Water Quality in the Western Lake Michigan Drainages

Wisconsin and Michigan, 1992–95

U.S. Department of the Interior
U.S. Geological Survey

Circular 1156

A COORDINATED EFFORT

Coordination among agencies and organizations is an integral part of the NAWQA Program. We thank the following agencies and organizations who contributed to the design of the studies and helped to review data presented in this report.

- American Water Resources Association — Wisconsin Chapter
- Bay-Lake Regional Planning Commission
- Brown County Regional Planning Commission
- East Central Wisconsin Regional Planning Commission
- Fox Wolf Basin 2000
- Great Lakes Environmental Research Laboratory
- Green Bay Metropolitan Sewage District
- Marquette County Land Conservation District
- Menominee Tribe of Indians of Wisconsin
- Michigan Department of Environmental Quality
- Michigan Department of Natural Resources
- Milwaukee Metropolitan Sewerage District
- National Oceanic and Atmospheric Agency
- National Wildlife Federation
- The Nature Conservancy
- North Central Wisconsin Regional Planning Commission
- Oneida Tribe of Indians of Wisconsin
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- Portage County Land Conservation District
- River Alliance of Wisconsin (Tomorrow/ Waupaca Watershed Association)
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Information on the NAWQA Program is also available on the Internet via the World Wide Web. You may connect to the NAWQA Home Page using the Universal Resources Locator (URL)
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The Western Lake Michigan Drainages Study Unit's Home Page is at URL:
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Water Quality in the Western Lake Michigan Drainages, Wisconsin and Michigan, 1992–95

By C.A. Peters, D.M. Robertson, D.A. Saad, D.J. Sullivan, B.C. Scudder, F.A. Fitzpatrick, K.D. Richards, J.S. Stewart, S.A. Fitzgerald, *and* B.N. Lenz

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Italicized words are defined in the glossary.

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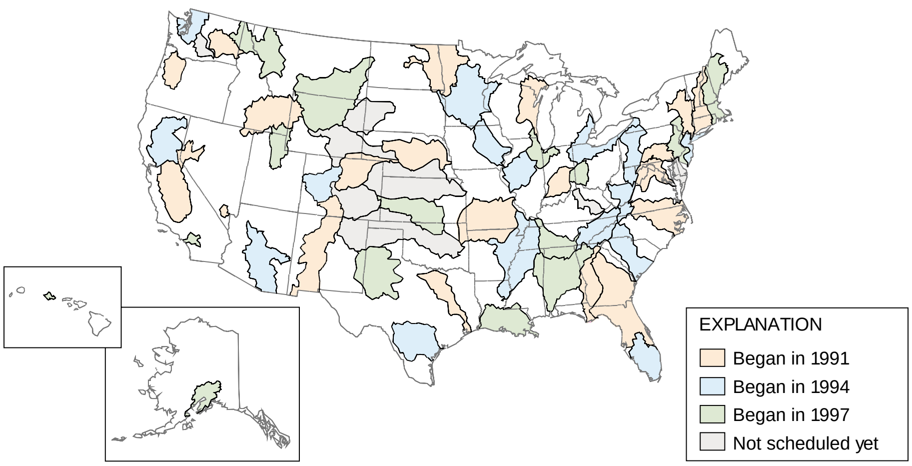


Knowledge of the quality of the Nation's streams and aquifers is important because of the implications to human and aquatic health and because of the significant costs associated with decisions involving land and water management, conservation, and regulation. In 1991, the U.S. Congress appropriated funds for the U.S. Geological Survey (USGS) to begin the National Water-Quality Assessment (NAWQA) Program to help meet the continuing need for sound, scientific information on the areal extent of the water-quality problems, how these problems are changing with time, and an understanding of the effects of human actions and natural factors on water-quality conditions.

The NAWQA Program is assessing the water-quality conditions of more than 50 of the Nation's largest river basins and aquifers, known as Study Units. Collectively, these Study Units cover about one-half of the United States and include sources of drinking water used by about 70 percent of the U.S. population. Comprehensive assessments of about one-third of the Study Units are ongoing at a given time. Each Study Unit is scheduled to be revisited every decade to evaluate changes in water-quality conditions. NAWQA assessments rely heavily on existing information collected by the USGS and many other agencies as well as the use of nationally consistent study designs and methods of sampling and analysis. Such consistency simultaneously provides information about the status and trends in water-quality conditions in a particular stream or aquifer and, more importantly, provides the basis to make comparisons among watersheds and improve our understanding of the factors that affect water-quality conditions regionally and nationally.

This report is intended to summarize major findings that emerged between 1992 and 1995 from the water-quality assessment of the Western Lake Michigan Drainages Study Unit and to relate these findings to water-quality issues of regional and national concern. The information is primarily intended for those who are involved in water-resource management. Indeed, this report addresses many of the concerns raised by regulators, water-utility managers, industry representatives, and other scientists, engineers, public officials, and members of stakeholder groups who provided advice and input to the USGS during this NAWQA Study-Unit investigation. Yet, the information contained here may also interest those who simply wish to know more about the quality of water in the rivers and aquifers in the area where they live.

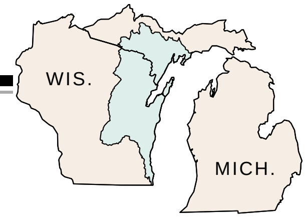
Robert M. Hirsch, Chief Hydrologist

"NAWQA has been enormously helpful in synthesizing data and developing a better understanding of a key ecoregion of the Great Lakes. Contributions from this study will be useful for years to come as this region is managed as an integrated natural resource."

William C. Sonzogni, University of Wisconsin–Madison, State Laboratory of Hygiene

"The NAWQA program is generating water quality and ecological information that will be useful to the Oneida Environmental, Health and Safety Department in managing tribal water resources. As the Tribe engages in efforts to improve conditions of its watershed, NAWQA data and reports should serve as a reference against which future changes in water quality can be compared."

Patrick J. Pelky, Oneida Tribe of Indians of Wisconsin, Environmental, Health and Safety Department



LEVELS OF SOME NATURALLY OCCURRING CHEMICALS HAVE THE POTENTIAL TO AFFECT HUMAN HEALTH AND AQUATIC LIFE. (p. 8)

Concentrations of naturally occurring constituents are variable in surface water and ground water of the study area. At some sites the concentrations exceed those considered harmful to human health and aquatic life.

- Dissolved solids concentrations above the United States Environmental Protection Agency's (USEPA) secondary maximum contaminant levels (SMCL) for drinking water were detected in 26 percent of samples from the confined part of the drinking-water aquifer.
- Arsenic concentrations in fine sediments in streams exceeded the Ontario Ministry of Environment and Energy lowest effect level (LEL), for aquatic biota, at 48 percent of sites sampled and the severe effect level (SEL) at one site.
- Radon, a carcinogen, was detected in all 29 drinking-water aquifer wells sampled in the study area. Radon activities in 66 percent of the wells exceeded the previously proposed USEPA standard of 300 picocuries per liter (pCi/L).
- Concentrations of dissolved iron exceeded the previously proposed USEPA maximum contaminant level (MCL) for drinking water of 300 micrograms per liter (µg/L) in 38 percent of drinking-water aquifer wells sampled.

FERTILIZERS AND LIVESTOCK WASTES INCREASE NUTRIENT CONCENTRATIONS IN STREAMS AND GROUND WATER. (p. 10)

Phosphorus and nitrate concentrations in surface water and ground water are highest in agricultural land-use areas. Nutrient concentrations in surface waters were highest during periods of precipitation runoff.

- Ninety-six percent of anthropogenic phosphorus input to the study area is from fertilizer and livestock wastes.
- Median phosphorus concentrations in surface water at four agricultural study sites exceeded the recommended USEPA limit to discourage excessive biotic growth in flowing water of 0.1 milligrams per liter (mg/L).
- Analysis of historical data indicated that phosphorus concentrations in surface water downstream from urban areas decreased significantly during the 1970s due to the reduction of phosphorus in detergents and improvements in sewage-treatment facilities.
- Nitrate concentrations in surface water from 92 percent of samples from agricultural Indicator Sites were high enough to contribute to algal blooms (greater than 0.3 mg/L) observed at several sites.
- Nitrate concentrations exceeded the USEPA MCL (10 mg/L) during three storms at the East River agricultural Indicator Site, in 9 percent of the samples from the drinking water aquifer, and 22 percent of the surficial alluvial aquifer samples.
- Nitrate concentrations, in the shallow alluvial aquifer where the surficial deposits were most permeable, exceeded the USEPA MCL in 37 percent of the samples.

VARIOUS FACTORS CONTROL PESTICIDE OCCURRENCE IN STREAMS AND GROUND WATER. (p. 12)

Fifteen pesticides were detected in ground water and 33 in surface water. Drinking water standards for atrazine were exceeded in 6 percent of surface-water samples and standards for simazine and alachlor were exceeded in 1 percent of the samples.

- Pesticides commonly applied to farm fields were typically detected in surface water in intensively farmed areas at concentrations 100 times higher than in less intensively farmed areas.
- Atrazine was detected in all 143 surface water samples collected, including some at very low concentrations (0.005 mg/L) from forested areas. Detection in forested areas is probably due to the presence of pesticides in precipitation in the area.
- Highest concentrations of pesticides in surface water occur during runoff in agricultural areas soon after pesticide applications to the farm fields.
- Pesticides were detected in 97 percent of samples from surficial aquifers in intensively farmed areas underlain by relatively permeable surficial deposits. Concentrations of atrazine plus deethylatrazine exceeded the State of Wisconsin's preventive action limit of 0.3 µg/L in 22 percent of surficial aquifer wells.
- Pesticides were detected in 25 percent of drinking water aquifer wells sampled. Eighty-six percent of these detections were in samples from wells in the part of the aquifer not covered by the relatively impermeable Sinnipee unit.

URBAN AREAS ARE A SOURCE OF TRACE ELEMENTS AND ORGANIC COMPOUNDS. (p. 14)

Concentrations of cadmium, copper, mercury, nickel, lead, and zinc and of many toxic synthetic organic compounds were highest in fine sediments in streams that drained urban areas compared to other land uses.

- Concentrations of PCBs in streambed sediments and fish tissue are 10 times higher in large-river sites draining urban areas than in smaller urban, agricultural, or forested land-use areas.
- Concentrations of DDT remain high in streambed sediments in urban areas and large-river sites more than 20 years after being banned.
- Eight trace elements in fine streambed sediment exceeded established LEL for bulk sediment. The chromium LEL was exceeded in all 42 samples collected. The LEL is the concentration that 95 percent of benthic biota can tolerate.
- Eighty percent of semivolatile organic compounds (SVOCs) analyzed for were detected in at least one sample. Two classes of SVOCs (PAHs and phthalates) were detected more frequently and in higher concentrations at urban-affected sites.

ENVIRONMENTAL SETTING AND LAND USE INFLUENCE AQUATIC LIFE. (p. 16)

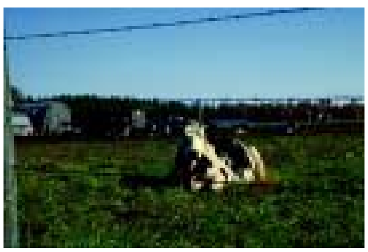
Water quality, as indicated by aquatic life, was most influenced by land use and type of surficial deposit.

- Aquatic life was most degraded in urban areas and least degraded in forested areas.
- Indexes of biotic integrity indicated degraded water quality at sites with clay surficial deposits.
- Water quality in streams in primarily agricultural areas was least degraded in the basins with the highest percentage of forested land use.
- In general, there was good agreement between biological indicator scores calculated for habitat, algae, benthic invertebrates, and fish.

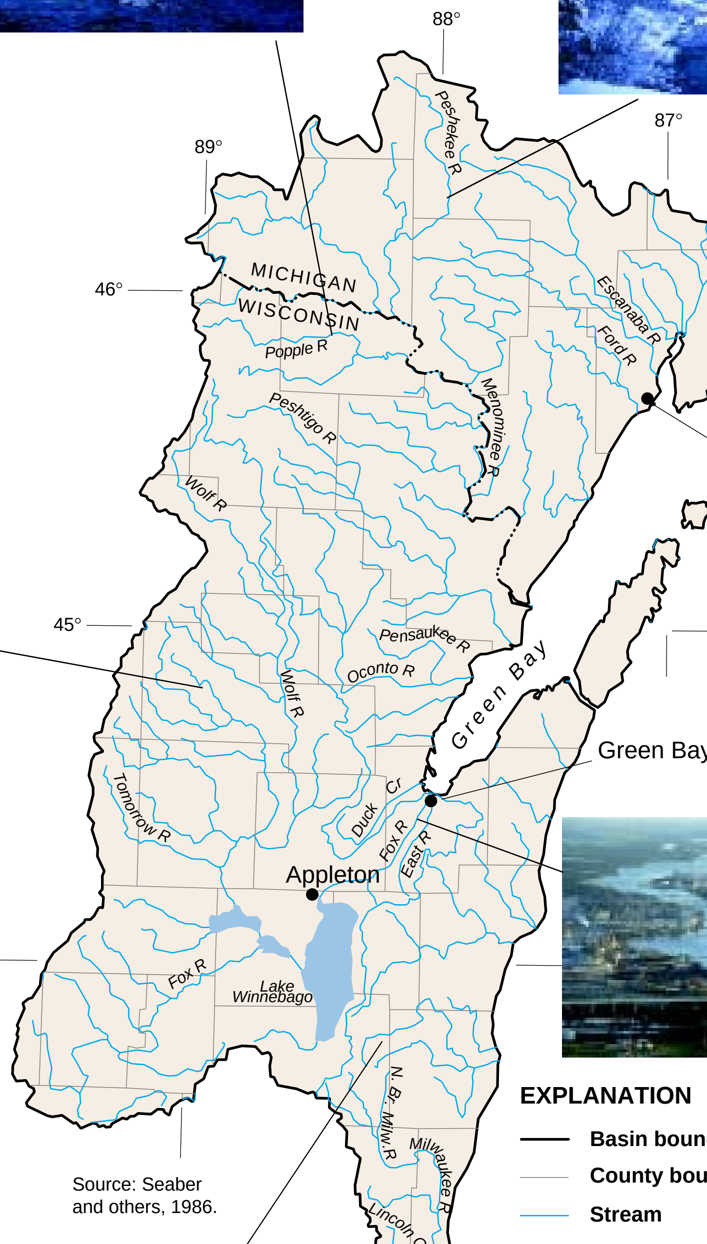
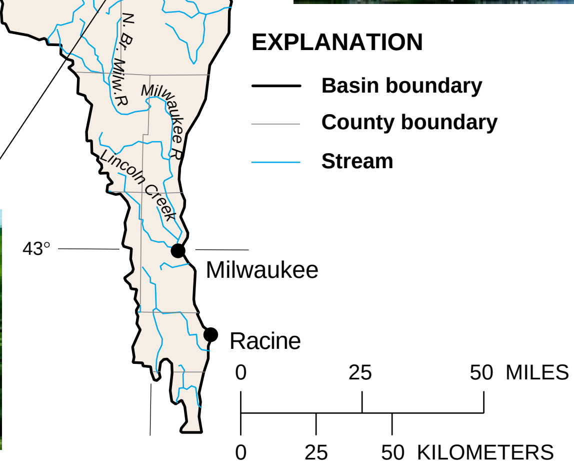
ENVIRONMENTAL SETTING AND HYDROLOGIC CONDITIONS in the Western Lake Michigan Drainages

The Western Lake Michigan Drainages *Study Unit* drains a 20,000-square-mile area in eastern Wisconsin and the Upper Peninsula of Michigan. The study area is comprised of the Fox-Wolf, Milwaukee, Menominee, Oconto, and Peshtigo River *Basins* in Wisconsin and the Ford and Escanaba River Basins in Michigan.

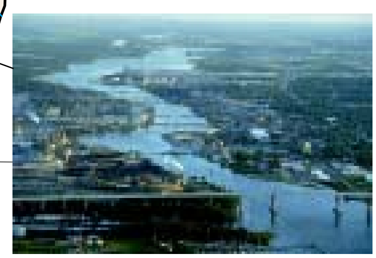
The overall population in the study area is about 2,435,000 (U.S. Department of Commerce, 1991). Major cities include Milwaukee, Green Bay, Racine, and Appleton. The Green Bay area, along the lower Fox River, has one of the highest densities of paper mills in the world. Lake Winnebago, a 137,000-acre lake in the Fox River Basin, is a major surface-water feature.

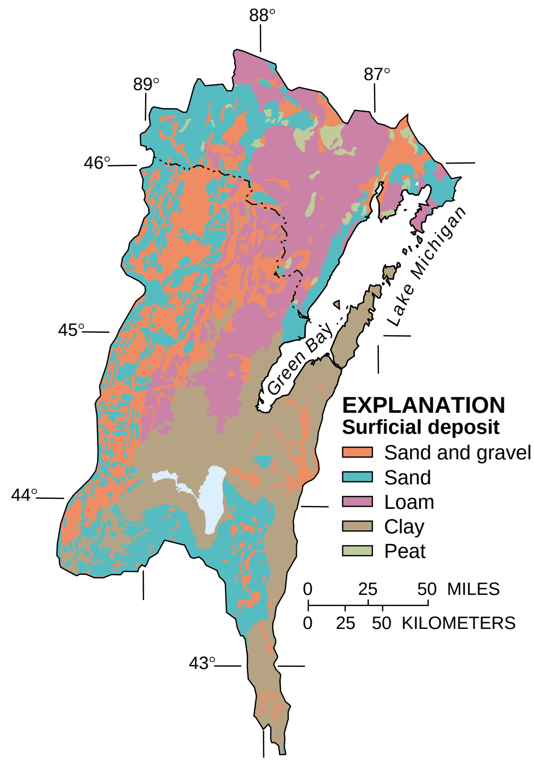


The primary water-quality issues in the study area include *contamination* and *nutrient* enrichment of *surface water* and *ground water* by agricultural chemicals, contamination of *bed sediments* of rivers and harbors by toxic substances, contamination and nutrient enrichment of rivers and lakes from industrial and municipal waste discharges, and acidification and mercury contamination of lakes and wetlands in the forested part of the study area

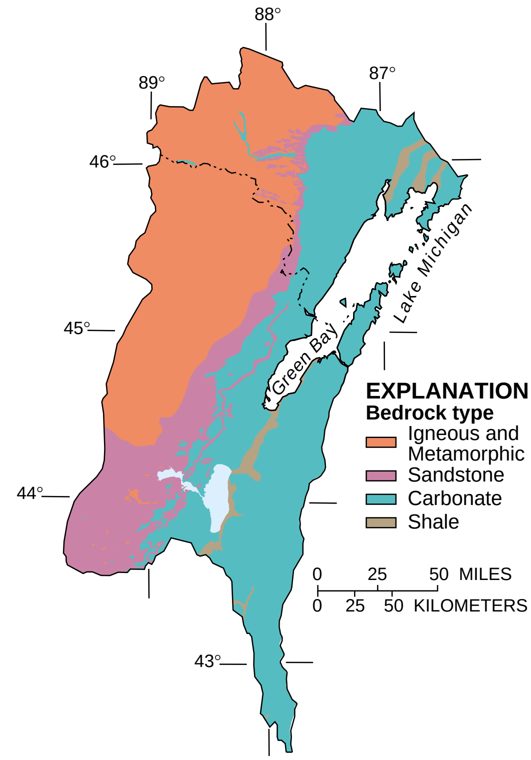



Source: Seaber and others, 1986.

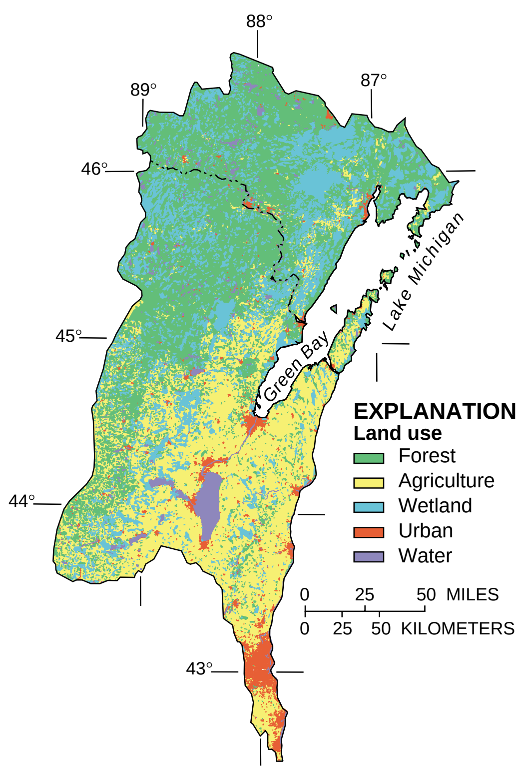




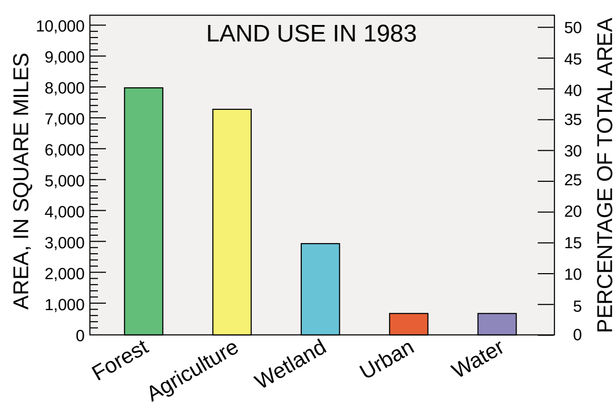
The topography of the study area was shaped by glaciation. *Surficial deposits* range in thickness from zero to several hundred feet.



The *bedrock* underlying the study area is composed of igneous, metamorphic and sedimentary (sandstone, carbonate, and shale) rock. Bedrock dips southeast toward Lake Michigan. The oldest rock subcrops in the northwest and the youngest in the southeast.



Land use ranges from forests in the north to agriculture and urbanized land in the southern and eastern parts of the study area.



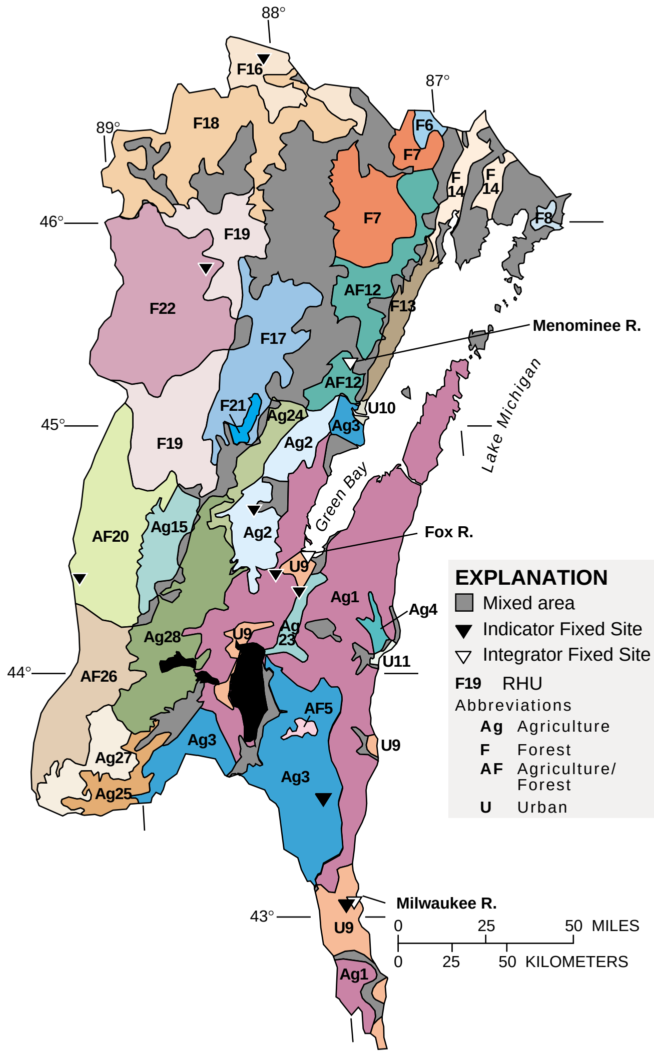
About 50 percent of the area is forested, with streams and lakes offering excellent fishing, canoeing, and other recreational opportunities. Agriculture is a major activity in the study area, with 37 percent of the area devoted to cropland and pasture land.

Water quality in the Western Lake Michigan Drainages is affected by natural and *anthropogenic* factors. In order to study the important water-quality issues, the basin was divided into 28 relatively homogeneous units (RHUs) with unique combinations of land use, surficial-deposit texture, and bedrock by overlaying digital thematic maps (p. 5) of these land features (Robertson and Saad, 1995).

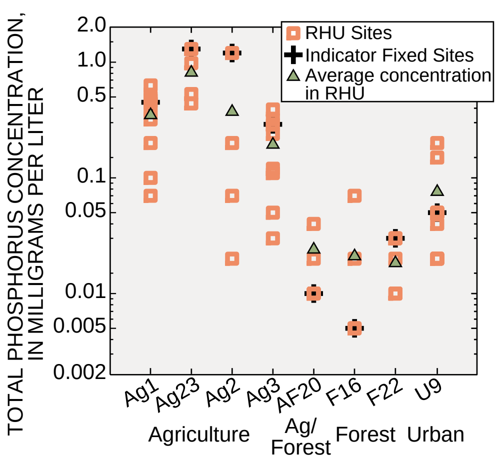
Not all of the 28 RHUs could be sampled; therefore, specific RHUs were selected for sampling on the basis of the major water-quality issues in the RHU. Eleven stream sites, called *Fixed Sites*, were chosen to describe the variability in *streamflow* and *concentrations* of nutrients, *major ions*, suspended sediment, and biological *communities*. Eight of the 11 Fixed Sites were *Indicator Sites*, sites selected to represent the quality of water draining from a specific RHU. Four Indicator Sites were on streams representing agricultural RHUs, two were on streams representing forested RHUs, and one each was on a stream representing an urban RHU and a mixed agriculture and forest RHU. The remaining three sites were *Integrator Sites*, sites located near the mouths of major rivers, where water quality is affected by various combinations of land use, surficial deposits, and bedrock geology. Each of these 11 sites was sampled at least monthly for 2.5 years.

Additionally, short-term synoptic studies were done to better define the variability in water quality throughout the study area. Figures on p. 24 and the table on p. 25 provide details of those studies.

One of the synoptic studies was conducted to determine if monitoring results from the Indicator Fixed Sites were representative of specific RHUs and the basin as a whole. The Indicator Fixed Site data were compared to results from a study of 83 sites throughout the basin. Results of that study, conducted during *base-flow* conditions, indicate that the Indicator Fixed Sites provide a fair representation of specific RHUs and the entire basin.



Water quality in the Western Lake Michigan Drainages is affected by natural and anthropogenic factors.



Indicator Fixed Site data are representative of the specific RHUs they were selected to represent (Robertson, 1998).

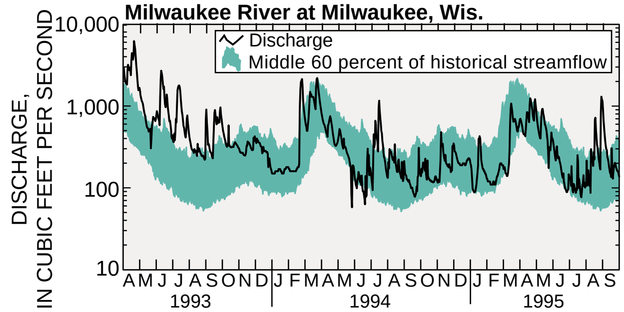
Fixed site (RHU)	Area (mi^2)	Land use (percent)	Surficial deposit (percent)	Bedrock
Duck Cr. (Ag1)	95	Agriculture (89)	Clay (76)	Carbonates
Pensaukee R. (Ag2)	36	Agriculture (86)	Loam (99)	Carbonates
N. Br. Milwaukee R. (Ag3)	51	Agriculture (88)	Sand (89)	Carbonates
East R. (Ag23)	47	Agriculture (92)	Clay (95)	Shale
Tomorrow R. (AF20)	44	Agriculture (58)/ Forest (31)	Sand (39)/ Sand & Gravel (61)	Igneous/ Metamorphic
Peshekee R. (F16)	49	Forest (98)	Loam (100)	Igneous/ Metamorphic
Popple R (F22)	139	Forest (90)	Sand (24)/ Sand & Gravel (76)	Igneous/ Metamorphic
Lincoln Cr. (U9)	10	Urban (100)	Clay (100)	Carbonates
Menominee R.	3,901	Integrator	Integrator	Integrator
Fox R.	6,035	Integrator	Integrator	Integrator
Milwaukee R.	688	Integrator	Integrator	Integrator

Fixed Sites in the Western Lake Michigan Drainages.

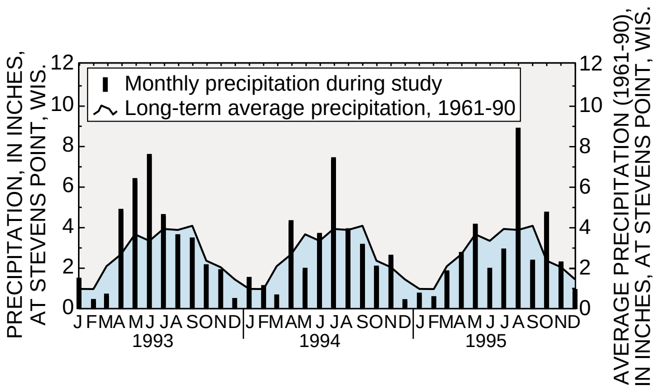
Ground water studies were also designed to look at the effects of land use, surficial deposit texture, and bedrock geology on water-quality variability. Ground water from the Cambrian-Ordovician *aquifer*, the most-used drinking-water aquifer in the study area, and from shallow aquifers associated with agricultural land use and two different surficial deposits were sampled to indicate this variability.

Understanding hydrologic and *climatic* conditions is important for interpreting water-quality data. During wet-weather periods, *runoff* can carry materials into the stream from the land, and concentrations of nutrients, *pesticides*, and *sediment* can increase above those at normal streamflow. Periods of excessive *precipitation* can cause ground-water levels to rise, contributing a larger ground-water component to streamflow and causing changes in streamwater chemistry. During dry periods, *point-source* discharges to streams may degrade stream-water quality. The seasonal timing of precipitation can also affect stream-water quality. For example, precipitation causing runoff early in the growing season, before crops come up and after pesticides and *fertilizers* have been applied, can produce significant potential for water contamination.

The average precipitation in the Wisconsin part of the study area during all of 1993 was about 39 inches, or 122 percent of the 30-year statewide average. Annual runoff in 1993 ranged from 240 to 280 percent of normal in the southern part of the study area. Precipitation in the study area measured about 31 inches during 1994 and about 29 inches during 1995. Annual runoff was near normal during both years.



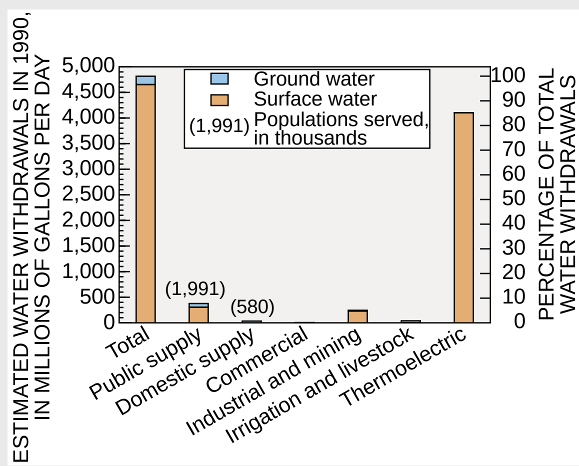
Annual *discharge* measured at the Milwaukee River in 1993 was the fourth largest recorded since the start of measurement (historical streamflow data covers the period of record from 1914–96).



Precipitation varies seasonally with 60 percent occurring between May and September (Peters, 1997). The 1993 growing season was much wetter than normal and was the wettest period during the 3-year investigation.

Extensive flooding occurred in the study area in the spring of 1993. These photos of the North Branch of the Milwaukee River were taken from near the same location (note location of bridge abutment) during normal flows in 1995 and during the spring 1993 floodflows.

Water use in the Western Lake Michigan Drainages



Public suppliers provide about 371 million gallons of water per day (Mgal/d), of which 69 Mgal/d is from ground-water sources. Rural domestic users obtain about 21 Mgal/d, of which 13 Mgal/d is from ground-water sources. Lakes Michigan and Winnebago provide most of the surface-water supply (Horn, written communication, 1997).

MAJOR ISSUES AND FINDINGS

Levels of Some Naturally Occurring Chemicals Have the Potential to Affect Human Health and Aquatic Life

Many naturally occurring chemicals are present in streams and ground water. It is important for water and land managers to understand the natural water chemistry in order to assess the effects of human activities on water quality.

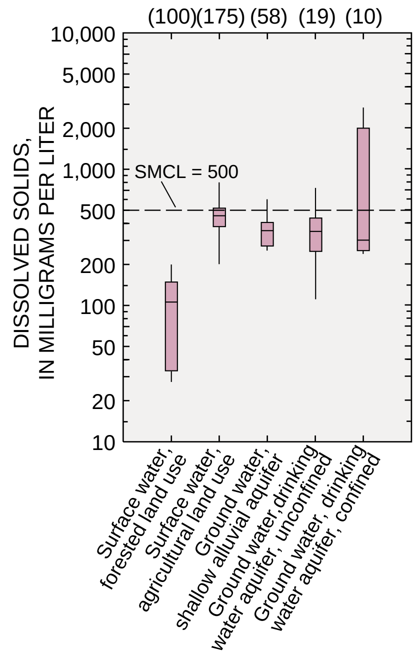
The chemical composition of natural water is primarily derived from the dissolution of minerals in surficial deposits and bedrock.

Dissolved constituents in rivers and ground water include the major cations (calcium, magnesium, sodium, potassium), major anions (bicarbonate, chloride, and sulfate), nutrients, *trace elements* (including iron and manganese), and radionuclides (uranium, radium, and *radon*).

The most common ions in most waters in the study area are calcium, magnesium, and bicarbonate. These ions provide many of the dissolved solids in study-area waters. *Median* dissolved-solids concentrations in surface waters range from about 50 *milligrams per liter (mg/L)* in forested parts of the study area to about 500 mg/L in agricultural basins. Median concentrations of dissolved solids in ground water range from about 250 mg/L in shallow *alluvial aquifers* to more than 2,500 mg/L in the drinking-water aquifer where it is confined by the Sinnipee *confining layer* (Richards and others, in press; Saad, 1996 and 1997).

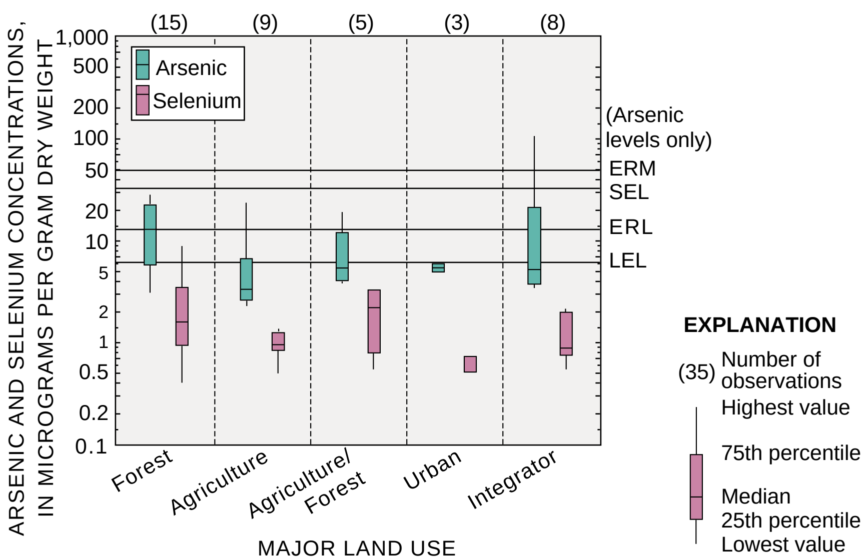
Concentrations of dissolved solids exceeded the USEPA *secondary maximum contaminant level (SMCL)* of 500 mg/L in 22 percent of surficial aquifer wells and 17 percent of deep drinking water wells sampled (Saad, 1996 and 1997).

Concentrations of arsenic and selenium in streambed sediment are variable in the study area. Median arsenic concentrations are highest in the forested land use area and are correlated with the igneous/metamorphic bedrock. Arsenic concentrations exceeded the concentrations that 95 percent of the *benthic biota* can tolerate, the *Lowest Effect Level (LEL)*, at 48 percent of sites sampled.



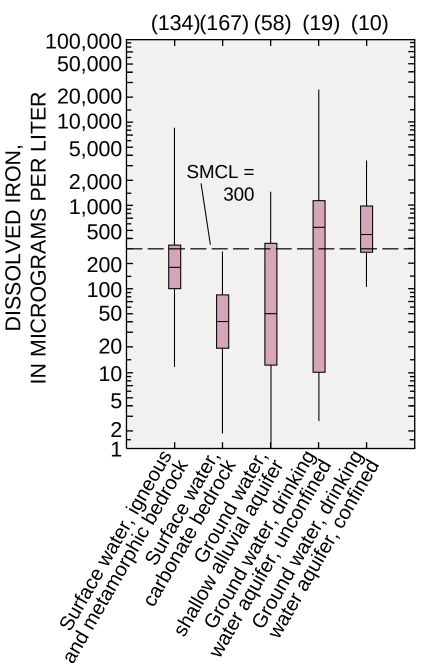
Dissolved solids concentrations are variable in the study area. Highest concentrations are found in the confined part of the drinking water aquifer, which may increase treatment costs. SMCL is secondary maximum contaminant level.

Runoff in agricultural areas may contribute significant suspended solids to stream water, resulting in streams with a muddy appearance.



Forested land use was related to high concentrations of arsenic and selenium in streambed sediment (Scudder and others, 1997). The igneous/metamorphic bedrock and sand and gravel surficial deposits that are found in most of the forested areas may be a source for these elements in the study area. Ontario Ministry of Environment and Energy values (Persaud and others, 1993) are shown for the Lowest Effect Level (LEL) and *Severe Effect Level (SEL)*. Sediment effect criteria from Ingersoll and others (1996) for *Effects Range Low (ERL)* and *Effects Range Median (ERM)* are for arsenic only.

Concentrations of iron in ground water varied from near zero to 23,000 *micrograms per liter* (*µg/L*). Concentrations of dissolved iron exceeded the USEPA SMCL of 0.3 mg/L in 38 percent of samples collected from drinking-water wells and 10 percent of shallow alluvial wells (Saad, 1996 and 1997). The source of the iron in the drinking water aquifer is probably the minerals in the Cambrian/Ordovician aquifer geologic material. The source of iron in the shallow alluvial aquifers may be the minerals in the alluvial materials derived from the igneous and metamorphic bedrock or possibly from supplemental iron that is in some fertilizers.

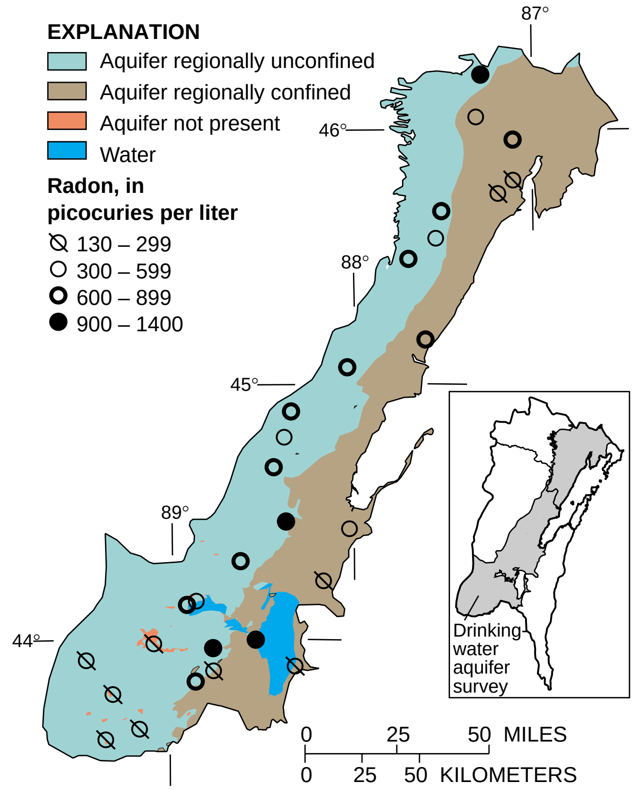


Dissolved iron concentrations are variable in the study area. SMCL is secondary maximum contaminant level.

Radon, which can cause lung cancer, is a radioactive, odorless, and chemically inert gas that occurs naturally in the air, soil, and ground water. Radon is a decay product of radium, which in turn is a decay product of uranium. Rocks break down mechanically and chemically to form sediments that contain various amounts of uranium, depending on the source rocks.

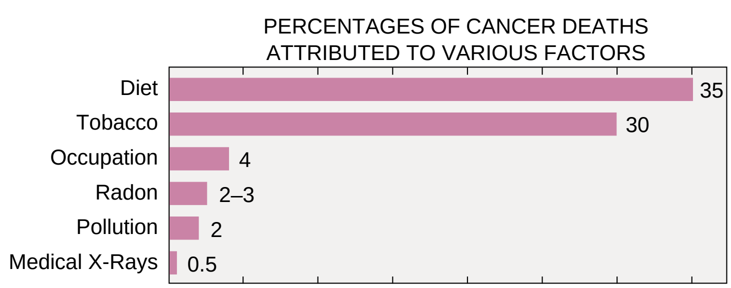
Radon in ground water affects radon concentrations in indoor air in homes because it escapes to the indoor air as people use water. Open water-distribution systems allow ground water to aerate and radon to escape. In small, closed water-distribution systems with short transit times, radon cannot escape from the system; therefore it escapes into the indoor air. Research suggests that ingestion of water with high radon concentrations also may pose risks, although these risks are believed to be much lower than those from inhalation of radon.

Until late 1996, the USEPA had proposed an MCL of 300 *picocuries per liter (pCi/L)* for radon in drinking water. However, this proposed *maximum contaminant level (MCL)* was withdrawn by USEPA for further evaluation; thus, no proposed MCL currently exists. Radon concentrations measured during this study were larger than the previously proposed MCL in 66 percent of the drinking-water aquifer wells (Saad, 1996).



Radon, a known carcinogen, exceeds the previously proposed USEPA standard of 300 picocuries per liter in many deep wells.

Radon concentrations greater than 300 pCi/L were detected in a variety of geohydrologic environments throughout most of the study area, with the exception of the southwest (Saad, 1996). Elevated radon concentrations do not appear to be related to a particular geologic formation or land use.

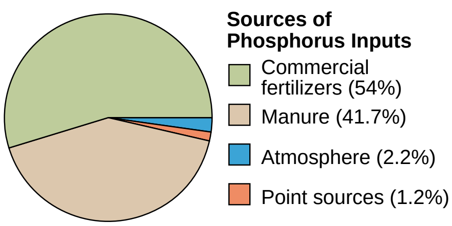


The three cancer risks greater than radon are all factors that can be controlled through life-style changes. This figure accounts for all exposures to radon, not only radon in water (not all factors are shown). Source: American Institute for Cancer Research (1992).

Fertilizers and Livestock Wastes Increase Nutrients in Streams and Ground Water

Applications of *phosphorus* and nitrogen to croplands, urban lawns, and golf courses, in the form of commercial fertilizers and(or) animal manure, are common in the study area. In drinking water, concentrations of *nitrate* in excess of 10 mg/L can cause methemoglobinemia or "*blue-baby syndrome*" which can be fatal to infants.

Nutrients are essential for aquatic plants; however, in high concentrations they can cause *eutrophication*, leading to nuisance algal blooms. Algal blooms can be detrimental to fish and other aquatic organisms.



More than 96 percent of the total anthropogenic phosphorus input to the study area is in the form of commercial fertilizers and livestock manures. Point sources such as sewage-treatment plants contribute only about 1.2 percent of the total input (Robertson, 1996a).

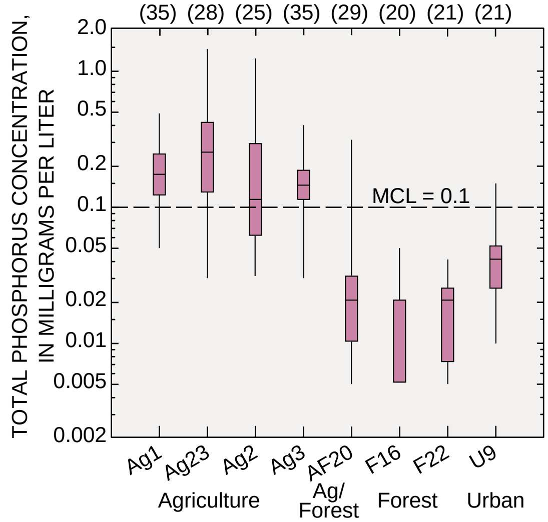
Animal manure is spread on farm fields, typically in the fall or winter months, as a fertilizer. Improper or excess application can result in runoff to streams or infiltration to ground water. The advent of "precision farming" methods will allow application of fertilizers to specific parts of fields based on need, and may lead to reduced inputs.

Phosphorus is naturally occurring and present in many clay soils in the study area. Man supplements this naturally occurring phosphorus with total annual inputs to the study area of 34 thousand tons (6.8 pounds per acre).

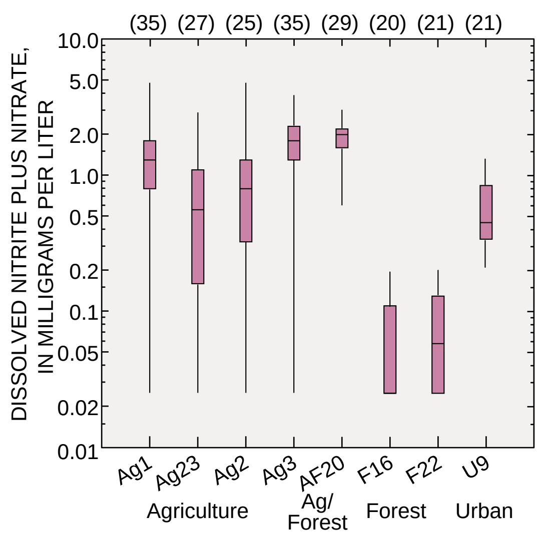
Phosphorus concentrations at the 11 Fixed Sites were primarily related to land use and secondarily related to clayey surficial deposits in the basin. Median phosphorus concentrations exceeded the USEPA suggested maximum total phosphorus concentration for flowing water of 0.1 mg/L (U.S. Environmental Protection Agency, 1986) in 57 percent of samples collected at the four agricultural sites (Richards and others, 1998).

Nitrate was detected in all 412 stream-water samples collected during the study. Concentrations in 66 percent of all stream samples and 92 percent of samples from agricultural sites were high enough to contribute to algal blooms (0.3 mg/L).

Median nitrate concentrations at the four agricultural sites and the mixed agriculture and forested sites were slightly higher than at the urban site and considerably higher than at the forested sites. Nitrate concentrations at the agricultural East River site exceeded the USEPA MCL (10 mg/L) during three storms in 1994 and 1995. Median nitrate concentrations in river water from Lincoln Creek, the urban site, were similar to the national average concentration (Smith and others, 1993) in urban areas and are probably elevated relative to forested land use areas due to the use of fertilizers on lawns and gardens.



Phosphorus concentrations in stream water at agricultural sites were considerably higher than at urban and forested sites during base flow conditions. (RHU labels correspond to the RHU figure on p. 6.)

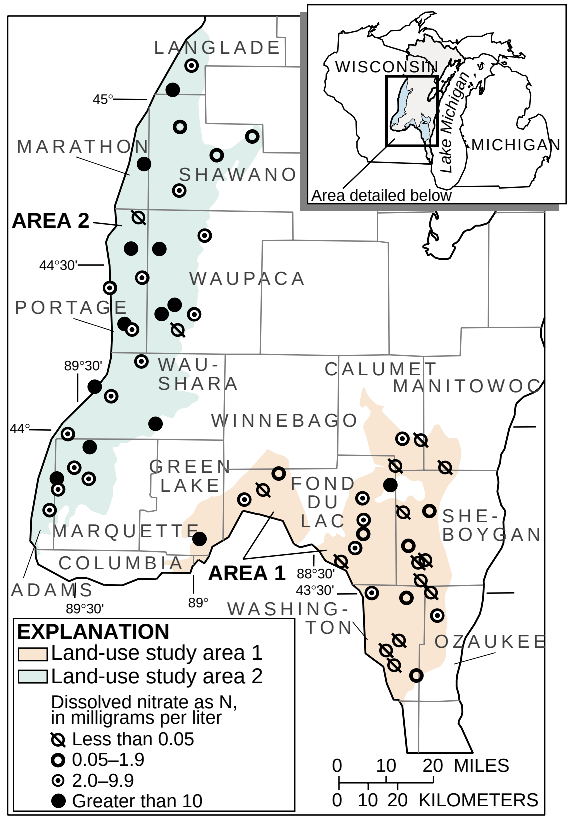


Median nitrate concentrations, during base-flow conditions, at two of the agricultural sites and the mixed agriculture and forested sites were twice the national average concentration for agricultural areas (Smith and others, 1993). (RHU labels correspond to the RHU figure on p. 6.)

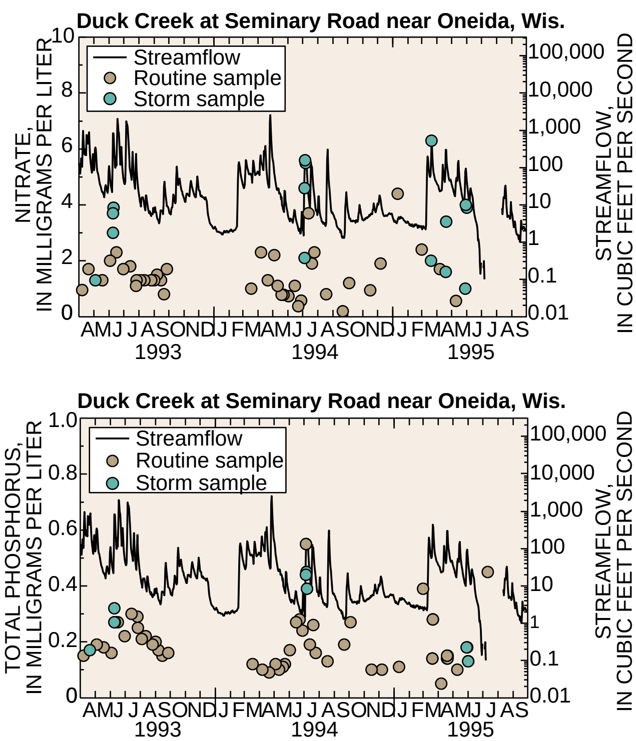
Nutrient concentrations vary seasonally in streams throughout the study area. The highest concentrations occur during stormwater runoff. At two agricultural streams in the study area, more phosphorus was carried during storms in June 1993 than during the next 24 months combined. Highest phosphorus concentrations during periods when storm runoff is absent (base flow) generally occur during the growing season (March to August), and the lowest concentrations occur during the winter (January and February). Highest nitrate concentrations during base-flow periods generally occur during the winter months. This may be due to the seasonal change in contributions from ground-water discharge to streams or to the seasonal cycle of algae growth in streams.

Nitrate was detected in all 76 ground-water samples collected. Concentrations of nitrate exceeded the USEPA MCL of 10 mg/L in 9 percent of samples from the drinking-water aquifer and in 22 percent of samples from the surficial alluvial aquifers.

In general, ground water had higher concentrations of nitrate in areas of agriculture or mixed agriculture and forested land use than in urbanized and forested *watersheds*. Ground water from the surficial alluvial aquifer generally had higher concentrations of nitrate than that from wells in the Cambrian-Ordovician drinking-water aquifer (Saad, 1996 and 1997). Concentrations of nitrate in the drinking water aquifer were highest in areas where the Sinnipee confining unit is not present. Ground water in areas where the surficial deposits were sand and gravel had higher nitrate concentrations than in areas where the surficial deposits were sand and clay *glacial till* (Saad, 1996).



Water samples from 22 percent of shallow alluvial wells sampled in agricultural land-use areas exceeded the USEPA maximum contaminant level for nitrate as nitrogen of 10 mg/L. Nitrate concentrations were higher in land use area 2 where surficial deposits were more permeable (Saad, 1997). Typically, these shallow wells are not drinking-water sources.



The highest nutrient concentrations occurred during periods of precipitation runoff.

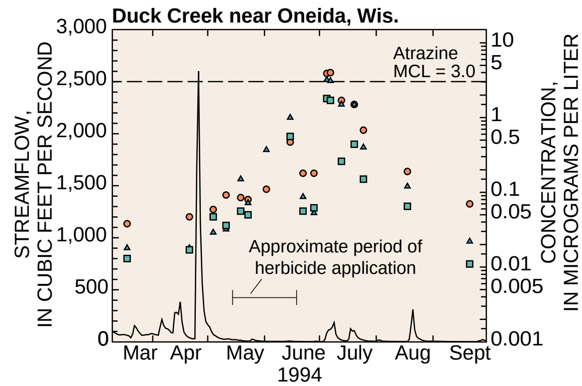
More than 20,000 samples from more than 500 stream sites and nearly 1,000 samples from about 800 wells in the study area were analyzed by various agencies for nutrients between 1970 and 1991 (Robertson and Saad, 1996; Saad 1994). *Retrospective analysis* of these data indicated that agricultural land use was the primary factor affecting the distribution of nutrient concentrations. Phosphorus concentrations decreased significantly in surface water downstream from urban areas during the 1970s because of the reduction of phosphorus in detergents and improvements in sewage-treatment facilities.

Various Factors Control Pesticide Occurrence in Streams and Ground Water

Fifteen pesticides were detected in ground water and 33 in surface water (Sullivan and Richards, 1996; Saad, 1996 and 1997). Most of the pesticides detected in surface water and ground water are *herbicides* used on corn, soy beans, small grains, and hay. However, there are a number of herbicides and insecticides, more commonly used on lawns and for specialty crops, that have been detected as well. The use of specific pesticides fluctuates over time as new pesticides are developed or as more information is ascertained regarding health effects and persistence.

Approximately 1,100 tons of pesticide active ingredient are applied to agricultural land in the study area each year.

Drinking-water standards (U.S. Environmental Protection Agency, 1996) were exceeded in only 11 of 143 surface-water samples. However, there are established standards for only about 20 percent of the 88 pesticides that were analyzed for as part of this study. There is no clear evidence that currently used pesticides are adversely effecting aquatic or human health; but at the same time, potential effects of long-term human and environmental exposure to both individual pesticides and to complex mixtures of pesticides and their *degradation products* are unknown (Goodbred and others, 1997; Girvin, 1996). The continuing presence of the once widely used insecticide *DDT* and its degradation products such as DDE, despite the ban on DDT use that was imposed in the early 1970s, demonstrates the persistence of certain toxic chemicals in the environment. Therefore, continued study of the types and amounts of pesticides in streams and ground water, coupled with the latest information on effects of pesticides on aquatic or human health, is in order.



Pesticide concentrations are highest during storms that occur soon after the herbicide application period. Pesticide concentrations exceeded USEPA MCLs on several occasions during these runoff periods.

EXPLANATION
— Streamflow
Atrazine
Metolachlor
Cyanazine

Concentrations of pesticides were 100 times higher in intensively farmed (row crop) areas of the study area than in nonagricultural areas or in less intensively farmed areas where grazing, hay production, and less herbicide-intensive crops are raised.

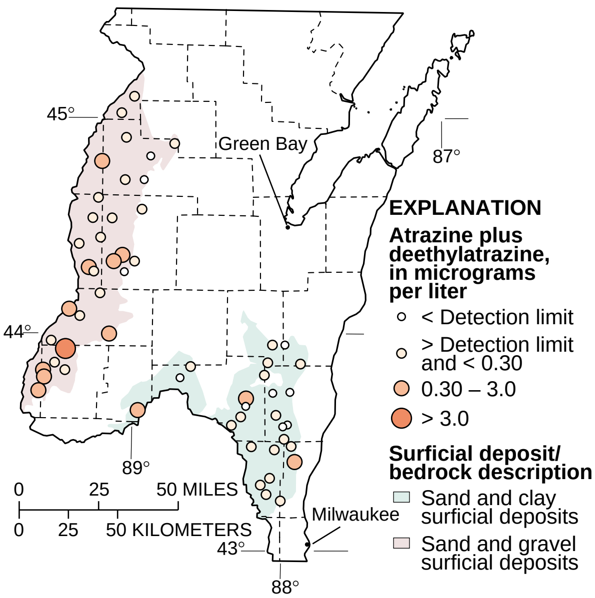
Pesticide concentration in streams show a seasonal pattern (Sullivan and Richards, 1996). The highest pesticide concentrations typically occur during the first several periods of runoff following the application of pesticides.

Numerous pesticides have been detected in precipitation in the study area (Majewski and Capel, 1995). Atrazine concentrations in precipitation in the study area are typically about 0.2 µg/L (Goolsby and others, 1994). The presence of atrazine in stream water from the two forested Indicator Sites at concentrations less than 0.005 µg/Lis probably due to *atmospheric deposition*.

Atrazine, the herbicide most commonly used on corn in the study area (Gianessi and Puffer, 1991) was detected in all of the stream samples and in more than half of the ground-water samples (Sullivan and Richards, 1996; Saad, 1996 and 1997). The herbicides simazine, metolachlor, cyanazine, prometon, and alachlor were detected in more than one-half of the stream samples.

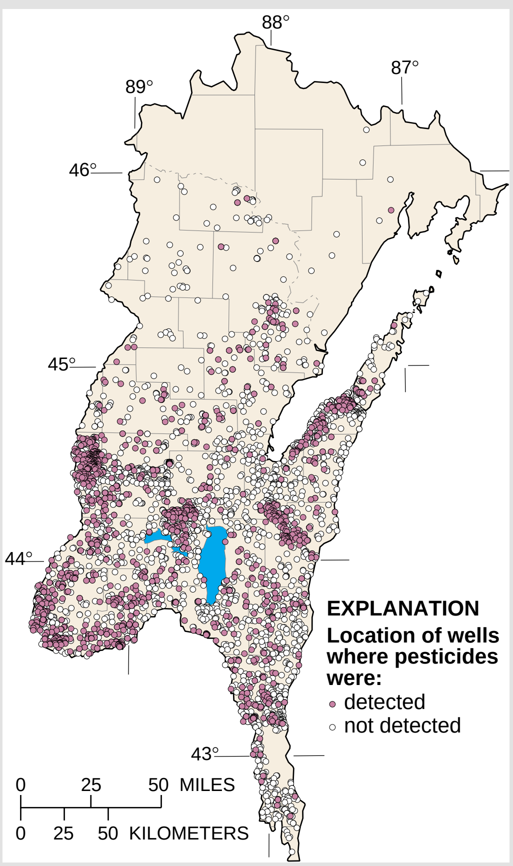
Pesticides applied at the land surface can be carried through the soil and subsoil to ground water with infiltrating rainfall. Pesticides were detected most frequently and in highest concentrations in ground water samples from shallow wells in intensively cultivated agricultural areas underlain by relatively *permeable* surficial deposits (Saad, 1997).

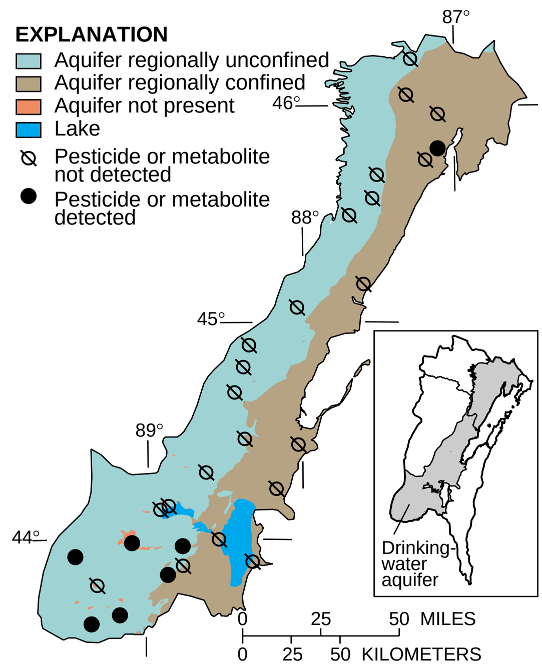
Pesticides were also detected in deeper ground-water aquifers that are used as drinking-water supplies. Pesticides detected in the deep ground water are generally from areas where the aquifer is not covered by the relatively impermeable Sinnipee confining unit (Saad, 1996).



Atrazine concentrations in shallow ground water were highest in areas with the most permeable surficial deposits. The shallow ground water targeted by these agricultural land use studies is seldom used for a drinking-water source.

Between 1983 and 1995, a total of 32,064 pesticide analyses were done on samples from 4,155 wells in the study area (Matzen and Saad, 1996). In 29 percent of the sampled wells, at least one pesticide was detected. Atrazine and its degradation products exceeded the Wisconsin preventive action limit (PAL) of 0.3 microgram per liter in about 10 percent of all wells sampled. Thousands of potential pesticide degradation products exist and these compounds are rarely included in laboratory analyses for pesticides. Therefore, it is likely that pesticide and degradation product occurrences in both surface and ground water have been, and currently are, underestimated in the study area and across the Nation.

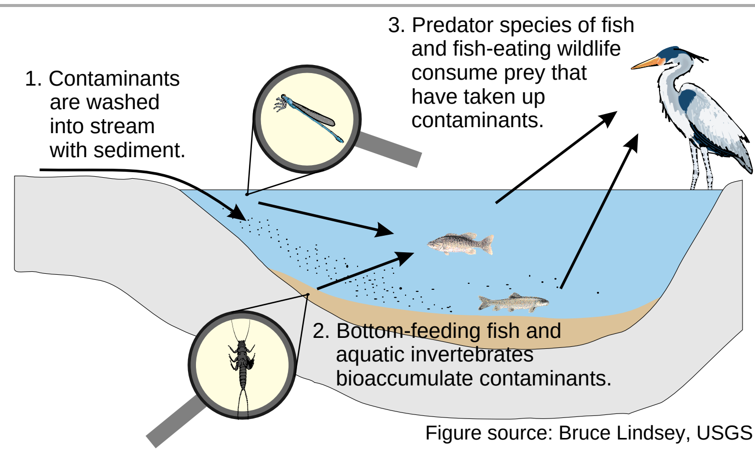




Pesticides were detected in seven drinking-water aquifer wells. Most of the detections were in wells in agricultural areas where the aquifer is not covered by the Sinnipee confining unit (Saad, 1996).

Urban Areas are a Source of Trace Elements and Organic Compounds

Industrial activities in urban areas of the study area have introduced contaminants into surface water and stream-bed sediments. Parts of the Menominee, Fox, Sheboygan, and Milwaukee Rivers have been designated "areas of concern" (AOCs) by the International Joint Commission, which represents U.S. and Canadian environmental and resource interests in the Great Lakes Region (International Joint Commission, 1989). Water, sediment, and biota in these four AOCs have been found to contain a wide array of inorganic and synthetic organic compounds (Wisconsin Department of Natural Resources, 1978 and 1993; Sullivan and Delfino, 1982). The severity of contamination in the AOCs has restricted the use of water for human and animal consumption and has limited the recreational uses.



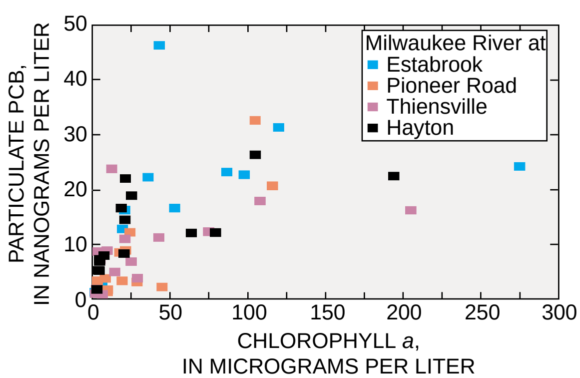
Contaminants attached to sediments can be transported from the land surface to surface water systems. The contaminants can enter the food chain and lead to *bioaccumulation* in larger species.

The industrialized lower Fox River Valley supports one of the largest concentrations of paper mills in the world.

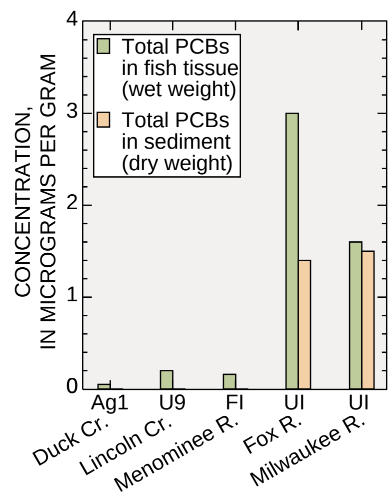
Concentrations of chemicals in the aquatic environment are of concern whenever and wherever organisms, including humans, may be at risk. One way to assess this risk is to measure the amount of contaminants biologically available to organisms, known as *bioavailability.* Measuring concentrations of contaminants in streambed sediments and in biotic *tissues* can provide information on the bioavailability of contaminants in sediments to particular organisms.

Polychlorinated biphenyls (PCBs), a set of 209 related chlorinated organic compounds, had various industrial uses in the study area such as in hydraulic fluids, cutting oils, sealants, and pesticides. Despite a manufacturing ban in the mid-1970s, PCBs continue to be of concern because of their persistent toxicity to organisms. PCBs are a listed contaminant in all of the designated AOCs.

Data collected during the *bed-sediment and tissue studies* in the study area indicate that PCB concentrations in the Lower Fox River and in the Milwaukee River may be linked to algal productivity. Highest particulate PCB concentrations were measured during the algae-rich summer months. Incorporation of PCBs into algae (Swackhamer and Skoglund, 1993) provides a pathway for these compounds to move from contaminated river sediments into other organisms, including fish and humans.



The relation between algae measured as chlorophyll-*a* and PCBs indicates that algal growth, sedimentation, and sediment resuspension may be important processes controlling the fate of PCBs in rivers (Fitzgerald and Steuer, 1996).



Concentrations of PCBs are 10 times higher in streambed sediments and biotic tissues at urban Integrator sites (Scudder and others, 1997) than in smaller urban, agricultural or forested land use areas. RHU labels correspond to the RHU figure on p. 6, "I" represents large-river (Integrator) sites.

Acute exposure (short term, high concentration) to certain trace elements can kill organisms, whereas chronic exposure (long term, low concentration) can result in mortality or nonlethal effects, such as stunted growth, reduced reproductive success, or deformities.

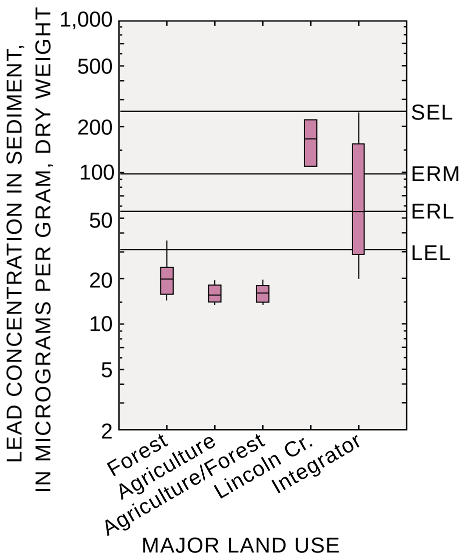
Concentrations of cadmium, copper, mercury, nickel, lead, and zinc were significantly higher in fine river sediments from large-river and *urban sites* than in other areas (Scudder and others, 1997). Trace elements and synthetic organic compound concentrations in sediment and fish tissue exceeded *aquatic-life criteria* at some sites.

Trace-element concentrations in streambed sediment.

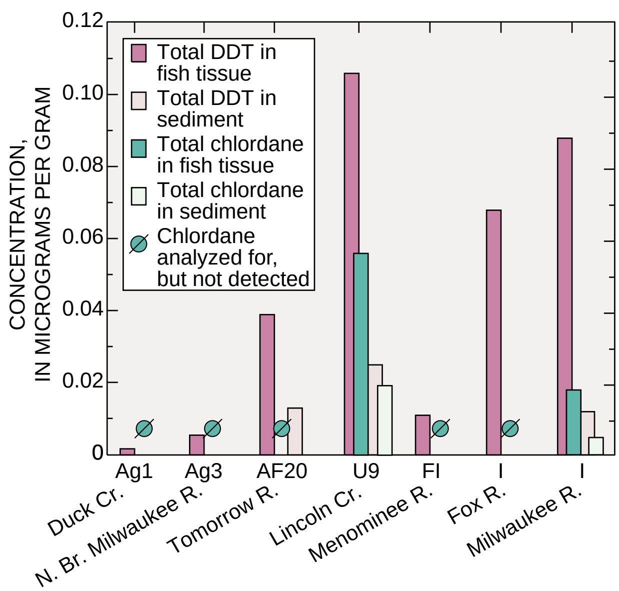
Trace element	Number of samples	OMEE LEL	SEC ERL	OMEE SEL	SEC ERM
Arsenic	40	18	12	1	1
Cadmium	41	25	19	0	2
Chromium	42	42	38	3	1
Copper	42	30	9	3	0
Mercury	42	8	--	2	--
Nickel	42	25	16	0	0
Lead	42	12	10	1	5
Zinc	42	17	17	1	3

Trace-element concentrations in fine (less than 63 micrometers) streambed sediment exceeded guidelines for bulk sediment in many samples. Comparisons of trace-element concentrations in fine sediment to bulk sediment guidelines may overestimate potential effects on biota. A number of observations from the Western Lake Michigan Drainages equaled or exceeded published guidelines for trace-element concentrations in sediment.

[Ontario Ministry of Environment and Energy values (Persaud and others, 1993) are for the Lowest Effect Level (OMEE LEL) and Severe Effect Level (OMEE SEL). The sediment effect criteria (SEC) are from Ingersoll and others (1996) for Effects Range Low (SEC ERL) and Effects Range Median (SEC ERM); --, no guidelines.]



Median concentrations of lead and mercury in streambed sediment exceeded the "lowest effect level" at urban and large river sites (see table at right). Lead is a known urban contaminant whose historical source is probably gasoline (Callender and Van Metre, 1997).

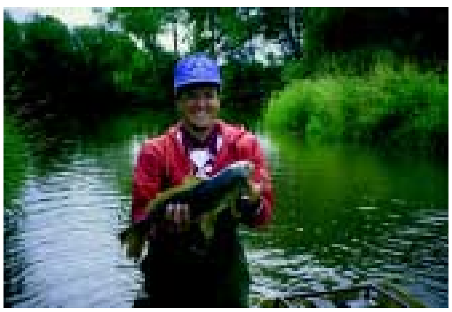


Concentrations of many toxic synthetic organic compounds were elevated in streambed sediments and tissues from urban and large-river sites relative to other land uses. (RHU labels refer to RHU figure on p. 6; "I" represents large-river (Integrator) sites.

Semivolatile organic compounds (SVOCs) were analyzed for in streambed sediments. Eighty percent of the SVOCs analyzed for in the study area were detected in at least one sample. Two classes of SVOCs (polycyclic aromatic hydrocarbons, PAHs, and phthalates) were detected more frequently and in higher concentrations at urban-affected sites (Scudder and others, 1997).

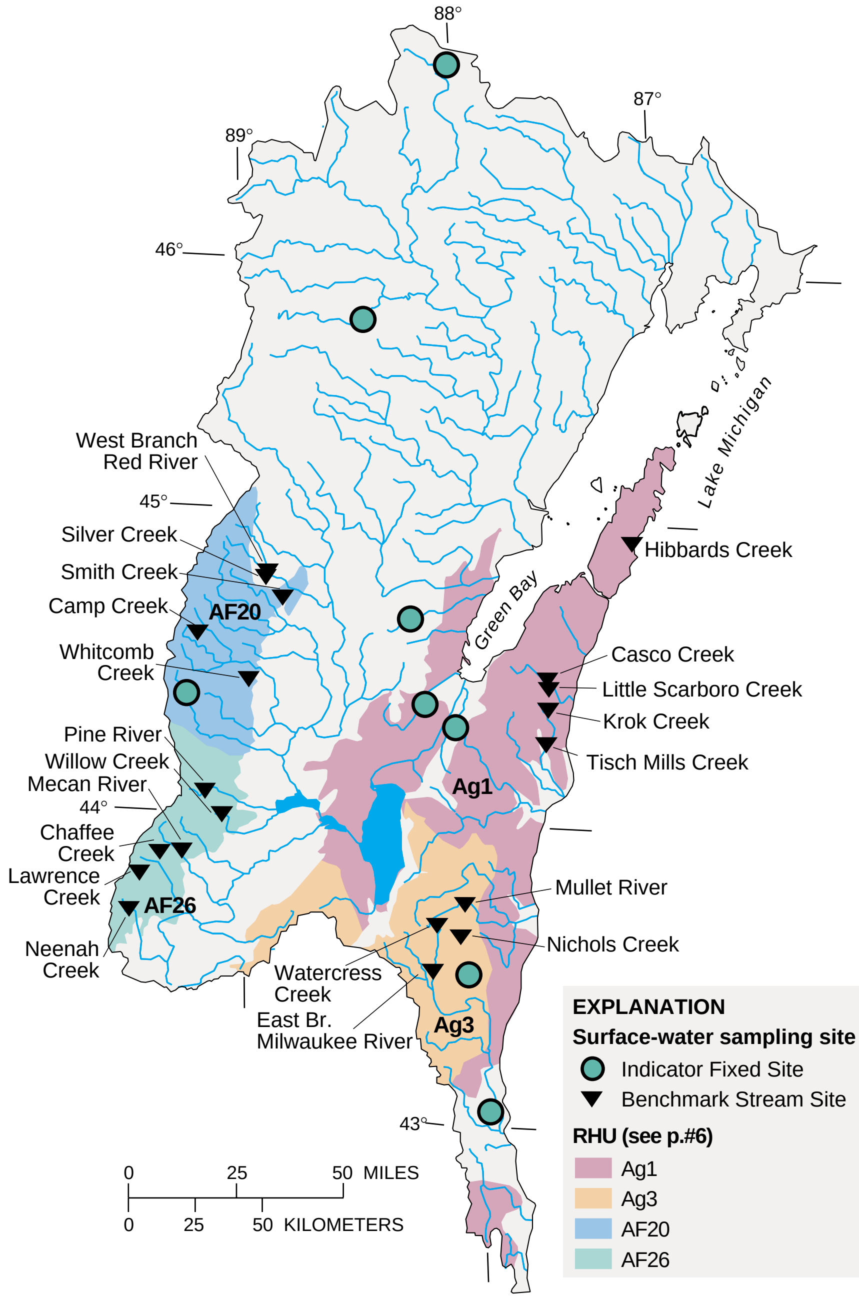
Stream ecology can be affected by a wide variety of human and natural factors. Sampling stream *habitat* and communities of fish, *benthic invertebrates*, and algae provides a unique assessment of the overall health of streams. Relating these findings to information about the natural and human features found in the sampled basins can provide important information for management of land and water resources.

Nearly 500 biological studies conducted in the study area between 1891 and 1996 were identified that relate to water-quality conditions. Most of these studies focused on populations and community structure of aquatic biota in streams thought to be degraded as a result of human activity (Scudder and others, 1996).



The number of each type of fish species present in streams provides an indication of stream-water quality. Twenty-one of the 28 streams sampled were classified as coldwater trout streams (Sullivan, 1997; Sullivan and Peterson, 1997).

Indexes of biotic integrity were calculated for each of the four ecological components for 28 streams in the study area. These biotic indexes were developed to provide an indication of water quality based on the ecological component sampled. Results of the calculated indexes for the Indicator and benchmark sites were compared to land use, surficial deposit, and bedrock information in each basin to determine the influence of these environmental factors on aquatic life in the basin.



Twenty *benchmark streams* in a predominantly agricultural part of the study area were selected for detailed ecological studies (Rheaume, Stewart, and Lenz, 1996). These studies were also done at the eight Indicator Fixed Sites (Sullivan and others, 1995). The ecological studies conducted at the 28 sites were designed to study the effects of *environmental setting* on aquatic life. The studies conducted at the 20 benchmark stream sites were also designed to define aquatic life conditions in less-degraded watersheds located in primarily agricultural areas.

In general, there was good agreement between individual ecological component scores. At only one of the 20 benchmark streams did results vary by more than one quality category. At four of the eight Indicator Fixed Sites scores varied by two quality categories.

Overall water quality at the benchmark streams, as indicated by the four ecological component scores, varied little within each of the four RHUs sampled. Biotic indexes indicated that water quality at the benchmark streams in RHU 26 were of slightly higher quality than benchmark streams in RHU 3. Benchmark streams in RHU 26 had nearly twice as much forested land in their basins than did RHU 3 streams.

Water quality, as indicated by biotic indexes, varied considerably between Indicator Fixed Sites. The urban site had the worst water quality and the forested sites the best water quality. At the agricultural Indicator Fixed Sites, water quality varied considerably. Scores were nearly as low as the urban site where percent agriculture in the basin was highest; and scores were as high as the forested sites where agricultural land use percentage was lowest.

Lowest overall scores were from basins with clay surficial deposits. There was no apparent correlation between biotic indexes and bedrock type or *drainage basin* area.

	River name	Area (mi^2)	RHU	Land use (percent)	Ecological Component: Habitat	Algae	Invertebrates	Fish	Total score
Indicator Fixed Sites	Peshekee River	49	16	F (98)	◓	◓	●	◓	13
	Popple River	139	22	F (90)	◓	◓	●	⊖	12
	Pensaukee River	36	2	Ag (86)	◓	◓	⊖	◓	11
	Duck Creek	95	1	Ag (89)	⊖	⊖	◓	◓	10
	Tomorrow River	44	20	Ag (58)/F (39)	◓	◓	●	◓	13
	East River	47	23	Ag (92)	⊖	◓	⊙	⊖	7
	N. Br. Milwaukee R.	51	3	Ag (88)	⊖	◓	●	●	13
	Lincoln Creek	10	9	U (100)	⊖	⊖	⊖	○	6
Benchmark Streams	Tisch Mills Creek	16	1	Ag (81)/W (11)	◓	◓	●	◓	13
	Krok Creek	78	1	Ag (61)/W (36)	◓	◓	◓	⊖	11
	Little Scarboro Creek	1	1	Ag (94)	◓	◓	●	◓	13
	Casco Creek	15	1	Ag (89)/F (7)	◓	◓	◓	⊖	11
	Hibbards Creek	16	1	Ag (73)/F (14)	◓	◓	◓	◓	12
	E. Br. Milwaukee R.	53	3	Ag (56)/F (32)	◓	●	⊖	⊖	11
	Nichols Creek	5	3	Ag (81)/F (19)	●	◓	●	●	13
	Mullet River	46	3	Ag (72)/F (15)	◓	◓	◓	⊙	10
	Watercress Creek	12	3	Ag (66)/F (31)	⊖	◓	◓	⊖	10
	Whitcomb Creek	8	20	F (63)/Ag (30)	⊖	◓	◓	◓	11
	W. Br. Red River	37	20	F (52)/Ag (38)	◓	●	●	◓	14
	Silver Creek	16	20	F (45)/Ag (35)/W (19)	●	●	●	●	16
	Smith Creek	2	20	F (60)/W (35)	◓	◓	⊖	◓	11
	Camp Creek	5	20	F (54)/W (28)/Ag (18)	◓	●	◓	●	13
	Lawrence Creek	8	26	Ag (49)/F (46)	◓	●	●	●	15
	Neenah Creek	25	26	Ag (58)/F (38)	◓	◓	●	◓	13
	Chaffee Creek	9	26	Ag (44)/F(26)/W (17)	◓	●	●	◓	14
	Mecan River	29	26	Ag (59)/F (40)	◓	◓	◓	◓	12
	Willow Creek	16	26	F (52)/Ag (41)	◓	●	●	◓	13
	Pine River	21	26	Ag (58)/F (42)	◓	◓	●	●	14

Biological indexes for habitat (Great Lakes Environmental Assessment, GLEAS; Michigan Department of Natural Resources, 1991), algae (Index of Biological Integrity, IBI; Bahls, 1993), benthic invertebrates (Hilsenhoff Biotic Indexes, HBI and FBI; Hilsenhoff, 1987), and fish (Index of Biological Integrity, IBI; Lyons, 1992 and Lyons and others, 1996) indicate the water quality of streams in the study area. Total score determined by assigning point values for each quality score as shown in parentheses. Abbreviations: Ag, agriculture; F, forest; W, wetland; Scores: Excellent ● (4); Good ◓ (3); Fair ⊖ (2); Poor ⊙ (1); Very Poor ○ (0)

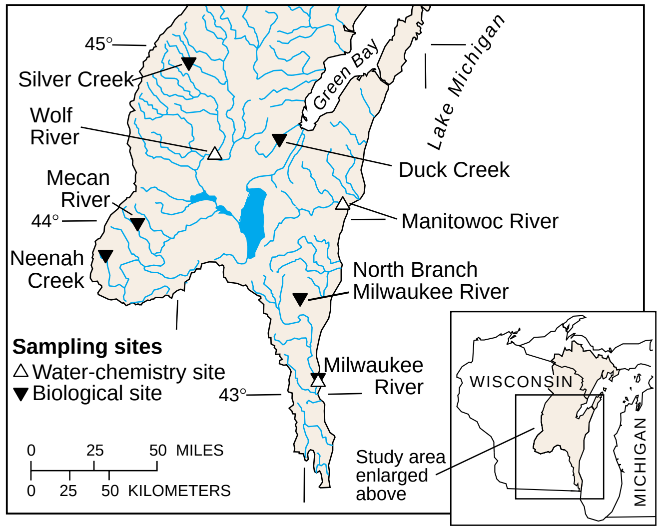
Caddisfly larvae are generally found where habitat and water quality conditions are good. Additional discussion of *habitat* conditions and invertebrate communities in the study area can be found in Fitzpatrick and Giddings, 1997; Fitzpatrick, Peterson and Stewart, 1996; and Rheaume, Lenz, and Scudder, 1996.

Are Biological and Water-Quality Data Collected by Different Methods Comparable?

Control of water pollution became a major environmental priority during the last three decades, and in response, water-quality monitoring has expanded rapidly. Today, Federal, State and local water-resource management agencies make a considerable investment in the collection of water-quality information. A wide variety of procedures are used to collect this information, often depending upon the objectives of the collection effort. A lack of information regarding the quality and comparability of the data collected can result in duplicated sampling efforts or the underutilization of available water-quality information.

To address these concerns, studies were done to determine the comparability of water-chemistry and aquatic-invertebrate data collected by different methods in Wisconsin (Lenz and Miller, 1996; Wisconsin Department of Natural Resources and U.S. Geological Survey, 1994).

These studies were coordinated with the Wisconsin Department of Natural Resources (WDNR), U.S. Forest Service (USFS), and a volunteer group, Water Action Volunteers (WAV), in conjunction with the Wisconsin Water Resources Coordination Project, a pilot program implementing the recommendations of the Intergovernmental Task Force on Monitoring Water Quality (ITFM).



Aquatic-biology method comparisons were done at six sites and water-chemistry method comparisons at three sites in the study area.

During 1993 and 1994, a study was done to compare water-chemistry results obtained using methods of the USGS and the WDNR (Wisconsin Department of Natural Resources and U.S. Geological Survey, 1994). Water-chemistry samples were collected four times, twice during base flow conditions and twice during storm runoff conditions, at three streams of various size that were chosen to represent stream variability in the study area. Duplicate samples were collected at each location using each collection, processing, and preservation method for analyses at both the USGS National Water-Quality Laboratory and the Wisconsin State Laboratory of Hygiene.

Total phosphorus, dissolved chloride, and suspended solids (sediment) were the water-chemistry parameters studied. Total phosphorus was chosen as an indicator constituent for nutrient concentrations, and dissolved chloride was chosen as an indicator for dissolved major ion concentrations.

Dissolved chloride in samples collected using the two agencies' methods were similar during both high- and low-flow conditions. Results indicated that concentrations of total suspended solids and suspended sediment concentrations were significantly higher for samples collected by the *equal-width increment* (EWI) *sample* method than using the *grab sample* method during high-flow conditions. Surprisingly, total phosphorus concentrations also were similar for each collection method and flow condition. It had been anticipated that total phosphorus would more closely mimic the suspended solids (sediment) results during high-flow conditions. There were significant differences between laboratories for analyses of concentrations of total phosphorus and dissolved chloride.

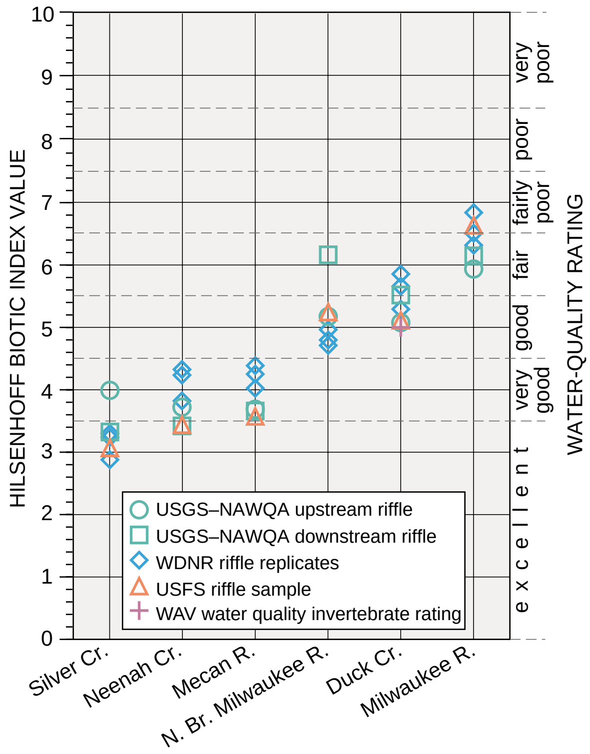
In general, laboratory analytical differences were more important than sample-collection-method differences. Samples collected for phosphorus and chloride by the two methods were comparable when analyzed by the same laboratory.

Results of USGS/WDNR water-chemistry methods comparison

Method tested	Total phosphorus	Dissolved chloride	Suspended sediment (SS)/ total suspended solids (TSS)
Differences between field-sampling methods	No difference	No difference	Concentrations of both SS and TSS were significantly higher in EWI samples
Within field-sampling method variability	No difference	No difference	SS concentrations more variable than TSS
Differences between field-processing methods	No difference	No difference	No difference
Differences between laboratories	USGS concentrations significantly lower	USGS concentrations significantly lower	Not applicable

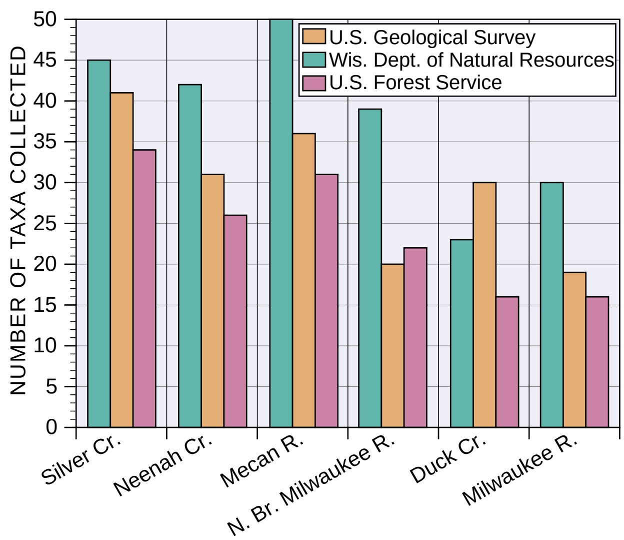
Aquatic-macroinvertebrate sampling methods used by the USGS, WDNR, and the USFS at *riffle* areas of streams were compared at six streams of various sizes in the study area. A volunteer group, WAV, performed an in-field invertebrate water-quality rating at one of the streams.

Results of the study indicated that differences in field-collection methods resulted in assessments of different habitats and the collection of different total numbers and proportions of individual species, indicating that field-collection methods need to be considered when comparing macroinvertebrate data among agencies (Lenz and Miller, 1996). However, the sampling methods resulted in similar water-quality ratings using the Hilsenhoff Biotic Index (HBI) a common benthic invertebrate environmental-tolerance measure.



Hilsenhoff Biotic Index (HBI) of environmental tolerance results from the three agencies and a volunteer group predicted water quality similarly.

In another study, USGS and WDNR data bases describing benthic macroinvertebrate communities in streams in the study area were paired with water-chemistry data to determine whether the data bases predicted water-quality conditions similarly. On the basis of the limited paired data available, the two data bases were shown to predict water-quality similarly using HBI (Lenz, 1997). However, results also indicated that benthic invertebrate data collected at different seasons should not be combined when using the data for water-quality assessments.



Different invertebrate sampling techniques resulted in different numbers of species collected.

Federal and State agencies work together to provide more comparable aquatic biology results.

The Intergovernmental Task Force On Monitoring Water Quality (ITFM) was a national program designed to coordinate monitoring programs; define efficient roles for Federal, State, and local agencies; evaluate diverse descriptions of aquatic conditions and trends; and develop a national water-information network (Intergovernmental Task Force on Monitoring Water Quality, 1994). The National Water-Quality Assessment Monitoring Council was established in May 1997 as the permanent successor to the ITFM.

Comparison of Stream Quality in the Western Lake Michigan Drainages with Nationwide NAWQA Findings

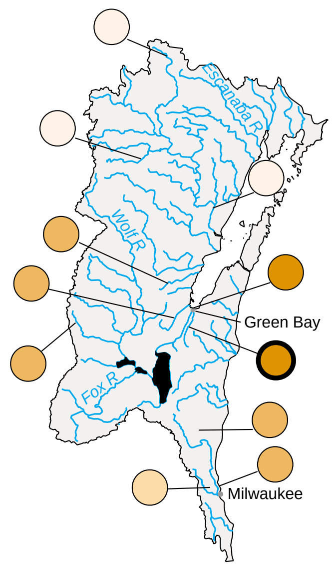
Seven major water-quality characteristics were evaluated for stream sites in each NAWQA Study Unit. Summary scores for each characteristic were computed for all sites that had adequate data. Scores for each site in the Western Lake Michigan Drainages were compared with scores for all sites sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA sites. Water-quality conditions at each site also are compared to established *criteria* for protection of aquatic life. Applicable criteria are limited to nutrients and pesticides in water and semivolatile organic compounds, organochlorine pesticides, and PCBs in sediment. (Methods used to compute rankings and evaluate aquatic-life criteria are described by Gilliom and others, in press.)

EXPLANATION

Ranking relative to national conditions– Darker colored circles generally indicate poorer quality. **Bold outline** of circle indicates one or more *aquatic-life criteria* were exceeded.

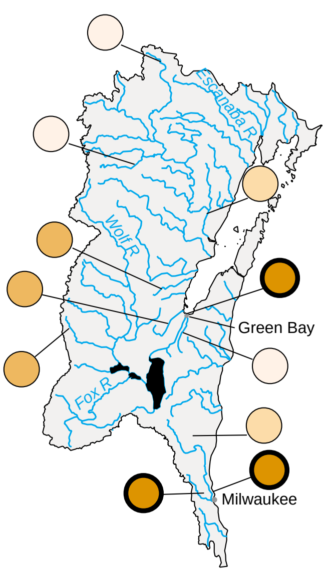
- **Greater than the 75th percentile** (among the highest 25 percent nationally)
- **Between the median and the 75th percentile**
- **Between the 25th percentile and the median**
- **Less than the 25th percentile** (among the lowest 25 percent nationally)

NUTRIENTS in water



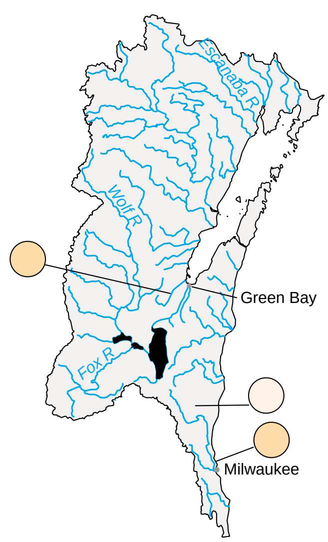
Nutrient concentrations in the study area were principally related to land use of the drainage basin. Relative to other Study Units nationally, low, moderate, and high nutrient levels were found in forested, urban, and agricultural basins, respectively. One agricultural site exceeded drinking-water standards during periods of stormwater runoff. Fertilizer and manure application to croplands is the major anthropogenic source of nutrients; however, point sources and atmospheric deposition also contribute to nutrient loading.

ORGANOCHLORINE PESTICIDES and PCBs in bed sediment and biological tissue

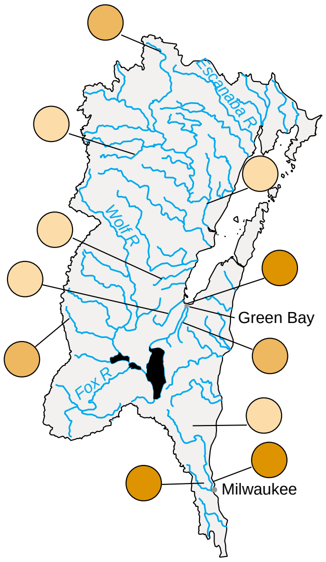


Concentrations of PCBs and *organochlorine compounds* in three streams that drain urban areas were among the highest of all NAWQA Study Unit sites nationally. The three urban sites also exceeded aquatic-life criteria; PCB concentrations in fish have been high enough to prompt bans on fish consumption for the protection of human health. A *metabolite* of the persistent compound DDT (*p,p'*-DDE) is also commonly detected at urban sites. Concentrations at agricultural sites were moderately high, whereas those in forested basins were low compared to other national NAWQA sites.

PESTICIDES in water

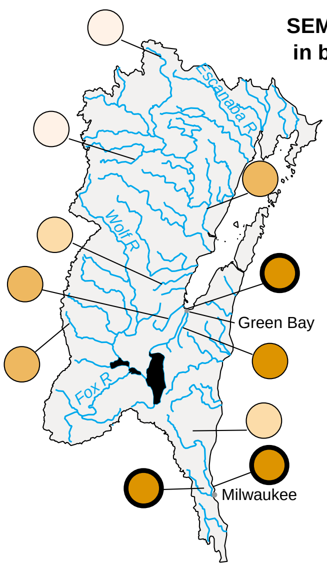


Atrazine was detected at all nine fixed sites where samples were analyzed for pesticides. However, concentrations were generally low, especially at sites draining basins with a low percentage of agricultural land use. At the three sites where sufficient data exist for comparison, pesticide concentrations were at or below the median national NAWQA concentration.



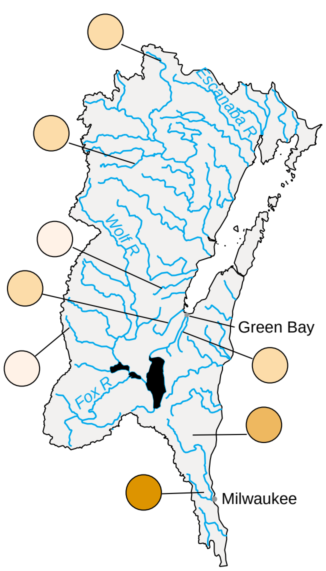
TRACE ELEMENTS in bed sediment

Some of the highest trace-element concentrations at NAWQA sites nationally were from the lower Fox and Milwaukee Rivers, major rivers in urban settings. Concentrations of arsenic, selenium, and mercury in forested basins in the study area were near the median of all NAWQA sites nationwide. Sites dominated by agricultural land use typically had low levels of trace elements compared to other NAWQA sites nationwide.



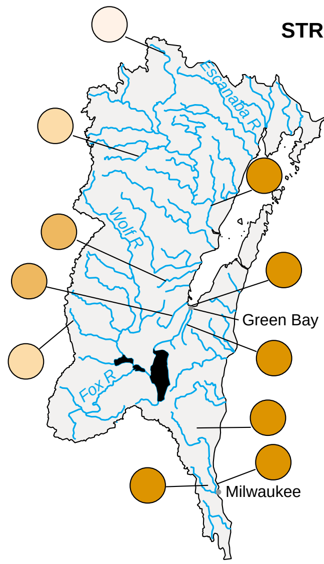
SEMIVOLATILE ORGANIC COMPOUNDS in bed sediment

Rivers in urban settings had some of the highest concentrations of SVOCs of all NAWQA sites nationwide. Three urban sites, the lower Fox and Milwaukee Rivers and Lincoln Creek, had concentrations of SVOCs that exceeded aquatic-life criteria. Forested and agricultural sites had low to moderate concentrations of SVOCs compared to sites nationwide.



FISH COMMUNITY DEGRADATION

Assessment of fish community degradation was based on several factors, including presence of non-native and *pollutant*-tolerant species, and percentage of diseased fish. Most sites within the study area have relatively high quality fish communities compared to the NAWQA sites in the rest of the Nation. However, Lincoln Creek, an urban site, had highly degraded fish community quality compared to other NAWQA sites.



STREAM HABITAT DEGRADATION

Degradation of stream habitat was based on several factors such as bank erosion, stream modification, and the stability and density of bank vegetation. The degree of stream-habitat degradation within the Study Unit depended on stream size and land use. Sites on streams draining agricultural or urbanized landscapes were degraded compared to NAWQA sites nationwide.

CONCLUSIONS

In the Western Lake Michigan Drainages, compared to other NAWQA Study Units:

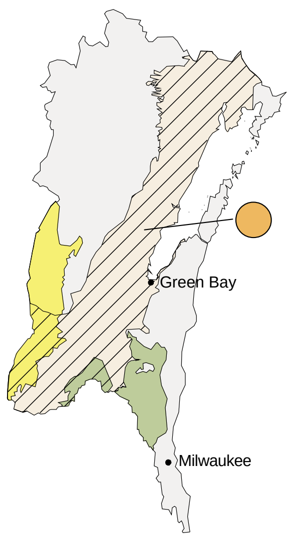
- Nutrient and pesticide concentrations are elevated in agricultural basins.
- Sites draining urban areas have elevated concentrations of trace elements, SVOCs, and PCBs.
- Northern forested basins have relatively good surface-water quality; however, trace element concentrations are slightly elevated and fish community quality is moderate.

Comparison of Ground-Water Quality in the Western Lake Michigan Drainages with Nationwide NAWQA Findings

Five major water-quality characteristics were evaluated for ground-water studies in each NAWQA Study Unit. Ground-water resources were divided into two categories: (1) drinking-water aquifers and (2) shallow ground water underlying agricultural or urban areas. Summary scores were computed for each characteristic for all aquifers and shallow ground-water areas that had adequate data. Scores for each aquifer and shallow ground-water area in the Western Lake Michigan Drainages were compared with scores for all aquifers and shallow ground-water areas sampled in the 20 NAWQA Study Units during 1992–95. Results are summarized by percentiles; higher percentile values generally indicate poorer quality compared with other NAWQA ground-water studies. Water-quality conditions for each drinking-water aquifer also are compared to established drinking-water standards and criteria for protection of human health. (Methods used to compute rankings and evaluate standards and criteria are described by Gilliom and others, in press.)

RADON

Radon levels for the Cambrian-Ordovician aquifer ranked relatively high among the national NAWQA sites. A natural product of the decay of uranium, radon is a radioactive gas that was detected in all samples collected from the Cambrian-Ordovician aquifer. Two-thirds of the samples exceeded a previously proposed maximum contaminant level of 300 picocuries per liter, although few samples in the southwestern part of the aquifer had high concentrations. The lack of data restricts the ability to speculate about the presence of radon in the shallow aquifers.



EXPLANATION

Aquifer unit (drinking water)

- Cambrian–Ordovician aquifer, west of Maquoketa Shale

Land-use studies (shallow ground water)

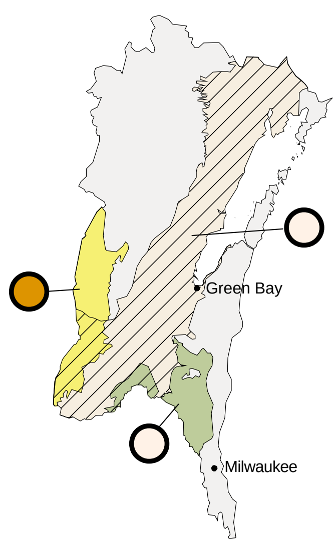
- Corn and alfalfa in glacial till
- Corn and alfalfa in sand and gravel

Ranking relative to national conditions– Darker colored circles generally indicate poorer quality. **Bold outline** of circle indicates one or more *drinking-water standards* or criteria were exceeded.

- **Greater than the 75th percentile** (among the highest 25 percent nationally)
- **Between the median and the 75th percentile**
- **Between the 25th percentile and the median**
- **Less than the 25th percentile** (among the lowest 25 percent nationally)

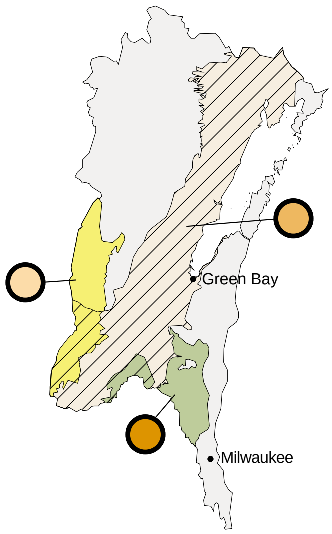
NITRATE

Nitrate concentrations in the shallow-aquifer area underlain by sand and gravel are some of the highest among the NAWQA sites nationwide, probably because highly permeable surficial deposits allow agriculturally derived nutrients to infiltrate to the ground water. The Cambrian-Ordovician drinking-water aquifer and the shallow aquifer overlain by glacial till both had low concentrations of nitrates compared to other national NAWQA data. All three areas had a few samples in which nitrate concentrations exceeded the drinking-water standard, a common occurrence in the Midwest farm belt.



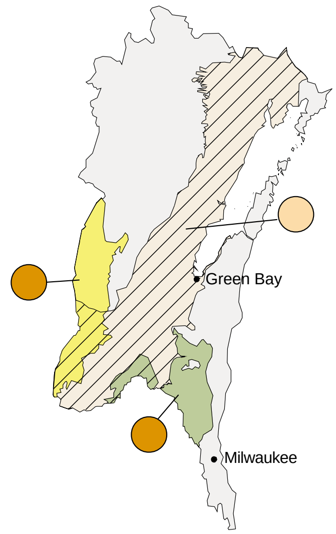
DISSOLVED SOLIDS

Concentrations of dissolved solids were relatively high compared to those in other Study Units. A few samples from each aquifer had concentrations of dissolved solids that exceeded the secondary maximum contaminant level. However, the shallow aquifers are seldom used as a drinking-water source. The area overlain by glacial till had among the highest concentrations of dissolved solids compared to other NAWQA sites nationally.



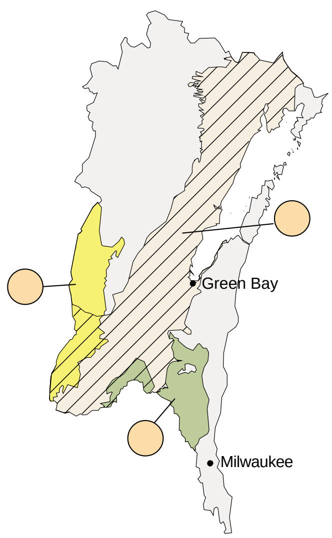
PESTICIDES

Pesticide detections in the Cambrian-Ordovician aquifer were similar to the median value from NAWQA sites; however, pesticide concentrations were high in both land-use study areas compared to aquifers in other Study Units. None of the ground-water samples exceeded drinking- water standards for pesticides; however, maximum contaminant levels (MCLs) have been established for only a small percentage of the pesticides detected.



VOLATILE ORGANIC COMPOUNDS

There was only one VOC (Trihalomethanes) detected in the Study Unit, and VOC concentrations at the two wells where detected were low. None of the samples tested above drinking-water standards. Industrial by-products and some pesticides are potential sources of VOCs in ground water.



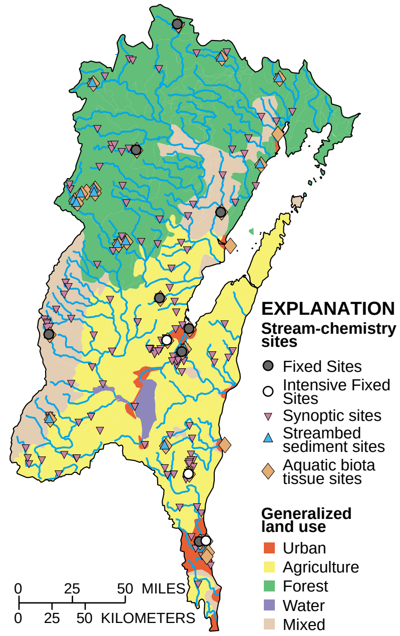
CONCLUSIONS

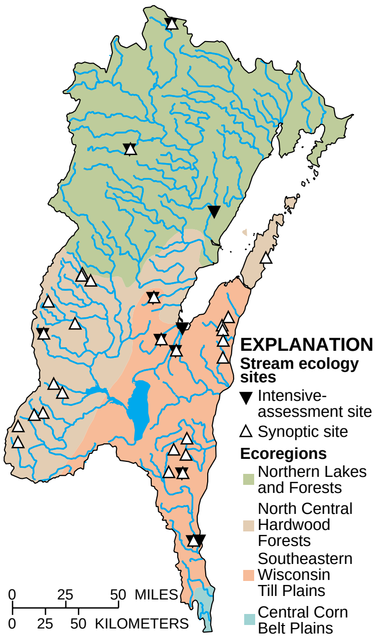
In the Western Lake Michigan Drainages, compared to other NAWQA Study Units:

- Nitrate and pesticide concentrations in shallow wells in agricultural areas were elevated; in areas with permeable surficial deposits, they were among the highest in the Nation.
- Drinking-water standards were exceeded in a few samples in each of the three ground-water study areas for nitrates and dissolved solids.
- Radon was elevated above the previously proposed maximum contaminant level in the drinking-water aquifer where it was sampled for.
- Land use is the primary influence on ground-water quality, whereas surficial deposits overlying an aquifer have a secondary influence. The confining unit overlying parts of the Cambrian-Ordovician aquifer provides some protection of the drinking water from the effects of human activities.

STREAM CHEMISTRY

Fixed Sites were established to examine differences in stream-water quality due to the environmental setting (land use, surficial deposits, and bedrock type) of the study area. Intensive Fixed Sites were sampled more frequently to determine seasonal variability in water quality and to test for 88 pesticides. Synoptic studies focused on sampling high and low flows to characterize concentration and spatial distribution of nutrients, pesticides, sediment, and other water-quality characteristics. Streambed sediments, aquatic insects, and fish tissue were analyzed for trace elements and organic compounds.



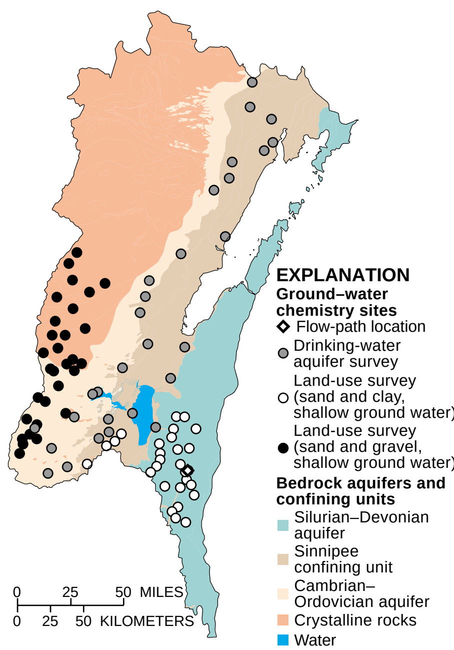


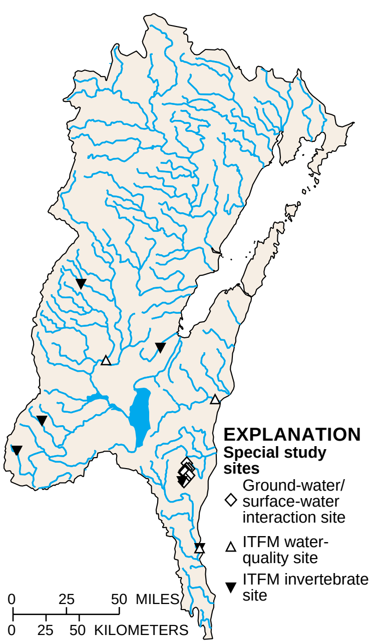
STREAM ECOLOGY

Intensive ecological assessments were done at the 11 Fixed Sites to define existing biological conditions to which future monitoring results will be compared and to assess temporal variations. Synoptic studies were designed to evaluate the spatial distribution of aquatic biological community structure.

GROUND-WATER CHEMISTRY

To evaluate the effects of agricultural land use and surficial deposits on shallow ground-water quality, one aquifer overlain by sand and clay and the other by sand and gravel were studied. A drinking-water aquifer survey assessed the water-quality in the most heavily used aquifer in the Study Unit. A study in an agricultural area was designed to determine changes in nutrient and pesticide concentrations along shallow ground-water *flow paths.*





SPECIAL STUDIES

Additional studies provided important information on the water resources of the study area. The interaction between ground water and surface water was investigated using water-chemistry data. A comparison of water-quality sample collection, preservation, shipping, and laboratory techniques of the USGS and the Wisconsin Department of Natural Resources (WDNR) were studied to determine comparability of water-chemistry results. Differences in macroinvertebrate-collection techniques of three agencies were investigated to evaluate comparability of results.

SUMMARY OF DATA COLLECTION IN THE WESTERN LAKE MICHIGAN DRAINAGES STUDY UNIT, 1992–95

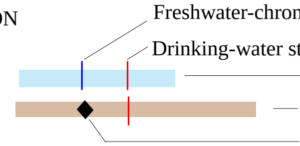
Study component	What data were collected and why	Types of sites sampled	Number of sites	Sampling frequency and period
Stream Chemistry				
Fixed Sites -- general water chemistry	Streamflow was measured continuously and samples were collected monthly for major ions, nutrients, organic carbon, suspended sediment, and physical properties to describe concentration, seasonal variability, and loads.	Streams draining basins ranging in size from 10 to 6,332 square miles and representing forested, agricultural, urban, and mixed land uses.	11	Monthly plus storms; April 1993-July 1995
Intensive Fixed Sites -- pesticides	In addition to the above constituents, samples were analyzed for 88 dissolved pesticides to describe concentration and seasonal variations.	A subset of Fixed Sites draining agricultural and urban land-use areas.	3	Monthly during growing season; 20 per year, 1993-94
Synoptic sites -- water chemistry	Streamflow, nutrients, pesticides, suspended sediments, and physical properties were determined for high- and(or) low-flow conditions to describe concentrations and spatial distributions.	Streams draining basins ranging in size from 2 to 6,332 square miles and representing forested, agricultural, urban, and mixed land uses.	145 total 42 high flow 59 low flow 95 low flow	Spring and summer 1994, summer 1994 July 1995
Contaminants -- streambed sediments	Streambed sediments were analyzed for trace elements and hydrophobic pesticides and other organic compounds to determine occurrence and spatial distribution.	Depositional zones at all Fixed Sites and numerous synoptic sites.	31	6-9 Fixed Sites in 1992(6), 1994(8), 1995(9); 7-12 synoptic sites in 1992(12), 1995(7)
Contaminants -- aquatic biota	Trace elements in fish livers and organic compounds in whole insects and whole fish were sampled and analyzed to determine occurrence and spatial distribution.	All Fixed Sites and some synoptic sites.	25	4-8 Fixed Sites in 1992(4), 1994(8), 1995(7); 6-7 synoptic sites in 1992(7), 1995(6)
Stream Ecology				
Intensive assessments	Fish, benthic invertebrates, algae, and aquatic and riparian habitats were sampled and described to assess aquatic biological community structure in different land uses and associated habitats.	Stream reaches collocated with Fixed Sites. Sites represent the variety of land uses, bedrock geology, and surficial texture within the basin.	11	8 Indicator Sites annually, 1993-95; three reaches sampled at 3 sites; 3 Integrator Sites, 1995
Synoptic studies	Fish, benthic invertebrates, algae, and aquatic and riparian habitats were described to assess spatial distribution of aquatic biological community structure of relatively pristine streams in an agricultural setting.	Benchmark stream reaches chosen to represent relatively pristine conditions in agricultural areas. Comparison sites determine variability within RHUs.	34	20 Benchmark sites, once in spring/summer 1993 and 1995; 12 RHU Comparison sites, 1993
Ground-Water Chemistry				
Land-use effects -- sand and clay -- shallow ground water	Major ions, nutrients, pesticides, volatile organic compounds (VOCs), tritium, dissolved organic carbon (DOC), chlorofluorocarbons (CFCs) and isotopes of oxygen, hydrogen, and uranium were sampled and analyzed for to determine effects of agriculture on the quality of recently recharged ground water in the alluvial aquifer.	Newly installed monitoring wells completed at water table located using a statistically random selection process. Predominantly agricultural land use (80%): corn and alfalfa are the main crops.	26 wells, 2 springs	Once in September 1993 and summer 1994
Land-use effects -- sand and gravel -- shallow ground water	Major ions, nutrients, pesticides, VOCs, tritium, DOC, CFCs, and isotopes of oxygen, hydrogen, and uranium were sampled and analyzed for to determine effects of agriculture on the quality of recently recharged ground water in the alluvial aquifer.	Sites with monitoring wells completed at water table chosen using a statistically random selection process. Predominantly agricultural land use (48%): corn and alfalfa are the main crops.	30	Once in September 1994
Drinking-water survey -- sandstone	Major ions, nutrients, pesticides, VOCs, radon, tritium, and DOC were sampled and analyzed for to assess the condition of ground-water quality in the most used aquifer in the study area (40% of ground-water use).	Existing domestic, institutional, or public supply wells completed in bedrock (<900 ft.) chosen using a statistically random selection process.	29	Once in June and August 1995
Flow path	Major ions, nutrients, pesticides, tritium, DOC, CFCs and isotopes of oxygen, hydrogen, and nitrogen and gas composition were sampled and analyzed to determine changes in nutrients and pesticides along a flow path.	Clusters of wells, lysimeters, and minipiezometers along an approximate line of a ground-water flow path (2,500 ft) in an agricultural area in Sheboygan County.	10 wells, 8 lysimeters, 8 minipiezometers, stream	1-3 times each in June 1994, May 1995, and August 1995
Special Studies				
Ground-water/ surface-water interactions	Major ions, nutrients, pesticides, and oxygen and hydrogen isotopes were analyzed to study ground-water/surface-water interaction in the vicinity of the flowpath study area.	Tributaries to North Branch Milwaukee River and shallow ground- water samples from three cross sections from the North Branch Milwaukee River.	10 tributaries, 12 minipiezometers	Once in August 1993
ITFM --water quality	Total phosphorus, dissolved chloride, and suspended sediment were determined to compare water-quality collection, preservation, shipping, and laboratory techniques used by the USGS and WDNR.	Rivers under low-flow and high-flow conditions.	3	August 1993-July 1994; 4 times each (2 low flow and 2 high flow)
ITFM --Benthic invertebrates	Benthic-invertebrate community structure in riffles was assessed to determine if various sampling methods predict water quality similarly.	Streams ranging in drainage area from 15 to 696 square miles, from cold to warm water, draining different land uses.	6	Once in May 1995

SUMMARY OF COMPOUND DETECTIONS AND CONCENTRATIONS

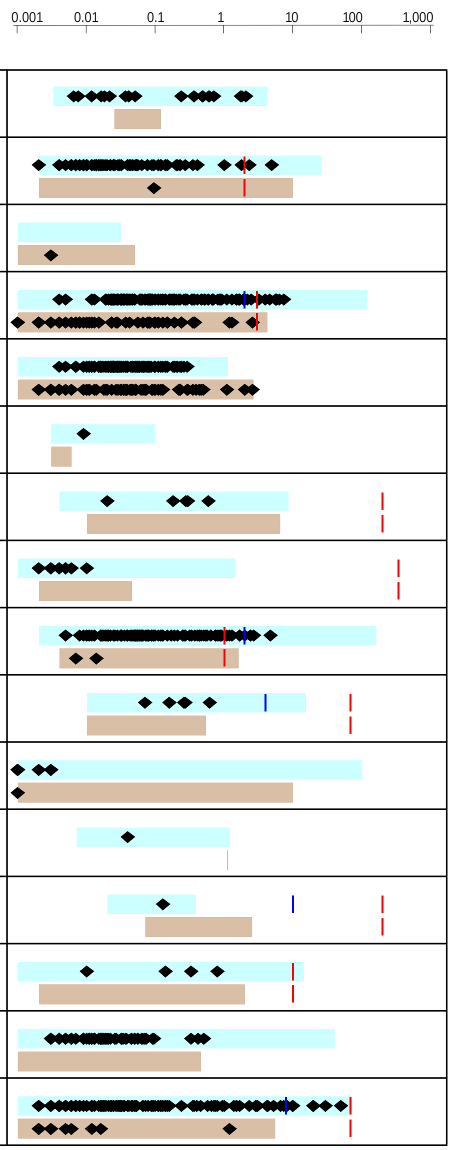
The following tables summarize data collected for NAWQA studies from 1992–1995 by showing results for the Western Lake Michigan Drainages Study Unit compared to the NAWQA national range for each compound detected. The data were collected at a wide variety of places and times. In order to represent the wide concentration ranges observed among Study Units, logarithmic scales are used to emphasize the general magnitude of concentrations (such as 10, 100, or 1,000), rather than the precise number. The complete dataset used to construct these tables is available upon request.

Concentrations of herbicides, insecticides, volatile organic compounds, and nutrients detected in ground and surface waters of the Western Lake Michigan Drainages Study Unit. [mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; %, percent; <, less than; - -, not measured; trade names may vary]

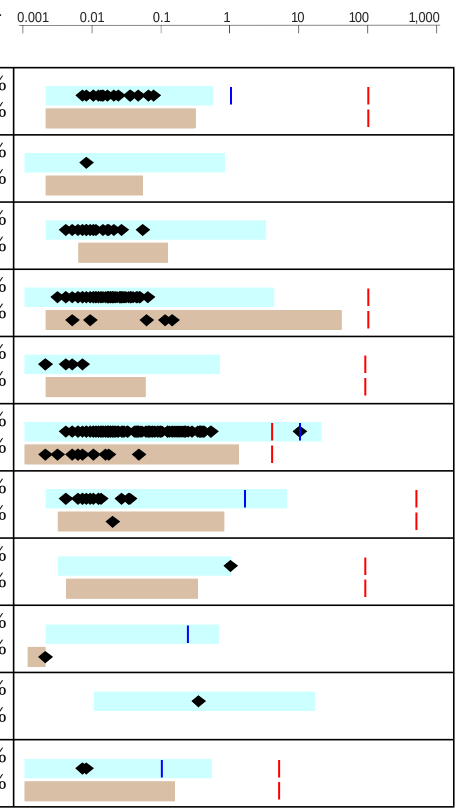
EXPLANATION



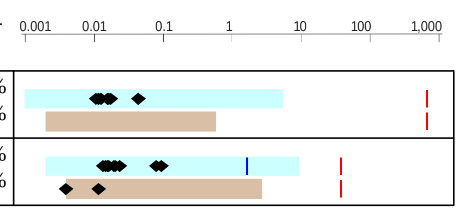
Herbicide (Trade or common name)	Rate of detection [b]	Concentration, in µg/L
Acetochlor	27% 0%	
Alachlor (Lasso)	46% 1%	
2,6-Diethylaniline (Alachlor metabolite)	0% <1%	
Atrazine (AAtrex, Gesaprim)	99% 34%	
Desethylatrazine[c] (Atrazine metabolite)	92% 47%	
Benfluralin (Balan, Benefin, Bonalan)	<1% 0%	
Bentazon (Basagran, bentazone)	4% 0%	
Butylate (Sutan, Genate Plus, butilate)	1% 0%	
Cyanazine (Bladex, Fortrol)	76% 1%	
2,4-D (2,4-PA)	4% 0%	
DCPA (Dacthal, chlorthal-dimethyl)	<1% <1%	
Dacthal, mono-acid (Dacthal metabolite)	1% 0%	
Dicamba (Banvel, Mediben, MDBA)	1% 0%	
Diuron (Karmex, Direx, DCMU)	3% 0%	
EPTC (Eptam)	34% 0%	
Metolachlor (Dual, Pennant)	65% 3%	



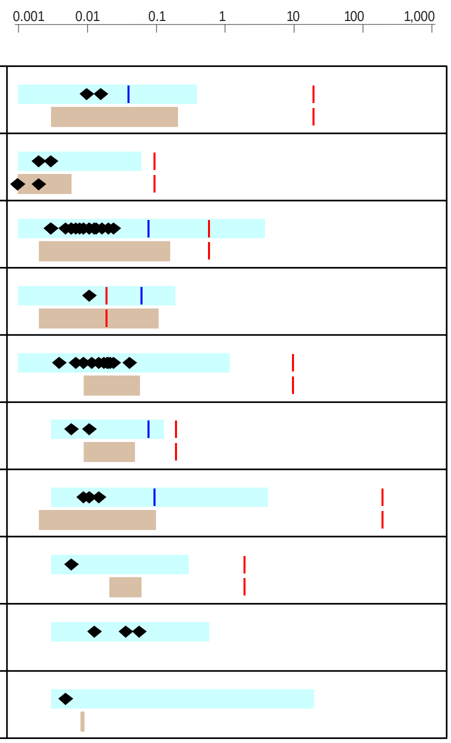
Herbicide (Trade or common name)	Rate of detection [b]	Concentration, in µg/L
Metribuzin (Lexone, Sencor)	9% 0%	
Pebulate (Tillam)	<1% 0%	
Pendimethalin (Prowl, Stomp)	5% 0%	
Prometon (Gesagram, prometone)	46% 4%	
Propachlor (Ramrod, propachlore)	<1% 0%	
Simazine (Aquazine, Princep, GEsatop)	82% 4%	
Tebuthiuron (Spike, Perflan)	5% 1%	
Terbacil[c] (Sinbar)	1% 0%	
Triallate (Far-Go)	0% <1%	
Triclopyr (Garlon, Grazon, Crossbow)	1% 0%	
Trifluralin (Treflan, Trinin, Elancolan)	<1% 0%	



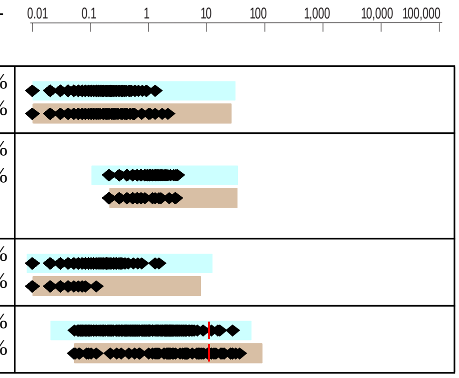
Insecticide (Trade or common name)	Rate of detection [b]	Concentration, in µg/L
Carbaryl[c] (Sevin, Savit)	7% 0%	
Carbofuran[c] (Furadan, Curaterr)	6% 1%	



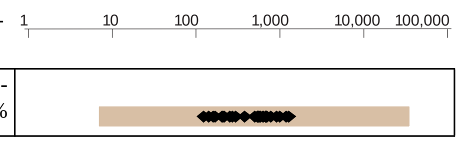
Insecticide (Trade or common name)	Rate of detection [b]	Concentration, in µg/L
Chlorpyrifos (Dursban, Lorsban)	1% 0%	
p,p'-DDE (*p,p'*-DDT metabolite)	<1% <1%	
Diazinon	5% 0%	
Dieldrin (Panoram D-31, Octalox)	1% 0%	
Fonofos (Dyfonate)	5% 0%	
gamma-HCH	1% 0%	
Malathion (maldison, malathon, Cythion)	2% 0%	
Methyl parathion (Penncap-M)	<1% 0%	
Phorate (Thimet, Rampart)	2% 0%	
Propargite (Comite, Omite, BPPS)	<1% 0%	



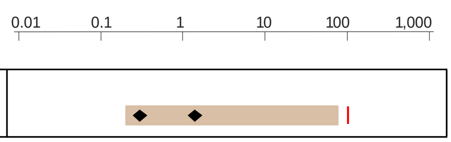
Nutrient (Trade or common name)	Rate of detection [b]	Concentration, in mg/L
Dissolved ammonia	92% 86%	
Dissolved ammonia plus organic nitrogen as nitrogen	95% 45%	
Dissolved phosphorus as phosphorus	80% 48%	
Dissolved nitrite plus nitrate	86% 56%	



Other	Rate of detection [b]	Concentration, in pCi/L
Radon 222	-- 100%	



Volatile organic compound (Trade or common name)	Rate of detection [b]	Concentration, in µg/L
total Trihalomethanes	-- 2%	



SUMMARY OF COMPOUND DETECTIONS AND CONCENTRATIONS

Herbicides, insecticides, volatile organic compounds, and nutrients not detected in ground and surface waters of the Western Lake Michigan Drainages Study Unit.

Herbicides

2,4,5-T

2,4,5-TP (Silvex, Fenoprop)

2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone)

Acifluorfen (Blazer, Tackle 2S)

Bromacil (Hyvar X, Urox B, Bromax)

Bromoxynil (Buctril, Brominal)

Chloramben (Amiben, Amilon-WP, Vegiben)

Clopyralid (Stinger, Lontrel, Reclaim, Transline)

Dichlorprop (2,4-DP, Seritox 50, Kildip, Lentemul)

Dinoseb (Dinosebe)

Ethalfluralin (Sonalan, Curbit)

Fenuron (Fenulon, Fenidim)

Fluometuron (Flo-Met, Cotoran, Cottonex, Meturon)

Linuron (Lorox, Linex, Sarclex, Linurex, Afalon)

MCPA (Rhomene, Rhonox, Chiptox)

MCPB (Thistrol)

Molinate (Ordram)

Napropamide (Devrinol)

Neburon (Neburea, Neburyl, Noruben)

Norflurazon (Evital, Predict, Solicam, Zorial)

Oryzalin (Surflan, Dirimal)

Picloram (Grazon, Tordon)

Pronamide (Kerb, Propyzamid)

Propanil (Stam, Stampede, Wham, Surcopur, Prop-Job)

Propham (Tuberite)

Thiobencarb (Bolero, Saturn, Benthiocarb, Abolish)

Insecticides

3-Hydroxycarbofuran (Carbofuran metabolite)

Aldicarb sulfone (Standak, aldoxycarb, aldicarb metabolite)

Aldicarb sulfoxide (Aldicarb metabolite)

Aldicarb (Temik, Ambush, Pounce)

Azinphos-methyl (Guthion, Gusathion M)

Disulfoton (Disyston, Di-Syston, Frumin AL, Solvirex, Ethylthiodemeton)

Ethoprop (Mocap, Ethoprophos)

alpha-HCH (*alpha*-BHC, *alpha*-lindane, *alpha*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

Methiocarb (Slug-Geta, Grandslam, Mesurol)

Methomyl (Lanox, Lannate, Acinate)

Oxamyl (Vydate L, Pratt)

Parathion (Roethyl-P, Alkron, Panthion, Phoskil)

cis-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

Propoxur (Baygon, Blattanex, Unden, Proprotox)

Terbufos (Contraven, Counter, Pilarfox)

Volatile organic compounds

1,1,1,2-Tetrachloroethane (1,1,1,2-TeCA)

1,1,1-Trichloroethane (Methylchloroform)

1,1,2,2-Tetrachloroethane

1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113, CFC 113)

1,1,2-Trichloroethane (Vinyl trichloride)

1,1-Dichloroethane (Ethylidene dichloride)

1,1-Dichloroethene (Vinylidene chloride)

1,1-Dichloropropene

1,2,3-Trichlorobenzene (1,2,3-TCB)

1,2,3-Trichloropropane (Allyl trichloride)

1,2,4-Trichlorobenzene

1,2,4-Trimethylbenzene (Pseudocumene)

1,2-Dibromo-3-chloropropane (DBCP, Nemagon)

1,2-Dibromoethane (EDB, Ethylene dibromide)

1,2-Dichlorobenzene (*o*-Dichlorobenzene, 1,2-DCB)

1,2-Dichloroethane (Ethylene dichloride)

1,2-Dichloropropane (Propylene dichloride)

1,3,5-Trimethylbenzene (Mesitylene)

1,3-Dichlorobenzene (*m*-Dichlorobenzene)

1,3-Dichloropropane (Trimethylene dichloride)

1,4-Dichlorobenzene (*p*-Dichlorobenzene, 1,4-DCB)

1-Chloro-2-methylbenzene (*o*-Chlorotoluene)

1-Chloro-4-methylbenzene (*p*-Chlorotoluene)

2,2-Dichloropropane

Benzene

Bromobenzene (Phenyl bromide)

Bromochloromethane (Methylene chlorobromide)

Bromomethane (Methyl bromide)

Chlorobenzene (Monochlorobenzene)

Chloroethane (Ethyl chloride)

Chloroethene (Vinyl chloride)

Chloromethane (Methyl chloride)

Dibromomethane (Methylene dibromide)

Dichlorodifluoromethane (CFC 12, Freon 12)

Dichloromethane (Methylene chloride)

Dimethylbenzenes (Xylenes (total))

Ethenylbenzene (Styrene)

Ethylbenzene (Phenylethane)

Hexachlorobutadiene

Isopropylbenzene (Cumene)

Methyl *tert*-butyl ether[d] (MTBE)

Methylbenzene (Toluene)

Naphthalene

Tetrachloroethene (Perchloroethene)

Tetrachloromethane (Carbon tetrachloride)

Trichloroethene (TCE)

Trichlorofluoromethane (CFC 11, Freon 11)

cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)

cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)

n-Butylbenzene (1-Phenylbutane)

n-Propylbenzene (Isocumene)

p-Isopropyltoluene (*p*-Cymene)

sec-Butylbenzene

tert-Butylbenzene

trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)

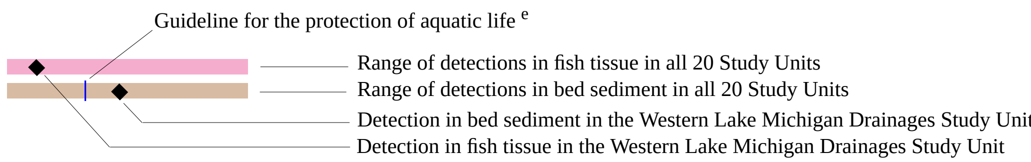
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)

Nutrients

No non-detects

Concentrations of semivolatile organic compounds, organochlorine compounds, and trace elements detected in fish tissue and bed sediment of the Western Lake Michigan Drainages Study Unit. [µg/g, micrograms per gram; µg/kg, micrograms per kilogram; %, percent; <, less than; - -, not measured; trade names may vary]

EXPLANATION

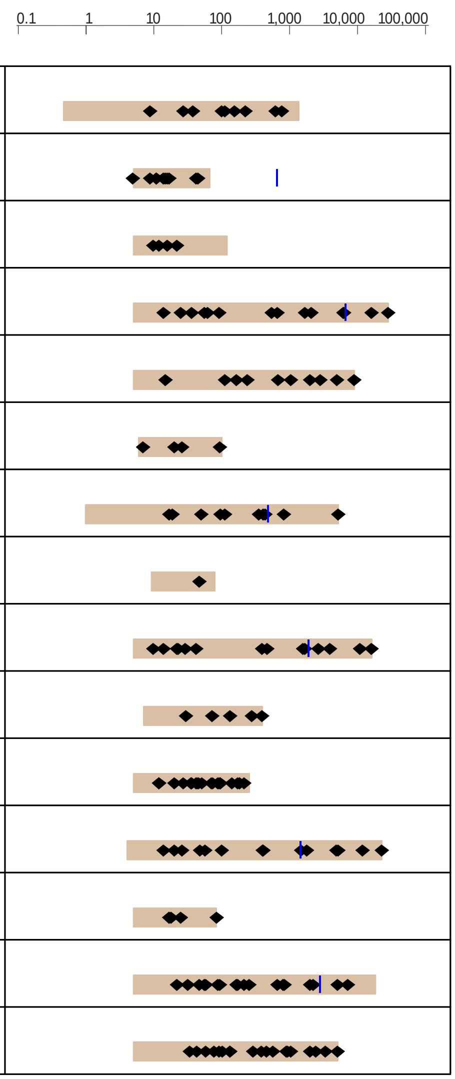


Semivolatile organic compound	Rate of detection [b]	Concentration, in µg/kg (0.1, 1, 10, 100, 1,000, 10,000, 100,000)
1,2,4-Trichlorobenzene	-- 4%	
1,2-Dichlorobenzene	-- 17%	
1,2-Dimethylnaphthalene	-- 33%	
1,4-Dichlorobenzene	-- 21%	
1,6-Dimethylnaphthalene	-- 42%	
1-Methyl-9H-fluorene	-- 25%	
1-Methylphenanthrene	-- 38%	
1-Methylpyrene	-- 38%	
2,2-Biquinoline	-- 4%	
2,3,6-Trimethylnaphthalene	-- 38%	
2,6-Dimethylnaphthalene	-- 62%	
2,6-Dinitrotoluene	-- 4%	
2-Ethylnaphthalene	-- 29%	
2-Methylanthracene	-- 29%	
4,5-Methylenephenanthrene	-- 29%	
4-Chloro-3-methylphenol	-- 4%	
9H-Carbazole	-- 33%	

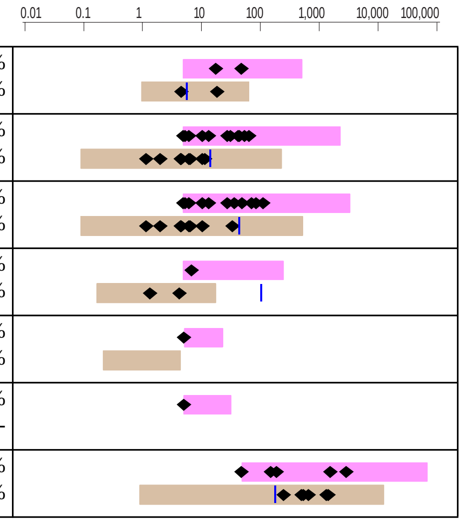
Semivolatile organic compound	Rate of detection [b]	Concentration, in µg/kg (0.1, 1, 10, 100, 1,000, 10,000, 100,000)
9H-Fluorene	-- 42%	
Acenaphthene	-- 38%	
Acenaphthylene	-- 42%	
Acridine	-- 21%	
Anthracene	-- 54%	
Anthraquinone	-- 29%	
Benz[*a*]anthracene	-- 50%	
Benzo[*a*]pyrene	-- 50%	
Benzo[*b*]fluoranthene	-- 54%	
Benzo[*ghi*]perylene	-- 46%	
Benzo[*k*]fluoranthene	-- 50%	
Butylbenzylphthalate	-- 38%	
C8-Alkylphenol	-- 13%	
Chrysene	-- 50%	
Di- *n* -butylphthalate	-- 75%	
Di- *n* -octylphthalate	-- 13%	
Dibenz[*a,h*]anthracene	-- 29%	

SUMMARY OF COMPOUND DETECTIONS AND CONCENTRATIONS

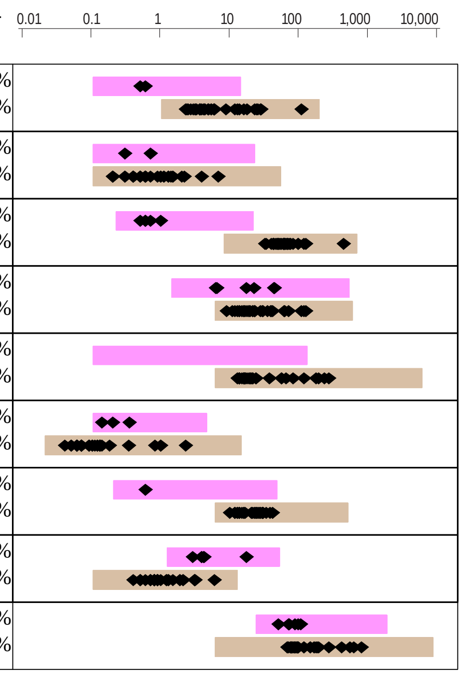
Semivolatile organic compound	Rate of detection [b]
Dibenzothiophene	-- 38%
Diethylphthalate	-- 42%
Dimethylphthalate	-- 17%
Fluoranthene	-- 58%
Indeno[1,2,3- *cd*] pyrene	-- 42%
Isoquinoline	-- 17%
Naphthalene	-- 42%
N-Nitrosodi-phenylamine	-- 4%
Phenanthrene	-- 58%
Phenanthridine	-- 21%
Phenol	-- 92%
Pyrene	-- 58%
Quinoline	-- 21%
bis(2-Ethyl-hexyl)phthalate	-- 75%
p-Cresol	-- 79%



Organochlorine compound (Trade name)	Rate of detection [b]
total-Chlordane	11% 8%
p,p'-DDE	61% 33%
total-DDT	61% 33%
Dieldrin (Panoram D-31, Octalox)	6% 8%
Heptachlor epoxide	6% 0%
Hexachlorobenzene	6% --
PCB, total	28% 25%



Trace element	Rate of detection [b]
Arsenic	33% 100%
Cadmium	33% 97%
Chromium	83% 100%
Copper	100% 97%
Lead	0% 100%
Mercury	50% 88%
Nickel	17% 100%
Selenium	100% 100%
Zinc	100% 100%



Semivolatile organic compounds, organochlorine compounds, and trace elements not detected in fish tissue and bed sediment of the Western Lake Michigan Drainages Study Unit.

Semivolatile organic compounds

1,3-Dichlorobenzene (*m*-Dichlorobenzene)

2,4-Dinitrotoluene

2-Chloronaphthalene

2-Chlorophenol

3,5-Dimethylphenol

4-Bromophenyl-phenylether

4-Chlorophenyl-phenylether

Azobenzene

Benzo [*c*] cinnoline

Isophorone

N-Nitrosodi-n-propylamine

Nitrobenzene

Pentachloronitrobenzene

bis (2-Chloroethoxy)methane

Organochlorine compounds

Aldrin (HHDN, Octalene)

Chloroneb (chloronebe, Demosan, Soil Fungicide 1823)

DCPA (Dacthal, chlorthal-dimethyl)

Endosulfan I (*alpha*-Endosulfan, Thiodan, Cyclodan, Beosit, Malix, Thimul, Thifor)

Endrin (Endrine)

Heptachlor (Heptachlore, Velsicol 104)

Isodrin (Isodrine, Compound 711)

Mirex (Dechlorane)

Pentachloroanisole (PCA, pentachlorophenol metabolite)

Toxaphene (Camphechlor, Hercules 3956)

alpha-HCH (*alpha*-BHC, *alpha*-lindane, *alpha*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

beta-HCH (*beta*-BHC, *beta*-hexachlorocyclohexane, *alpha*-benzene hexachloride)

cis-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

delta-HCH (*delta*-BHC, *delta*-hexachlorocyclohexane, *delta*-benzene hexachloride)

gamma-HCH (Lindane, *gamma*-BHC, Gammexane, Gexane, Soprocide, *gamma*-benzene hexachloride, *gamma*-hexachlorocyclohexane, *gamma*-benzene)

o,p'-Methoxychlor

p,p'-Methoxychlor (Marlate, methoxychlore)

trans-Permethrin (Ambush, Astro, Pounce, Pramex, Pertox, Ambushfog, Kafil, Perthrine, Picket, Picket G, Dragnet, Talcord, Outflank, Stockade, Eksmin, Coopex, Peregin, Stomoxin, Stomoxin P, Qamlin, Corsair, Tornade)

Trace elements

No non-detects

[a] Selected water-quality standards and guidelines (Gilliom and others, in press).

[b] Rates of detection are based on the number of analyses and detections in the Study Unit, not on national data. Rates of detection for herbicides and insecticides were computed by only counting detections equal to or greater than 0.01 µg/L in order to facilitate equal comparisons among compounds, which had widely varying detection limits. For herbicides and insecticides, a detection rate of "<1%" means that all detections are less than 0.01 µg/L, or the detection rate rounds to less than 1 percent. For other compound groups, all detections were counted and minimum detection limits for most compounds were similar to the lower end of the national ranges shown. Method detection limits for all compounds in these tables are summarized in (Gilliom and others, in press).

[c] Detections of these compounds are reliable, but concentrations are determined with greater uncertainty than for the other compounds and are reported as estimated values (Zaugg and others, 1995).

[d] The guideline for methyl *tert*-butyl ether is between 20 and 40 µg/L; if the tentative cancer classification C is accepted, the lifetime health advisory will be 20 µg/L (Gilliom and others, in press).

[e] Selected sediment-quality guidelines (Gilliom and others, in press).

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The terms in this glossary were compiled from numerous sources. Some definitions have been modified and may not be the only valid ones for these terms.

Alluvial aquifer - A water-bearing deposit of unconsolidated material (sand and gravel) left behind by a river or other flowing water.

Anthropogenic - Occurring because of, or influenced by, human activity.

Aquatic-life criteria - Water-quality guidelines for protection of aquatic life. Often refers to U.S. Environmental Protection Agency water-quality criteria for protection of aquatic organisms. *See also* Water-quality guidelines and Water-quality criteria.

Aquifer - A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

Atmospheric deposition - The transfer of substances from the air to the surface of the Earth, either in wet form (rain, fog, snow, dew, frost, hail) or in dry form (gases, aerosols, particles).

Base flow - Sustained, low flow in a stream; ground-water discharge is the source of base flow in most places.

Basin - *See* Drainage basin.

Bedrock - General term for consolidated (solid) rock that underlies soils or other unconsolidated material.

Bed sediment - The material that temporarily is stationary in the bottom of a stream or other watercourse.

Bed sediment and tissue studies - Assessment of concentrations and distributions of trace elements and hydrophobic organic contaminants in streambed sediment and tissues of aquatic organisms to identify potential sources and to assess spatial distribution.

Benchmark streams - Sites selected to represent standards of reference for comparison to other streams in similar physical settings.

Benthic - Refers to plants or animals that live on the bottom of lakes, streams, or oceans.

Cattle may destroy habitat and increase nutrient concentrations in streams.

Benthic invertebrates - Insects, mollusks, crustaceans, worms, and other organisms without a backbone that live in, on, or near the bottom of lakes, streams, or oceans.

Bioaccumulation - The biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment or medium. Also, the process whereby a substance enters organisms through the gills, epithelial tissues, dietary, or other sources.

Bioavailability - The capacity of a chemical constituent to be taken up by living organisms either through physical contact or by ingestion.

Biota - Living organisms.

Blue-baby syndrome - A condition that can be caused by ingestion of high amounts of nitrate resulting in the blood losing its ability to effectively carry oxygen. It is most common in young infants and certain elderly people.

Carbonate rocks - Rocks (such as limestone or dolostone) that are composed primarily of minerals (such as calcite and dolomite) containing the carbonate ion (CO_3^{-2}).

Climate - The sum total of the meteorological elements that characterize the average and extreme conditions of the atmosphere over a long period of time at any one place or region of the Earth's surface.

Community - In ecology, the species that interact in a common area.

Concentration - The amount or mass of a substance present in a given volume or mass of sample. Usually expressed as micrograms per liter (water sample) or micrograms per kilogram (sediment or tissue sample).

Confined aquifer (artesian aquifer) - An aquifer that is completely filled with water under pressure and that is overlain by material that restricts the movement of water.

Confining layer - A layer of sediment or lithologic unit of low permeability that bounds an aquifer.

Constituent - A chemical or biological substance in water, sediment, or biota that can be measured by an analytical method.

Contamination - Degradation of water quality compared to original or natural conditions due to human activity.

Criterion - A standard rule or test on which a judgment or decision can be based.

Cubic foot per second (ft^3/s, or cfs) - Rate of water discharge representing a volume of 1 cubic foot passing a given point during 1 second, equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meter per second.

Degradation products - Compounds resulting from transformation of an organic substance through chemical, photochemical, and/or biochemical reactions.

DDT - Dichloro-diphenyl-trichloroethane. An organochlorine insecticide no longer registered for use in the United States.

Discharge - Rate of fluid flow passing a given point at a given moment in time, expressed as volume per unit of time.

Dissolved constituent - Operationally defined as a constituent that passes through a 0.45-micrometer filter.

Dissolved solids - Amount of minerals, such as salt, that are dissolved in water; amount of dissolved solids is an indicator of salinity or hardness.

Drainage basin - The portion of the surface of the Earth that contributes water to a stream through overland runoff, including tributaries and impoundments.

Drinking-water standard or guideline - A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Ecological studies - Studies of biological communities and habitat characteristics to evaluate the effects of physical and chemical characteristics of water and hydrologic conditions on aquatic biota and to determine how biological and habitat characteristics differ among environmental settings in NAWQA Study Units.

Effects Range Low (ERL) - Concentration below which effects are rarely observed or predicted among sensitive life stages and (or) species of biota for Sediment Effect Concentrations used to evaluate sediment concentrations of trace elements and synthetic organic compounds.

Effects Range Median (ERM) - Concentration above which effects are frequently or always observed among most species of biota for Sediment Effect Concentrations used to evaluate sediment concentrations of trace elements and synthetic organic compounds.

Environmental setting - Land area characterized by a unique combination of natural and human-related factors, such as row-crop cultivation or glacial-till soils.

Equal-width increment (EWI) sample - A composite sample across a section of stream with equal spacing between verticals and equal transit rates within each vertical that yields a representative sample of stream conditions.

Eutrophication - The process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Fertilizer - Any of a large number of natural or synthetic materials, including manure and nitrogen, phosphorus, and potassium compounds, spread on or worked into soil to increase its fertility.

Fish community - *See* Community.

Fixed Sites - Sites on streams at which streamflow is measured and samples are collected for temperature, salinity, suspended sediment, major ions and metals, nutrients, and organic carbon to assess the broad-scale spatial and temporal character and transport of inorganic constituents of streamwater in relation to hydrologic conditions and environmental settings. *See also* Intensive Fixed Sites.

Flow path - An underground route for ground-water movement, extending from a recharge (intake) zone to a discharge (output) zone such as a shallow stream.

Flow path study - Network of clustered wells located along a flowpath extending from a recharge zone to a discharge zone, preferably a shallow stream. The studies examine the relations of land-use practices, ground-water flow, and contaminant occurrence and transport. These studies are located in the area of one of the land-use studies.

Glacial till - An unsorted deposit of a wide range of grain sizes directly related to a glacier.

Grab sample - A sample collected from one to three points in a stream using a Van Dorn sampler.

Ground water - In general, any water that exists beneath the land surface, but more commonly applied to water in fully saturated soils and geologic formations.

Habitat - The part of the physical environment where plants and animals live.

Herbicide - A chemical or other agent applied for the purpose of killing undesirable plants. *See also* Pesticide.

Indexes of biological integrity were calculated for fish, algae, invertebrates and habitat at 28 sites in the study area.

Indicator Sites - Stream sampling sites located at outlets of drainage basins with relatively homogeneous land use and physiographic conditions; most Indicator-Site basins have drainage areas ranging from 20 to 200 square miles.

Integrator or Mixed-Use Site - Stream sampling site located at an outlet of a drainage basin that contains multiple environmental settings. Most Integrator Sites are on major streams with relatively large drainage areas.

Intensive Fixed Sites - Fixed Sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides for 1 year. Most NAWQA Study Units have one to two Integrator Intensive Fixed Sites and one to four Indicator Intensive Fixed Sites.

Land-use Study - A network of shallow wells in an area having a relatively uniform land use. These studies are to be as a subset of the Study-Unit Survey and have the goal of relating the quality of shallow ground water to land use. *See also* Study-Unit Survey.

Lowest Effect Level (LEL) - Concentration that 95% of the benthic biota can tolerate as part of the Ontario Ministry of Environment and Energy's established guidelines for evaluating sediment concentration of trace elements and synthetic organic compounds as based on freshwater biota.

Major ions - Constituents commonly present in concentrations exceeding 1.0 milligram per liter. Dissolved cations generally are calcium, magnesium, sodium, and potassium; the major anions are sulfate, chloride, fluoride, nitrate, and those contributing to alkalinity, most generally assumed to be bicarbonate and carbonate.

Maximum contaminant level (MCL) - Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Median - The middle or central value in a distribution of data ranked in order of magnitude. The median is also known as the 50th percentile.

Metabolite - A substance produced in or by biological processes.

Micrograms per liter (µg/L) - A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most stream water and ground water. One thousand micrograms per liter equals 1 mg/L.

Milligrams per liter (mg/L) - A unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; equivalent to one part per million in most streamwater and ground water. One thousand micrograms per liter equals 1 mg/L.

Monitoring - Repeated observation or sampling at a site, on a scheduled or event basis, for a particular purpose.

Monitoring well - A well designed for measuring water levels and testing ground-water quality.

Nitrate - An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

Nutrient - Element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Organochlorine compound - Synthetic organic compounds containing chlorine. As generally used, term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

Permeable - The ability to allow fluids or gases to move through material such as ground water moving through a porous aquifer.

Pesticide - A chemical applied to crops, rights of way, lawns, or residences to control weeds, insects, fungi, nematodes, rodents or other "pests."

Phosphorus - A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Picocurie (pCi) - One trillionth (10^{-12}) of the amount of radioactivity represented by a curie (Ci). A curie is the amount of radioactivity that yields 3.7×10^{10} radioactive disintegrations per second (dps). A picocurie yields 2.22 disintegrations per minute (dpm) or 0.037 dps.

Point source - A source at a discrete location such as a discharge pipe, drainage ditch, tunnel, well, concentrated livestock operation, or floating craft.

Pollutant - Any substance that, when present in a hydrologic system at sufficient concentration, degrades water quality in ways that are or could become harmful to human and(or) ecological health or that impair the use of water for recreation, agriculture, industry, commerce, or domestic purposes.

Polychlorinated biphenyl (PCB) - A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Precipitation - Any or all forms of water particles that fall from the atmosphere, such as rain, snow, hail, and sleet.

Radon - A naturally occurring, colorless, odorless, radioactive gas formed by the disintegration of the element radium; damaging to human lungs when inhaled.

Recharge - Water that infiltrates the ground and reaches the saturated zone.

Retrospective analysis - Review and analysis of existing data in order to address NAWQA objectives, to the extent possible, and to aid in the design of NAWQA studies.

Riffle - A shallow part of the stream where water flows swiftly over completely or partially submerged obstructions to produce surface agitation.

Runoff - Excess rainwater or snowmelt that is transported to streams by overland flow, tile drains, or ground water.

Secondary Maximum Contaminant Level (SMCL) - The maximum contamination level in public water systems that, in the judgement of the U.S. Environmental Protection Agency (USEPA), are required to protect the public welfare. SMCLs are secondary (nonenforceable) drinking water regulations established by the USEPA for contaminants that may adversely affect the odor or appearance of such water.

Sediment - Particles, derived from rocks or biological materials, that have been transported by a fluid or other natural process, suspended or settled in water.

Semivolatile organic compound (SVOC) - Operationally defined as a group of synthetic organic compounds that are solvent-extractable and can be determined by gas chromatography/mass spectrometry. SVOCs include phenols, phthalates, and polycyclic aromatic hydrocarbons (PAHs).

Severe Effect Level (SEL) - Concentration at which pronounced effects can be expected for the benthic community as part of the Ontario Ministry of Environment and Energy's established guidelines for evaluating sediment concentration of trace elements and synthetic organic compounds as based on freshwater biota.

Streamflow - A type of channel flow, applied to that part of surface runoff in a stream whether or not it is affected by diversion or regulation.

Study Unit - A major hydrologic system of the United States in which NAWQA studies are focused. Study Units are geographically defined by a combination of ground- and surface-water features and generally encompass more than 4,000 square miles of land area.

Logging can increase sediment concentrations and reduce habitat in streams.

Surface water - An open body of water, such as a lake, river, or stream.

Surficial deposits - Material, usually unconsolidated, overlying bedrock. Surficial deposits in the Study Unit are primarily glacial and alluvial related.

Suspended (as used in tables of chemical analyses) - The amount (concentration) of undissolved material in a water-sediment mixture. It is associated with the material retained on a 0.45-micrometer filter.

Tissue study - The assessment of concentrations and distributions of trace elements and certain organic contaminants in tissues of aquatic organisms.

Trace element - An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

Urban Site - A site that has greater than 50 percent urbanized and less than 25 percent agricultural area.

Water-quality criteria - Specific levels of water quality which, if reached, are expected to render a body of water unsuitable for its designated use. Commonly refers to water-quality criteria established by the U.S. Environmental Protection Agency. Water-quality criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.

Water-quality guidelines - Specific levels of water quality which, if reached, may adversely affect human health or aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

Water-quality standards - State-adopted and U.S. Environmental Protection Agency-approved ambient standards for water bodies. Standards include the use of the water body and the water-quality criteria that must be met to protect the designated use or uses.

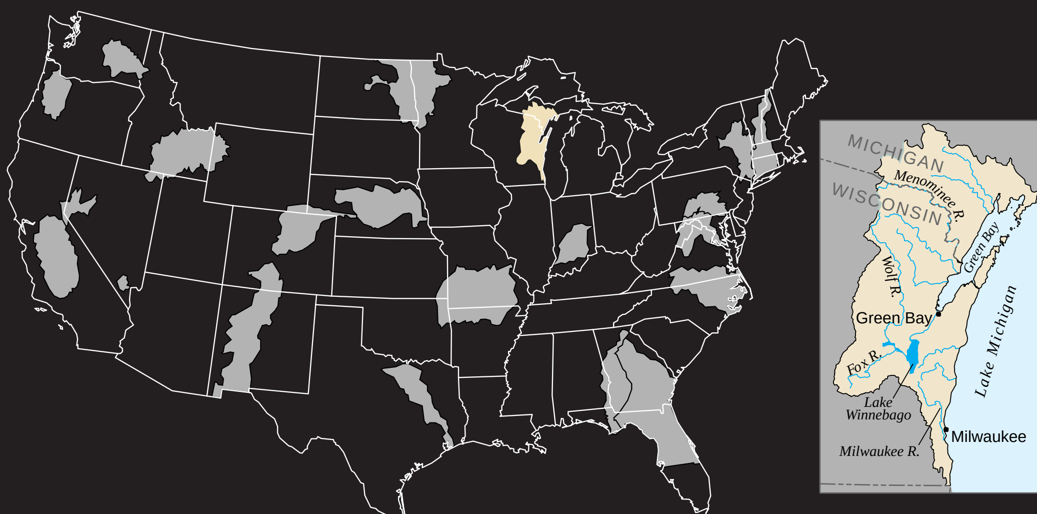
Watershed - *See* Drainage basin.

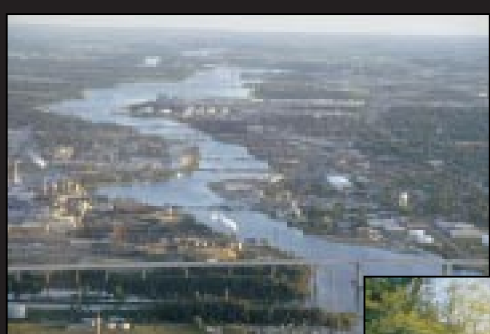
Water table - The point below the land surface where ground water is first encountered and below which the earth is saturated. Depth to the water table varies widely across the country.

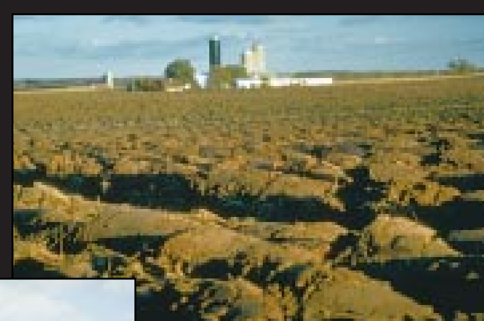
Wetlands - Ecosystems whose soil is saturated for long periods seasonally or continuously including marshes, swamps, and ephemeral ponds.

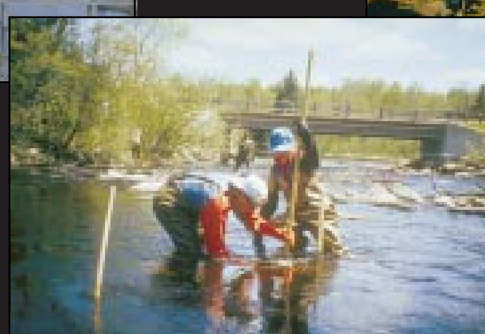
NAWQA

National Water-Quality Assessment (NAWQA) Program
Western Lake Michigan Drainages









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