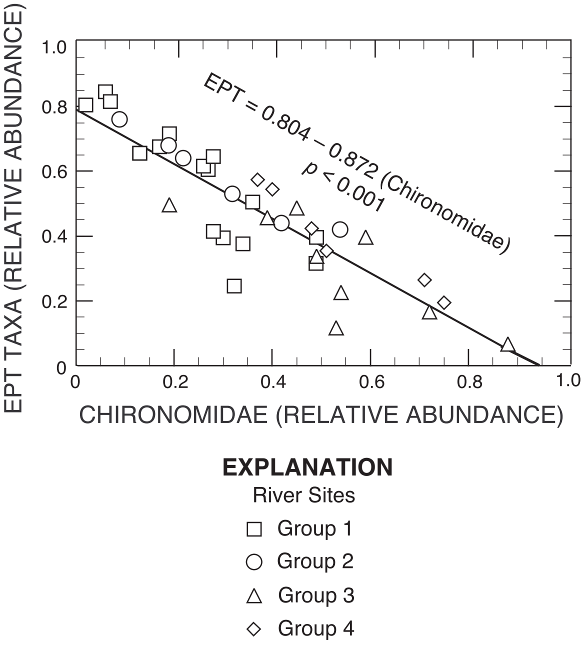

Figure 4. Linear regression of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa and Chironomidae as relative abundance in 37 samples from 31 basic fixed and synoptic sites in the Eastern Iowa Basins, Iowa and Minnesota, 1966–97.

sampled in 1996–98. The biplot of the ordination of 86 invertebrate measures (74 taxa and 12 derived metrics) and 37 samples (12 basic fixed and 25 synoptic sites) was used to assess temporal variability among the six sites duplicated in the two studies.

Spatial Variability

TWINSPAN analysis of quantitative, multiple-reach data for 1997 included 53 taxa and three reaches at sites 5, 19, and 21. Ten samples were analyzed that included an additional sample from a fourth reach at site 19 that was submitted for field-collection and laboratory-processing quality control. Samples in the TWINSPAN analysis segregated by site, with the variation within a site less than that observed among sites. A considerable range in percent similarity on the basis of taxonomic composition was present within each site for both the quantitative data and the combined quantitative and qualitative data (table 6). Overall, Jaccard coefficients of community for pairs of reaches ranged from 38 to 77 percent, with mean values from 52.7 at site 21 and 52.8 at site 19 to 68.0 at site 5.

Jaccard coefficients of community for pairs of reaches generally decreased with the inclusion of taxa collected in qualitative samples at sites 5 and 21, but increased for nearly all pairs at site 19. Although the number of taxa per reach for the combined quantitative and qualitative samples increased in every instance over that observed for only the quantitative samples (table 6), the taxa added by each qualitative sample varied considerably from reach to reach.

Only three of the 53 taxa included in the TWINSPAN analysis were present in all reaches sampled. These were the mayfly *Baetis intercalaris*, the net-spinning caddisfly *Hydropsyche simulans*, and the chironomid *Polypedilum*. Nine additional taxa were found at all three sites, but not in all reaches sampled. These included small oligochaete worms in the family Naididae; the mayflies *Heptagenia diabasia*, *Heptagenia flavescens*, and *Stenonema*; the net-spinning caddisfly *Hydropsyche bidens*; the riffle beetle *Stenelmis*; the chironomids *Stenochironomus* and *Thienemannimyia* group; and the dance fly *Hemerodromia*. Ubiquitous and predominant taxa often possess opportunistic characteristics, such as high reproductive rates or successful dispersal mechanisms, rather than tolerance to pollution (Johnson and others, 1993).

Variation in the presence of taxa among multiple samples from the same reach or site is common. Typically, the abundance of a few taxa is high while most are represented by only a few individuals (Johnson and others, 1993). Benthic invertebrate taxa are patchy in distribution (Williams and Feltmate, 1992). This result is expressed in multiple collections from the same site that exhibit considerable differences in numbers and kinds of taxa, and abundance. Large numbers of samples are required to overcome these localized differences in populations. Canton and Chadwick (1988) and Voshell and others (1989), as reported by Resh and McElravy (1993), concluded that six samples would typically provide estimates of only ±40 percent of the mean total number of organisms.

Temporal Variability

TWINSPAN analysis of quantitative, multiple-year data included a total of 82 taxa in nine samples collected at sites 5, 19, and 21 during 1996–98. Samples from the 3 years generally segregated by site with two exceptions—site 19 in 1998 grouped with site 21 for 1997–98, and site 21 in 1996 grouped with site 19 for 1996–97. Differences in discharge (fig. 2) support these observations. Mean discharge (January through September) at site 19 in 1998 (14.7 m^3/s) was

Table 8. Correlations of detrended correspondence analysis (DCA) axis scores and environmental variables from 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996

[*r*-value, correlation coefficient from Fisher's *R* to *z* test; *p*-value, attained level of significance from Fisher's *R* to *z* test; *p*-value in **boldface type**, attained level of significance less than or equal to 0.05; km^2, square kilometer; <, less than; %, percent; population data, see Sorenson and others, 1999; kg/km^2, kilograms per square kilometer; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; S, sulfur; µg/L, micrograms per liter; ESA, ethanesulfonic acid; °C, degrees Celsius; ; µS/cm, microsiemens per centimeter at 25 degrees Celsius; m, meter; m/km, meters per kilometer; m/s, meters per second; g O_2/m^3/hr, grams of oxygen per cubic meter per hour]

Environmental variable	DCA Axis 1		DCA Axis 2	
	r-value	*p*-value	*r*-value	*p*-value
Site Characterization				
General				
basin area (km^2)	-0.94	**<0.01**	0.01	0.98
Geology & Land Use/ Land Cover (% of basin area)				
Des Moines Lobe	-.32	.32	-.29	.38
Iowan Surface	-.50	.10	.64	**.02**
Iowan Karst	-.50	.10	.25	.44
Southern Iowa Drift Plain	-.56	.06	-.40	.20
Agriculture	.81	**<.01**	-.23	.49
Barren	-.76	**<.01**	.24	.46
Grassland	-.52	.08	-.13	.70
Row crop	.65	**.02**	.16	.62
Urban	-.88	**<.01**	-.01	.97
Wetland	-.17	.60	.59	**.04**
Wooded	-.84	**<.01**	-.16	.63
Population Data (1990)				
Human population density (number/km^2)	-.92	**<.01**	-.10	.75
Agricultural Use of Nitrogen, Phosphorus, and Pesticides (kg/km^2 in basin)				
Pesticides applied, total	.15	.64	.08	.53
Nitrogen from:				
atmosphere	<.01	.99	.18	.42
inorganic fertilizer	.15	.64	.55	.06
manure	.30	.35	<.01	.98
Phosphorus from:				
inorganic fertilizer	.15	.64	.54	.07
manure	.32	.32	-.04	.91
Water-Column Chemistry				
Water Quality (mg/L)				
Alkalinity (as $CaCO_3$)	.62	**.03**	-.48	.12
Bicarbonate (as $CaCO_3$)	.65	**.02**	-.45	.15
Carbonate (as $CaCO_3$)	-.63	**.03**	.18	.58
Calcium, dissolved	.64	**.02**	-.46	.14
Carbon, organic:				
dissolved	-.21	.52	.05	.88
suspended	-.93	**<.01**	.21	.53
Chloride, dissolved	-.75	**<.01**	.14	.67
Fluoride, dissolved	-.08	.81	-.57	.06
Hardness, total (as $CaCO_3$)	-.63	**.03**	.18	.58
Iron, dissolved	-.29	.37	.65	**.02**
Magnesium, dissolved	.03	.92	-.64	**.02**
Manganese, dissolved	.76	**<.01**	-.08	.81
Nitrogen (as N):				
ammonia + organic, dissolved	-.01	.99	-.16	.62
ammonia + organic, total	-.73	**<.01**	.31	.33
ammonia, dissolved	.21	.53	-.05	.88
nitrite + nitrate, dissolved	.53	.08	-.58	**.05**
nitrite, dissolved	.23	.47	-.14	.67
Phosphorus (as P):				
dissolved	.62	**.03**	-.48	.12
ortho, dissolved	.61	**.03**	-.44	.16
total	-0.63	**0.03**	-0.01	0.97
Potassium, dissolved	-.27	.41	.14	.67
Silicon, dissolved	.68	**.01**	-.49	.11
Sodium, dissolved	-.73	**.01**	.04	.91
Sulfate, dissolved (as S)	-.68	**.01**	-.22	.50
Herbicides and Degradation Products (µg/L)				
Fonofos	.19	.56	-.42	.18
Chlorpyrifos	.28	.38	-.31	.34
Diazinon	-.31	.33	.32	.32
Carbofuran	.16	.63	.54	.07
Triazine				
Atrazine	-.31	.34	-.37	.24
Deethylatrazine	-.15	.66	-.02	.95
Deisopropylatrazine	-.56	.06	-.57	**.05**
Atrazine + metabolites	-.40	.20	-.51	.09
Cyanazine	-.46	.14	-.30	.35
Cyanazine amide	-.55	.06	-.55	.06
Hydroxylatrazine	-.26	.42	-.11	.73
Prometon	.37	.25	.18	.59
Simazine	-.43	.17	-.16	.63
Chloroacetamide				
Acetochlor	.18	.59	-.27	.42
Acetochlor ESA	-.14	.66	-.66	**.02**
Acetochlor oxanilic acid	-.30	.36	-.09	.78
Acetochlor + metabolites	-.07	.83	-.15	.65
Alachlor	.29	.37	-.03	.93
Alachlor ESA	-.16	.64	-.08	.80
Alachlor oxanilic acid	.40	.20	.04	.90
Alachlor + metabolites	-.11	.75	-.08	.81
Metolachlor	.17	.61	-.33	.30
Metolachlor ESA	.39	.22	-.11	.74
Metolachlor oxanilic acid	.11	.74	-.42	.18
Metolachlor + metabolites	.36	.26	-.24	.47
Single Measurement and Continuous-Monitoring Data				
Water temperature (°C):				
time of sampling	-.45	.15	-.19	.57
4-month low	-.48	.12	-.06	.85
Specific conductance (µS/cm):				
time of sampling	.53	.07	-.63	**.03**
4-month low	.38	.22	-.63	**.03**
pH:				
time of sampling	-.50	.10	.20	.54
4-month low	-.65	**.02**	-.07	.83
Dissolved oxygen:				
time of sampling (mg/L)	-.45	.14	-.12	.72
4-month low (mg/L)	-.23	.49	-.06	.86
saturation, 4-month low (%)	-.42	.18	-.05	.88
Habitat				
Bank height (m):				
mean	-.40	.20	-.50	.10
maximum	-.35	.27	-.45	.14
Bank vegetation stability:				
mean	.60	**.04**	-.15	.65

Table 8. Correlations of detrended correspondence analysis (DCA) axis scores and environmental variables from 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996—Continued

Environmental variable	DCA Axis 1		DCA Axis 2		Environmental variable	DCA Axis 1		DCA Axis 2	
	r-value	*p*-value	*r*-value	*p*-value		*r*-value	*p*-value	*r*-value	*p*-value
maximum	0.38	0.23	0.08	0.82	Sinuosity, stream segment	-0.02	0.96	0.14	0.67
Bank width (m):					Stream depth (m):				
mean	-.40	.20	-.38	.23	mean	-.71	**.01**	.13	.69
maximum	-.21	.52	.14	.68	maximum	-.79	**<.01**	.22	.51
Bottom material:					Stream width (m):				
% clay	-.48	.12	-.25	.44	wetted channel	-.90	**<.01**	-.03	.92
% sand	-.27	.40	.14	.66	maximum	-.88	**<.01**	-.05	.89
% silt	.44	.15	.11	.73	Velocity (m/s):				
Canopy angle (degrees):					mean	-.57	**.05**	.11	.74
mean (sum both sides)	.75	**<.01**	.08	.82	maximum	-.55	.06	.02	.95
maximum	.82	**<.01**	.12	.72	**Stream Productivity**				
Gradient, stream segment (m/km)	.63	**.03**	.14	.67	g $O_2/m^3/hr$ by calculation	-.53	.08	-.09	.79

several times greater than measured during the same period in 1996 and 1997; this value was comparable to those observed at site 21 in 1997 and 1998 (11.3 and 11.2 m^3/s, respectively). Similarly, in 1996, the discharge at site 21 was 57 percent (6.4 m^3/s) of the values measured for the same period in 1997 and 1998; this value was comparable to those observed at site 19 in 1996 and 1997 (3.5 and 5.7 m^3/s, respectively). Although discharge at site 5, a large-river site, varied among the years (244 to 431 m^3/s), discharges at that site were considerably greater and more similar to each other among years compared to the other two sites.

Over the 3-year period, temporal differences in benthic invertebrate populations at a site exceeded spatial differences within a site (tables 6 and 7). Jaccard coefficients of community for pairs of years ranged from 16 to 43 percent, with mean values of 24.0 (site 19) and 27.3 (site 21) to 39.0 (site 5) (table 6). None of the 82 taxa included in the TWINSPAN analysis was found at all sites in all years sampled although 14 taxa were collected at all three sites. Eight of these were among the predominant taxa present in the EIWA study unit (table 4), including the mayflies *Baetis intercalaris*, *Stenonema*, and *Tricorythodes*; the net-spinning caddisflies *Hydropsyche bidens* and *H.*

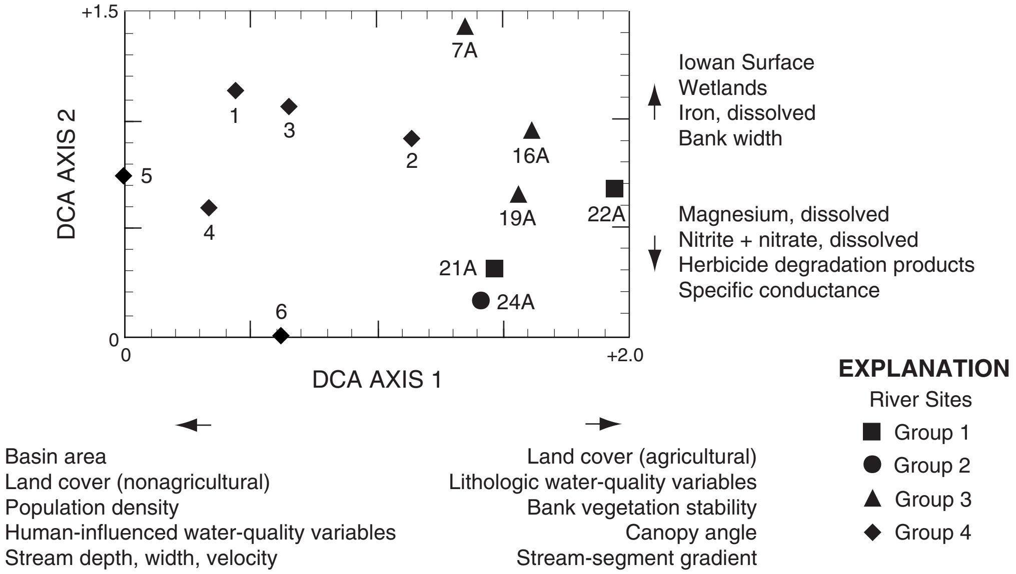

Figure 5. Detrended correspondence analysis (DCA) biplot of benthic invertebrates in relation to 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996.

Table 9. Mean concentration or value of environmental variables in four site groups used to describe 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996

[Site groups identified using TWINSPAN analysis. *p*-value, attained level of significance from Kruskal-Wallis test; *p*-value in **boldface type**, attained level of significance less than or equal to 0.05; parentheses in header (2), number of sites in group; km^2, square kilometer; %, percent; population data, see Sorenson and others, 1999; x10^3, multiply mean value by 1,000; kg/km^2, kilogram per square kilometer; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; N, nitrogen; P, phosphorus; S, sulfur; µg/L, micrograms per liter; <, less than; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; m, meter; m/km, meters per kilometer; m/s, meters per second; g O_2/m^3/hr, grams of oxygen per cubic meter per hour]

Environmental variable	Mean concentration or value by indicated site group or total					*p*-value
	1 (2)	2 (1)	3 (3)	4 (6)	All sites (12)	
Site Characterization						
General						
basin area (km^2)	832	522	664	15,089	7,893	**0.03**
Geology and Land Use/Land Cover (% of basin area)						
Des Moines Lobe	10.0	0.0	0.0	23.1	28.2	**.04**
Iowan Surface	.0	.0	66.7	35.2	34.3	.22
Iowan Karst	.0	.0	33.3	13.8	15.3	.63
Southern Iowa Drift Plain	.0	10.0	.0	27.9	22.3	**.05**
Agriculture	97.4	95.8	96.0	93.4	94.9	.24
Barren	.1	.2	.8	1.0	.7	.07
Grassland	12.1	38.1	2.0	25.9	23.1	.06
Row crop	84.6	56.1	76.2	64.8	7.2	.10
Urban	.7	1.4	.8	2.0	1.4	**.04**
Wetland	.4	.0	.4	.3	.3	.50
Wooded	2.5	4.8	2.4	6.6	4.7	.06
Population Data (1990)						
Human population density (number/km^2)	7.3	12.9	8.5	20.4	14.6	**.03**
Human population of basin (x10^3)	6.9	6.7	5.9	341	174	**.04**
Agricultural Use of Nitrogen, Phosphorus, and Pesticides (kg/km^2 in basin)						
Pesticides applied, total	161	107	142	139	141	**.02**
Nitrogen from:						
atmosphere	569	604	552	578	573	.49
inorganic fertilizer	6,839	4,659	6,078	5,949	6,022	**.03**
manure	3,031	1,837	1,639	1,910	2,023	.16
Phosphorus from:						
inorganic fertilizer	924	620	819	800	810	**.02**
manure	1,507	754	695	845	910	.09
Water-Column Chemistry						
Water Quality (mg/L)						
Alkalinity (as $CaCO_3$)	269	172	183	176	193	.19
Bicarbonate (as $CaCO_3$)	328	210	223	208	232	.19
Carbonate (as $CaCO_3$)	0	0	0	9	5	0.15
Calcium, dissolved	82.5	56.0	66.7	56.7	63.4	.27
Carbon, organic:						
dissolved	4.0	2.9	2.4	3.8	3.4	.16
suspended	1.2	.8	1.4	3.9	2.6	**.04**
Chloride, dissolved	18.0	17.0	18.0	26.2	22.0	.16
Fluoride, dissolved	.30	.30	.20	.28	.26	.45
Hardness, total (as $CaCO_3$)	325	230	230	228	245	.19
Iron, dissolved	2.8	3.0	8.5	15.3	1.5	.38
Magnesium, dissolved	28.5	21.0	16.0	21.3	21.2	.13
Manganese, dissolved	.28	.96	.31	.03	.22	.06
Nitrogen (as N):						
ammonia + organic, dissolved	.45	.20	.17	.32	.29	.10
ammonia + organic, total	.70	.30	.63	2.27	1.43	**.03**
ammonia, dissolved	.04	.04	.03	.04	.04	.71
nitrite + nitrate, dissolved	6.50	9.40	7.77	4.61	6.11	.27
nitrite, dissolved	.05	.03	.04	.03	.04	.39
Phosphorus (as P):						
dissolved	.10	.07	.07	.06	.07	.65
ortho, dissolved	.11	.09	.08	.07	.08	.71
total	.13	.08	.10	.28	.19	**.05**
Potassium, dissolved	2.8	1.3	2.0	2.5	2.3	.34
Silicon, dissolved	22.5	13.0	11.2	8.5	11.9	.15
Sodium, dissolved	7.9	12.0	9.6	16.2	12.8	.19
Sulfate, dissolved (as S)	3.0	23.0	25.3	39.7	33.1	.07
Herbicides and Degradation Products (µg/L)						
Fonofos	<.01	.01	<.01	<.01	<.01	**.01**
Chlorpyrifos	<.01	.01	<.01	<.01	<.01	.17
Diazinon	<.01	<.01	<.01	<.01	<.01	.80
Carbofuran	<.01	<.01	.01	<.01	<.01	.39
Triazine						
Atrazine	.19	.48	.27	.59	.43	.23
Deethylatrazine	.13	.20	.12	.20	.17	.28
Deisopropylatrazine	.05	.14	.05	.12	.09	.19

Table 9. Mean concentration or value of environmental variables in four site groups used to describe 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota, 1996—Continued

Environmental variable	Mean concentration or value by indicated site group or total					*p*-value
	1 (2)	2 (1)	3 (3)	4 (6)	All sites (12)	
Atrazine + metabolites	0.36	0.82	0.44	0.91	0.69	0.06
Cyanazine	.00	.11	.02	.04	.03	.19
Cyanazine amide	.03	.23	.03	.09	.07	**.05**
Hydroxylatrazine	.37	.45	.23	.31	.31	.86
Prometon	.06	.01	.02	.02	.03	.33
Simazine	.00	.00	.00	.01	.00	.56
Chloroacetamide						
Acetochlor	.01	.02	.01	.01	.01	.45
Acetochlor ethanesulfonic acid	.19	1.25	.16	.32	.34	.33
Acetochlor oxanilic acid	.10	.29	.10	.19	.16	.33
Acetochlor + metabolites	.29	1.56	.82	.90	.83	.63
Alachlor	.01	.01	.01	.01	.01	.60
Alachlor ethanesulfonic acid	1.89	1.74	1.36	1.64	1.62	.95
Alachlor oxanilic acid	.10	.28	.24	.10	.15	.07
Alachlor + metabolites	2.00	2.03	1.61	1.75	1.78	.95
Metolachlor	.29	.11	.08	.19	.17	.26
Metolachlor ethanesulfonic acid	7.07	2.58	4.37	3.16	4.06	.19
Metolachlor oxanilic acid	1.84	.74	.34	.62	.76	.10
Metolachlor + metabolites	9.20	3.43	4.79	3.97	5.00	.18
Single Measurements and Continuous-Monitoring Data						
Water temperature (°C):						
time of sampling	24.3	21.4	20.7	24.5	23.3	.13
4-month low	23.6	18.6	20.4	23.9	22.5	.16
Specific conductance (µS/cm):						
time of sampling	698	504	481	443	500	.16
4-month low	664	517	502	453	506	.15
pH:						
time of sampling	8.0	8.0	7.7	8.3	8.1	.28
4-month low	8.3	8.0	8.0	8.4	8.2	.06
Dissolved oxygen:						
time of sampling (mg/L)	8.6	8.1	8.0	11.0	9.6	.20
4-month low (mg/L)	8.5	9.9	8.1	8.8	8.7	0.39
saturation, 4-month low (%)	104	107	96	109	105	.56
Habitat						
Bank height (m):						
mean	1.4	6.2	1.6	3.2	2.7	.14
maximum	2.2	7.5	2.3	4.2	3.7	.16
Bank vegetation stability						
mean	1.9	2.8	2.6	1.8	2.1	.18
maximum	3.0	4.0	4.0	3.3	3.5	.29
Bank width (m):						
mean	3.4	6.6	4.0	5.7	4.9	.23
maximum	8.0	9.9	9.5	14.6	11.8	.73
Bottom material (lab analysis):						
% sand	58	45	59	40	48	.67
% silt	26	41	25	42	35	.67
% clay	16	14	16	19	17	.84
Canopy angle (degrees):						
mean (sum both sides)	57	65	62	22	41	.12
maximum	70	78	79	30	53	.08
Gradient, stream segment (m/km)	.68	.57	.57	.31	.46	.41
Sinuosity, stream segment	1.23	1.26	1.22	1.28	1.26	.90
Stream depth (m):						
mean	.48	.21	.28	1.00	.67	**.04**
maximum	.80	.59	.69	2.10	1.40	**.03**
Stream width (m):						
wetted channel	22.4	16.3	17.8	123	7.9	**.04**
maximum	31.9	19.8	2.8	156	9.1	**.03**
Velocity (m/s):						
mean	.29	.34	.26	.44	.36	**.04**
maximum	.51	.49	.41	.62	.54	.15
Stream Productivity						
g O_2/m^3/hr by calculation	.30	.26	.20	.36	.30	**.02**

Table 10. Responses of benthic invertebrates and associated metrics to concentrations of organic carbon, nitrogen, and phosphorus, and reported tolerance values for each taxon

[Taxa ranked by mean relative abundance among all samples (table 4). Taxa and chemical variables collected at 12 basic fixed sites in 1996 and 25 synoptic sites in 1997. Tolerance value, a water-quality rating between 0 (intolerant) and 10 (tolerant) derived from Iowa Department of Natural Resources data (T. Wilton, Iowa Department of Natural Resources, written commun., 1998); –, correlation between relative abundance of a taxon or value of a metric and the concentration of a variable not significant (*p* greater than 0.05) from Fisher's *R* to *z* test; positive, significant (*p* less than or equal to 0.05) positive correlation between relative abundance of a taxon or value of a metric and the concentration of a variable; negative, significant (*p* less than or equal to 0.05) negative correlation between relative abundance of a taxon or value of a metric and the concentration of a variable; N/A, tolerance value not available; EPT, Ephemeroptera, Plecoptera, and Trichoptera taxa; %, percent]

Variable	Organic carbon		Nitrogen					Phosphorus			Tolerance value from literature
	Dissolved	Sus-pended	Ammonia plus organic, dissolved	Ammonia plus organic, total	Ammonia, dissolved	Nitrite, dissolved	Nitrate plus nitrite, dissolved	Total	Dissolved	Ortho, dissolved	
Invertebrate taxa											
Tricorythodes	–	–	–	–	–	–	–	–	–	–	4
Polypedilum	–	positive	positive	–	–	–	–	–	–	–	6
Hydropsyche bidens	–	positive	positive	–	–	–	–	–	negative	–	3
Rheotanytarsus	–	–	–	–	–	–	–	–	–	–	6
Baetis intercalaris	–	–	–	–	–	–	–	–	–	–	6
Hydropsyche simulans	–	–	–	–	–	–	–	–	–	–	7
Glyptotendipes	–	–	–	–	–	–	–	–	–	–	10
Naididae	–	–	–	–	–	positive	–	negative	–	negative	7.6
Macronychus glabratus	–	negative	negative	–	–	–	–	negative	–	–	4
Cricotopus/Orthocladius	–	negative	–	–	–	–	–	negative	–	–	7/6
Stenonema terminatum	–	negative	–	–	–	–	–	–	–	–	4
Fallceon quilleri	–	–	–	–	–	–	–	–	–	–	6
Stenonema	–	–	–	–	–	–	–	–	–	–	3.7
Thienemannimyia group	–	–	–	positive	–	positive	–	–	–	–	6
Acentrella	negative	negative	negative	negative	–	–	–	–	–	–	6
Tanytarsus	–	–	–	–	–	–	–	–	–	–	6
Ceratopsyche	–	–	–	–	–	–	–	–	–	–	4.5
Stenochironomus	–	–	–	–	–	–	–	–	–	–	5
Cricotopus bicinctus group	–	–	–	–	–	–	positive	–	–	–	6
Caenis	–	–	–	–	–	–	–	–	–	–	7
Corixidae	positive	–	–	positive	positive	–	–	–	–	–	5
Dicrotendipes	positive	–	–	positive	positive	–	negative	positive	positive	positive	8
Simuliidae	–	–	–	–	–	–	positive	–	–	–	6
Hydrachnidia	–	–	–	–	–	–	negative	–	–	–	N/A
Hemerodromia	–	–	positive	–	–	–	–	positive	–	–	6
Stenelmis grossa	–	–	–	–	–	–	–	–	–	–	5
Atherix variegata	–	–	–	–	–	–	–	–	–	–	2
Cheumatopsyche	–	negative	–	–	–	positive	–	–	–	–	5
Cladotanytarsus	–	–	–	–	–	–	–	–	–	–	7

Table 10. Responses of benthic invertebrates and associated metrics to concentrations of organic carbon, nitrogen, and phosphorus, and reported tolerance values for each taxon—Continued

Variable	Organic carbon		Nitrogen					Phosphorus			Tolerance value from literature
	Dissolved	Sus-pended	Ammonia plus organic, dissolved	Ammonia plus organic, total	Ammonia, dissolved	Nitrite, dissolved	Nitrate plus nitrite, dissolved	Total	Dissolved	Ortho, dissolved	
Invertebrate taxa–Continued											
Centroptilum/Procloeon	–	–	–	positive	positive	–	–	positive	positive	positive	2/6
Parakiefferiella	–	negative	–	–	–	–	–	–	–	–	6
Pseudocloeon	–	–	–	–	–	–	positive	–	positive	positive	4
Chironomus	–	–	–	–	–	–	–	–	–	–	10
Heptagenia diabasia	negative	–	–	–	–	–	–	–	–	–	3
Stenacron	–	–	–	positive	–	–	–	–	positive	–	7
Potamyia flava	–	positive	–	–	–	–	–	–	–	–	5
Coenagrionidae	positive	–	–	positive	–	–	–	–	–	–	8
Rheocricotopus	negative	–	negative	–	–	–	positive	–	–	–	6
Phaenopsectra	–	–	–	–	–	–	–	–	–	–	7
Stenonema mexicanum	–	–	–	–	–	–	–	–	–	–	4
Hydropsyche orris	–	positive	–	–	–	–	–	–	–	–	5
Hydroptila	–	negative	negative	–	–	–	–	negative	–	–	6
Thienemanniella	negative	negative	negative	negative	–	–	positive	–	–	–	6
Heptagenia flavescens	–	–	–	–	–	–	–	–	–	–	4
Isonychia	–	–	–	–	–	–	–	–	positive	positive	2
Amercaenis ridens	–	–	–	–	–	–	positive	–	–	positive	7
Tubificidae	positive	–	–	–	–	–	–	–	–	–	10
Saetheria	–	–	–	–	–	–	–	–	–	–	4
Parachironomus	–	–	–	–	–	–	–	–	–	–	10
Nanocladius	–	–	–	–	–	–	–	–	–	–	3
Paratanytarsus	–	–	–	–	–	positive	–	–	–	–	6
Dubiraphia	positive	–	positive	–	positive	–	negative	positive	positive	positive	6
Nilotanypus	–	negative	–	–	–	–	–	–	–	–	6
Brillia	negative	–	–	–	–	–	–	–	–	–	5
Brachycentrus numerosus	–	–	–	–	–	positive	–	negative	–	–	1
Mayatrichia ayama	–	–	–	–	–	–	–	–	–	–	6
Hexagenia	–	–	–	–	–	–	–	–	–	–	6
Ablabesmyia	–	–	–	–	–	–	–	–	–	–	8
Nectopsyche candida	positive	–	–	positive	positive	–	negative	positive	positive	positive	3
Corynoneura	–	–	–	–	–	–	positive	–	–	–	7
Nematoda	–	–	–	–	–	–	–	–	–	–	N/A
Veliidae	–	–	–	–	–	–	negative	–	–	–	N/A

Table 10. Responses of benthic invertebrates and associated metrics to concentrations of organic carbon, nitrogen, and phosphorus, and reported tolerance values for each taxon—Continued

Variable	Organic carbon		Nitrogen					Phosphorus			Tolerance value from literature
	Dissolved	Sus-pended	Ammonia plus organic, dissolved	Ammonia plus organic, total	Ammonia, dissolved	Nitrite, dissolved	Nitrate plus nitrite, dissolved	Total	Dissolved	Ortho, dissolved	
Invertebrate taxa–Continued											
Paranyctiophylax	–	–	–	positive	–	–	–	–	–	–	5
Labrundinia	–	–	–	–	–	–	–	–	–	–	6
Ancyronyx variegata	–	–	–	–	–	–	–	–	–	–	6
Atrichopogon	–	–	–	–	–	–	–	–	–	–	6.8
Cryptochironomus	–	–	–	–	–	–	–	–	–	–	8
Helichus lithophilus	–	–	–	–	positive	–	–	–	–	positive	5
Gomphidae	–	–	–	–	–	–	–	positive	positive	positive	5
Nectopsyche diarina	–	–	–	–	–	–	–	–	positive	positive	3
Acroneuria	–	–	–	–	–	–	–	–	–	–	0
Pteronarcys	–	–	–	–	–	–	–	–	–	–	0
Bryozoa	–	–	–	–	–	–	–	–	–	–	N/A
Pycnopsyche	–	–	–	–	–	–	–	–	–	–	4
Invertebrate assemblage metrics											
Taxa richness	–	negative	negative	–	–	–	–	–	positive	–	N/A
EPT taxa richness	–	negative	–	–	–	–	–	–	–	–	N/A
Shredders/total abundance	–	–	–	–	–	–	–	–	–	–	N/A
Scrapers/collector-filterers	–	–	–	–	–	–	–	–	–	–	N/A
Dominant taxa (%)	–	positive	positive	–	–	–	–	–	–	–	N/A
EPT abundance (%)	–	–	–	–	–	–	–	–	negative	–	N/A
Chironomidae abundance (%)	–	–	–	–	–	–	–	–	–	–	N/A
Invertebrate functional feeding groups (% total abundance)											
Shredder	–	–	–	–	–	–	–	–	–	–	N/A
Scraper	–	–	–	–	–	–	–	–	–	–	N/A
Collector-filterer	–	positive	positive	–	–	–	–	–	negative	–	N/A
Collector-gatherer	–	negative	negative	–	–	–	–	–	–	–	N/A
Predator	positive	–	–	positive	positive	–	–	–	–	–	N/A

simulans; and the Chironomidae *Polypedilum*, *Stenochironomus*, and *Thienemannimyia* group.

Six pairs of sites sampled in 1996 and 1997 (fig. 3) illustrate the results of a multivariate ordination of sites by taxa for 31 locations in the EIWA study unit. Sites in figure 3 were assigned to one of four TWINSPAN groups on the basis of taxonomic composition and the correspondence of sites with attributes of the benthic invertebrate assemblages (metrics). One-half of the site pairs were assigned to the same group. These were samples from sites 21, 22, and 24. There was more temporal variation observed for sites 7, 16, and 19 between 1996 and 1997, with the sites assigned to different groups. Sites 7, 16, and 19 sampled in 1996 (suffix "A" in fig. 3) are in group 3, one characterized by the numerical importance of the Chironomidae. Assemblages collected at these same sites in 1997 are present in group 1, which is characterized by the numerical importance of EPT taxa.

Sampling time was relatively consistent among years, but precedent hydrologic conditions varied somewhat. Discharge within the EIWA study unit was lower in 1996 than in subsequent years (fig. 2). Johnson and others (1993) observed that merely changing the time of sampling from one year to the next, such as from late summer to early autumn, altered the TWINSPAN classification of lakes. In addition, considerable natural spatial and temporal variations of benthic invertebrates have been documented for life-history aspects, such as emergence, feeding and growth, and movements and migration (Resh and Rosenberg, 1989). The relations between EPT taxa and Chironomidae may relate more to natural factors such as climate or hydrology than land use, which remained constant during the study.

Differences in Benthic Invertebrates Among Site Groups

An ordination that used benthic invertebrate data and derived metrics for 37 samples at 31 sites (fig. 3) identified relations among sites and confirmed that the patterns in community structure were consistent with site groups. Assignment to a group was consistent between the TWINSPAN and DCA analyses with one exception (site 28 in fig. 3). This consistency in assignment to a group is not unusual because TWINSPAN and DCA are both based on reciprocal averaging (Hill, 1979; ter Braak and Smilauer, 1998). Site scores from the first two DCA axes were correlated with the invertebrate assemblage and metric data to identify which taxa or metrics contributed significantly to the relations observed among the sites. The first two axes of the DCA explained 22.3 percent of the variance.

The DCA axis 1 identified two groups of sites based on the importance of Chironomidae (positively correlated with DCA axis 1) and EPT taxa (negatively correlated with DCA axis 1). Chironomidae became increasingly dominant with increasing basin area. Groups 1 and 2, where the relative abundance of EPT taxa was higher and that of Chironomidae lower (table 5), represented sites with smaller basin areas (mean 556.6 km^2). Groups 3 and 4, where the relative abundance of Chironomidae was higher and that of EPT taxa lower, contained the sites with larger basin areas (group 3, mean 773.7 km^2; group 4, mean 15,089.0 km^2). The relative abundance of EPT taxa did not correlate significantly with basin area, discharge, or discharge per unit area using data from the 37 samples at 31 sites in 1996–97. The relative abundance of Chironomidae was significantly correlated with basin area and discharge. The regression plot in figure 4 shows that the frequently more tolerant Chironomidae generally increase significantly in abundance from group 1 to 4, while the more environmentally sensitive EPT taxa decrease in abundance.

Other benthic invertebrate taxa and derived metrics that positively correlated with site scores on DCA axis 1 included the net-spinning caddisfly *Hydropsyche orris* and the chironomid *Polypedilum*. The net-spinning caddisflies, including *H. bidens* and *Potamyia flava*, are among the most common filter-feeding insects in streams and rivers; they use salivary secretions to spin nets on any solid surface to filter coarse particles (Lamberti and Moore, 1984). One reason for their abundance in eastern Iowa streams could be their ability to exploit a wider food base than other filter-feeding organisms by feeding on algae, detritus, associated microflora, and any animal material that they harvest from their nets (Lamberti and Moore, 1984). The relative abundance of *Polypedilum*, the second most common and widely distributed aquatic insect observed among the sites, increased from about 6 to nearly 18 percent from group 1 to 4 (table 4). *Rheotanytarsus*, also widely distributed among all groups, was more abundant in group 4. Whereas *Polypedilum* is able to exploit sandy substrates, *Rheotanytarsus* is a sedentary species that uses snags and other woody debris to colonize (Minshall, 1984). Simpson and Bode (1980) observed that *Polypedilum* was usually associated with *Rheotanytarsus*, *Cheumatopsyche*, and *Nais* in New York streams and considered these taxa as community indicators of abundant sources of suspended food.

The percentage of total abundance represented by the shredder functional feeding group was also positively correlated with DCA axis 1. Shredders were significantly more abundant in groups 3 and 4, reflecting the importance of the chironomid genera *Polypedilum* and *Glyptotendipes* (tables 4 and 5). Simpson and Bode (1980) characterized *Glyptotendipes* as a burrower favoring soft substrates in slow-moving streams and rivers. Fewer taxa were classified as shredders than any other functional feeding group of benthic invertebrates. Other numerically important taxa classified as shredders include the Chironomidae *Cricotopus/Orthocladius*, *Cricotopus bicinctus*, and *Brillia* and caddisflies in the genus *Nectopsyche*.

The relative abundances of the chironomid *Nilotanypus* and the microcaddisfly genus *Hydroptila* were negatively correlated with site scores on DCA axis 1. *Nilotanypus* was widely distributed at sites in groups 1 and 2, but its presence declined sharply in group 3, and it was not collected in group 4. *Hydroptila* exhibited a similar pattern. Available ecological information for species of *Nilotanypus* suggests that the larvae are found in uncontaminated, small- to medium-sized, cool streams and rivers. *Nilotanypus* lives in sand and gravel substrates, occasionally on rocks, in shallow, flowing water (Roback, 1986). These conditions were not characteristic of the sites in groups 3 and 4. *Hydroptila* is an herbivorous genus of microcaddisfly whose larval instars pierce filamentous algal cells and consume the contents; it might also feed on periphyton (Wiggins, 1996). It is possible that *Hydroptila* has ecological requirements similar to those of *Nilotanypus* because its food source probably is not limited in groups 3 and 4.

Taxa and associated metrics positively correlated significantly with site scores on DCA axis 2 included the relative abundance of two detritivores that filter fine particles from the water column for food (net-spinning caddisflies such as *Potamyia flava* and the chironomid *Rheotanytarsus*) and the relative abundance of the collector-filterer functional feeding group. These variables effectively separated sites in group 4 from those in groups 1, 2 and 3 (fig. 3). Fifty percent of the organisms present at sites in group 4 were classified as collector-filterers, capable of exploiting the significantly higher concentrations of suspended organic carbon (table 9). The percentage of collector-filterers was significantly higher than in any other group because of the abundances of *Hydropsyche bidens*, *Polypedilum*, and *Rheotanytarsus*.

Site scores on DCA axis 2 were negatively correlated significantly with the percent total abundance of the collector-gatherer functional feeding group, the ratio of scrapers to collector-filterers, and the relative abundance and distribution of five genera of Chironomidae (*Ablabesmyia*, *Labrundinia*, *Thienemannimyia, Phaenopsectra*, *Brillia*). The collector-gatherer functional feeding group predominated among all samples combined, with an overall relative abundance of 42.7 percent (table 5). It predominated in site groups 1, 2, and 3, groups with much smaller watersheds (mean basin area 634.7 km^2, range 308 to 1,487 km^2) than group 4 (mean basin area 15,089.0 km^2, range 6,050 to 32,365 km^2). The collector-filterer functional feeding group dominated at the large-river sites of group 4.

Taxa classified as collector-gatherers are more generalized or opportunistic feeders that collect finely divided organic material that has settled on the sediments in depositional zones, such as pools or stream margins (Lamberti and Moore, 1984). Predominant collector-gatherers included the aquatic oligochaete worms in the families Naididae and Tubificidae; the mayflies *Tricorythodes*, *Baetis intercalaris*, *Fallceon quilleri*, *Acentrella*, *Caenis*, *Centroptilum/Procloeon*, *Pseudocloeon*, *Stenacron*, and *Hexagenia*; the riffle beetles *Macronychus glabratus* and *Ancyronyx variegata*; and a number of Chironomidae (for example, *Dicrotendipes*, *Parakiefferiella*, *Chironomus*, *Rheocricotopus*, *Thienemanniella*, *Saetheria*, *Nanocladius*, and *Corynoneura*).

Taxa that feed by grazing on the algae and detritus on the surface of rocks and other solid objects are classified as scrapers. Although these organisms were most abundant in groups 1 and 2, decreased in abundance in group 3, and even more in group 4, their abundance was low compared to that of the collector functional feeding groups in the study area. Among abundant taxa classified as scrapers were mayflies in the genus *Stenonema* and *Heptagenia diabasia*, the caddisfly *Mayatrichia ayama*, the beetles *Stenelmis grossa* and *Helichus lithophilus*, and the chironomid *Phaenopsectra*.

Because scrapers are herbivores, their distribution and abundance are influenced by the patterns of primary productivity in streams (Gregory, 1983) and linked to suitable hard substrates for the development of their algal food source. Other investigators have suggested that the relative abundance of scrapers would be greatest in the intermediate reaches, such as those in site groups 1, 2, and 3, that are found along a longitudinal gradient from first-order, headwater streams to large rivers (Vannote and others, 1980). At the large-river sites in group 4, hard substrates were limited to snags and woody debris whose horizontal surfaces were thickly covered by sand and fine sediments at the time of sampling, which may have limited the growth of periphytic algae. The low values associated with the ratio of scrapers to collector-filterers is another indication of the low frequency of scraper taxa and the importance of collector-filterers at sites in group 4 (table 5).

The five genera of Chironomidae (*Ablabesmyia*, *Labrundinia*, *Thienemannimyia, Phaenopsectra*, *Brillia*) were either abundant in group 3 or collected infrequently or not at all at the large-river sites of group 4. The chironomid taxa expressing this pattern of distribution crossed functional feeding designations, including several predators (*Ablabesmyia*, *Labrundinia*, and *Thienemannimyia*), a shredder (*Brillia*), and a scraper (*Phaenopsectra*).

Group 4 was the most biologically distinct site group, with six sites having high scores on DCA axes 1 and 2 (fig. 3). These were river sites with the largest basin areas (greater than 6,000 km^2); high productivity (mean 0.36 g $O_2/m^3/hr$); channels that were significantly wider (mean width 122.8 m), deeper (mean depth 1.0 m), and faster (mean velocity 0.44 m/s); and high concentrations of nutrients and suspended organic carbon (table 9). Biologically in group 4, the relative abundance of Chironomidae was significantly higher, a few taxa predominated the invertebrate populations to a higher degree (55.9 percent) than in the other site groups, and collector-filterers were significantly more abundant (50.5 percent) (tables 4 and 5). The organisms that filter particles from the water column probably responded to the higher concentrations of suspended organic matter available at these large-river sites (table 9).

Taxa richness, the number of distinct taxa in a collection or at a site, is a component and estimate of community structure (Resh and Jackson, 1993). Taxa richness was significantly lower among group 4 sites (table 5). Richness often increases with improved water quality, habitat diversity, or habitat suitability (Weber, 1973; Resh and Grodhaus, 1983; Plafkin and others, 1989) but might also reflect mild organic enrichment in some situations. Lower taxa richness and the predominance of a few taxa might represent invertebrate assemblages under stress (Plafkin and others, 1989) or merely the natural changes in populations attributable to longitudinal succession (Fisher, 1983).

Commenting on the predictability of changes in stream systems from source to mouth, Stanford and Ward (1983) stated that, whereas constancy prevailed in the headwaters and higher stream orders (above stream order 7; none among the 31 sites sampled in the EIWA Basins), environmental conditions such as temperature and discharge in the middle reaches (stream orders 5 to 7) were highly variable. Stanford and Ward (1983) agreed with Vannote and others (1980) that species diversity should be greatest within the middle reaches of the stream continuum because the range of annual change in temperature and discharge across stream orders is greatest for stream orders 5 to 7. Within the EIWA study unit, taxa richness was highest in groups 2 and 3, EPT taxa richness increased from group 1 to 2, and the abundance of the shredder and collector-gatherer functional feeding groups did not decline sharply until downstream at group 4 sites. Many taxa displayed this general pattern of abundance within groups 2 and 3, including the small riffle beetle *Dubiraphia*; the caddisfly *Nectopsyche candida*; and the Chironomidae *Brillia*, *Cricotopus bicinctus* group, *Paratanytarsus*, *Saetheria*, and *Tanytarsus* (table 4).

INFLUENCE OF PHYSICAL AND CHEMICAL CHARACTERISTICS OF STREAMS ON BENTHIC INVERTEBRATE ASSEMBLAGES

Environmental variables monitored at the 12 basic fixed sites were used to assess their potential influence on the benthic invertebrate assemblages in an ordination with a data set of 33 taxa and 12 sites (fig. 5). The first two axes of the DCA accounted for 41.3 percent of the variance observed in the invertebrate populations. Site scores from the first two DCA axes were correlated with the environmental variables to identify those that were important in describing relations among the invertebrate assemblages (table 8).

Identification of Important Environmental Variables

Environmental variables with significant positive correlations with site scores on DCA axis 1 included agricultural land use and land cover (row crops, other agriculture), stream-segment gradient, stream-habitat features (bank vegetation stability, canopy angle), forms of phosphorus (dissolved phosphorus, dissolved orthophosphate), and some other water-quality variables (pH; concentrations of manganese, dissolved silica, calcium, alkalinity, bicarbonate) (fig. 5; table 8). Sites with low scores on DCA axis 1 are associated with nonagricultural land cover and land use, lower stream-segment gradient, and less bank stability and shading of the stream by riparian vegetation (table 9).

Environmental variables with significant negative correlations with site scores on DCA axis 1 included basin area, nonagricultural features of land use and land cover (barren, urban, wooded), variables associated with population or possible human influences on water quality (population density; concentrations of sodium, chloride, sulfate, total ammonia plus organic nitrogen, suspended organic carbon, total phosphorus), and features of stream habitat (stream width, depth, velocity) (fig. 5; table 8). Sites with low scores on DCA axis 1 are associated with deeper and wider stream channels, higher mean velocities, larger basin areas, more land in nonagricultural use, greater population densities, probable human influences on water quality (for example, higher concentrations of sodium, chloride, sulfate, total ammonia plus organic nitrogen, suspended organic carbon, and total phosphorus). Basin area is a principal factor in the distribution of sites along DCA axis 1. Basin areas of the six sites in group 4 range from 6,050 to more than 32,300 km^2. The basin areas of the remaining six sites in groups 1, 2, and 3 have smaller watersheds that range from 389 to 1,083 km^2. Sites with high scores on DCA axis 1 were located in smaller watersheds in headwaters, other upstream areas, or tributaries.

The environmental variables correlated significantly with site scores on DCA axis 2 include geological features and contribute additional evidence of the importance of point and nonpoint sources of organic and nutrient enrichment from urban development and agriculture that affect the structure and composition of benthic invertebrate assemblages (fig. 5). Environmental variables positively correlated with site scores on DCA axis 2 included the percentage of the basin area on the Iowan Surface landform, the percentage of the basin area occupied by wetlands, bank width, and dissolved iron. Nutrients (dissolved nitrite plus nitrate), herbicides (particularly the degradation products deisopropylatrazine and acetochlor ethanesulfonic acid), and some other water-quality variables (magnesium and specific conductance) were all negatively correlated with site scores on DCA axis 2.

Sites are arranged along DCA axis 2 by the percentage of the basin area that includes each of four geological landforms, especially the Iowan Surface. The basin areas of sites in group 4 are large enough to encompass two to four of the recognized landforms in the EIWA study unit (fig. 1). The watersheds of the remaining six sites are each sufficiently small to be contained within only one geological landform. The sites assigned to group 1 (sites 21 and 22) are entirely within the Des Moines Lobe landform. The watershed of site 24, the only representative of group 2 among the basic fixed sites, is entirely within the Southern Iowa Drift Plain. Group 3 includes sites 7, 16, and 19, all of which are within the Iowan Surface or the Iowan Karst, a subgroup of the Iowan Surface. Other investigators have observed distinguishable regional differences in the distribution patterns of aquatic biota, especially fishes, in Iowa (Griffith and others, 1994). Paragamian (1990) noted that the composition and habitat of assemblages of fishes varied among five landform regions in Iowa. Menzel (1987) concluded that features such as geology, topography, soils, vegetation, drainage features, and land use within each landform influenced the regional distribution of fishes in Iowa.

The remaining area that is classified as wetlands might be considered as a surrogate for riparian vegetation because 87 to 96 percent of the basin area has been converted to some form of agriculture. Bottomland forest, a wetland type, is extensive in the upper Wapsipinicon River Basin (site 7). Preliminary data reviewed by Schnoebelen and others (1999) suggested that the Wapsipinicon River might have a more extensive riparian zone than other large rivers in the EIWA study unit. They speculated that an extensive riparian zone could reduce the transport of nutrients and pesticides to the river. Streams might be less turbid and periphytic algae of more significance with increased stream gradient, bank vegetation stability, and canopy shading (variables positively correlated along DCA axis 1) (M.A. Harris and S.D. Porter, U.S. Geological

Survey, written commun., 2000) and lower concentrations of the variables with negative correlations on DCA axis 2. The negatively correlated variables that reflect increased herbicide and nutrient concentrations and poorer water quality are evident at sites farthest downstream (for example, sites 4 to 6) and in areas with concentrations of confined, high-density hog-feeding operations (for example, sites 21 and 22 in the upper Iowa River watershed). Fewer of these operations are in the watersheds of sites 7, 16, and 19. Schnoebelen and others (1999) commented on the number of hog-production operations that began in the 1990's in the study unit. They noted that the upper parts of the Iowa and Skunk River Basins had more than twice the number of permits issued from 1993 to 1996 compared to 1987–93 and speculated generally on the possibility of negative effects on surface-water quality.

Distinctions Among Site Groups

The invertebrate assemblages in the four site groups reflect the cumulative effects of land use (agricultural and urban), point and nonpoint sources of organic and nutrient enrichment, landform, and longitudinal stream succession (Fisher, 1983). These factors, especially the natural changes from upstream to downstream, were influential in describing the benthic invertebrate assemblages defining the site groups.

The invertebrate assemblage associated with the sites in group 4, those with the largest basin areas, was clearly defined. This group was distinct, although it is difficult to distinguish among the contributions of large basin area, concentrations of nutrients and pesticides, and decreasing instream habitat diversity. Of 74 taxa included in the ordination of 31 sites (fig. 3, table 4), 25 taxa were not represented in group 4, another 15 were present at the lowest relative abundance observed among all samples, and 11 were present at the highest abundances recorded. Of these 11, significant differences in relative abundance among site groups were found for the net-spinning caddisflies *Hydropsyche bidens*, *H. orris*, and *Potamyia flava*; the Chironomidae *Polypedilum*, *Rheotanytarsus*, *Parachironomus*, and *Corynoneura*; and the dance fly *Hemerodromia*. Among the invertebrate metrics, the percent abundance of the three dominant taxa, Chironomidae, and the collector-filterer functional feeding group were highest in group 4. Taxa richness, EPT taxa richness, the ratio of scrapers to collector-filterers, and the percent abundance of the functional feeding groups of scrapers, collector-gatherers, and predators were lowest in group 4.

Sites in groups 1, 2, and 3 reflect conditions found more commonly in smaller streams, such as higher stream-segment gradients and the potential for more diverse or extensive riparian habitat.

Groups 1 and 2 were distinct from groups 3 and 4 in many respects. This result seems to be the most definitive distinction among the benthic invertebrate assemblages identified in eastern Iowa streams. The two pairs of groups were distinguished principally by the relative abundance of the EPT taxa (higher in groups 1 and 2) and Chironomidae (lower in groups 1 and 2) (fig. 4, table 5). Of 74 taxa included in the ordination of 31 sites (fig. 3, table 4), 10 taxa were not represented in groups 1 and 2, 8 were present at the lowest relative abundance observed among all samples, and 27 were present at the highest abundances recorded.

Although most of the 27 taxa were still present at low abundances, mayflies, stoneflies, and caddisflies predominated. Cumulatively, they contributed to the principal factor that distinguished these two pairs of site groups—the difference in relative abundance of the EPT taxa and Chironomidae. Using data from the 37 samples at 31 sites during 1996–97, the relative abundance of EPT taxa was not significantly related to increasing basin area or discharge whereas the relative abundance of Chironomidae was. In general, the majority of EPT taxa are considered to be environmentally sensitive groups (Lenat, 1988; Plafkin and others, 1989). Their abundance is assumed to reflect less disturbed or enriched conditions, whereas chironomids tend to increase in dominance in terms of relative abundance or taxonomic composition along a gradient of increasing organic and nutrient enrichment and basin area (Merritt and others, 1984).

In their assessment of 69 small- to moderate-sized Illinois, Iowa, and Minnesota streams, Harris and Porter (M.A. Harris and S.D. Porter, written commun., 2000) concluded that stream velocity influenced whether invertebrate assemblages were dominated by EPT taxa (sites with faster velocity) or Chironomidae (sites with slower velocity). Although neither the relative abundance of EPT taxa nor Chironomidae correlated significantly with mean velocity in the present study, velocity was one of several significant variables that contributed to the relations among the invertebrate populations at the 12 basic fixed sites (fig. 5). As basin area, stream depth, width, and velocity increased, the relative abundance of Chironomidae increased (tables 1, 5, and 9). None of the basin areas of streams studied by Harris and Porter (M.A. Harris and S.D. Porter, written commun., 2000) exceeded 2,771 km^2; six sites in the present study exceeded 6,000 km^2. Velocity contributes to the explanation of the composition of benthic invertebrate assemblages in the streams in eastern Iowa, but may be less important locally than in the regional context of Harris and Porter.

Hydrology influenced the composition of the invertebrate assemblages, particularly the abundances of EPT taxa and Chironomidae collected at some sites in 1996 and 1997. Because these two groups of taxa were influential in assigning sites to a group, differences in the composition of assemblages at three sites between years caused temporal shifts in site membership between groups 1 (abundance of EPT taxa) and 3 (abundance of Chironomidae) (fig. 3). The shift in group membership was attributed to differences observed in rainfall-runoff and streamflow conditions. Discharge within the study unit was lower in 1996 than in 1997 (fig. 2). Although time of sampling was relatively consistent between years, precedent hydrologic conditions varied. With lower flow, the composition of the invertebrate populations shifted to favor Chironomidae. Harris and Porter (M.A. Harris and S.D. Porter, written commun., 2000) also concluded that spatial and temporal (for example, from year to year) differences in regional rainfall conditions were likely to influence the structure of invertebrate communities and the interpretation of water-quality conditions. They recommended that invertebrate communities in streams and rivers probably should be evaluated during contrasting (wet and dry) years before assigning water-quality classifications or criteria to specific water bodies.

Ground water from the limestone bedrock aquifers contributes to the flow of rivers such as the Cedar and Wapsipinicon on the Iowan Surface landform during low-flow periods (Prior, 1991). In a study that included 69 stream reaches in Illinois, Iowa, and Minnesota, Harris and Porter (M.A. Harris and S.D. Porter, written commun., 2000) found that streams in eastern Iowa receiving proportionally more ground-water sources, such as those in the upper parts of the Cedar and Wapsipinicon Basins, had greater total taxa and EPT taxa richness. They speculated that differences between physicochemical conditions in ground-water discharges compared to surface-water sources and increased microhabitat complexity in streams with substantial ground-water contributions could provide additional niches for exploitation by invertebrate taxa, leading to higher taxa and EPT taxa richness. Newbury (1984) commented that the variety of sources of streamflow contributed to the variability of the water quality of insect habitats. He reported that concentrations of major ions were abruptly diluted as surface flows and shallow, temporary ground-water flows entered streams during snowmelt or rainstorms.

Responses of Benthic Invertebrates to Nutrients and Organic Enrichment

The responses of benthic invertebrates to environmental variables, especially nutrients and indicators of organic enrichment, or specific contaminants, are used in biotic indices to evaluate water or habitat quality. States, including Iowa, developed biocriteria and associated indices to perform rapid biological assessments for wadeable streams and rivers (T.F. Wilton, Iowa Department of Natural Resources, written commun., 1998). As the basis for these indices, a taxon is assigned a rating from 0 (most sensitive) to 10 (least sensitive) or a category (for example, tolerant, intolerant or sensitive, facultative) based on the objective derivation of tolerance values (see Lenat, 1993, for discussion) or “expert opinions.” Organisms classified as facultative are able to survive under a range of conditions, are more “intermediate” in their preferences—not exactly fitting either the tolerant or intolerant categories (Olive and Dambach, 1973).

Following a procedure used by Cuffney and others (1997) to describe the tolerance of algal taxa to nutrients, the relative abundances of 74 taxa from 31 sites in the EIWA study unit were correlated with concentrations of forms of organic carbon, nitrogen, and phosphorus. The purpose was to identify relations with benthic invertebrate taxa and to refine tolerance values used for streams in eastern Iowa. Although the responses of individual taxa to organic carbon and nutrient concentrations varied, nearly 50 percent were found to be facultative, showing no significant correlation to any of the variables (table 10). Many of the predominant taxa in table 4 could be classified as facultative, such as the mayflies *Tricorythodes*, *Baetis* *intercalaris*, *Fallceon quilleri*, *Stenonema*, and *Caenis*; the net-spinning caddisflies *Hydropsyche simulans* and *Ceratopsyche*; the riffle beetle *Stenelmis grossa*; and the Chironomidae *Rheotanytarsus*, *Glyptotendipes*, *Tanytarsus*, *Stenochironomus*, and *Cladotanytarsus*.

Most of the remaining taxa showed significant correlations with one to three of the 10 constituents examined, reflecting either tolerance (significant positive correlation) or sensitivity (significant negative correlation) to a particular form of organic carbon, nitrogen, or phosphorus (table 10). Only six of the remaining taxa (mayflies *Acentrella* and *Centroptilum/Procloeon*, caddisfly *Nectopsyche candida*, elmid beetle *Dubiraphia*, and Chironomidae *Dicrotendipes* and *Thienemanniella*) had more than three significant correlations with the 10 variables examined.

Tolerance values, compiled by the Iowa Department of Natural Resources from its own data and published sources (particularly Hilsenhoff, 1988; Lenat, 1993) (T.F. Wilton, Iowa Department of Natural Resources, written commun., 1998), were included in table 10 to determine if site-specific data for the invertebrates were comparable to existing values or could be used to refine values for streams in eastern Iowa. Facultative taxa have values near the midrange between 0 and 10; values between 4.5 to 6.5 roughly correspond to those described by Lenat (1993). Values less than 4.5 are considered as sensitive or intolerant; values higher than about 6.5, tolerant.

The tolerance values of most taxa in the EIWA study unit that might be classified as facultative (that is, no significant correlation to any variable examined) ranged from 4.5 to 6.5 (table10). Facultative taxa whose tolerance values probably should be lower for streams in eastern Iowa included the mayfly *Caenis*; net-spinning caddisfly *Hydropsyche simulans*; and the Chironomidae *Glyptotendipes*, *Cladotanytarsus*, *Chironomus*, *Phaenopsectra*, *Parachironomus*, *Ablabesmyia*, and *Cryptochironomus*. Facultative taxa whose tolerance values probably should be higher for streams in eastern Iowa included the mayflies *Tricorythodes*, *Stenonema*, and *Heptagenia flavescens*; the stoneflies *Acroneuria* and *Pteronarcys*; the caddisfly *Pycnopsyche*; the true fly *Atherix variegata*; and the chironomid *Nanocladius*.

Taxa with significant correlations to one or more forms of organic carbon, nitrogen, and phosphorus and whose tolerance values probably should be higher for streams in eastern Iowa include the mayflies *Pseudocloeon* and *Isonychia*; and the caddisflies *Hydropsyche bidens*, *Brachycentrus numerosus*, *Nectopsyche candida*, and *N. diarina*. Taxa with significant correlations to one or more of the variables and whose tolerance values probably should be lower for streams in eastern Iowa include the Chironomidae *Cricotopus/Orthocladius* and *Thienemanniella*, and the mayfly *Acentrella* (table 10).

SUMMARY

Over 250 benthic invertebrate taxa were identified from snags and woody debris in streams and rivers of the Wapsipinicon, Cedar, Iowa, and Skunk River Basins in the Eastern Iowa Basins (EIWA) study unit of the U.S. Geological Survey National Water-Quality Assessment Program. The composition, distribution, and abundance of 74 predominant taxa were related to environmental conditions in the study unit, using habitat, hydrologic, and water-quality data. Four groups of sites were defined, based on the distribution and relative abundance of taxa. Detrended correspondence analysis was used to identify relations in the structure of the invertebrate assemblages, and the correspondence of taxa and sites in the groups was related to habitat, hydrologic, and water-quality information. Responses of invertebrate assemblages were explained by natural factors, such as surficial geology or physical habitat conditions, as well as human influences, such as agriculture or high-density hog-feeding operations.

Mayflies, caddisflies, and true flies were well represented in streams and rivers of the EIWA study unit. The mayflies *Tricorythodes* and *Baetis intercalaris*, the net-spinning caddisflies *Hydropsyche bidens* and *H. simulans*, and the Chironomidae *Glyptotendipes*, *Polypedilum*, and *Rheotanytarsus* predominated. Spatial variation in benthic invertebrate assemblages within a site was less than that observed among sites. Assemblages from 3 years of sampling generally grouped by site, with exceptions related to differences in discharge among years.

The benthic invertebrate assemblages associated with the four groups of sites reflected the cumulative effects of agricultural and urban land use, sources of nutrient and organic enrichment, and longitudinal stream succession—the natural sequence of communities in streams from headwaters to large rivers. These factors, especially the natural changes from upstream to downstream, were influential in characterizing the benthic invertebrate assemblages of the site groups.

Stream size, a reflection of basin area, was a principal influence in categorizing the benthic invertebrate assemblages, with sites that have the largest basin areas forming a separate group. Although it is difficult to distinguish among the contributions of large basin area, increased concentrations of nutrients and pesticides, and decreasing instream habitat diversity, the resulting invertebrate assemblage described was distinct. Of 74 taxa considered in this study, 33 percent was not present at these larger sites, another 20 percent was found at the lowest relative abundance observed, and 15 percent reached the highest abundances recorded. Numerically important taxa at these larger stream sites included the mayfly *Amercaenis ridens*; the net-spinning caddisflies *Hydropsyche bidens*, *H. orris*, and *Potamyia flava*; and the Chironomidae *Polypedilum* and *Rheotanytarsus*. Other attributes of the invertebrate assemblage, such as differences in relative abundances by functional feeding group or taxa richness, also were distinct for this group of larger sites and reflected natural changes in population with longitudinal stream succession.

The remaining sites were headwater or tributary streams. They reflected conditions found more commonly in smaller streams, such as higher gradients and the potential for more diverse or extensive riparian habitat, but were distinguished by landform. Following basin area in importance, landform contributed to the differences observed among the benthic invertebrate communities at the remaining sites. Sites separated by the percentage of the basin area included each of four geological landforms, primarily the Iowan Surface. Sites with the larger basin areas encompassed two to four of the recognized landforms in the EIWA study unit whereas the remaining sites typically had basin areas occupying only one landform.

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SUPPLEMENTAL DATA

Table 11. Percentages of land use/land cover and landform at 31 stream-site basins in the Eastern Iowa Basins, Iowa and Minnesota

[%, percent; human population data, see Sorenson and others, 1999; no./km^2, number per square kilometer; –, not available]

Site number (fig. 1)	U.S. Geological Survey station identification	Human population density, 1990 (no./km^2)	Land use/land cover (% of total basin area)							Landform (% of total basin area)			
			Agri-culture	Barren	Grass-land	Row crop	Urban	Wetland	Wooded	Des Moines Lobe	Iowan Surface	Iowan Karst	Southern Iowa Drift Plain
1	05464020	24.9	91	0.1	5.9	85	3	2	4	28.2	32.1	39.7	0
2	05453100	13.3	91	.1	9.9	81	3	2	4	44.5	18.4	0	37.2
3	05422000	13.2	87	0	10	78	2	3	7	0	84.3	0	15.7
4	05465000	28.2	89	.1	8.9	82	3	2	4	19.0	43.9	26.7	10.4
5	05465500	24.6	89	.1	10.9	79	3	2	5	21.8	32.4	16.6	29.2
6	05474000	18.5	87	0	15	72	3	2	8	25.3	0	0	74.7
7	05420680	9.5	89	0	8	81	2	4	5	0	100	0	0
8	05420720	9.0	90	0	7	84	1	3	5	–	–	–	–
9	05420900	12.8	89	.1	5.9	84	2	1	7	–	–	–	–
10	05421700	10.6	90	0	10	80	1	2	7	–	–	–	–
11	05421870	16.5	95	0	9	86	2	0	3	–	–	–	–
12	05456510	11.0	91	0	6	87	2	2	3	–	–	–	–
13	05457950	6.1	93	0	6	88	1	2	3	–	–	–	–
14	05458870	5.2	95	0	5	90	1	1	3	–	–	–	–
15	05459300	11.5	91	0	10	82	2	3	3	–	–	–	–
16	05461390	6.9	95	0	3	92	1	1	3	0	0	100	0
17	05462770	7.3	95	0	5	91	1	1	2	–	–	–	–
18	05463510	13.6	95	0	4	92	2	1	1	–	–	–	–
19	05464220	9.2	96	0	5	90	2	1	2	0	100	0	0
20	05449200	11.7	95	.1	1.9	93	2	1	2	–	–	–	–
21	05449500	10.7	95	.1	3.9	90	2	2	2	100	0	0	0
22	05451210	4.0	95	0	4	91	1	1	3	100	0	0	0
23	05452020	7.4	93	0	15	78	2	1	4	–	–	–	–
24	05455100	12.9	92	0	23	69	3	1	4	0	0	0	100
25	05455500	7.6	91	0	23	68	3	1	5	–	–	–	–
26	05465310	12.2	91	0	12	79	2	1	6	–	–	–	–
27	05469980	11.3	94	0	4	90	3	1	2	–	–	–	–
28	05471120	11.1	94	0	5	89	2	1	3	–	–	–	–
29	05473060	12.8	90	0	11	80	2	1	6	–	–	–	–
30	05473400	14.1	85	0	17	69	2	2	10	–	–	–	–
31	05473550	28.8	87	0	15	73	3	1	8	–	–	–	–

Table 12. Pesticide and fertilizer applications in stream-site basins, and physical variables at 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota

[x 10^6, multiply by one million; °C, degrees Celsius; kg, kilograms; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; –, not available]

Site number (fig. 1)	U.S. Geological Survey station identification	Reach	Chemicals applied in basin (kg x 10^6)			Nutrients from manure applied in basin (kg x 10^6)		Nitrogen from atmosphere in basin (kg x 10^6)	pH	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Water temperature (°C)
			Pesticides	Nitrogen	Phosphorus	Nitrogen	Phosphorus					
						1996						
1	05464020	main	2.05	87.6	11.8	21.9	9.66	7.17	8.47	416	13.1	25.1
2	05453100	main	1.02	43.4	5.85	16.7	7.86	4.33	8.24	450	10.1	23.0
3	05422000	main	.859	37.5	4.99	12.8	5.27	3.69	8.48	334	10.9	24.3
4	05465000	main	2.93	125	16.8	32.6	14.2	11.2	9.12	423	12.6	24.8
5	05465500	main	4.48	191	25.8	59.6	26.5	18.4	8.44	455	7.4	25.0
6	05474000	main	1.29	54.9	7.42	21.8	9.78	6.82	7.22	577	11.7	24.8
7	05420680	main	.128	5.48	.737	1.94	.798	.499	7.60	422	6.7	21.0
16	05461390	main	.048	2.04	.276	.426	.194	.169	7.49	446	8.4	17.0
19	05464220	main	.105	4.49	.603	1.11	.458	.445	8.10	575	8.9	24.0
21	05449500	main	.173	7.32	.991	2.13	1.04	.599	7.81	720	8.2	22.6
22	05451210	main	.094	4.02	.542	2.38	1.2	.34	8.08	675	9.0	26.0
24	05455100	main	.056	2.43	.324	.959	.393	.315	8.03	504	8.1	21.4
						1997 Multiple reach						
5	05465500	upper	–	169	.607	72.5	31.7	17.9	8.36	548	10.6	27.9
5	05465500	main	–	169	.607	72.5	31.7	17.9	8.35	565	8.6	29.3
5	05465500	lower	–	169	.607	72.5	31.7	17.9	8.26	557	10.3	26.5
19	05464220	upper	–	3.94	26.0	1.53	.637	.417	7.74	640	8.2	21.5
19	05464220	main	–	3.94	26.0	1.53	.637	.417	7.97	598	8.2	25.4
19	05464220	lower	–	3.94	26.0	1.53	.637	.417	8.02	604	8.4	22.3
21	05449500	upper	–	6.68	1.02	2.03	1.06	.554	8.02	576	10.4	22.3
21	05449500	main	–	6.68	1.02	2.03	1.06	.554	8.21	583	12.9	25.2
21	05449500	lower	–	6.68	1.02	2.03	1.06	.554	7.74	575	8.6	19.8
						1998						
5	05465500	main	–	–	–	–	–	–	7.87	539	7.7	25.5
19	05464220	main	–	–	–	–	–	–	7.78	599	8.2	21.5
21	05449500	main	–	–	–	–	–	–	7.71	709	7.8	20.9

Table 13. Streambank characteristics and canopy shading at 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota

[m, meters; %, percent; mean, average of measurements taken along a transect; max., maximum]

Site number (fig. 1)	U.S. Geological Survey station identification	Reach	Bank width (m)		Bank height (m)		Bank vegetation stability		Canopy shading (%)	
			mean	max.	mean	max.	mean	max.	mean	max.
1996										
1	05464020	main	6.4	13.7	4.0	6.0	1.7	3	14.5	24.4
2	05453100	main	3.0	7.7	2.8	4.2	2.1	4	33.3	46.1
3	05422000	main	5.9	37.3	1.1	1.5	1.4	3	33.4	46.1
4	05465000	main	3.7	5.3	2.3	2.7	1.6	3	12.7	18.9
5	05465500	main	5.6	11.4	3.7	5.5	1.5	3	9.3	11.1
6	05474000	main	9.3	12.2	5.1	5.4	2.3	4	26.0	34.4
7	05420680	main	2.6	4.9	1.2	1.4	2.0	4	73.4	100
16	05461390	main	5.1	16.3	1.6	2.8	2.9	4	85.7	100
19	05464220	main	4.2	7.4	1.9	2.7	2.8	4	25.6	38.3
21	05449500	main	2.7	5.5	1.2	2.0	1.2	2	65.5	77.2
22	05451210	main	4.0	10.5	1.6	2.3	2.6	4	48.1	62.8
24	05455100	main	6.6	9.9	6.2	7.5	2.8	4	65.2	77.8
1997 Multiple reach										
5	05465500	upper	3.3	8.1	2.5	3.3	1.3	2	9.7	12.8
5	05465500	main	31.9	125	2.3	3.3	1.7	3	9.1	12.8
5	05465500	lower	15.1	52.4	2.2	3.1	1.2	2	12.8	18.9
19	05464220	upper	7.9	15.0	2.0	2.7	2.5	4	19.5	33.3
19	05464220	main	2.6	5.5	1.7	2.4	3.4	4	19.4	34.4
19	05464220	lower	4.4	7.6	2.2	3.3	3.3	4	71.3	100
21	05449500	upper	2.8	5.4	1.4	2.0	1.4	2	67.2	100
21	05449500	main	3.3	5.1	1.6	2.4	1.1	2	56.1	73.3
21	05449500	lower	5.9	25.4	1.4	2.0	3.7	4	15.1	19.4
1998										
5	05465500	main	3.0	11.0	1.4	2.3	1.0	1	9.6	12.8
19	05464220	main	2.3	9.1	1.8	2.6	2.8	4	25.9	30.6
21	05449500	main	3.4	11.6	1.4	3.4	1.0	1	63.2	78.9

Table 14. Streambed materials and stream characteristics at 12 basic fixed sites in the Eastern Iowa Basins, Iowa and Minnesota

[%, percent; m/s, meters per second; m/km, meters per kilometer; max., maximum; –, not available]

Site number (fig. 1)	U.S. Geological Survey station identification	Reach	Bottom material, 1995 (%)			Stream width, wetted channel (m)		Stream depth (m)		Stream velocity (m/s)		Sinu-osity	Stream gradient (m/km)
			clay	silt	sand	mean	max.	mean	max.	mean	max.		
1996													
1	05464020	main	18	23	59	104	114	.94	1.82	0.46	0.57	1.06	0.36
2	05453100	main	21	42	37	101	134	1.39	2.37	.53	.60	1.41	.30
3	05422000	main	28	57	15	97.5	125	.95	2.40	.44	.63	1.61	.47
4	05465000	main	9	20	71	133	200	.56	1.39	.50	.84	1.25	.32
5	05465500	main	21	74	5	214	262	1.43	3.23	.34	.61	1.23	.27
6	05474000	main	16	34	50	88.4	99.4	.74	1.39	.36	.46	1.14	.15
7	05420680	main	21	16	63	15.5	19.2	.40	1.05	.28	.42	1.26	.35
16	05461390	main	11	14	75	8.3	9.1	.15	.36	.23	.30	1.08	.78
19	05464220	main	16	45	39	29.5	34.2	.30	.65	.28	.50	1.31	.59
21	05449500	main	30	45	25	30	42.7	.59	.86	.24	.42	1.25	.16
22	05451210	main	2	7	91	14.7	21	.37	.74	.34	.60	1.21	1.2
24	05455100	main	14	41	45	16.3	19.8	.21	.59	.34	.49	1.26	.57
1997 Multiple reach													
5	05465500	upper	–	–	–	229	232	4.66	3.66	.74	1.07	1.23	.27
5	05465500	main	21	74	5	214	262	1.78	3.63	.59	1.40	1.23	.27
5	05465500	lower	–	–	–	129	179	2.29	5.61	.63	1.11	1.23	.27
19	05464220	upper	–	–	–	25.1	31.0	.35	.73	.35	.64	1.31	.59
19	05464220	main	16	45	39	30.4	33.0	.33	.64	.35	.48	1.31	.59
19	05464220	lower	–	–	–	19.2	27.5	.46	.76	.36	.63	1.31	.59
21	05449500	upper	–	–	–	26.9	36.6	.47	.82	.18	.23	1.25	.16
21	05449500	main	30	45	25	26.8	33.0	.50	.75	.19	.24	1.25	.16
21	05449500	lower	–	–	–	26.8	32.0	.38	.88	.22	1.30	1.25	.16
1998													
5	05465500	main	21	74	5	225	265	2.23	3.30	.81	1.16	1.23	.27
19	05464220	main	16	45	39	29.7	35.0	.40	.70	.19	.25	1.31	.59
21	05449500	main	30	45	25	28.7	34.7	.72	1.04	.30	.47	1.25	.16