Influence of Natural Factors on the Quality of Midwestern Streams and Rivers

By Stephen D. Porter, Mitchell A. Harris, and Stephen J. Kalkhoff

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 00–4288

Denver, Colorado
2001

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

Regional Hydrologist
U.S. Geological Survey
Box 25046, Mail Stop 406
Denver Federal Center
Denver, CO 80225–0046

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225

Influence of Natural Factors on the Quality of Midwestern Streams and Rivers

—Stephen D. Porter, Mitchell A. Harris, and Stephen J. Kalkhoff

Streams flowing through cropland in the Midwestern Corn Belt differ considerably in their chemical and ecological characteristics, even though agricultural land use is highly intensive throughout the entire region. These differences likely are attributable to differences in riparian vegetation, soil properties, and hydrology. This conclusion is based on results from a study of the upper Midwest region conducted during seasonally low-flow conditions in August 1997 by the U.S. Geological Survey (USGS) National Water Quality Assessment (NAWQA) Program. This report summarizes significant results from the study and presents some implications for the design and interpretation of water-quality monitoring and assessment studies based on these results.

Contents

Introduction

The Midwestern Corn Belt is one of the most productive agricultural regions in the world. Nearly 80 percent of the Nation's corn and soybeans is grown in the region. More than 6 million metric tons of nitrogen fertilizer and over 100,000 metric tons of pesticides are applied to cropland in the Midwest annually (Goolsby and others, 1993). The 1997 growing season produced the largest soybean crop and second-largest corn crop recorded in the Midwest.

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program conducted a water-quality study in the upper Midwest region during seasonally low-flow conditions in August 1997. Chemical and biological samples were collected from 70 streams and rivers in the Minnesota, Wapsipinicon, Cedar, Iowa, Skunk, and lower Illinois River basins of southern Minnesota, eastern Iowa, and western Illinois (fig. 1). Sampling locations were chosen to represent a range of soil-drainage conditions in stream basins and the percentage of trees in buffer zones along riparian segments. Census data from the U.S. Department of Agriculture (USDA) for 1997 were used in this study to quantify cropland, livestock, and chemical application in each basin. A complete description of the study design, methods, and data can be found in Sorenson and others (1999). This report summarizes significant results from the study and presents some implications for the design and interpretation of water-quality monitoring and assessment studies based on these results.

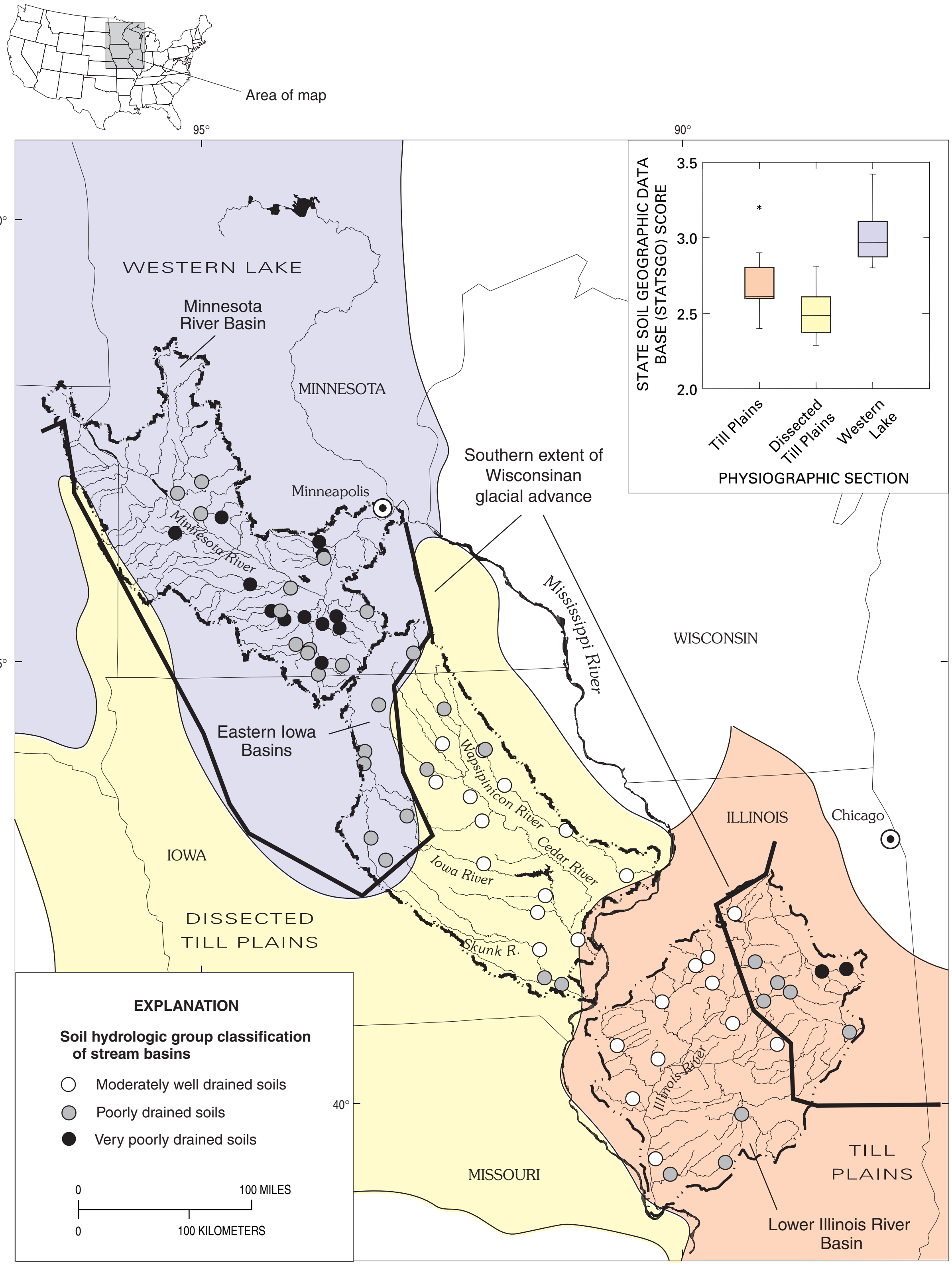


Figure 1. *Soil drainage in basins for the 70 streams and rivers sampled during August 1997 varied from very poor in the Western Lake physiographic section to moderately well drained in the Dissected Till Plains section.*

Differences in landscape terrain and soil characteristics among drainage basins in the upper Midwest region are associated with historical patterns of glacial advance and retreat. The spatial distribution of soils corresponds generally with physiographic sections (Fenneman and Johnson, 1946) in the upper Midwest region (fig. 1). For example, soils generally are moderately well drained in the Dissected Till Plains section of eastern Iowa, and the proportion of stream water that is derived from ground-water inflow is substantially greater than in adjacent sections (Winter and others, 1998). In contrast, soils with poor drainage, high runoff potential, and relatively higher organic nitrogen content are found in the Western Lake section of southern Minnesota and northern Iowa. Agricultural drainage systems (tiles and ditches) are prevalent throughout the study area. The USDA State Soil Geographic data base (STATSGO) was used to calculate Soil Hydrologic Group scores for each basin (Sorenson and others, 1999). Soil Hydrologic Groups are classified on the basis of drainage, runoff potential, permeability, depth to water table, and related characteristics. Stream basins with STATSGO scores of 2.6 or less were characterized as having “moderately well drained” soils; basins with scores exceeding 2.6, “poorly drained;” and basins with scores exceeding 3.0, “very poorly drained” (fig. 1).

Resource agencies such as the USDA encourage maintenance of strips of trees or grass between agricultural fields and streams as a best management practice. These “riparian buffer zones” are thought to intercept runoff of sediment and chemicals from fields, promote bank stability, and provide shading and habitat for aquatic life (Osborne and Kovacic, 1993). For this study, riparian vegetation density, referred to hereinafter as “tree density,” was determined at two spatial scales: segment and reach. At the segment scale, tree density was classified based on the percentage of trees in a 100-meter-wide zone on each side of the stream for a distance of 2 to 3 miles upstream from the sampling location (Sorenson and others, 1999). Tree density was considered “low” if 35 percent or less of the area was forested and “high” if more than 35 percent was forested. At the reach scale (refer to Fitzpatrick and others, 1998), tree density was the percentage of the land surface covered by trees in replicate 20-square-meter vegetation plots along transects at the sampling location (Sorenson and others, 1999). Tree density was considered low if the percentage was less than 5 and high if 5 percent or more.

Natural Factors Influence Chemical Indicators of Water Quality

Nutrient concentrations in water samples from Midwestern streams and rivers were not correlated with measures of agricultural intensity, such as the percentage of cropland, rates of fertilizer application, or the number of livestock in the basin. About one-half of the variance in dissolved nutrient concentrations among sites can be explained by runoff relations with rainfall. Figure 2 shows that concentrations of dissolved nitrogen increased with the amount of streamflow relative to basin drainage area (unit basin water yield). Differences in unit basin yield among streams in the Till Plains, Dissected Till Plains, and Western Lake physiographic sections (fig. 2) are associated with differences in the amount of rainfall during the month preceding the study (fig. 3). In streams with low tree density, average dissolved orthophosphorus concentrations

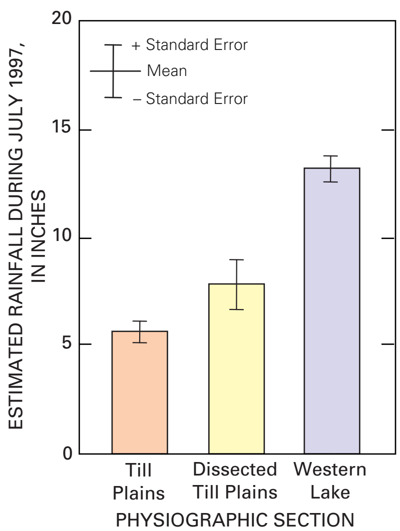


Figure 3. *Average rainfall in stream basins differed among physiographic sections in the upper Midwest region.*

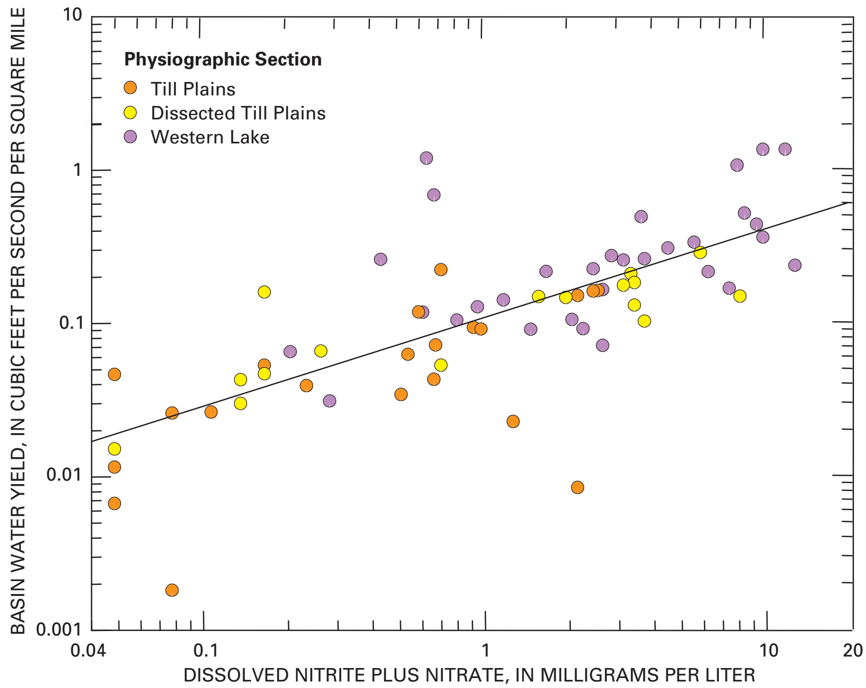
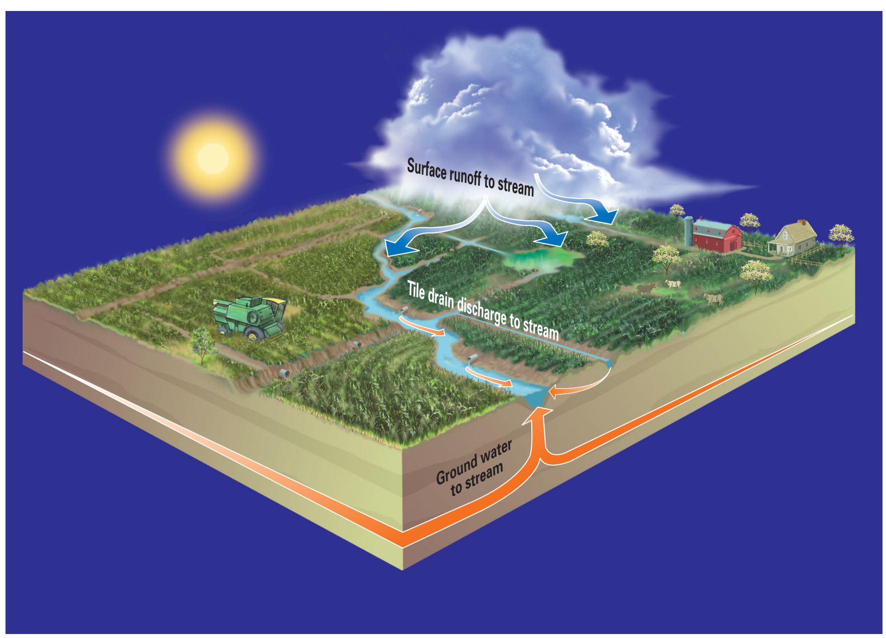
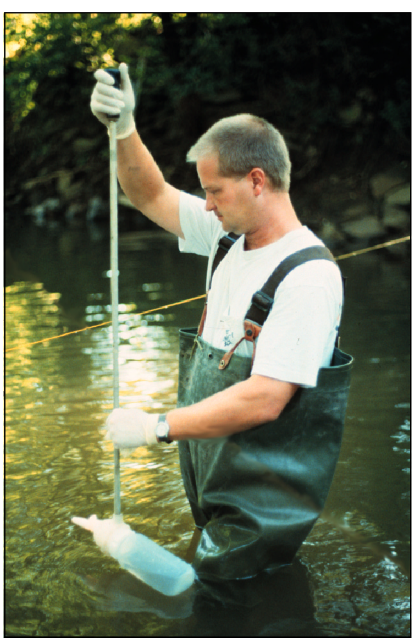


Figure 2. *Dissolved nitrogen concentrations increased with unit water yield from stream basins in August 1997, which was associated with regional differences in recent runoff.*



were smaller in basins with poorly drained soils than those with moderately well drained soils (fig. 4). Although the application of nutrient fertilizers to cropland is considerable in all stream basins, nutrient concentrations vary among streams because of differences in natural factors such as riparian tree density, soil properties, and unit basin water yield.

Average concentrations of suspended sediment were more than 40 percent smaller in streams with high tree density in riparian segments, but only in basins with poorly drained soils (fig. 5). Riparian zones with high tree density appeared to be effective in reducing runoff of agricultural soils into streams, particularly in the Western Lake section where soil drainage is very poor (fig. 1) and antecedent rainfall was high (fig. 3). Beneficial effects of buffers on nutrient and sediment concentrations in streams were less pronounced in sections where rainfall was relatively lower, soils were moderately well drained, and ground-water discharge contributed substantially to total streamflow.



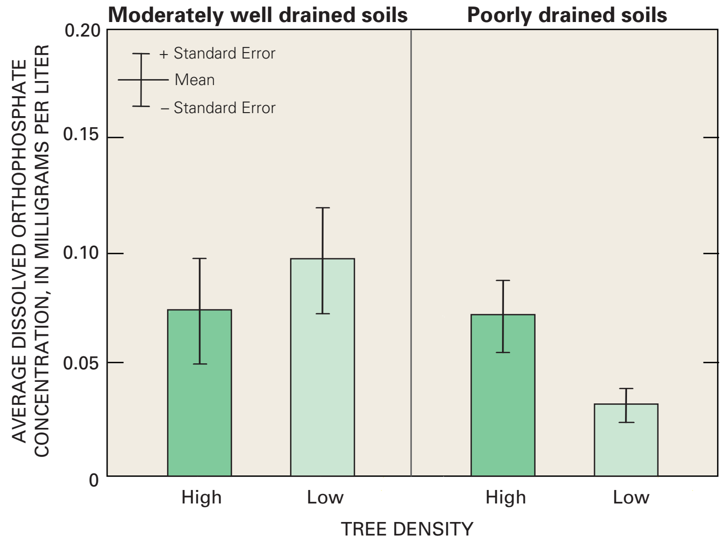


Figure 4. *Average dissolved orthophosphorus concentrations were smallest in streams with low tree density in basins with poorly drained soils.*

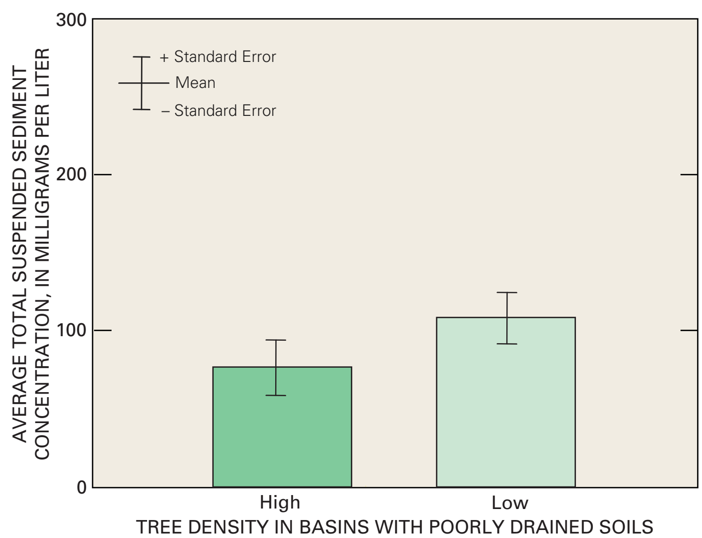


Figure 5. *Average concentrations of suspended sediment were smaller in streams with high riparian-tree density in buffer segments, but only in basins with poorly drained soils.*

Concentrations of herbicides in Midwestern streams were proportional to herbicide use (fig. 6; Sorenson and others, 1999); however, relations between parent and degradation compounds differed with respect to riparian tree density and soil conditions. Average concentrations of triazine herbicides (for example, atrazine and cyanazine) were larger in streams with high tree density in riparian segments (fig. 7). However, the ratio of triazine parent to degradation compounds was largest in streams with low tree density

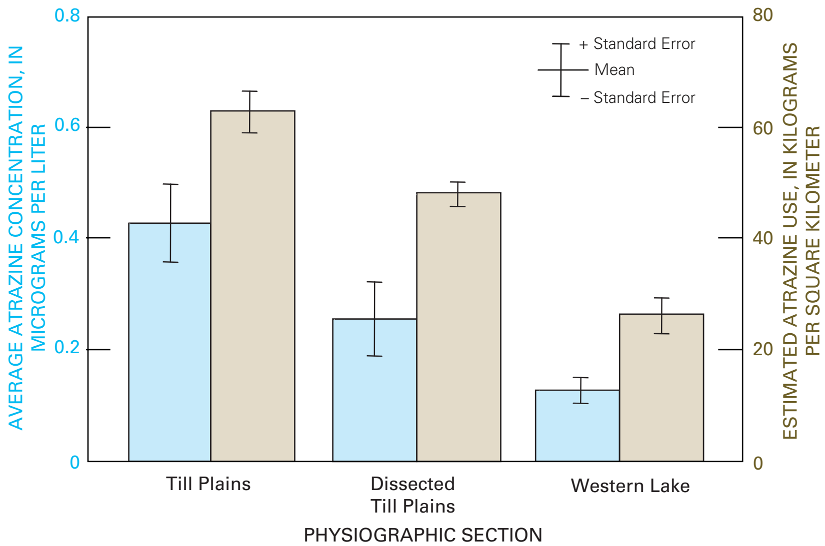


Figure 6. *Atrazine application rates varied among physiographic sections; stream concentrations were proportional to herbicide use.*

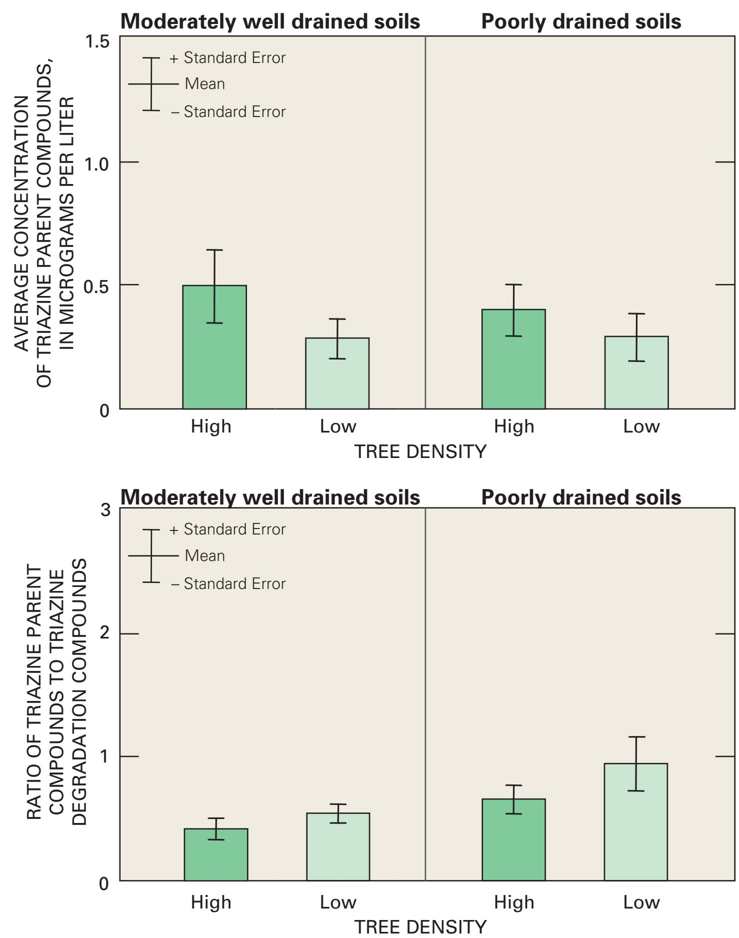


Figure 7. *Average concentrations of triazine herbicides were larger in streams with high tree density in riparian segments. The ratio of parent to degradation compounds was largest in poorly drained basins with low tree density.*

in basins with poorly drained soils (fig. 7), indicating slower rates of triazine herbicide degradation in those streams. Atrazine and its degradation compounds (notably hydroxyatrazine) are retained in poorly drained soils, such as those in the Western Lake section, because of adsorption to clay or organic matter in soils (Lerch and others, 1998). The use of atrazine on corn is lower in the Western Lake section (fig. 6), possibly because of potential carry-over of atrazine in soils that could adversely affect the growth of soybeans grown during the following season.

Average concentrations of acetanilide herbicides (for example, acetochlor and metolachlor) were also larger in streams with high riparian tree density (fig. 8) and, consequently, greater shading. Acetanilide parent-to-degradation compound ratios were larger in streams with high riparian tree density, indicating that rates of degradation are slower in shaded streams, regardless of soil-drainage conditions. Previous research has suggested that photolysis (degradation by sunlight) may be an important process by which herbicide parent compounds are broken down into compounds that are presumed to be less toxic (Kolpin and Kalkhoff, 1993; Torrents and others, 1997). Rates of acetanilide herbicide degradation may be inhibited by canopy shading in streams with high riparian tree density. However, average acetanilide parent-to-degradation compound ratios (less than 0.04; fig. 8) were an order of magnitude less than those for triazine herbicides (greater than 0.4; fig. 7), possibly indicating that acetanilide herbicides degrade more rapidly than triazine herbicides.

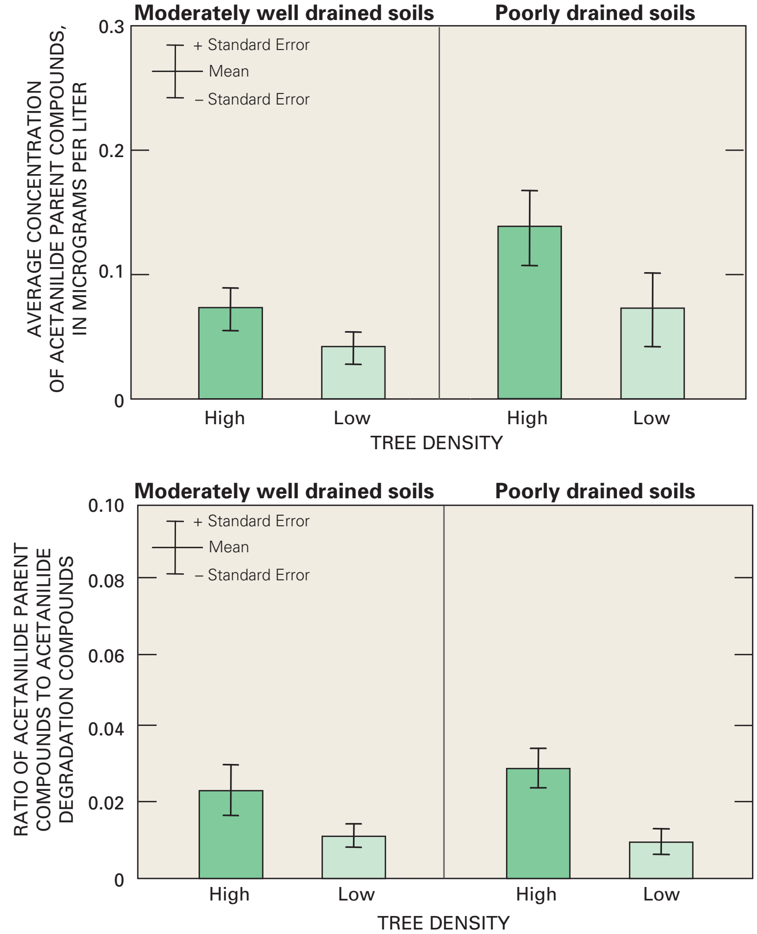


Figure 8. *Average concentrations of acetanilide herbicides, as well as parent-to-degradation compound ratios, were larger in streams with high tree density in riparian segments.*

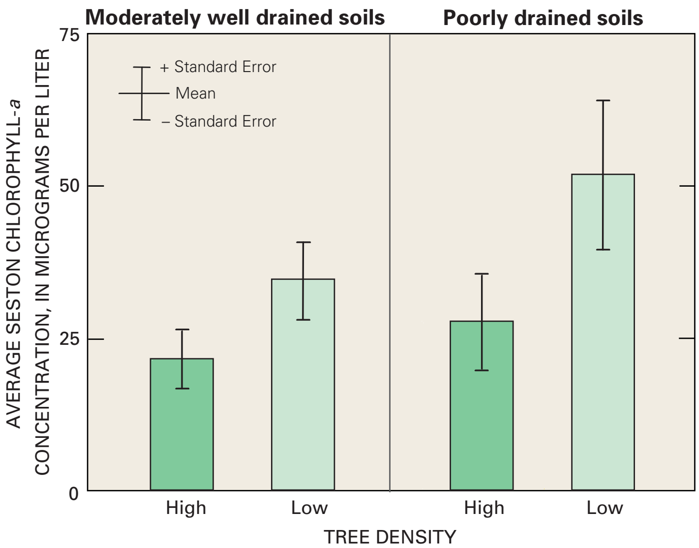


***Figure 9.** The relative abundance of algal seston was greater in streams with a low density of trees in the riparian segment.*

Natural Factors Influence Biological Indicators of Water Quality

Algal seston (phytoplankton; algae suspended in the water) can be an indicator of the amount of total nutrients and organic enrichment in Midwestern streams during low-flow conditions, such as those during August 1997. Organic enrichment from excessive algal production can increase rates of microbial respiration in streams, reducing dissolved oxygen (DO) to concentrations that are detrimental for sensitive invertebrate and fish species. Rates of dissolved nutrient uptake by algae and other aquatic plants are closely associated with rates of primary production (Borchardt, 1996). Streams with low tree density in riparian segments contained relatively large growths of algal seston at levels considered indicative of eutrophication (Porter, 2000). The relative abundance of algal seston, as measured by chlorophyll-*a* (CHL*a*) concentrations, was largest in streams with low tree density in basins with poorly drained soils (fig. 9). In addition, seston CHL*a* concentrations were positively correlated with total organic nitrogen and carbon concentrations in water samples, as well as maximum rates of stream productivity (P_{max}) and respiration (R_{max}) (Porter, 2000; Sorenson and others, 1999).
Concentrations of dissolved nitrogen in Midwestern streams decreased with increases in seston CHL*a* and P_{max} (fig. 10), and mean dissolved orthophosphate concentrations were smallest in poorly shaded streams in basins with poorly drained soils (fig. 4) where seston CHL*a* (fig. 9) and P_{max} were higher. Thus, shading from tree cover in riparian segments can influence nutrient concentrations in streams indirectly by reducing the growth of algal seston and rates of stream metabolism.

Periphyton (algae attached to submerged tree branches and logs) abundance was largest in streams draining the Dissected Till Plains section (fig. 11), where water clarity and riparian tree density generally were high (Porter, 2000), soils were moderately well drained, and ground-water contributions to streamflow were appreciable (Winter and others, 1998). Streams

with above-average periphyton CHL*a* (but low seston CHL*a*) were productive; however, rates of stream respiration were relatively low (Porter, 2000). The composition of periphyton communities (fig. 12) varied from a dominance of diatoms, a desirable food source for invertebrates and fish, to blue-green algae, which are not consumed. The percentage of blue-green algae in the periphyton community increased with the concentration of total

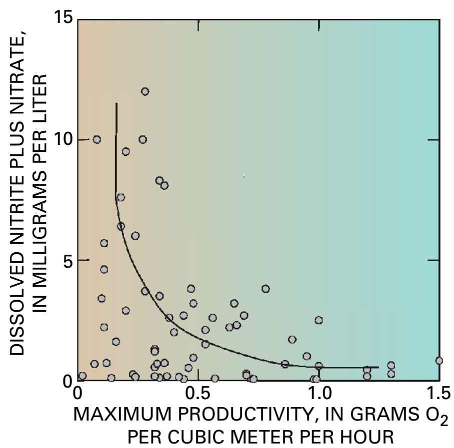


Figure 10. *Concentrations of dissolved nitrogen decreased with increasing stream productivity.*

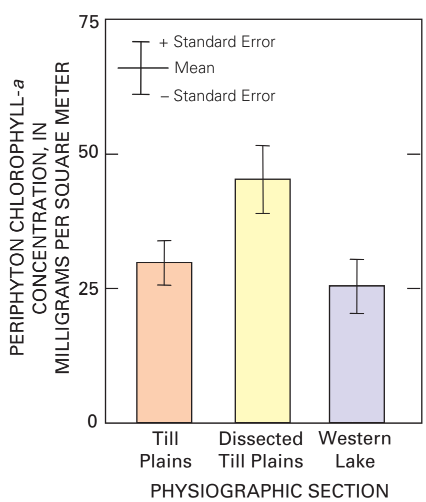


Figure 11. *Average periphyton abundance was largest in streams of the Dissected Till Plains section.*

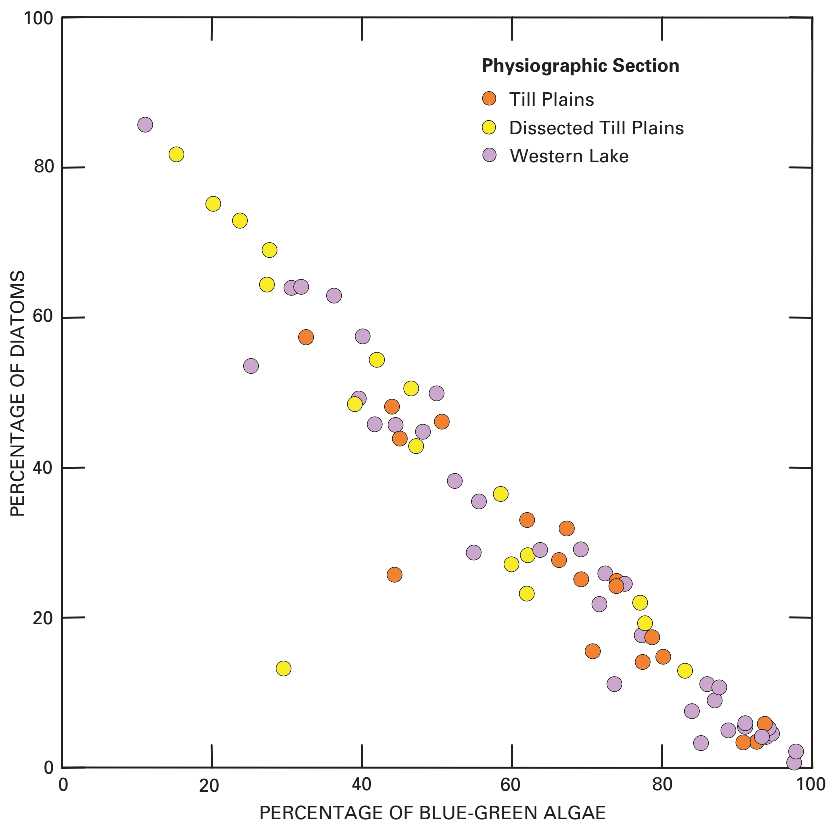


Figure 12. *Periphyton community structure varies from a predominance of diatoms to blue-green algae in Midwestern streams and rivers.*

triazine-herbicide compounds and was larger in streams with large amounts of algal seston (Porter, 2000). As expected, average periphyton biomass was smaller in streams with a large abundance of benthic invertebrates that consume algae (scrapers) (fig. 13).

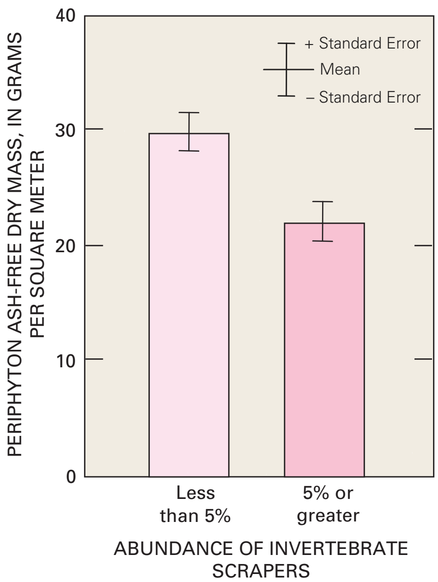


Figure 13. *Average periphyton biomass was smaller in streams with a large abundance of invertebrates that consume algae.*

Benthic invertebrate communities were influenced by stream velocity, minimum DO concentrations, tree density in the sampling reach, and the abundance of periphyton. The composition of invertebrate communities (fig. 14) varied from a dominance of EPT taxa (mayflies, stoneflies, and caddisflies), which are relatively sensitive to organic enrichment, to a group of taxa (midges, true flies, beetles, and worms) considered to be tolerant of organic enrichment and resultant low DO concentrations

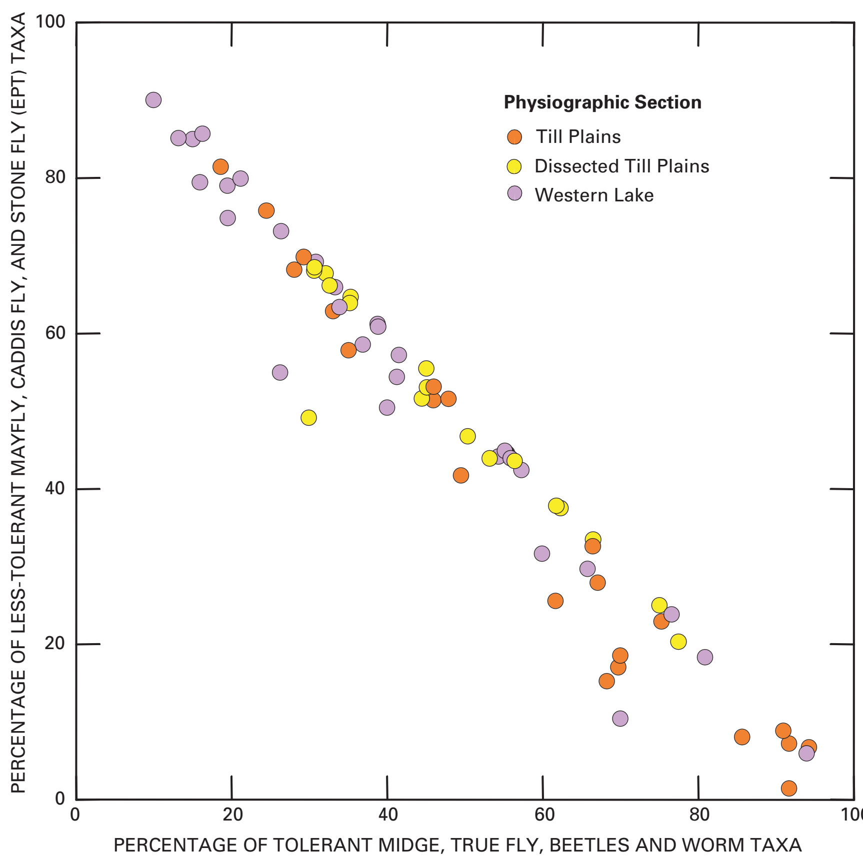


Figure 14. *Benthic invertebrate community composition and tolerance to organic enrichment varies among Midwestern streams and rivers.*

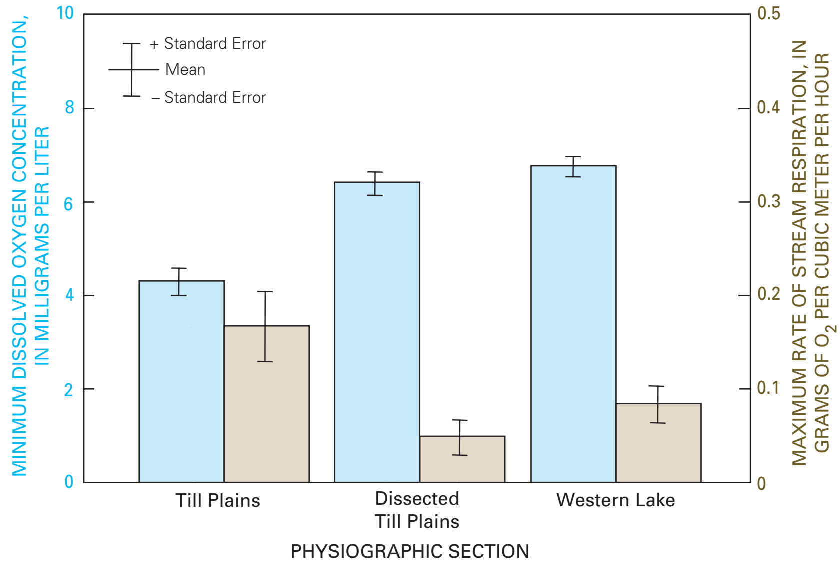


Figure 16. *Minimum dissolved oxygen concentrations were associated with higher rates of stream metabolism in the Till Plains physiographic section.*

(Klemm and others, 1990; Johnson and others, 1993). Sensitive stream invertebrates, such as EPT taxa, require flowing waters with high oxygen content to survive. Invertebrate indicators of water-quality degradation in many Till Plains streams may have been responding more to stresses associated with low-flow conditions than any substantial differences in agricultural intensity across the upper Midwest. Below average basin water yield and stream velocity (fig. 15) in the Till Plains basins probably were a result of

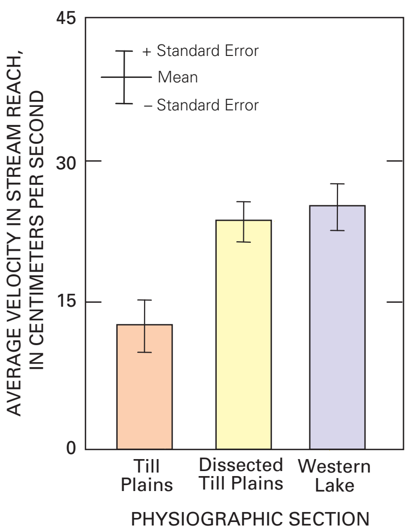


Figure 15. *Average velocity was slowest in Till Plains streams, probably because of less rainfall and water yield in those basins prior to the date of sampling.*

relatively low rainfall (fig. 3) prior to August 1997, the month of sample collection. Minimum DO concentrations in these streams were lower than in the other physiographic sections, and rates of stream metabolism (notably R_{max}) were higher (fig. 16), indicative of organic enrichment. Relatively fewer invertebrate taxa were found in streams in the Western Lake section (Sorenson and others, 1999; Mitchell Harris, written commun., 2000), despite favorable velocity and DO conditions. Extended (and variable) high streamflow conditions in the section during spring and early summer 1997 (USGS streamflow data; Porter, 2000), associated with above-average rainfall (fig. 3), may have been unfavorable for species that are unable to withstand hydrologic disturbances.

In general, biological indicators represented better water quality in Midwestern streams with riparian zones characterized by high tree density, particularly when velocity and DO conditions were favorable. Overall, the number of invertebrate taxa was over 20 percent larger in streams with high tree density along the sampling reach (fig. 17). Submerged woody debris in these streams enhances the complexity of aquatic habitats, and seasonal leaf fall into the streams, in addition to the periphyton, provides diverse food resources. In a related study, Stauffer and others (2000) also found that fish communities indicated better overall conditions in agricultural streams with wooded riparian zones than those with more open canopy.

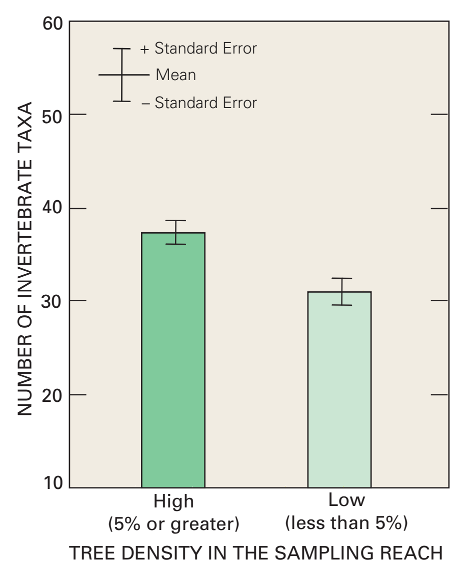


Figure 17. *More invertebrate taxa were found in streams with high tree density than in streams with low density.*

Implications for Water-Quality Monitoring and Assessment

The assessment and management of water resources could benefit from an improved understanding of the influence of natural landscape and hydrologic factors on chemical and biological indicators of water quality. For example, nutrient concentrations in Midwestern streams during late summer were related more to antecedent runoff and algal-nutrient processes than rates of fertilizer or manure application. Herbicide concentrations in agricultural streams during the same time period were proportional to herbicide use in the basin; however, basin soil conditions and riparian tree density along stream segments appear to influence the fate of herbicide parent compounds and the rate of herbicide-degradation processes. The effectiveness of riparian zones as a buffer for intercepting runoff of agricultural contaminants may be influenced by soil properties, drainage characteristics, and the amount of rainfall in stream basins prior to water-quality assessment. Biological indicators of water quality were influenced by physical factors such as streamflow and riparian conditions; however, algal and invertebrate indicators of degraded water quality increased with the intensity of organic enrichment, as indicated by large amounts of algal seston and dominance by blue-green algae, high rates of stream productivity and respiration, and commensurately low DO concentrations that occur during early morning hours (Porter, 2000; Sorenson and others, 1999). Thus, temporal and spatial variability of natural factors are likely to influence the chemical and biological classification of water quality in streams and rivers, as well as the effectiveness of land-use management practices.

References Cited

Borchardt, M.A., 1996, Nutrients, *in* Stevenson, R.J., Bothwell, M.L., and Lowe, R.L., eds., Algal ecology—Freshwater benthic ecosystems: San Diego, Calif., Academic Press, Inc., p. 183–227.

Fenneman, N.M., and Johnson, D.W., 1946, Physical divisions of the United States: U.S. Geological Survey, accessed April 30, 2001, http://water.usgs.gov/GIS/metadata/usgswrd/physio.html.

Fitzpatrick, F.A., Waite, I.R., D'Arconte, P.J., Meador, M.R., Maupin, M.A., and Gurtz, M.E., 1998, Revised methods for characterizing stream habitat in the National Water-Quality Assessment Program: U.S. Geological Survey Water-Resources Investigations Report 98–4052, p. 21–26.

Goolsby, D.A., Boyer, L.L., and Mallard, G.E., eds., 1993, Selected papers on agricultural chemicals in water resources of the midcontinental United States: U.S. Geological Survey Open-File Report 93–418, 89 p.

Johnson, R.K., Wiederholm, T., and Rosenberg, D.M., 1993, Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates, *in* Rosenberg, D.M., and Resh, V.H., eds., Freshwater biomonitoring and benthic macroinvertebrates: New York, Chapman and Hall, p. 41–158.

Klemm, D.J., Lewis, P.A., Fulk, F., and Lazorchak, J.M., 1990, Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters: Cincinnati, Ohio, U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, EPA/600/4–90/030, p. 207–244.

Kolpin, D.W., and Kalkhoff, S.J., 1993, Atrazine degradation in a small stream in Iowa: Environmental Science and Technology, v. 27, p. 134–139.

Lerch, R.N., Blanchard.P.E., and Thurman, E.M., 1998, Contribution of hydroxylated atrazine degradation products to the total atrazine load in Midwestern streams: Environmental Science and Technology, v. 32, p. 40–48.

Osborne, L.L., and Kovacic, D.A., 1993, Riparian vegetated buffer strips in water-quality restoration and stream management: Freshwater Biology, v. 29, p. 243–258.

Porter, S.D., 2000, Upper Midwest river systems—Algal and nutrient conditions in streams and rivers in the upper Midwest region during seasonal low-flow conditions, *in* Nutrient Criteria Technical Guidance Manual, Rivers and Streams: Washington, D.C., U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, EPA–822–B–00–002, p. A–25—A–42.

Sorenson, S.K., Porter, S.D., Akers, K.K.B., Harris, M.A., Kalkhoff, S.J., Lee, K.E., Roberts, L.R., and Terrio, P.J., 1999, Water quality and habitat conditions in upper Midwest streams relative to riparian vegetation and soil characteristics, August 1997—Study design, methods, and data: U.S. Geological Survey Open-File Report 99–202, 53 p.

Stauffer, J.C., Goldstein, R.M., and Newman, R.M., 2000, Relationship of wooded riparian zones and runoff potential to fish community composition in agricultural streams: Canadian Journal of Fisheries and Aquatic Sciences, v. 57, p. 307–316.

Torrents, A., Anderson, B.G., Bilboulian, S., Johnson W.E., and Hapeman, C.J., 1997, Atrazine photolysis—Mechanistic investigations of direct and nitrate-mediated hydroxy radical processes and the influence of dissolved organic carbon from the Chesapeake Bay: Environmental Science and Technology, v. 31, p. 1475–1482.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998, Ground water and surface water—A single resource: U.S. Geological Survey Circular 1139, 79 p.