National Water-Quality Assessment Program

Effects of Urbanization on Stream Ecosystems in the South Platte River Basin, Colorado and Wyoming

By Lori A. Sprague, Robert E. Zuellig, and Jean A. Dupree

Chapter A of
Effects of Urbanization on Stream Ecosystems in Six Metropolitan Areas of the United States

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (http://www.usgs.gov/). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (http://water.usgs.gov/nawqa). The NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are 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. From 1991–2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (http://water.usgs.gov/nawqa/studyu.html).

Multiple national and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are reassessed. These assessments extend the findings in the Study Units by determining status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and ground water. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with many of the Nation's largest community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between *sources* of contaminants, the *transport* of those contaminants through the hydrologic system, and the potential *effects* of contaminants on humans and aquatic ecosystems. Included are topics on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. These topical studies are conducted in those Study Units most affected by these issues; they comprise a set of multi-Study-Unit designs for systematic national assessment. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS 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 cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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Conversion Factors and Acronyms

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
angstrom (Å)	1.000×10^{-08}	centimeter (cm)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
milliliter (mL)	0.0002642	gallon (gal)
milliliter (mL)	1,000	microliter (µL)
cubic meter (m^3)	0.0008110	acre-foot (acre-ft)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
kilogram (kg)	2.205	pound, avoirdupois (lb)
gram (g)	0.00220	pound, avoirdupois (lb)
dalton	1.000	atomic mass unit, 1998
	Pressure	
torr	0.03937	inch of mercury at 60°F (in Hg)
torr	0.001316	atmosphere, standard (atm)
millibar	0.0009869	atmosphere, standard (atm)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F–32)/1.8

Temperature in Kelvin (K) may be converted to degrees Celsius (°C) as follows:
°C=K–273.15

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

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

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

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

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

Acronyms

DTH	depositional targeted habitat
E. coli	*Escherichia coli*
EPT	Ephemeroptera, Plecoptera, Trichoptera
GIS	Geographic Information System
IDAS	Invertebrate Data Analysis System
MRLC	Multiresolution Land Characteristics
NAWQA	National Water-Quality Assessment Program
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PTI	pesticide toxicity index
QMH	qualitative multi-habitat
RTH	richest targeted habitat
SPMD	semipermeable membrane device
STATSGO	State Soils Geographic Database
TEQ	Expression of the gene CYP1A1, reported as the amount of dioxin in toxic equivalents
UII	urban intensity index
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WHPE	Western High Plains Ecoregion

Chapter A
Effects of Urbanization on Stream Ecosystems in the South Platte River Basin, Colorado and Wyoming

By Lori A. Sprague, Robert E. Zuellig, and Jean A. Dupree

Abstract

This report describes the effects of urbanization on physical, chemical, and biological characteristics of stream ecosystems in 28 basins along an urban land-use gradient in the South Platte River Basin, Colorado and Wyoming, from 2002 through 2003. Study basins were chosen to minimize natural variability among basins due to factors such as geology, elevation, and climate and to maximize coverage of different stages of urban development among basins. Because land use or population density alone often are not a complete measure of urbanization, land use, land cover, infrastructure, and socioeconomic variables were integrated in a multimetric urban intensity index to represent the degree of urban development in each study basin. Physical characteristics studied included stream hydrology, stream temperature, and habitat; chemical characteristics studied included nutrients, pesticides, suspended sediment, sulfate, chloride, and fecal bacteria concentrations; and biological characteristics studied included algae, fish, and invertebrate communities. Semipermeable membrane devices (SPMDs), passive samplers that concentrate trace levels of hydrophobic organic contaminants like polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), also were used. The objectives of the study were to (1) examine physical, chemical, and biological responses along the gradient of urbanization; (2) determine the major physical, chemical, and landscape variables affecting the structure of aquatic communities; and (3) evaluate the relevance of the results to the management of water resources in the South Platte River Basin.

Commonly observed effects of urbanization on instream physical, chemical, and biological characteristics, such as increased flashiness, higher magnitude and more frequent peak flows, increased concentrations of chemicals, and changes in aquatic community structure, generally were not observed in this study. None of the hydrologic, temperature, habitat, or chemical variables were correlated strongly (Spearman's rho greater than or equal to 0.7) with urban intensity, with the exception of some of the SPMD-based toxicity and chemical variables. SPMD-based measures of potential toxicity and PAH concentrations were positively correlated with urban intensity. The PAH concentrations also were positively correlated with measures of road density and negatively correlated with distance to the nearest road, indicating that automobile exhaust is a major source of these compounds in the study area. This source may be localized enough that the transport of PAHs would be minimally affected by water-management practices such as diversion or storage upstream. In contrast, the predominant sources of nutrients, bacteria, suspended sediment, sulfate, chloride, and pesticides may be more dispersed throughout the drainage area and, therefore, their transport to downstream sites may be subject to greater disruption by water regulation. Although no direct link was found between most water-chemistry characteristics and urbanization, invertebrate, algae, and fish-community characteristics were strongly associated with nutrients, pesticides, sulfate, chloride, and suspended sediment.

None of the biological community variables were strongly correlated with the urban intensity index. Algal biomass predominantly was associated with total nitrogen concentrations, nitrite-plus-nitrate concentrations, and the duration of high flows. Fish communities predominantly were associated with housing age, the percentage of suspended sediment finer than 0.063 millimeters and chloride concentrations. Invertebrate communities predominantly were associated with the frequency of rising and falling flow events, the duration of high flows, total nitrogen concentrations, nitrite-plus-nitrate concentrations, and total herbicide concentrations.

Historical records indicate that aquatic communities in the region may have been altered prior to any substantial urban development by early agricultural and water-management practices. Present-day aquatic communities are composed primarily of tolerant species even in areas of minimal urban development; when development does occur, the communities already may be resistant to disturbance. In addition to the effects of historical stressors on aquatic community structure, it is possible that current water-management practices in the study basins are having an effect. In the absence of natural, unaltered hydrologic conditions, more sensitive taxa may be unable to recolonize urban streams. The movement and storage of water also may lead to a disconnect between the land surface and streams, resulting in instream physical, chemical, and biological characteristics that, to some degree, are independent of land-cover characteristics.

Introduction

Stream ecosystems in urban areas are affected by human-induced changes on the land surface. As urbanization progresses, streamflow, water quality, and instream habitat can be substantially altered, which in turn can result in the deterioration of aquatic communities (Paul and Meyer, 2001; Walsh and others, 2005).

Impervious surfaces—impenetrable surfaces such as parking lots, rooftops, and roads—can alter the movement of water above and below the land surface in urbanizing areas. Impervious surfaces prevent rainfall from infiltrating into soil and ground water, leading to increased runoff to streams. With rainfall moving to streams more quickly and in greater amounts over these surfaces, streamflow conditions can change more rapidly, the magnitude of the peak streamflow may be greater, and the frequency of flooding may increase in urban areas (McMahon and others, 2003; Poff and others, 1997; U.S. Environmental Protection Agency, 1997a). Because impervious surfaces decrease the amount of water infiltrating to ground water, urban areas often have lower streamflow during dry weather because of decreased contributions to the stream from ground water (Burton and Pitt, 2002).

Increased storm runoff to streams often leads to changes in water quality as well. Runoff can transport contaminants to streams from a variety of urban sources, including automobiles (hydrocarbons and metals); rooftops (metals); wood preservatives (hydrocarbons); construction sites (sediment and any adsorbed contaminants); and golf courses, parks, and residential areas (pesticides, nutrients, bacteria) (for example, Pitt and others, 1995; House and others, 1993). Contaminants can enter the stream from additional sources, including wastewater-treatment plants, industrial discharge, leaking septic systems, and ground water. Concentrations of some contaminants may be higher during dry periods than wet periods because of the dilution capacity of rainwater during wet periods (Burton and Pitt, 2002).

Urbanization also can affect physical habitat directly through development and indirectly through changes in runoff and streamflow. Commercial, residential, and industrial development often involves (1) soil disturbance, which leads to increased transport of sediment to the stream, and (2) the removal of riparian vegetative cover, which leads to loss of sheltered areas and stream canopy (Jacobson and others, 2001). In addition, stream channels in many urban areas have been straightened, deepened, and widened from their natural states to promote drainage and prevent flooding (Klein, 1979); stream bottoms in these channels may be artificially smooth or homogenous. During storms, higher streamflows can alter or remove instream habitat such as pools or riffles and can change the particle-size distribution of the bottom substrate (Jacobson and others, 2001; Burton and Pitt, 2002).

Physical habitat and stream hydrology alterations in urbanizing areas can contribute to changes in stream temperature (LeBlanc and others, 1997; Sinokrot and Stefan, 1993). When stream canopy is lost, more radiation can reach the stream during the day and more can be lost from the stream at night, leading to greater daily fluctuations in stream temperature (Sinokrot and Stefan, 1993). Channelizing and widening streams exacerbates this situation by increasing the surface area of the stream available for radiation exchange (LeBlanc and others, 1997). In addition, lower streamflows resulting from decreased ground-water contributions during dry weather can lead to greater daily temperature fluctuations, as less energy is needed to heat smaller volumes of water (LeBlanc and others, 1997).

Changes in stream hydrology, water quality, physical habitat, and water temperature can have profound effects on aquatic communities. Periods of high streamflow can eliminate some aquatic organisms, particularly in channelized streams where refuge areas such as boulders and woody debris are lacking (Winterbourne and Townsend, 1991). In addition, higher flows are associated with increased transport of sediments to streams, which can affect aquatic communities by decreasing photosynthesis, degrading stream-bottom habitat, interfering with visual and filter feeding, and increasing invertebrate drift (Waters, 1995). Low flows during dry weather can lead to increased water temperatures, decreased dilution of contaminants, and decreased forage opportunities for aquatic organisms; in extreme cases, some small streams may become intermittent after urbanization (Burton and Pitt, 2002). High contaminant concentrations and stream temperatures can adversely affect migration, growth, reproduction, species competition, and disease progression within communities (Fitzgerald and others, 1999; LeBlanc and others, 1997).

Although the degradation of stream ecosystems in response to individual urban stressors is well recognized, the effect of multiple and simultaneous stressors is poorly understood. In addition, many previous studies of stream ecosystems have focused on either very pristine areas or highly developed areas; little is known about how the gradual progression of urban development between these two extremes affects stream ecosystems. As a result, the U.S. Geological Survey (USGS) conducted a study through its National Water-Quality Assessment (NAWQA) Program to determine the effects of urbanization on stream ecosystems in the South Platte River Basin. Study basins were located along an urban land-use gradient—that is, they had various degrees of urban development, from minimal development to a very high degree of development.

Purpose and Scope

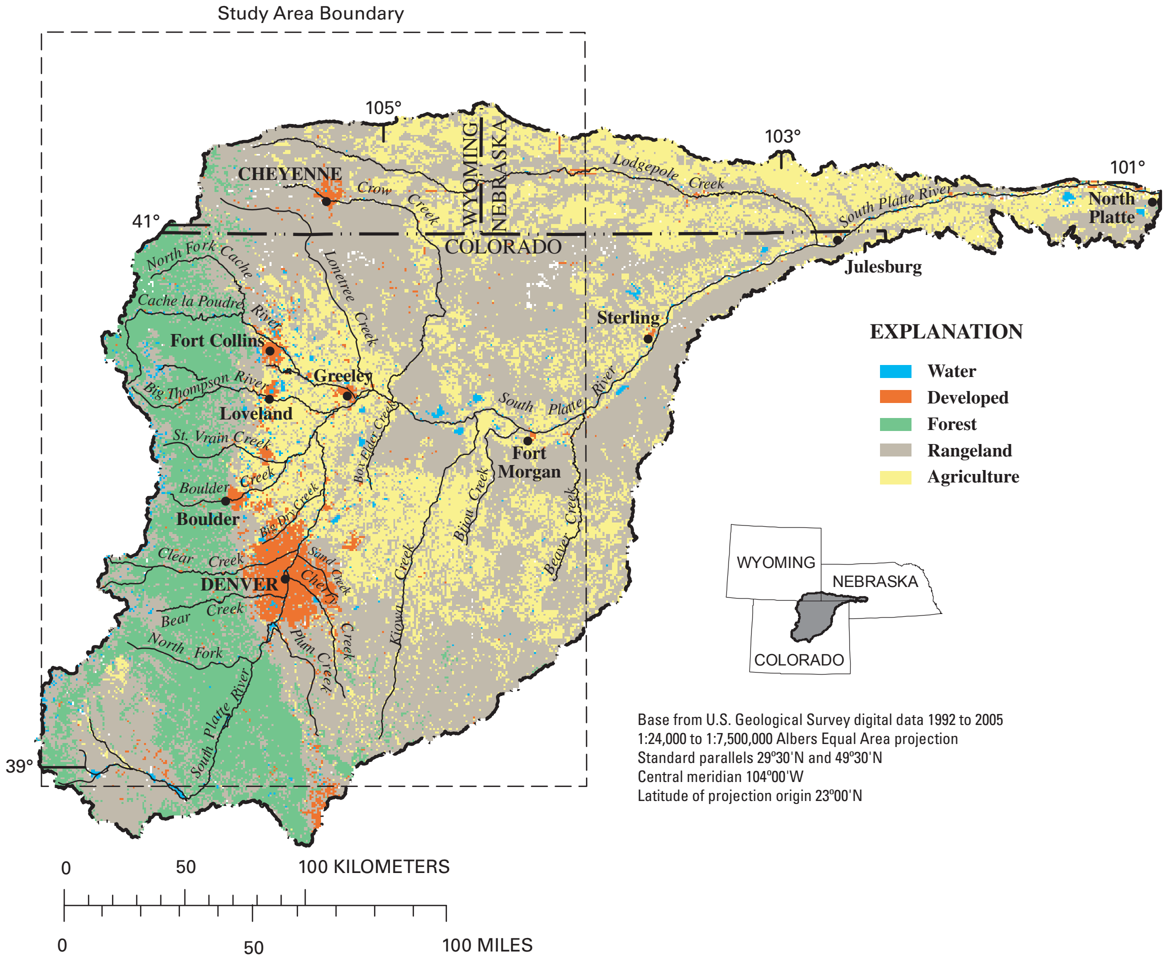
This report describes the effects of urbanization on physical, chemical, and biological characteristics of stream ecosystems in 28 basins along an urban land-use gradient in the South Platte River Basin from 2002 through 2003. Study basins were chosen to minimize natural variability between basins due to factors such as geology, elevation, and climate and to maximize coverage of different degrees of urban development among basins. Physical characteristics studied in each basin include stream stage, water temperature, and habitat; chemical characteristics studied include nutrients, pesticides, suspended sediment, sulfate, chloride, and fecal bacteria concentrations; and biological characteristics studied include algae, invertebrate, and fish communities. The objectives of the study were to (1) examine physical, chemical, and biological responses along the gradient of urbanization; (2) determine the major physical, chemical, and landscape variables associated with aquatic communities; and (3) evaluate the relevance of the results to the management of water resources in the South Platte River Basin.

A large number of variables are discussed in this report. All variable abbreviations and associated definitions are listed in the report appendixes. Abbreviations are used in most tables to make them simpler and more concise; the corresponding appendixes containing the variable definitions are listed in the header of each table. Abbreviations are not used extensively in the text. The text discussions include the variable names for ease of interpretation whenever practical; on occasion, when a large number of variables are being discussed, abbreviations are used. These discussions are always based on information contained in a table, and appendixes containing the variable definitions are listed in the table's header.

Study Area

The South Platte River Basin has a drainage area of about 62,940 square kilometers and is located in parts of three States (fig. 1)—Colorado (79 percent of the basin), Nebraska (15 percent of the basin), and Wyoming (6 percent of the basin). The South Platte River originates in the Rocky Mountains of central Colorado at the Continental Divide and flows about 725 kilometers northeast across the Great Plains to its confluence with the North Platte River at North Platte, Nebraska.

Land use in the basin is dominated by rangeland and agriculture, at 41 percent and 37 percent, respectively (Vogelmann and others, 2001). Rangeland is present across all areas of the basin except in the high mountain forests. Agricultural land is present primarily in the plains areas. Forested area is the third largest land cover, at 16 percent, and is present in a north-south band in the mountains. Urban areas cover only 3 percent of the basin, but those urban areas are concentrated in the transition zone between the mountains and the plains, in an area known as the Front Range urban corridor. More than 2.8 million people currently (2005) live along the Front Range in the South Platte River Basin; the population increased by about 670,000 people from 1990 through 2000 (U.S. Census Bureau, 2000).



Base from U.S. Geological Survey digital data 1992 to 2005
1:24,000 to 1:7,500,000 Albers Equal Area projection
Standard parallels 29°30'N and 49°30'N
Central meridian 104°00'W
Latitude of projection origin 23°00'N

Figure 1. Land use in the South Platte River Basin and location of study area boundary.

The basin has a continental-type climate modified by topography, resulting in irregular seasonal and annual precipitation (Gaggiani and others, 1987). Most precipitation on the plains results from rainfall, which primarily occurs between April and September, whereas most precipitation in the mountains results from snowfall, which primarily occurs during the winter. Perennial flow in the South Platte River and its major tributaries originating in the Rocky Mountains is derived primarily from snowmelt runoff. Smaller tributaries in the plains and along the Front Range are often ephemeral and contribute little flow to the South Platte River except during spring and summer thunderstorms. A complex network of canals and pipes moves water between different areas of the basin for domestic water supply, agricultural irrigation, and power generation. This complex irrigation canal network was well established by the early 1900's (Eschner and others, 1983).

During 2002, the first year of this study, drought conditions occurred throughout Colorado, including the South Platte River Basin. Snow-pack levels in the Upper South Platte and Upper Colorado River Basins—two major sources of water in the South Platte River Basin—were at 32 and 36 percent, respectively, of their long-term averages in 2002 at the time of their typical peaks in early to mid-April (Denver Water, 2004). Statewide precipitation levels in Colorado during July 2001 through June 2002 were at the lowest level of any single year since 1895 (National Oceanic and Atmospheric Administration, 2002). Values of the local Palmer Drought Index—an index of the scope, severity, and frequency of prolonged periods of abnormally dry or wet weather—ranged from –3.37 to –7.27 throughout the South Platte River Basin during the summer of 2002, indicating severe to extreme drought conditions (Colorado State University, 2004). During 2003, the second year of this study and the year during which most of the data were collected, precipitation and streamflow levels returned to near average conditions.

There are two major physiographic provinces in the basin, the Southern Rockies and the Great Plains, which correspond to three major Level III ecoregions, the Southern Rockies, the Southwestern Tablelands, and the Western High Plains (Omernik, 1987) (fig. 2). Ecoregions describe geographic areas on the basis of common natural characteristics, such as soil type, elevation, climate, and potential natural vegetation; as such, they delineate areas within which ecosystems potentially are similar. The Western High Plains Ecoregion (WHPE) encompasses the part of the Great Plains just east of the Rocky Mountains and generally contains smooth to irregular plains and grama-buffalo grass. The Southern Rockies Ecoregion encompasses the Rocky Mountains and intervening valleys and generally contains high and steep mountains and coniferous forests of fir and pine trees. The Southwestern Tablelands Ecoregion encompasses the semiarid elevated tablelands and grasslands of the Great Plains and generally contains grama-buffalo and mesquite-buffalo grass.

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Approach

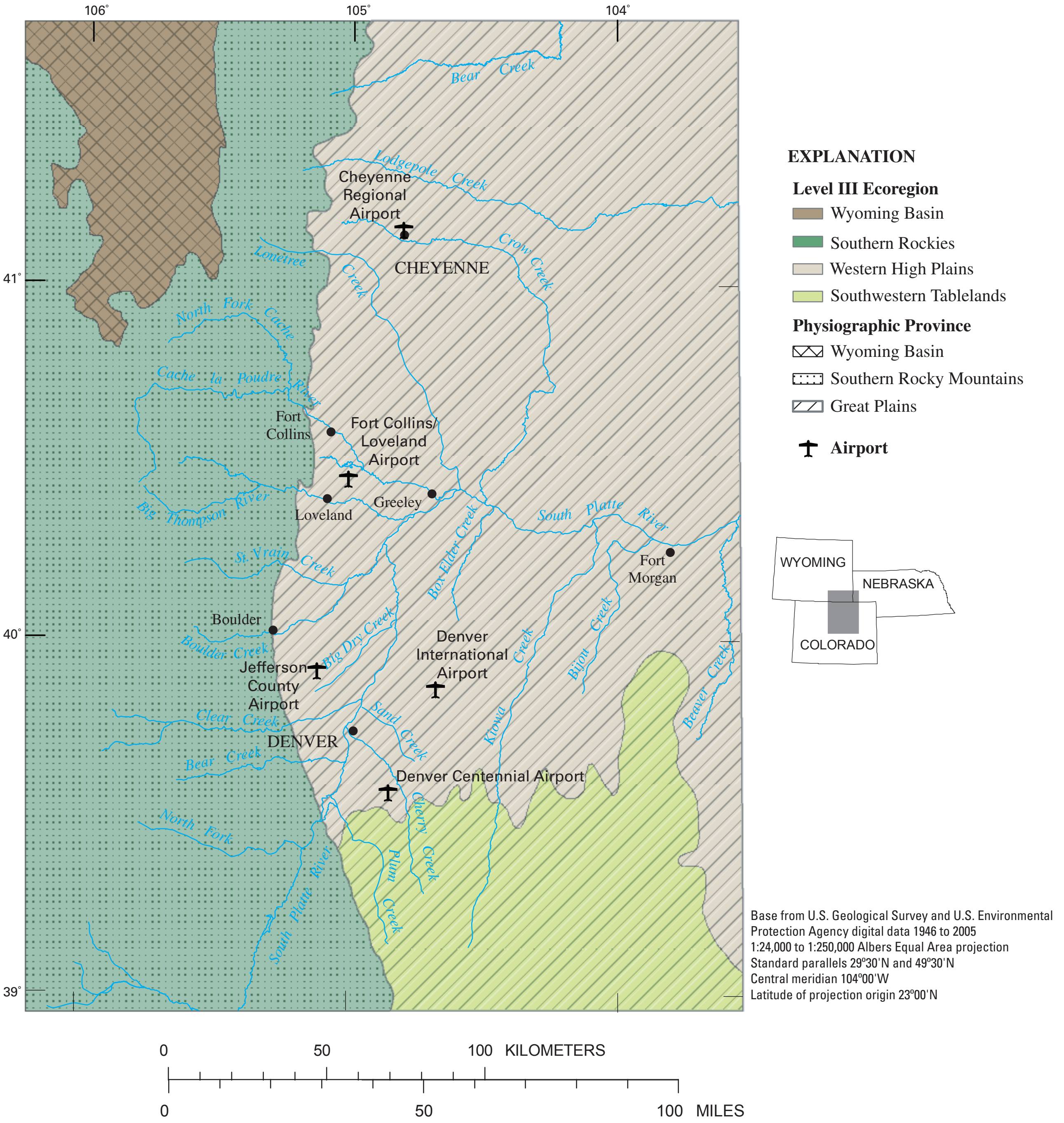
Twenty-eight sites encompassing minimal natural variability and a range of urbanization were selected for physical, chemical, and biological data collection. During the study, 96 water-quality samples and 28 algae, invertebrate, and fish samples were collected. In addition, stream stage and temperature were monitored at each site throughout the study, semipermeable membrane devices (SPMDs) were deployed at each site, and physical-habitat variables were measured once at each site. Methods of site selection, data collection, and data analysis are described below.

Site Selection

Sites were selected on the basis of three major factors: (1) variability in natural landscape features, (2) gradient in the degree of urbanization, and (3) suitability of local site conditions.

Variability in Natural Landscape Features

Study sites were selected to minimize natural variability between basins to reduce the potential for natural factors to confound the interpretation of the physical, chemical, and biological responses along the urban land-use gradient. Study basins first were constrained to a single Level III ecoregion, the WHPE. Although many streams in the South Platte River Basin traverse the three ecoregions present in the basin, much of the water in these rivers is removed or impounded for irrigation, municipal water supply, or power generation before reaching the Front Range. For example, the Bear Creek drainage area contains more than 200 active diversions, reservoirs, and impoundments, the majority of which are in the Southern Rockies ecoregion (Colorado Division of Water Resources, 2005) (fig. 3). As a result, much of the water in streams within the WHPE often is derived locally. Therefore, potential study basins were limited to the WHPE; the entire basin was used

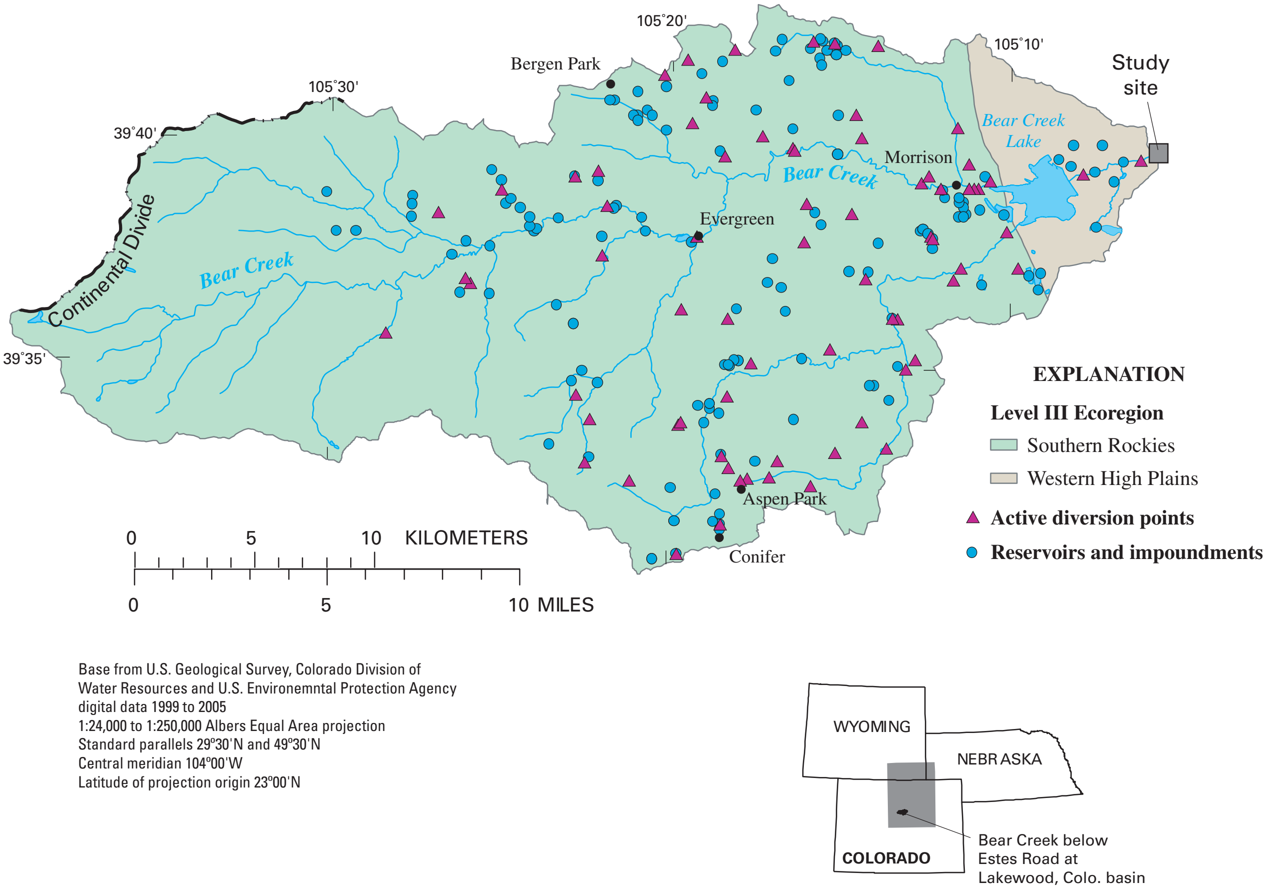


Base from U.S. Geological Survey and U.S. Environmental
Protection Agency digital data 1946 to 2005
1:24,000 to 1:250,000 Albers Equal Area projection
Standard parallels 29°30'N and 49°30'N
Central meridian 104°00'W
Latitude of projection origin 23°00'N

Figure 2. Physiographic provinces and ecoregions in the South Platte River Basin.

when it was entirely contained within the WHPE, whereas the part of the basin within the WHPE was used when the entire basin covered multiple ecoregions.

Using a Geographic Information System (GIS) and the 30-meter USGS National Elevation Dataset (NED), 275 candidate sites were identified and basin boundaries were generated. Several GIS datasets, including land use and land cover, topography, environmental landscape, and stream-segment morphology, were overlaid with these basin boundaries to generate a matrix of 106 basin-characteristic variables for each site. All basin-characteristic variables and associated references are listed in tables 1.1 and 1.2 in Appendix 1. Two categories of land-use variables were derived from the 1992 USGS Multiresolution Land Characteristics (MRLC) dataset: (1) study basin-scale land-use/land-cover variables, and (2) land-use/land-cover variables for a 120-meter riparian buffer zone created by overlaying MRLC data and stream locations in the National Hydrography Dataset (NHD). All MRLC categories were included, with the exception of category 2 (developed). Environmental landscape



Base from U.S. Geological Survey, Colorado Division of Water Resources and U.S. Environemntal Protection Agency digital data 1999 to 2005
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Central meridian 104°00'W
Latitude of projection origin 23°00'N

Figure 3. Water diversions and reservoirs in the Bear Creek below Estes Road at Lakewood, Colo., basin.

information was derived from four GIS datasets: (1) the U.S. Department of Agriculture's State Soils Geographic Database (STATSGO) was used for a variety of soil variables, such as soil composition, erodibility, organic content, and texture; (2) hydrologic soils groups data, derived from STATSGO, were used to separate soils into groups based on decreasing soil infiltration rate; (3) the U.S. Environmental Protection Agency (USEPA) Level III and Level IV (Omernik,1987) ecoregions dataset was used to stratify basin terrain with regard to their environmental resource content; and (4) hydrologic landscape regions, developed by the USGS (Winter, 2001), was used to provide information on the regional hydrologic framework for each basin. Topographic variables such as elevation statistics, slope, relief, the proportion of upland and lowland areas having low relief, and wetness index were generated using the USGS 30-meter NED data. Measures of stream-segment morphology also were derived from NED data, from NED derivatives, and from the NHD; the stream segment variable used for site selection was valley gradient.

Spearman's rank correlation analysis was used to determine the strength of the relations among the 106 variables. Based on the correlation analysis, 19 uncorrelated (Spearman's rho less than 0.7) variables were extracted for use in a divisive hierarchical cluster analysis with calculation of posterior probability of cluster membership (Brown, 1998). Eight clusters (groups 1–8) were identified from the resulting dendogram; natural settings represented by each cluster (such as slope, valley morphology, ecoregion, land cover, soil texture, hydrologic landscape region, and topography) are summarized in table 1.3 in Appendix 1. Boxplots of the environmental variables within each cluster group were used to determine similarities in the environmental settings among the clusters, and 106 candidate basins within the most similar clusters (1, 5, and 6, see table 1.3 in Appendix 1) were retained for subsequent field reconnaissance. All analyses described above were done in S-plus version 6.1, release 1 (Insightful Corporation, 2002).

Gradient in the Degree of Urbanization

Rather than studying a single site over a long period of time as it urbanized, the goal of this study was to look at a large number of sites over a short period of time that ranged from minimally to highly developed. In theory, the pattern of ecosystem response among environmentally homogenous sites spanning a range of urbanization in space could reflect the same pattern of response that would be seen as a minimally disturbed site urbanized over time. Therefore, the second consideration for site selection was the need to obtain study sites that covered a gradient of urbanization.

Results from previous studies in urban ecosystems have indicated that land use alone is not an adequate measure of urbanization (McMahon and Cuffney, 2000; Grove and Burch, 1997). In this study, land cover, infrastructure, and socioeconomic variables were integrated in a multimetric urban intensity index (UII). Thirty-seven additional urban GIS variables were derived for each site, including infrastructure, urban MRLC land use/land cover variables, and demographic variables. All urban variables and associated references are listed in tables 1.1 and 1.4 in Appendix 1. Three GIS datasets provided infrastructure information for basins inventoried during site selection: (1) the U.S. Census Bureau Topologically Integrated Geographic Encoding and Reference line roads dataset to generate measures for road network length, road surface area, and vehicular traffic; (2) the USEPA National Pollutant Discharge Elimination System online dataset to derive counts of regulated point-source dischargers within each basin; and (3) the USEPA toxics release inventory sites dataset to derive a count of toxic-chemical release sites within each basin. In addition, 1990 Census block population data and block group socioeconomic data were used to describe the demographics of each candidate basin.

A UII value was calculated for each of the 104 candidate basins by using a five-step procedure described in McMahon and Cuffney (2000). In brief, the procedure consisted of: (1) adjusting urban variables for basin size and measurement units, (2) standardizing the original variables so their values ranged from 0 to 100, (3) retaining variables correlated with population density (absolute value of Spearman's rank correlation coefficient greater than or equal to 0.5) and uncorrelated with basin area (absolute value of Spearman's rank correlation coefficient less than or equal to 0.5) and adjusting the variables so they all increased with increasing population density, (4) averaging retained variables across each site to obtain a UII, and (5) standardizing the UII at each site so the values collectively ranged from 0 to 100.

As a result of these steps, measures of road area; urban (developed), herbaceous, and agricultural (planted/cultivated) land cover; population density; housing density, size, and age; and population demographics were incorporated into the UII used for site selection (table 1.4 in Appendix 1). Increasing urban intensity (as measured by the UII) in the study basins was related to increasing population density, increasing housing density, larger proportions of the population living in urban as compared to rural areas, and smaller proportions of older homes. Also as urban intensity increased, road density and the amount of developed land area increased. The amount of forested and agricultural land area decreased, however, indicating that agricultural and previously undisturbed areas are being developed.

Suitability of Local Site Conditions

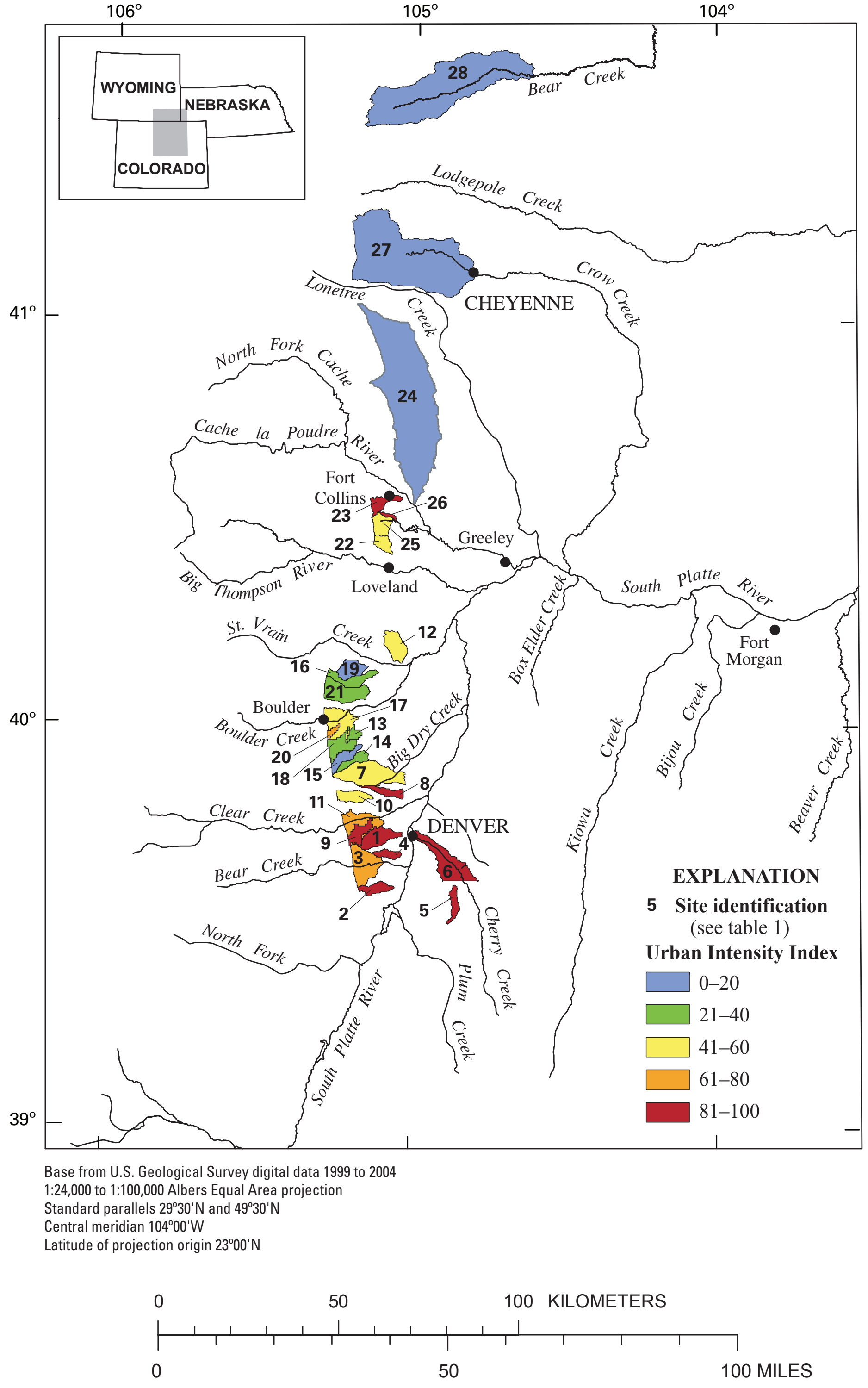
Once the 104 candidate sites were identified through cluster analysis and the UII values were calculated for each, field reconnaissance took place to ground-truth the GIS data and to evaluate logistical issues such as site access and safety conditions. Some sites were relocated short distances up or downstream to provide better access, to obtain reaches with cobble or riffle substrate, or to minimize local effects from wastewater-treatment-plant effluent, major diversions, or upstream reservoir releases. Some sites automatically were excluded based upon evidence that the stream was ephemeral during much of the year. Other sites were excluded if access permissions could not be obtained from landowners.

Additional new sites also were considered if they filled spatial gaps in an area of the basin environmentally similar to the clustered sites or if they had been used in previous water-quality or biological studies within the USGS or other local, State, or Federal agencies. For example, sites from cluster group 2 were added for consideration because it became apparent that these sites only differed from sites in cluster group 1 in the proportion of their basin area in the mountains. Because characterization of the study basins ultimately was limited to the area within the WHPE, these basins were considered to be more similar than was indicated by the original cluster analysis. Finally, because of lack of undisturbed basins along the Front Range of the South Platte River Basin, a location in the North Platte River Basin in Wyoming was added to serve as a potential reference site. The last step in the site-selection process was selecting a group of sites that collectively encompassed a range of urbanization (as described by the UII), ranging from minimally to highly developed.

Ultimately, 28 basins were selected for inclusion in the study (fig. 4; table 1). With few exceptions, the 28 basins occupy only three Level IV ecoregions within the Level III WHPE (as defined by current (2005) USEPA draft Level IV ecoregion boundaries for Colorado and final Level IV ecoregions boundaries for Wyoming)—Front Range Fans, Flat to Rolling Plains, and Moderate Relief Plains. A small section of Pine-Oak Woodlands Level IV ecoregion in the Southwestern Tablelands Level III ecoregion is occupied by the headwaters of one basin, Cottonwood Creek above Newark Street near Greenwood Village, Colo., and small sections of three study basins—Bear Creek above Little Bear Creek near Little Bear, Wyo.; Crow Creek at Morrie Avenue at Cheyenne, Wyo.; and Boxelder Creek at mouth near Fort Collins, Colo.—are situated in the Foothill Shrublands Level IV ecoregion within the Southern Rockies Level III ecoregion.

Data Collection

The data-collection methods used in the study conform to standardized procedures established by the USGS and the NAWQA Program (U.S. Geological Survey, 1997 to present; Moulton and others, 2002; Fitzpatrick and others, 1998). These methods are described briefly below. The only nonstandard methods used in the study were measurement of stream stage and measurement of potential stream toxicity with SPMDs; these methods are described in detail below.



Base from U.S. Geological Survey digital data 1999 to 2004
1:24,000 to 1:100,000 Albers Equal Area projection
Standard parallels 29°30'N and 49°30'N
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Figure 4. Location and range of urban-intensity-index values of the 28 study basins.

Table 1. Description of study basins.

[High-intensity-sampling sites are highlighted; ID, identification; USGS, U.S. Geological Survey; m^2, square meters; m, meters; WHPE, Western High Plains ecoregion; a and b subscripts differentiate sites with the same urban-intensity-index value]

Site ID	Site name	USGS station number	Total drainage area (m^2)	Drainage area in WHPE (m^2)	Mean elevation (m)	Urban intensity index
1	Lakewood Gulch above Knox Court at Denver, Colo.	394409105020501	15.7	15.7	1,722	100
2	Dutch Creek at Weaver Park near Columbine Valley, Colo.	393557105033101	9.67	8.22	1,750	97_{a}
3	Bear Creek below Estes Road at Lakewood, Colo.	393948105053501	249	24.3	1,782	68
4	Sanderson Gulch above Lowell Avenue at Denver, Colo.	394107105021001	5.43	5.43	1,689	94
5	Cottonwood Creek above Newark Street near Greenwood Village, Colo.	393613104511401	6.97	6.97	1,790	83
6	Cherry Creek at Denver, Colo.	06713500	411	31.2	1,680	99
7	Big Dry Creek below Hyland Circle at Westminster City Park, Colo.	395324105035001	35.6	35.4	1,729	53_{a}
8	Little Dry Creek below Lowell Boulevard near Westminster, Colo.	394921105015701	7.07	7.07	1,672	97_{b}
9	Lena Gulch at Lewis Meadows Park at Wheat Ridge, Colo.	394553105075101	11.2	8.91	1,802	82
10	Ralston Creek above Simms Street at Arvada, Colo.	394919105074601	55.5	9.83	1,757	54
11	Clear Creek below Kipling Street at Wheat Ridge, Colo.	394629105063101	437	25.3	1,771	74
12	Spring Gulch at Sandstone Ranch Park near Longmont, Colo.	400925105023201	14.8	14.8	1,535	45
13	Dry Creek above Baseline Road near Boulder, Colo.	395958105113501	4.07	4.06	1,666	37_{a}
14	Rock Creek above Rock Creek Parkway at Superior, Colo.	395554105085601	7.24	7.24	1,780	37_{b}
15	Coal Creek above McCaslin Road at Superior, Colo.	395707105100401	26.8	8.93	1,816	18
16	Left Hand Creek above Pike Road at Longmont, Colo.	400810105071301	70.2	11.8	1,591	28
17	Boulder Creek at 61st Street near Boulder, Colo.	400217105123701	290	33.8	1,678	60
18	South Boulder Creek above Baseline Road at Boulder, Colo.	400000105125400	130	12.4	1,742	24
19	Dry Creek below Airport Road at Longmont, Colo.	400855105090501	11.9	11.9	1,593	17
20	Bear Creek above Wellman Feeder Canal at Boulder, Colo.	400023105142301	4.61	2.36	1,718	64
21	Dry Creek below Niwot Road at Niwot, Colo.	400607105094401	23.2	21.6	1,623	40
22	Dry Creek at US 287 at Loveland, Colo.	402549105043101	6.81	6.81	1,565	52
23	Spring Creek at Edora Park at Fort Collins, Colo.	403356105024001	8.72	8.72	1,564	81
24	Boxelder Creek at mouth near Fort Collins, Colo.	403308105001601	289	216	1,728	3
25	Fossil Creek at College Avenue at Fort Collins, Colo.	403048105042701	10.7	10.3	1,571	53_{b}
26	Mail Creek near mouth at Fort Collins, Colo.	403035105035301	1.60	1.60	1,542	93
27	Crow Creek at Morrie Avenue at Cheyenne, Wyo.	410714104480101	290	197	2,024	0
28	Bear Creek above Little Bear Creek near Little Bear, Wyo.	413659104370001	177	177	1,837	1

Physical Characteristics

Physical characteristics determined at each site included stream hydrology, stream temperature, and selected habitat variables (tables 2.1, 2.2, and 2.3 in Appendix 2).

Stream Hydrology

Stevens Water Monitoring Systems Model PS310 pressure transducers with an internal data logger and a range of 0 to 30 meters were used to measure stream-stage fluctuation during the study (Greenspan Technology User Manual, 7th edition, is available online at *http://www.stevenswater.com/catalog/products/water_quality_sensors/manual/Smart2-manual.pdf*, accessed on December 7, 2005). Stage data from the Model PS310 have a precision of ±0.036 meter, which does not meet USGS requirements for the precision of stage data (±0.003 meter) (Sauer, 2002). The transducers were installed prior to chemical and biological sampling at most sites. At site 19, chemistry sampling had begun before the transducer could be installed because of a delay in obtaining site access permission from the landowner. Stage was measured relative to an arbitrary datum, and recording intervals were set to 15 minutes. To prevent ice-related damage, the transducers were removed during the winter months at all sites, with the exception of two of the larger streams (sites 11 and 6). At two sites where streamgages were already in operation (sites 23 and 25), transducers were not installed; data from the streamgages were obtained for use in data analysis (Jedd Sondergard, City of Fort Collins, written commun., 2003). At another site where a streamgage was already in operation (site 6), a transducer was installed to compare the data to that from a conventional streamgage (Crowfoot and others, 2004).

This transducer model was unvented; that is, there was no vent tube to offset changes in atmospheric pressure. Changes in stage were recorded as a result of water-level changes and atmospheric-pressure changes. As a result, the data were corrected for fluctuations in atmospheric pressure by using hourly barometric pressure data from nearby airports, including Centennial, Jefferson County, Fort Collins/Loveland, and Cheyenne Regional airports (fig. 2); continuous barometric pressure records were not available at the study sites. The airport data were obtained from the National Oceanic and Atmospheric Administration's National Data Center (*http://www.ncdc.noaa.gov*) and matched to the shorter 15-minute time step of the transducer data through linear interpolation between the hourly readings. Because a difference in altitude between the airport and the study site could have lead to a difference in ambient barometric pressure between the two locations, the following equation was used to determine barometric pressure at the study site from the corresponding barometric pressure at the airport:

$$h = \frac{T * 287 * \ln(\frac{P_0}{P_1})}{9.8} \qquad (1)$$

where

h is the difference in altitude between the airport and the study site (in meters);

T is the average temperature of the layer of the atmosphere, assumed from the ambient airport temperature (in Kelvin);

ln is the natural logarithm;

P_0 is the station pressure of the airport or site, whichever is at the lower altitude (in millibars); and

P_1 is the station pressure of the airport or site, whichever is at the higher altitude (in millibars).

The uncorrected transducer stage record was corrected for barometric pressure fluctuations by comparing the barometric pressure at the time of each reading to the initial barometric pressure (to which the transducer was zeroed); the change from the initial barometric pressure at the time of each subsequent reading was converted to equivalent water depth and added to or subtracted from the uncorrected stage to obtain a corrected stage. One millibar of barometric pressure change was considered to be equivalent to a 0.0102-meter change in water level (Jason Harrington, Stevens Water Monitoring Systems, written commun., 2003).

After the barometric-pressure correction was completed, the last stage reading in each transducer data file was compared to the concurrent stage reading taken from a fixed external point during each site visit; any deviations from this external stage reading indicated the occurrence of instrument drift since the time of calibration. When deviations were found, a prorated correction was applied to all of the stage data recorded by the transducer between the first and last values in the file. Figure 5 provides an illustration of the performance of the transducers and the success of the correction procedure by comparing the corrected stage record from the transducer to the stage record from a co-located conventional USGS stream gage. Although these stage data do not have the level of accuracy normally seen from USGS stage data, they are acceptable for the purposes of this study.

Stream Temperature

The same Stevens Water Monitoring Systems Model PS310 pressure transducers used to measure stream stage also were used to measure water temperature during the study. Water-temperature data were collected at 15-minute intervals. Pressure transducers were not installed at sites 23 and 25. Water-temperature data were collected concurrently with stream-stage data at site 23; these data were obtained from the city of Fort Collins along with the stage data. Water-temperature data at site 25 were obtained using an Onset Computer Corporation Optic StowAway® Temp monitor. By using controlled temperature baths, temperature readings from 20 percent of the transducers were verified with readings from a National Institute of Standards and Technology (NIST) thermometer prior to installation in the field; accuracy was within ±0.01 degrees Celsius.

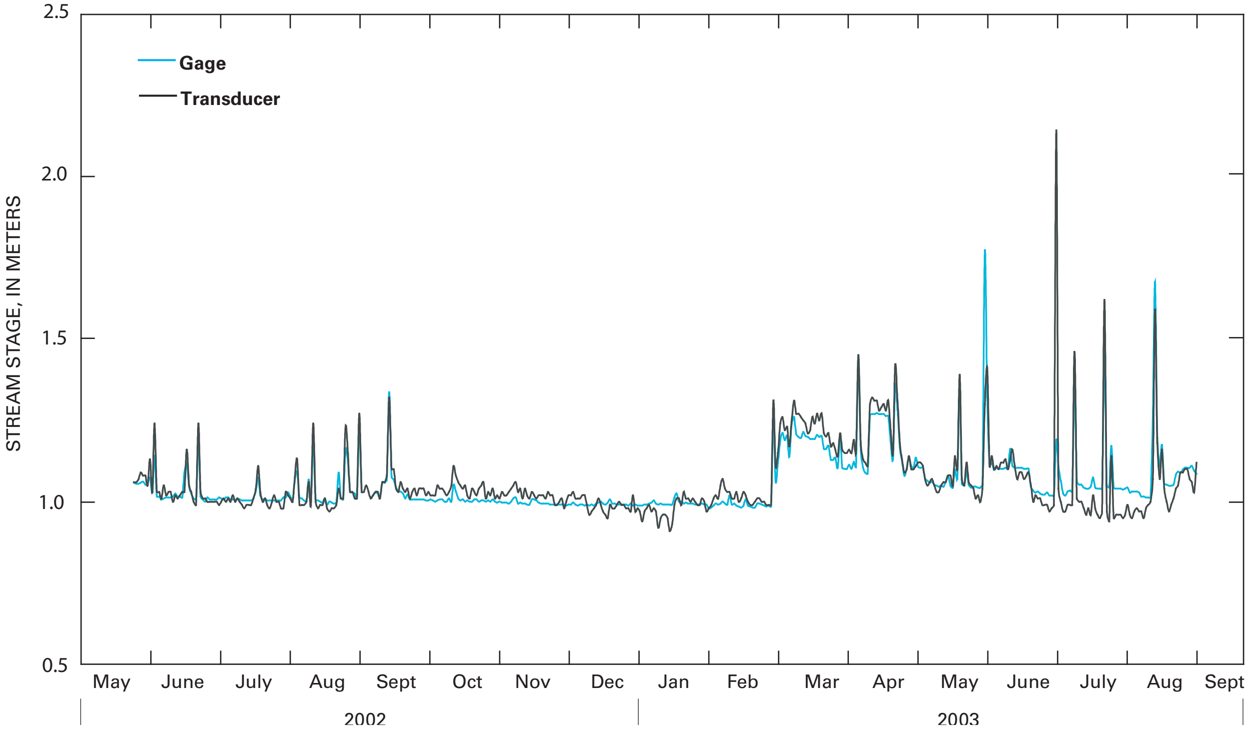


Figure 5. Comparison of stage readings from the U.S. Geological Survey streamgage and the study transducer at the Cherry Creek at Denver, Colo., site.

Habitat

Basin-level characterization of habitat provides information on the upstream geologic, climatic, hydrologic, morphologic, and vegetational influences at a site. Basin-level habitat variables determined in this study included drainage area, drainage density, basin length, drainage shape, basin relief, drainage texture, and cumulative perennial stream length for each site. Other basin-level information included the land-cover, lithological, soil, and riparian variables incorporated in the site selection process. Segment-level characterization of habitat provides information on finer scale influences in the relatively homogenous stream length between tributary or point inflows. Segment-level variables determined in this study include sinuosity, slope, segment length, and channel gradient.

Basin-level and segment-level characteristics were derived by using GIS or topographic maps, because their size makes field-data collection prohibitive. Reach-level characterization, which requires site visits, was the principal means for describing local-scale influences within a segment (Fitzpatrick and others, 1998). In this study, habitat measurements were made during low-flow conditions in July and August 2003, within a few days of invertebrate and algae sampling. Stream depth, stream width, bed substrate, habitat cover, bank morphology, canopy closure, stream velocity, and bank vegetation were measured at 11 equally spaced transects along each reach (mesoscale characterization). Additionally, point velocity, substrate, and depth measurements were collected where richest targeted habitat algae and invertebrate samples were collected (microscale characterization). Reach length was determined by multiplying the mean wetted channel width by 20 to ensure that all habitat types (pools, riffles, runs) were represented within the reach. A complete list of habitat variables is listed in table 2.3 in Appendix 2.

More detailed information on habitat data-collection methods and variables may be found in Fitzpatrick and others (1998).

Chemical Characteristics

Water-chemistry samples were collected from October 2002 through September 2003. Of the 28 total sites sampled, 10 were designated as “high-intensity” sites to be sampled 6 times throughout the year and the remaining 18 were designated as “low-intensity” sites to be sampled 2 times throughout the year (table 1). The low-intensity sites were sampled in June and August, to bracket the biological sampling in July and August. Water-chemistry conditions during these months were considered more likely to have a direct effect on biological response in the streams than conditions earlier in the study period. The high-intensity sites were sampled bimonthly (including in June and August), to document the seasonal variability in water chemistry that may have been missed by sampling only twice at the low-intensity sites. The high-intensity sites were selected to represent the full range of the UII, in the event that seasonality patterns differed in basins with differing levels of urbanization.

All sites were sampled for sulfate, chloride, nutrients, pesticides, dissolved and particulate carbon, suspended sediment, and *Escherichia coli* (*E. coli*) bacteria (table 3.1 in Appendix 3). In addition, field measurements were obtained for water temperature, dissolved oxygen, pH, specific conductance, and discharge at the time of sampling. Samples were collected using standardized depth- and width-integrating techniques and were processed and preserved onsite using standard methods described in U.S. Geological Survey (1997–present). Nutrient, pesticide, sulfate, chloride, and carbon samples were analyzed at the USGS National Water-Quality Laboratory in Denver, Colo., by using methods described in Fishman (1993), Zaugg and others (1995), Fishman and Friedman (1989), Brenton and Arnett (1993), and U.S. Environmental Protection Agency (1997b). Suspended-sediment samples were analyzed at the USGS Iowa Water Science Center Sediment Laboratory in Iowa City, Iowa. *E. coli* samples were filtered and plated onsite using the modified m-TEC method (U.S. Geological Survey, 1997–present) and counted after incubation in the Colorado Water Science Center Laboratory in Denver, Colo. Quality-control samples, including field blanks, replicates, and laboratory spikes, were collected throughout the study.

Six-inch SPMDs, passive samplers that concentrate trace levels of hydrophobic organic contaminants in aquatic systems, were placed at each site for 4 to 6 weeks beginning in May 2003. The samplers are designed to mimic the bioaccumulation of organic contaminants in the fatty tissues of aquatic organisms. The SPMDs were constructed from low-density polyethylene (LDPE) lay-flat tubing with approximately 10-angstrom-diameter cavities (Huckins and others, 1993). Because of the cavity size, only dissolved (that is, readily bioavailable) organic contaminants could diffuse through the membrane to be sequestered over the deployment period. The sequestration media consisted of a thin film of the neutral lipid triolein (found in most aquatic organisms) and the LDPE membrane. Among the organic contaminants that may be sequestered by the SPMDs are polychlorinated dioxins and furans, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine insecticides, and pyrethroid insecticides.

At the end of the deployment period, contaminant residues concentrated in the SPMDs were recovered and separated from the lipid by dialysis in an organic solvent at Environmental Sampling Technologies, in St. Joseph, Mo., by using methods described in Huckins and others (1990). Two assays were run on the dialysates from each site at the USGS Columbia Environmental Research Center in Columbia, Mo.—an ultraviolet fluorescence scan (Johnson and others, 2004) and a Microtox® bioassay (Johnson, 1998). The ultraviolet fluorescence scan provided a semiquantitative screen for PAHs, which fluoresce under ultraviolet light. A standard curve was developed by using various concentrations of pyrene under a specific wavelength of ultraviolet light. The SPMD dialysates then were exposed to the same conditions, and the resulting florescence was reported as a pyrene index in milligrams per SPMD dialysate. The Microtox® bioassay measured the light production of photo-luminescent bacteria when exposed to the SPMD dialysates; the biochemical pathway for light production is lowered by a wide range of compounds sequestered by the SPMDs. Results were reported as EC50, the concentration of the SPMD dialysate that caused a 50-percent decrease in light production. An additional assay, the P450RGS test, was run by the U.S. Army Corp of Engineers Environmental Laboratory in Vicksburg, Ms. (Murk and others, 1996). The P450RGS assay provides a rapid screen for aryl hydrocarbon receptor type compounds that include PCBs, PAHs, dioxins, and furans. All vertebrates produce detoxifying enzymes upon exposure to aryl hydrocarbon receptor compounds; the amount of enzymes produced is directly proportional to the concentration of the compounds. Quantifying one of these enzymes (the gene CYP1A1) serves as a measure of aryl hydrocarbon receptor activity. The concentration of aryl hydrocarbon receptor compounds in the SPMD dialysate that induces CYP1A1 production is expressed as the amount of dioxin, in toxic equivalents (TEQs), that would induce the same response.

Part of each SPMD dialysate also was sent to the NWQL for identification and quantitation of the target compounds (Thomas Leiker, U.S. Geological Survey, written commun., 2005). The SPMD dialysates were concentrated to approximately 0.250 milliliter while still in the original ampoule. After concentration, the dialysates were transferred to 1.8-milliliter amber glass vials with 400-microliter inserts, and the volume was adjusted to 400 microliters. Internal standards and injection internal standards were added to the dialysates just prior to gas chromatography/mass spectrometry analysis. The dialysates were analyzed by capillary gas chromatography under two different ionization conditions. First, electron-capture negative ionization was used to measure constituents like pesticides, PCBs, and brominated diphenyl ethers in the SPMD dialysates (table 3.2 in Appendix 3). The electron-capture negative ionization scan range was selective for compounds ranging from 35 to 600 Daltons, the scan cycle rate was 1.3 seconds, the modifying gas was methane, and the source pressure was 4.2×10^{4} torr. Second, electron ionization, the conventional method for analyzing dialysates by use of mass spectrometry, was used to measure constituents like alkyl phenols, polycyclic musks, and plant and fecal steroids (table 3.2 in Appendix 3). The electron ionization scan range also was selective for compounds ranging from 35 to 600 Daltons, the scan cycle rate was 1.3 seconds, and the source pressure was 2×10^{-5} torr. Mass spectra for individual target compounds and retention times from sample dialysates were compared with authentic standards from the standard curve for identification. A six-point linear calibration curve was used for quantitation.

Because the SPMDs are passive samplers that integrate chemical conditions over an extended period of time, typically encompassing low-flow and high-flow conditions, they may offer a more complete representation of potential chemical exposure than intermittent point sampling (Huckins and others, 1993). In addition, examining the tissue of aquatic organisms to determine chemical exposure often is problematic, because organisms metabolize these compounds, making it difficult to determine the initial exposure level in the stream, and because organisms are mobile and can migrate away from the source of the exposure. Therefore, SPMDs, which remain in a fixed location and are chemically nonreactive, provide some advantages over tissue sampling for bioassessment. However, there are limitations with SPMDs. Because of the composition of the sequestering media, the membrane is only permeable to nonionic compounds, and the sequestering rates can be affected by the physical and chemical properties of the individual nonionic compounds (Huckins and others, 1993). Also, ambient environmental conditions at the site—in particular temperature, flow velocity, and biofouling on the exterior membrane surface—can affect uptake by the SPMD (Huckins and others, 1993). Exposure duration is another major factor in the total amount of chemicals concentrated in the SPMD; in general, longer exposure times can increase the mass of concentrated chemicals. The SPMD deployed at site 1 had to be replaced about 2 weeks into the SPMD study period; as a result, its exposure duration was approximately two-thirds of that at other sites. In addition, the SPMDs deployed at sites 3, 6, 11, 16, 17, 26, and 27 were lost at some point during deployment, likely because of either high streamflows or vandalism.

Quality-control samples for the SPMDs included dialysis, solvent, and trip blanks. During processing in the laboratory, dialysis blanks and solvent blanks were collected to monitor for possible manufacturing and laboratory contamination. Trip blanks were collected in the field by exposing an SPMD to the air for the amount of time it took to remove an SPMD from the canister and place it in the stream, and then to remove the same SPMD from the stream and place it back into the canister. With the trip blank, however, the SPMD was left in the canister whereas the field-SPMDs were deployed in the stream. In this way, the trip blank mimicked exposure to airborne chemical contamination that field-deployed SPMDs experienced during deployment and retrieval. In addition to the trip blanks, replicate SPMDs were deployed at three sites.

Biological Characteristics

Algae, fish, and invertebrate community samples were collected once during the study period at each of the 28 sites following protocols described in Moulton and others (2002). Invertebrate and algae samples were collected during June 2003, and fish communities were sampled during August 2003. Methods used to sample biological communities are described briefly below.

Algae Communities

Two types of quantitative periphyton algae community samples were collected at each site. The first quantitative sample was collected using the top rock scrape method described in Moulton and others (2002), where periphyton algae were scraped from five cobbles selected from five riffle areas at each site. The surface area scraped on each cobble was quantified by wrapping the scraped area with aluminum foil and digitizing the area of the foil. The contents scraped off each of the five cobbles were combined in a slurry in the field to form the algae richest targeted habitat (RTH) sample. Aliquots of the combined slurry from the algae RTH sample were collected for chlorophyll *a* and ash-free dry-mass analysis. The aliquots collected for chlorophyll *a* and ash-free dry-mass analysis were filtered through a 45-micron glass-fiber filter. The filters were wrapped in foil, sealed, packed on dry ice, and sent to the USGS National Water-Quality Laboratory for analysis. The remaining slurry from the algae RTH sample was used to assess community structure.

The second quantitative algae sample was collected from five depositional areas along the sampling reach using a 47-millimeter petri dish and a spatula (Moulton and others, 2002). The petri dish was inverted and pressed gently into the depositional sediments; the spatula then was slid underneath to aid in the removal of the sediments contained in the petri dish. The five samples from each reach were combined in the field to form the algae depositional targeted habitat (DTH) sample. All algae water samples were preserved in 10-percent buffered formalin solution and sent to the Academy of Natural Sciences of Philadelphia for taxa identification and enumeration following protocols described by Charles and others (2002).

Fish Communities

Fish communities were sampled several weeks after invertebrate, algae, and habitat sampling to allow fish communities to recover from any disturbance associated with earlier sampling. Fish were collected using a Smith-Root Model BP2 backpack electroshocker, with two separate upstream passes supplemented with three discrete seine hauls. Mesh size in all capture nets and seines was 6 millimeters. After capture, fish were held in live wells supplemented with an aeration system. All fish were identified and enumerated in the field. The first 30 individuals of each species were weighed to the nearest 0.1 gram, measured to the nearest millimeter, and checked for anomalies (Moulton and others, 2002). The remaining individuals of each species were enumerated and weighed in a single batch. Representative specimens of each species were labeled and preserved in 10-percent buffered formalin solution and sent to the Larval Fish Laboratory at Colorado State University, Fort Collins, Colo., for verification of field identifications. All voucher specimens were deposited in the holdings of the Larval Fish Laboratory.

Invertebrate Communities

A semiquantitative aquatic-invertebrate community sample was collected from five riffle areas at each site. A slack sampler equipped with 500-micron mesh and a 0.25 square-meter sampling grid was used to collect each sample. The five samples from each riffle area were combined in the field to represent the aquatic invertebrate community from the RTH at each site. Additionally at each site, a qualitative multihabitat (QMH) aquatic invertebrate sample was collected using a dip net equipped with 500-micron mesh. The dip net was used to sample the various microhabitats present at each site. The contents of the dip net at each microhabitat were combined in the field. All aquatic invertebrate community samples were preserved in 10-percent buffered formalin in the field and transported to the USGS National Water-Quality Laboratory for taxa identification and enumeration following protocols described by Moulton and others (2000).

Data Analysis

Physical and chemical variables, along with summarizations of the biological data, were analyzed to determine their responses to the UII and other individual measures of urbanization. The data then were combined to examine the correspondence between the biological data and important chemical, physical, and landscape gradients.

Correlation analysis was used to assess the strength of the association between the UII and all physical, chemical, and biological variables. Because of the potential for nonlinear relations, Spearman's rho, which is based on the ranks of the values and thus can account for monotonic curvilinearity, was used as the measure of correlation. Spearman's rho correlation analysis also was used to assess the strength of the association between the physical, chemical, and biological variables and individual measures of urbanization, to determine which (if any) indicators of urbanization (for example, infrastructure and land cover) were most strongly associated with the responses. A scatterplot with lowess smoothing was made to examine the form of the relation between the responses and the explanatory variables; when the absolute value of rho was greater than 0.5 and a distinct pattern was evident, the variables were retained for further analysis. The correlation between two variables was considered to be strong when the absolute value of rho was greater than 0.7 and moderate when it was between 0.5 and 0.7.

The use of principal components analysis to reduce redundancy in related groups of explanatory variables prior to correlation analysis with all physical, chemical, and biological variables was explored. However, principal components analysis was found to have limited utility in such small data sets (n=28 sites) because it did not provide a meaningful representation of patterns in the data; often, the first component explained less than 40 percent of the variation in the original data, and loadings for individual variables were low and of similar value, usually less than 0.3. Therefore, individual explanatory variables rather than principal components were used in all correlation analyses.

All data analysis was done in S-plus version 6.1, release 1 (Insightful Corporation, 2002). Additional data-analysis methods specific to GIS variables, stream hydrology, stream temperature, chemistry, algae, invertebrates, and fish are described below.

GIS Variables

Calculation of the Final Urban Intensity Index

Land-cover and census data from the early 1990's were updated with 2001 land cover and census data to recalculate a "final" UII that was used for data analysis. Basin boundaries for the 28 final sites were refined using 1:24,000-scale USGS Digital Raster Graphics topographic maps. The 1992 land-use/land-cover data used for site selection were updated to USGS National Land Cover Dataset (NLCD) 2001 data. Because NLCD 2001 data for the South Platte River Basin were not yet available at the time of the study, LANDSAT 7 Enhanced Thematic Mapper image classification was completed following the NLCD 2001 method to derive land-use categories (Homer and others, 2002). This classification included derivation of an impervious surface metric. Census variables also were revised to reflect 2000 Census data. Because of changes in the long-form parameters collected for the 1990 Census compared to the 2000 Census, the variables used for the final data analysis are not the same as those used for site selection. Two minor deviations from the method used to calculate the UII for site selection (McMahon and Cuffney, 2000) were adapted to calculate the final UII: (1) values for individual socioeconomic variables were used in place of scores from a principal components analysis of these variables and, (2) one of a pair of correlated variables was removed prior to calculation of the UII to avoid biased weighting of the final UII values. Of the 132 land cover, infrastructure, and socioeconomic variables originally incorporated into the UII derivation, 16 were included in the final calculation (table 2 and table 1.5 in Appendix 1). These include measures of road area; urban, forested, and agricultural land cover; population change from 1990 through 2000; housing density, size, and age; and population demographics.

Additional GIS Variables

Additional GIS variables beyond those used in the site selection process were derived to aid in describing the response of the physical, chemical, and biological variables to urbanization. Additional infrastructure variables were added to catalog the number of dams, reservoirs, and diversions in each watershed. Several stream-segment variables were added to measure the number of road intersections within a stream-segment buffer, number of dams along a segment, and land-use/land-cover variables for a riparian buffer around the segment. The full set of environmental GIS variables used in data analysis is listed in table 1.6 in Appendix 1.

To study spatial land-use patterns, Fragstats variables were generated using Level I NLCD 2001 land use/land cover (McGarigal and others, 2002). Fragstats variables quantify the degree of fragmentation—the size, configuration, and connectivity—of urban and nonurban land area (table 1.7 in Appendix 1). Disruption of continuous forested areas or increased connectivity between urban areas can impede movement of organisms and interfere with processes needed

Table 2. Variables that were used to derive the final urban intensity index.

[See table 1.4 in Appendix 1 for a list of all variables originally included in the calculation of the urban intensity index. NLCD, National Land Cover Dataset]

Variable code	Description	Spearman's rho correlation with population density
	Infrastructure variables	
RDARDEN	Road area index in watershed normalized by watershed area (index sum per square kilometer)	0.95
	NLCD 2001 land-use/land-cover variables	
NLCD1_2	Aggregated NLCD 2001 "level 1" category: developed (square kilometer)	0.95
NLCD1_7	Aggregated NLCD 2001 "level 1" category: herbaceous upland natural/seminatural vegetation (includes all level 2 categories 70–79) (square kilometer)	–0.81
NLCD1_8	Aggregated NLCD 2001 "level 1" category: herbaceous planted/cultivated (square kilometer)	–0.70
NLCD2_95	Watershed area in NLCD 2001, Wetlands, Emergent Herbaceous Wetlands (square kilometer)	–0.52
	2000 Census block and block-group variables	
POP90_00	Proportional change in population from 1990–2000 (2000 census block-based)	0.71
HUDEN	Density of housing units (housing units/square kilometer) (2000 census block-group based)	0.98
PPURBAN	Proportion of population living in urban area (2000 census block-group based)	0.86
PHH2	Proportion of households that are 2-person households (2000 census block-group based)	–0.58
PC_ST95	Proportion of citizens living in same State more than 5 years (since 1995) (2000 census block-group based)	0.63
PMRETAIL	Proportion of population greater than 16 years old who are males employed in retail (2000 census block-group based)	0.54
PH_2PERS	Proportion of households occupied by 2 persons (2000 census block-group based)	–0.54
PHU_G60	Proportion of housing units built prior to 1939 (2000 census block-group based)	–0.54
PHLP	Percent of occupied housing units using liquid petroleum gas as fuel (2000 census block-group based)	–0.58
PHWOOD	Percent of occupied housing units using wood as fuel (2000 census block-group based)	–0.65
P_HU3RM	Proportion of total housing units that have three bedrooms (2000 census block-group based)	–0.57

for population persistence, biodiversity, and ecosystem health (Alberta and Marzluff, 2004). Land-use data were subdivided into two Level I land-use classes using Fragstats—urban and nonurban.

Physical Characteristics

Stream Hydrology

In the South Platte River Basin, drainage area is a poor indicator of streamflow because of the high degree of water regulation and the movement of water between basins. As a result, stream stage change, even in basins with similar drainage areas, is not always a valid measurement to use in comparing hydrologic characteristics among sites. Ideally, continuous discharge data derived from a stage–discharge relation specific to each site would be used to compare hydrologic conditions among sites. However, stage–discharge relations could not be adequately developed within the approximately 1-year study period; as a result, continuous discharge data could not be calculated for this study. To compensate for limitations of the stage measurements, stage was converted to cross-sectional area to obtain continuous flow-area data. This conversion was accomplished by first surveying the stream cross section at each site and then by determining the cross-sectional area at various stream stages. This stage–cross-sectional area rating then was used to convert the continuous stage data to continuous flow-area data.

No single descriptor can represent all major hydrologic changes that may occur in urbanizing areas or that may influence aquatic organisms (Clausen and Biggs, 2000). As a result, a suite of variables describing overall variability (regularity of streamflows), magnitude (amount of water moving past a given point per unit of time), flashiness (how quickly streamflow changes from one magnitude to another), duration (length of time associated with specific streamflow conditions), and frequency (how often streamflows above or below a certain magnitude recur) were calculated for the flow-area data (McMahon and others, 2003). These variables are listed in table 2.1 in Appendix 2. The variables were calculated for data from May 1 through September 30, 2003, during which most sites had a complete or near-complete record. An hourly time step was used in the analysis. Separate flow-area variables were calculated for use in the analysis of SPMD data; these variables were calculated for the period beginning 2 weeks prior to deployment of the SPMDs through their retrieval dates.

Stream Temperature

As with hydrologic condition, no single descriptor of water temperature can represent all changes that may occur in response to urbanization or that may affect the response of aquatic organisms. A suite of variables similar to those used for hydrology were calculated for water temperature (table 2.2 in Appendix 2). The variables were calculated for data from May 1 through September 30, 2003, during which most sites had a complete or near-complete record, and an hourly time step was used in the analysis.

Habitat

Means and coefficients of variation from the 11 transects at a site were calculated for each habitat variable so that single values for each variable could be used in subsequent analyses. A complete list of habitat variables is presented in table 2.3 in Appendix 2.

Chemical Characteristics

Water-chemistry conditions can differ substantially between base-flow and storm-runoff conditions because of differing transport mechanisms and instream dilution capacities (Burton and Pitt, 2002). The scope of this study was not large enough to fully characterize chemical conditions during base-flow and stormflow conditions, so whenever possible, chemical samples were collected during base-flow conditions. Water-chemistry conditions also can vary substantially over time. Because the objective of this study was to compare sites spatially, samples were collected as close together in time as possible. However, it was not always possible to collect samples closely together in time and collect only base-flow samples. In addition, many of the basins are highly regulated—throughout the year, stream levels fluctuate in response to upstream reservoir releases or diversions for water supply or irrigation. The timing and duration of these releases and diversions usually are unpredictable. Further, some of the study basins also are affected by mountain snowmelt runoff during April through July. Because of the complex hydrologic systems in the study basins and the time constraint imposed by the study design, some samples were collected during snowmelt, reservoir releases, or localized storm runoff. Examination of the hydrographs at each site indicates that approximately 15 percent of the samples were collected during elevated streamflow conditions; these samples were collected at sites covering a wide range of UII values. Such samples will increase the “natural” variability in the data. However, only one water-chemistry sample was collected at each site during each target period (for example, in June, prior to biological sampling), and the power of any spatial analysis comparing sites during a given target period would be greatly decreased if these elevated flow samples were removed from the data set. Because of this, and because 15 percent is likely to be low enough to avoid obscuring strong patterns of chemical response to urbanization, all samples were left in the data set.

Quality-control samples, including field blanks, replicates, and laboratory spikes, were evaluated prior to analysis of the chemical data. With the exception of a few constituents, all concentrations in blanks were below the reporting limit, concentrations reported for replicate samples were consistent with those of the environmental samples, and all spike recoveries were within acceptable ranges. Low concentrations of dissolved organic carbon and total particulate nitrogen in water were detected in one or more blanks during the study. In addition, low concentrations of bromodiphenyl ether 47, d-limonene, acetophenone, naphthalene, 2-methylnapthalene, 2-methyl benzothiophene, 1-methylnapthalene, 2,6-dimethylnapthalene, diethyl phthalate, benzophenone, phenanthrene, acetyl hexamethyl tetrahydronaphthalene, diethylhexyl phthalate, and cholesterol were detected in one or more SPMD blanks during the study (tables 4.3 and 4.4 in Appendix 4). For constituents detected in one or more blanks, the 95th-percentile concentration in the pooled blanks was calculated. Environmental concentrations less than 10 times this 95th-percentile concentration were not included in further analysis. Because the manufacturing and analysis of the SPMDs used in three NAWQA study areas (the South Platte River Basin, the Albemarle–Pamlico Drainage, and the Apalachicola–Chattahoochee–Flint River Basin) (U.S. Geological Survey, 2004) occurred contemporaneously, potential sources of processing contamination likely were the same for all three. Therefore, dialysis and solvent blanks from all three areas were pooled for quality-control analysis. Contamination in trip blanks, however, would be specific to each individual study area, so only trip blanks from the South Platte River Basin were used in this quality-control analysis. Adjustments to the environmental data based on blank data from the SPMD toxicity assays were not made. Different mixtures or concentrations of chemicals may cause different responses in these assays, and such differences likely were present between the blanks and the environmental samples. Without a predictable change in toxicity as the number or concentration of chemicals increases, the environmental samples could not be adjusted accurately for contamination in the blanks. Therefore, the environmental toxicity results presented in this report may have been influenced to a small degree by nonenvironmental contamination.

Seasonal Variability

Chemical data at each high-intensity-sampling site were compared over the year to determine if substantial variability in water chemistry may have been missed by sampling only twice at the low-intensity-sampling sites. These data also were plotted against the UII to examine whether seasonality patterns differed in basins with differing levels of urbanization.

Spatial Variability

Spatial analyses of the chemistry data were done separately for the 2 months, June and August, during which all 28 sites were sampled. The separate analyses by month allowed the different biological variables to be linked to the chemical data that were collected closest to the time of sampling (that is, June chemistry data with early July algae data and August chemistry data with August fish data). The separate analyses also allowed a comparison of the chemical response to urbanization in two different time periods to determine whether temporal variability in the pattern or strength of the response existed. Although restricted to June and August, the spatial analysis using all 28 sites is more powerful than a similar analysis using only the 10 low-intensity sites during a full year.

As a supplement to the spatial comparison of chemical constituents, a pesticide toxicity index (PTI) was calculated for the June and August samples at each site. The PTI combines pesticide concentrations detected in a water sample with toxicity estimates for those pesticides to provide a measure of relative toxicity among sites (Munn and Gilliom, 2001). The PTI was calculated by summing toxicity quotients (measured concentration divided by the median toxicity concentration from bioassays for each taxonomic group) for every pesticide detected in a water sample. There are several important limitations in the calculation and use of the PTI—toxicity values are based on bioassays of acute exposure and do not incorporate effects of chronic exposure; environmental factors that can affect bioavailability and toxicity are not accounted for; any synergistic and antagonistic effects from mixtures of pesticides in streams are not included; the number of bioassay results among pesticides ranged from 0 to 165; and not all species found locally had been included in bioassays. Even with these limitations, the PTI can be useful in comparing the potential toxicity of sites on a relative basis. PTI values were calculated for two freshwater taxonomic groups, fish and invertebrates.

When a water-chemistry parameter was strongly correlated with the UII and additional urban and hydrologic variables, the multivariate nature of the relations was examined using multiple regression. In order to avoid problems with inflated correlation coefficients and mis-specified model coefficients (Brown, 1998), the initial group of explanatory variables related to a water-chemistry parameter was reduced by randomly retaining one out of a group of correlated variables until no more than four uncorrelated explanatory variables remained. The use of principal components analysis to accomplish this reduction was explored but was found to have limited utility because loadings for individual variables on each axis were low, and the groupings of variables were difficult to meaningfully interpret. Principal components analysis also has restrictions on sample to variable ratios (Osborne and Costello, 2004), and the reduction of variables usually was necessary for principal components analysis and for multiple regression; therefore, it offered little advantage here.

For each response variable, the best-fit multiple linear regression model was determined for all possible subsets of the final explanatory variables using the “leaps” procedure in S-plus (Insightful Corporation, 2002). Best fit was determined through minimization of Mallow’s Cp and maximization of adjusted R^2 values. Regression diagnostics were examined for each best-fit model; if the normality and homoscedasticity assumptions of the model were not met, all variables were log-transformed and the procedure was repeated. If neither of these approaches produced a valid model, nonparametric regression using generalized additive models was performed. Generalized additive models allow for a non-normal underlying distribution and estimate each of the individual additive terms using a univariate smoother (Hastie and Tibshirani, 1990). The natural logarithm of each water-chemistry response variable was modeled using the forward and backward stepwise “step.gam” procedure in S-plus, beginning with a null model (no covariate terms) and iterating through combinations of explanatory variables with either a loess smooth (span=0.5) or smoothing splines (degrees of freedom=4) (Insightful Corporation, 2002). The function loess is an extension of the function lowess into one, two, or more dimensions (Venables and Ripley, 2002). The smoothing method producing the lowest model deviance was used, and the model with the lowest Akaike’s information criterion value was considered the best fit. The final models only were used to identify the important variables describing a particular response; the sample size in this study was too small to use the models for prediction purposes (Osborne, 2000).

Biological Characteristics

Algae, fish, and invertebrate fish data were summarized using multimetric and multivariate techniques. Summarized community data were explored for relations with the UII and other measures of urbanization. Summarized community data also were explored for relations with the water chemistry, hydrology, and habitat data sets described previously.

Resolving Ambiguities

Ambiguities in community data sets occur when closely related specimens are identified at different levels of taxonomic resolution. This usually occurs because the variation in life history of closely related species results in a wide range of individual maturity. Characteristics used to separate species or genera are developed from mature specimens and may not be present in earlier instars or damaged individuals. As a result, a sample may contain a group of individuals from the same genus, but not all can be identified to the species level; the resulting taxa list may show some identified as different species and others only identified as the same genus. When characteristics needed to identify an organism to a finer level (for example, species level) are not present, assumptions about their identity beyond the coarser level (for example, genus level) lead to ambiguities. Including ambiguous taxa in a data set can inflate richness or other measures of community structure.

Ambiguities resulting from differing levels of identification in algae and invertebrate samples were resolved using methods described in Coles and others (2004). Invertebrate ambiguities were resolved using the Invertebrate Data Analysis System (IDAS) software (Cuffney, 2003). For QMH samples, the coarser level resolution identifications were deleted and only the finer level resolution identifications were retained. For RTH samples, individuals identified at coarser levels were distributed in proportion to their abundance to finer levels for a given taxon. Algae ambiguities were resolved in the same manner as the QMH invertebrate samples. All fish were identified to species; as a result, taxonomic ambiguities were not present in the fish data set.

Community Summarization

Richness, functional feeding group, tolerance variables, and community composition variables were calculated to summarize the algae, invertebrate, and fish communities. The IDAS program was used to calculate 30 invertebrate variables commonly used in bioassessment and monitoring for QMH and RTH samples (Barbour and others, 1999; Karr and Chu, 1999). Richness, functional group, and tolerance variables were calculated for QMH samples and community composition variables expressed as percent composition were calculated for RTH samples. Individual invertebrate taxa also were evaluated for their response to urbanization. A total of 18 periphyton algae community variables were calculated for DTH and RTH samples based on autecological information (for example, pollution tolerance of a known taxon) gathered from the literature (Van Dam and others, 1994 and citations therein). If autecological information was not available, then the taxon was not included in the variable calculations, eliminating the need to remove ambiguous taxa before calculating most of the algae variables. All algae variables were expressed as relative percent. Fish variables were calculated based on previous regional work (Schrader, 1989). A complete list of algae, fish, and invertebrate variables are listed in tables 5.1, 5.2, and 5.3 in Appendix 5. Algae, fish, and invertebrate community data also were summarized using nonmetric multidimensional scaling (McCune and Grace, 2002) and other multivariate techniques such as correspondence analysis and detrended correspondence analysis.

Effects of Urbanization on Stream Ecosystems

Response of Physical Characteristics

Stream Hydrology

Commonly observed effects of urbanization on stream hydrology—increased flashiness, shorter duration of high flows, higher magnitude and more frequent peak flows (Poff and others, 1997; U.S. Environmental Protection Agency, 1997)—generally were not observed in this study. None of the hydrologic variables measured were strongly correlated with the UII (table 3).

The UII had moderate positive correlations with the skew of cross-sectional area and two measures of flow duration, the maximum duration of high cross-sectional-area pulses and the maximum duration of consecutive periods of falling cross-sectional area. These relations indicate that urbanization is somewhat related to an increased proportion of high magnitude flow events and an increased duration of peak flows and decreasing flow conditions (as during and after a storm event), but that the effects of urbanization may be small compared to other, unidentified factors.

In contrast, an inverse relation between urbanization and the duration of high and falling flow conditions has been seen in other parts of the Nation, where more rapid changes in flow were observed in urbanizing areas. In previous urban-gradient studies conducted in the Birmingham, Ala., and Boston, Mass., metropolitan areas, urbanization measures were positively correlated with stream flashiness (McMahon and others, 2003). In Birmingham, urbanization also was negatively correlated with the duration of high stream stage, and positively correlated with the duration of low stream stages; the opposite relations were found in Boston. The different patterns of high-flow

Table 3. Spearman's rho values for correlations of stream-hydrology variables with the urban intensity index and individual measures of urbanization.

[See table 1.6 in Appendix 1 and table 2.1 in Appendix 2 for full lists of variables included in this analysis. See figure 6.1 in Appendix 6 for scatterplots of relations listed in table. Number in parentheses is the number of total variables within that group. a_skew, skew of cross-sectional area over all hours in period of record; a_maxfall, maximum duration of consecutive periods of falling cross-sectional area over period of record; a_MXH_95, maximum duration of high cross-sectional-area pulses greater than the 95th percentile over the period of record; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	a_skew	a_maxfall	a_MXH_95
Urban intensity index (1)			
UII	0.57	0.53	0.54
Basin-area variables (2)	--	--	--
Infrastructure variables (12)	--	--	--
NLCD 2001 riparian-buffer variables (2)	--	--	--
NLCD 2001 land-use/land-cover variables (6)	--	--	--
2000 Census block and block-group variables (16)	--	--	--
NLCD 2001 segment variables (4)	--	--	--
Segment variables (5)	--	--	--
Fragstats variables (5)	--	--	--

duration in response to urbanization may have been a result of the higher number of detention/retention structures in the Boston area. Because these structures slow the rate at which water moves through the system, high stream stages persist for longer periods of time than in systems relatively unaffected by detention/retention structures, such as are found in the Birmingham area. However, these structures did not completely remove the effects of urbanization, as urbanization was still positively correlated with stream flashiness in the Boston area.

Correlations between urbanization and all hydrologic characteristics in the Salt Lake City, Utah, metropolitan area generally were much weaker than in Birmingham and Boston (McMahon and others, 2003). The few significant relations largely were between urbanization and overall variability and flashiness. The weaker relations in the Salt Lake City area likely were because of the extensive water regulation that occurs in the area, including reservoir storage and release and transbasin diversions.

In the South Platte River Basin, water regulation is more extensive than in even the Salt Lake City area. In all streams in the basin, water is withdrawn, added, or stored, often at multiple points along its length. There are approximately 880 reservoirs and dams in the basin, and nearly 555,067,000 cubic meters of water are brought into the basin each year by transmountain diversions (Colorado Water Conservation Board, 2003). In the study basins alone, there are more than 400 active diversions (Colorado Division of Water Resources, 2005). Although some of this water regulation is related to urbanization and population growth, agricultural operations have a major influence; approximately 70 percent of the water in the South Platte River Basin is used for irrigation (Dennehy and others, 1998). Water regulation likely contributed to the lack of strong correlation between the UII and hydrologic characteristics and the contradictory moderate positive correlation between the UII and the duration of peak and falling flows observed in this study.

Water regulation, as defined by the volume of water diverted, stored, or added to a stream relative to the volume of water in the stream, is difficult to quantify. In addition, this relative volume of water changes over time as calls for water come in from various water users in the basin. Currently (2005), comprehensive water-use records for streams in the South Platte River Basin are difficult to obtain; as a result, the influence of water regulation on stream hydrology cannot be directly explored. Indirect evidence from this study, however, indicates that the hydrology of these streams is being driven by factors that have not been accounted for here and that the effects of urbanization on stream hydrology may be smaller than the effects of water regulation.

Stream Temperature

As with stream hydrology, measures of stream temperature were not strongly correlated with the UII or with any individual measure of urbanization, with the exception of one segment-scale variable (table 4). Segment-scale land-cover variables, characterizations limited to the stream reach from the study site to the nearest upstream tributary, may provide insight into more localized influences; in these smaller stream reaches, there often were fewer withdrawals or additions. In the study basins, the percentage of high-intensity development in the segment was negatively correlated with the duration of falling stream temperatures (table 4). This result indicates that with greater development in the segment, temperatures are decreasing more rapidly in the stream. In part, this may be due to a decrease in base-flow discharge to the stream as impervious area in the segment increases. Because ground-water temperatures generally fluctuate less than stream temperatures, base-flow discharge can moderate stream temperatures; thus, with less base-flow discharge, stream temperatures may be falling more quickly. These results are inconclusive, however, because the duration of rising temperatures in the stream was not found to be similarly affected.

Table 4. Spearman’s rho values for correlations of stream-temperature variables with the urban intensity index, individual measures of urbanization, and habitat and stream-hydrology variables.

[See table 1.6 in Appendix 1 and tables 2.1, 2.2, and 2.3 in Appendix 2 for full lists of variables included in this analysis. See figure 6.2 in Appendix 6 for scatterplots of relations listed in table. Absolute values of Spearman’s rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. t_medianfall, maximum duration of consecutive periods of falling stream temperature over period of record; --, variables all did not have an absolute value of Spearman’s rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	t_medianfall
Urban intensity index (1)	--
Basin-area variables (2)	--
Infrastructure variables (12)	--
NLCD 2001 riparian-buffer variables (2)	--
NLCD 2001 land-use/land-cover variables (6)	--
2000 Census block and block-group variables (16)	--
NLCD 2001 segment variables (4)	
NLCD_S24	**–0.73**
Segment variables (5)	--
Fragstats variables (5)	--
Stream-hydrology variables (50)	--
Habitat variables (53)	--

Habitat

None of the habitat measurements were strongly correlated with the UII or any other individual measures of urbanization. Only two habitat measurements were moderately correlated with the UII or individual measures of urbanization. Average flow stability was moderately and negatively correlated with the UII and with measures of road density, percentage of developed land, and impervious surface (table 5). Average flow stability was moderately and positively correlated with mean distance from the nearest road and housing age. The relations with average flow stability indicate that streams may have a somewhat greater potential for flashiness in more urbanized and more recently developed areas.

The lack of strong correlation between habitat and urbanization is somewhat surprising, because habitat changes as streams become more urbanized are obvious upon visual inspection. Previous studies have found that few habitat measures used by the NAWQA program are strongly related to urbanization (Short and others, 2005; Coles and others, 2004). Short and others indicated that the weak relations observed between habitat and urbanization were a result of underlying natural conditions in stream slope and drought that could not be separated from urban effects. In this study, other factors that influence stream geomorphology, such as water regulation, may have masked any strong relations between urbanization and habitat.

In a previous study of unregulated streams, urbanization was found to have an indirect effect on temperature through decreased baseflow discharge, the removal of riparian vegetation, and channel enlargement (LeBlanc and others, 1997). In this study, none of the habitat variables were strongly correlated with the temperature variables. Unlike streams in other parts of the Nation, streams in the South Platte River Basin have little riparian shading even under natural conditions.

Response of Chemical Characteristics

Seasonal Characteristics

Four general seasonal patterns in chemical data from the high intensity sites were observed (fig. 6). The first group of constituents, such as dissolved oxygen, varied seasonally because of their chemical properties. Dissolved-oxygen concentrations generally were higher in December and February because oxygen is more soluble at colder temperatures (fig. 6*A*). Because this is an inherent chemical property and not a result of anthropogenic influences, the seasonal

Table 5. Spearman's rho values for correlations of habitat variables with the urban intensity index and individual measures of urbanization.

[See table 1.6 in Appendix 1 and table 2.3 in Appendix 2 for full lists of variables included in this analysis. See figure 6.3 in Appendix 6 for scatterplots of relations listed in table. Number in parentheses is the number of total variables within that group. FlowStblAvg, mean flow stability ratio; OCanAngleAvg, mean open-canopy angle; VelocAvg, mean velocity; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	FlowStblAvg	OCanAngleAvg	VelocAvg
Urban intensity index (1)			
UII	–0.52	--	--
Basin-area variables (2)	--	--	--
Infrastructure variables (12)			
ROADDEN	–0.50	--	--
RDARDEN	–0.52	--	--
RDTRDEN	–0.53	--	--
NLCD 2001 riparian-buffer variables (2)			
P_NLCD1_B2	–0.59	--	--
P_NLCD_BIS	–0.57	--	--
NLCD 2001 land-use/land-cover variables (6)			
P_NLCD1_2	–0.59	--	--
P_NLCD2_22	–0.52	--	--
P_NLCD2_23	–0.58	--	--
P_NLCD2_24	–0.59	--	--
P_NLCD_IS	–0.57	--	--
2000 Census block and block-group variables (16)			
PHU_G50	--	--	0.51
PHU_G60	0.53	--	--
NLCD 2001 segment variables (4)			
NLCD_S21	--	–0.64	--
Segment variables (5)			
SEG_RMD	0.56	--	--
Fragstats variables (5)			
PAM_U	–0.62	--	--
LPI_U	–0.59	--	--
PLA_U	–0.53	--	--
Stream-hydrology variables (50)	--	--	--

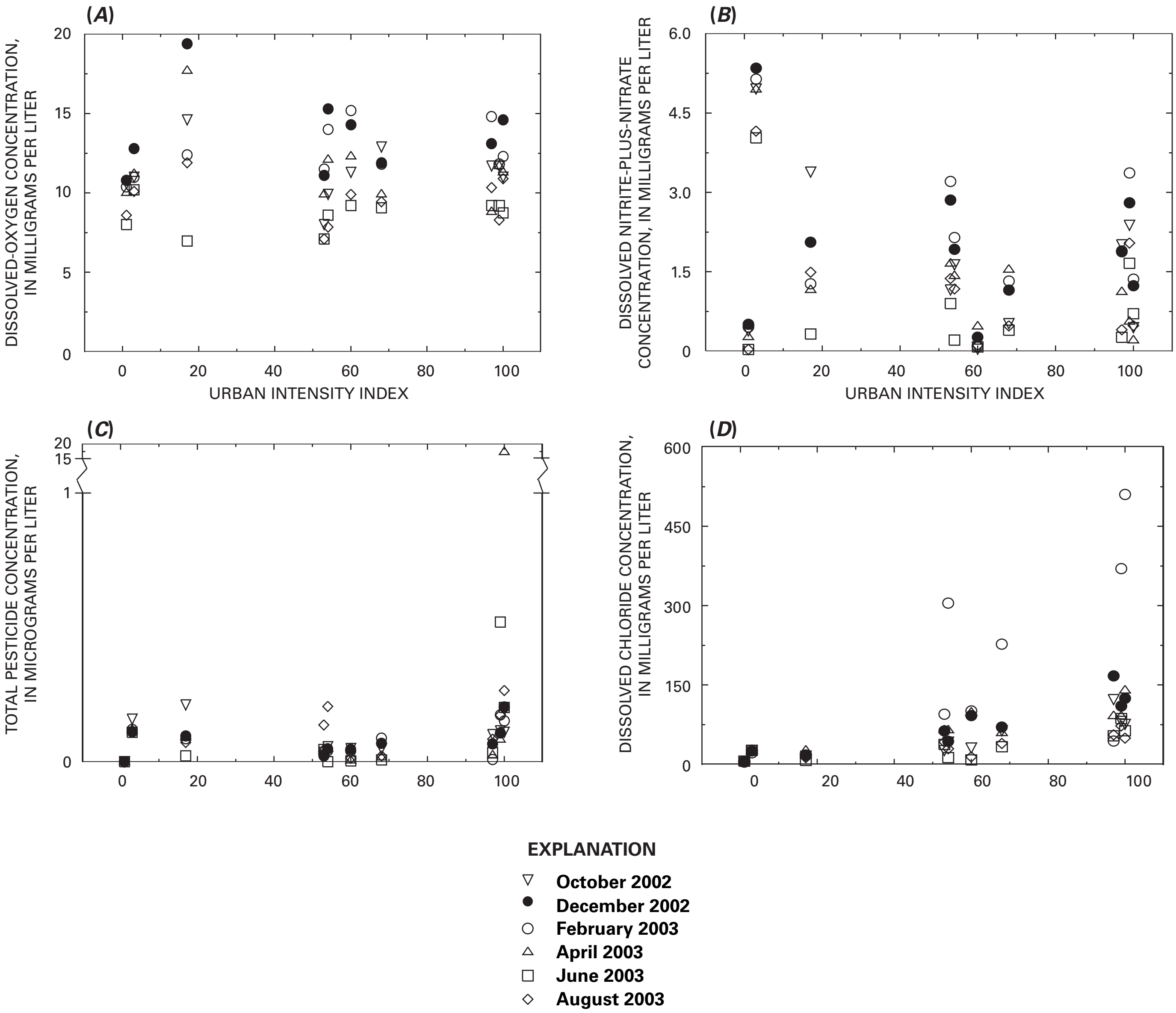


Figure 6. Seasonal pattern of water chemistry over the urban intensity index at the high-intensity-sampling sites, October 2002 through August 2003.

pattern of dissolved-oxygen concentrations varied little as urbanization increased. The second group of constituents, such as dissolved nitrite-plus-nitrate, varied partly in response to seasonal changes in instream biological activity. Dissolved nitrite-plus-nitrate concentrations generally were lowest in June and August, when biological uptake of nutrients is greatest (fig. 6*B*). Nutrient concentrations and, in turn, the amount of biological activity in a stream, can be influenced by urbanization, but concentrations and seasonality did not consistently increase as urbanization increased. This may be due to the additional influence of agriculture at some of the study sites. The third group of constituents, such as total pesticide concentrations, showed seasonal patterns related to the timing of their application or use. Total pesticide concentrations often were highest in August and October, although there was more variation in the timing of maximum concentrations than was observed with constituents like dissolved nitrite-plus-nitrate (fig. 6*C*). The timing of maximum concentrations of individual pesticides can vary substantially, depending on their use, which can vary as areas urbanize. The maximum values and annual variability of total pesticide concentrations did not consistently increase with urbanization, likely because of the additional influence of agriculture at some of the study sites. The fourth group of chemicals, like dissolved chloride, showed a marked increase in annual variability as urbanization increased. Above an urban intensity index of about 50, concentrations tended to be higher during the winter, when magnesium chloride is added to roads as a deicer (fig. 6*D*). These results indicate that some variability in concentration was missed by sampling the majority of sites only twice during this study. The proportion of variability missed was greater at the more urbanized sites for some, but not all, constituents. As a result, any subsequent conclusions about the effects of urbanization on water chemistry are limited to those effects seen in the late spring and summer.

Spatial Characteristics

Water Chemistry

Many previous studies have documented increased conductivity, nutrients, bacteria, and suspended sediment in response to urbanization (Coles and others, 2004; Cheung and others, 2003; Bowen and Valiela, 2001; Zampella, 1994; Hall and Anderson, 1988). However, in this study, none of the 95 water-chemistry variables were strongly correlated with the UII in either June or August (table 6). Just one water-chemistry variable—chloride concentrations—was moderately correlated with the UII in August; none were moderately correlated in June.

In August, three water-chemistry variables were strongly correlated with a small number of the individual measures of urbanization (table 6). Sulfate concentrations increased in more rapidly growing areas (represented by a greater proportional population change from 1990 to 2000) and chloride concentrations increased with decreasing distance from the stream segment to the nearest road. The increasing chloride and sulfate concentrations may have been due to increased use and runoff from impervious areas such as roads in urbanizing areas. In a recent study of watersheds in the Northeastern United States, mean annual chloride concentrations were found to be a function of impervious surface area, and chloride concentrations during the spring and summer months were as much as 100 times greater in urban streams than in forested and agricultural streams (Kaushal and others, 2005). In addition, suspended-sediment concentrations in this study were negatively correlated with the number of housing units built before 1959. In older communities, more mature vegetative cover and lack of surface disturbance from new construction may aid in decreasing the amount of sediment in runoff. In a study of small construction sites in Wisconsin, suspended-sediment concentrations during the active construction phase were 10 times larger than in other urban areas in the region, and concentrations decreased substantially once the soil at the sites had been stabilized through landscaping (Owens and others, 2000). A 40-year study of a stream in Baltimore found that as the watershed urbanized, the stream went through an early phase of aggradation followed by incision, with sediment loads decreasing over time (Colosimo, 2002). The results of this study indicate that once development has peaked, erosion rates and, in turn, instream suspended-sediment concentrations may decrease because of stabilization of the land surface.

Overall, few correlations were found in the August data. In the June data, no correlations between any of the chemical variables and the UII or any individual measures of urbanization were found (table 6). Snowmelt runoff in the larger study basins originating in the mountains occurs during June, increasing streamflows throughout the month; smaller study basins originating in the plains have much lower streamflows during this month. This natural variability in hydrologic conditions likely contributed to the lack of strong correlations in June. But in August, streamflows generally are low across the study area. The low number of strong correlations in August

Table 6. Spearman's rho values for correlations of water-chemistry variables in June[1] and August with the urban intensity index, individual measures of urbanization, and stream-hydrology variables.

[See table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.1 in Appendix 3 for full lists of variables included in this analysis. See figure 6.4 in Appendix 6 for scatterplots of relations listed in table. Absolute values of Spearman's rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. CHLOR, chloride concentration; SULFA, sulfate concentration; SUSSED, suspended-sediment concentration; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	CHLOR (August)	SULFA (August)	SUSSED (August)
Urban intensity index (1)			
UII	0.60	--	--
Basin-area variables (2)	--	--	--
Infrastructure variables (12)	--	--	--
NLCD 2001 riparian-buffer variables (2)	--	--	--
NLCD 2001 land-use/land-cover variables (6)	--	--	--
2000 Census block and block-group variables (16)			
POP90_00	--	**0.71**	--
PHU_G40	--	--	**–0.73**
NLCD 2001 segment variables (4)	--	--	--
Segment variables (5)			
SEG_RMD	–0.66	--	--
Fragstats variables (5)	--	--	--
Stream-hydrology variables (50)	--	--	--

[1] No strong correlations in the June data.

indicates that variations in streamflow because of differences in basin size do not fully explain the lack of strong correlations in the overall water-chemistry data. In addition, none of the chemical variables in either month were related to any of the hydrologic variables (table 6).

The small number of correlations between measures of urbanization and water-chemistry variables in this study indicates that the effects of increasing development on stream chemistry are minimal, at least during the spring and summer baseflow conditions sampled during this study. As with the lack of correlation between stream hydrology and the UII, the small number of correlation, in part, may be due to water regulation. Withdrawal, addition, movement, and storage of water in the South Platte River Basin may have lead to a disconnect between the land surface and water in the streams, resulting in water-chemistry characteristics that to some degree are independent of land-cover characteristics.

SPMD-Based Toxicity and Chemistry

In contrast to the water-chemistry variables, SPMD-based toxicity and chemistry variables often were strongly correlated with the UII (table 7). Potential toxicity measured through CYP1A1 production as toxic equivalents and through ultraviolet fluorescence were positively correlated with the UII, indicating that the potential for toxicity from compounds sequestered in the SPMDs increased with urbanization. Toxicity as measured through the Microtox® EC50 bioassay was not correlated with the UII; it is likely that the chemical(s) that

Table 7. Spearman's rho values for correlations of SPMD-based toxicity and chemistry with the urban intensity index, individual measures of urbanization, and stream-hydrology variables.

[See table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3 for full lists of variables included in this analysis. See figure 6.5 in Appendix 6 for scatterplots of relations listed in table. Absolute values of Spearman's rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. SPMD, semipermeable membrane device; SPMDTEQ, SPMD toxicity measured through CYP1A1 production; SPMDUV, SPMD toxicity measured through ultraviolet fluorescence; S_FLUOR, fluoranthene concentrations in the SPMD; S_PYRE, pyrene concentration in the SPMD; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	SPMDTEQ	SPMDUV	S_FLUOR	S_PYRE
Urban intensity index (1)				
UII	**0.85**	**0.72**	**0.80**	**0.82**
Basin-area variables (2)	--	--	--	--
Infrastructure variables (12)				
ROADDEN	**0.78**	--	--	**0.73**
RDARDEN	**0.75**	--	--	**0.73**
RDTRDEN	**0.77**	--	**0.71**	**0.74**
NLCD 2001 riparian-buffer variables (2)				
P_NLCD1_B2	**0.76**	--	--	--
P_NLCD_BIS	**0.77**	--	--	--
NLCD 2001 land-use/land-cover variables (6)				
P_NLCD2_24	**0.85**	--	**0.71**	**0.76**
P_NLCD1_2	**0.82**	--	**0.72**	**0.77**
P_NLCD2_23	**0.81**	--	**0.71**	**0.76**
P_NLCD2_22	**0.79**	--	**0.72**	**0.75**
P_NLCD_IS	**0.82**	--	**0.71**	**0.76**
2000 Census block and block-group variables (16)				
HHDEN	**0.79**	--	--	**0.74**
HUDEN	**0.78**	--	--	**0.73**
POPDEN90	**0.77**	--	**0.71**	**0.75**
PHU_G60	**–0.75**	--	**–0.73**	**–0.74**
POPDEN00	**0.72**	--	--	--
PPURBAN	--	--	**0.73**	**0.73**
NLCD 2001 segment variables (4)	--	--	--	--
Segment variables (5)				
SEG_RMD	**–0.75**	**–0.73**	**–0.72**	**–0.76**
Fragstats variables (5)				
LPI_U	**0.83**	--	**0.73**	**0.78**
PLA_U	**0.82**	--	--	**0.74**
PAM_U	**0.74**	--	--	**0.71**
Stream-hydrology variables (50)				
a_rb_flash	**0.75**	--	--	--
a_skew	--	--	**0.76**	**0.73**

cause a decrease in light production from the photoluminescent bacteria also were not related to the UII. No individual chemical was consistently found at all sites that had high toxicity as measured through the EC50 bioassay (fig. 7), so the reasons for the pattern in this response are unclear.

Potential toxicity measured through CYP1A1 production as toxic equivalents and through ultraviolet fluorescence also were strongly correlated with each other (rho=0.735, not shown in table 7). Because the ultraviolet fluorescence measurement was based on a pyrene index, a strong positive correlation between these two measures of toxicity indicates that potential toxicity in large part could be due to the presence of the PAH pyrene in the water. This finding is supported by the presence of pyrene in every SPMD sample; pyrene and another PAH fluoranthene were the only constituents detected in every sample and, as such, are the only individual chemicals shown in table 7 (fig. 7). As with the two toxicity variables, pyrene and fluoranthene also were positively correlated with the UII.

Pyrene, fluoranthene, and both toxicity variables also correlated strongly with individual measures of urbanization (table 7). Potential toxicity measured through CYP1A1 production as toxic equivalents, pyrene, and fluoranthene were positively correlated with measures of impervious surface area, developed area, and housing, road, and population density and negatively correlated with distance from the stream segment to the nearest road and measures of housing age. Potential toxicity measured through ultraviolet fluorescence, which had a slightly weaker correlation with the UII than the other three, had fewer additional correlations—only one negative correlation with distance from the stream segment to the nearest road. Fragmentation of the landscape also was associated with changes in potential toxicity measured through CYP1A1 production as toxic equivalents, pyrene, and fluoranthene. All three increased as the size of completely urban patches of land increased and as these patches became less fragmented and more contiguous. This relation indicates that increasing the fragmentation of the urban landscape—interspersing forested or otherwise minimally disturbed areas into large urban areas—may lead to a decrease in the occurrence of these PAHs in the stream and contribute to a concomitant decrease in potential toxicity.

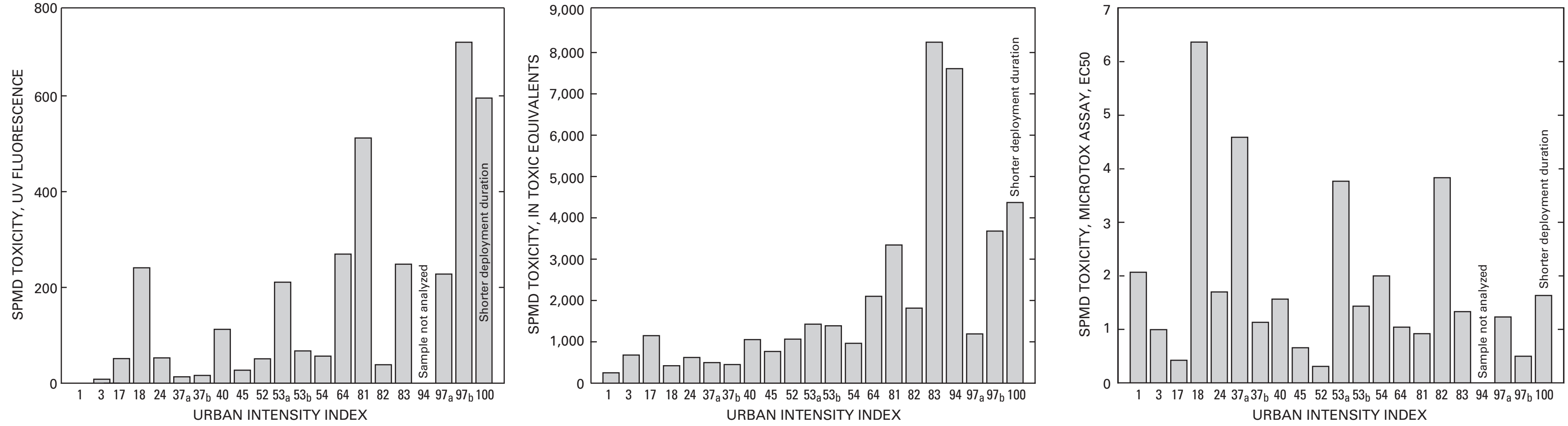
Pyrene and fluoranthene SPMD-based concentrations also were positively correlated with the skew of stream cross-sectional area, a measure of streamflow magnitude (table 7). This result indicates that an increased proportion of high-magnitude storm events were related to increasing pyrene and fluoranthene occurrence in the stream. Potential toxicity measured through CYP1A1 production as toxic equivalents was positively correlated with the modified Richards-Baker flashiness index. This measure of flashiness reflects the frequency and rapidity of short-term changes in streamflow (Baker and others, 2004); as streams became flashier, the potential toxicity of the water increased.

Additional chemicals beyond pyrene and fluoranthene were sequestered by the SPMDs (fig. 7). At low urban intensities, the largest proportion of the overall measured concentration most often was composed of beta-sitosterol, a naturally occurring phytosterol found in most plants. Beta-coprostanol, a fecal steroid, also was detected frequently at low urban intensities; beta-coprostanol can originate from wildlife, domestic animals, or humans. At high urban intensities, anthraquinone, another PAH, commonly was detected. But pyrene and fluoranthene were the constituents detected most frequently and at the highest levels across the UII.

PAHs in the atmosphere largely are a by-product of the incomplete combustion of solid and liquid fuels such as coal, wood, and gasoline (Van Metre and others, 2000). Areas downwind of major mountain ranges, like the study basins along the eastern slope of the Rocky Mountains, are prone to temperature inversions, where warm air overlies cooler air near the surface. Inversions reduce vertical motion and mixing, effectively trapping contaminants in the atmosphere near the surface. Denver frequently has “brown clouds,” visible haze caused by light scattering through particles less than 2.5 micrometers. Automobile emissions have been shown to be the largest contributor to Denver’s particulate mass, followed by power plants and wood-burning emissions (Lewis and others, 1986). Particulate material in the atmosphere, including PAHs like fluoranthene and pyrene, can be deposited in streams and lakes in surrounding areas by precipitation (Motelay-Massei and others, 2002, Tsai and others, 2002, Buehler and others, 2001). PAHs also have been found in urban runoff that contains gasoline, tire debris, and road dust from asphalt wear. One recent study found that runoff from sealcoated parking lots could account for the majority of PAH loading to streams in developed areas around Austin, Tex. (Mahler and others, 2005). The high molecular weight, nonalkylated compounds fluoranthene and pyrene are derived from combustion sources like automobile exhaust and wood and coal burning, as opposed to noncombustion sources like crude oil and refined petroleum products (Van Metre and others, 2000). Their strong positive correlation with measures of road density and negative correlation with distance to the nearest road indicates that automobile exhaust is most likely the largest source of these constituents in the study basins.

The various landscape and hydrologic variables that were strongly correlated with pyrene, fluoranthene, and potential toxicity measured through CYP1A1 production as toxic equivalents and through ultraviolet fluorescence were combined with the UII in a multiple regression analysis of each response variable. The assumptions of the multiple linear regression models were not met in any scenario, so generalized additive models were developed for each response variable. With predictor variables including combinations of UII (urban intensity index), P_NLCD1_B2 (percent of riparian buffer in developed land cover), PHU_G60 (percent of housing units built prior to 1939), a_rb_flash (flashiness of stream cross-sectional area), and a_skew (skew of stream cross-sectional area) (table 8), the generalized additive models showed that the UII alone best described all four response variables. The UII predictor, however, was not significant in any of the models, which indicates that other factors might be more important (table 8). It is

(*A*) Toxicity



(*B*) Chemistry

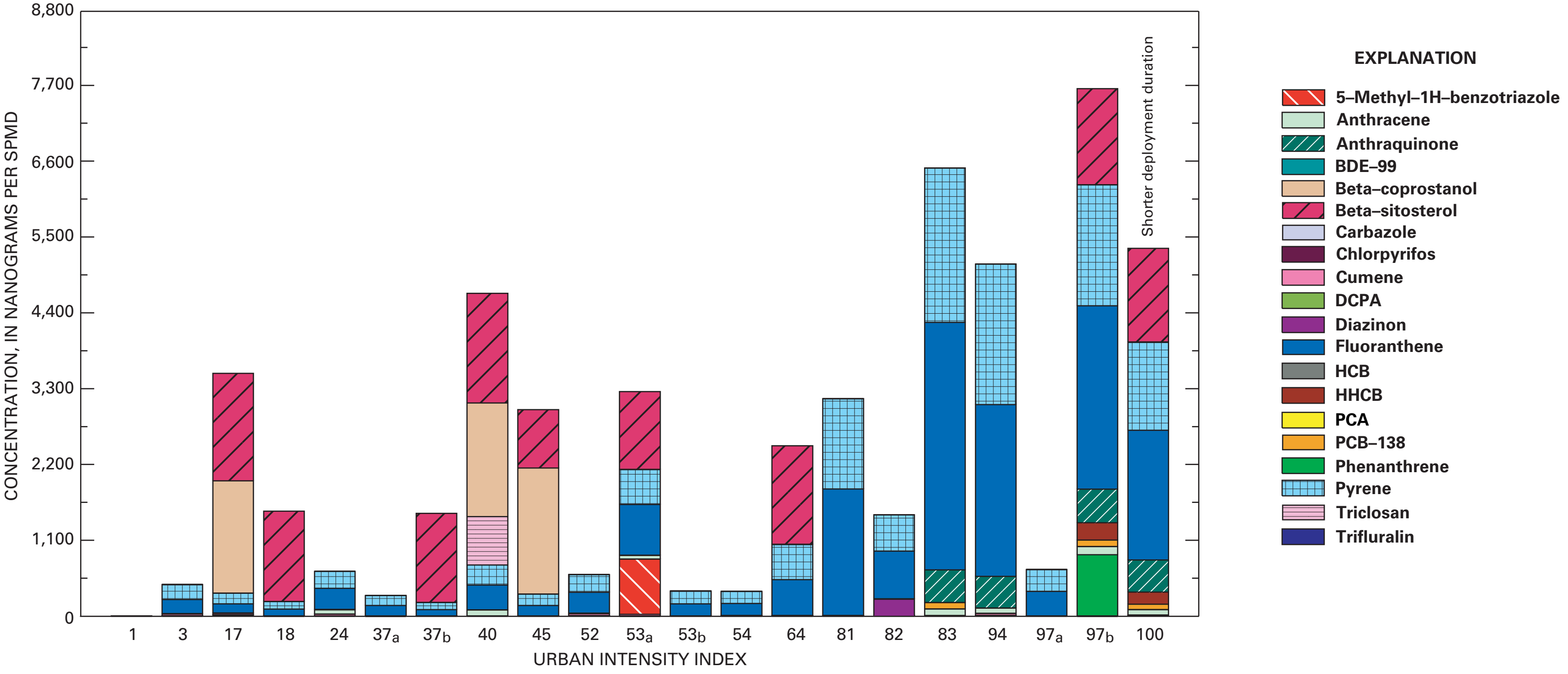


Figure 7. Comparison of semipermeable membrane device (SPMD)-based (*A*) toxicity and (*B*) chemistry over the urban intensity index.

Table 8. Results of generalized additive models of SPMD-based toxicity and chemistry variables with strongly correlated urban and stream-hydrology variables.

[Strongly correlated variables had a Spearman's rank correlation coefficient greater than 0.7. See table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3 for variable definitions. SPMD, semipermeable membrane device; SPMDTEQ, SPMD toxicity measured through CYP1A1 production; SPMDUV, SPMD toxicity measured through ultraviolet fluorescence; S_FLUOR, fluoranthene concentrations in the SPMD; S_PYRE, pyrene concentration in the SPMD; UII, urban intensity index; P_NLCD1_B2, percent of watershed buffer area in developed land area; PHU_G60, percent of housing units built prior to 1939; a_rb_flash, version of Richards-Baker index of stream cross-sectional-area flashiness; a_skew, skew of cross-sectional area over all hours in period of record; RDTRDEN, road traffic index in watershed normalized by watershed area; SEG_RMD, mean distance from stream segment to nearest road; lo, loess smooth; s, smoothing spline]

(A) Model fit with UII and other noncorrelated variables

Initial explanatory variables	Best-fit model terms	Residual deviance	F-statistic	p-value
SPMDTEQ				
UII, P_NLCD1_B2, PHU_G60, a_rb_flash	s(UII)	0.839	1.28	0.32
SPMDUV				
UII	lo(UII)	1.71	2.04	0.15
S_FLUOR				
UII, PHU_G60, a_skew	s(UII)	6.18	1.90	0.17
S_PYRE				
UII, PHU_G60, a_skew	s(UII)	5.88	2.03	0.15

(B) Model fit with noncorrelated traffic-related variables and no UII term

Initial explanatory variables	Best-fit model terms	Residual deviance	F-statistic	p-value
SPMDTEQ				
RDTRDEN, SEG_RMD, PHU_G60, a_rb_flash	lo(SEG_RMD)	0.975	4.28	0.019
SPMDUV				
SEG_RMD	lo(SEG_RMD)	2.26	1.36	0.30
S_FLUOR				
RDTRDEN, SEG_RMD, PHU_G60, a_skew	s(SEG_RMD)	2.30	6.57	0.0047
S_PYRE				
RDTRDEN, SEG_RMD, PHU_G60, a_skew	s(SEG_RMD)	1.58	9.50	0.00092

possible that the UII, a multimetric combination of numerous urban factors, was too broad a measure to produce a significant model for these particular response variables. Given the likely combustion source of the PAHs in this region, an *a posteriori* analysis of traffic-related variables in place of the UII was conducted. Traffic-related variables strongly correlated with each response variable were identified and reduced to avoid multicollinearity and overfitting; the two resulting variables—SEG_RMD (mean distance from stream segment to the nearest road) and RDTRDEN (road traffic index in the watershed, normalized to watershed area)—replaced the UII in the stepwise generalized additive modeling. (SPMDUV was not strongly correlated with RDTRDEN, so only SEG_RMD replaced the UII for that response variable.) The resulting best fit models showed that SEG_RMD alone was a significant influence on potential toxicity measured through CYP1A1 production as toxic equivalents, fluoranthene, and pyrene (table 8). The partial response curves in figure 8 show the relation of SEG_RMD with potential toxicity measured through CYP1A1 production as toxic equivalents, fluoranthene, and pyrene in the absence of other simultaneous influences (accomplished by plotting model residuals plus the modeled influence of SEG_RMD in relation to SEG_RMD). These response curves show the strong negative response of potential toxicity measured through CYP1A1 production as toxic equivalents, fluoranthene, and pyrene to the distance between stream segments and the nearest road, particularly at the low and high values of SEG_RMD.

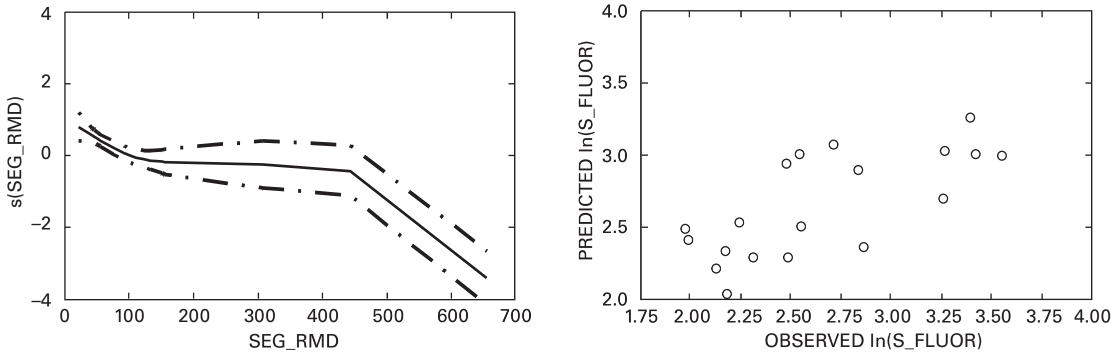
Comparison of Water Chemistry and SPMD-Based Toxicity and Chemistry

Results from this study show that instream concentrations of PAHs may be increasing with urbanization in the study area, whereas spring/summer baseflow concentrations of nutrients, bacteria, suspended sediment, sulfate, chloride, and pesticides are not. This in part may be due to water regulation in the study basins. The most likely source of PAHs, automobile exhaust, often is in close proximity to urbanizing streams, and distance from the stream segment to the nearest road was a significant influence on measures of PAH chemistry and toxicity. Traffic sources may be localized enough that the transport of PAHs would be minimally affected by water diversions and storage upstream. The predominant sources of nutrients, bacteria, suspended sediment, sulfate, chloride, and pesticides, however, may be more dispersed throughout each basin and, therefore, their transport to downstream sites may be subject to greater disruption by water regulation.

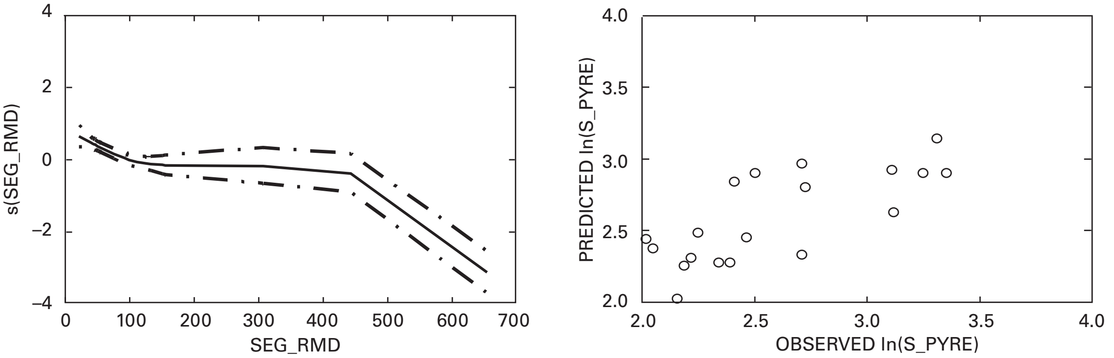
It also is likely that the difference in the response of the SPMD variables is, in part, an artifact of the study design. The SPMDs were deployed for 4 to 6 weeks, during which

A **B**

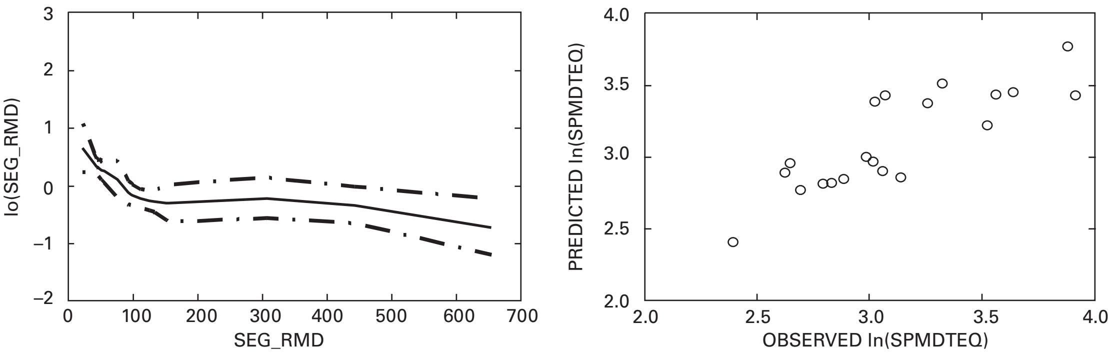
Fluoranthene concentration, in nanograms per SPMD (S_FLUOR)



Pyrene concentration, in nanograms per SPMD (S_PYRE)



SMPD toxicity measured through CYP1A1 production (SPMDTEQ)



EXPLANATION

lo	**loess smooth**
s	**smoothing spline**
ln	**natural logarithm**

Figure 8. Results from best-fit generalized additive models of semipermeable membrane device (SPMD) variables: (*A*) Partial response curves with 95-percent pointwise confidence intervals, and (*B*) associated plots of observed against predicted values. SEG_RMD, mean distance from stream segment to the nearest road.

time they were exposed to multiple storm-runoff events. Water samples for the other chemical variables were collected at a single point in time under baseflow conditions. Changes in water chemistry in urbanizing areas often occur during storm events, when runoff can transport contaminants to streams from a variety of sources. The inclusion of additional storm samples in the study design might have led to a different outcome; further study would be needed to test this hypothesis.

Response of Biological Characteristics

Biological data were summarized by calculating various variables that describe community structure among sites. Several multivariate ordination techniques such as non-metric multidemensional scaling, correspondence analysis, and detrended correspondence analysis were applied to the biological data sets. Overall, the multivariate ordination techniques had little utility in summarizing the biological community data in the context of the UII. Few patterns were apparent in subsequent indirect gradient analysis with environmental variables using site scores based on species composition from correspondence analysis or detrended correspondence analysis. Additionally, stress values associated with non-metric multidemensional scaling ordination indicated that caution should be used in interpretation (Clarke and Warwick, 2001). Community composition was similar across sites with the exception of one site with a low UII that was likely highly influential in the overall ordinations. Because patterns in the biology data also were highly influenced by the type of transformation and level of taxonomic resolution used, ordination was not pursued further.

Algal Communities

Algal Response to Urbanization

Since the early part of the 20th century, algae have been used as indicators of organic pollution (Kollwitz and Marsson, 1908); however, the response of algae communities to urbanization is not well understood (Paul and Meyer, 2001). In this study, none of the periphyton algae community variables were strongly associated with the UII or other individual measures of urbanization (table 9). In a previous study of the Boston metropolitan area, several algal community variables were found to be strongly associated with urban intensity (Coles and others, 2004); however, the authors suggest that algal communities may have been responding to other environmental factors such as water chemistry and habitat equally as strongly as they were to urban intensity. Other studies in Birmingham, Ala., and Salt Lake City, Utah, also found that environmental factors had a stronger influence than urban intensity on algal community structure (Potapova and others, 2005).

Some of the periphyton algae community variables were moderately correlated with the UII and individual measures of urbanization. Measures of tolerant taxa and motile diatoms, primarily from RTH samples, were positively correlated with road density, developed land, housing density, and measures of urban fragmentation (table 9). Motile diatoms are those that can move freely through fine sediment and silt; siltation can increase in streams during the early stages of urban development, when the construction of houses, roads, and buildings disturbs the land surface (Dunne and Leopold, 1978). In the study basins, streams flow through highly erosive soils, so construction disturbance on the landscape has the potential to result in increased siltation in streams, providing favorable conditions for motile diatoms.

Algal Response to Hydrology and Habitat

Only two algae variables were strongly correlated with one of the hydrology variables. Total biovolume of diatoms and cell density of diatoms from DTH samples were negatively correlated with the maximum duration of high cross-sectional-area events greater than the 90th percentile (table 9). This hydrology variable is a measure of the duration of high flows; increased duration of high flows would likely scour any depositional areas of algal communities. Additional measures of the duration of high flows also were negatively and moderately correlated with measures of algal biovolume and cell density. As with the strong correlations, all moderate correlations were with samples from depositional areas (DTH samples). Streamflow magnitude, flashiness, duration, and frequency apparently did not strongly influence algal cell density or biovolume found in riffle areas (RTH samples).

None of the habitat variables were strongly correlated with any of the algal community variables (table 9); however, total biovolume of diatoms, percent abundance of *Achnanthidium minutissimum*, and measures of atrophic diatoms were moderately correlated with measures of siltation. *Achnanthidium minutissimum* is a diatom that often is the first to colonize after a scouring event (Peterson and Stevenson, 1992). This variable also was moderately correlated with average flow velocity and the Froude number, both indirect measures of stream scour. Additionally, the percentage of motile diatoms was moderately correlated with measures of flow and channel shape.

Algal Response to Water Chemistry

Several algal community variables were strongly correlated with water chemistry (table 9). Most relations were positive and with RTH samples. Nutrient concentrations, total pesticide concentrations, and specific conductance values were strongly and positively correlated with measures of biovolume and cell density. The strongest relations in total cell density and biovolume of diatoms were with total nitrogen and nitrite-plus-nitrate concentrations. Additionally, taxa considered tolerant to atrophic conditions were strongly correlated with total nitrogen, nitrite-plus-nitrate, and total herbicide concentrations. The relation between nutrients and stream algal biomass often is unpredictable because of several competing controlling factors such as light availability, flow disturbance, and grazing (Cattaneo, 1987). Previous studies found similar relations between biovolume and nutrients in the

Table 9. Spearman's rho values for correlations of algae variables calculated from DTH and RTH samples with the urban intensity index, individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables.

[See table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 5.1 in Appendix 5 for a full list of variables included in this analysis. See figure 6.6 in Appendix 6 for scatterplots of relations listed in table. Absolute values of Spearman's rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. BioDtms, biovolume of diatoms; Biovol_tot, total algal biovolume per square centimeter; CellDens_tot, total algal cells per square centimeter; AcMinPct, percent of total abundance composed of *Achnanthidium minutissimum*; SiltIdx, percent of total abundance composed of diatom genera that contain mostly motile species as described by Bahls (1992); TR_ET_DP, percent of total abundance composed of eutrophic taxa as described by Van Dam and others (1993); PT_VT_DP, very tolerant as described by Lange-Bertalot (1979); RTH, richest-targeted habitat; DTH, depositional targeted habitat; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	BioDtms RTH / DTH	Biovol_tot RTH / DTH	CellDens_tot RTH / DTH	AcMinPct RTH / DTH	SiltIdx RTH / DTH	TR_ET_DP RTH / DTH	PT_VT_DP RTH / DTH
Urban intensity index (1)							
UII	-- / --	-- / --	-- / --	-- / --	0.56 / --	-- / --	-- / --
Basin-area variables (2)	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --
Infrastructure variables (12)							
ROADDEN	-- / --	-- / --	-- / --	-- / --	0.52 / --	-- / --	-- / --
RDARDEN	-- / --	-- / --	-- / --	-- / --	0.53 / --	-- / --	-- / --
RDTRDEN	-- / --	-- / --	-- / --	-- / --	0.51 / --	-- / --	-- / --
NLCD 2001 riparian-buffer variables (2)							
P_NLCD1_B2	-- / --	-- / --	-- / --	-- / --	0.58 / --	-- / --	-- / --
P_NLCD_BIS	-- / --	-- / --	-- / --	-- / --	0.57 / --	-- / --	-- / --
NLCD 2001 land-use/land-cover variables (6)							
P_NLCD2_22	-- / --	-- / --	-- / --	-- / --	0.51 / --	-- / --	-- / --
P_NLCD2_23	-- / --	-- / --	-- / --	-- / --	0.61 / --	-- / --	0.52 / --
P_NLCD2_24	-- / --	-- / --	-- / --	-- / --	0.60 / --	-- / --	-- / --
2000 Census block and block-group variables (16)							
HHDEN	-- / --	-- / --	-- / --	-- / --	0.50 / --	-- / --	-- / --
PHU_G30	-- / --	-- / --	-- / --	-- / --	-- / --	-- / –0.55	-- / --
PHU_G40	-- / --	-- / --	-- / --	-- / --	-- / --	-- / –0.61	-- / --
PHU_G50	-- / --	-- / --	-- / --	-- / --	-- / --	-- / –0.53	-- / --
PHU_G60	-- / --	-- / --	-- / --	-- / --	–0.51 / –0.55	-- / --	-- / --
NLCD 2001 segment variables (4)							
NLCD_S22	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --	0.50 / --
NLCD_S23	-- / --	-- / --	-- / --	-- / --	0.60 / 0.52	-- / --	0.64 / --
NLCD_S24	-- / --	-- / --	-- / --	-- / --	0.59 / --	-- / --	0.59 / --
Segment variables (5)							
SEG_RMD	-- / --	-- / --	-- / --	-- / --	–0.53 / –0.54	-- / --	–0.59 / --
Fragstats variables (10)							
LPI_U	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --	0.52 / --
PAM_U	-- / --	-- / --	-- / --	-- / --	0.55 / --	-- / --	-- / --
PLA_U	-- / --	-- / --	-- / --	-- / --	0.57 / --	-- / --	0.50 / --

Table 9. Spearman’s rho values for correlations of algae variables calculated from DTH and RTH samples with the urban intensity index, individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables.—Continued

[See table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 5.1 in Appendix 5 for a full list of variables included in this analysis. See figure 6.6 in Appendix 6 for scatterplots of relations listed in table. Absolute values of Spearman’s rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. BioDtms, biovolume of diatoms; Biovol_tot, total algal biovolume per square centimeter; CellDens_tot, total algal cells per square centimeter; AcMinPct, percent of total abundance composed of *Achnanthidium minutissimum*; SiltIdx, percent of total abundance composed of diatom genera that contain mostly motile species as described by Bahls (1992); TR_ET_DP, percent of total abundance composed of eutrophic taxa as described by Van Dam and others (1993); PT_VT_DP, very tolerant as described by Lange-Bertalot (1979); RTH, richest-targeted habitat; DTH, depositional targeted habitat; --, variables all did not have an absolute value of Spearman’s rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	BioDtms RTH / DTH	Biovol_tot RTH / DTH	CellDens_tot RTH / DTH	AcMinPct RTH / DTH	SiltIdx RTH / DTH	TR_ET_DP RTH / DTH	PT_VT_DP RTH / DTH
Habitat variables (53)							
EmbedPctAvg	0.56 / --	-- / --	-- / --	-- / --	–0.55 / –0.62	0.63 / --	-- / --
FlowStblAvg	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --
Froude	-- / --	-- / --	-- / --	-- / 0.54	-- / --	-- / --	-- / --
SiltCovPct	-- / --	-- / --	-- / --	-- / –0.53	-- / --	-- / 0.56	-- / --
DomSub3Pct	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --
VelocAvg	-- / --	-- / --	-- / --	-- / 0.50	-- / –0.50	-- / --	-- / --
VelocCv	-- / --	-- / --	-- / --	-- / --	-- / 0.51	-- / --	-- / --
WetPerimAvg	-- / --	-- / --	-- / --	-- / --	-- / –0.54	-- / --	-- / --
WetXAreaAvg	-- / --	-- / --	-- / --	-- / --	-- / –0.56	-- / --	-- / --
Stream-hydrology variables (50)							
a_MXH_90	-- / **–0.70**	-- / --	-- / **–0.75**	-- / --	-- / --	-- / --	-- / --
a_MXH_95	-- / –0.53	-- / --	-- / –0.62	-- / --	-- / --	-- / --	-- / --
June water chemistry (96)							
SPCOND	**0.70** / --	-- / --	0.54 / --	-- / –0.53	-- / --	0.65 / --	-- / --
CHLOR	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --
SULFA	0.62 / --	-- / --	-- / --	-- / --	-- / --	-- / --	-- / --
TKNITR	0.59 / --	-- / --	0.62 / --	–0.51 / –0.53	-- / --	0.66 / --	-- / --
NOX	**0.77** / --	0.60 / --	0.60 / --	-- / –0.65	-- / --	**0.78** / --	-- / --
TOTALP	-- / --	-- / --	-- / --	-- / --	0.58 / --	0.55 / --	-- / --
TOTALN	**0.78** / --	0.59 / --	0.66 / --	–0.61 / –0.64	-- / --	**0.74** / --	-- / --
TPCONC	-- / --	-- / --	-- / --	-- / --	-- / --	**0.78** / --	-- / --
THCONC	**0.72** / --	0.62 / --	-- / --	-- / –0.51	-- / --	**0.72** / --	-- / --

Boston metropolitan area but not in the Salt Lake City, Utah, or Birmingham, Ala., areas (Potapova and others, 2005). In the Boston area, flow stability, light, and nutrients were important in describing algal biomass, whereas in Birmingham, grazing was important, and in Salt Lake City, watershed slope and stream depth were important. All of the relations described by Potapova and others (2005) were much weaker than those in this study.

Several algal community variables also were strongly correlated with hydrologic variables (table 9). The duration of high cross-sectional events over the 90th percentile was strongly correlated with biovolume; increased scouring associated with increased durations of high flows appear to be suppressing algal biomass. Surprisingly, total herbicide concentrations also were strongly and positively correlated with total biovolume of diatoms and taxa tolerant to atrophic conditions. It is possible that there was a community shift and that only those taxa tolerant to herbicides were increasing as herbicide concentrations increased. It also is possible that algal communities were not responding directly to increasing herbicide concentrations, but to another unidentified factor that varied together with herbicide concentrations. In this study, total herbicide concentrations were strongly and positively correlated with nutrient concentrations. There is little evidence from previous studies that algal community shifts occur in response to increasing herbicide concentrations in streams, so the observed algal community response may have been more closely related to changes in nutrient concentrations than to changes in herbicide concentrations.

These results indicate that algal biomass in the study area was influenced predominantly by total nitrogen concentrations, nitrite-plus-nitrate concentrations, and the duration of high flows and not measures of urbanization.

Fish Communities

Fish Response to Urbanization

Several previous studies have shown that fish community structure can change with increasing urbanization (Long and Schorr, 2005; Albanese and Matlack, 1999; Wang and others, 1997). Typically, diversity declines and the abundance of tolerant species increases with increasing urbanization (Paul and Meyer, 2001). In this study, none of the fish community variables were strongly associated with the UII, and only one (the percentage of omnivorous invertivores) was strongly and negatively correlated with an individual measure of urbanization, housing age (table 10). This relation is inconclusive, however, because other related measures of housing age were not strongly correlated with this or any other related fish variable.

Only a few moderate correlations were found between fish community variables and individual measures of urbanization. The percentage of omnivorous invertivores was positively correlated with percent impervious area and the percent of individuals with deformities, eroded fins, lesions, or tumors was negatively correlated with the percentage of high intensity development in the basin. Omnivorous invertivores were represented by three species in this study—sand shiner (*Notropis stramineus*), fathead minnow (*Pimephales promelas*), and common carp (*Cyprinus carpio*). The percentage of omnivorous invertivores was highly influenced by the abundance of fathead minnow, as fathead minnows composed more than 90 percent of the total abundance of these three species.

Other studies that have shown strong relations between fish communities and urbanization were conducted in study areas containing relatively diverse fish communities, typically composing assemblages of more than 30 species at any given site. In this study, the highest number of species found at a site was 11, with 75 percent of the sites having 6 or fewer species present, most of which were considered tolerant (Barbour and others, 1999; Schrader, 1989).

Little is known about historical fish distribution in the South Platte River Basin prior to the advent of irrigated agriculture in the 1860's, as only a few collections were made prior to 1900 (Fausch and Bestgen, 1997). Under natural conditions, fish assemblages of streams in the Great Plains physiographic region typically are more tolerant than those in less extreme habitats (Matthews, 1986). The naturally tolerant fish fauna in plains streams likely were reduced further because of modification of streamflow and localized pollution before 1914 (Ellis, 1914; Jordan, 1891). Human-induced streamflow modifications and habitat alterations have occurred for nearly 150 years in the study area (Fausch and Bestgen, 1997). Currently (2005), there are approximately 32 confirmed native species in the South Platte River Basin; of these, 2 have been extirpated (Propst and Carlson, 1986) and 13 are listed by the State of Colorado as endangered, threatened, or of special concern (Nesler and others, 1997). State-listed fish rarely are observed in the transition zone between the mountains and plains, unless it is through a recollection of individual fish from a known population at specific sites. The present-day depauperate (diminished) and tolerant fish fauna, a result of natural and anthropogenic stressors, probably minimized the effects of urbanization on fish communities in the study area. A similar situation has been observed in the Coastal Plain streams of Maryland, where early modifications to stream systems truncated local fish faunas, possibly masking fish-community response to contemporary urbanization (Morgan and Cushman, 2005).

Fish Response to Hydrology and Habitat

None of the stream-hydrology or habitat variables were strongly correlated with any of the fish community variables (table 10). The percentage abundance of nonnative species was moderately correlated with measures of channel shape, and measures of fish trophic structure were moderately correlated with measures of channel shape, flow stability, and embeddedness.

The relation between stream habitat, hydrology, and fish communities has been a central area of research for decades. Many studies have focused on fish communities downstream from dams, where alterations in hydrology substantially reduce habitat availability and the response of specific organisms varies depending on their life stage at the time of alteration (Poff and others, 1997). Altered hydrology in response to urbanization could have similar effects on fish communities, because a change in hydrology and subsequent changes in the availability of habitat in urban streams could structure communities toward more tolerant taxa, which are better suited to the altered conditions. In a study relating altered hydrology to fish community shifts in urban areas, Roy and others (2003) found a seasonal connection between altered hydrology, habitat, and changes in fish community structure.

The hydrology and habitat in streams in the study area have been altered by water regulation and channelization associated with stormwater conveyance. Historically, streams in the transition zone area between the mountains and the plains were described as having stable base flows, relatively low peak flows, and fringing riparian forests that likely contributed large woody debris (Brown and Matthews, 1995). Some small parts of riparian forests still exist today; however, large woody debris is removed continually from streams in urban areas to prevent bridge damage and flooding during high flows. Substrates associated with many stream reaches also have changed drastically from cobble and gravel to silt, fine clay, and muck (Fausch and Bestgen, 1997). Historical hydrologic and habitat modifications likely contributed to the present-day tolerant and depauperate fish fauna, minimizing the effects of current habitat and hydrologic conditions on fish communities.

Fish Response to Water Chemistry

A small number of water-chemistry variables were strongly correlated with fish community variables. The percentage of suspended sediment finer than 0.063 millimeter was strongly and negatively correlated with total number of taxa, and chloride concentrations were strongly and positively correlated with the percentage of omnivorous invertivores (table 10). The total number of taxa and the total number of

Table 10. Spearman's rho values for correlations of fish variables with the urban intensity index, individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables.

[See table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 5.2 in Appendix 5 for a full list of variables included in this analysis. See figure 6.7 in Appendix 6 for scatterplots of relations listed in table. Absolute values of Spearman's rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. pAIntro, percent of total abundance composed of nonnative species; pDELT, percent of total abundance composed with Deformities, Eroded fins, Lesions, Tumors (DELT anomalies) as described by Sanders and others (1999); pAOm, percent of total abundance composed of trophic omnivores; pAOmInvert, percent of total abundance composed of trophic omnivorous-invertivores; pASpecial, percent of total abundance composed of trophic specialists; Inter, total number of intermediate tolerant species; Intro, total number of nonnative species; Tol, total number of tolerant species; Ttaxa, total number of species; Cyprin, total number of cyprinid species; pAnonGard, percent of total abundance composed of nonguarding lithophilic spawners; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	pAIntro	pDELT	pAOm	pAOmInvert	pASpecial	Inter
Urban intensity index (1)	--	--	--	--	--	--
Basin-area variables (2)	--	--	--	--	--	--
Infrastructure variables (12)	--	--	--	--	--	--
NLCD 2001 riparian-buffer variables (2)	--	--	--	--	--	--
2001 Urban land-use/land-cover variables (5)					--	
P_NLCD2_24	--	–0.50	--	--	--	--
2000 Census block and block-group variables (16)						
PHU_G60	--	--	--	**–0.70**	--	--
NLCD 2001 segment variables (4)	--	--	--	--	--	--
Segment variables (5)	--	--	--	--	--	--
Fragstats variables (5)						
PLA_U	--	--	--	0.53	--	--
Habitat variables (53)						
DepthAvg	0.53	--	--	–0.50	--	--
DepthCv	–0.50	--	--	--	--	--
HydRadAvg	0.56	--	--	–0.51	--	--
WetXAreaAvg	0.59	--	--	--	--	--
VelocAvg	0.52	--	--	--	--	--
FlowStblAvg	--	--	–0.57	--	0.57	--
EmbedPctAvg	--	--	--	0.51	--	--
Stream-hydrology variables (50)	--	--	--	--	--	--
August water-chemistry variables (96)						
TOTALN	--	--	--	--	--	--
PCTFINES	--	--	--	--	--	–0.55
CHLOR	--	--	--	**0.76**	--	--
TOTALP	--	--	--	--	--	--

Table 10.—Continued

Explanatory variable code	Intro	Tol	Ttaxa	Cyprin	pAnonGard
Urban intensity index (1)	--	--	--	--	--
Basin-area variables (2)	--	--	--	--	--
Infrastructure variables (12)	--	--	--	--	--
NLCD 2001 riparian-buffer variables (2)	--	--	--	--	--
2001 Urban land-use/land-cover variables (5)			--	--	
P_NLCD2_24	--	--	--	--	--
2000 Census block and block-group variables (16)					
PHU_G60	--	--	--	--	--
NLCD 2001 segment variables (4)	--	--	--	--	--
Segment variables (5)	--	--	--	--	--
Fragstats variables (5)					
PLA_U	--	--	--	--	--
Habitat variables (53)					
DepthAvg	--	--	--	--	--
DepthCv	--	--	--	--	--
HydRadAvg	--	--	--	--	0.52
WetXAreaAvg	--	--	--	--	--
VelocAvg	--	--	--	--	--
FlowStblAvg	--	--	--	--	--
EmbedPctAvg	--	--	--	--	--
Stream-hydrology variables (50)	--	--	--	--	--
August water-chemistry variables (96)					
TOTALN	--	--	--	0.60	--
PCTFINES	–0.69	--	**–0.71**	--	--
CHLOR	--	--	--	--	--
TOTALP	--	0.52	--	--	--

generalist species were highly correlated because almost all of the species present in the study streams were considered generalists. The effects of suspended sediment on warm-water fish communities are not well understood; most previous work has focused on salmonids (Waters, 1995). The effects of sedimentation on fish communities in transition zone streams likely are similar to its effects on salmonids. Suspended sediment can deposit on the streambed, filling interstitial spaces between gravel and cobble as well as pools or other low velocity habitat important for overwintering or rearing. The filling of the streambed also is likely to decrease the reproductive success of many species that require clean gravel for spawning and species that broadcast over open substrates.

Additional moderate water-chemistry associations with fish communities were with the percentage of suspended sediment finer than 0.063 millimeter and nutrients (table 10). The total number of tolerant species and the total number of cyprinids, which are related because most cyprinids in these communities are tolerant, were moderately and positively correlated with nutrients. The total number of nonnative species and intermediate tolerant species were moderately and negatively correlated with the percentage of suspended sediment finer than 0.063 millimeter.

These results indicate that response of the fish communities in the study area were predominantly influenced by housing age, the percentage of suspended sediment finer than 0.063 millimeter, and chloride concentrations.

Invertebrate Communities

Invertebrate Response to Urbanization

None of the invertebrate community variables were strongly correlated with the UII or other measures of urbanization (table 11). In contrast, several previous studies have found strong relations between benthic invertebrate communities and urbanization (Coles and others, 2004; Roy and others, 2003; Kennen, 1999; Jones and Clark 1987). Typically, pollution tolerant taxa (Diptera, Oligochaeta, Gastropoda) replaced pollution sensitive taxa (Ephemeroptera, Plecoptera, Trichoptera [EPT]) as urbanization increased in these studies. Decreased diversity and overall invertebrate abundances also were typical in areas of increasing urbanization (Paul and Meyer, 2001).

A small number of moderate correlations were found between invertebrate variables and measures of road density, housing age, and the distance from the site to the nearest road (table 11). Coleoptera, Diptera, and collector-gatherer richness were negatively correlated with measures of road density. Predator richness, mainly consisting of Coleoptera and Odonata larvae, somewhat decreased when the percentage of houses built more than 20 years ago increased but somewhat increased when the percentage of houses built less than 20 years ago increased. These relations indicate that predator richness was somewhat lower in areas of older development,

Table 11. Spearman's rho values for correlations of invertebrate variables from RTH and QMH samples with the urban intensity index, individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables.

[See table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 5.3 in Appendix 5 for a full list of variables included in this analysis. See figure 6.8 in Appendix 6 for scatterplots of relations listed in table. Richness variables were calculated from qualitative multi-habitat (QMH) samples and abundance variables were calculated from richest targeted habitat (RTH) samples. Absolute values of Spearman's rho greater than 0.70 are bolded. Number in parentheses is the number of total variables within that group. ABUND, total number of organisms in the sample; CG_Rich, richness composed of collector-gatherers; PR_Rich, richness composed of predators; pSC_Rich, percent of richness composed of scrapers; EPEMp, percent of total abundance composed of mayflies; NONINSp, percent of total abundance composed of noninsects; COLEOPR, richness composed of Coleoptera; DIPR, richness composed of Diptera; EPEMR, richness composed of mayflies; EPTR, richness composed of Ephemeroptera, Plecoptera, Tricoptera (mayflies, stoneflies, caddisflies); ORTHOR, richness composed of Orthocladiinae midges; ABUNDTOL, abundance weighted U.S. Environmental Protection Agency tolerance value for sample; RICHTOL, richness based average U.S. Environmental Protection Agency tolerance value for sample; --, variables all did not have an absolute value of Spearman's rho greater than 0.5 or did not show a distinct pattern with any response variable; NLCD, National Land Cover Dataset]

Explanatory variable code	ABUND	CG_Rich	PR_Rich	pSC_Rich	EPEMp	NONINSp	COLEOPR
Urban intensity index (1)	--	--	--	--	--	--	--
Basin-area variables (2)	--	--	--	--	--	--	--
Infrastructure variables (12)							
RAWMILES	--	–0.56	--	--	--	--	--
RDARINDX	--	–0.52	--	--	--	--	--
RDLENGTH	--	–0.55	--	--	--	--	--
RDTRINDX	--	–0.50	--	--	--	--	--
RDTRDEN	--	--	--	--	--	--	–0.54
ROADDEN	--	--	--	--	--	--	–0.52
NLCD 2001 riparian-buffer variables (2)	--	--	--	--	--	--	--
2001 Urban land-use/land-cover variables (5)	--	--	--	--	--	--	--
2000 Census block and block-group variables (16)							
PHU_G20	--	--	–0.58	--	--	--	--
PHU_L5	--	--	0.51	--	--	--	--
PHU_L10	--	--	0.55	--	--	--	--
PHU_L20	--	--	0.58	--	--	--	--
NLCD 2001 segment variables (4)	--	--	--	--	--	--	--
Segment variables (5)							
SEG_RMD	--	--	--	--	--	–0.52	--
Fragstats variables (5)	--	--	--	--	--	--	--
Habitat variables (53)							
EmbedPctAvg	--	--	--	--	–0.54	--	--
SiltCovPct	--	--	--	--	–0.58	--	--
DomSub2Pct	--	--	--	--	--	--	--
WetShapeAvg	--	--	--	0.58	--	--	--
WetPerimAvg	--	--	--	--	0.50	--	--
WetXAreaAvg	--	--	--	--	0.56	--	--
Stream-hydrology variables (50)							
a_MXH_75	--	**--**	--	--	**0.70**	--	--
a_periodf3	--	**--**	–0.50	--	--	--	–0.52
a_periodf5	--	**--**	–0.57	--	--	--	**–0.73**
a_periodf7	--	**--**	–0.56	--	--	--	**–0.70**
a_periodf9	--	**--**	--	--	--	--	–0.60
a_periodr3	--	**--**	–0.63	--	--	--	–0.67
a_periodr5	--	**--**	–0.52	--	--	--	**–0.73**
a_periodr7	--	**--**	--	--	--	--	–0.65
a_periodr9	--	**--**	--	--	--	--	–0.66
June water-chemistry variables (96)							
CHLOR	--	--	--	--	--	--	--
SPCOND	0.51	--	--	--	--	--	--
NOX	--	--	0.55	--	--	--	--
THCONC	--	--	--	--	--	0.57	--
TPCONC	--	--	--	--	--	0.59	--
SULFA	0.50	--	0.50	--	--	--	--
TKNITR	--	--	0.63	--	--	--	--
TOTALN	0.51	--	0.58	--	--	--	--
TICONC	--	--	--	--	--	0.57	--

Table 11.—Continued

Explanatory variable code	DIPR	EPEMR	EPTR	ORTHOR	ABUND-TOL	RICHTOL
Urban intensity index (1)	--	--	--	--	--	--
Basin-area variables (2)	--	--	--	--	--	--
Infrastructure variables (12)						
RAWMILES	–0.63	--	--	–0.51	--	--
RDARINDX	–0.61	--	--	–0.50	--	--
RDLENGTH	--	--	--	--	--	--
RDTRINDX	–0.56	--	--	--	--	--
RDTRDEN	--	--	--	--	--	--
ROADDEN	--	--	--	--	--	--
NLCD 2001 riparian-buffer variables (2)	--	--	--	--	--	--
2001 Urban land-use/land-cover variables (5)	--	--	--	--	--	--
2000 Census block and block-group variables (16)						
PHU_G20	--	--	--	--	--	--
PHU_L5	--	--	--	--	--	--
PHU_L10	--	--	--	--	--	--
PHU_L20	--	--	--	--	--	--
NLCD 2001 segment variables (4)	--	--	--	--	--	--
Segment variables (5)						
SEG_RMD	--	--	0.50	--	--	--
Fragstats variables (5)	--	--	--	--	--	--
Habitat variables (53)						
EmbedPctAvg	--	--	--	--	--	0.61
SiltCovPct	--	--	--	--	--	0.54
DomSub2Pct	0.52	--	--	--	--	--
WetShapeAvg	--	--	--	--	--	--
WetPerimAvg	--	--	--	--	--	--
WetXAreaAvg	--	--	--	--	--	--
Stream-hydrology variables (50)						
a_MXH_75	--	--	--	--	--	--
a_periodf3	--	--	--	--	--	--
a_periodf5	--	--	--	--	--	--
a_periodf7	--	--	--	--	--	--
a_periodf9	--	--	--	--	--	--
a_periodr3	--	--	--	--	--	--
a_periodr5	--	--	--	--	--	--
a_periodr7	--	--	--	--	--	--
a_periodr9	--	--	--	--	--	--
June water-chemistry variables (96)						
CHLOR	--	–0.56	–0.59	--	--	--
SPCOND	--	–0.58	–0.53	--	--	--
NOX	--	–0.61	–0.61	--	--	**0.74**
THCONC	--	–0.67	–0.65	--	0.58	**0.70**
TPCONC	--	–0.63	–0.62	--	0.56	0.68
SULFA	--	--	--	--	--	0.61
TKNITR	--	--	--	--	--	0.69
TOTALN	--	--	--	--	--	**0.75**
TICONC	--	--	--	--	--	0.61

where maximum incision may have already occurred, leaving less lentic-like habitat (pools) favored by many Coleoptera and Odonata.

Variables constructed around the richness of the three orders EPT have been found to respond to land-use changes, because many EPT species are considered sensitive to disturbance (Barbour and others, 1999). In some studies showing strong relations between invertebrate communities and urbanization, maximum EPT richness values were as high as 35 when most taxa were identified to the species level (Coles and others, 2004) and as high as 31 when most taxa were identified to the genus level (Roy and others, 2003). In contrast, the maximum EPT richness value (most taxa identified to the species level) in this study was 16, with 21 of the 28 sites having EPT richness values less than 10. All of the EPT taxa collected during this study are considered relatively tolerant forms of these normally sensitive groups, and only one individual stonefly (*Perlesta decipiens*) was collected at any of the sites.

As with fish communities, it appears that present-day invertebrate communities have been truncated to a short list of tolerant species by past anthropogenic activities in these basins. Invertebrate communities on the plains naturally may be more tolerant than those from less extreme habitats, but historical evidence indicates that several species have been locally extirpated from the study area during the last 150 years. The stoneflies *Isogenoides elongatus* and *Taenionema pacificum,* and the mayfly *Macdunnoa persimplex,* have been extirpated from regional streams (Kondratieff and Baumann, 2002; McCafferty and others, 1993). Additionally, the mayfly *Ephemera compar* is probably extinct, as it has not been collected since 1875, when it was described in an "unknown area near Denver" (Hagen, 1875). A relatively recent inventory of Unionid mussels in Colorado determined that 6 of 9 historically known species have been eliminated from plains streams (Cordeiro, 1999) and that only 1 of 10 previously known lotic Unionid mussel populations remains. As with fish communities, the lack of sensitive taxa and a depauperate fauna may have made it difficult to relate the response of invertebrate communities to urbanization in this study.

Other larger scale studies in the South Platte River Basin have linked land-use characteristics to invertebrate community structure. In one of the studies, sites were distributed along a strong elevation gradient, enhancing natural differences among sites (Tate and Heiny, 1995). The natural differences in taxa across these major natural gradients likely contributed to the many relations found in that study. In contrast, sites in this current study were selected to minimize natural differences so that any effects of urbanization could be isolated. In another study comparing data collected in the Big Thompson and Cache la Poudre Rivers to data from regional reference sites in other basins, a significant influence of urbanization on invertebrate communities in both rivers was found (Voelz and others, 2005). That study included sites downstream from major wastewater-treatment plants, which may have influenced their findings. Tate and Heiny (1995) similarly found decreased diversity and the absence of more sensitive taxa downstream from wastewater-treatment plants. The combination of a depauperate fauna, limited natural differences between sites, and the minimal influence of wastewater at any of the sites likely contributed to the contrasting response of invertebrate communities to urbanization in this study.

Invertebrate Response to Hydrology and Habitat

A few invertebrate community variables were strongly correlated with hydrologic characteristics. The percentage of mayflies was strongly and positively correlated with the maximum duration of high flows (table 11). The dominant mayfly in these systems, *Baetis tricaudatus*, is one of the most ubiquitous mayflies in North America. This species can inhabit a variety of habitats and is usually one of the first species to colonize after major disturbance events (Vieira, 2003; Zuellig and others, 2001). In this study, aquatic Coleoptera (beetle) richness was strongly and negatively correlated with the frequency of rising and falling flow events. With the exception of a few riffle beetle taxa and the Dyticid genus *Agabus*, most Coleoptera associated with these sites were lentic (pool) forms. Within the WHPE, the study streams have relatively low gradients, so it is not surprising that more lentic forms of Coleoptera were associated with the study sites and responded negatively to the maximum duration of high flows.

Several moderate relations between hydrologic characteristics and invertebrates also were found (table 11). Predator richness was negatively correlated with rising and falling flow events (flashiness of streams). Most of the predators were Coleoptera and Odonata larvae typical of more lentic systems, and flashy streams are likely to have a detrimental effect on lentic taxa.

No strong relations were found between habitat characteristics and invertebrate communities (table 11). Measures of siltation were moderately and positively associated with Diptera richness and community tolerance based on richness and negatively associated with the percentage of mayflies. The percentage of mayflies and richness composed of scrapers also was positively associated with channel shape.

Invertebrate Response to Water Chemistry

A few measures of invertebrate community structure were strongly related to water-chemistry variables (table 11). Community tolerance based on richness was strongly and positively related to total nitrogen, nitrite-plus-nitrate, and total herbicide concentrations. The invertebrate response probably was not related directly to increasing herbicide concentrations but rather to unidentified factors that varied together with herbicide concentrations. Several additional measures of invertebrate community structure, such as the richness of mayflies and caddisflies, were moderately and negatively related to nutrient and chloride concentrations and specific-conductance values. Additionally, total abundance, community tolerance based on abundance, and the percentage of noninsect taxa were moderately and positively related to pesticide, nutrient, sulfate and chloride concentrations. The abundance of noninsects, typically the most tolerant taxa in these systems, highly influenced total abundance and, therefore, likely was driving the positive correlation with pesticide, nutrient, and major ion concentrations.

These results indicate that the response of the invertebrate communities in the study area were influenced predominantly by the frequency of rising and falling flow events, the duration of high flows, total nitrogen concentrations, nitrite-plus-nitrate concentrations, and total herbicide concentrations.

Major Findings from Response Characteristics

Commonly observed effects of urbanization on instream physical, chemical, and biological characteristics, such as increased flashiness, higher magnitude and more frequent peak flows, increased concentrations of chemicals, and changes in aquatic community structure, generally were not observed in this study. The few strong relations among chemical, physical, biological, and urban variables are summarized in figure 9.

None of the physical characteristics (hydrology, temperature, and habitat) were strongly correlated with the urban intensity index. Only one strong correlation was found between the physical characteristics and individual measures of urbanization—the percentage of high-intensity development in the stream segment was negatively correlated with the duration of falling temperatures (fig. 9). A small number of the hydrologic variables were strongly correlated with some invertebrates and algae variables, but not with any fish variables (fig. 9). Measures of stream flashiness and duration of high flows influenced algae communities in depositional areas and lentic invertebrate taxa. None of the habitat or temperature variables were strongly correlated with the invertebrate, algae, or fish community responses.

None of the spring/summer base-flow chemical variables were strongly correlated with the urban intensity index. In the summer, two water-chemistry variables were strongly correlated with individual measures of urbanization—sulfate concentrations increased in more rapidly growing areas, and suspended-sediment concentrations decreased as housing age increased (fig. 9). In the spring, none of the water-chemistry variables were strongly correlated with any individual measure of urbanization. Measures of potential toxicity and PAH concentrations from the SPMDs were strongly and positively correlated with urban intensity. The PAH concentrations also were positively correlated with measures of road density and negatively correlated with distance to the nearest road (fig. 9), indicating that automobile exhaust is most likely the largest source of these constituents in the study area. Automobile sources may be localized enough that the transport of PAHs to the study sites would have been minimally affected by water movement and storage upstream, whereas transport of constituents like nutrients and pesticides to downstream sites may have been subject to greater disruption by water regulation. The disparity in the response to urbanization of SPMD-based chemical measures and spring/summer baseflow chemical measures may be a result of the SPMD deployment period; during the 4- to 6-week deployment period, the SPMDs were exposed to multiple storm-runoff

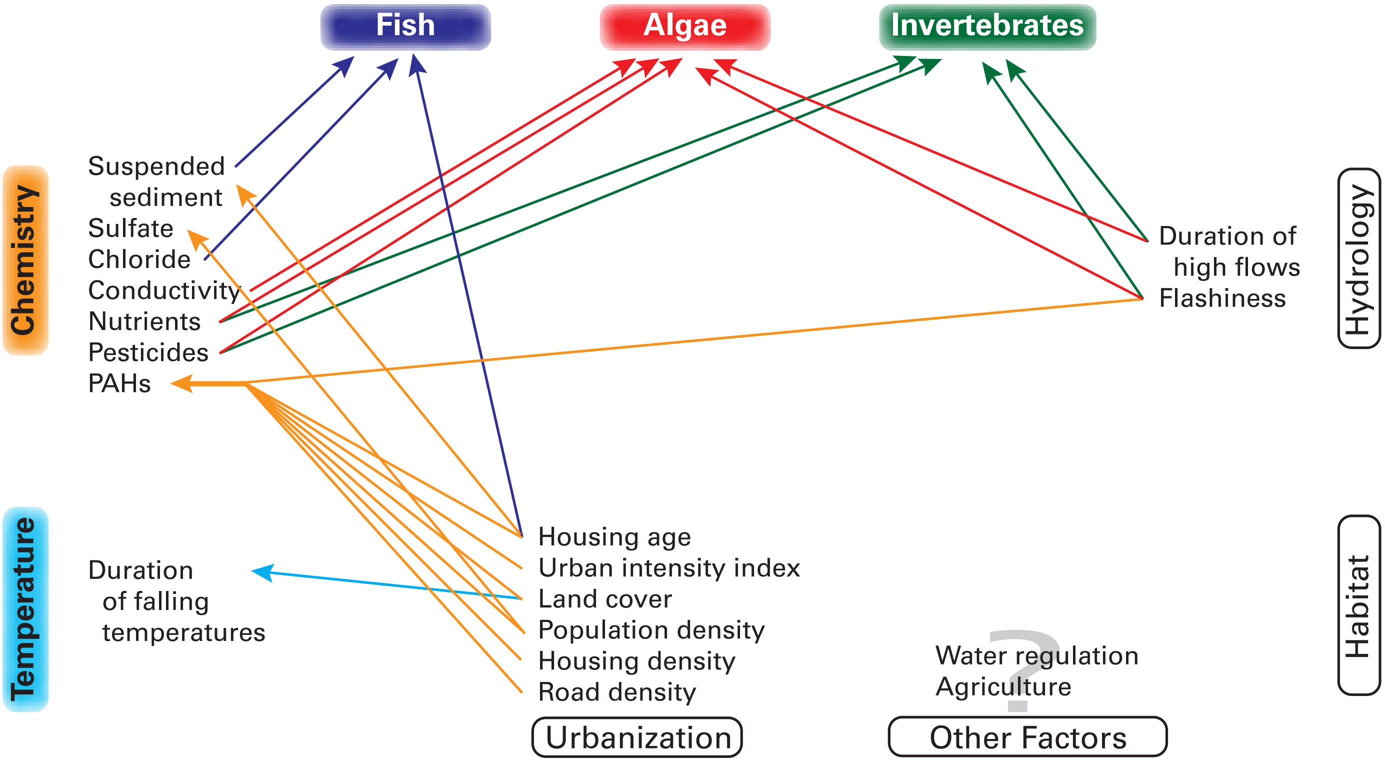


Figure 9. Relations between 52 urban variables, 225 chemistry variables, 50 hydrology variables, 53 habitat variables, 50 stream-temperature variables, 26 fish variables, 19 algae variables, and 30 invertebrate variables. The strong correlations are indicated in this diagram. The punctuation mark, ?, indicates relation unknown.

events. Although there were very few strong correlations between spring/summer base-flow chemistry measures and urbanization, nutrients, pesticides, sulfate, and chloride concentrations were strongly correlated with biological community response (fig. 9). In contrast, SPMD-based measures of potential toxicity and PAH concentrations were strongly correlated with urbanization, but not with biological community response (fig. 9).

None of the biological community variables were strongly correlated with the urban intensity index. One fish-community variable, the percentage of omnivorous invertivores, increased as housing age decreased (fig. 9). Algal biomass was related predominantly to total nitrogen concentrations, nitrite-plus-nitrate concentrations, and the duration of high flows; fish communities were related predominantly to housing age, the percentage of suspended sediment finer than 0.063 millimeter, and chloride concentrations; and invertebrate communities were related predominantly to the frequency of rising and falling flow events, the duration of high flows, total nitrogen concentrations, nitrite-plus-nitrate concentrations, and total herbicide concentrations (fig. 9).

Summary and Conclusions

As land areas urbanize, stream ecosystems can be substantially altered. Impervious surfaces can prevent rainfall from infiltrating into soil and ground water, leading to increased runoff to streams. With rainfall moving to streams more quickly and in greater amounts over these surfaces, changes in stream hydrology, water quality, physical habitat, and water temperature can result. These changes can adversely affect migration, growth, reproduction, species competition, and disease progression within aquatic communities of algae, invertebrates, and fish.

Most previous studies of stream ecosystems have focused on either very pristine areas or highly developed areas; little is known about how the gradual progression of urban development between these two extremes affects stream ecosystems. To address this, the USGS conducted a study from 2002 through 2003 through its National Water-Quality Assessment (NAWQA) Program to determine the effects of urbanization on the physical, chemical, and biological characteristics of stream ecosystems in South Platte River Basin. The 28 study basins were located along the Front Range of the Rocky Mountains in the transition zone between the mountains and the plains. Study basins were chosen to represent (1) a wide range in the degree of urban development and (2) minimal natural variability due to factors such as geology, elevation, and climate, which also can affect steam ecosystems and, therefore, mask the effects of urbanization. Physical characteristics studied included stream hydrology, stream temperature, and habitat; chemical characteristics studied included nutrients, pesticides, suspended sediment, sulfate, chloride, and fecal bacteria concentrations; and biological characteristics studied included algae, invertebrate, and fish communities. Semipermeable membrane devices (SPMDs), passive samplers that concentrate trace levels of hydrophobic organic contaminants like polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), also were used.

Commonly observed effects of urbanization on instream physical, chemical, and biological characteristics generally were not observed in this study. None of the physical characteristics (hydrology, temperature, and habitat) were strongly correlated with the urban intensity index. Only one strong correlation was found between the physical characteristics and individual measures of urbanization—the percentage of high-intensity development in the stream segment was negatively correlated with the duration of falling temperatures. A small number of the hydrologic variables were strongly correlated with some invertebrates and algae variables but not with any fish variables. Measures of stream flashiness and duration of high flows influenced algae communities in depositional areas and lentic invertebrate taxa. None of the habitat or temperature variables were strongly correlated with the invertebrate, algae, or fish-community responses.

None of the spring/summer baseflow chemical variables were strongly correlated with the urban intensity index. In the summer, three water-chemistry variables were strongly correlated with individual measures of urbanization—sulfate concentrations increased in more rapidly growing areas, chloride concentrations increased with decreasing distance from the stream segment to the nearest road, and suspended-sediment concentrations decreased as housing age increased. In the spring, none of the water-chemistry variables were strongly correlated with any individual measure of urbanization. Measures of potential toxicity and PAH concentrations from the SPMDs were strongly and positively correlated with urban intensity. The PAH concentrations also were positively correlated with measures of road density and negatively correlated with distance to the nearest road, indicating that automobile exhaust is most likely the largest source of these constituents in the study area. Automobile sources may be localized enough that the transport of PAHs to the study sites would have been minimally affected by water movement and storage upstream, whereas transport of constituents like nutrients and pesticides to downstream sites may have been subject to greater disruption by water regulation. The disparity in the response to urbanization of SPMD-based chemical measures and spring/summer baseflow chemical measures may be a result of the SPMD deployment period; during the 4- to 6-week deployment period, the SPMDs were exposed to multiple storm-runoff events. Although there were very few strong correlations between spring/summer baseflow chemistry measures and urbanization, nutrients, pesticides, and major ion concentrations were strongly correlated with biological community response. In contrast, SPMD-based measures of potential toxicity and PAH concentrations were strongly correlated with urbanization, but not with biological community response.

None of the biological community variables were strongly correlated with the urban intensity index. One fish-community variable, the percentage of omnivorous invertivores, increased as housing age decreased. Algal biomass was related predominantly to total nitrogen concentrations, nitrite-plus-nitrate concentrations, and the duration of high flows; fish communities were related predominantly to housing age, the percentage of suspended sediment finer than 0.063 millimeter, and chloride concentrations; and invertebrate communities were related predominantly to the frequency of rising and falling flow events, the duration of high flows, total nitrogen concentrations, nitrite-plus-nitrate concentrations, and total herbicide concentrations.

Under natural conditions, aquatic communities in these transition-zone streams likely would be more tolerant than those from less extreme habitats, but historical records indicate that aquatic communities in these streams were more diverse prior to the advent of irrigated agriculture and water regulation. Early surveys noted impaired aquatic communities in this region as early as 1900. Present-day aquatic communities are composed primarily of tolerant species even in areas of minimal urban development; when development does occur, the communities already may be resistant to disturbance. The effects of urbanization on stream ecosystems are stronger in other parts of the world, where development may occur in areas with previously undisturbed and more sensitive aquatic communities.

In addition to the effects of historical stressors on aquatic community structure, it is possible that current (2005) water-regulation practices in the study basins are having an effect. In the absence of natural, unaltered hydrologic conditions, more sensitive taxa may be unable to reestablish in transition-zone streams. In addition, the movement and storage of water may lead to a disconnect between the land surface and streams, resulting in instream physical, chemical, and biological characteristics that are to some degree independent of land-cover characteristics.

Urbanization has been established as a significant stressor on aquatic ecosystems in other parts of the world. The lack of a strong link between urbanization and aquatic ecosystem response in transition-zone streams along the Front Range of Colorado and Wyoming does not mean that urbanization has no effect on aquatic ecosystems in this region. Rather, it is likely that these ecosystems are affected by multiple interacting stressors, including but not limited to urban development, agriculture, and water management. Maintenance or protection of stream ecosystems likely will involve supplementing the best management practices currently used in urbanizing areas with additional steps to mitigate the effects of other stressors that may be as or more important. Identifying the most important stressors ultimately will allow for better management of stream ecosystems in the face of continued urban development.

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Appendix 1

GIS Variables

Table 1.1. Sources of GIS and digital information used to derive study variables.

Basin characteristic	GIS data theme	Data theme source	Scale	Reference or data source
Data sets used to derive basin boundaries				
Watershed boundaries	National Elevation Dataset (NED)	U.S. Geological Survey	24,000	U.S. Geological Survey, 1999, and U.S. Geological Survey Seamless Data Distribution System Web site: *http://seamless.usgs.gov*; data extracted, 2001 and 2005
	Digital Raster Graphics (DRG)	U.S. Geological Survey and National Geographic Society	24,000	National Geographic Society TOPO!® Web site: *http://www.nationalgeographic.com/topo*; data extracted, 2003
	National Watershed Boundary Dataset (WBD)	Natural Resources Conservation Service	24,000	Natural Resources Conservation Service Web site: *http://www.ncgc.nrcs.usda.gov/products/datasets/watershed/*; data extracted, 2004
Data sets used to derive variables				
Infrastructure	Census 2000 Topologically Integrated Geographic Encoding and Referencing system (TIGER) Line® files	U.S. Census Bureau	100,000	Census TIGER site: *http://census.gov/geo/www/tiger/index.html*
	National Pollutant Discharge Elimination System (NPDES)	U.S. Environmental Protection Agency	Unknown, assumed 24,000	U.S. Environmental Protection Agency Envirofacts Web site: *http://www.epa.gov/enviro/index_java.html*; data extracted, 2001
	Toxics Release Inventory (TRI)	U.S. Environmental Protection Agency	Unknown, assumed 24,000	U.S. Environmental Protection Agency Envirofacts Web site: *http://www.epa.gov/enviro/index_java.html*; data extracted, 2001
	National Inventory of Dams (NID)	U.S. Army Corps of Engineers	2,000,000	U.S. Army Corps of Engineers National Inventory of Dams Web site: *http://crunch.tec.army.mil/nid/webpages/nid.cfm*; data extracted, 2005
	Colorado Decision Support System (CDSS) reservoirs	Colorado Division of Water Resources	Unknown, assumed 24,000	Colorado Decision Support System Web site: *http://cdss.state.co.us/*; data extracted, 2004
Land use/land cover, including riparian bufer zone	Multi-Resolution Land Characteristic Data (MRLC), 1992	U.S. Geological Survey	100,000	U.S. Geological Survey Multi-Resolution Land Characteristic Data Web site: *http://gisdata.usgs.net/website/MRLC/*; data extracted, 2001
	National Land Cover Dataset (NLCD), 2001	U.S. Geological Survey	100,000	Falcone, 2005
	National Hydrography Dataset (NHD)	U.S. Geological Survey	100,000	U.S. Geological Survey National Hydrography Dataset Web site: *http://nhd.usgs.gov/*; data extracted, 2005
Demography	Census Blocks and Block Groups 2000, short (SF1) and long forms (SF3)	U.S. Census Bureau	100,000	Geolytics Census 2000 Blocks short form CD and Census CD/DVD 2000 long form
Soil	State Soils Geographic (STATSGO) Database	Natural Resources Conservation Service	250,000	Natural Resources Conservation Service Web site: *http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/*; data extracted, 2002
Hydrologic soil groups	Hydrologic soil groups	Natural Resources Conservation Service	250,000	Natural Resources Conservation Service Web site: *http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/*; data extracted, 2002

Table 1.1. Sources of GIS and digital information used to derive study variables.—Continued

Basin characteristic	GIS data theme	Data theme source	Scale	Reference or data source
		Data sets used to derive variables—Continued		
Hydrologic landscape regions	Hydrologic landscape regions	U.S. Geological Survey	1,000,000	U.S. Geological Survey Web site: *http://water.usgs.gov/GIS/metadata/usgswrd/XML/hlrus.xml*; data extracted, 2001
Ecoregion	Ecoregions	U.S. Environmental Protection Agency	250,000 and 7,500,000	U.S. Environmental Protection Agency Web site: *http://www.epa.gov/wed/pages/ecoregions/level_iii.htm* and *http://www.epa.gov/wed/pages/ecoregions/level_iv.htm*; data extracted, 2001 and 2005; Omernik, 1987
Topography	National Elevation Dataset (NED)	U.S. Geological Survey	24,000	U.S. Geological Survey, 1999, and U.S. Geological Survey Seamless Data Distribution System Web site: *http://seamless.usgs.gov*; data extracted, 2001 and 2005
Stream segment	National Elevation Dataset (NED)	U.S. Geological Survey	24,000	U.S. Geological Survey, 1999, and U.S. Geological Survey Seamless Data Distribution System Web site: *http://seamless.usgs.gov*; data extracted, 2001 and 2005
	National Hydrography Dataset (NHD)	U.S. Geological Survey	100,000	U.S. Geological Survey National Hydrography Dataset Web site: *http://nhd.usgs.gov/*; data extracted, 2005
	National Inventory of Dams (NID)	U.S. Army Corps of Engineers	2,000,000	U.S. Army Corps of Engineers National Inventory of Dams Web site: *http://crunch.tec.army.mil/nid/webpages/nid.cfm*; data extracted, 2005
	Multi-Resolution Land Characteristic Data (MRLC), 1992	U.S. Geological Survey	100,000	U.S. Geological Survey Multi-Resolution Land Characteristic Data Web site: *http://gisdata.usgs.net/website/MRLC/*; data extracted, 2001
	National Land Cover Dataset (NLCD), 2001	U.S. Geological Survey	100,000	Falcone, 2005
	Census Topologically Integrated Geographic Encoding and Referencing system (TIGER) Line® files	U.S. Census Bureau	100,000	U.S. Census Bureau TIGER site: *http://www.census.gov/geo/www/tiger/index.html*; data extracted, 2005
Climate	Daymet Climatological Summaries for the Conterminous United States, 1980–97	University of Montana, Numerical Terradynamic Simulation Group and National Center for Atmospheric Research (NCAR)	1,000-meter grids	Daymet Web site: *http://daymet.ntsg.umt.edu/data/data.htm*; data extracted, 2005
FRAGSTATS	National Land Cover Dataset (NLCD), 2001	U.S. Geological Survey	100,000	Falcone, 2005; FRAGSTATS Web site: *http://www.umass.edu/landeco/research/fragstats/fragstats.html*; data extracted, 2005

Table 1.2. Basin-characteristic variables used for site selection.

[km^2, square kilometers; km, kilometers; NLCD, National Land Cover Dataset; MRLC, Multi-Resolution Land Characteristics; %, percent; cm/cm, centimeters per centimeter; cm/h, centimeters per hour; m, meters; g/m^2, grams per square meter; USDA, U.S. Department of Agriculture; ln, natural logarithm; m/m, meters per meter]

Variable code	Description
	Basin identifier and area variables
COUNT	Cell count, from 30-meter resolution grid defining analysis area
SQKM	Watershed area (km^2)
STREAMMI	Length of stream centerline within watershed (km)
STREAMDEN	Stream density (stream length divided by watershed area [1 divided by km])
	NLCD 1992 riparian buffer variables
P_LCBUF_1	Buffer area in MRLC level 1 category: water (% of watershed riparian buffer)
P_LCBUF_3	Buffer area in MRLC level 1 category: barren or transitional (% of watershed riparian buffer)
P_LCBUF_4	Buffer area in MRLC level 1 category: forest, upland (% of watershed riparian buffer)
P_LCBUF_5	Buffer area in MRLC level 1 category: shrub (% of watershed riparian buffer)
P_LCBUF_7	Buffer area in MRLC level 1 category: herbaceous upland/seminatural vegetation (grasslands) (% of watershed riparian buffer)
P_LCBUF_8	Buffer area in MRLC level 1 category: agricultural/urban grassland (includes all categories in level 1: planted/cultivated class) (% of watershed riparian buffer)
P_LCBUF_9	Buffer area in MRLC level 1 category: wetlands (% of watershed riparian buffer)
	Soil and litho-chemical variables
AWCH	Mean high-range available water capacity (cm/cm)
AWCL	Mean low-range available water capacity (cm/cm)
CLYH	Mean high-range clay (%)
CLYL	Mean low-range clay (%)
KFCH	Mean soil erodibility factor (K factor) including rock fragments (dimensionless)
KFCL	Mean soil erodibility factor (K factor) not including rock fragments (dimensionless)
ORMH	Mean high-range organic matter (%)
ORML	Mean low-range organic matter (%)
PERH	Mean high-range permeability (cm/h)
PERL	Mean low-range permeability (cm/h)
SNDH	Mean high-range sand (%)
SNDL	Mean low-range sand (%)
SAND	Average sand (%) with respect to centroid of field-assessed texture
CLAY	Average clay (%) with respect to centroid of field-assessed texture
WTDH	Mean high-range depth to water table (m)
WTDL	Mean low-range depth to water table (m)
SOC100CM	Soil organic carbon, first 100-centimeter soil depth (g/m^2)
SOCM30CM	Soil organic carbon, first 30-centimeter soil depth (g/m^2)
P_TEXTURE1	Simplified USDA soil texture classification (Shirazi): coarse (% of watershed)
P_TEXTURE2	Simplified USDA soil texture classification (Shirazi): moderately coarse (% of watershed)

Table 1.2. Basin-characteristic variables used for site selection.—Continued

[km^2, square kilometers; km, kilometers; NLCD, National Land Cover Dataset; MRLC, Multi-Resolution Land Characteristics; %, percent; cm/cm, centimeters per centimeter; cm/h, centimeters per hour; m, meters; g/m^2, grams per square meter; USDA, U.S. Department of Agriculture; ln, natural logarithm; m/m, meters per meter]

Variable code	Description
	Soil and litho-chemical variables—Continued
P_TEXTURE3	Simplified USDA soil texture classification (Shirazi): medium coarse (% of watershed)
P_TEXTURE4	Simplified USDA soil texture classification (Shirazi): moderately fine (% of watershed)
P_TEXTURE5	Simplified USDA soil texture classification (Shirazi): fine (% of watershed)
P_HSG_1	Hydrologic soil group A: minimum infiltration rate 8–12 millimeters per hour (% of watershed)
P_HSG_2	Hydrologic soil group B: minimum infiltration rate 4–8 millimeters per hour (% of watershed)
P_HSG_3	Hydrologic soil group C: minimum infiltration rate 1–4 millimeters per hour (% of watershed)
P_HSG_4	Hydrologic soil group D: minimum infiltration rate 0–1 millimeter per hour (% of watershed)
	Ecoregion variables (Wyoming level III and draft Colorado level IV)
P_ECO_21	Omernik's level III: Southern Rockies, undifferentiated (% of watershed)
P_ECO_25	Omernik's level III: Western High Plains, undifferentiated (% of watershed)
P_ECO_211	Omernik's level IV: Southern Rockies, high-elevation tundra (% of watershed)
P_ECO_212	Omernik's level IV: Southern Rockies, cool and moist forests of the middle to high elevations (% of watershed)
P_ECO_213	Omernik's level IV: Southern Rockies, warm and dry forests of the middle to low elevations (% of watershed)
P_ECO_214	Omernik's level IV: Southern Rockies, low- to middle-elevation semidesert shrublands (% of watershed)
P_ECO_251	Omernik's level IV: Western High Plains, rolling sand plains (% of watershed)
P_ECO_252	Omernik's level IV: Western High Plains, moderate relief rangeland (% of watershed)
P_ECO_253	Omernik's level IV: Western High Plains, flat to rolling cropland (% of watershed)
P_ECO_261	Omernik's level IV: Southwestern Tablelands, grasslands (% of watershed)
	Hydrologic landscape region variables
P_HL_2	Hydrologic landscape region 2: wet plains having highly permeable surface and moderately permeable subsurface (% of watershed)
P_HL_5	Hydrologic landscape region 5: arid plains having moderately permeable surface and moderately to highly permeable subsurface (% of watershed)
P_HL_6	Hydrologic landscape region 6: wet plains having poorly permeable surface and poorly permeable subsurface (% of watershed)
P_HL_8	Hydrologic landscape region 8: semiarid plains having poorly permeable surface and poorly permeable subsurface (% of watershed)
P_HL_10	Hydrologic landscape region 10: semiarid plateaus having moderately to poorly permeable surface and highly permeable subsurface (% of watershed)
P_HL_12	Hydrologic landscape region 12: semiarid plateaus having highly to moderately permeable surface and poorly permeable subsurface (% of watershed)
P_HL_13	Hydrologic landscape region 13: semiarid plateaus having poorly permeable surface and poorly permeable subsurface (% of watershed)
P_HL_17	Hydrologic landscape region 17: semiarid mountains having moderately permeable surface and poorly permeable subsurface (% of watershed)
P_HL_18	Hydrologic landscape region 18: variably wet mountains having moderately permeable surface and poorly permeable subsurface (% of watershed)
	1992 Land-use/land-cover variables
P_MRLC_1	Aggregated MRLC level 1 category: water (% of watershed)
P_MRLC_3	Aggregated MRLC level 1 category: barren or transitional (% of watershed)
P_MRLC_4	Aggregated MRLC level 1 category: forest (% of watershed)
P_MRLC_5	Aggregated MRLC level 1 category: shrub (% of watershed)
P_MRLC_6	Aggregated MRLC level 1 category: orchard (includes all categories in level 1: nonnatural woody class) (% of watershed)

Table 1.2. Basin-characteristic variables used for site selection.—Continued

[km^2, square kilometers; km, kilometers; NLCD, National Land Cover Dataset; MRLC, Multi-Resolution Land Characteristics; %, percent; cm/cm, centimeters per centimeter; cm/h, centimeters per hour; m, meters; g/m^2, grams per square meter; USDA, U.S. Department of Agriculture; ln, natural logarithm; m/m, meters per meter]

Variable code	Description
	1992 Land-use/land-cover variables—Continued
P_MRLC_7	Aggregated MRLC level 1 category: herbaceous upland natural/seminatural vegetation (grassland) (% of watershed)
P_MRLC_8	Aggregated MRLC level 1 category: agricultural/urban grassland (includes all categories in level 1: planted/cultivated class) (% of watershed)
P_MRLC_9	Aggregated MRLC level 1 category: wetlands (% of watershed)
P_MRLC_11	Watershed area in open water (% of watershed)
P_MRLC_31	Watershed area in bare rock/sand/clay (% of watershed)
P_MRLC_32	Watershed area in quarries/strip mines/gravel pits (% of watershed)
P_MRLC_33	Watershed area in transitional cover (% of watershed)
P_MRLC_41	Watershed area in deciduous forest (% of watershed)
P_MRLC_42	Watershed area in evergreen forest (% of watershed)
P_MRLC_43	Watershed area in mixed forest (% of watershed)
P_MRLC_51	Watershed area in deciduous shrubland (% of watershed)
P_MRLC_61	Watershed area in orchards/vineyards/other (% of watershed)
P_MRLC_71	Watershed area in grasslands/herbaceous (% of watershed)
P_MRLC_81	Watershed area in pasture/hay (% of watershed)
P_MRLC_82	Watershed area in row crops (% of watershed)
P_MRLC_83	Watershed area in small grains (% of watershed)
P_MRLC_84	Watershed area in fallow (% of watershed)
P_MRLC_85	Watershed area in urban/recreational grasses (% of watershed)
P_MRLC_91	Watershed area in woody wetlands (% of watershed)
P_MRLC_92	Watershed area in emergent herbaceous wetlands (% of watershed)
	Topographic variables
MIN_ELEV	Minimum watershed elevation (m)
MAX_ELEV	Maximum watershed elevation (m)
MEANELEV	Mean watershed elevation (m)
RELIEF	Watershed relief (maximum minus minimum elevation) (m)
MIDPOINT	Midpoint elevation, calculated as the sum of minimum elevation and relief divided by 2
PFLATLOW	% of watershed area that is flat (slope less than 1 percent) and low (elevation less than midpoint)
P_FLATUP	% of watershed area that is flat (slope less than 1 percent) and upland (elevation greater than or equal to midpoint)
P_FLAT	% of watershed area that is flat (slope less than 1 percent)
SLOPE_X	Mean watershed slope (%)
WET_MEAN	Mean value of wetness index across all cells in watershed (ln [watershed area above cell divided by gradient of upstream cells])
WET_STD	Standard deviation of wetness index across all cells in watershed (ln [watershed area above cell divided by gradient of upstream cells])
	Segment variables
VGRAD	Estimated valley gradient of calculated segment (m/m)

Table 1.3. Cluster analysis groups and comparison of group characteristics for the eight clusters developed from 275 preliminary study basins.

[1–8, cluster group number; A, hydrologic soil group A consists of soils derived from well to excessively drained sands or gravels and have a low runoff potential and high infiltration rates; B, hydrologic soil group B consists of moderately well to well-drained soils with a moderately fine to moderately coarse texture and a moderate infiltration rate; C, hydrologic soil group C includes layers that impede downward water movement and have low infiltration rates; D, hydrologic soil group D consists of clayey soils that have a very low infiltration rate; WHPE, Western High Plains Ecoregion]

Cluster group	1	2	3	4	5	6	7	8
Slope	Variable, mild to steep	Generally steep	Rolling	Moderate, flat to rolling	Flat to mild	Flat to mild	Flat to mild	Flat to mild
Valleys	Generally narrow, variably steeper	Narrow, variably steeper	Narrow, variably steeper	Narrow, variably steeper	Wide, low gradient	Wide, low gradient	Wide, low gradient	Variably wider, low gradient
Topography	Variably higher divides	Generally high, highest divides	Higher outlets, generally higher divides	Variably higher outlets, variably higher divides	Generally lower	Generally lower	Generally lower	Lowest
Land cover	More grassland than croplands, variable percentage urban	More forest than grasslands	Much more grasslands than croplands	Grass dominant	Much more croplands than grasslands, some riparian	More croplands than grasslands, variably percentage riparian	Much more grasslands than croplands	Much more grasslands than croplands
Soil texture	Clayey, moderately fine texture dominant	Moderately sandy, moderately coarse much more than moderately fine	Variable, moderately coarse more than medium coarse texture	Sandy, moderately coarse texture dominant	Less sandy, medium coarse texture dominant	Moderately sandy, moderately coarse much more than moderately fine	Moderately sandy, medium coarse very dominant	Very sandy, moderately coarse dominant
Hydrologic soil groups A, B, C, or D	C dominant, low infiltration	C = D > B, dominantly low to very low infiltration rates	B > C, moderate infiltration rate	Variable, B > D, moderate infiltration rate	B = C, moderate to low infiltration rate	B > C, moderate infiltration rate	Variable, B > C, moderate infiltration rate	A dominantly, high infiltration rate

Table 1.3. Cluster analysis groups and comparison of group characteristics for the eight clusters developed from 275 preliminary study basins.—Continued

[1–8, cluster group number; A, hydrologic soil group A consists of soils derived from well to excessively drained sands or gravels and have a low runoff potential and high infiltration rates; B, hydrologic soil group B consists of moderately well to well-drained soils with a moderately fine to moderately coarse texture and a moderate infiltration rate; C, hydrologic soil group C includes layers that impede downward water movement and have low infiltration rates; D, hydrologic soil group D consists of clayey soils that have a very low infiltration rate; WHPE, Western High Plains Ecoregion]

Cluster group	1	2	3	4	5	6	7	8
Hydrologic landscape	Variable, dominantly semiarid plateaus, high-moderately permeable surface, poorly permeable subsurface	Variable dominantly variably wet mountains, moderately permeable surface, poorly permeable subsurface	Dominantly semiarid plateaus, high-moderately permeable surface, poorly permeable subsurface	Dominantly semiarid plateaus having moderately to poorly permeable surface, poorly permeable subsurface	Variable, dominantly semiarid plateaus, high-moderately permeable surface, poorly permeable subsurface	Dominantly arid plains, moderately permeable surface, moderately to highly permeable subsurface	Variable, semiarid plains with permeable soils and impermeable bedrock, to a lesser extent arid plains with permeable soils and bedrock	Variable dominantly semiarid plateaus, high-moderately permeable surface, poorly permeable subsurface
Ecoregions	Variable, WHPE cropland dominates WHPE moderate relief rangeland	Variable, Southern Rockies Ecoregion much more represented than WHPE	Variable, mainly WHPE moderate relief rangeland, some Southwestern Tablelands Ecoregion grasslands, and lesser WHPE cropland	WHPE moderate relief rangeland dominant	WHPE cropland dominant	WHPE cropland dominant	WHPE moderate relief rangeland dominant	Variable, WHPE sand plains very dominant over cropland
Particular traits	Clayey soil, mountain plains transition, some basins head in mountains	Head in mountains	Upper rangeland over Denver Basin	Upper rangeland over High Plains	Cropland, best soil	Cropland, permeable rocks, arid plains with permeable soils and bedrock	Lower rangeland	Sandy soil, lower rangeland

Table 1.4. Variables used to derive the urban intensity index used for site selection.

[TIGER, Topologically Integrated Geographic Encoding and Referencing system; km, kilometers; CFCC, Census Feature Class Code; km^2, square kilometers; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; MRLC, Multi-Resolution Land Characteristics; %, percent]

Variable code	Description
	Infrastructure variables
RAWMILES	Cartographic road length in watershed (kilometers): length of 2000 TIGER roads within watershed (km)
RDLENGTH	Road network length in watershed (kilometers): road length $_i$ = SUM $_j$ (length $_{ij}$ multiplied by vehicle network weight $_{ij}$) for watershed $_i$ and CFCC TIGER code $_j$ (km)
RDARINDX	Road area index in watershed (weighted kilometers): road area index $_i$ = SUM $_j$ (length $_{ij}$ multiplied by surface area weight $_{ij}$) for watershed $_i$ and CFCC TIGER code $_j$
RDTRINDX	Road traffic index in watershed (weighted kilometers): road traffic index $_i$ = SUM $_j$ (length $_{ij}$ multiplied by vehicular traffic weight $_{ij}$) for watershed $_i$ and CFCC TIGER code $_j$
ROADDEN	Road density in watershed = (RDLENGTH [kilometers] divided by watershed area [km^2])
RDARDEN	Road area index in watershed normalized by watershed area (index sum per square kilometer) = (RDARINDX divided by watershed area [km^2])
RDTRDEN	Road traffic index in watershed normalized by watershed area (index sum per square kilometer) = (RDTRINDX divided by watershed area [km^2])
PSCOUNT	Number of point source dischargers in watershed (USEPA database–National Pollutant Discharge Elimination System [NPDES])
TRICOUNT	Number of Toxics Release Inventory sites in watershed
	NLCD 1992 riparian buffer variables
P_LCBUF_2	Buffer area in MRLC level 1 category: developed (% of watershed riparian buffer)
	1992 Land-use/land-cover variables
P_MRLC_2	Aggregated MRLC level 1 category: developed (% of watershed)
P_MRLC_21	Watershed area in low-intensity residential (% of watershed)
P_MRLC_22	Watershed area in high-intensity residential (% of watershed)
P_MRLC_23	Watershed area in commercial/industrial/transportation (% of watershed)
	1990 Census block and block-group variables
POP2000	2000 Population (2000 census block based)
POP1990	1990 Population (2000 census block based)
POP90_00	Proportional change in population from 1990–2000 (2000 census block based)
POPDEN00	2000 Population density (people per square mile) (2000 census block based)
SEI_1_90	Socioeconomic Index 1 (first principal component) (1990 census block-group based)
SEI_2_90	Socioeconomic Index 2 (second principal component) (1990 census block-group based)
SEI_3_90	Socioeconomic Index 3 (third principal component) (1990 census block-group based)
SEI_4_90	Socioeconomic Index 4 (fourth principal component) (1990 census block-group based)
PCTBCH	% of population who have bachelor's degrees or higher, 1990 (1990 census block-group based)

Table 1.4. Variables used to derive the urban intensity index used for site selection.—Continued

[TIGER, Topologically Integrated Geographic Encoding and Referencing system; km, kilometers; CFCC, Census Feature Class Code; km^2, square kilometers; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; MRLC, Multi-Resolution Land Characteristics; %, percent]

Variable code	Description
	1990 Census block and block-group variables—Continued
P_65P90	% of 1990 population 65 years and over (1990 census block-group based)
P_WRK16	% of persons 16 and older in the workforce, 1990 (1990 census block-group based)
MEDHHI89	Median household income, 1989 (dollars) (1990 census block-group based)
PERCAP90	Per capita income, 1989 (dollars) (1990 census block-group based)
P_POV90	% of all persons below poverty level, 1990 (1990 census block-group based)
MEDAGE99	Median age of population, 1999 (years) (1990 census block-group based)
PHHI_14	% of households with income less than 14,999 (dollars), 1990 (1990 census block-group based)
PHHI_100	% of households with income greater than 100,000 (dollars), 1990 (1990 census block-group based)
P_FHHF90	% of families with female head of household, 1990 (1990 census block-group based)
P_OWN90	% of occupied housing units that are owner occupied, 1990 (1990 census block-group based)
P_RENT90	% of occupied housing units that are renter occupied, 1990 (1990 census block-group based)
P_NWHT90	% of 1990 population who are nonwhite (1990 census block-group based)
ANNEX99	Average annual household expenditures, 1999 (dollars) (1990 census block-group based)
FPCTWF	% females 16 years old and older in work force, 1990 (1990 census block-group based)

Table 1.5. Variables used to derive the final urban intensity index.

[UII, Urban Intensity Index; mi^2, square miles; km^2, square kilometers; TIGER, Topologically Integrated Geographic Encoding and Referencing system; CFCC, Census Feature Class Code; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; +, positively correlated with population density; –, negatively correlated with population density; %, percent]

Variable code	Description	Included in final UII value
	Basin area variables	
SQKM	Watershed area (km^2)	
	Infrastructure variables	
RAWMILES	Cartographic road length in watershed (kilometers): length of 2000 TIGER roads within watershed (km)	
RDLENGTH	Road network length in watershed (kilometers): road length $_i$ = SUM $_j$ (length $_{ij}$ multiplied by vehicle network weight $_{ij}$) for watershed $_i$ and CFCC TIGER code $_j$ (km)	
RDARINDX	Road area index in watershed (weighted kilometers): road area index $_i$ = SUM $_j$ (length $_{ij}$ multiplied by road surface weight $_{ij}$) for watershed $_i$ and CFCC TIGER code $_j$	
RDTRINDX	Road traffic index in watershed (weighted kilometers): road traffic index $_i$ = SUM $_j$ (length $_{ij}$ multiplied by vehicular traffic weight $_{ij}$) for watershed $_i$ and CFCC TIGER code $_j$	
ROADDEN	Road density in watershed (RDLENGTH [kilometers] divided by watershed area [km^2])	
RDARDEN	Road area index in watershed normalized by watershed area (index sum per square kilometer)	+
RDTRDEN	Road traffic index in watershed normalized by watershed area (index sum per square kilometer)	
PSCOUNT	Number of point source dischargers in watershed (USEPA database–National Pollutant Discharge Elimination System [NPDES])	
TRICOUNT	Number of Toxics Release Inventory sites in watershed	
RESCOUNT	Number of reservoirs in watershed (Colorado Decision Support System database)	
	NLCD 2001 riparian buffer variables	
NLCD1_B1	Buffer area in aggregated NLCD 2001 level 1 category: water (km^2)	
NLCD1_B2	Buffer area in aggregated NLCD 2001 level 1 category: developed (km^2)	
NLCD1_B3	Buffer area in aggregated NLCD 2001 level 1 category: barren (includes all level 2 barren and unconsolidated categories) (km^2)	
NLCD1_B4	Buffer area in aggregated NLCD 2001 level 1 category: forest (km^2)	
NLCD1_B5	Buffer area in aggregated NLCD 2001 level 1 category: shrubland (includes all level 2 shrub and scrub categories) (km^2)	
NLCD1_B7	Buffer area in aggregated NLCD 2001 level 1 category: herbaceous upland natural/seminatural vegetation (includes all level 2 categories 70–79) (km^2)	
NLCD1_B8	Buffer area in aggregated NLCD 2001 level 1 category: herbaceous planted/cultivated (km^2)	
NLCD1_B9	Buffer area in aggregated NLCD 2001 level 1 category: wetlands (km^2)	
NLCD_BIS	NLCD 2001 mean % impervious surface within buffer area	
	NLCD 2001 land-use/land-cover variables	
NLCD1_1	Aggregated NLCD 2001 level 1 category: water (km^2)	
NLCD1_2	Aggregated NLCD 2001 level 1 category: developed (km^2)	+
NLCD1_3	Aggregated NLCD 2001 level 1 category: barren (includes all level 2 barren and unconsolidated categories) (km^2)	
NLCD1_4	Aggregated NLCD 2001 level 1 category: forest (km^2)	
NLCD1_5	Aggregated NLCD 2001 level 1 category: shrubland (includes all level 2 shrub and scrub categories) (km^2)	
NLCD1_7	Aggregated NLCD 2001 level 1 category: herbaceous upland natural/seminatural vegetation (includes all level 2 categories 70–79) (km^2)	–

Table 1.5. Variables used to derive the final urban intensity index.—Continued

[UII, Urban Intensity Index; mi^2, square miles; km^2, square kilometers; TIGER, Topologically Integrated Geographic Encoding and Referencing system; CFCC, Census Feature Class Code; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; +, positively correlated with population density; –, negatively correlated with population density; %, percent]

Variable code	Description	Included in final UII value
	NLCD 2001 land-use/land-cover variables—Continued	
NLCD1_8	Aggregated NLCD 2001 level 1 category: herbaceous planted/cultivated (km^2)	–
NLCD1_9	Aggregated NLCD 2001 level 1 category: wetlands (km^2)	
NLCD2_11	Watershed area in NLCD 2001: water, open water (km^2)	
NLCD2_21	Watershed area in NLCD 2001: water, open space (km^2)	
NLCD2_22	Watershed area in NLCD 2001: developed, low intensity (km^2)	
NLCD2_23	Watershed area in NLCD 2001: developed, medium intensity (km^2)	
NLCD2_24	Watershed area in NLCD 2001: developed, high intensity (km^2)	
NLCD2_31	Watershed area in NLCD 2001: barren, rock/clay/sand (km^2)	
NLCD2_41	Watershed area in NLCD 2001: forest, deciduous forest (km^2)	
NLCD2_42	Watershed area in NLCD 2001: forest, evergreen forest (km^2)	
NLCD2_43	Watershed area in NLCD 2001: forest, mixed forest (km^2)	
NLCD2_52	Watershed area in NLCD 2001: shrubland, shrub/scrub (km^2)	
NLCD2_71	Watershed area in NLCD 2001: herbaceous upland natural/seminatural vegetation, grasslands/herbaceous (km^2)	
NLCD2_81	Watershed area in NLCD 2001: herbaceous planted/cultivated, pasture/hay (km^2)	
NLCD2_82	Watershed area in NLCD 2001: herbaceous planted/cultivated, cultivated crops (km^2)	
NLCD2_90	Watershed area in NLCD 2001: wetlands, woody wetlands (km^2)	
NLCD2_95	Watershed area in NLCD 2001: wetlands, emergent herbaceous wetlands (km^2)	–
NLCD_IS	NLCD 2001 mean % impervious surface within watershed area	
	2000 Census block and block-group variables	
POP2000	2000 Population (2000 census block based)	
POP1900	1990 Population (1990 census block based)	
POP90_00	Proportional change in population from 1990–2000 (2000 census block based)	+
POPDEN00	2000 Population density (people per square kilometer) (2000 census block based)	
POPDEN90	1990 Population density (people per square kilometer) (2000 census block based)	
HHDEN	Household density (occupied housing units per square kilometer) (2000 census block-group based)	
HUDEN	Density of housing units (housing units per square kilometer) (2000 census block-group based)	+
PPURBAN	% of population living in urban area (2000 census block-group based)	+
PPRURAL	% of population living in rural area (2000 census block-group based)	
PHH2	% of households that are two-person households (2000 census block-group based)	–
PHH3	% of households that are three-person households (2000 census block-group based)	
PHH4	% of households that are four-person households (2000 census block-group based)	
PHH5	% of households that are five-person households (2000 census block-group based)	

Table 1.5. Variables used to derive the final urban intensity index.—Continued

[UII, Urban Intensity Index; mi^2, square miles; km^2, square kilometers; TIGER, Topologically Integrated Geographic Encoding and Referencing system; CFCC, Census Feature Class Code; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; +, positively correlated with population density; –, negatively correlated with population density; %, percent]

Variable code	Description	Included in final UII value
	2000 Census block and block-group variables—Continued	
PHH6	% of households that are six-person households (2000 census block-group based)	
PHH7	% of households that are seven-person households (2000 census block-group based)	
PHO_L3P	% of households occupied by less than three people (2000 census block-group based)	
PHO_G4P	% of households occupied by four or more people (2000 census block-group based)	
PP_SH95	% of population living in same house as in 1995 (2000 census block-group based)	
PC_CTY95	% of citizens living in same county more more than 5 years (since 1995) (2000 census block-group based)	
PC_ST95	% of citizens living in same State more more than 5 years (since 1995) (2000 census block-group based)	+
PDRIVE	% of workers age 16 or greater who drive to work alone (2000 census block-group based)	
PCARPOOL	% of workers age 16 or greater who carpool to work (2000 census block-group based)	
PPUBTRAN	% of workers age 16 or greater who use public transportation to work (2000 census block-group based)	
PMCONST	% of population greater than 16 years old who are males employed in construction (2000 census block-group based)	
PMMFG	% of population greater than 16 years old who are males employed in manufacturing (2000 census block-group based)	
PMRETAIL	% of population greater than 16 years old who are males employed in retail (2000 census block-group based)	+
PMPROF	% of population greater than 16 years old who are males employed in professional, scientific, management, administration, waste-management services (2000 census block-group based)	
PMEDUC	% of population greater than 16 years old who are males employed in educational, health, and social services (2000 census block-group based)	
PFCONST	% of population greater than 16 years old who are females employed in construction (2000 census block-group based)	
PFMFG	% of population greater than 16 years old who are females employed in manufacturing (2000 census block-group based)	
PFRETAIL	% of population greater than 16 years old who are females employed in retail (2000 census block-group based)	
PFPROF	% of population greater than 16 years old who are females employed in professional, scientific, management, administration, waste-management services (2000 census block-group based)	
PFEDU	% of population greater than 16 years old who are females employed in educational, health, and social services	
P_OCCUPY	% of housing units that are occupied (2000 census block-group based)	
P_VACANT	% of housing units that are vacant (2000 census block-group based)	
PH_1PERS	% of households occupied by one person (2000 census block-group based)	
PH_2PERS	% of households occupied by two persons (2000 census block-group based)	–
PH_3PERS	% of households occupied by three persons (2000 census block-group based)	
PH_4PERS	% of households occupied by four persons (2000 census block-group based)	
PH_5PERS	% of households occupied by five persons (2000 census block-group based)	
PH_6PERS	% of households occupied by six persons (2000 census block-group based)	
PH_7PERS	% of households occupied by seven or more persons (2000 census block-group based)	
PHU_L5	% of housing units built between 1995–2000 (2000 census block-group based)	

Table 1.5. Variables used to derive the final urban intensity index.—Continued

[UII, Urban Intensity Index; mi^2, square miles; km^2, square kilometers; TIGER, Topologically Integrated Geographic Encoding and Referencing system; CFCC, Census Feature Class Code; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; +, positively correlated with population density; –, negatively correlated with population density; %, percent]

Variable code	Description	Included in final UII value
	2000 Census block and block-group variables—Continued	
PHU_L10	% of housing units built between 1990–2000 (2000 census block-group based)	
PHU_L20	% of housing units built between 1980–2000 (2000 census block-group based)	
PHU_G20	% of housing units built prior to 1979 (1939 or earlier to 1979) (2000 census block-group based)	
PHU_G30	% of housing units built prior to 1969 (1939 or earlier to 1969) (2000 census block-group based)	
PHU_G40	% of housing units built prior to 1959 (1939 or earlier to 1959) (2000 census block-group based)	
PHU_G50	% of housing units built prior to 1949 (1939 or earlier to 1949) (2000 census block-group based)	
PHU_G60	% of housing units built prior to 1939 (2000 census block-group based)	–
PHUT	% of occupied housing units using utility gas (natural gas) as fuel (2000 census block-group based)	
PHLP	% of occupied housing units using liquid petroleum gas as fuel (2000 census block-group based)	–
PHEL	% of occupied housing units using electricity as fuel (2000 census block-group based)	
PHOIL	% of occupied housing units using oil as fuel (2000 census block-group based)	
PHWOOD	% of occupied housing units using wood as fuel (2000 census block-group based)	–
P_HU0RM	% of total housing units that have zero bedrooms (2000 census block-group based)	
P_HU1RM	% of total housing units that have one bedroom (2000 census block-group based)	
P_HU2RM	% of total housing units that have two bedrooms (2000 census block-group based)	
P_HU3RM	% of total housing units that have three bedrooms (2000 census block-group based)	–
P_HU4RM	% of total housing units that have four bedrooms (2000 census block-group based)	
P_HU5RM	% of total housing units that have five bedrooms (2000 census block-group based)	
PERCAPIN	Per capita income (2000 census block-group based)	

Table 1.6. Final environmental variables used in data analysis.

[km^2, square kilometers; km, kilometers; TIGER, Topologically Integrated Geographic Encoding and Referencing system; CFCC, Census Feature Class Code; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; %, percent; cm/cm, centimeters per centimeter; cm/h, centimeters per hour; USDA, United States Department of Agriculture; m, meters; g/m^2, grams per square meter; MRLC, Multi-Resolution Land Characteristics; ln, natural logarithm; log10, logarithm to the base 10; m/km, meters per kilometer]

Variable code	Description
	Basin area variables
SQKM	Area of watershed within the Western High Plains ecoregion (km^2)
FULLBA	Area of entire watershed, not just portion within the Western High Plains ecoregion (km^2)
	Infrastructure variables
RAWMILES	Cartographic road length in watershed (kilometers): length of 2000 TIGER roads within watershed (km)
RDLENGTH	Road network length in watershed (kilometers): road length$_i$ = SUM$_j$ (length$_{ij}$ multiplied by vehicle network weight$_{ij}$) for watershed$_i$ and CFCC TIGER code$_j$ (km)
RDARINDX	Road area index in watershed (weighted kilometers): road area index$_i$ = SUM$_j$ (length$_{ij}$ multiplied by surface area weight$_{ij}$) for watershed$_i$ and CFCC TIGER code$_j$
RDTRINDX	Road traffic index in watershed (weighted kilometers): road traffic index$_i$ = SUM$_j$ (length$_{ij}$ multiplied by vehicular traffic weight$_{ij}$) for watershed$_i$ and CFCC TIGER code$_j$
ROADDEN	Road density in watershed = (RDLENGTH [kilometers] divided by watershed area [km^2])
RDARDEN	Road area index in watershed normalized by watershed area (index sum per square kilometer) = (RDARINDX divided by watershed area [km^2])
RDTRDEN	Road traffic index in watershed normalized by watershed area (index sum per square kilometer) = (RDTRINDX divided by watershed area [km^2])
D_PSCOUNT	Number of point source dischargers in watershed (USEPA database–National Pollutant Discharge Elimination System [NPDES]) (number per 100 km^2)
D_DAMCOUNT	Number of dams in watershed (number per 100 km^2)
D_TRICOUNT	Number of Toxics Release Inventory sites in watershed (number per 100 km^2)
D_RESCOUNT	Number of reservoirs in watershed (number per 100 km^2)
D_DIVCOUNT	Number of active diversions in watershed (number per 100 km^2)
	NLCD 2001 riparian buffer variables
P_NLCD1_B2	Buffer area in aggregated NLCD 2001 level 1 category: developed (% of watershed riparian buffer)
P_NLCD_BIS	NLCD 2001 mean % impervious surface within buffer area
	2001 Land-use/land-cover variables
P_NLCD1_2	Aggregated NLCD 2001 level 1 category: developed (% of watershed)
P_NLCD2_21	Watershed area in NLCD 2001: developed, open space (% of watershed)
P_NLCD2_22	Watershed area in NLCD 2001: developed, low intensity (% of watershed)
P_NLCD2_23	Watershed area in NLCD 2001: developed, medium intensity (% of watershed)
P_NLCD2_24	Watershed area in NLCD 2001: developed, high intensity (% of watershed)
P_NLCD_IS	NLCD 2000 mean % impervious surface within watershed area
	2000 Census block and block-group variables
POP2000	2000 Population (2000 census block-based)
POP1990	1990 Population (2000 census block based)
POP90_00	Proportional change in population from 1990–2000 (2000 census block based)
POPDEN00	2000 Population density (people per square mile) (2000 census block based)
POPDEN90	1990 Population density (people per square mile) (2000 census block based)

Table 1.6. Final environmental variables used in data analysis.—Continued

[km^2, square kilometers; km, kilometers; TIGER, Topologically Integrated Geographic Encoding and Referencing system; CFCC, Census Feature Class Code; USEPA, U.S. Environmental Protection Agency; NLCD, National Land Cover Dataset; %, percent; cm/cm, centimeters per centimeter; cm/h, centimeters per hour; USDA, United States Department of Agriculture; m, meters; g/m^2, grams per square meter; MRLC, Multi-Resolution Land Characteristics; ln, natural logarithm; log10, logarithm to the base 10; m/km, meters per kilometer]

Variable code	Description
	2000 Census block and block-group variables—Continued
HHDEN	Household density (occupied housing units per square kilometer) (2000 census block-group based)
HUDEN	Density of housing units (housing units/square kilometer) (2000 census block-group based)
PPURBAN	% of population living in urban area (2000 census block-group based)
PHU_L5	% of housing units built between 1995–2000 (2000 census block-group based)
PHU_L10	% of housing units built between 1990–2000 (2000 census block-group based)
PHU_L20	% of housing units built between 1980–2000 (2000 census block-group based)
PHU_G20	% of housing units built prior to 1979 (1939 or earlier to 1979) (2000 census block-group based)
PHU_G30	% of housing units built prior to 1969 (1939 or earlier to 1969) (2000 census block-group based)
PHU_G40	% of housing units built prior to 1959 (1939 or earlier to 1959) (2000 census block-group based)
PHU_G50	% of housing units built prior to 1949 (1939 or earlier to 1949) (2000 census block-group based)
PHU_G60	% of housing units built prior to 1939 (2000 census block-group based)
	NLCD 2001 segment variables
NLCD_S21	% NLCD 2001: developed, open space in stream segment buffer (90 meters on each side of stream; stream is an additional 30-meter cell)
NLCD_S22	% NLCD 2001: developed, low intensity in stream segment buffer (90 meters on each side of stream; stream is an additional 30-meter cell)
NLCD_S23	% NLCD 2001: developed, medium intensity in stream segment buffer (90 meters on each side of stream; stream is an additional 30-meter cell)
NLCD_S24	% NLCD 2001: developed, high intensity in stream segment buffer (90 meters on each side of stream; stream is an additional 30-meter cell)
	Segment variables
SEG_DAM	U.S. Army Corps of Engineers National Inventory of Dams (NID) identifier of dam in segment if dam is present
SEG_DAMD	Dam distance upstream (m)
SEG_RSX	Number of road-stream intersections per stream segment
SEG_RSXK	Number of road-stream intersections per stream segment kilometer
SEG_RMD	Mean distance from stream segment to nearest road
	FRAGSTATS variables[1]
PD_U	Patch density - class 2 - urban
LPI_U	Largest patch index - class 2 - urban
PAM_U	Mean patch area - class 2 - urban
EDM_U	Euclidean nearest neighbor distance, mean - class 2 - urban
PLA_U	Proportion of like adjacencies - class 2 - urban

[1] See table 1.7 in Appendix 1 for detailed descriptions of Fragstats variables.

Table 1.7. Detailed definitions of FRAGSTATS variables. See table 1.1 in Appendix 1 for reference.

[%, percent; ha, hectares; m, meters]

FRAGSTATS variable	Definition
Patch	Discrete areas of homogeneous land-cover types that differ from their surroundings
Patch density	Number of patches per 100 hectares of watershed area
Largest patch index	% of basin area composed of the largest patch
Mean patch area	Mean patch area (ha)
Euclidean nearest neighbor distance, mean	Mean nearest neighbor distance for patches comprising the land-cover class (m). Measure of how dispersed the patches are.
Proportion of like adjacencies	% of patch adjacencies that are the same land-cover class. If patches are surrounded by similar patches, this will be a high number. If patches are mostly surrounded by a different kind of patch, it will be a low number.

Appendix 2

Physical Variables

Table 2.1. Stream-hydrology variables.

[POR, period of record; log, logarithm; m^2, square meters; <, less than; >, greater than; m^2/d, square meters per day; ≥, greater than or equal to; hr, hour]

Variable code	Definition
	Measures of central tendency, variability, and magnitude
a_cv	Coefficient of variation of cross-sectional area over all hours in POR
a_skew	Skew of cross-sectional area over all hours in POR
a_cv_log	Coefficient of variation of hourly cross-sectional-area values, where cross-sectional-area values are equal to log of 1 plus cross-sectional area
a_coeff_disp	(75th-percentile cross-sectional area minus 25th-percentile cross-sectional area), divided by median cross-sectional area (dimensionless)
a_mean	Mean cross-sectional-area value over POR (m^2)
a_pct_50	Median (50th-percentile) cross-sectional-area value over POR (m^2)
a_pct_99n	99th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_pct_95n	95th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_pct_90n	90th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_pct_75n	75th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_pct_25n	25th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_pct_10n	10th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_pct_5n	5th-percentile cross-sectional-area value over POR, divided by median cross-sectional-area value over POR (dimensionless)
a_sum_5	Number of hours over POR with cross-sectional area <5th-percentile cross-sectional-area value
a_sum_10	Number of hours over POR with cross-sectional area <10th-percentile cross-sectional-area value
a_sum_25	Number of hours over POR with cross-sectional area <25th-percentile cross-sectional-area value
a_sum_75	Number of hours over POR with cross-sectional area >75th-percentile cross-sectional-area value
a_sum_90	Number of hours over POR with cross-sectional area >90th-percentile cross-sectional-area value
a_sum_95	Number of hours over POR with cross-sectional area >95th-percentile cross-sectional-area value
	Measures of flashiness
a_day_pctchange	Sum of the absolute value of the relative change in daily mean cross-sectional area, divided by the daily mean cross-sectional area (dimensionless)
a_rb_flash	Version of Richards-Baker flashiness index (Baker and others, 2004), calculated as the sum of the absolute value of the relative change in daily mean cross-sectional area, divided by the sum of the daily mean cross-sectional area for the POR (dimensionless)
a_cummulative_change	Sum of the absolute value of the total rise and fall in cross-sectional area over POR (m^2)
a_cumm_median	Sum of the absolute value of the total rise and fall in cross-sectional area over POR, divided by median cross-sectional area over POR (dimensionless)
a_cumm_day	Sum of the absolute value of the total rise and fall in cross-sectional area over POR, divided by the number of days in record (m^2/d)
a_periodr1	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥1 multiplied by the median rise over POR (number of hourly time periods)
a_periodr3	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥3 multiplied by the median rise over POR (number of hourly time periods)
a_periodr5	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥5 times the median rise over POR (number of hourly time periods)
a_periodr7	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥7 multiplied by the median rise over POR (number of hourly time periods)
a_periodr9	Frequency of rising cross-sectional-area events, where hourly cross-sectional-area change is ≥9 multiplied by the median rise over POR (number of hourly time periods)

Table 2.1. Stream-hydrology variables.—Continued

[POR, period of record; log, logarithm; m^2, square meters; <, less than; >, greater than; m^2/d, square meters per day; ≥, greater than or equal to; hr, hour]

Variable code	Definition
	Measures of flashiness—Continued
a_periodf1	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥1 multiplied by the median fall over POR (number of hourly time periods)
a_periodf3	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥3 multiplied by the median fall over POR (number of hourly time periods)
a_periodf5	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥5 multiplied by the median fall over POR (number of hourly time periods)
a_periodf7	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥7 multiplied by the median fall over POR (number of hourly time periods)
a_periodf9	Frequency of falling cross-sectional-area events, where hourly cross-sectional-area change is ≥9 multiplied by the median fall over POR (number of hourly time periods)
a_maxrise	Maximum duration of consecutive periods of rising cross-sectional area over POR (hr)
a_medianrise	Median duration of consecutive periods of rising cross-sectional area over POR (hr)
a_maxfall	Maximum duration of consecutive periods of falling cross-sectional area over POR (hr)
a_medianfall	Median duration of consecutive periods of falling cross-sectional area over POR (hr)
	Duration of high-flow conditions
a_MXH_75	Maximum duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >75th percentile
a_MXH_90	Maximum duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >90th percentile
a_MXH_95	Maximum duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >95th percentile
a_MDH_75	Median duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >75th percentile
a_MDH_90	Median duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >90th percentile
a_MDH_95	Median duration of high cross-sectional-area pulses over POR (hr); high cross-sectional area >95th percentile
	Duration of low-flow conditions
a_MXL_25	Maximum duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <25th percentile
a_MXL_10	Maximum duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <10th percentile
a_MXL_5	Maximum duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <5th percentile
a_MDL_25	Median duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <25th percentile
a_MDL_10	Median duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <10th percentile
a_MDL_5	Median duration of low cross-sectional-area pulses over POR (hr); low cross-sectional area <5th percentile

Table 2.2. Stream-temperature variables.

[POR, period of record; log, logarithm; °C, degrees Celsius; <, less than; >, greater than; °C/d, degrees Celsius per day; ≥, greater than or equal to; hr, hour]

Variable code	Definition
	Measures of central tendency, variability, and magnitude
t_cv	Coefficient of variation of stream temperature over all hours in POR
t_skew	Skew of stream temperature over all hours in POR
t_cv_log	Coefficient of variation of hourly stream-temperature values, where stream-temperature values are equal to log of 1 plus stream temperature
t_coeff_disp	(75th-percentile stream temperature minus 25th-percentile stream temperature), divided by median stream temperature (dimensionless)
t_mean	Mean stream-temperature value over POR (°C)
t_pct_50	Median (50th-percentile) stream-temperature value over POR (°C)
t_pct_99n	99th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_95n	95th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_90n	90th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_75n	75th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_25n	25th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_10n	10th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_5n	5th-percentile stream-temperature value over POR, divided by median stream-temperature value over POR (dimensionless)
t_pct_99a	99th-percentile stream-temperature value over POR (°C)
t_pct_95a	95th-percentile stream-temperature value over POR (°C)
t_pct_90a	90th-percentile stream-temperature value over POR (°C)
t_pct_75a	75th-percentile stream-temperature value over POR (°C)
t_pct_25a	25th-percentile stream-temperature value over POR (°C)
t_pct_10a	10th-percentile stream-temperature value over POR (°C)
t_pct_5a	5th-percentile stream-temperature value over POR (°C)
t_sum_5	Number of hours over POR with stream temperature <5th-percentile stream-temperature value
t_sum_10	Number of hours over POR with stream temperature <10th-percentile stream-temperature value
t_sum_25	Number of hours over POR with stream temperature <25th-percentile stream-temperature value
t_sum_75	Number of hours over POR with stream temperature >75th-percentile stream-temperature value
t_sum_90	Number of hours over POR with stream temperature >90th-percentile stream-temperature value
t_sum_95	Number of hours over POR with stream temperature >95th-percentile stream-temperature value
	Measures of flashiness
t_day_pctchange	Sum of the absolute value of the relative change in daily mean stream temperature, divided by the daily mean stream temperature (dimensionless)
t_rb_flash	Version of Richards-Baker flashiness index (Baker and others, 2004), calculated as the sum of the absolute value of the relative change in daily mean stream temperature, divided by the sum of the daily mean stream temperature for the POR (dimensionless)
t_cummulative_change	Sum of the absolute value of the total rise and fall in stream temperature over POR (°C)
t_cumm_median	Sum of the absolute value of the total rise and fall in stream temperature over POR, divided by median stream temperature over POR (dimensionless)
t_cumm_day	Sum of the absolute value of the total rise and fall in stream temperature over POR, divided by the number of days in record (°C/d)
t_periodr1	Frequency of rising stream-temperature events, where hourly stream-temperature change is ≥1 multiplied by the median rise over POR (number of hourly time periods)

Table 2.2. Stream-temperature variables.—Continued

[POR, period of record; log, logarithm; °C, degrees Celsius; <, less than; >, greater than; °C/d, degrees Celsius per day; ≥, greater than or equal to; hr, hour]

Variable code	Definition
	Measures of flashiness—Continued
t_periodr3	Frequency of rising stream-temperature events, where hourly stream-temperature change is ≥3 multiplied by the median rise over POR (number of hourly time periods)
t_periodr5	Frequency of rising stream-temperature events, where hourly stream-temperature change is ≥5 times the median rise over POR (number of hourly time periods)
t_periodr7	Frequency of rising stream-temperature events, where hourly stream-temperature change is ≥7 multiplied by the median rise over POR (number of hourly time periods)
t_periodr9	Frequency of rising stream-temperature events, where hourly stream-temperature change is ≥9 multiplied by the median rise over POR (number of hourly time periods)
t_periodf1	Frequency of falling stream-temperature events, where hourly stream-temperature change is ≥1 multiplied by the median fall over POR (number of hourly time periods)
t_periodf3	Frequency of falling stream-temperature events, where hourly stream-temperature change is ≥3 multiplied by the median fall over POR (number of hourly time periods)
t_periodf5	Frequency of falling stream-temperature events, where hourly stream-temperature change is ≥5 multiplied by the median fall over POR (number of hourly time periods)
t_periodf7	Frequency of falling stream-temperature events, where hourly stream-temperature change is ≥7 multiplied by the median fall over POR (number of hourly time periods)
t_periodf9	Frequency of falling stream-temperature events, where hourly stream-temperature change is ≥9 multiplied by the median fall over POR (number of hourly time periods)
t_maxrise	Maximum duration of consecutive periods of rising stream temperature over POR (hr)
t_medianrise	Median duration of consecutive periods of rising stream temperature over POR (hr)
t_maxfall	Maximum duration of consecutive periods of falling stream temperature over POR (hr)
t_medianfall	Median duration of consecutive periods of falling stream temperature over POR (hr)
	Duration of high-temperature conditions
t_MXH_75	Maximum duration of high stream-temperature pulses over POR (hr); high stream temperature >75th percentile
t_MXH_90	Maximum duration of high stream-temperature pulses over POR (hr); high stream temperature >90th percentile
t_MXH_95	Maximum duration of high stream-temperature pulses over POR (hr); high stream temperature >95th percentile
t_MDH_75	Median duration of high stream-temperature pulses over POR (hr); high stream temperature >75th percentile
t_MDH_90	Median duration of high stream-temperature pulses over POR (hr); high stream temperature >90th percentile
t_MDH_95	Median duration of high stream-temperature pulses over POR (hr); high stream temperature >95th percentile
	Duration of low-temperature conditions
t_MXL_25	Maximum duration of low stream-temperature pulses over POR (hr); low stream temperature <25th percentile
t_MXL_10	Maximum duration of low stream-temperature pulses over POR (hr); low stream temperature <10th percentile
t_MXL_5	Maximum duration of low stream-temperature pulses over POR (hr); low stream temperature <5th percentile
t_MDL_25	Median duration of low stream-temperature pulses over POR (hr); low stream temperature <25th percentile
t_MDL_10	Median duration of low stream-temperature pulses over POR (hr); low stream temperature <10th percentile
t_MDL_5	Median duration of low stream-temperature pulses over POR (hr); low stream temperature <5th percentile

Table 2.3. Habitat variables.

[%, percent; m, meters; m/km^2, meters per square kilometer; m^2, square meters; m^2/km^2, square meters per square kilometer; m^3/s, cubic meters per second; >, greater than; mm, millimeters; m/s, meters per second]

Variable code	Definition
	Bank characteristics
BankErosPct	Occurrence of bank erosion (%)
BankVegCovAvg	Mean bank vegetative cover (%)
BankSub	Bank substrate type
BankAngle	Bank angle (degrees)
BankHt	Bank height (m)
	Bankfull channel characteristics
BFWidthAvg	Mean bankfull channel width (m)
BFWidthDA	Mean bankfull channel width divided by drainage area (m/km^2) (excluding pools)
BFDepthAvg	Mean bankfull depth (m)
BFDepthDA	Mean bankfull depth divided by drainage area (m/km^2) (excluding pools)
BFWidthDepthAvg	Mean bankfull-channel width-depth ratio for reach (dimensionless)
BFArea	Mean bankfull channel cross-sectional area (m^2)
BFAreaDA	Mean bankfull channel cross-sectional area divided by drainage area (m^2/km^2) (excluding pools)
	Discharge
DischM3Sec	Instantaneous discharge (m^3/s)
	Embeddedness
EmbedPctAvg	Mean embeddedness (%)
	Flow stability
FlowStbl	Flow stability = depth of water at low flow divided by bankfull depth (dimensionless)
FlowStblAvg	Mean flow stability ratio
CHStbl	Channel stability = ratio of mean bankfull to wetted cross-sectional areas
	Froude
Froude	Froude number = mean flow velocity divided by [(acceleration due to gravity multiplied by mean depth of water) exponent $^{0.5}$]
	Gradient
WaterSurfGrad	Reach water-surface gradient (dimensionless)
	Hydraulic radius
HydRadAvg	Mean wetted channel hydraulic radius (m)
	Habitat cover
HabCvrPtAnyPct	% occurrence of transect points having at least one habitat cover feature
HabCvrPtAMPct	% occurrence of aquatic macrophyte habitat cover feature for reach
HabCvrPtBOPct	% occurrence of boulder habitat cover feature for reach
HabCvrPtMSPct	% occurrence of manmade structure habitat cover feature for reach
HabCvrPtOVPct	% occurrence of points having overhanging vegetation habitat cover feature for reach
HabCvrPtUBPct	% occurrence of points having undercut bank habitat cover feature for reach
HabCvrPtWDPct	% occurrence of woody debris instream habitat cover feature for reach
	Manning's roughness
ManRoughAvg	Mean Manning's roughness for reach = (mean hydraulic radius exponent $^{2/3}$) multiplied by (water-surface gradient exponent $^{0.5}$) divided by mean reach velocity
	Riparian vegetation
CanClosrBnkAvg	Mean canopy closure, bank readings (left bank shade, right bank shade) (%)
OCanAngleAvg	Mean open-canopy angle (degrees)
OCanAngleCv	Coefficient of variation of open-canopy angle
RipLu	Riparian land use = disturbed land cover in 30-meter buffer (%, out of 22 transect endpoints)
	Substrate
SiltCovPct	% occurrence of transect points where silt layer was observed on streambed
DomSub1Pct	% occurrence of transect points where the dominant substrate consists of smooth bedrock/concrete/hardpan
DomSub2Pct	% occurrence of transect points where the dominant substrate consists of silt/clay/marl/muck/organic detritus

Table 2.3. Habitat variables.—Continued

[%, percent; m, meters; m/km^2, meters per square kilometer; m^2, square meters; m^2/km^2, square meters per square kilometer; m^3/s, cubic meters per second; >, greater than; mm, millimeters; m/s, meters per second]

Variable code	Definition
	Substrate—Continued
DomSub3Pct	% occurrence of transect points where the dominant substrate consists of sand (>0.062–2 mm)
DomSub4Pct	% occurrence of transect points where the dominant substrate consists of fine/medium gravel (>2–16 mm)
DomSub5Pct	% occurrence of transect points where the dominant substrate consists of coarse gravel (>16–32 mm)
DomSub6Pct	% occurrence of transect points where the dominant substrate consists of very coarse gravel (>32–64 mm)
DomSub7Pct	% occurrence of transect points where the dominant substrate consists of small cobble (>64–128 mm)
DomSub8Pct	% occurrence of transect points where the dominant substrate consists of large cobble (>128–256 mm)
DomSub9Pct	% occurrence of transect points where the dominant substrate consists of small boulder (>256–512 mm)
DomSub10Pct	% occurrence of transect points where the dominant substrate consists of large boulder, irregular bedrock, irregular hardpan, irregular artificial surface (>512 mm)
	Velocity
VelocAvg	Mean velocity (m/s)
VelocCv	Coefficient of variation of velocity
	Wetted channel characteristics
WidthWetAvg	Mean wetted channel width (m)
DepthAvg	Mean wetted channel depth (m)
DepthCv	Coefficient of variation of wetted channel depth
WidthDepthAvg	Mean wetted-channel width-depth ratio of reach
WetPerimAvg	Mean perimeter of wetted channel (m)
WetXAreaAvg	Mean wetted cross-sectional area of channel (m^2)
WetShape	Wetted channel shape = (wetted channel width divided by mean depth of water) exponent $^{\text{(mean depth of water divided by maximum depth of water)}}$ (dimensionless)
WetShapeAvg	Mean wetted channel shape (dimensionless)

Appendix 3

Chemical Variables

Table 3.1. Water-chemistry variables.

[USGS, U.S. Geological Survey, na, not applicable; ft^3/s, cubic feet per second; na, not applicable; °C, degrees Celsius; col/100mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; mm, millimeters; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, U.S. Geological Survey parameter code not available]

Variable code	Description	USGS parameter code	Chemical class	Use	Parent compound
	Field parameters				
INSTDIS	Discharge, instantaneous (ft^3/s)	00061	na	na	na
WTEMP	Temperature, water (°C)	00010	na	na	na
ECOLI	*Escherichia coli*, modified m-TEC membrane filtration method, water (col/100mL)	90902	na	na	na
DISSOX	Dissolved oxygen, water, unfiltered (mg/L)	00300	na	na	na
PH	pH, water, unfiltered, field (standard units)	00400	na	na	na
SPCOND	Specific conductance, water, unfiltered (µS/cm)	00095	na	na	na
	Suspended sediment				
PCTFINES	Suspended sediment, sieve diameter (% smaller than 0.063 mm)	70331	na	na	na
SUSSED	Suspended sediment concentration (mg/L)	80154	na	na	na
	Major ions				
CHLOR	Chloride, water, filtered (mg/L)	00940	na	na	na
SULFA	Sulfate, water, filtered (mg/L)	00945	na	na	na
	Nutrients				
TKNITR	Ammonia plus organic nitrogen, water, unfiltered (mg/L as N)	00625	na	na	na
AMMON	Ammonia, water, filtered (mg/L as N)	00608	na	na	na
NITRATE	Nitrate, water, filtered (mg/L as N)	00618	na	na	na
NOX	Nitrite plus nitrate, water, filtered (mg/L as N)	00631	na	na	na
NITRITE	Nitrite, water, filtered (mg/L as N)	00613	na	na	na
ORTHOP	Orthophosphate, water, filtered (mg/L as P)	00671	na	na	na
PARTN	Particulate nitrogen, suspended in water (mg/L as N)	49570	na	na	na
TOTALP	Phosphorus, water, unfiltered (mg/L as P)	00665	na	na	na
TOTALN	Total nitrogen, water, unfiltered (mg/L as N)	00600	na	na	na
	Carbon				
TPARTC	Carbon (inorganic plus organic), particulate, total (mg/L)	00694	na	na	na
PINORGC	Inorganic carbon, particulate, total (mg/L)	00688	na	na	na
PORGC	Organic carbon, particulate, total (mg/L)	00689	na	na	na
DISORGC	Organic carbon, water, filtered (mg/L)	00681	na	na	na
	Pesticides				
NAPHT	1-Naphthol, water, filtered, recoverable (µg/L)	49295	Phenol	Degradate	Carbaryl, napropamide
DIETH	2,6-Diethylaniline, water, filtered, recoverable (µg/L)	82660	Degradate	Degradate	Alachlor
PROPA	2-[(2-Ethyl-6-methylphenyl)-amino]-1-propanol, water, filtered, recoverable (µg/L)	61615	Aniline	Degradate	Metolachlor

Table 3.1. Water-chemistry variables.—Continued

[USGS, U.S. Geological Survey, na, not applicable; ft^3/s, cubic feet per second; na, not applicable; °C, degrees Celsius; col/100mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; mm, millimeters; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, U.S. Geological Survey parameter code not available]

Variable code	Description	USGS parameter code	Chemical class	Use	Parent compound
	Pesticides—Continued				
CHLDI	2-Chloro-2’,6’-diethylacetanilide, water, filtered, recoverable (µg/L)	61618	Acetanilide	Degradate	Alachlor
CHLIS	2-Chloro-4-isopropylamino-6-amino-s-triazine, water, filtered, recoverable (µg/L)	04040	Triazine	Degradate	Atrazine
ETHYL	2-Ethyl-6-methylaniline, water, filtered, recoverable (µg/L)	61620	Aniline	Degradate	Metolachlor
DICHL	3,4-Dichloroaniline, water, filtered, recoverable (µg/L)	61625	Aniline	Degradate	Diuron/propanil/linuron/neburon
CHLME	4-Chloro-2-methylphenol, water, filtered, recoverable (µg/L)	61633	Phenol	Degradate	MCPA/MCPB
ACETO	Acetochlor, water, filtered, recoverable (µg/L)	49260	Acetanilide	Herbicide	na
ALACH	Alachlor, water, filtered, recoverable (µg/L)	46342	Acetanilide	Herbicide	na
ATRAZ	Atrazine, water, filtered, recoverable (µg/L)	39632	Triazine	Herbicide	na
AZMEO	Azinphos-methyl oxygen analog, water, filtered, recoverable (µg/L)	61635	Organophosphate	Degradate	Azinphos-methyl
AZMET	Azinphos-methyl, water, filtered, recoverable (µg/L)	82686	Organophosphate	Insecticide	na
BENFL	Benfluralin, water, filtered, recoverable (µg/L)	82673	Dinitroaniline	Herbicide	na
CARBA	Carbaryl, water, filtered, recoverable (µg/L)	82680	Carbamate	Insecticide	na
CHLOX	Chlorpyrifos oxygen analog, water, filtered, recoverable (µg/L)	61636	Organophosphate	Degradate	Chlorpyrifos
CHLOP	Chlorpyrifos, water, filtered, recoverable (µg/L)	38933	Organophosphate	Insecticide	na
PERME	cis-Permethrin, water, filtered, recoverable (µg/L)	82687	Pyrethroid	Insecticide	na
CYFLU	Cyfluthrin, water, filtered, recoverable (µg/L)	61585	Pyrethroid	Insecticide	na
CYPER	Cypermethrin, water, filtered, recoverable (µg/L)	61586	Pyrethroid	Insecticide	na
DCPA	Dacthal (DCPA), water, filtered, recoverable (µg/L)	82682	Chlorobenzoic acid ester	Herbicide	na
DESFI	Desulfinyl fipronil, water, filtered, recoverable (µg/L)	62170	Phenyl pyrazole	Degradate	Fipronil
DIAZO	Diazinon oxygen analog, water, filtered, recoverable (µg/L)	61638	Organophosphate	Degradate	Diazinon
DIAZI	Diazinon, water, filtered, recoverable (µg/L)	39572	Organophosphate	Insecticide	na
DICRO	Dicrotophos, water, filtered, recoverable (µg/L)	38454	Organophosphate	Insecticide	na
DIELD	Dieldrin, water, filtered, recoverable (µg/L)	39381	Organochlorine	Insecticide/degradate	Aldrin
DIMET	Dimethoate, water, filtered, recoverable (µg/L)	82662	Organophosphate	Insecticide	na
ETHIM	Ethion monoxon, water, filtered, recoverable (µg/L)	61644	Organophosphate	Degradate	Ethion
ETHIO	Ethion, water, filtered, recoverable (µg/L)	82346	Organophosphate	Insecticide	na
FENSN	Fenamiphos sulfone, water, filtered, recoverable (µg/L)	61645	Organophosphate	Degradate	Fenamiphos
FENSX	Fenamiphos sulfoxide, water, filtered, recoverable (µg/L)	61646	Organophosphate	Degradate	Fenamiphos
FENAM	Fenamiphos, water, filtered, recoverable (µg/L)	61591	Organophosphate	Nematocide	na

Table 3.1. Water-chemistry variables.—Continued

[USGS, U.S. Geological Survey, na, not applicable; ft^3/s, cubic feet per second; na, not applicable; °C, degrees Celsius; col/100mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; mm, millimeters; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, U.S. Geological Survey parameter code not available]

Variable code	Description	USGS parameter code	Chemical class	Use	Parent compound
		Pesticides—Continued			
DESAM	Desulfinylfipronil amide, water, filtered, recoverable (µg/L)	62169	Phenyl pyrazole	Degradate	Fipronil
FIPSD	Fipronil sulfide, water, filtered, recoverable (µg/L)	62167	Phenyl pyrazole	Degradate	Fipronil
FIPSN	Fipronil sulfone, water, filtered, recoverable (µg/L)	62168	Phenyl pyrazole	Degradate	Fipronil
FIPRO	Fipronil, water, filtered, recoverable (µg/L)	62166	Phenyl pyrazole	Insecticide	na
FONOX	Fonofos oxygen analog, water, filtered, recoverable (µg/L)	61649	Organophosphate	Degradate	Fonofos
FONOF	Fonofos, water, filtered, recoverable (µg/L)	04095	Organophosphate	Insecticide	na
HEXAZ	Hexazinone, water, filtered, recoverable (µg/L)	04025	Triazine	Herbicide	na
IPROD	Iprodione, water, filtered, recoverable (µg/L)	61593	Dicarboximide	Fungicide	na
ISOFE	Isofenphos, water, filtered, recoverable (µg/L)	61594	Organophosphate	Insecticide	na
MALAO	Malaoxon, water, filtered, recoverable (µg/L)	61652	Organophosphate	Degradate	Malathion
MALAT	Malathion, water, filtered, recoverable (µg/L)	39532	Organophosphate	Insecticide	na
METAL	Metalaxyl, water, filtered, recoverable (µg/L)	61596	Amino acid derivative	Fungicide	na
METHI	Methidathion, water, filtered, recoverable (µg/L)	61598	Organophosphate	Insecticide	na
METPX	Methyl paraoxon, water, filtered, recoverable (µg/L)	61664	Organophosphate	Degradate	Methyl parathion
METPT	Methyl parathion, water, filtered, recoverable (µg/L)	82667	Organophosphate	Insecticide	na
METOL	Metolachlor, water, filtered, recoverable (µg/L)	39415	Acetanilide	Herbicide	na
METRI	Metribuzin, water, filtered, recoverable (µg/L)	82630	Triazine	Herbicide	na
MYCLO	Myclobutanil, water, filtered, recoverable (µg/L)	61599	Triazole	Fungicide	na
PENDI	Pendimethalin, water, filtered, recoverable (µg/L)	82683	Dinitroaniline	Herbicide	na
PHOOX	Phorate oxygen analog, water, filtered, recoverable (µg/L)	61666	Organophosphate	Degradate	Phorate
PHORA	Phorate, water, filtered, recoverable (µg/L)	82664	Organophosphate	Insecticide	na
PHOSO	Phosmet oxygen analog, water, filtered, recoverable (µg/L)	61668	Organophosphate	Degradate	Phosmet
PHOSM	Phosmet, water, filtered, recoverable (µg/L)	61601	Organophosphate	Insecticide	na
PROME	Prometon, water, filtered, recoverable (µg/L)	04037	Triazine	Herbicide	na
PROMY	Prometryn, water, filtered, recoverable (µg/L)	04036	Triazine	Herbicide	na
PRONA	Pronamide, water, filtered, recoverable (µg/L)	82676	Amide	Herbicide	na
SIMAZ	Simazine, water, filtered, recoverable (µg/L)	04035	Triazine	Herbicide	na
TEBUT	Tebuthiuron, water, filtered, recoverable (µg/L)	82670	Urea	herbicide	na
TERBO	Terbufos oxygen analog sulfone, water, filtered, recoverable (µg/L)	61674	Organophosphate	Degradate	Terbufos
TERBF	Terbufos, water, filtered, recoverable (µg/L)	82675	Organophosphate	Insecticide	na

Table 3.1. Water-chemistry variables.—Continued

[USGS, U.S. Geological Survey, na, not applicable; ft³/s, cubic feet per second; na, not applicable; °C, degrees Celsius; col/100mL, colonies per 100 milliliters; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; mm, millimeters; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; --, U.S. Geological Survey parameter code not available]

Variable code	Description	USGS parameter code	Chemical class	Use	Parent compound
		Pesticides—Continued			
TERBU	Terbuthylazine, water, filtered, recoverable (µg/L)	04022	Triazine	Herbicide	na
TRIFL	Trifluralin, water, filtered, recoverable (µg/L)	82661	Dinitroaniline	Herbicide	na
DICHL	Dichlorvos, water, filtered, recoverable (µg/L)	38775	Organophosphate	Insecticide, fumigant, degradate	Naled
TPCONC	Total pesticide concentration (µg/L)	--	na	na	na
THCONC	Total herbicide concentration (µg/L)	--	na	na	na
TICONC	Total insecticide concentration (µg/L)	--	na	na	na
NUMP	Number of pesticides detected	--	na	na	na
NUMH	Number of herbicides detected	--	na	na	na
NUMI	Number of insecticides detected	--	na	na	na
		Pesticide toxicity indices			
PTIINV	Pesticide toxicity index for benthic invertebrates	--	na	na	na
PTIFISH	Pesticide toxicity index for freshwater fish	--	na	na	na

Table 3.2. Semipermeable membrane device-based chemistry and toxicity variables.

[SPMD, semipermeable membrane device; na, not applicable; EC_{50}, concentration at which 50 percent of test organisms exhibited nonlethal response; EI, electron ionization; ECNI, electron-capture negative ionization]

Variable code	Definition	Ionization technique
	Toxicity	
SPMDTEQ	SPMD toxicity, CYP1A1 production (toxic equivalents)	na
SPMDUV	SPMD toxicity, ultraviolet fluourescence (micrograms pyrene)	na
SPMDEC50	SPMD toxicity, Microtox assay (EC_{50})	na
	Chemistry[1]	
S_14DICH	1,4-Dichlorobenzene	EI
S_1MENAP	1-Methylnapthalene	EI
S_DMENAP	2,6-Dimethylnapthalene	EI
S_2MBENZ	2-Methyl benzothiophene	EI
S_2MENAP	2-Methylnapthalene	EI
S_34DICH	3,4-Dichlorophenyl isocyanate	EI
S_CUMYL	4-Cumylphenol	EI
S_OCTYL	4-Octylphenol	EI
S_TOCTYL	4-tert-Octylphenol	EI
S_MHBENZ	5-Methyl-1H-benzotriazone	EI
S_ACET	Acetophenone	EI
S_AHTN	Acetyl hexamethyl tetrahydronaphthalene (AHTN)	EI
S_ALDRIN	Aldrin	ECNI
S_AHCH	Alpha-HCH	ECNI
S_ANTHRC	Anthracene	EI
S_ANTHRQ	Anthraquinone	EI
S_BDE100	2,2’,4,4’,6-Pentabromodiphenyl ether (BDE 100)	ECNI
S_BDE153	2,2’,4,4’,5,5’-Hexabromodiphenyl ether (BDE 153)	ECNI
S_BDE154	2,2’,4,4’,5,6’-Hexabromodiphenyl ether (BDE 154)	ECNI
S_BDE47	2,2´,4,4´-Tetrabromodiphenyl ether (BDE 47)	ECNI
S_BDE99	2,2’,4,4’,5-Pentabromodipenyl ether (BDE 99)	ECNI
S_BENFL	Benfluralin	ECNI
S_BAPYR	Benzo-(a)-pyrene	EI
S_BENZO	Benzophenone	EI
S_BCOPR	Beta-coprostanol	EI
S_BHCH	Beta-HCH	ECNI
S_BSITO	Beta-sitosterol	EI
S_BHA	3-tert-Butyl-4-hydroxy anisole (BHA)	EI
S_BISPH	Bisphenol A	EI
S_BROMA	Bromacil	EI
S_BROMO	Bromoform	EI
S_CAFF	Caffeine	EI
S_CAMPH	Camphor	EI
S_CARBA	Carbaryl	EI
S_CARBAZ	Carbazole	EI
S_CHLOP	Chlorpyrifos	ECNI
S_CHOL	Cholesterol	EI
S_CCHLOR	cis-Chlordane	ECNI
S_CNONAC	cis-Nonachlor	ECNI
S_COTIN	Cotinine	EI

Table 3.2. Semipermeable membrane device-based chemistry and toxicity variables.—Continued

[SPMD, semipermeable membrane device; na, not applicable; EC_{50}, concentration at which 50 percent of test organisms exhibited nonlethal response; EI, electron ionization; ECNI, electron-capture negative ionization]

Variable code	Definition	Ionization technique
	Chemistry[1]—Continued	
S_CUMEN	Cumene	EI
S_DCPA	Dacthal (DCPA)	ECNI
S_DHCH	Delta-HCH	ECNI
S_DIAZI	Diazinon	EI
S_DIELD	Dieldrin	ECNI
S_DPHTA	Diethyl phtalate	EI
S_DHPHTA	Diethylhexyl phthalate	EI
S_DEET	N,N-Diethyl-meta-toluamide (DEET)	EI
S_DPYRAZ	Diphenyl pyrazole	EI
S_LIMO	d-Limonene	EI
S_ENDOI	Endosulfan I	ECNI
S_ENDOII	Endosulfan II	ECNI
S_ENDOSF	Endosulfan sulfate	ECNI
S_ENDRN	Endrin	ECNI
S_ENDRNA	Endrin aldehyde	ECNI
S_ENDRNK	Endrin ketone	ECNI
S_ETHPH	Ethanol, 2-butoxy-, phosphosphate	EI
S_ECITR	Ethyl citrate	EI
S_FIPRO	Fipronil	ECNI
S_FLUOR	Fluoranthene	EI
S_GHCH	Gamma-HCH	ECNI
S_HCB	Hexachlorobenzene (HCB)	ECNI
S_HEPTEP	Heptachlor epoxide	ECNI
S_HHCB	Hexahydrohexamethylcyclopentabenzopyran (HHCB)	EI
S_INDOLE	Indole	EI
S_ISOBO	Isoborneol	EI
S_ISOPHO	Isophorone	EI
S_ISOQU	Isoquinoline	EI
S_MENTH	Menthol	EI
S_METAL	Metalaxyl	EI
S_MSALI	Methyl salicylate	EI
S_METOL	Metolachlor	EI
S_MIREX	Mirex	ECNI
S_NAPTH	Napthalene	EI
S_NPEO1	Nonylphenol monoethoxylate (NPEO1)	EI
S_NPEO2	Nonylphenol diethoxylate (NPEO2)	EI
S_OPDDD	o,p’-DDD	ECNI
S_OPDDE	o,p’-DDE	ECNI
S_OPDDT	o,p’-DDT	ECNI
S_OCTSTY	Octachlorostyrene	ECNI
S_OPEO1	Octylphenol monoethoxylate (OPEO1)	EI
S_OPEO2	Octylphenol diethoxylate (OPEO2)	EI
S_OXYCHL	Oxychlordane	ECNI
S_PPDDD	p,p’-DDD	ECNI
S_PPDDE	p,p’-DDE	ECNI

Table 3.2. Semipermeable membrane device-based chemistry and toxicity variables.—Continued

[SPMD, semipermeable membrane device; na, not applicable; EC_{50}, concentration at which 50 percent of test organisms exhibited nonlethal response; EI, electron ionization; ECNI, electron-capture negative ionization]

Variable code	Definition	Ionization technique
	Chemistry[1]—Continued	
S_PPDDT	p,p'-DDT	ECNI
S_PCRES	p-Cresol	EI
S_PNONYL	p-Nonylphenol, total	EI
S_PCA	Pentachloroanisole (PCA)	ECNI
S_PCB70	2,3'4',5-Tetrachlorobiphenyl (PCB 70)	ECNI
S_PCB101	2,2',4,5,5'-Pentachlorobiphenyl (PCB 101)	ECNI
S_PCB110	2,3,3',4',6-Pentachlorobiphenyl (PCB 110)	ECNI
S_PCB118	2,3',4,4',5-Pentachlorobiphenyl (PCB 118)	ECNI
S_PCB138	2,2',3,4,4',4',5-Hexachlorobiphenyl (PCB 138)	ECNI
S_PCB146	2,2',3,4',5,5'-Hexachlorobiphenyl (PCB 146)	ECNI
S_PCB149	2,2',3,4',5',6-Hexachlorobiphenyl (PCB 149)	ECNI
S_PCB151	2,2',3,5,5',6-Hexachlorobiphenyl (PCB 151)	ECNI
S_PCB170	2,2',3,3',4,4',5-Heptachlorobiphenyl (PCB 170)	ECNI
S_PCB174	2,2',3,3',4,5,6'-Heptachlororbiphenyl (PCB 174)	ECNI
S_PCB177	2,2',3,3',4,5',6'-Heptachlorobiphenyl (PCB 177)	ECNI
S_PCB180	2,2',3,4,4',5,5'-Heptachlorobiphenyl (PCB 180)	ECNI
S_PCB183	2,2',3,4,4',5',6- Heptachlorobiphenyl (PCB 183)	ECNI
S_PCB187	2,2',3,4',5,5',6-Heptachlorobiphenyl (PCB 187)	ECNI
S_PCB194	2,2',3,3',4,4',5,5'-Octachlorobiphenyl (PCB 194)	ECNI
S_PCB206	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl (PCB 206)	ECNI
S_PHENA	Phenanthrene	EI
S_PHENO	Phenol	EI
S_PROME	Prometon	EI
S_PYRE	Pyrene	EI
S_SKAT	3-Methyl-1(H)-indole (skatole)	EI
S_STIG	Stigmastanol	EI
S_TOXAPH	Toxaphene	ECNI
S_TCHLOR	Trans-chlordane	ECNI
S_TNONAC	Trans-nonachlor	ECNI
S_TCPHOS	Tris (2-chloroethyl) phosphate	EI
S_TDPHOS	Tri (dichloroisopropyl) phosphate	EI
S_TBPHOS	Tributylphosphate	EI
S_TRICL	Triclosan	EI
S_TRIFL	Trifluralin	ECNI
S_TPPHOS	Triphenyl phosphate	EI

[1] In nanograms per SMPD.

Appendix 4

Data from Semipermeable Membrane Devices (SPMDs)

Table 4.1. Semipermeable membrane device toxicity environmental data.

[SPMD, semipermeable membrane device; SPMDTEQ, SPMD toxicity measured through CYP1A1 production; SPMDEC50, SPMD toxicity measured through the Microtox® assay; EC_{50}, concentration at which 50 percent of test organisms exhibited nonlethal response; SPMDUV, SPMD toxicity measured through ultraviolet fluorescence; na, not applicable; --, no data available; values in bold are the method detection limit for that constituent]

Site identification[1]	SPMDTEQ (toxic equivalents)	SPMDEC50 (EC_{50})	SPMDUV (micrograms pyrene)	Deployment duration (days)
	100	**10**	**3**	**na**
1	4,370	1.63	605	23.0
2	1,190	1.23	237	35.2
4	7,610	--	--	35.3
5	8,260	1.33	257	35.4
7	1,430	3.77	220	35.2
8	3,730	0.36	784	35.1
9	1,820	3.83	47.5	35.1
10	962	2.00	65.3	36.0
12	763	0.48	40.5	35.1
13	583	8.17	18.3	34.7
14	447	1.13	25.2	34.7
15	419	6.37	250	34.7
18	621	1.70	61.7	34.8
19	1,150	0.42	60.4	34.9
20	2,110	1.04	279	34.7
21	1,060	1.57	121	35.8
22	1,070	0.31	59.7	34.9
23	3,350	0.92	521	34.9
24	677	1.00	17.1	34.9
25	1,390	1.43	76.2	32.8
28	250	2.07	5.80	34.9

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.2. Semipermeable membrane device toxicity quality-control data.

[SPMD, semipermeable membrane device; SPMDTEQ, SPMD toxicity measured through CYP1A1 production; SPMDEC50, SPMD toxicity measured through the Microtox® assay; EC_{50}, concentration at which 50 percent of test organisms exhibited nonlethal response; SPMDUV, SPMD toxicity measured through ultraviolet fluorescence; MDL, method detection limit; >, greater than; <, less than; na, not applicable; values in bold are the MDL for that constituent]

Sample type	Site identification	SPMDTEQ (toxic equivalents)	SPMDEC50 (EC_{50})	SPMDUV (micrograms pyrene)	Deployment duration (days)
		100	**10**	**3**	**na**
REP	8	3633	0.64	658	35.1
REP	12	766	0.84	31.7	35.1
REP	13	410	1.01	26.3	34.7
TB	na	216	>10	12.7	na
TB	na	<100	>10	7.5	na
TB	na	184	>10	7	na
DB	na	301	>10	3.4	na
SB	na	217	>10	<3	na

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	1,4-Dichlorobenzene	1-Methylnapthalene*	2,6-Dimethylnapthalene*	2-Methyl benzothiophene*	2-Methylnapthalene*	3,4-Dichlorophenyl isocyanate	4-Cumylphenol	4-Octylphenol	4-tert-Octylphenol	5-Methyl-1H-benzotriazone	Acetophenone*
	Concentration, in nanograms per SPMD										
	25	**25**	**25**	**100**	**25**	**25**	**25**	**50**	**50**	**800**	**25**
1	<25	71.2	94.6	<100	59.0	<25	<25	<50	<50	<800	58.8
2	<25	61.1	80.9	<100	39.7	<25	<25	<50	<50	<800	42.8
4	<25	68.5	86.0	<100	55.8	<25	<25	<50	<50	<800	86.4
5	<25	65.0	87.2	<100	40.7	<25	<25	<50	<50	<800	50.5
7	<25	55.0	72.1	<100	37.0	<25	<25	<50	<50	<800	82.0
8	<25	80.5	112	<100	74.3	<25	<25	<50	<50	<800	71.3
9	<25	70.6	92.0	<100	53.8	<25	<25	<50	<50	<800	74.4
10	<25	68.4	83.2	<100	50.4	<25	<25	<50	<50	<800	62.2
12	<25	91.6	114	<100	64.2	<25	<25	<50	<50	<800	69.1
13	<25	60.3	78.7	<100	30.2	<25	<25	<50	<50	<800	50.9
14	<25	57.7	73.9	<100	32.9	<25	<25	<50	<50	<800	67.3
15	<25	58.8	77.7	<100	32.1	<25	<25	<50	<50	<800	64.7
18	<25	61.9	78.5	<100	39.6	<25	<25	<50	<50	<800	75.5
19	<25	70.5	92.4	<100	39.6	<25	<25	<50	<50	<800	80.0
20	<25	68.8	92.6	<100	42.3	<25	<25	<50	<50	<800	67.2
21	<25	73.0	94.0	<100	47.6	<25	<25	<50	<50	<800	84.2
22	<25	103	127	<100	86.8	<25	<25	<50	<50	<800	100
23	<25	103	151	<100	61.9	<25	<25	<50	<50	<800	73.7
24	<25	115	143	<100	74.8	<25	<25	<50	<50	<800	102
25	<25	80.4	104	<100	50.7	<25	<25	<50	<50	<800	80.9
28	<25	101	127	<100	56.6	<25	<25	<50	<50	<800	76.2

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	Acetyl hexamethyl tetrahydronaphthalene (AHTN)*	Aldrin	Alpha-HCH	Anthracene	Anthraquinone	2,2′,4,4′,6-Pentabromodiphenyl ether (BDE 100)	2,2′,4,4′,5,5′-Hexabromodiphenyl ether (BDE 153)	2,2′,4,4′,5,6′-Hexabromodiphenyl ether (BDE 154)	2,2′,4,4′-Tetrabromodiphenyl ether (BDE 47)*	2,2′,4,4′,5-Pentabromodipenyl ether (BDE 99)	Benfluralin	Benzo-(a)-pyrene	Benzophenone*
	Concentration, in nanograms per SPMD												
	50	**16**	**16**	**25**	**250**	**2**	**2**	**2**	**2**	**2**	**2**	**25**	**25**
1	238	<16	<16	81.2	467	<2	<2	<2	3.07	<2	<2	<25	185
2	209	<16	<16	<25	<250	<2	<2	<2	3.85	<2	<2	<25	151
4	200	<16	<16	80.0	459	<2	<2	<2	3.48	<2	<2	<25	168
5	200	<16	<16	99.9	476	<2	<2	<2	--	<2	<2	<25	173
7	173	<16	<16	57.1	<250	<2	<2	<2	<2	<2	<2	<25	132
8	219	<16	<16	118	483	<2	<2	<2	<2	<2	<2	<25	198
9	210	<16	<16	<25	<250	<2	<2	<2	4.38	<2	<2	<25	174
10	208	<16	<16	<25	<250	<2	<2	<2	3.31	<2	<2	<25	150
12	<50	<16	<16	<25	<250	<2	<2	<2	2.59	<2	<2	<25	202
13	<50	<16	<16	<25	<250	<2	<2	<2	2.76	<2	<2	<25	147
14	184	<16	<16	<25	<250	<2	<2	<2	<2	<2	<2	<25	134
15	<50	<16	<16	<25	<250	<2	<2	<2	4.54	2.4	<2	<25	140
18	<50	<16	<16	64.5	<250	<2	<2	<2	3.43	<2	<2	<25	150
19	<50	<16	<16	<25	<250	<2	<2	<2	2.79	<2	<2	<25	167
20	223	<16	<16	<25	<250	<2	<2	<2	3.51	<2	<2	<25	167
21	237	<16	<16	84.8	<250	<2	<2	<2	2.60	<2	<2	<25	175
22	297	<16	<16	<25	<250	<2	<2	<2	3.61	<2	<2	<25	201
23	321	<16	<16	<25	<250	<2	<2	<2	3.38	<2	<2	<25	282
24	368	<16	<16	<25	<250	<2	<2	<2	2.90	<2	<2	<25	257
25	<50	<16	<16	<25	<250	<2	<2	<2	2.82	<2	<2	<25	185
28	<50	<16	<16	<25	<250	<2	<2	<2	2.60	<2	<2	<25	228

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	Beta-coprostanol	Beta-HCH	Beta-sitosterol	3-tert-Butyl-4-hydroxy anisole (BHA)	Bisphenol A	Bromacil	Bromoform	Caffeine	Camphor	Carbaryl	Carbazole	Chlorpyrifos	Cholesterol*	cis-Chlordane	cis-Nonachlor	Cotinine	Cumene	Dacthal (DCPA)	Delta-HCH	Diazinon
	Concentration, in nanograms per SPMD																			
	25	**nd**	**200**	**25**	**250**	**250**	**25**	**50**	**25**	**250**	**25**	**4**	**200**	**8**	**8**	**200**	**25**	**2**	**32**	**100**
1	<25	nd	1,360	<25	<250	<250	<25	<50	<25	<250	78.9	<4	3,480	<8	<8	<200	<25	2.14	<32	<100
2	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,520	<8	<8	<200	<25	<2	<32	<100
4	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,950	<8	<8	<200	27.0	3.36	<32	<100
5	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	91.4	<4	1,780	<8	<8	<200	<25	<2	<32	<100
7	<25	nd	1,130	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,030	<8	<8	<200	27.1	<2	<32	<100
8	<25	nd	1,380	<25	<250	<250	<25	<50	<25	<250	94.2	<4	2,400	<8	<8	<200	<25	<2	<32	<100
9	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	4.16	3,220	<8	<8	<200	<25	2.18	<32	238
10	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,180	<8	<8	<200	<25	2.66	<32	<100
12	1,900	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,010	<8	<8	<200	<25	<2	<32	<100
13	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,990	<8	<8	<200	<25	<2	<32	<100
14	<25	nd	1,290	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,050	<8	<8	<200	<25	<2	<32	<100
15	<25	nd	1,310	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,820	<8	<8	<200	<25	<2	<32	<100
18	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,790	<8	<8	<200	26.5	<2	<32	<100
19	1,630	nd	1,560	<25	<250	<250	<25	<50	<25	<250	<25	185 E	2,260	<8	<8	<200	25.6	<2	<32	<100
20	<25	nd	1,430	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,060	<8	<8	<200	<25	2.73	<32	<100
21	1,650	nd	1,590	<25	<250	<250	<25	<50	<25	<250	<25	<4	3,650	<8	<8	<200	<25	<2	<32	<100
22	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,050	<8	<8	<200	34.8	<2	<32	<100
23	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,100	<8	<8	<200	<25	2.44	<32	<100
24	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,660	<8	<8	<200	30.0	<2	<32	<100
25	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,500	<8	<8	<200	<25	<2	<32	<100
28	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,860	<8	<8	<200	<25	<2	<32	<100

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	Dieldrin	Diethyl phtalate*	Diethylhexyl phthalate*	N,N-Diethyl-meta-toluamide (DEET)	Diphenyl pyrazole	d-Limonene*	Endosulfan I	Endosulfan II	Endosulfan sulfate	Endrin	Endrin aldehyde	Endrin ketone	Ethanol, 2-butoxy-phosphosphate	Ethyl citrate	Fipronil	Fluoranthene	Gamma-HCH	Hexachlorobenzene (HCB)	Heptachlor epoxide
Concentration, in nanograms per SPMD																			
	64	**25**	**50**	**25**	**25**	**25**	**8**	**16**	**8**	**128**	**64**	**128**	**250**	**100**	**16**	**25**	**8**	**2**	**8**
1	<64	338	1,740	<25	<25	50.1	<8	<16	<8	<128	<64	<128	<250	<100	<16	1,880	<8	4.25	<8
2	<64	250	829	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	356	<8	<2	<8
4	<64	246	1,240	<25	<25	32.3	<8	<16	<8	<128	<64	<128	<250	<100	<16	2,490	<8	3.67	<8
5	<64	238	880	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	3,590	<8	<2	<8
7	<64	228	1,090	<25	<25	168	<8	<16	<8	<128	<64	<128	<250	<100	<16	735	<8	<2	<8
8	<64	265	1,340	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	2,780	<8	<2	<8
9	<64	287	1,540	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	695	<8	2.46	<8
10	<64	268	903	<25	<25	39.2	<8	<16	<8	<128	<64	<128	<250	<100	<16	178	<8	<2	<8
12	<64	302	1,090	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	150	<8	<2	<8
13	<64	240	628	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	170	<8	<2	<8
14	<64	212	755	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	95.4	<8	<2	<8
15	<64	218	652	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	99.5	<8	<2	<8
18	<64	231	636	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	309	<8	<2	<8
19	<64	228	1,010	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	135	<8	<2	<8
20	<64	254	1,230	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	524	<8	<2	<8
21	<64	224	1,150	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	362	<8	<2	<8
22	<64	244	804	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	305	<8	2.30	<8
23	<64	310	1,490	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	1,840	<8	<2	<8
24	<64	371	1,240	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	207	<8	<2	<8
25	<64	322	882	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	176	<8	<2	<8
28	<64	279	873	<25	<25	<25	<8	<16	<8	<128	<64	<128	<250	<100	<16	<25	<8	<2	<8

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[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	Hexahydrohexamethylcyclopentabenzopyran (HHCB)	Indole	Isoborneol	Isophorone	Isoquinoline	Menthol	Metalaxyl	Methyl salicylate	Metolachlor	Mirex	Napthalene*	Nonylphenol monoethoxylate (NPEO1)	Nonylphenol diethoxylate (NPEO2)	o,p′-DDD	o,p′-DDE	o,p′-DDT	Octachlorostyrene	Octylphenol monoethoxylate (OPEO1)	Octylphenol diethoxylate (OPEO2)	Oxychlordane	p,p′-DDD	p,p′-DDE
	Concentration, in nanograms per SPMD																					
	50	**25**	**25**	**25**	**25**	**25**	**250**	**25**	**250**	**64**	**25**	**1,500**	**2,000**	**128**	**64**	**nd**	**2**	**100**	**250**	**16**	**nd**	**64**
1	175	<25	<25	<25	<25	<25	<250	<25	<250	<64	53.0	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
2	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	37.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
4	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	63.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
5	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	43.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
7	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	36.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
8	219	<25	<25	<25	<25	<25	<250	<25	<250	<64	72.1	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
9	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	52.0	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
10	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	57.6	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
12	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	55.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
13	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
14	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	31.7	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
15	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	26.6	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
18	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	41.3	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
19	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	35.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
20	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	31.4	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
21	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	45.8	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
22	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	59.0	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
23	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	44.5	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
24	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	69.4	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
25	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	49.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64
28	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64	53.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	p,p′-DDT	p-Cresol	p-Nonylphenol-total	Pentachloroanisole (PCA)	2,3′4′,5-Tetrachlorobiphenyl (PCB 70)	2,2′,4,5,5′-Pentachlorobiphenyl (PCB 101)	2,3,3′,4′,6-Pentachlorobiphenyl (PCB 110)	2,3′,4,4′,5-Pentachlorobiphenyl (PCB 118)	2,2′,3,4,4′,4′,5-Hexachlorobiphenyl (PCB 138)	2,2′,3,4′,5,5′-Hexachlorobiphenyl (PCB 146)	2,2′,3,4′,5′,6-Hexachlorobiphenyl (PCB 149)
	Concentration, in nanograms per SPMD										
	nd	**25**	**200**	**2**	**64**	**32**	**32**	**2**	**2**	**2**	**64**
1	nd	<25	<200	4.85	<64	<32	<32	<2	<2	<2	<64
2	nd	<25	<200	2.88	<64	<32	<32	<2	<2	<2	<64
4	nd	<25	<200	4.72	<64	<32	<32	<2	<2	<2	<64
5	nd	<25	<200	4.15	<64	<32	<32	<2	<2	<2	<64
7	nd	<25	<200	<2	<64	<32	<32	<2	<2	<2	<64
8	nd	<25	<200	<2	<64	<32	<32	<2	<2	<2	<64
9	nd	<25	<200	2.62	<64	<32	<32	<2	<2	<2	<64
10	nd	<25	<200	2.26	<64	<32	<32	<2	<2	<2	<64
12	nd	<25	<200	2.24	<64	<32	<32	<2	<2	<2	<64
13	nd	<25	<200	2.06	<64	<32	<32	<2	<2	<2	<64
14	nd	<25	<200	<2	<64	<32	<32	<2	<2	<2	<64
15	nd	<25	<200	<2	<64	<32	<32	<2	<2	<2	<64
18	nd	<25	<200	2.71	<64	<32	<32	<2	<2	<2	<64
19	nd	<25	<200	2.10	<64	<32	<32	<2	<2	<2	<64
20	nd	<25	<200	2.67	<64	<32	<32	<2	<2	<2	<64
21	nd	<25	<200	3.02	<64	<32	<32	<2	<2	<2	<64
22	nd	<25	<200	3.31	<64	<32	<32	<2	<2	<2	<64
23	nd	<25	<200	2.26	<64	<32	<32	<2	<2	<2	<64
24	nd	<25	<200	2.80	<64	<32	<32	<2	2.02	<2	<64
25	nd	<25	<200	2.27	<64	<32	<32	<2	<2	<2	<64
28	nd	<25	<200	2.05	<64	<32	<32	<2	<2	<2	<64

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	2,2′,3,5,5′,6-Hexachlorobiphenyl (PCB 151)	2,2′,3,3′,4,4′,5-Heptachlorobiphenyl (PCB 170)	2,2′,3,3′,4,5,6′-Heptachlororbiphenyl (PCB 174)	2,2′,3,3′,4,5′,6′-Heptachlorobiphenyl (PCB 177)	2,2′,3,4,4′,5,5′-Heptachlorobiphenyl (PCB 180)	2,2′,3,4,4′,5′,6-Heptachlorobiphenyl (PCB 183)	2,2′,3,4′,5,5′,6-Heptachlorobiphenyl (PCB 187)	2,2′,3,3′,4,4′,5,5′-Octachlorobiphenyl (PCB 194)
	Concentration, in nanograms per SPMD							
	16	**2**	**2**	**2**	**4**	**2**	**2**	**2**
1	<16	<2	<2	<2	<4	<2	<2	<2
2	<16	<2	<2	<2	<4	<2	<2	<2
4	<16	<2	<2	<2	<4	<2	<2	<2
5	<16	<2	<2	<2	<4	<2	<2	<2
7	<16	<2	<2	<2	<4	<2	<2	<2
8	<16	<2	<2	<2	<4	<2	<2	<2
9	<16	<2	<2	<2	<4	<2	<2	<2
10	<16	<2	<2	<2	<4	<2	<2	<2
12	<16	<2	<2	<2	<4	<2	<2	<2
13	<16	<2	<2	<2	<4	<2	<2	<2
14	<16	<2	<2	<2	<4	<2	<2	<2
15	<16	<2	<2	<2	<4	<2	<2	<2
18	<16	<2	<2	<2	<4	<2	<2	<2
19	<16	<2	<2	<2	<4	<2	<2	<2
20	<16	<2	<2	<2	<4	<2	<2	<2
21	<16	<2	<2	<2	<4	<2	<2	<2
22	<16	<2	<2	<2	<4	<2	<2	<2
23	<16	<2	<2	<2	<4	<2	<2	<2
24	<16	<2	<2	<2	<4	<2	<2	<2
25	<16	<2	<2	<2	<4	<2	<2	<2
28	<16	<2	<2	<2	<4	<2	<2	<2

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.3. Selected semipermeable membrane device chemistry environmental data.[1]—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); E, estimated value; values in bold are the MDL for that constituent]

Site identification[2]	2,2′,3,3′,4,4′,5,5′,6-Nonachlorobiphenyl (PCB 206)	Phenanthrene*	Phenol	Prometon	Pyrene	3-Methyl-1(H)-indole (skatole)	Stigmastanol	Toxaphene	Trans-chlordane	Trans-nonachlor	Tris (2-chloroethyl) phosphate	Tri(dichloroisopropyl) phosphate	Tributylphosphate	Triclosan	Trifluralin	Triphenyl phosphate
Concentration, in nanograms per SPMD																
	2	**25**	**25**	**100**	**25**	**25**	**400**	**2,500**	**8**	**8**	**100**	**250**	**500**	**250**	**2**	**250**
1	<2	496	<25	<100	1,280	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	2.16	<250
2	<2	122	<25	<100	318	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
4	<2	442	<25	<100	2,040	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
5	<2	476	<25	<100	2,240	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
7	<2	213	<25	<100	508	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
8	<2	851	<25	<100	1,810	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
9	<2	173	<25	<100	525	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
10	<2	91.7	<25	<100	177	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
12	<2	66.0	<25	<100	168	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
13	<2	125	<25	<100	157	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
14	<2	39.2	<25	<100	105	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
15	<2	46.4	<25	<100	111	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
18	<2	222	<25	<100	247	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
19	<2	59.7	<25	<100	153	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	16.1	<250
20	<2	176	<25	<100	512	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
21	<2	236	<25	<100	292	<25	<400	<2,500	<8	<8	<100	<250	<500	701	<2	<250
22	<2	79.0	<25	<100	257	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
23	<2	362	<25	<100	1,310	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
24	<2	81.7	<25	<100	218	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
25	<2	72.6	<25	<100	187	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
28	<2	50.4	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250

[1] Environmental data for all other chemical constituents are available online at *http://waterdata.usgs.gov/usa/nwis/qw/* and can be retrieved using the U.S. Geological Survey station number in table 1 of the report.

[2] Site-identification numbers are defined in table 1 of the report.

*Constituent was detected in one or more blanks. Environmental concentrations of this constituent were corrected for blank contamination prior to data analysis.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	1,4-Dichlorobenzene	1-Methylnapthalene	2,6-Dimethylnapthalene	2-Methyl benzothiophene	2-Methylnapthalene	3,4-Dichlorophenyl isocyanate	4-Cumylphenol	4-Octylphenol	4-tert-Octylphenol	5-Methyl-1H-benzotriazone
			Concentration, in nanograms per SPMD									
			25	**25**	**25**	**100**	**25**	**25**	**25**	**50**	**50**	**800**
REP	SPLT	8	<25	79.5	111	<100	73.1	<25	<25	<50	<50	<800
REP	SPLT	12	<25	80.3	103	<100	50.0	<25	<25	<50	<50	<800
REP	SPLT	13	<25	59.1	77.8	<100	34.9	<25	<25	<50	<50	<800
TB	SPLT	na	<25	116	153	<100	44.3	<25	<25	<50	<50	<800
TB	SPLT	na	<25	94.8	119	<100	52.7	<25	<25	<50	<50	<800
TB	SPLT	na	--	--	--	--	--	--	--	--	--	--
DB	SPLT	na	<25	56.6	76.5	<100	37.9	<25	<25	<50	<50	<800
SB	SPLT	na	<25	<25	<25	<100	<25	<25	<25	<50	<50	<800
DB	ALBE	na	<25	35.7	56.2	<100	49.0	<25	<25	<50	<50	<800
SB	ALBE	na	<25	<25	<25	<100	<25	<25	<25	<50	<50	<800
DB	ACFB	na	<25	<25	<25	465	28.8	<25	<25	<50	<50	<800
SB	ACFB	na	<25	<25	<25	452	<25	<25	<25	<50	<50	<800

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	Acetophenone	Acetyl hexamethyl tetrahydronaphthalene (AHTN)	Aldrin	Alpha-HCH	Anthracene	Anthraquinone	2,2′,4,4′,6-Pentabromodiphenyl ether (BDE 100)	2,2′,4,4′,5,5′-Hexabromodiphenyl ether (BDE 153)	2,2′,4,4′,5,6′-Hexabromodiphenyl ether (BDE 154)	2,2′,4,4′-Tetrabromodiphenyl ether (BDE 47)	2,2′,4,4′,5-Pentabromodipenyl ether (BDE 99)	Benfluralin
			Concentration, in nanograms per SPMD											
			25	**50**	**16**	**16**	**25**	**250**	**2**	**2**	**2**	**2**	**2**	**2**
REP	SPLT	8	72.4	218	<16	<16	115	492	<2	<2	<2	4.42	<2	<2
REP	SPLT	12	72.3	<50	<16	<16	<25	<250	<2	<2	<2	2.88	<2	<2
REP	SPLT	13	71.9	<50	<16	<16	<25	<250	<2	<2	<2	3.05	<2	<2
TB	SPLT	na	50.0	<50	<16	<16	<25	<250	<2	<2	<2	3.01	<2	<2
TB	SPLT	na	65.5	<50	<16	<16	<25	<250	<2	<2	<2	2.56	<2	<2
TB	SPLT	na	--	--	<16	<16	--	--	<2	<2	<2	2.74	<2	<2
DB	SPLT	na	64.4	210	<16	<16	<25	<250	<2	<2	<2	3.26	<2	<2
SB	SPLT	na	<25	<50	<16	<16	<25	<250	<2	<2	<2		<2	<2
DB	ALBE	na	45.2	<50	<16	<16	<25	<250	<2	<2	<2	<2	<2	<2
SB	ALBE	na	<25	<50	<16	<16	<25	<250	<2	<2	<2	<2	<2	<2
DB	ACFB	na	58.3	<50	<16	<16	<25	<250	<2	<2	<2	<2	<2	<2
SB	ACFB	na	<25	<50	<16	<16	<25	<250	<2	<2	<2	<2	<2	<2

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	Benzo-(a)-pyrene	Benzophenone	Beta-coprostanol	Beta-HCH	Beta-sitosterol	3-tert-Butyl-4-hydroxy anisole (BHA)	Bisphenol A	Bromacil	Bromoform	Caffeine	Camphor	Carbaryl	Carbazole	Chlorpyrifos	Cholesterol	cis-Chlordane	cis-Nonachlor
			Concentration, in nanograms per SPMD																
			25	**25**	**25**	**nd**	**200**	**25**	**250**	**250**	**25**	**50**	**25**	**250**	**25**	**4**	**200**	**8**	**8**
REP	SPLT	8	<25	206	<25	nd	1,410	<25	<250	<250	<25	<50	<25	<250	97.7	<4	2,480	<8	<8
REP	SPLT	12	<25	188	1,760	nd	1,690	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,890	<8	<8
REP	SPLT	13	<25	141	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,940	<8	<8
TB	SPLT	na	<25	<25	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	2,090	<8	<8
TB	SPLT	na	<25	215	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,800	<8	<8
TB	SPLT	na	--	--	--	nd	--	--	--	--	--	--	--	--	--	<4	--	<8	<8
DB	SPLT	na	<25	142	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	3,720	<8	<8
SB	SPLT	na	<25	<25	<25	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	<200	<8	<8
DB	ALBE	na	<25	92.6	<200	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	1,450	<8	<8
SB	ALBE	na	<25	<25	<200	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	<200	<8	<8
DB	ACFB	na	<25	36.5	<200	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	239	<8	<8
SB	ACFB	na	<25	<25	<200	nd	<200	<25	<250	<250	<25	<50	<25	<250	<25	<4	<200	<8	<8

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	Cotinine	Cumene	Dacthal (DCPA)	Delta-HCH	Diazinon	Dieldrin	Diethyl phtalate	Diethylhexyl phthalate	N,N-Diethyl-meta-toluamide (DEET)	Diphenyl pyrazole	d-Limonene	Endosulfan I	Endosulfan II	Endosulfan sulfate	Endrin	Endrin aldehyde	Endrin ketone
			Concentration, in nanograms per SPMD																
			200	**25**	**2**	**32**	**100**	**64**	**25**	**50**	**25**	**25**	**25**	**8**	**16**	**8**	**128**	**64**	**128**
REP	SPLT	8	<200	25.7	3.1	<32	<100	<64	276	1,550	<25	<25	35.1	<8	<16	<8	<128	<64	<128
REP	SPLT	12	<200	<25	<2	<32	<100	<64	272	1,190	<25	<25	<25	<8	<16	<8	<128	<64	<128
REP	SPLT	13	<200	<25	<2	<32	<100	<64	233	663	<25	<25	<25	<8	<16	<8	<128	<64	<128
TB	SPLT	na	<200	<25	<2	<32	<100	<64	274	849	<25	<25	<25	<8	<16	<8	<128	<64	<128
TB	SPLT	na	<200	<25	<2	<32	<100	<64	291	820	<25	<25	<25	<8	<16	<8	<128	<64	<128
TB	SPLT	na	--	--	<2	<32	--	<64	--	--	--	--	--	<8	<16	<8	<128	<64	<128
DB	SPLT	na	<200	<25	<2	<32	<100	<64	257	1,980	<25	<25	<25	<8	<16	<8	<128	<64	<128
SB	SPLT	na	<200	<25	<2	<32	<100	<64	108	1,440	<25	<25	<25	<8	<16	<8	<128	<64	<128
DB	ALBE	na	<200	<25	<2	<32	<100	<64	<25	1,480	<25	<25	36.8	<8	<16	<8	<128	<64	<128
SB	ALBE	na	<200	<25	<2	<32	<100	<64	<25	<50	<25	<25	<25	<8	<16	<8	<128	<64	<128
DB	ACFB	na	<200	<25	<2	<32	<100	<64	348	1,050	<25	<25	65.3	<8	<16	<8	<128	<64	<128
SB	ACFB	na	<200	<25	<2	<32	<100	<64	29.1	<50	<25	<25	<25	<8	<16	<8	<128	<64	<128

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	Ethanol, 2-butoxy-, phosphosphate	Ethyl citrate	Fipronil	Fluoranthene	Gamma-HCH	Hexachlorobenzene (HCB)	Heptachlor epoxide	Hexahydrohexamethylcyclopentabenzopyran (HHCB)	Indole	Isoborneol	Isophorone	Isoquinoline	Menthol	Metalaxyl	Methyl salicylate	Metolachlor	Mirex
			Concentration, in nanograms per SPMD																
			250	**100**	**16**	**25**	**8**	**2**	**8**	**50**	**25**	**25**	**25**	**25**	**25**	**250**	**25**	**250**	**64**
REP	SPLT	8	<250	<100	<16	2,540	<8	2.24	<8	281	<25	<25	<25	<25	<25	<250	<25	<250	<64
REP	SPLT	12	<250	<100	<16	152	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
REP	SPLT	13	<250	<100	<16	137	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
TB	SPLT	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
TB	SPLT	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
TB	SPLT	na	--	--	<16	--	<8	<2	<8	--	--	--	--	--	--	--	--	--	<64
DB	SPLT	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
SB	SPLT	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
DB	ALBE	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
SB	ALBE	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
DB	ACFB	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64
SB	ACFB	na	<250	<100	<16	<25	<8	<2	<8	<50	<25	<25	<25	<25	<25	<250	<25	<250	<64

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	Naphthalene	Nonylphenol monoethoxylate (NPEO1)	Nonylphenol diethoxylate (NPEO2)	o,p′-DDD	o,p′-DDE	o,p′-DDT	Octachlorostyrene	Octylphenol monoethoxylate (OPEO1)	Octylphenol diethoxylate (OPEO2)	Oxychlordane	p,p′-DDD	p,p′-DDE	p,p′-DDT	p-Cresol	p-Nonylphenol-total	Pentachloroanisole (PCA)	2,3′4′,5-Tetrachlorobiphenyl (PCB 70)
Concentration, in nanograms per SPMD																			
			25	**1,500**	**2,000**	**128**	**64**	**nd**	**2**	**100**	**250**	**16**	**nd**	**64**	**nd**	**25**	**200**	**2**	**64**
REP	SPLT	8	72.5	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	3.06	<64
REP	SPLT	12	42	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	2.38	<64
REP	SPLT	13	29.7	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	2.06	<64
TB	SPLT	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
TB	SPLT	na	47.2	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
TB	SPLT	na	--	--	--	<128	<64	nd	<2	--	--	<16	nd	<64	nd	--	--	<2	<64
DB	SPLT	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
SB	SPLT	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
DB	ALBE	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
SB	ALBE	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
DB	ACFB	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64
SB	ACFB	na	<25	<1,500	<2,000	<128	<64	nd	<2	<100	<250	<16	nd	<64	nd	<25	<200	<2	<64

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	2,2′,4,5,5′-Pentachlorobiphenyl (PCB 101)	2,3,3′,4′,6-Pentachlorobiphenyl (PCB 110)	2,3′,4,4′,5-Pentachlorobiphenyl (PCB 118)	2,2′,3,4,4′,4′,5-Hexachlorobiphenyl (PCB 138)	2,2′,3,4′,5,5′-Hexachlorobiphenyl (PCB 146)	2,2′,3,4′,5′,6-Hexachlorobiphenyl (PCB 149)	2,2′,3,5,5′,6-Hexachlorobiphenyl (PCB 151)	2,2′,3,3′,4,4′,5-Heptachlorobiphenyl (PCB 170)
			Concentration, in nanograms per SPMD							
			32	**32**	**2**	**2**	2	**64**	**16**	**2**
REP	SPLT	8	<32	<32	3.04	3.16	<2	<64	<16	2.23
REP	SPLT	12	<32	<32	<2	<2	<2	<64	<16	<2
REP	SPLT	13	<32	<32	<2	<2	<2	<64	<16	<2
TB	SPLT	na	<32	<32	<2	<2	<2	<64	<16	<2
TB	SPLT	na	<32	<32	<2	<2	<2	<64	<16	<2
TB	SPLT	na	<32	<32	<2	<2	<2	<64	<16	<2
DB	SPLT	na	<32	<32	<2	<2	<2	<64	<16	<2
SB	SPLT	na	<32	<32	<2	<2	<2	<64	<16	<2
DB	ALBE	na	<32	<32	<2	<2	<2	<64	<16	<2
SB	ALBE	na	<32	<32	<2	<2	<2	<64	<16	<2
DB	ACFB	na	<32	<32	<2	<2	<2	<64	<16	<2
SB	ACFB	na	<32	<32	<2	<2	<2	<64	<16	<2

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identfication[1]	2,2′,3,3′,4,5,6′-Heptachlororbiphenyl (PCB 174)	2,2′,3,3′,4,5′,6′-Heptachlorobiphenyl (PCB 177)	2,2′,3,4,4′,5,5′-Heptachlorobiphenyl (PCB 180)	2,2′,3,4,4′,5′,6-Heptachlorobiphenyl (PCB 183)	2,2′,3,4′,5,5′,6-Heptachlorobiphenyl (PCB 187)	2,2′,3,3′,4,4′,5,5′-Octachlorobiphenyl (PCB 194)	2,2′,3,3′,4,4′,5,5′,6-Nonachlorobiphenyl (PCB 206)	Phenanthrene
			Concentration, in nanograms per SPMD							
			2	**2**	**4**	**2**	**2**	**2**	**2**	**25**
REP	SPLT	8	<2	<2	<4	<2	<2	<2	<2	932
REP	SPLT	12	<2	<2	<4	<2	<2	<2	<2	65.6
REP	SPLT	13	<2	<2	<4	<2	<2	<2	<2	98.0
TB	SPLT	na	<2	<2	<4	<2	<2	<2	<2	51.8
TB	SPLT	na	<2	<2	<4	<2	<2	<2	<2	44.7
TB	SPLT	na	<2	<2	<4	<2	<2	<2	<2	--
DB	SPLT	na	<2	<2	<4	<2	<2	<2	<2	48.0
SB	SPLT	na	<2	<2	<4	<2	<2	<2	<2	<25
DB	ALBE	na	<2	<2	<4	<2	<2	<2	<2	62.4
SB	ALBE	na	<2	<2	<4	<2	<2	<2	<2	<25
DB	ACFB	na	<2	<2	<4	<2	<2	<2	<2	30.8
SB	ACFB	na	<2	<2	<4	<2	<2	<2	<2	<25

[1] Site-identification numbers are defined in table 1 of the report.

Table 4.4. Selected semipermeable membrane device chemistry quality-control data.—Continued

[SPMD, semipermeable membrane device; MDL, method detection limit; <, less than; SUID, study area; SPLT, South Platte River Basin; ALBE, Albemarle-Pamlico Drainage; ACFB, Apalachicola-Chattahoochee-Flint River Basin; REP, replicate; TB, trip blank; DB, dialysis blank; SB, solvent blank; nd, compound not detected in highest standard, no detection limit established (Tom Leiker, U.S. Geological Survey, written commun., 2005); na, not applicable; --, no data available; values in bold are the MDL for that constituent]

Sample type	SUID	Site identification[1]	Phenol	Prometon	Pyrene	3-Methyl-1(H)-indole (skatole)	Stigmastanol	Toxaphene	Trans-chlordane	Trans-nonachlor	Tris (2-chloroethyl) phosphate	Tri(dichloroisopropyl) phosphate	Tributylphosphate	Triclosan	Trifluralin	Triphenyl phosphate
			Concentration, in nanograms per SPMD													
			25	**100**	**25**	**25**	**400**	**2,500**	**8**	**8**	**100**	**250**	**500**	**250**	**2**	**250**
REP	SPLT	8	<25	<100	1,700	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
REP	SPLT	12	<25	<100	164	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
REP	SPLT	13	<25	<100	130	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
TB	SPLT	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
TB	SPLT	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
TB	SPLT	na	--	--	--	--	--	<2,500	<8	<8	--	--	--	--	<2	--
DB	SPLT	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
SB	SPLT	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
DB	ALBE	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
SB	ALBE	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
DB	ACFB	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250
SB	ACFB	na	<25	<100	<25	<25	<400	<2,500	<8	<8	<100	<250	<500	<250	<2	<250

[1] Site-identification numbers are defined in table 1 of the report.

Appendix 5

Biological Variables

Table 5.1. Algae variables.

[$\mu m^3/cm^2$, cubic micrometers per square centimeter; mg/m^2, milligrams per square meter; g/m^2, grams per square meter; $cells/cm^2$, cells per square centimeter; %, percent]

Variable code	Definition
	All algae—Biovolume metrics
BioDtms	Biovolume of diatoms ($\mu m^3/cm^2$)
BioGA	Biovolume of green algae ($\mu m^3/cm^2$)
BioRA	Biovolume of red algae ($\mu m^3/cm^2$)
Biovol_tot	Total algal biovolume per square centimeter ($\mu m^3/cm^2$)
	All algae—Density metrics
CellDenGA	Cell density of green algae ($cells/cm^2$)
CellDenRA	Cell density of red algae ($cells/cm^2$)
CellDens_tot	Total algal cells per square centimeter ($cells/cm^2$)
	All algae—Percent abundance metrics
AcMinPct	% of total abundance composed of *Achnanthidium minutissimum*
SiltIdx	% of total abundance composed of diatom genera that contain mostly motile species as described by Bahls and others (1992)
	All algae—Percent abundance richness metrics
CP	Ratio of centrales to pennales
	All algae—Richness metrics
NumTax_all	Total taxa richness including ambiguous taxa
	Diatoms—Density metrics
CDenDtms	Cell density of diatoms ($cells/cm^2$)
	Diatoms—Percent abundance trophic metrics
TR_ET_DP	% of total abundance composed of eutrophic taxa as described by Van Dam and others (1994)
TR_ME_DP	% of total abundance composed of mesoeutrophic taxa as described by Van Dam and others (1994)
TR_OL_DP	% of total abundance composed of oligotrophic taxa as described by Van Dam and others (1994)
	Diatoms—Richness metrics
NumTax_dtm	Number of diatom taxa, diatom species richness
	Diatoms—Tolerance metrics
PC_SN_DP	% of total abundance composed of sensitive taxa as described by Bahls (1993)
PT_LB_DP	Less tolerant group 3b as described by Lange-Bertalot (1979)
PT_VT_DP	Very tolerant as described by Lange-Bertalot (1979)

Table 5.2. Fish variables.

[%, percent]

Variable code	Definition
	Abundance metrics
pAInter	% of total abundance composed of intermediately tolerant species
pAIntro	% of total abundance composed of non-native species
pATol	% of total abundance composed of tolerant species
pDELT	% of total abundance composed with Deformities, Eroded fins, Lesions, Tumors (DELT anomalies) as described by Sanders and others (1999)
rpWS	% of total abundance composed of white suckers
Tabund	Total abundance
	Functional group abundance metrics
pAGeneral	% of total abundance composed of trophic generalists
pAHerb	% of total abundance composed of trophic herbivores
pAInvert	% of total abundance composed of trophic invertivores
pAOm	% of total abundance composed of trophic omnivores
pAOmCarn	% of total abundance composed of trophic omnivorous-carnivores
pAOmHerb	% of total abundance composed of trophic omnivorous-herbivores
pAOmInvert	% of total abundance composed of trophic omnivorous-invertivores
pASpecial	% of total abundance composed of trophic specialists
	Functional group richness metrics
Generalsp	Total number of trophic generalist species
Inter	Total number of intermediate tolerant species
Intro	Total number of nonnative species
Specsp	Number of trophic specialist species
Suck	Total number of sucker species
Sun	Total number of sunfish species
Tol	Total number of tolerant species
Ttaxa	Total number of species
	Richness metrics
Aintro	Total abundance of nonnative species
Cyprin	Total number of cyprinid species
	Spawning trait abundance metrics
pAbnonGuardexWS	% of total abundance composed of nonguarding lithophilic spawners excluding white sucker
pAnonGuard	% of total abundance composed of nonguarding lithophilic spawners

Table 5.3. Invertebrate variables.

[EPT, Ephemeroptera, Plecoptera, Tricoptera (mayflies, stoneflies, caddisflies); %, percent; USEPA, U.S. Environmental Protection Agency]

Variable code	Definition
	Abundance metrics
ABUND	Total number of organisms in the sample
	Functional group richness metrics
CG_Rich	Richness composed of collector-gatherers
FC_Rich	Richness composed of filtering-collectors
pCG_Rich	% of richness composed of collector-gatherers
pFC_Rich	% of richness composed of filtering-collectors
pPR_Rich	% of richness composed of predators
PR_Rich	Richness composed of predators
pSC_Rich	% of richness composed of scrapers
pSH_Rich	% of richness composed of shredders
SC_Rich	Richness composed of scrapers
SH_Rich	Richness composed of shredders
	Percent abundance metrics
CHp	% of total abundance composed of midges
COLEOPp	% of total abundance composed of Coleoptera
EPEMp	% of total abundance composed of mayflies
EPTp	% of total abundance composed of EPT
NONINSp	% of total abundance composed of noninsects
THRICHp	% of total abundance composed of caddisflies
	Richness metrics
CHR	Richness composed of midges
COLEOPR	Richness composed of Coleoptera
DIPR	Richness composed of Diptera
EPEMR	Richness composed of mayflies
EPTR	Richness composed of EPT
NCHDIPR	Richness composed of nonmidge Diptera
NONINSR	Richness composed of noninsects
ORTHOR	Richness composed of Orthocladiinae midges
RICH	Total number of nonambiguous taxa
TANYR	Richness composed of Tanytarsini
TRICHR	Richness composed of caddisflies
	Tolerance metrics
ABUNDTOL	Abundance weighted USEPA tolerance value for sample
RICHTOL	Richness based average USEPA tolerance value for sample

Appendix 6

Scatterplots of Variables Presented in Report Tables

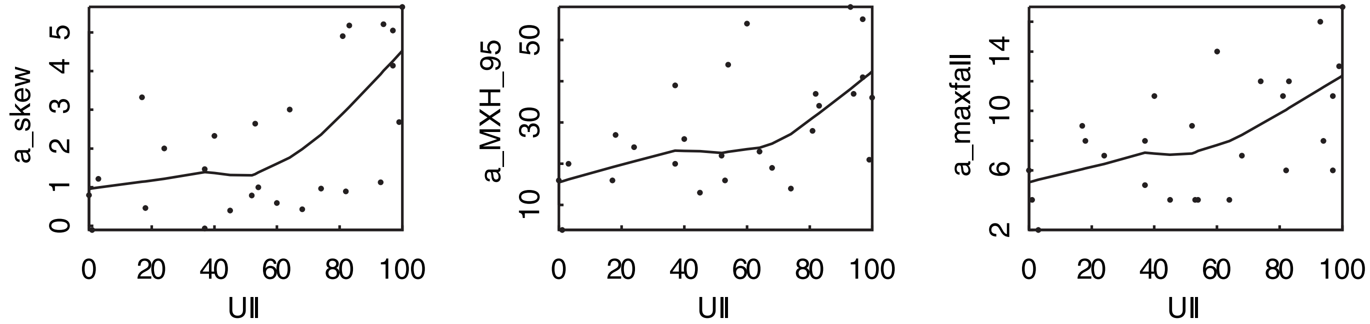


Figure 6.1. The responses of cross-sectional area metrics to the urban intensity index (UII) and individual measures of urbanization, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1 and table 2.1 in Appendix 2. Correlation coefficients are listed in table 3.

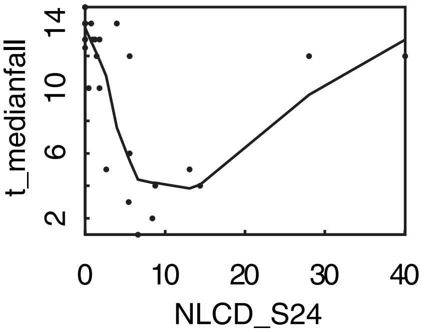


Figure 6.2. The responses of water-temperature metrics to the urban intensity index (UII) and individual measures of urbanization, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1 and tables 2.1, 2.2, and 2.3 in Appendix 2. Correlation coefficients are listed in table 4.

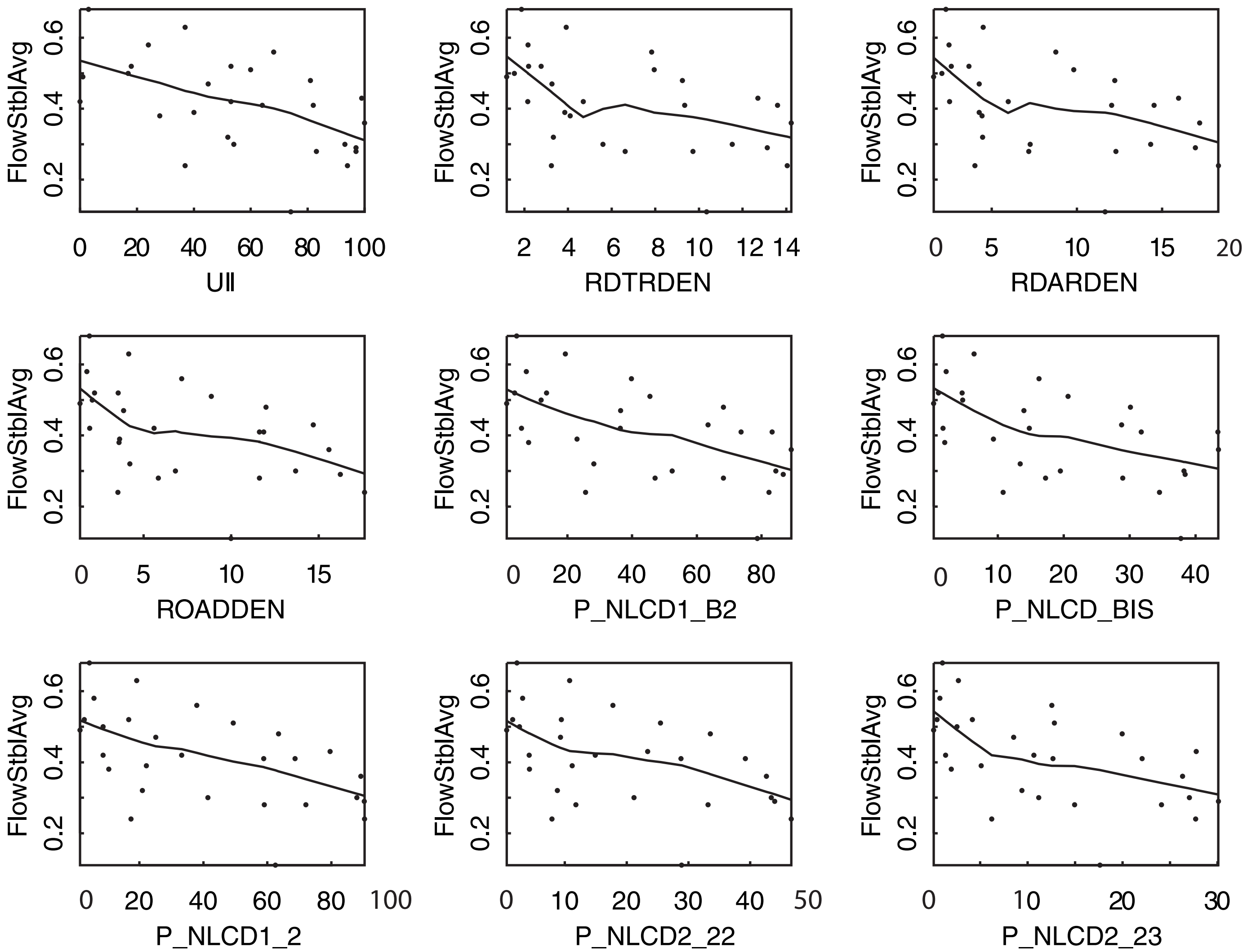


Figure 6.3. The responses of habitat variables to the urban intensity index (UII) and individual measures of urbanization, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1 and table 2.3 in Appendix 2. Correlation coefficients are listed in table 5.

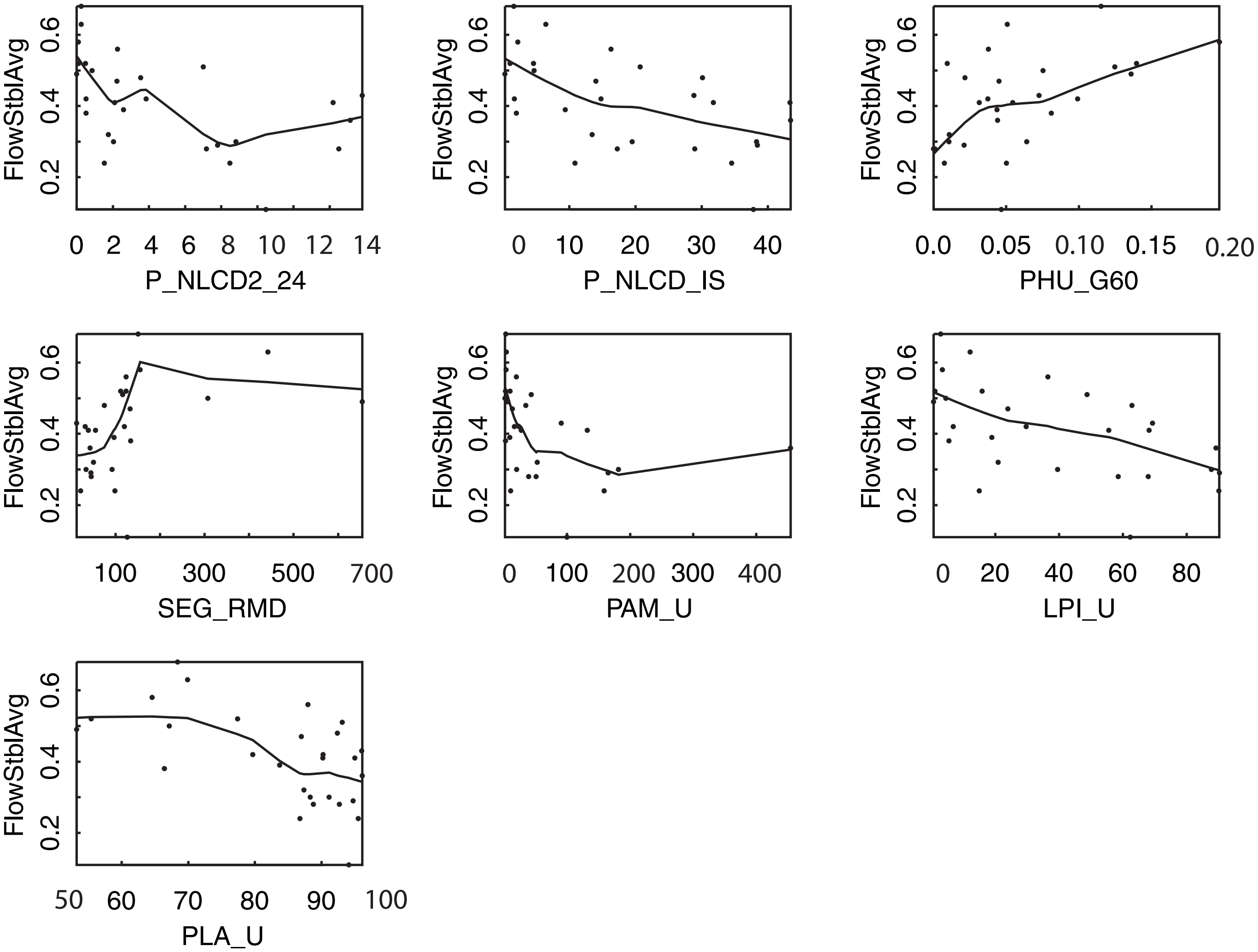


Figure 6.3. The responses of habitat variables to the urban intensity index (UII) and individual measures of urbanization, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1 and table 2.3 in Appendix 2. Correlation coefficients are listed in table 5.—Continued

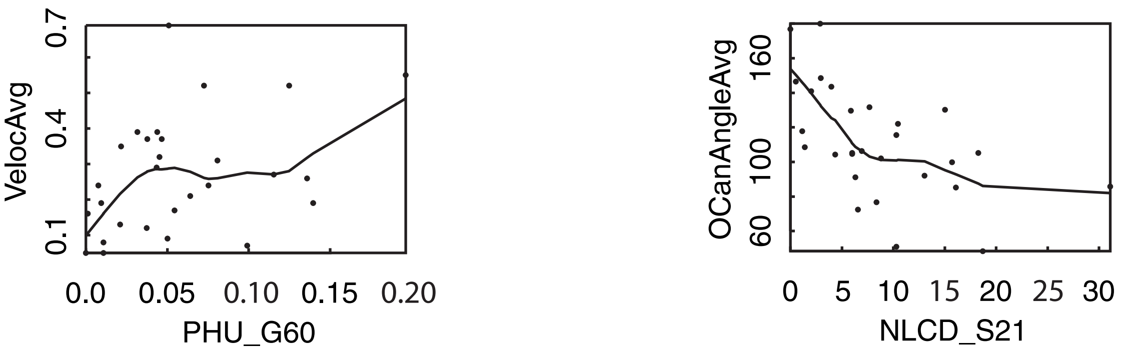


Figure 6.3. The responses of habitat variables to the urban intensity index (UII) and individual measures of urbanization, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1 and table 2.3 in Appendix 2. Correlation coefficients are listed in table 5.—Continued

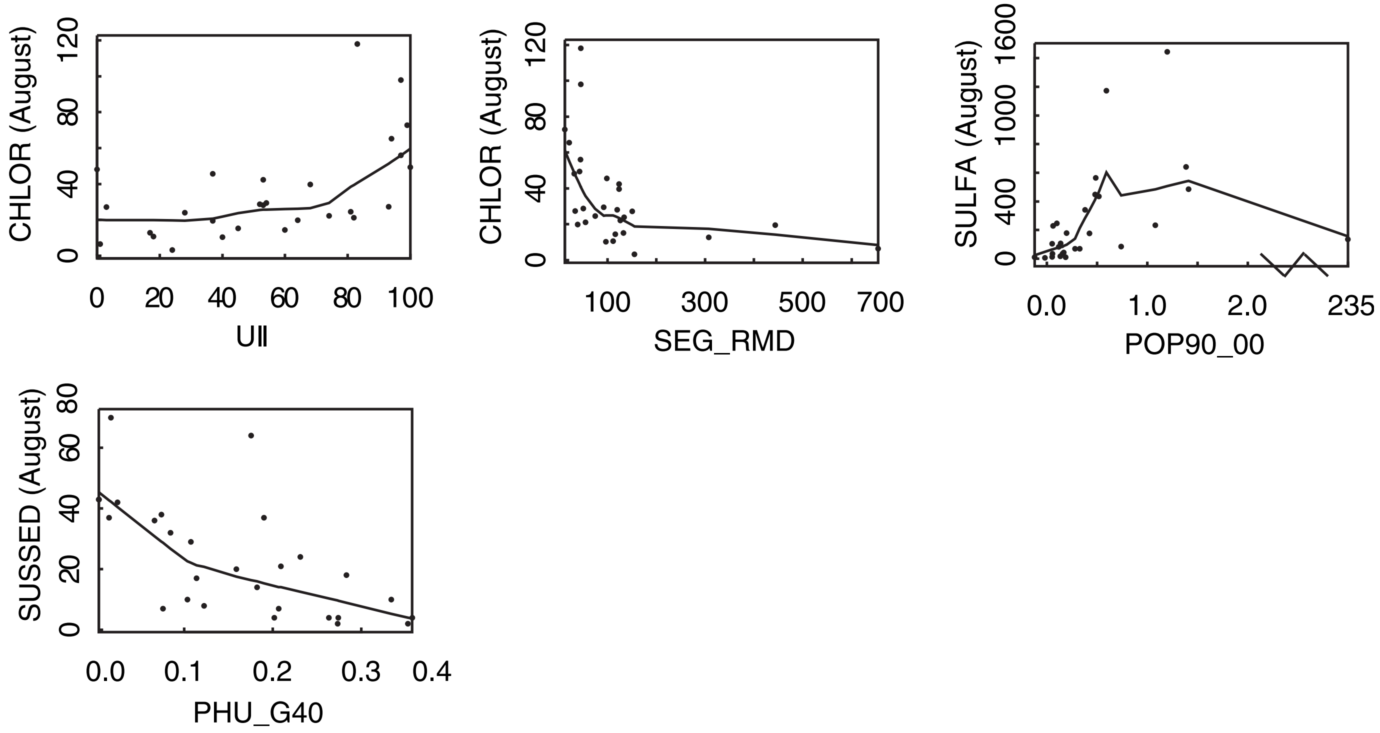


Figure 6.4. The responses of water-chemistry variables to the urban intensity index (UII) and individual measures of urbanization, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.1 in Appendix 3. Correlation coefficients are listed in table 6.

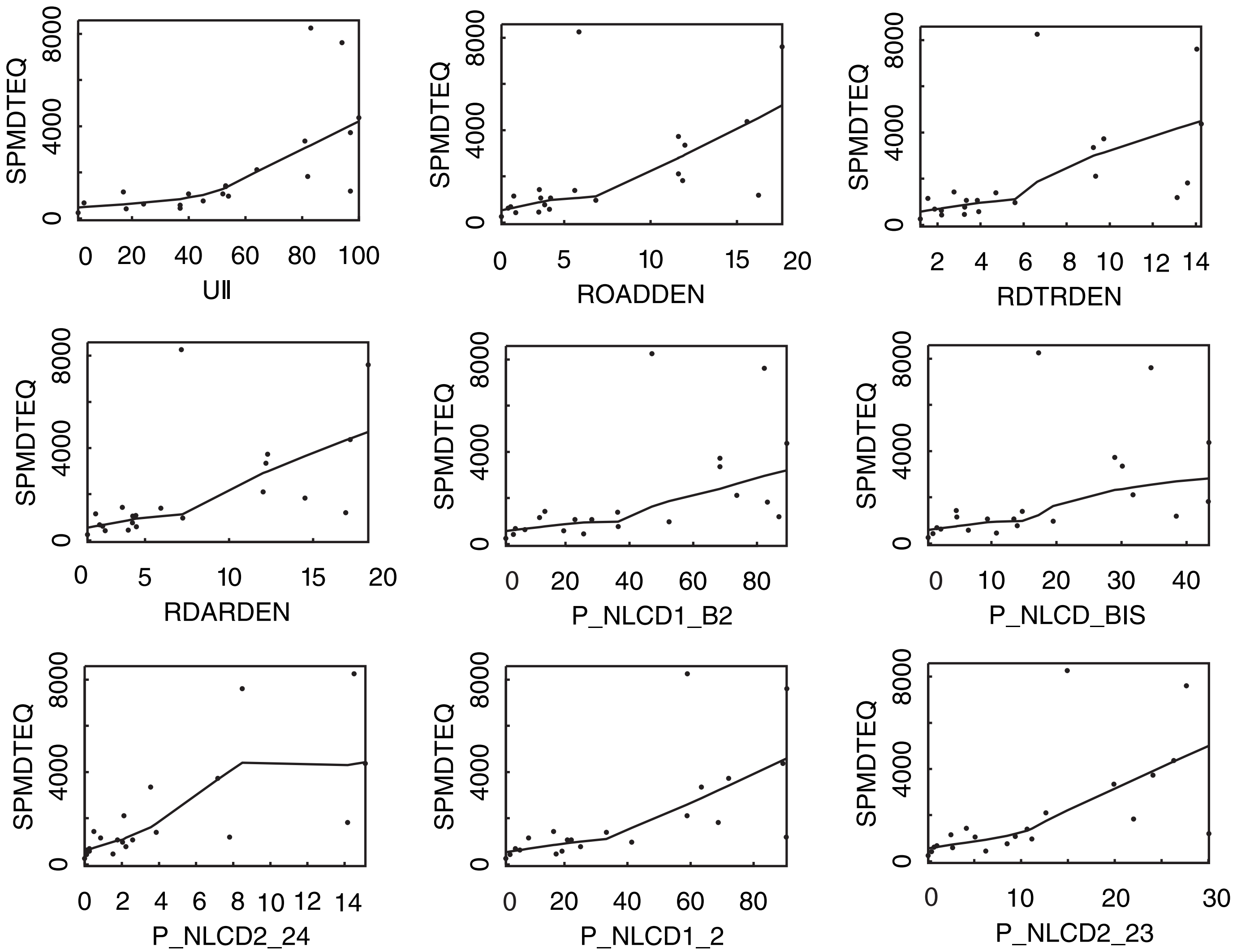


Figure 6.5. The responses of SPMD-based (semipermeable-membrane device) toxicity and chemistry variables to the urban intensity index (UII), individual measures of urbanization, and stream-hydrology variables, with a lowess smooth line. Variable pairs are only shown here if the absolute values of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3. Correlation coefficients are listed in table 7.

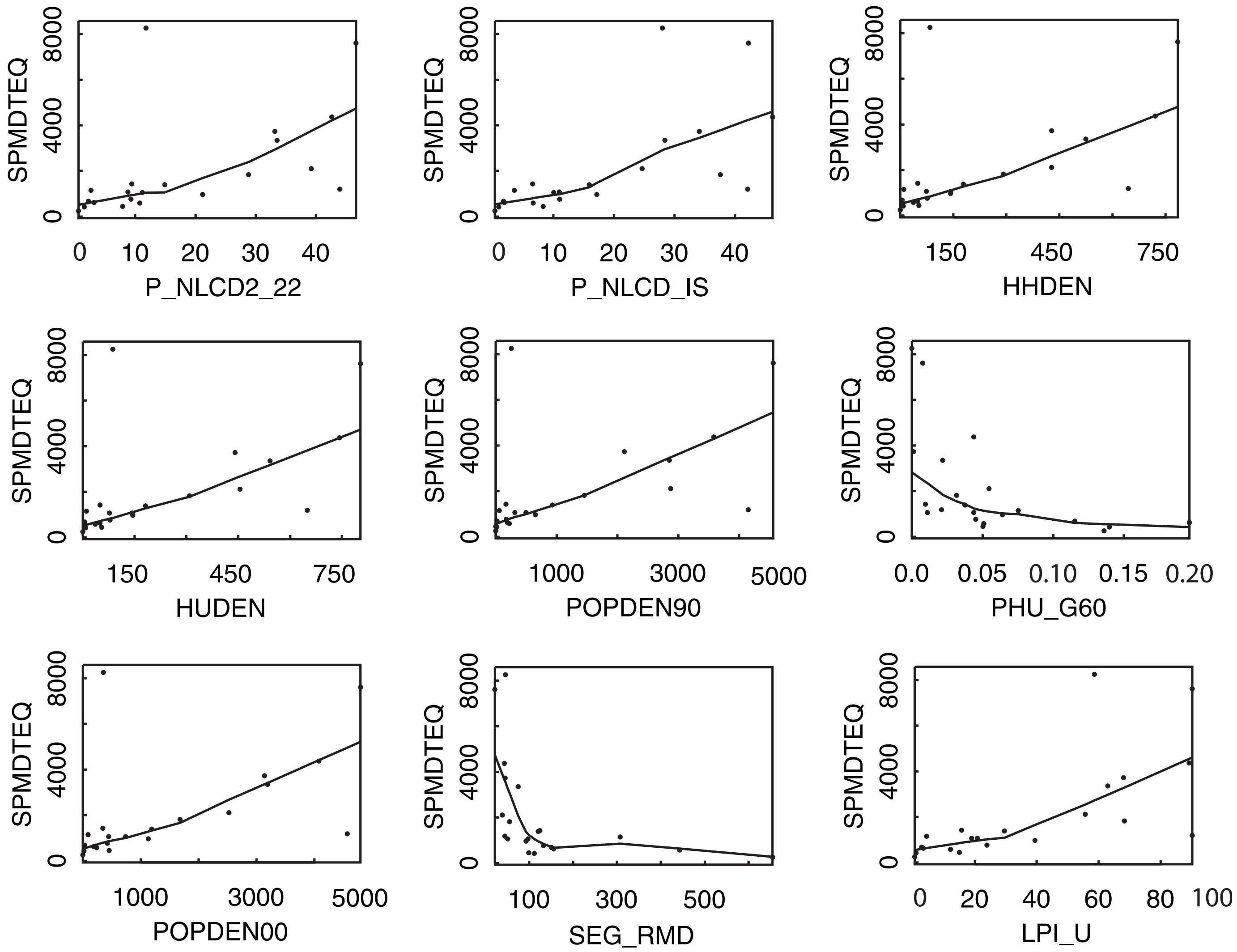


Figure 6.5. The responses of SPMD-based (semipermeable-membrane device) toxicity and chemistry variables to the urban intensity index (UII), individual measures of urbanization, and stream-hydrology variables, with a lowess smooth line. Variable pairs are only shown here if the absolute values of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3. Correlation coefficients are listed in table 7.—Continued

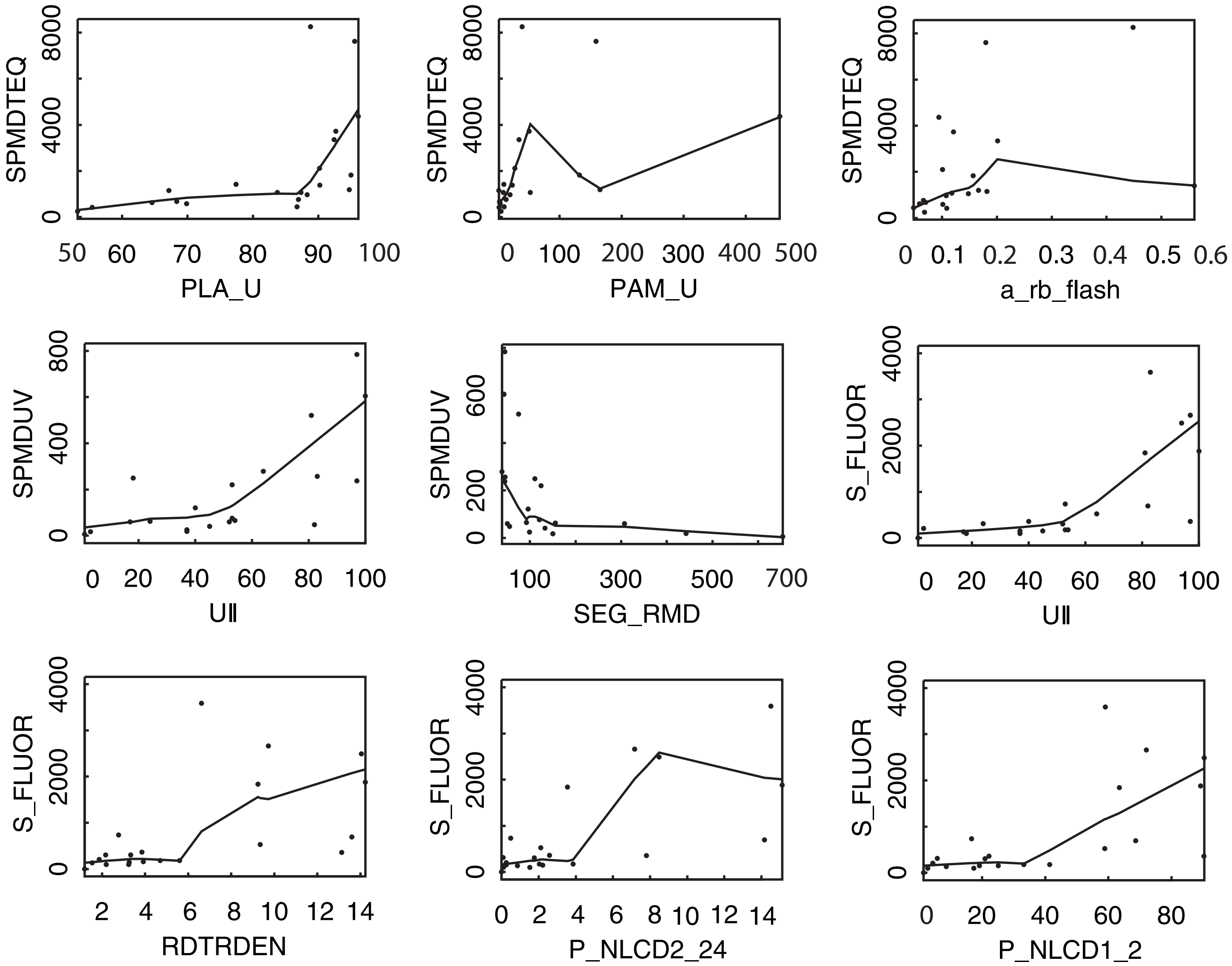


Figure 6.5. The responses of SPMD-based (semipermeable-membrane device) toxicity and chemistry variables to the urban intensity index (UII), individual measures of urbanization, and stream-hydrology variables, with a lowess smooth line. Variable pairs are only shown here if the absolute values of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3. Correlation coefficients are listed in table 7.—Continued

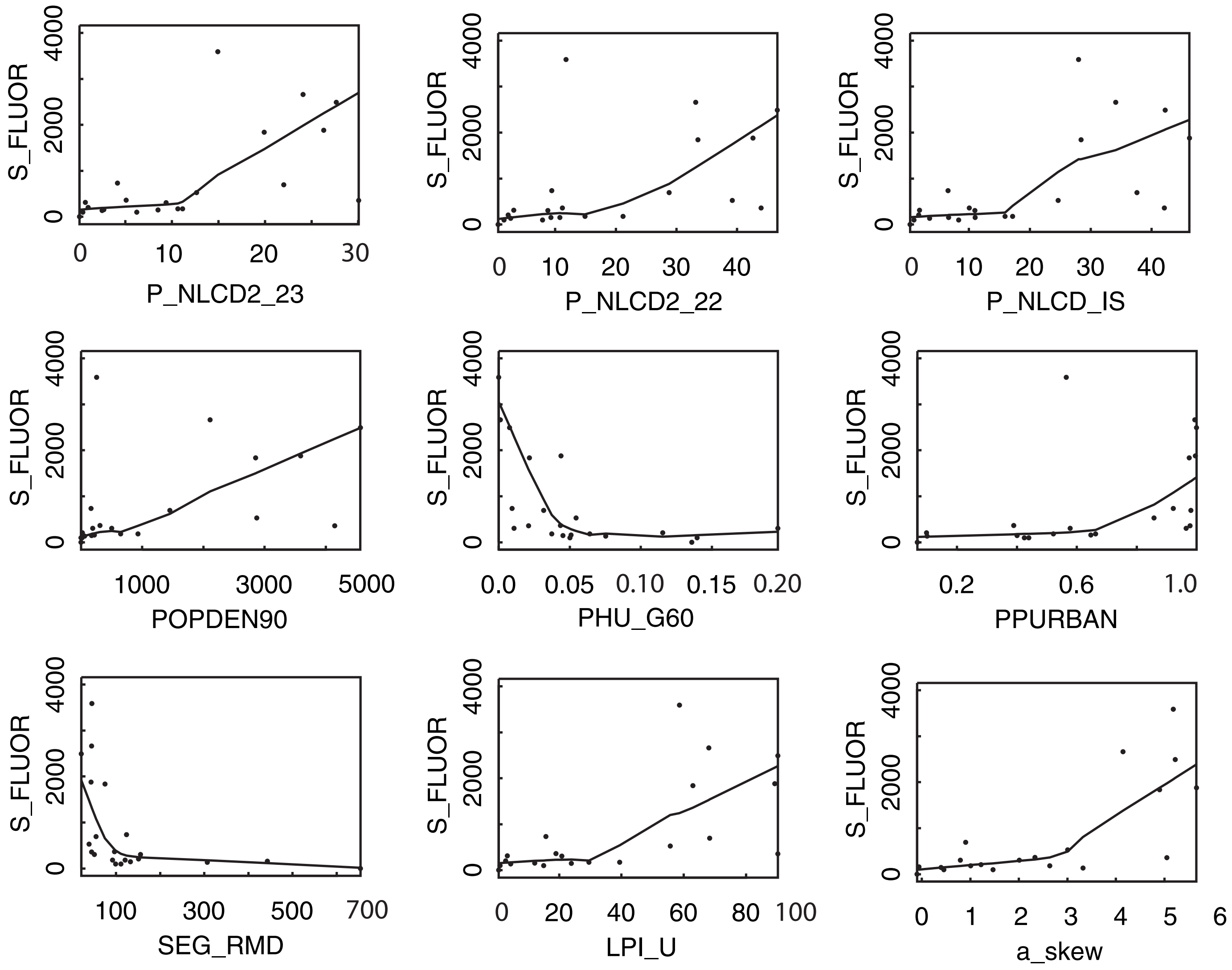


Figure 6.5. The responses of SPMD-based (semipermeable-membrane device) toxicity and chemistry variables to the urban intensity index (UII), individual measures of urbanization, and stream-hydrology variables, with a lowess smooth line. Variable pairs are only shown here if the absolute values of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3. Correlation coefficients are listed in table 7.—Continued

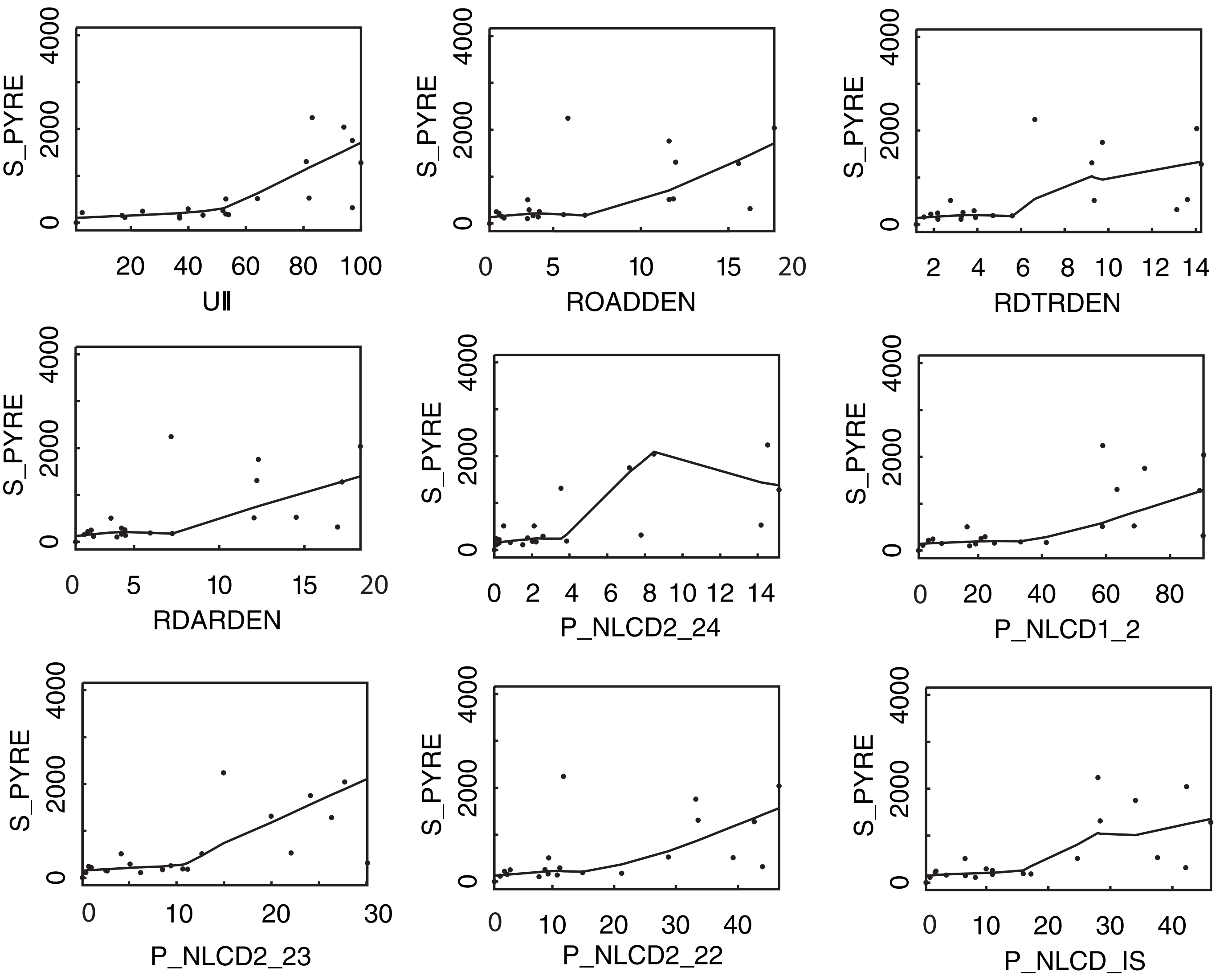


Figure 6.5. The responses of SPMD-based (semipermeable-membrane device) toxicity and chemistry variables to the urban intensity index (UII), individual measures of urbanization, and stream-hydrology variables, with a lowess smooth line. Variable pairs are only shown here if the absolute values of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3. Correlation coefficients are listed in table 7.—Continued

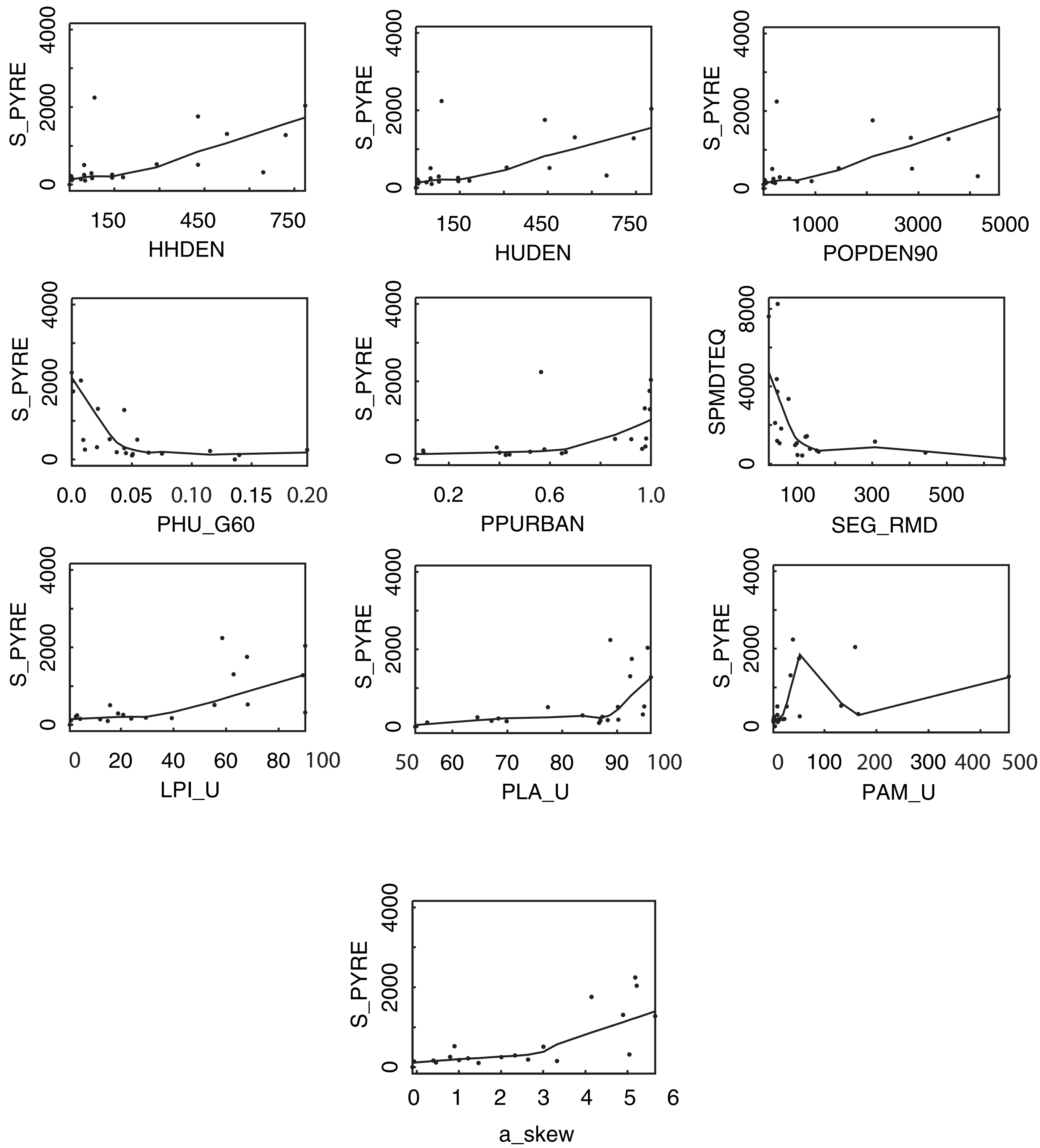


Figure 6.5. The responses of SPMD-based (semipermeable-membrane device) toxicity and chemistry variables to the urban intensity index (UII), individual measures of urbanization, and stream-hydrology variables, with a lowess smooth line. Variable pairs are only shown here if the absolute values of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; table 2.1 in Appendix 2; and table 3.2 in Appendix 3. Correlation coefficients are listed in table 7.—Continued

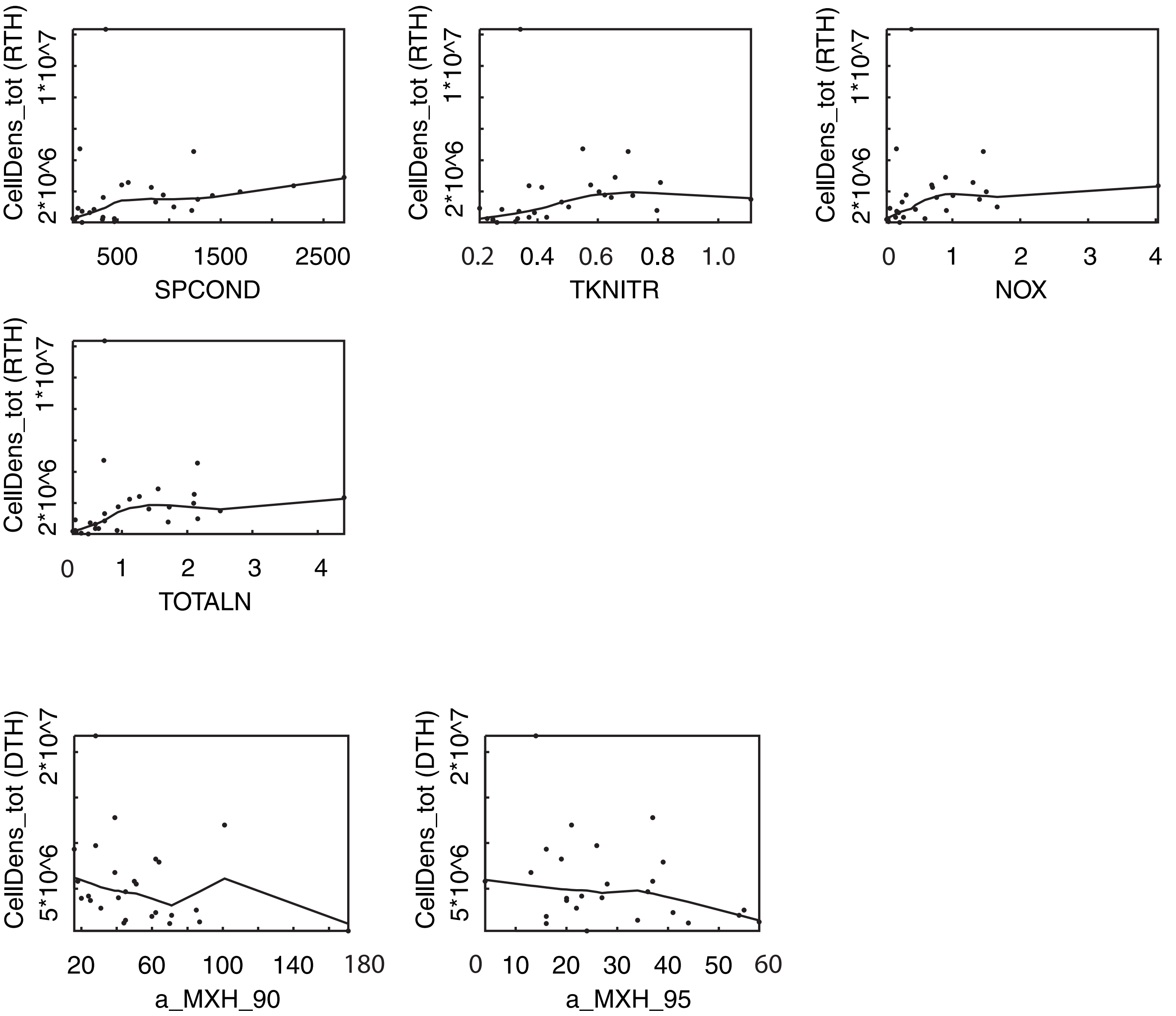
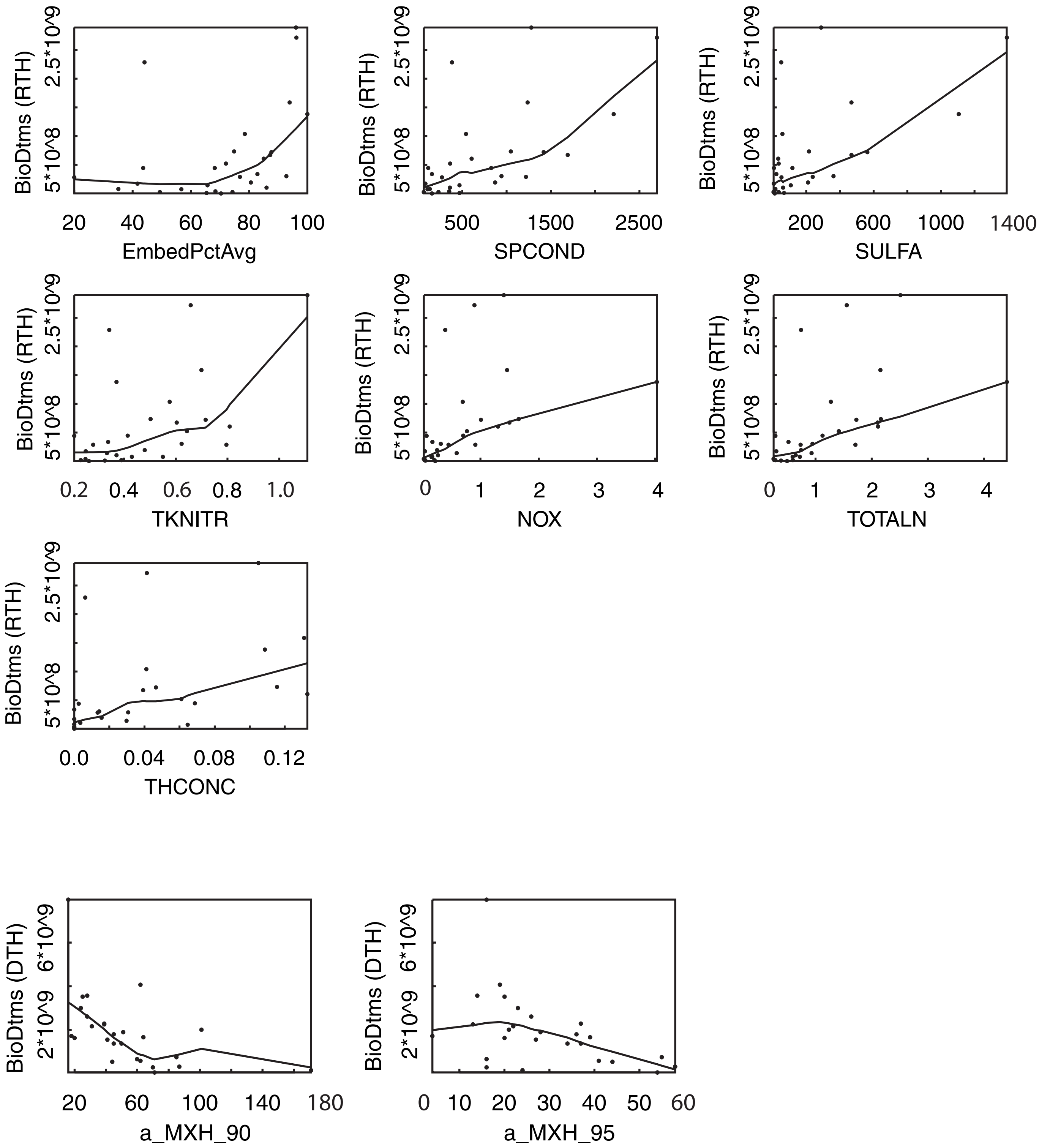


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.



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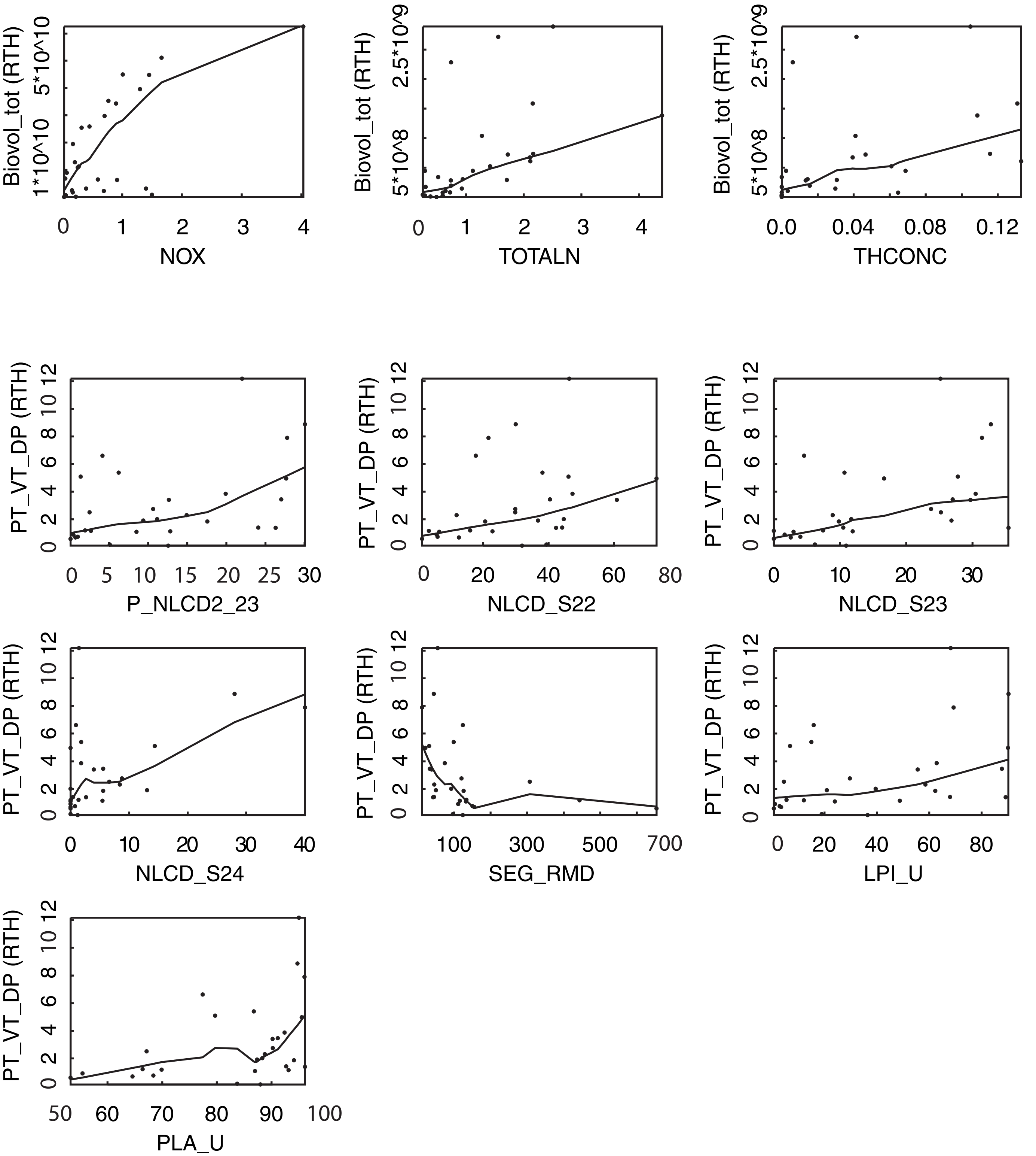


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

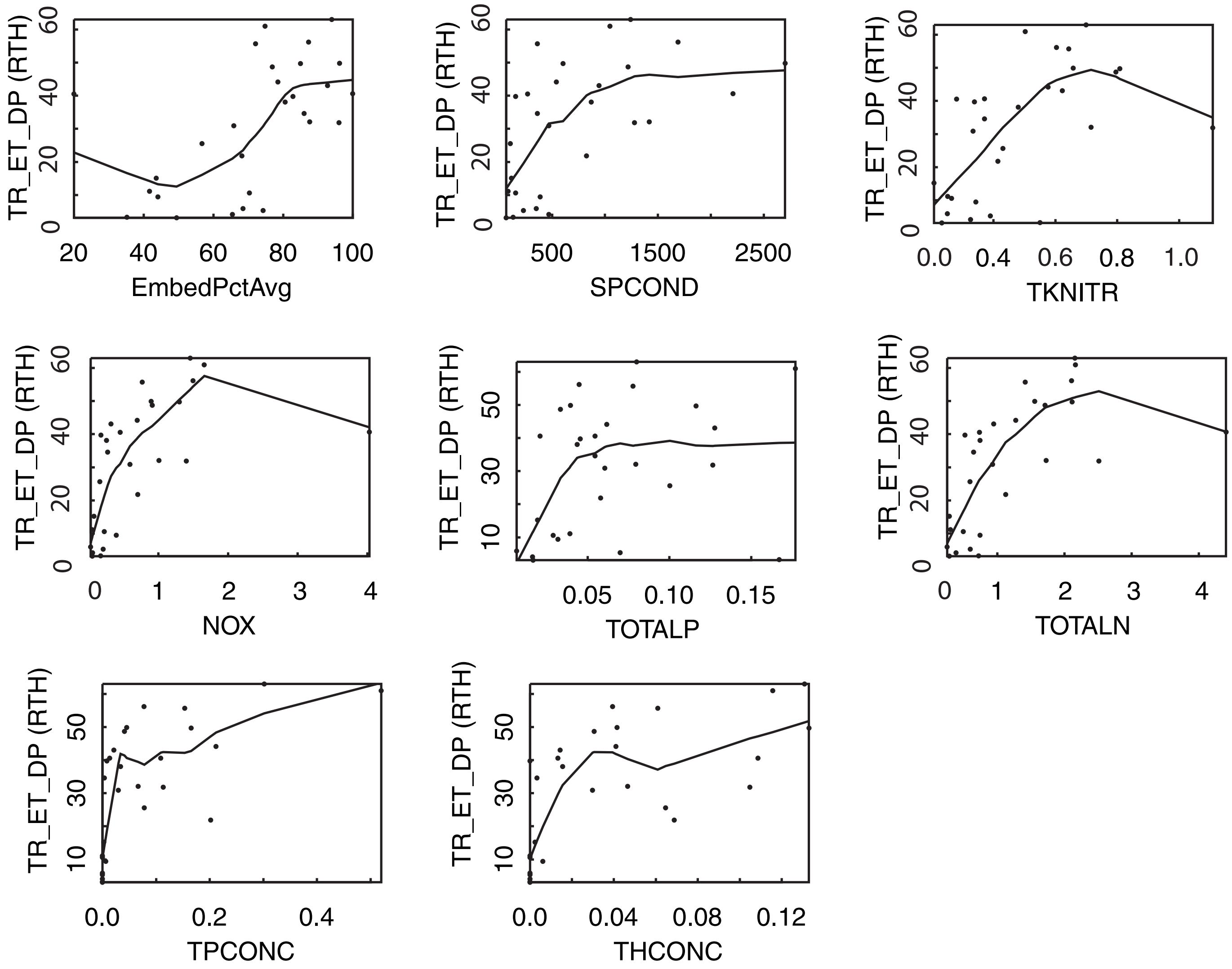


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

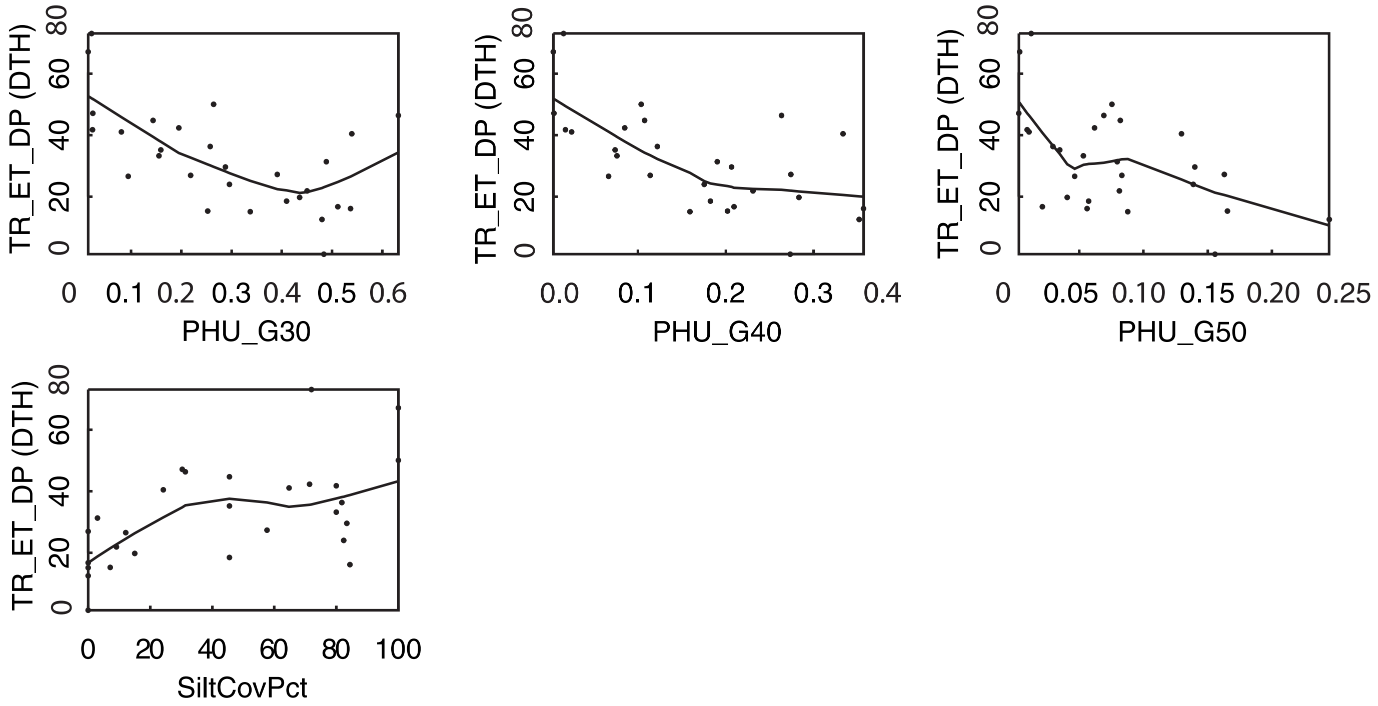


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

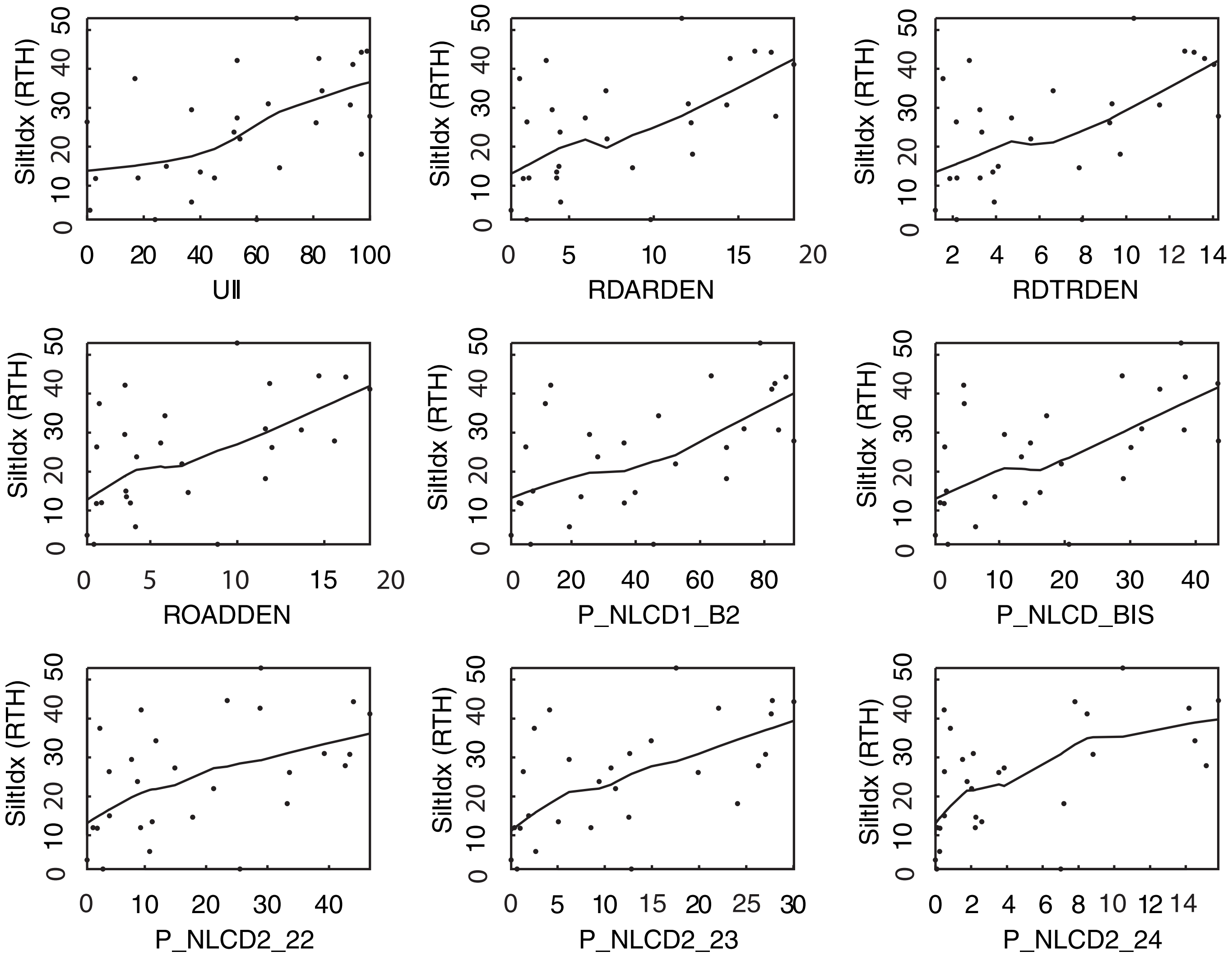


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

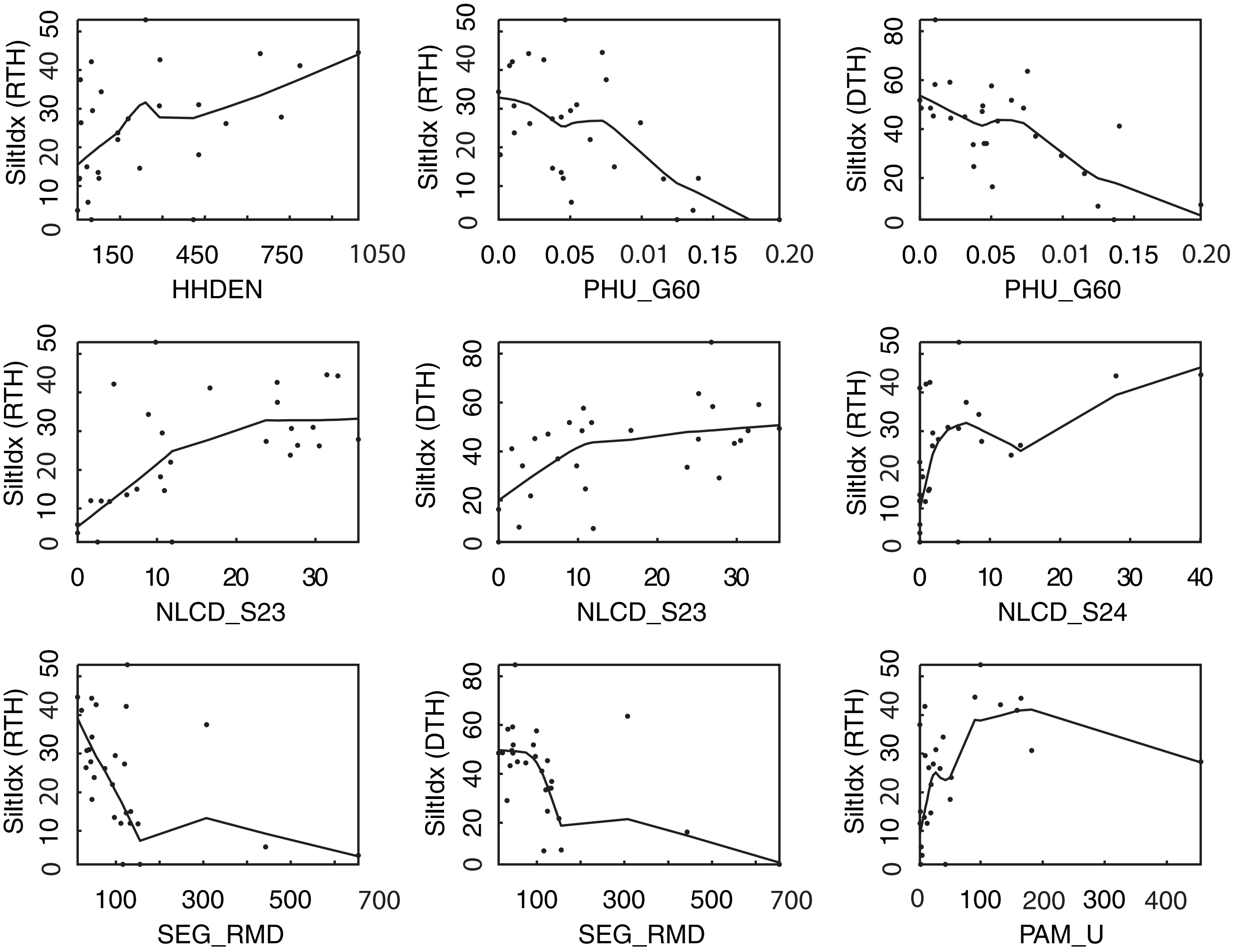


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

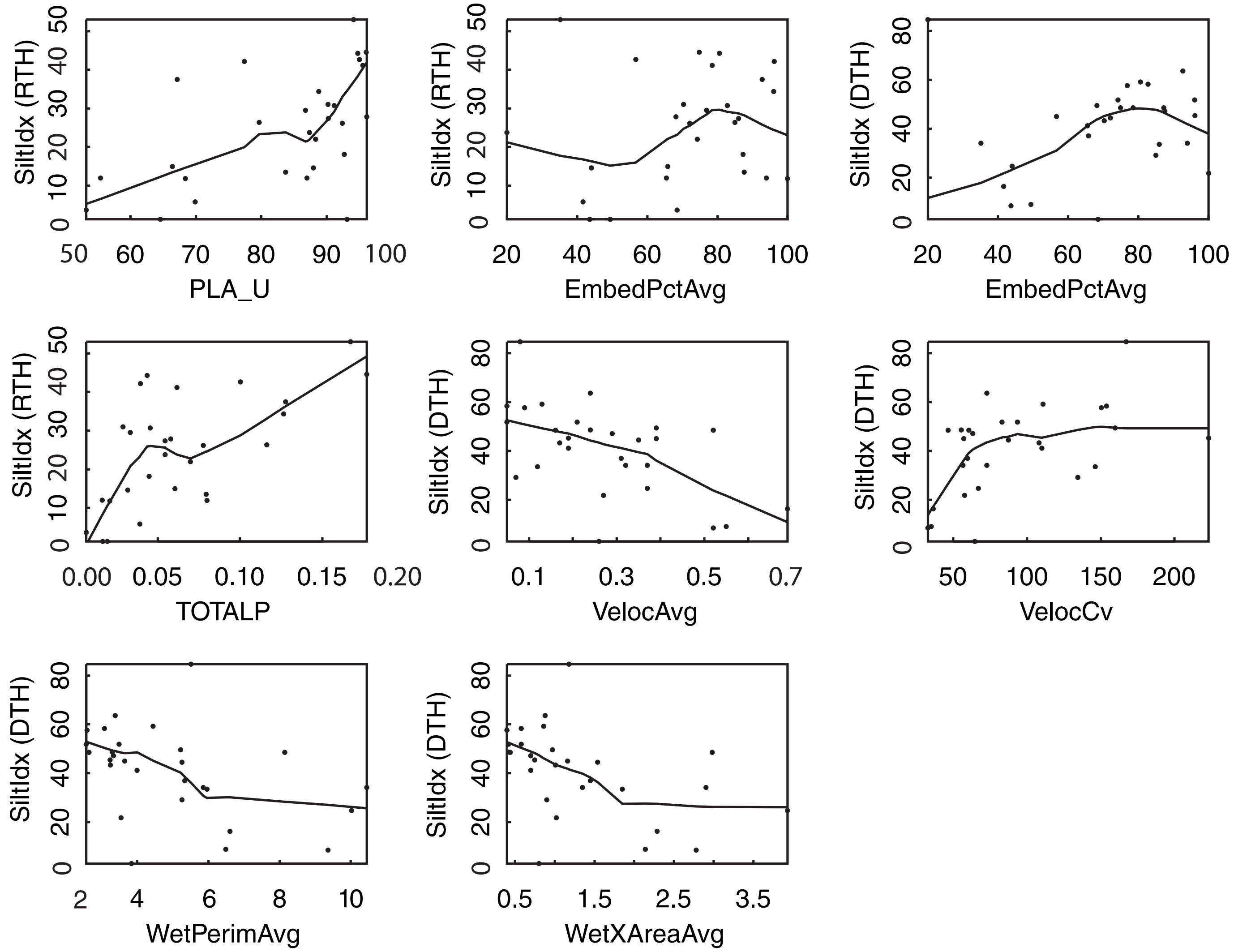


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

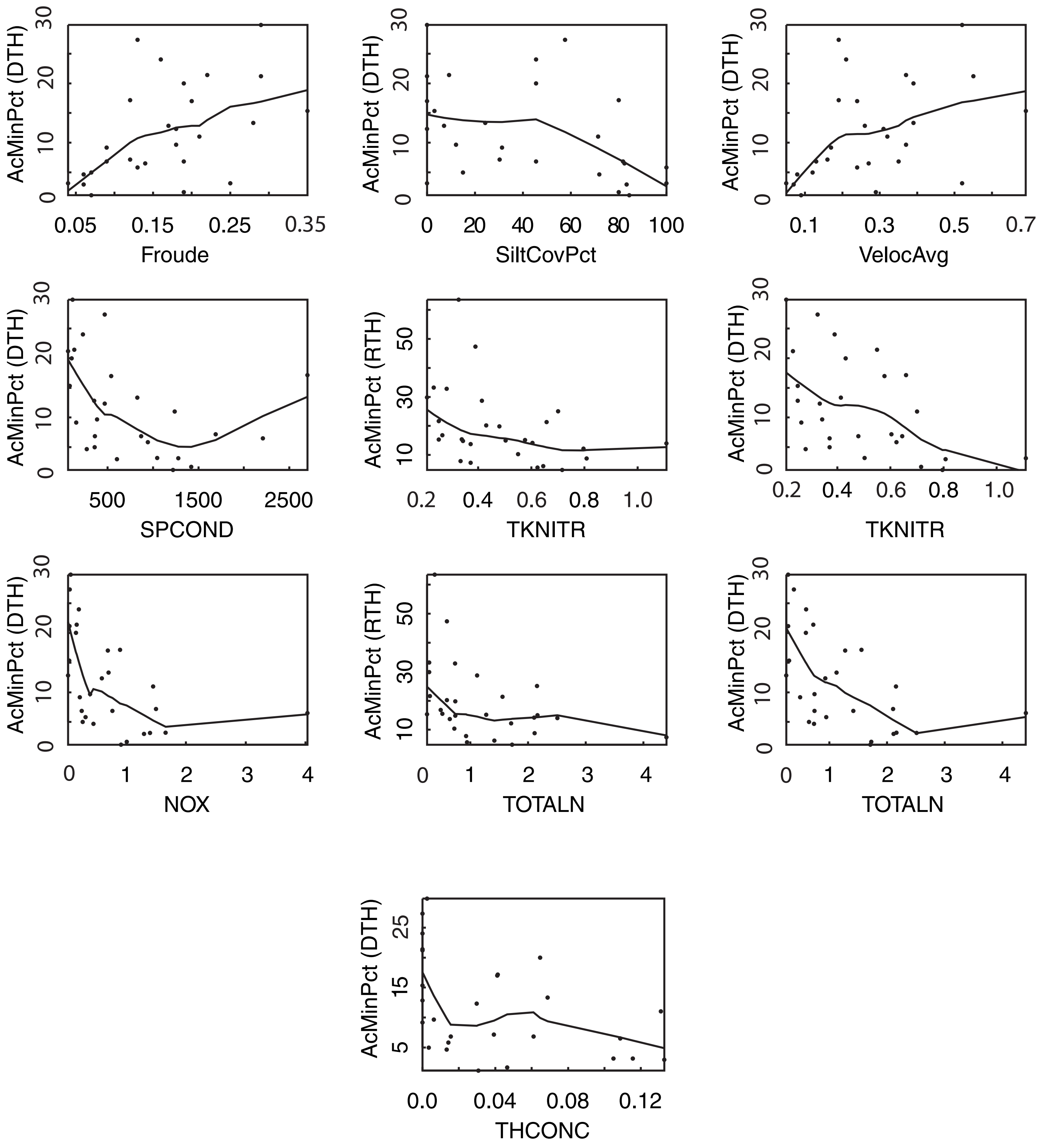


Figure 6.6. The responses of algae variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.1 in Appendix 4. Correlation coefficients are listed in table 9.—Continued

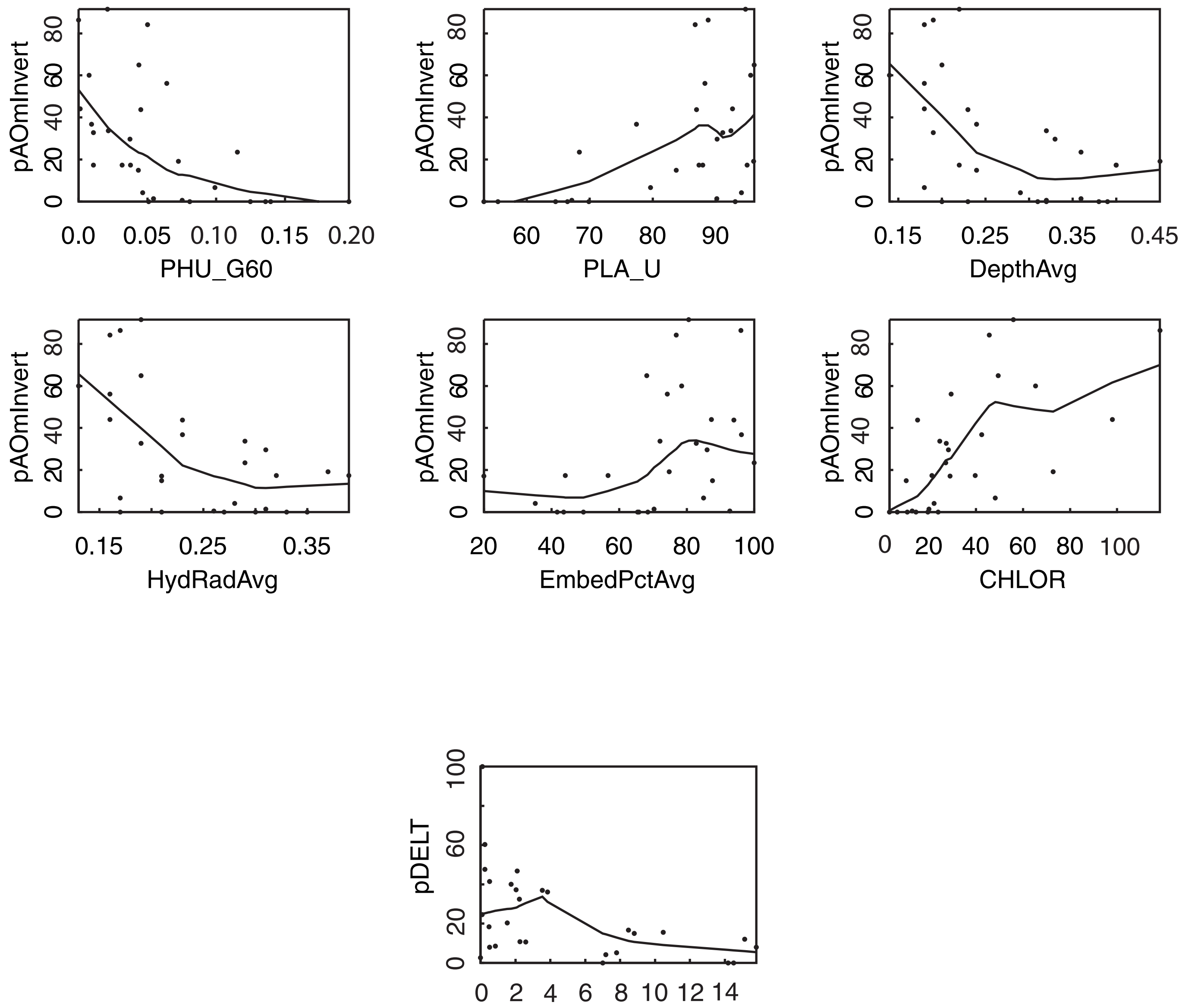


Figure 6.7. The responses of fish variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.2 in Appendix 4. Correlation coefficients are listed in table 10.

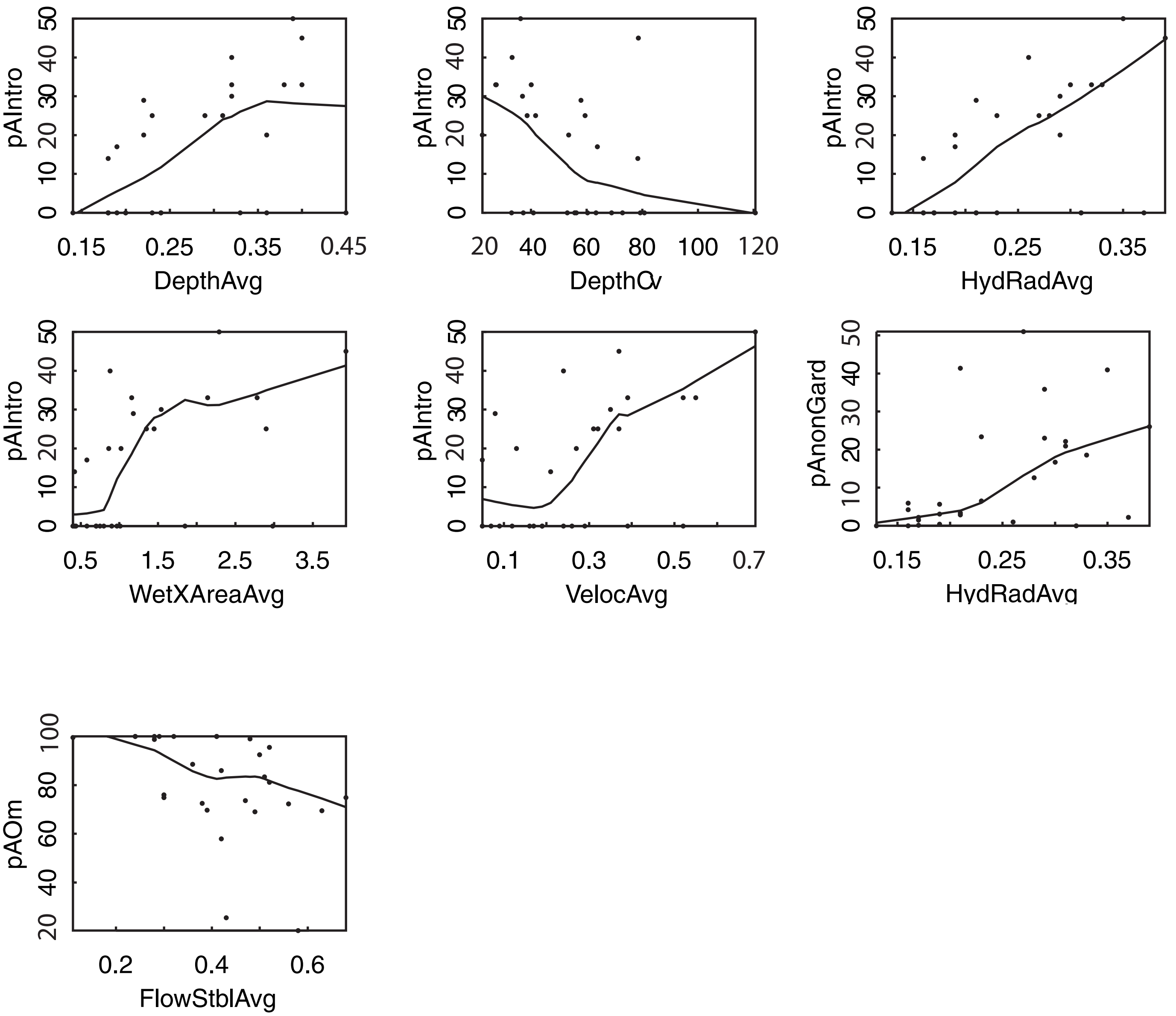


Figure 6.7. The responses of fish variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.2 in Appendix 4. Correlation coefficients are listed in table 10—Continued.

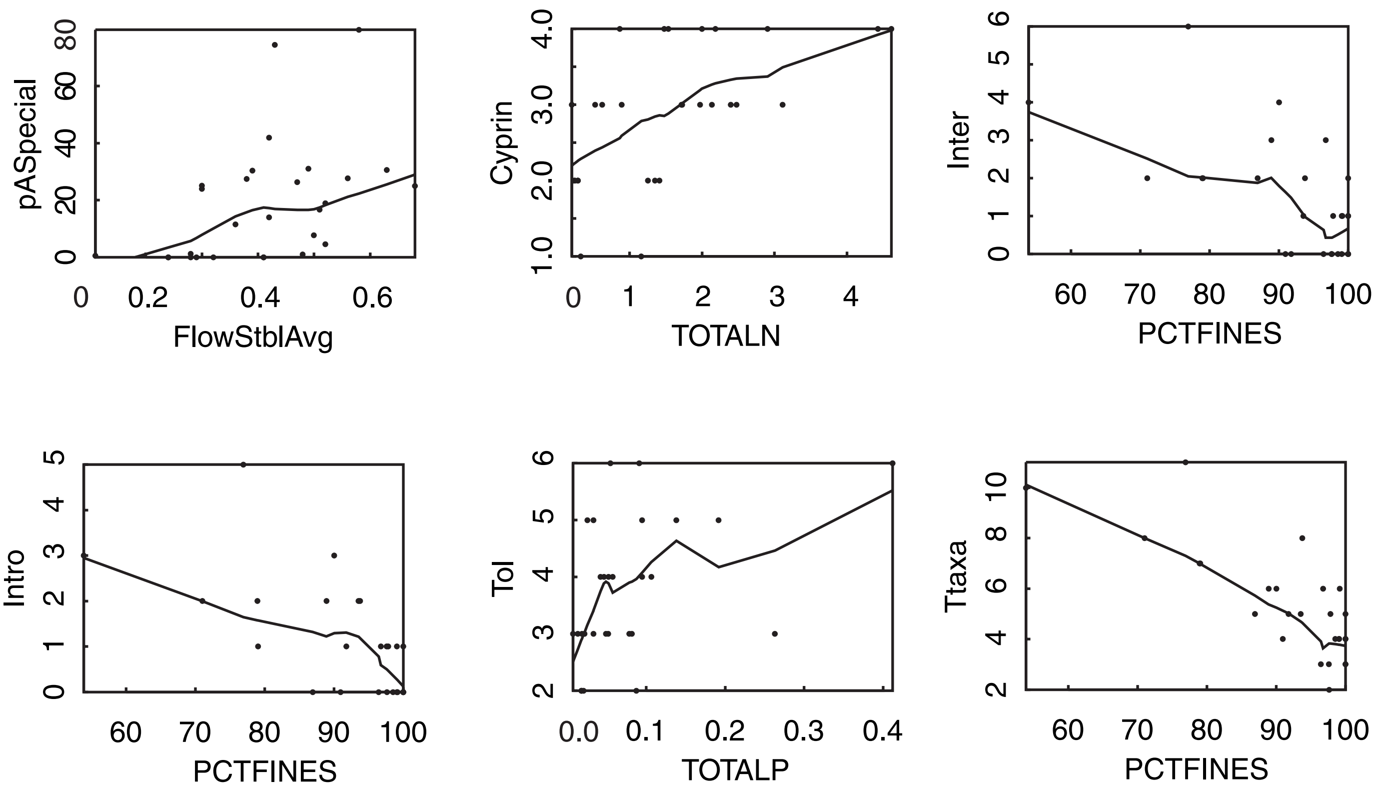


Figure 6.7. The responses of fish variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.2 in Appendix 4. Correlation coefficients are listed in table 10—Continued.

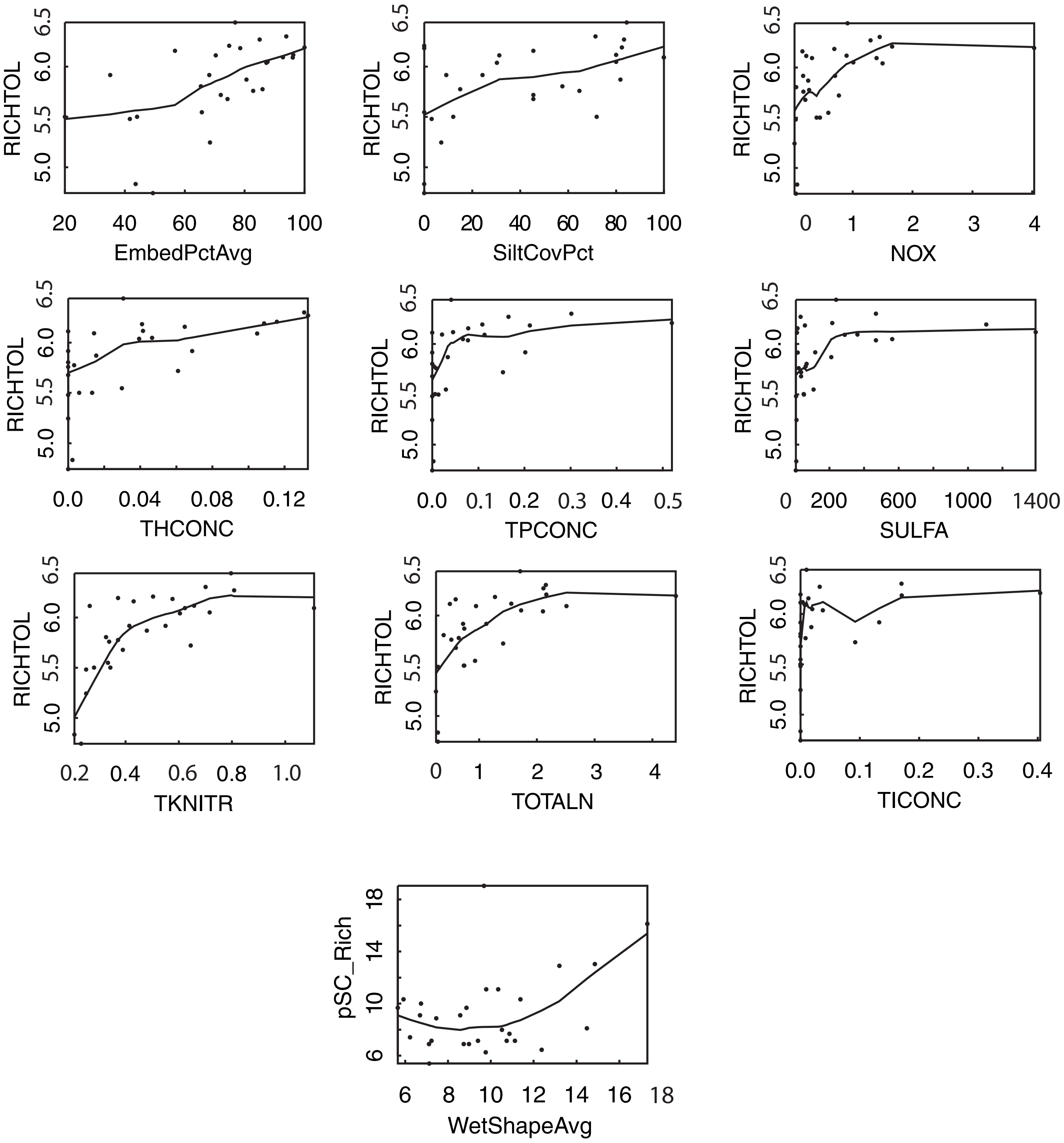


Figure 6.8. The responses of invertebrate variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.3 in Appendix 4. Correlation coefficients are listed in table 11.

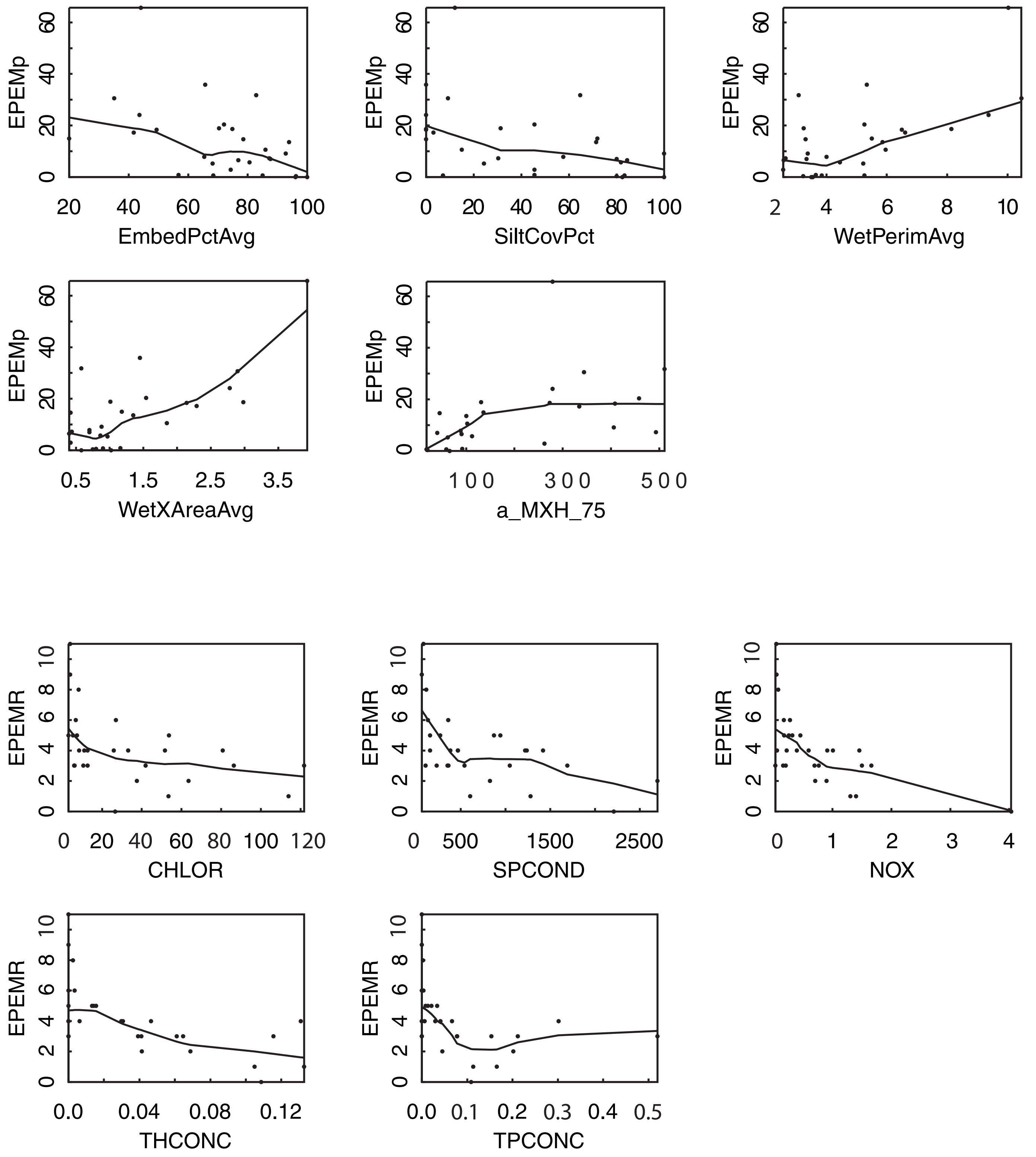


Figure 6.8. The responses of invertebrate variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.3 in Appendix 4. Correlation coefficients are listed in table 11.—Continued

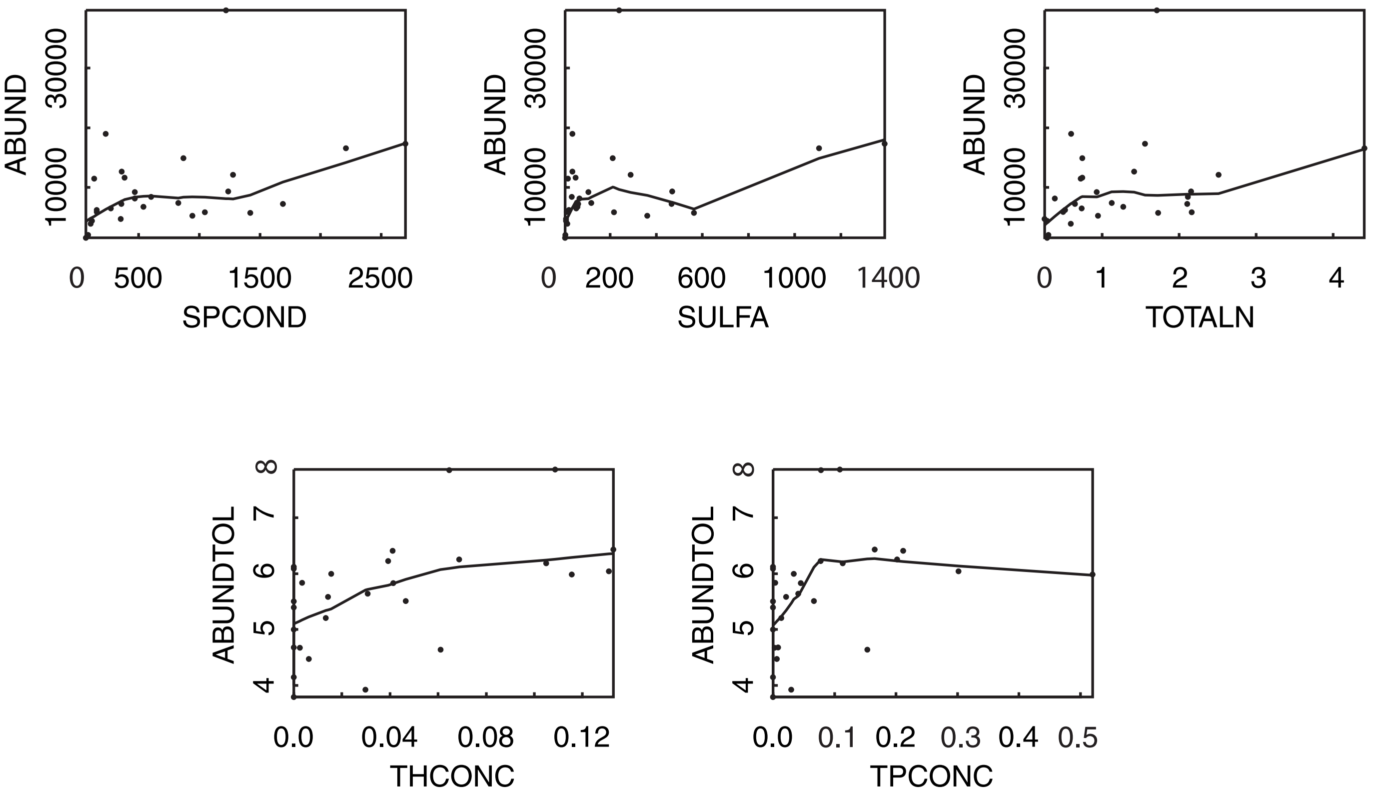


Figure 6.8. The responses of invertebrate variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.3 in Appendix 4. Correlation coefficients are listed in table 11.—Continued

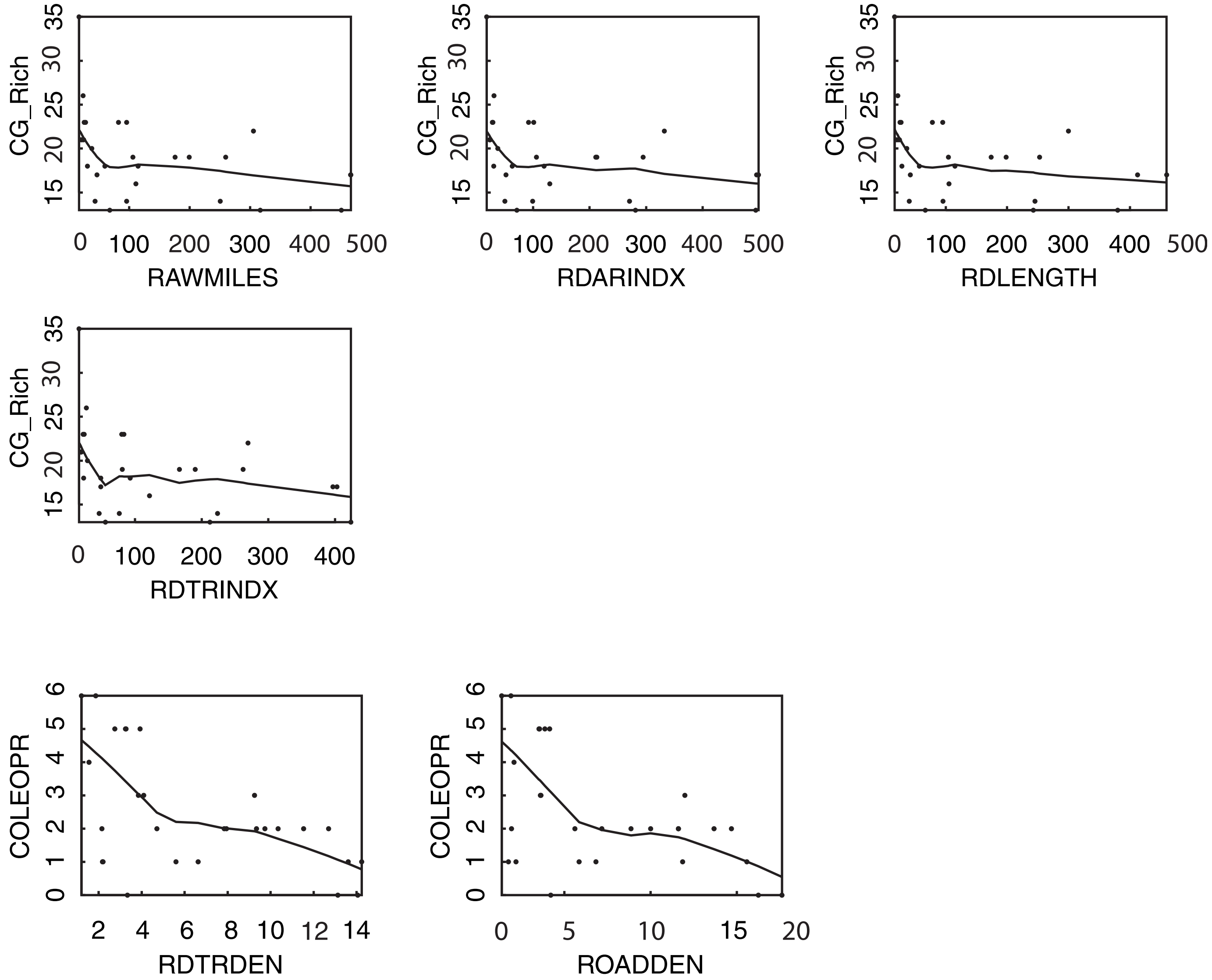


Figure 6.8. The responses of invertebrate variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.3 in Appendix 4. Correlation coefficients are listed in table 11.—Continued

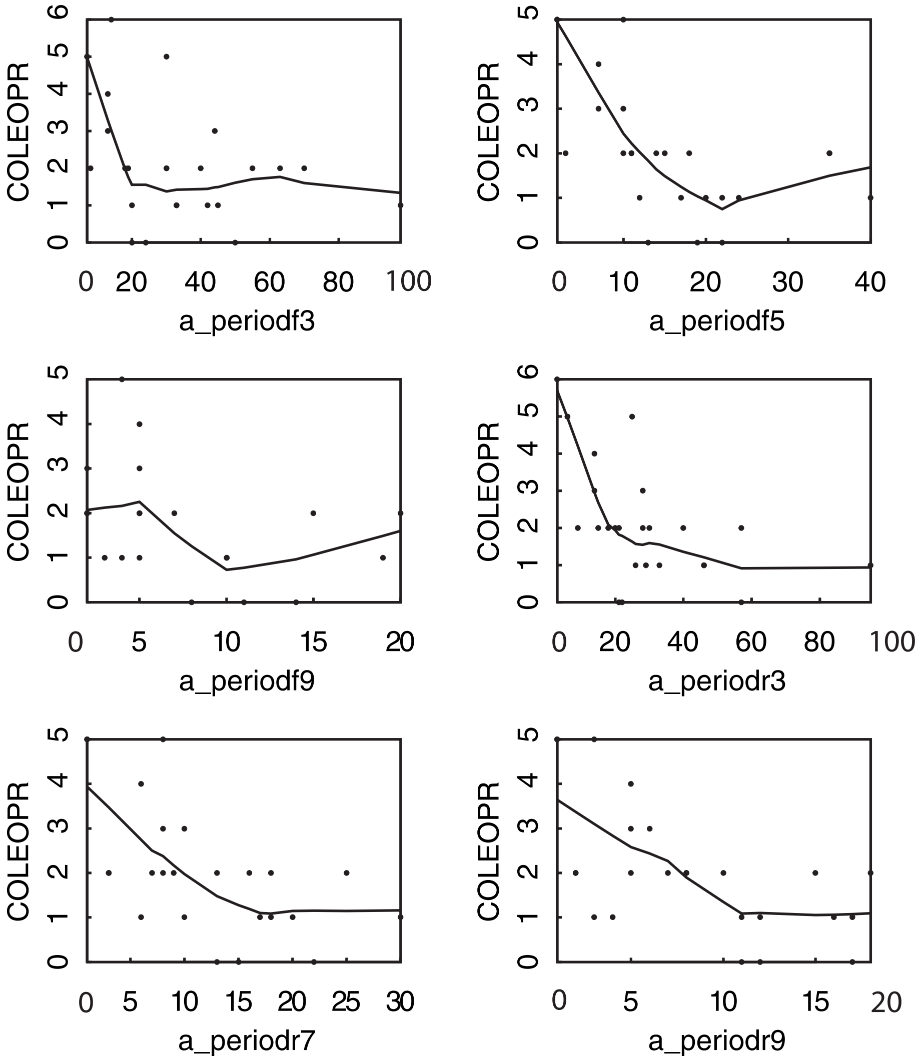
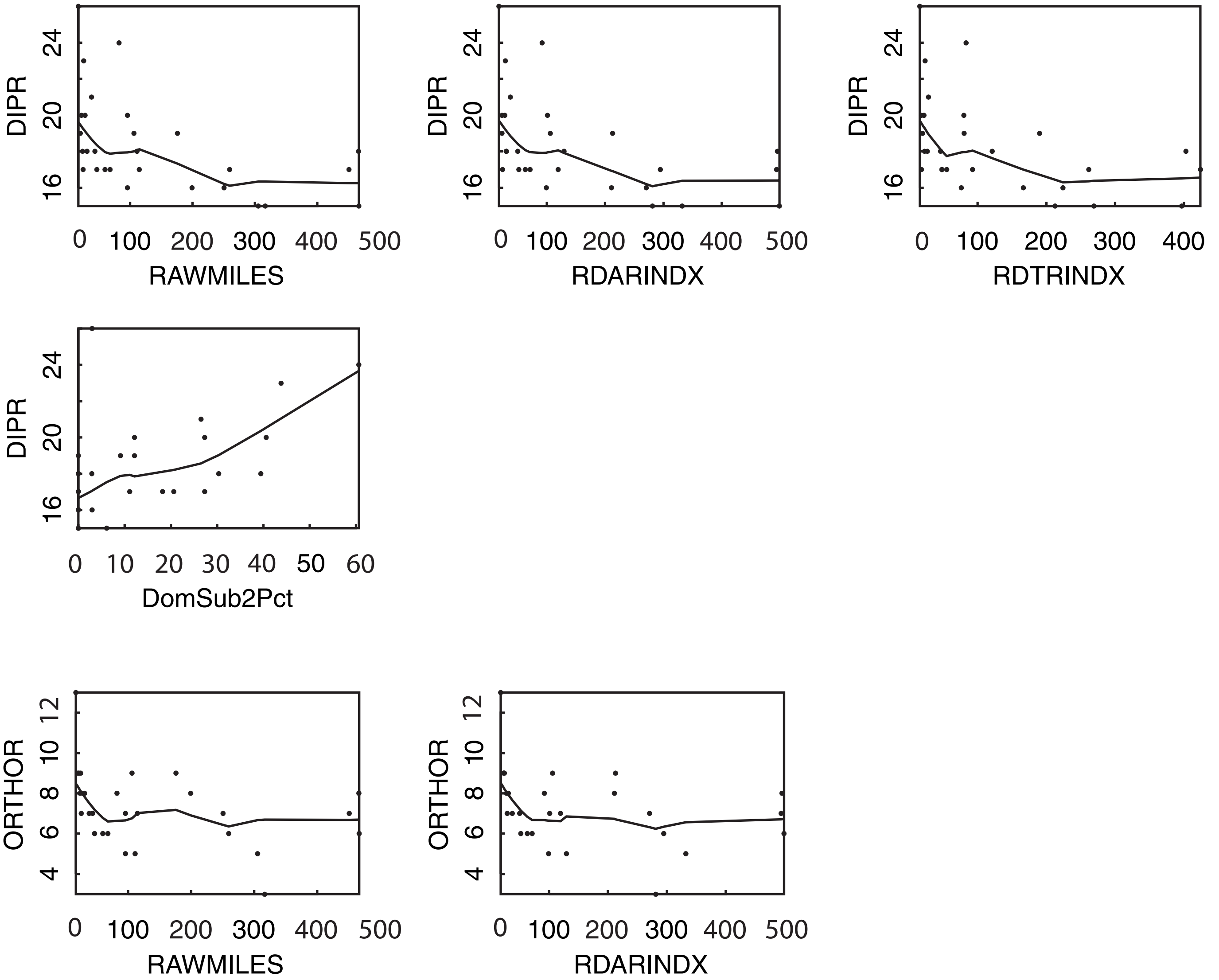


Figure 6.8. The responses of invertebrate variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.3 in Appendix 4. Correlation coefficients are listed in table 11.—Continued



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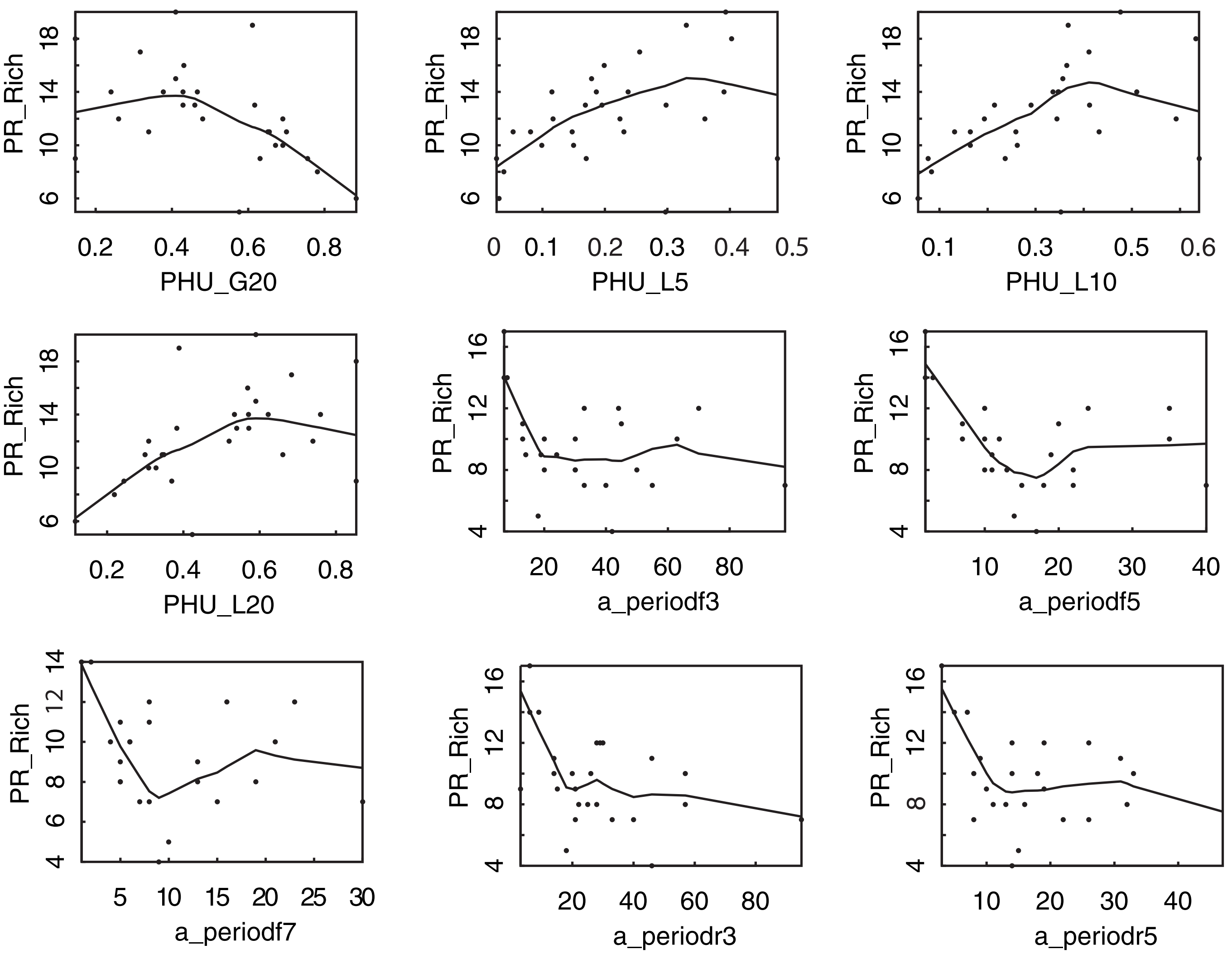
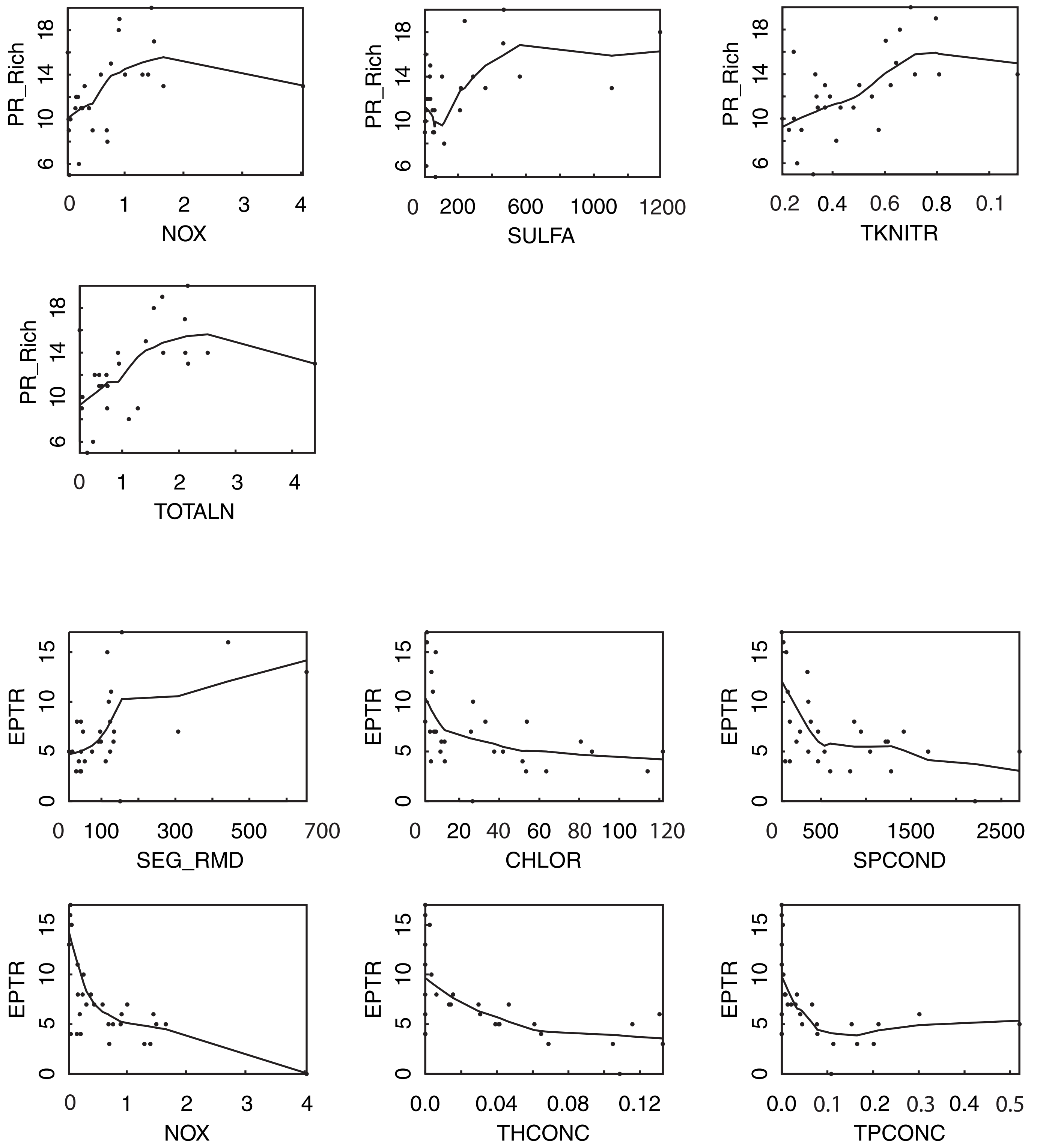


Figure 6.8. The responses of invertebrate variables to the urban intensity index (UII), individual measures of urbanization, and habitat, stream-hydrology, and water-chemistry variables, with a lowess smooth line. Variable pairs are only shown here if the absolute value of the Spearman's rho correlation coefficient was greater than 0.5 and a distinct pattern was evident in the data. Variables are defined in table 1.6 in Appendix 1; tables 2.1, 2.2, and 2.3 in Appendix 2; tables 3.1 and 3.2 in Appendix 3; and table 4.3 in Appendix 4. Correlation coefficients are listed in table 11.—Continued



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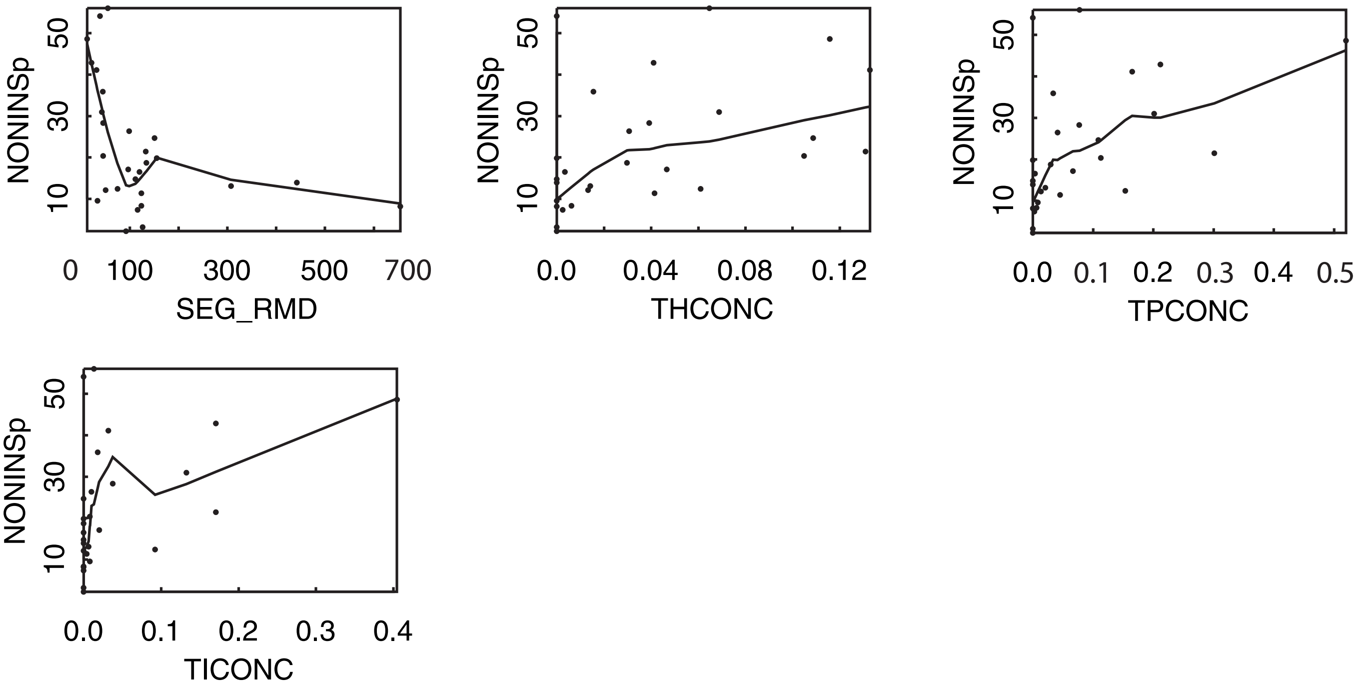

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