Prepared in cooperation with the Milwaukee Metropolitan Sewerage District

Physical and Chemical Stressors on Algal, Invertebrate, and Fish Communities in 14 Milwaukee Area Streams, 2004–2013

Introduction

In 2004, the U.S. Geological Survey (USGS) began sampling 14 wadable streams in urban or urbanizing watersheds near Milwaukee, Wisconsin (fig. 1). The overall goal of the study is to assess the health of the aquatic communities in the Milwaukee Metropolitan Sewerage District planning area to inform current and future watershed management. In addition to collection of biological data on aquatic communities, physical and chemical data were also collected to evaluate effects of potential environmental stressors on the aquatic communities. This fact sheet summarizes the primary results of the study from 2004 to 2013. Detailed information is described in Scudder Eikenberry and others (2020a), and all data are available in Scudder Eikenberry and others (2020b; https://doi.org/10.5066/P9FWMODL).

Evaluations of aquatic communities using multiple groups of organisms—algal, invertebrate, and fish assemblages—and multiple measures or “metrics” of the groups are needed to fully understand environmental tolerances of the communities to chemical and physical stressors related to urban development (Coles and others, 2012). Each assemblage and each species have different tolerances to environmental stressors, different ranges of mobility, and different life spans. Algae reproduce quickly, living from days to weeks, and can indicate short-term changes in their environment. Algae form the base of the food web in streams and contribute to the processing of nutrients such as nitrogen and phosphorus, with excess nutrients often reflected by high algal biovolumes. Invertebrates are good indicators of water quality because of their relatively longer lifespans of months to years in comparison to algae, and their mostly stationary nature when compared to predators like fish make them indicative of site-specific conditions. Fish generally live longer than other aquatic organisms, so fish assemblages integrate longer time periods of exposure to pollutants and other stressors. Fish are more mobile than invertebrates, so fish may better reflect conditions within a larger area, such as a watershed. Use of all three assemblages helps provide a complete picture of the health of the aquatic community and the overall stream condition.

Urban development can degrade streams physically and chemically through changes in characteristics such as streamflow, water quality, and habitat, which can in turn act as stressors on aquatic communities and adversely affect the overall ecological health of streams. Examples of stressors that can alter urban streams and aquatic communities in urban streams are increased runoff from impervious surfaces; straightening and armoring of natural streams; removal of trees and other vegetation along streams; and chemical inputs from sewage, road salt, and pesticides. Multiple lines of evidence, integrating key stressors and responses to them, are critical for understanding how different stressors adversely affect aquatic communities, which stressors are most important, and how the effects of those stressors may be lessened through watershed management actions. Long-term (10 years or more) monitoring of biological, physical, and chemical characteristics of streams provides a way to evaluate the effects of different stressors on aquatic communities.

Base modified from Southeastern Wisconsin Regional Planning Commission regional base map, 1:2,000, 1995
U.S. Geological Survey digital line graph hydrography, 1:100,000, 1989
Wisconsin Department of Natural Resources version 2 hydrography, 1:24,000, 2002
Wisconsin Transverse Mercator projection, referenced to North American Datum of 1983, 1991 adjustment

Figure 1. The U.S. Geological Survey has sampled aquatic communities every 3 years since 2004 at 14 sampling sites in the Milwaukee Metropolitan Sewerage District planning area of Wisconsin.

Lincoln Creek, 2013. Photograph taken by Nic Buer, U.S. Geological Survey.

Methods

Biological and stream habitat data were collected along a length or "reach" of a stream once every 3 years during late summer/early fall using standard USGS methods, except in 2007 when habitat data were not collected (Fitzpatrick and others, 1998; Moulton and others, 2002). Algae and invertebrates were collected in rocky riffle areas of streams—algae directly from the rocks and invertebrates by disturbing the rocks and other substrate and collecting them in a net, except at one site where algae and invertebrates were collected from woody snags because rocks were unavailable. Fish were collected by electrofishing the entire reach, supplemented by seining areas where electrofishing was less effective such as deep holes; fish were then identified and counted on site and released live back into the stream. Habitat data were collected in the same reaches as the algae, invertebrates, and fish. Potential stressors were assessed using physical data (such as streamflow from USGS streamgages), land use/land cover, watershed-scale stream habitat using Geographic Information Systems, reach-scale stream habitat, microhabitat at invertebrate collection locations, and water chemistry data. Water chemistry data were collected primarily by the Milwaukee Metropolitan Sewerage District and were averaged for each year of biological data, with additional samples collected by the USGS. Statistical methods used in data analyses included basic descriptive statistics, graphing, and nonparametric correlations.

For a comprehensive assessment of aquatic community health at each site, a subset of six metrics that indicate sensitivity to water quality and other physical and chemical stressors was selected across assemblages. The metrics for algae were the percentage of most tolerant diatoms and the percentage of sensitive diatoms. The metrics for invertebrates were the Shannon index of diversity scores; the percentage of pollution-sensitive insects that are mayflies, stoneflies, and caddisflies (orders Ephemeroptera, Plecoptera, and Trichoptera or "EPT" as a group); and the Hilsenhoff Biotic Index scores (HBI–10, Hilsenhoff, 1998). The metric for fish was the Wisconsin Index of Biotic Integrity or IBI (Lyons, 1992). The metrics were ranked and averaged for each assemblage, and the means of the ranks were compared across all assemblages to yield aggregate bioassessment rankings for each site. Sites were then divided into four groups by percentiles (quartiles) based on the 2013 rankings.

Health of Aquatic Communities Varied Between 2004 and 2013

The health of aquatic communities varied between 2004 and 2013 based on various metrics, but the reasons for variation differed between streams. Details of stream-specific results are provided in Scudder Eikenberry and others (2020a). Urban sites in the central part of the Milwaukee metropolitan area had significantly less pollution-sensitive diatoms than sites in more outlying areas of the metropolitan area (fig. 2*A*), and most sites had more pollution-tolerant diatoms in 2013 than in 2004. Less pollution-sensitive diatoms and more pollution-tolerant diatoms indicate degradation of algal assemblages and water quality at sites (Porter, 2008).

For invertebrates, HBI–10 scores for 2013 indicated water quality ratings ranging from "fairly poor" to "good" at sampling sites (fig. 2*B*). Compared with HBI–10 ratings for 2004, HBI–10 ratings for 2013 were the same at 7 sites; worse at 5 sites; and better at 2 sites, indicating similar water quality changes at the sites. Most sites had fewer invertebrate taxa (types, such as species or genera) in 2013 than in 2004, another indicator of degrading invertebrate assemblages at many sites.

Although most sites consistently ranked between "fair" and "very poor" for the fish IBI ratings in 2013, IBI ratings were the same at 8 sites, worse at 2 sites (including one site that had no fish), and better at 4 sites when compared to 2004 (fig. 2*C*). Fish species that are considered tolerant of environmental degradation accounted for at least half of the fish at sites in 2013; however, when comparing between years, percentages of pollution-tolerant fish decreased by at least 10 percent at four sites, indicating healthier fish assemblages at several sites. Of concern is that the number of fish collected was nearly 50 percent lower at more than half the streams in 2013 compared to 2004, higher at 3 sites, and relatively unchanged at 2 sites.

Figure 2. Results from 14 sampling sites in the Milwaukee Metropolitan Sewerage District planning area, Wisconsin, 2004–13 showing *A*, presence of pollution-sensitive diatoms; *B*, Hilsenhoff Biotic Index ratings for fall samples of invertebrates and *C*, Wisconsin Index of Biotic Integrity ratings for fish.

Aggregate Metrics Provide Insights to Overall Stream Stressors

Metrics computed from the three assemblages (algae, invertebrates, and fish) together with species-specific pollution tolerances were used to gain a holistic view of differences in aquatic communities over the study period. These aggregate bioassessments indicated some level of degraded health at most of the 14 sites (table 1). The least degraded sites (in order, starting with the best overall condition) were the Milwaukee River near Cedarburg, Menomonee River at Menomonee Falls, Jewel Creek, and Milwaukee River at Milwaukee. The most degraded sites (in order, ending with the worst overall condition) were Menomonee River at Wauwatosa, Root River at Greenfield, Lincoln Creek, and the concrete-lined Kinnickinnic River. Differences in aggregate bioassessments indicate that aquatic communities at the Menomonee River at Wauwatosa and the Root River at Greenfield were worse in 2013 than in 2004; however, communities at Oak Creek and Honey Creek sites were better in 2013. Results also indicate that the Menomonee River degrades downstream as the watershed becomes more urban from Menomonee Falls to Wauwatosa, and the Root River improves downstream as it becomes less urban from Greenfield to Franklin. Despite differences in outcomes for algal, invertebrate, and fish assessments at a few sites in 2013, use of all three assemblages provided the most robust evaluation of aquatic communities compared with single assemblage assessments because differences in pollution tolerances, mobility, and lifespans of all three assemblages were accounted for in the evaluation.

Table 1. Single (algae, invertebrate, and fish) and aggregate (site) bioassessment rankings for 14 sampling sites in the Milwaukee Metropolitan Sewerage District planning area, Wisconsin, in 2013 and 2004.

[The fill color indicates the group based on percentiles of the ranked data for single assemblages of aquatic organisms and for multiple assemblages aggregated for sites (group 1 or less than the 25th percentile [least degraded], blue; group 2 or between the 25th and 49th percentile/median, light blue; group 3 or between the 50th to 74th percentile, light orange; group 4 or greater than the 75th percentile [most degraded], orange; each column is considered independently). Lower percentiles indicate better stream condition.]

Site name	Mean trophic-level ranking for 2013			Aggregate bioassessment ranking for 2013	Aggregate bioassessment ranking for 2004
	Algae[1]	Invertebrates[2]	Fish[3]		
Group 1					
Milwaukee River near Cedarburg, Wisconsin	5.0	1.7	1.0	2.56	1.44
Menomonee River at Menomonee Falls, Wisconsin	3.0	3.3	3.0	3.11	5.44
Jewel Creek at Muskego, Wisconsin	1.5	6.7	5.0	4.39	3.50
Milwaukee River at Milwaukee, Wisconsin	10.5	5.0	2.0	5.83	3.56
Group 2					
Little Menomonee River at Milwaukee, Wisconsin	4.0	7.0	8.0	6.33	7.28
Root River near Franklin, Wisconsin	4.5	5.7	9.0	6.39	6.39
Willow Creek at Maple Road near Germantown, Wisconsin	9.5	6.7	6.0	7.39	6.33
Group 3					
Oak Creek at South Milwaukee, Wisconsin	4.0	7.7	12.0	7.89	9.61
Honey Creek at Wauwatosa, Wisconsin	10.0	7.3	7.0	8.11	9.33
Underwood Creek at Wauwatosa, Wisconsin	10.5	12.0	4.0	8.83	9.17
Group 4					
Menomonee River at Wauwatosa, Wisconsin	10.0	7.7	11.0	9.56	9.11
Root River at Grange Avenue at Greenfield, Wisconsin	5.0	11.7	13.0	9.89	8.56
Lincoln Creek at 47th Street at Milwaukee, Wisconsin	12.5	8.7	10.0	10.39	11.11
Kinnickinnic River at South 11th Street at Milwaukee, Wisconsin	13.0	12.7	14.0	13.22	13.06

[1]Averaged bioassessment rankings for algae included the percentage of most tolerant diatoms and the percentage of sensitive diatoms.

[2]Averaged bioassessment rankings for invertebrates included the Shannon index of diversity scores; the percentage of Ephemeroptera, Plecoptera, and Trichoptera taxa; and the Hilsenhoff Biotic Index scores, modified to limit the number of individuals per taxon to 10 for index computation.

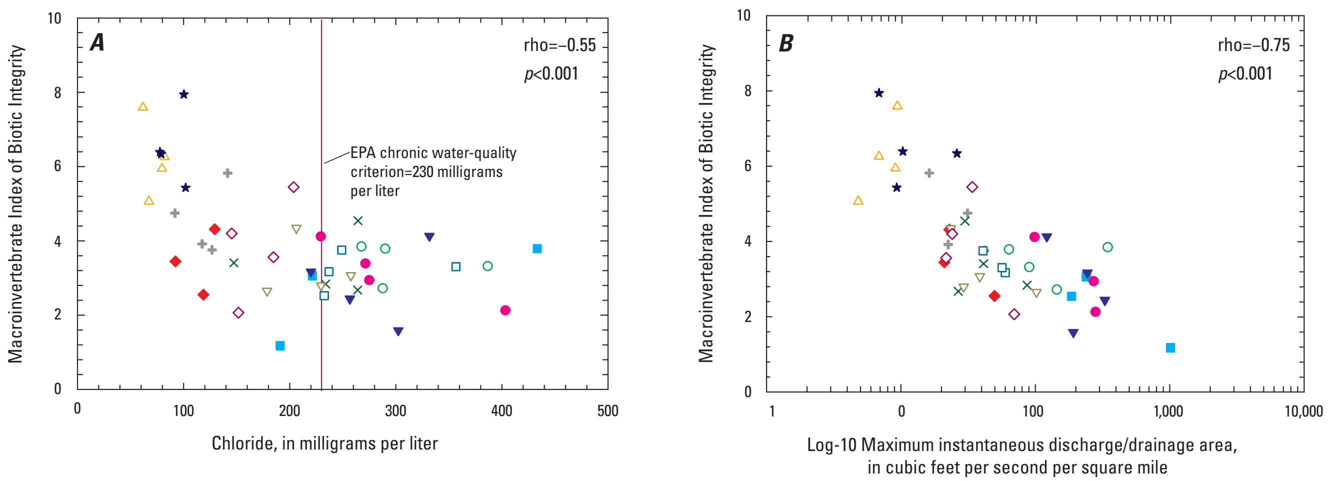
[3]Averaged bioassessment rankings for fish included only Index of Biotic Integrity scores.

Urban Stressors on Aquatic Communities were Physical and Chemical

Kinnickinnic River at 11th Street, 2013. Photograph taken by Ben Young, U.S. Geological Survey.

One overarching finding from our study was that local urban-related physical and chemical characteristics were related to degraded aquatic communities. Although correlations for some stressors were significant for only one assemblage, several stressor metrics correlated with poorer health of all three assemblages: higher peak streamflow with flood and scour effects, more fecal contamination, and more urban/developed land in the watershed and along the stream. More frequent floods and scour effects from higher peak streamflow are common problems with streams subjected to urban runoff; higher peak streamflow was highly correlated to higher percentages of urban developed land (increasing correlations from low to medium to high developed land), developed land within 30-meters on each side of a stream, impervious surface, fecal contamination, and chloride (fig. 3).

Fecal contamination is a nutrient source to algae that can cause oxygen stress for invertebrates and fish. Storm runoff can carry chemicals such as chloride from road salt into streams. Increased mean chloride concentrations in stream water correlated with increased degradation of invertebrate and fish assemblages across sites. Mean annual chloride concentrations were above the U.S. Environmental Protection Agency chronic water-quality criterion for the protection of aquatic life in one or more years at all sites in the two most degraded aggregate assessment groups (table 1). These results underscore the harmful effects of developed land on aquatic communities through runoff from impervious surfaces into nearby streams. Details on additional stressors and site-specific stressors are provided in Scudder Eikenberry and others (2020a).



EXPLANATION

[rho, Spearman's rank correlation coefficient; *p*, probability value; <, less than; MRC, Milwaukee River near Cedarburg; LCM, Lincoln Creek at 47th Street at Milwaukee; MRM, Milwaukee River at Milwaukee; WCG, Willow Creek at Maple Road, near Germantown; MRMF, Menonomee River at Menomonee Falls; LMM, Little Menomonee River at Milwaukee; UCW, Underwood Creek at Wauwatosa; HCW, Honey Creek at Wauwatosa; MRW, Menomonee River at Wauwatosa; KRM, Kinnickinnic River at South 11th Street at Milwaukee; OCSM, Oak Creek at South Milwaukee; RRG, Root River at Grange Avenue at Greenfield; RRF, Root River at Franklin; JCM, Jewel Creek at Muskego; EPA, U.S. Environmental Protection Agency; mg/L, milligram per liter]

△ MRC ★ MRM ✚ MRMF ○ UCW × MRW ▽ OCSM ◇ RRF
■ LCM ▲ WCG ◆ LMM ● HCW ▼ KRM □ RRG ▲ JCM

Figure 3. Local urban-related stressors were related to degraded aquatic communities (invertebrate relations shown). *A*, increased mean chloride in stream water. *B*, higher peak streamflow with flood and scour effects.

Summary

Over the 10-year period from 2004 to 2013, differences in the health of aquatic communities and streams were seen for algal, invertebrate, and fish assemblages at the 14 streams sampled in the Milwaukee Metropolitan Sewerage District planning area. Among varying amounts of urban development, some assemblages and some stream ecosystems were better, some were worse, and others stayed fairly similar but were often in fair or poor condition. The variability in stressor effects across assemblages and time underscores the importance of long-term monitoring (more than 10 years) of physical, chemical, and biological components of streams using multiple assemblages to evaluate the effects of different stressors on aquatic communities and streams. Key urban-related stressors on all three assemblages were flashy runoff (as indicated by high peak streamflow) and untreated sewage (as indicated by high fecal coliform bacteria counts). An additional stressor on invertebrates and fish was high chloride concentrations with averages at some sites above the U.S. Environmental Protection Agency's chronic water-quality criterion for the protection of aquatic life. All three stressors reflected an urban signature connected to urban developed land in the watershed and along the stream and higher percentages of impervious surface in the watershed. These urban metrics were also significantly correlated with each other. Our results underscore the harmful effects of urban developed land on aquatic communities through runoff from impervious surfaces to nearby streams. These stressors must be reduced before overall biotic assemblages can improve; local stream habitat improvements will not be sufficient.

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Milwaukee River at Cedarburg, 2013.
Photograph taken by Ben Young, U.S. Geological Survey.

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