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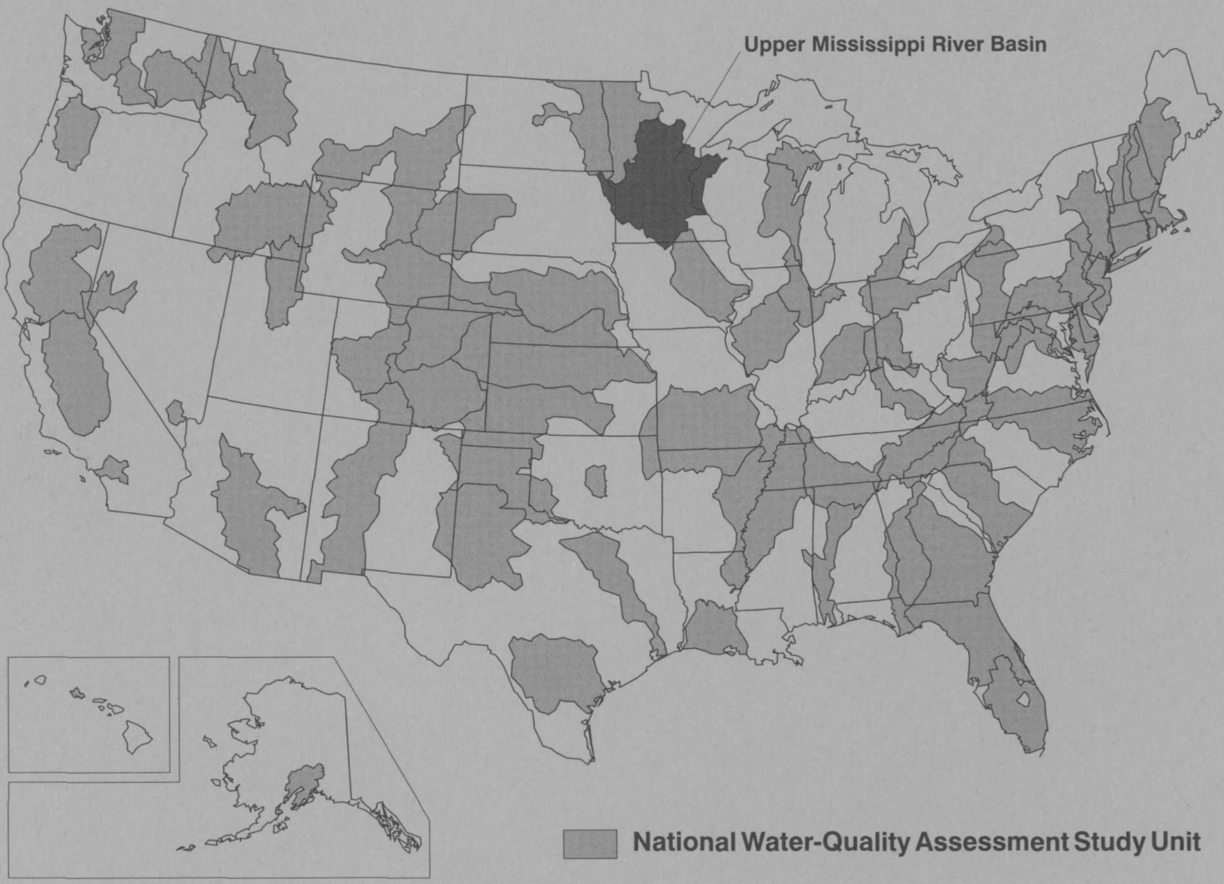
Water-Quality Assessment of the Upper Mississippi River Basin, Minnesota and Wisconsin—Polychlorinated Biphenyls in Common Carp and Walleye Fillets, 1975-95

Water-Resources Investigations Report 98-4126



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Water Quality Assessment of the Upper Mississippi River Basin, Minnesota and Wisconsin—Polychlorinated Biphenyls in Common Carp and Walleye Fillets, 1975-95

By Kathy E. Lee and Jesse P. Anderson

Water-Resources Investigations Report 98-4126

U.S. Department of the Interior

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Mounds View, Minnesota, 1998

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Conversion Factors, Abbreviated Water Quality Units, and Abbreviations

Multiply	By	To Obtain
gallon per day (gal/d)	3.785	liter per day
square miles (mi^2)	2.590	square kilometers
million gallons/day (Mgal/d)	1.547	cubic foot per second (ft^3/s)
degree Fahrenheit (°F)	(temperature °F -32)/1.8	degree Celsius (°C)
inches (in.)	2.54	centimeter

Polychlorinated biphenyl (PCB) concentrations in fish fillet tissue are given in units of milligrams per kilogram (mg/kg). Mg/kg is a unit expressing the concentration of PCBs in a ratio of one mg of PCBs to 1 kg of tissue. Mg/kg is equivalent to parts per million (ppm).

Abbreviations used in this report:

BEST	Biomonitoring of Environmental Status and Trends
LD	Lock and dam
LNPCB	Lipid normalized polychlorinated biphenyl
MCES	Metropolitan Council, Environmental Services
MCL	Maximum contaminant level
MDH	Minnesota Department of Health
MDNR	Minnesota Department of Natural Resources
MFCMP	Minnesota Fish Contaminant Monitoring Program
MN	Minnesota River
MPCA	Minnesota Pollution Control Agency
NAWQA	National Water Quality Assessment Program
NCBP	National Contaminant Biomonitoring Program
PCB	Polychlorinated biphenyl
SC	St. Croix River
TCMA	Twin Cities metropolitan area
UMIS	Upper Mississippi River Basin
UMR	Upper Mississippi River
USFDA	Food and Drug Administration
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources

Water-Quality Assessment of the Upper Mississippi River Basin, Minnesota and Wisconsin—Polychlorinated Biphenyls in Common Carp and Walleye Fillets, 1975-95

By Kathy E. Lee and Jesse P. Anderson

Abstract

Spatial and temporal distribution of polychlorinated biphenyls (PCBs) in common carp (*Cyprinus carpio*) and walleye (*Stizostedion vitreum*) fillets from rivers in the Upper Mississippi River Basin upstream of the outlet of Lake Pepin are summarized. PCB concentrations in common carp and walleye fillets collected from rivers in the UMIS during 1975-95 by the Minnesota Fish Contaminant Monitoring Program (MFCMP) and the Wisconsin Department of Natural Resources (WDNR) were analyzed. PCBs in fish tissue are of concern because PCBs are potentially toxic, teratogenic, and are linked to poor fetal development and endocrine disruption in fish and other animals including humans, that consume fish. This summary was part of an analysis of historical data for the Upper Mississippi River (UMIS) study unit of the National Water-Quality Assessment (NAWQA) Program. The UMIS study unit is a 47,000 square-mile basin that includes the drainage of the Mississippi River upstream of the outlet of Lake Pepin and encompasses the Twin Cities metropolitan area. PCB concentrations for individual samples at all sites ranged from 0.07 to 33.0 milligrams per kilograms (mg/kg) for common carp and from 0.07 to 9.8 mg/kg for walleye during 1975-95. During 1975-79 and 1980-87, 10 and 4 percent of walleye samples and 45 and 36 percent of common carp samples, respectively, exceeded the U.S. Food and Drug Administration guideline of 2 mg/kg PCB in fish tissue. PCB concentrations in individual common carp and walleye samples were below 2 mg/kg after 1987. Median PCB concentrations at individual sites and within stream segments were generally greatest in common carp and walleye from Mississippi River segments in the TCMA during 1975-79 and 1980-87. There was a significant difference among lipid-normalized PCB (LNPCB) concentrations in common carp, considering all stream segments combined, during all three time periods (1975-79, 1980-87, and 1988-95). LNPCB concentrations in common carp and walleye at those stream segments upstream or outside the TCMA were generally lower than those in UMR segments within the TCMA. The spatial distribution of PCB and LNPCB concentrations in common carp and walleye correspond with historical point- and non point-source PCB inputs in the densely populated TCMA, and concentrations in fish were greater in areas that historically had elevated PCB concentrations in bed sediment.

Median PCB concentrations in common carp and walleye at individual sites were greatest during 1975-79 and 1980-87, and least during 1988-95 at most sites. Most of the river segments exhibited over 80 percent decline in median PCB concentrations in common carp and walleye between the 1975-79 and 1988-95 time periods. The results from these temporal analyses were similar to those of other studies in the United States and in Minnesota and Wisconsin that reported a significant downward trend in PCB concentrations in fish. Although, PCB concentrations have decreased during 1975-95, low concentrations of PCBs still remain in the aquatic environment despite the fact that PCBs were banned nearly 20 years ago.

Introduction

In 1991, the USGS began full implementation of the NAWQA Program. Long-term goals of the NAWQA Program are to describe the status of and trends in the quality of large representative areas of the Nation's surface-water, aquatic-community, and ground-water resources, and to identify some of the natural and human factors that affect the quality of these resources (Gilliom and others, 1995). To meet these goals, nationally consistent data are being collected and analyzed. Because assessment of the water quality in the entire Nation is impractical, major activities of the NAWQA Program take place within a set of hydrologic systems called study units. Study units comprise diverse hydrologic systems of river basins, aquifer systems, or both.

The UMIS NAWQA study unit, which encompasses an area of about 47,000 mi^2, includes the entire drainage of the Mississippi River upstream from the outlet of Lake Pepin located downstream of Red Wing, Minnesota (fig. 1). Diverse land cover, including forests, wetlands, and agricultural and urban areas, characterizes the UMIS study unit. A complete description of the environmental setting of the study unit can be found in Stark and others (1996).

Three major rivers (Mississippi, St. Croix, and Minnesota) flow through the UMIS study unit. The Mississippi River begins at Lake Itasca in northern Minnesota, and flows generally south through extensive forested and wetland areas. It also flows through the TCMA, which is the largest population center in the UMIS having an estimated population of 2.3 million (Stark and others, 1996). The Mississippi River provides drinking water, commercial transportation, wastewater dilution, and recreation. Lock and dam structures on the Mississippi River create a system of pooled areas upstream of dams (fig 2). Pool 2, the largest pool in the TCMA, receives most of the major industrial and municipal discharges (greater than 1 Mgal/d) (Anderson, 1997). The Minnesota River primarily drains agricultural land in southwestern Minnesota, and passes through small urbanized areas prior to flowing through the TCMA. The St. Croix River drains primarily forested land in eastern Minnesota and western Wisconsin; however, the St. Croix River is more urbanized downstream of St. Croix Falls (fig. 1).

Background

PCBs are a family of organic compounds that are produced by substituting chlorine atoms for hydrogen atoms on a biphenyl molecule. There are 209 possible PCB isomers, depending on the number and location of chlorine atoms surrounding the biphenyl molecule (Eisler, 1986). PCBs tend to sorb to sediment because they are not readily soluble in water. PCBs are on the U.S. Environmental Protection Agency's Priority Pollutant list of toxic chemicals for which the agency intends to promulgate discharge control standards (Chapman and others, 1982). Commercial PCB mixtures on the priority pollutant list include Aroclors 1016, 1221, 1232, 1242, 1248, 1254, and 1260 (Chapman and others, 1982). The first two digits of the Aroclors signify the number of carbon atoms in the biphenyl molecule, and the last two numbers indicate the percent of the sample, by weight, that is chlorinated (Eisler, 1986). Degradation of PCBs is slow, and forms with a greater percentage of chlorine are generally more persistent (Eisler, 1986).

PCBs were commonly used in dielectric fluids, hydraulic fluids, heat-transfer fluids, sealants, and marine paint from 1929-74. After 1974, PCBs were used in closed systems such as dielectric fluid in transformers (U.S. Environmental Protection Agency, 1992). An estimated 90 percent of all capacitors manufactured in the 1970's contained PCBs and over 90 million capacitors were produced yearly (Durfee, 1976). Production of PCBs in the United States ceased in 1977 and production of PCBs was banned in the United States in 1979. Despite this ban, PCBs are still widely detected in the aquatic environment (Sullivan, 1988; Eisler, 1986; Schmitt and others, 1990).

PCBs have been detected in fish tissue and sediment from every major river in the United States, probably due to runoff from contaminated surfaces, dispersal of contaminated sediments within rivers, atmospheric deposition, and point source discharges (Eisler, 1986; Schmitt and others, 1990). The major anthropogenic factor that affects PCB occurrence in streams is the location of the stream relative to PCB sources such as transformers, point source discharges from wastewater treatment, nonpoint sources such as storm-water runoff from contaminated surfaces, and atmospheric deposition from incinerators (Hora, 1984; Sullivan, 1988). These sources generally occur with greater frequency in urban areas.

Natural factors also affect the movement and distribution of PCBs in streams. PCBs tend to be sorbed to sediments and are transported and deposited with sediments. Sediments tend to be deposited in pools and backwaters in large rivers, and can be resuspended during periods of high flow or dredging. Sediment re-suspension during high-flow events and dredging can reintroduce PCBs into the aquatic environment and extend their environmental impacts (Sullivan, 1988).

Fish and other aquatic organisms are exposed to PCBs through direct intake of contaminated water and sediments, or through consumption of contaminated food. Concentrations of PCBs in fish tissue are primarily dependent upon where the fish live (their habitat), what they feed upon (their trophic status), and other factors such as their lipid content and age. Fish that live in close contact with sediments and feed on organisms that live in the sediments are likely to ingest PCBs from contaminated prey and incidentally from contaminated sediments. Fish that inhabit areas that are not associated with sediment receive PCBs mainly through ingestion of contaminated prey.

Once PCBs have entered the food chain in organisms at the lower trophic levels (algae, macrophytes, and benthic invertebrates), they are passed to organisms higher on the food chain such as fish, birds, and ultimately humans.

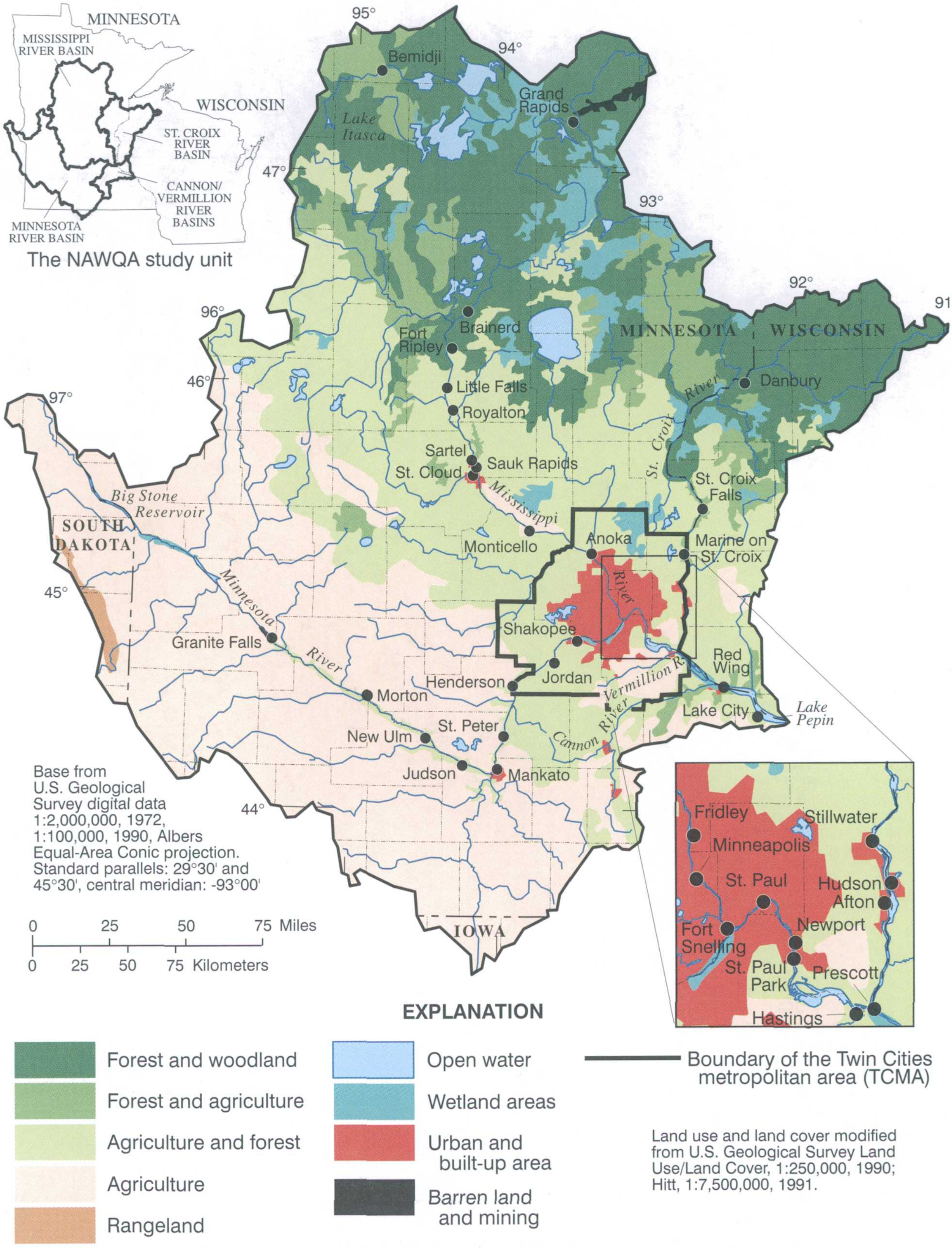

Figure 1.--Land use and land cover, selected towns and major cities in the Upper Mississippi River Basin study unit.

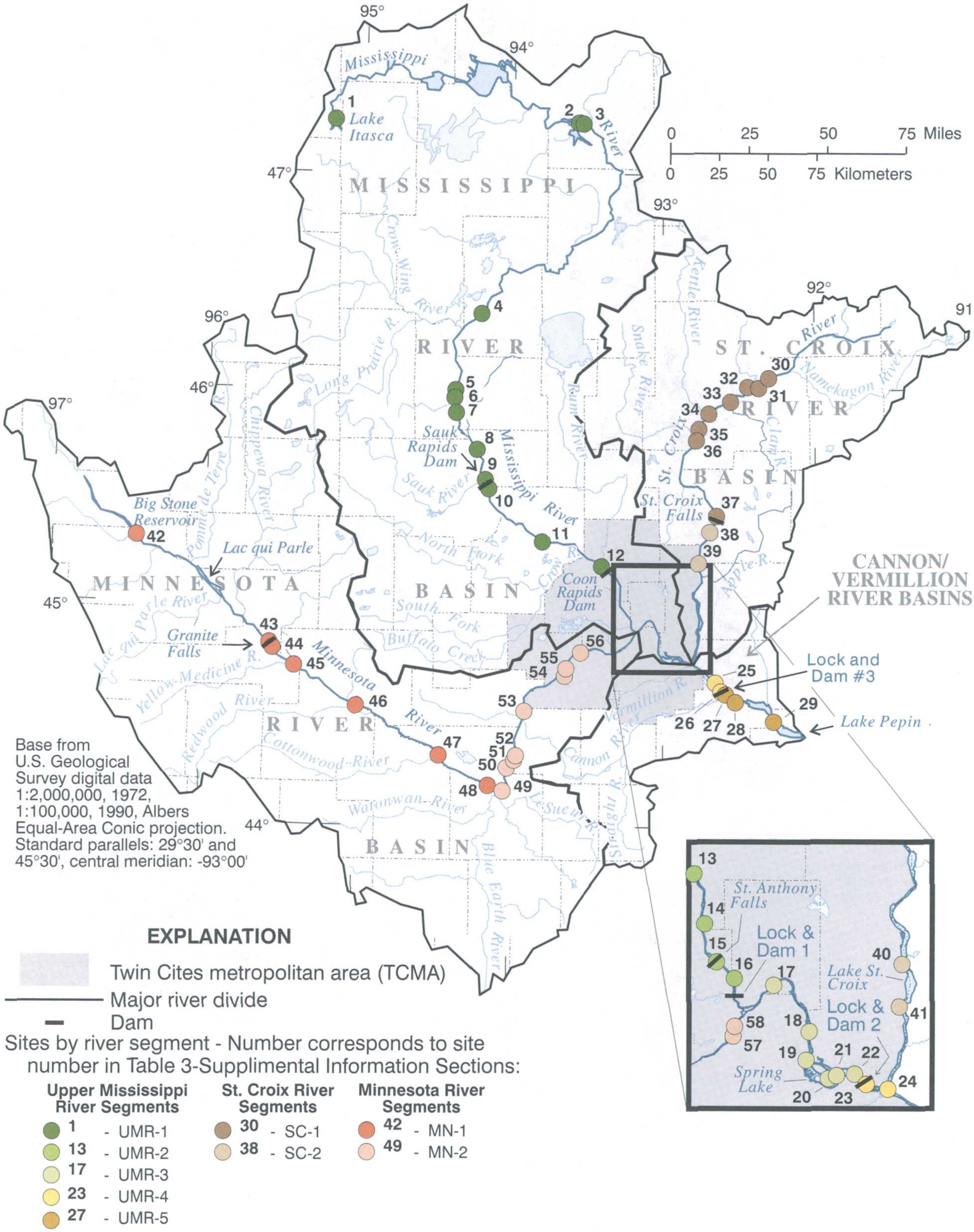

Figure 2.--Hydrography, dams, and location of sites sampled by the Minnesota Fish Contaminants Monitoring Program, the Metropolitan Council Environmental Services, the U.S. Fish and Wildlife Service , and the Wisconsin Department of Natural Resources in the Upper Mississippi River Basin study unit (1975-95).

PCBs have the potential to bioaccumulate in organisms and biomagnify through food chains. Bioaccumulation occurs because less PCBs are excreted or metabolized than are ingested. Biomagnification occurs when PCB concentrations are increased at each step higher in the food chain.

Locally, in Minnesota and Wisconsin, PCBs in fish are a human and ecosystem health concern. Both Minnesota and Wisconsin Departments of Health have established fish-consumption advisories for PCBs (Minnesota Department of Health, 1998; Wisconsin Department of Health and Wisconsin Department of Natural Resources, 1997). PCBs became an important issue in Minnesota and Wisconsin in 1975 when the USFDA restricted the interstate shipment of common carp (*Cyprinus carpio*) taken from Lake Pepin because PCB concentrations exceeded the 5 milligrams per kilogram (mg/kg) commercial action level (Interagency Task Force, 1976; Hora, 1984; Sullivan, 1988). This USFDA action prompted the development of an Interagency Task Force to determine the extent of PCB contamination in Minnesota and Wisconsin (Interagency Task Force, 1976). The Interagency Task Force, which was comprised of local, state and Federal agencies, completed a study in 1975 to identify PCB concentrations in fish, sediment, water, and point sources.

Several other studies of PCBs have been completed nationwide and in the UMIS. PCBs in bed and suspended sediment, fish and invertebrate tissues have historically been greater within and downstream of the TCMA than upstream (Hora, 1984; Sullivan, 1988; Biedron and Helwig, 1991; Steingraeber and others, 1994; Rostad and others, 1995). Other studies have shown that PCB concentrations in sediment and fish have declined after the compounds were banned in 1979 (Hora, 1984; Sullivan, 1988; Schmitt and others 1990; Biedron and Helwig, 1991).

PCBs in fish tissue are of concern because PCBs are potentially toxic, teratogenic, and have been linked to poor fetal development and endocrine disruption in fish and other animals including humans, that consume fish, (Eisler, 1986; Colburn and Clement, 1992; Jacobson and Jacobson, 1993). Because of the potential effects of PCBs on environmental and human health, it is important to develop strategies of management of PCBs. An understanding of PCB spatial and temporal trends is necessary to develop these strategies.

Purpose and Scope

The purpose of this report is to describe the spatial distribution and the temporal trends of total PCBs in common carp and walleye (*Stizostedion vitreum*) fillets collected from rivers in the UMIS study unit for 1975-95. Data from the three major rivers in the study unit—the Mississippi, the Minnesota, and the St. Croix Rivers—are summarized. Data are analyzed through graphical and statistical methods.

Acknowledgments

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Data Sources and Analyses

Data Sources

PCB concentration data for common carp and walleye fillets were obtained from electronic data bases and paper files from monitoring programs conducted by the MFCMP (a joint effort of the MDH, MDNR, and MPCA) MCES, USFWS, and the WDNR. Each agency had specific purposes for data collection.

The primary objective of the MFCMP is to determine the extent of chemical contamination of fish in Minnesota waters and to develop a fish-consumption advisory to protect human health (Minnesota Department of Natural Resources, 1994). The first advisory was published in 1985 and annual updates have been published since 1991 (Minnesota Department of Health, 1998). The MFCMP fish-collection program focuses on sites with a suspected contamination source, popular angling waters, and in areas where trends are being tracked. PCB monitoring under the MFCMP began in 1975 and continues presently. From 1975-89 the MPCA maintained the contaminant-monitoring program. After 1989, the MDNR assumed the primary responsibility for the operation of the Program. Various laboratories, from 1975 through 1995, analyzed PCBs in fish for the MFCMP. A detailed description of methods for fish collection, and laboratory analyses for the data can be found in the 1990-92 data document (Minnesota Department of Natural Resources, 1994). PCB concentrations in fish were reported as total PCBs.

The WDNR monitors PCBs in fish tissue in streams and lakes in Wisconsin primarily for the development of a fish consumption advisory to protect human health (Wisconsin Department of Natural Resources, 1997). WDNR's fish-collection program focuses on sites with a suspected contamination source, popular angling waters, and in areas where trends are being tracked (Wisconsin Department of Health and Wisconsin Department of Natural Resources, 1997). PCB concentrations in fish were reported as total PCBs. Common carp and walleye fillet data were collected at sites in the St. Croix and Mississippi Rivers within the Wisconsin portion of the UMIS study unit during 1975-95.

The MCES collected common carp fillets during 1984-88 at nine sites in the TCMA. PCB concentration in fish fillets were collected as part of a toxics monitoring program designed to provide information about the effectiveness of an industrial pretreatment program and to monitor compliance with standards and criteria for toxic pollutants (Metropolitan Council Environmental Services, 1988). Fish fillets were analyzed for PCB Aroclors 1016, 1221, 1232, 1242,1248, 1254, and 1260.

The USFWS monitored contaminants in fish as part of the NCBP during 1967-84, and as part of the BEST Program since 1991. Under these two programs, the USFWS determined concentrations of contaminants (including PCBs) in fish tissue across the United States (Schmitt and others, 1983). Fish were analyzed for PCB Aroclors 1248, 1254, and 1260 at two sites in the UMIS study unit; at the Mississippi River at Little Falls, Minnesota; and the Mississippi River at Lake City, Minnesota (Schmitt and others, 1996).

Data Analyses

PCB concentrations in common carp and walleye fillets, with skin attached, were used for the analyses in this report. Because PCB data were not normally distributed, nonparametric statistical tests with a 0.05 significance level were used. The MFCMP and the WDNR collected common carp and walleye during 1975-95, had the greatest number of PCB analyses for common carp and walleye, and reported total PCB concentrations. A comparison of PCB (lipid normalized, see below) concentrations in common carp and walleye was made between the MFCMP and WDNR data collected during 1975 at Lake Pepin. No significant differences between the data sets were observed for common carp, based on the Mann-Whitney nonparametric statistical test. Therefore, the MFCMP and WDNR data sets were combined. Data from the MCES and USFWS are reviewed, however they were not combined with the MFCMP and WDNR data sets because the periods over which MCES and USFWS data were collected did not extend over the entire 20 year time period. In addition, concentration of individual Aroclors was reported by MCES and USFWS, in contrast to total PCB concentration reported by MFCMP and WDNR.

In the original data sets from the MFCMP and WDNR, PCB concentrations were reported for individual fish, and for composite samples of 2 to 11 fish. No attempt was made to adjust data analyses for number of fish composited per sample. The number of PCB samples varied among rivers and time periods. The greatest number of samples were collected from the Mississippi River, followed by the Minnesota River, and the St. Croix River among all time periods (table 1).

PCB concentrations in fish vary through space and time. To account for these factors, data were separated spatially (into distinct river segments), and temporally (into three time periods). Data from the Mississippi River were divided into five segments (UMR 1-5) based on the locations of dams (fig. 2, and table 2). Data from the St. Croix River were divided into 2 segments; one upstream (SC-1) and one downstream of St. Croix Falls (SC-2) to the confluence with the Mississippi River. Data from the Minnesota River were divided into two segments: one upstream of Mankato (MN-1) and one from Mankato downstream to the confluence with the Mississippi River (MN-2). Because PCBs in fish tissue are known to have declined during 1975-95, data were divided into three discrete time periods:1975-79, 1980-87, and 1988-95. The 1975-79 time period preceded the ban of PCB production. The other two periods were split between 1980 and 1995.

Lipid content and fish length (surrogate for fish age) may influence PCB concentrations in fish. Lipid content in fish is important because PCBs are partitioned into and stored in lipid tissue. Fish age (as estimated by fish length) indicates the potential exposure period for contaminants. Because fish bioaccumulate PCBs, concentrations in older

Table 1. Number of common carp and walleye samples used for analyses, by river and time period

River	1975-1979		1980-1987		1988-1995		Total	
	Common carp	Walleye	Common carp	Walleye	Common carp	Walleye	Common carp	Walleye
Mississippi River	82	19	96	35	31	15	209	69
St. Croix River	10	0	9	5	13	13	32	18
Minnesota River	23	2	16	5	13	5	52	12
Total	115	21	121	45	57	33	293	99

fish are expected to be greater than in younger fish of the same species. Without actually determining fish age through analyses of fish scales or calcified body parts, the exact age of the fish can only be estimated by fish length.

Spearman correlations were used to determine the association of lipid content and fish length with PCB concentration for common carp and walleye within all river segments for each time period. Lipid content ranged from 0.6 to 18.9 percent in common carp samples and from 0.1 to 5.7 percent in walleye samples among all stream segments and time periods. In common carp, percent lipid content was positively correlated (r>0.5) with PCB concentrations in 50 percent of the river segments during all time periods. Lipid content in common carp also was found to be statistically different among river segments within each time period. Most walleye data sets generally were not large enough (>5 samples) to determine the relation between lipid content and PCB concentration; however, when there were sufficient data within a set, a positive correlation between lipid content and PCB concentration was observed. Therefore, PCB concentrations were normalized according to lipid content. Lipid normalization for common carp and walleye samples was accomplished by determining the milligrams of PCB per kilogram of lipid in each fish fillet, and is indicated as LNPCB in the text.

The association of fish length and PCB concentration was not consistent among all stream segments. There were no significant differences in common carp length among stream segments during any time period except during 1980-87. The correlations between length and PCB concentration were negative in approximately 15 percent of the segments and not strongly correlated (r < 0.3) in approximately 52 percent of the segments. The association of length and PCB concentration for walleye was difficult to determine due to small data set size. Therefore, to reduce potential variability due to fish length (age), data analyses were restricted to fish with lengths ranging from 15.0-24.9 in. This range in length coincides with the 15-20 in. and 20-25 in. size ranges used for the Minnesota Fish Consumption Advisory (Minnesota Department of Health, 1998).

The MFCMP and WDNR data sets contained censored values, which are concentrations that were reported below an analytical detection limit. There were multiple detection limits from 0.01 to 0.07 mg/kg, for common carp and walleye samples. Multiple detection limits pose a problem for data interpretation and statistical analyses. Therefore, the value for the highest detection limit (0.07 mg/kg) was substituted for any sample with a concentration less than 0.07 mg/kg. The percent of censored data during 1975-79 and 1980-87 was generally small (less than 10 percent for both common carp and walleye) so little information was lost by substituting 0.07 for all censored values. However, during 1988-95, the percent of censored data was 43 percent and 64 percent for common carp and walleye, respectively. Therefore, substitution of the highest value may result in some information loss and may overestimate median values for that time period (Helsel and Hirsh, 1992). However, the focus of this study was on greater differences in PCB concentrations among segments and time periods.

Spatial analyses of PCB concentrations in common carp and walleye include graphic comparisons among individual sites and both graphic and statistical comparisons among stream segments on the Mississippi, St. Croix, and Minnesota Rivers during each of three time periods (1975-79, 1980-87, and 1988-95) (figs. 3-6). Because of small data set sizes, no statistical comparisons for spatial analyses were made for walleye data.

Spatial analyses among individual sites were accomplished by displaying the median concentration for each site during each time period (figs. 3 and 4). There are 29 sites on the Mississippi

Table 2. Rivers, segments, and segment descriptions for sites sampled in the Upper Mississippi River Study Unit
[MN, Minnesota; SC, St. Croix River; UMR, Upper Mississippi River]

River	Segment	Segment description
Mississippi	UMR-1	Lake Itasca downstream to Coon Rapids Dam
Mississippi	UMR-2	Coon Rapids Dam downstream to Lock and Dam 1
Mississippi	UMR-3	Lock and Dam 1 downstream to Lock and Dam 2
Mississippi	UMR-4	Lock and Dam 2 downstream to Lock and Dam 3
Mississippi	UMR-5	Lock and Dam 3 downstream to the outlet of Lake Pepin
St. Croix	SC-1	St. Croix River upstream of St. Croix Falls, MN
St. Croix	SC-2	St. Croix River downstream of St. Croix Falls, MN to the confluence with the Mississippi River
Minnesota	MN-1	Minnesota River upstream of Mankato, MN
Minnesota	MN-2	Minnesota River near Mankato, MN downstream to the confluence with the Mississippi River

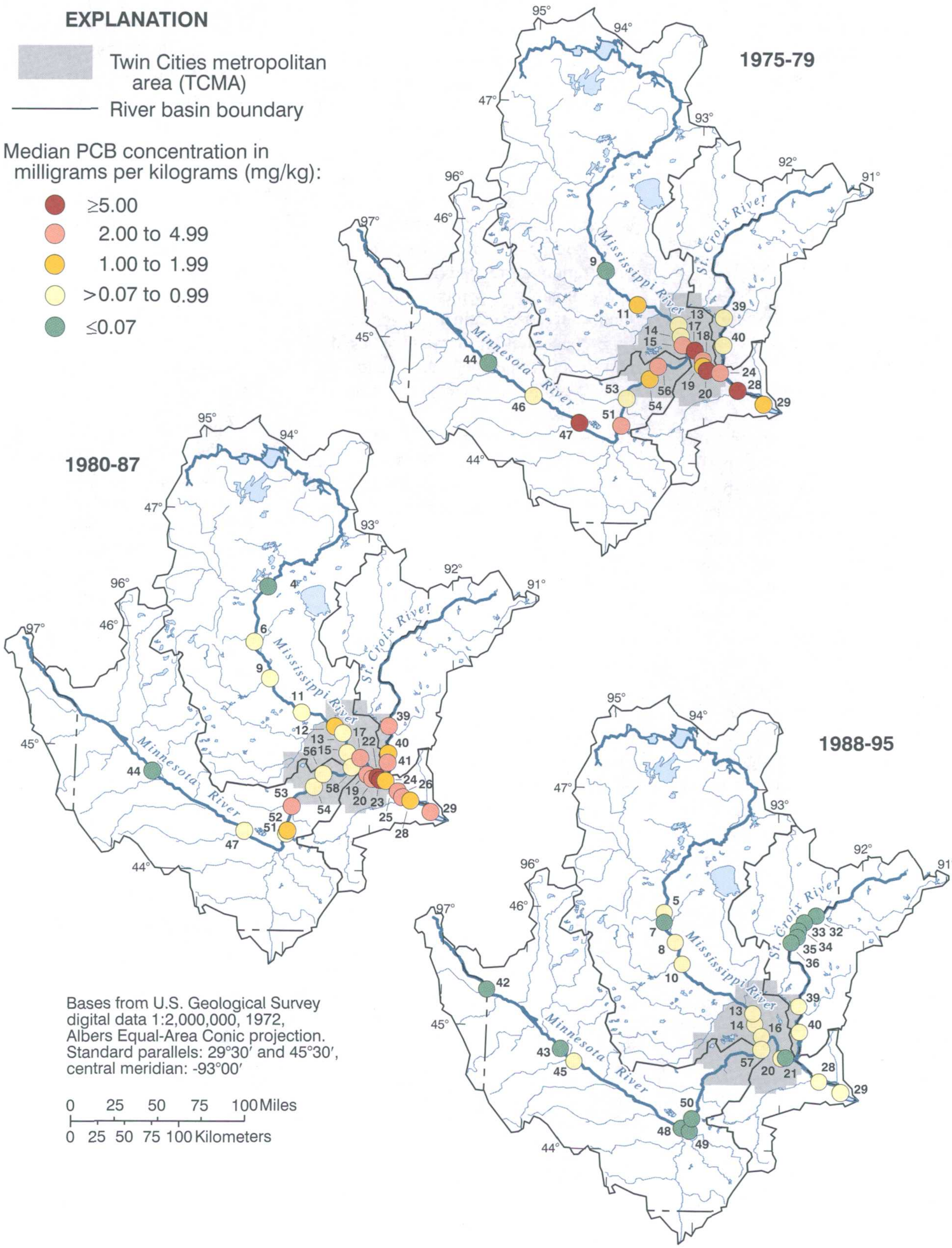

Figure 3.--Median concentrations of PCBs in carp common fillets in the Minnesota, St. Croix Rivers, and in the Mississippi River upstream of the outlet of Lake Pepin, 1975-95 (Data from Minnesota Fish Contaminant Monitoring Program and Wisconsin Department of Natural Resources).

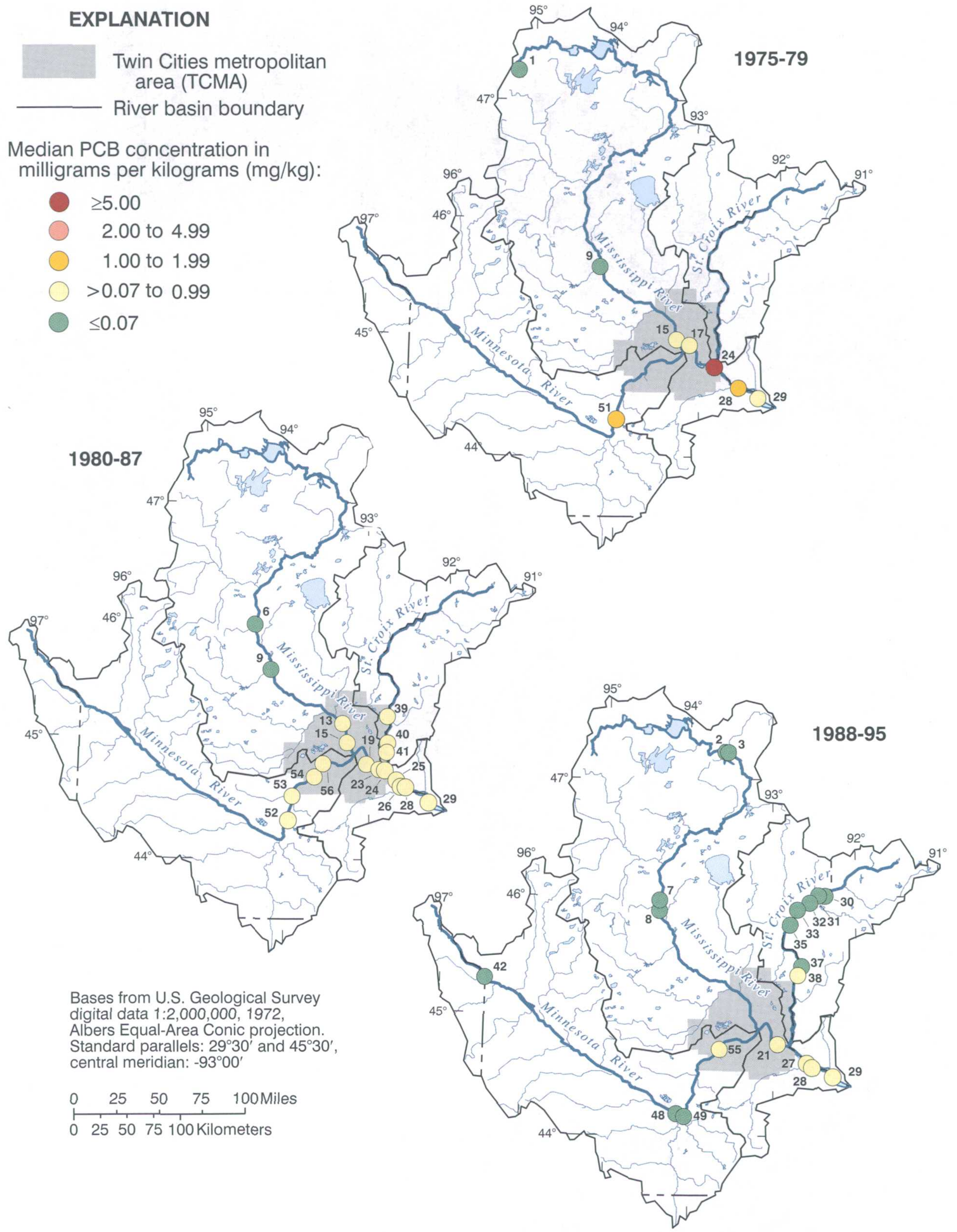

Figure 4.--Median concentrations of PCBs in walleye fillets in the Minnesota, St. Croix Rivers and in the Mississippi River upstream of the outlet of Lake Pepin, 1975-95 (*Data from Minnesota Fish Contaminant Monitoring Program and the Wisconsin Department of Natural Resources*).

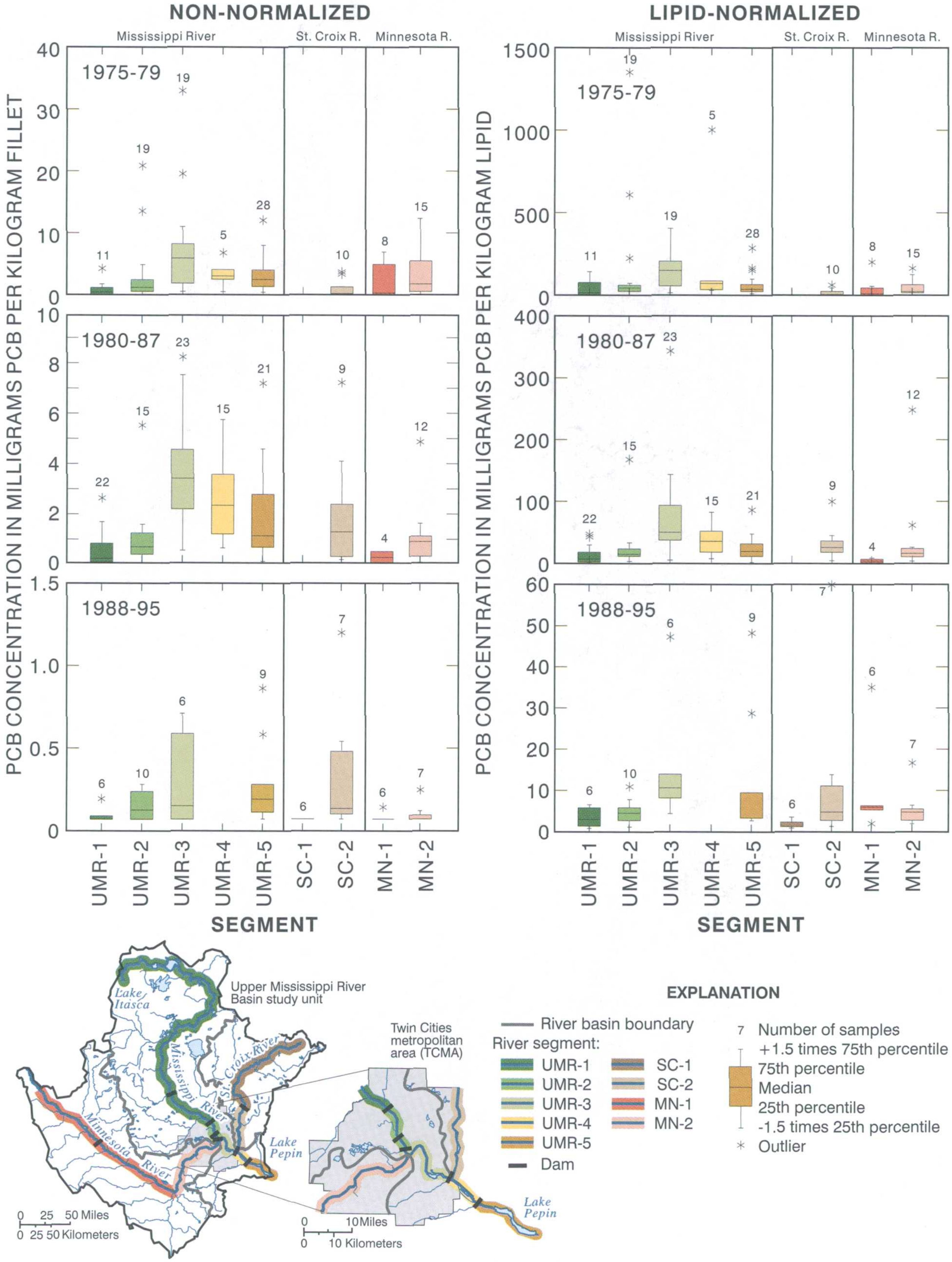

Figure 5.--Non-normalized and lipid-normalized PCB concentration in common carp fillets from river segments in the Upper Mississippi River basin, 1975-95).

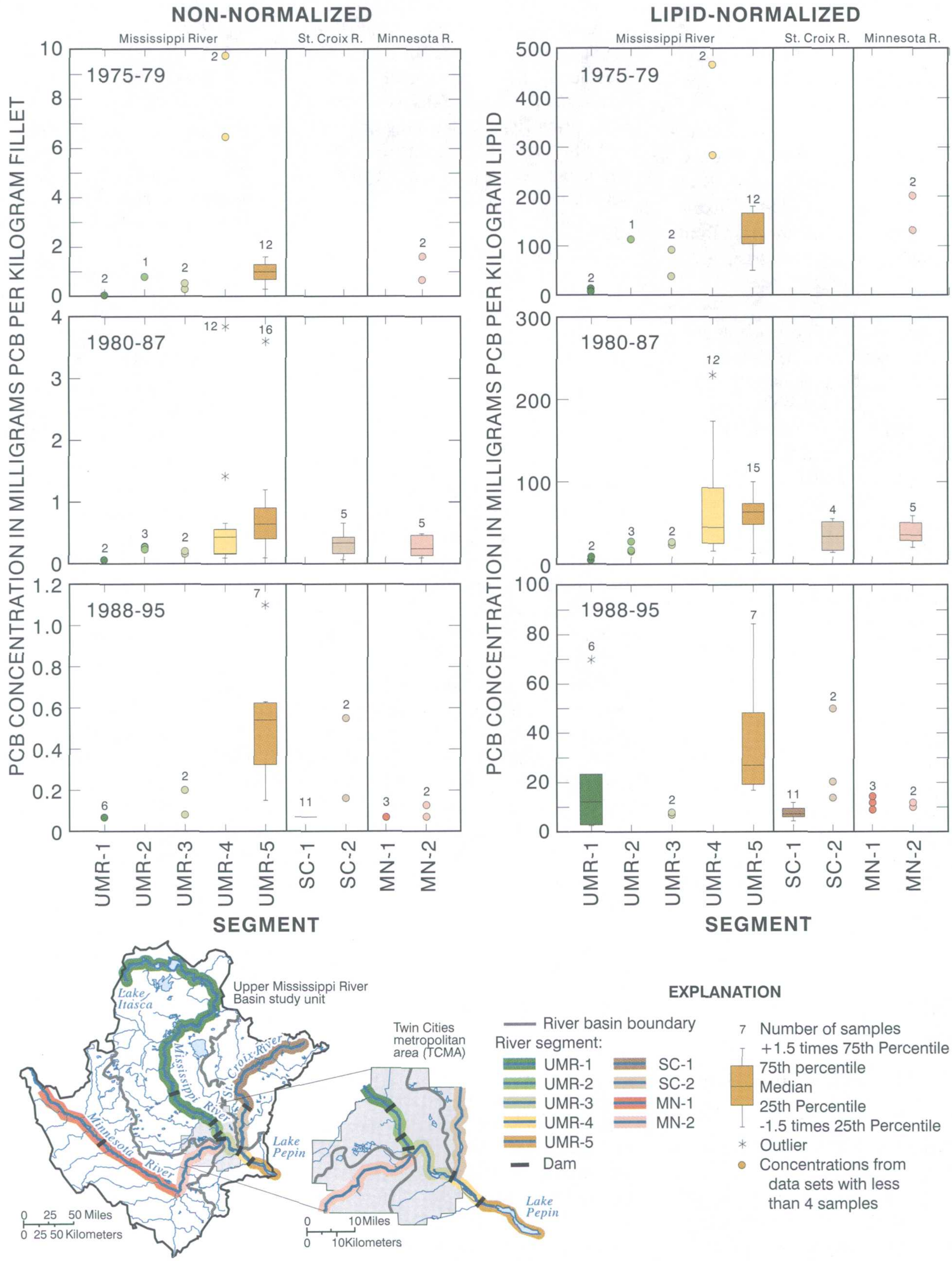

Figure 6.--Non-normalized and lipid-normalized PCB concentration in walleye fillets from river segments in the Upper Mississippi River basin, 1975-95).

River (site numbers 1-29), 12 sites on the St. Croix River (site numbers 30-41), and 17 sites on the Minnesota River (site numbers 42-58) (table 3, Supplemental Information section). Site locations are associated with a river mile location. River miles for sites on the Mississippi River are given in miles upstream of the Mississippi River at Cairo, Illinois. River miles on the Minnesota and St. Croix Rivers are given as miles upstream from their confluence with the Mississippi River.

Comparisons of PCB concentrations among river segments are assessed graphically using boxplot diagrams, and statistically with Kruskal-Wallis and Mann-Whitney tests (Helsel and Hirsh, 1992). Both non-normalized and LNPCB concentrations are shown on boxplots; however, statistical analyses were performed only on the LNPCB concentrations. Differences in LNPCB concentrations among all segments were determined using the Kruskal-Wallis test, and differences between all pairs of segments were determined using the Mann-Whitney test.

Temporal trend evaluation of PCB concentrations in carp and walleye included descriptive and statistical analyses. Maps and graphs were used to describe the temporal distribution of LNPCB concentrations in common carp and walleye within each of the three rivers. The Kruskal-Wallis test was used to test for differences in LNPCB concentration among the three time periods within each stream segment.

Spatial Distribution of Polychlorinated Biphenyls in Common Carp and Walleye in the Mississippi, Minnesota, and St. Croix Rivers

Sites were not sampled every year or regularly throughout 1975-95. Figures 3 and 4 show the spatial distribution of median PCB concentrations of common carp and walleye, respectively, at individual sites during each of the three time periods. Sampling sites were not the same during each period. For example, sites upstream (sites 30-37) and downstream (sites 38-41) of St. Croix Falls on the St. Croix River were not always sampled during the same years; all sites upstream of St. Croix Falls were sampled during 1988-95, and only two sites in the St. Croix River downstream of St. Croix Falls were sampled during that period.

Comparison Among Individual Sites

PCB concentrations of samples at individual sites ranged from 0.07 to 33.0 mg/kg for common carp and from 0.07 to 9.8 mg/kg for walleye during 1975-95 (tables 4 and 5, Supplemental Information section). Maximum PCB concentrations for individual common carp and walleye samples were greatest in the Mississippi River (33.0 mg/kg and 9.8 mg/kg, respectively) followed by the Minnesota (12.3 and 1.6 mg/kg, respectively) and St. Croix (3.6 in common carp) Rivers during 1975-79 (tables 4 and 5, Supplemental Information section).

During 1975-79 and 1980-87, 10 and 4 percent of walleye samples and 45 and 36 percent of common carp samples, respectively, exceeded the USFDA guideline of 2 mg/kg PCB in fish tissue (U.S. Food and Drug Administration, 1989). PCB concentrations in common carp and walleye tissues were below the 2 mg/kg commercial USFDA limit set for commercial fisheries after 1987.

Whereas median PCB concentrations in walleye at individual sites were generally lower than those in common carp during the 1975-79 and 1980-87 time periods, the spatial trends were similar (figs. 3 and 4). Median PCB concentrations in common carp and walleye at individual sites were generally greatest in the Mississippi River within and downstream of the TCMA (sites 13-29) during 1975-79 and 1980-87 (figs. 3 and 4). During 1975-79 and 1980-87, median PCB concentrations in common carp at individual sites in the Minnesota River downstream of New Ulm (sites 47-58) and individual sites in the St. Croix River downstream of St. Croix Falls (sites 38-41) were within the range of those observed for sites in the Mississippi River within and downstream of the TCMA (sites 13-29). During 1980-87 and 1988-95, PCB concentrations in walleye in the St. Croix River downstream of St. Croix Falls and in the Minnesota River downstream of Mankato were within the range those observed for sites in the Mississippi River within and below the TCMA.

Comparison Among River Segments

Spatial comparison of PCB concentrations were made among 5 segments on the Mississippi River and 2 segments on both the St. Croix and Minnesota Rivers (fig. 2, and table 2) within the three time periods. During the three time periods, the spatial trend was similar, although the ranges of PCB concentrations were different (fig. 5). Ranges and median non-normalized and LNPCB concentrations generally were greater in common carp from Mississippi River segments in the TCMA (UMR 3-4) than in river segments upstream or outside the TCMA during all time periods.

There was a significant difference ($P < 0.05$) among LNPCB concentrations in common carp, considering all river segments combined, during all three time periods. Median LNPCB concentrations in common carp increased downstream in the Mississippi River from UMR-1 to UMR-3 and then decreased from UMR-3 to UMR-5 during all time periods (fig. 5, and table 4, Supplemental Information section). Common carp in UMR-3 and 4 in the TCMA generally had greater LNPCB concentrations than other river segments. During 1975-79, UMR-3 had greater LNPCB concentrations than all other stream segments except UMR-4 ($P < 0.05$). During 1980-87, UMR-3 had greater LNPCB concentrations than all other segments ($P < 0.05$). During 1988-95, UMR-3 had greater median PCB concentrations than UMR-1 and SC-1.

Non-normalized and LNPCB concentrations in common carp at UMR-1, SC-1 and MN-1 (those segments upstream of or outside the TCMA) generally were lower than in UMR segments in or near the TCMA (UMR-2,3,4,5). During 1980-87, MN-1 and UMR-1 had lower LNPCB concentrations than UMR segments in and downstream of the TCMA (P< 0.05). During 1988-95, SC-1 had similar LNPCB concentrations to UMR-1 and lower LNPCB concentrations than all other river segments (P < 0.05).

Generally, median non-normalized and LNPCB concentrations in common carp in MN-2 and SC-2 were lower than those in UMR-3, but similar to other UMR segments within and downstream of the TCMA. During 1975-79 and 1980-87, MN-2 had lower LNPCB concentrations than UMR-3 and similar to UMR-4 and 5 (P<0.05). During 1988-95, MN-2 was similar to all other UMR segments (p<0.05). During 1980-87, SC-2 had similar LNPCB concentrations to UMR-2,4, and 5 (P<0.05). During 1988-95, SC-2 had similar LNPCB concentrations to all other river segments but greater LNPCB concentrations than SC-1 (p<0.05).

The spatial distribution of PCB concentrations in walleye is more difficult to determine than for common carp due to smaller data set sizes. Median PCB concentrations in walleye samples were less than those of common carp samples in all segments of the Mississippi River during 1975-79 and 1980-87 except UMR-4 during 1975-79 (figs. 5 and 6, tables 4 and 5, Supplemental Information section). Median non-normalized and LNPCB concentrations in walleye were greatest in UMR-4 during 1975-79, and in UMR-5 during 1980-87 in contrast to PCB concentrations in common carp, which were greatest in UMR-3 during those time periods. During 1975-79, MN-2 had a similar median non-normalized and LNPCB concentration to UMR-2,3 and 5 in the TCMA. During 1980-87, median PCB concentrations in walleye in SC-2 and MN-2 were similar to those observed in UMR- 2-4 in the TCMA. During 1988-95, median PCB concentrations in walleye were greater in SC-2 than in SC-1.

Temporal Distribution of Polychlorinated Biphenyls in Common Carp and Walleye in the Mississippi, Minnesota, and St. Croix Rivers

Median PCB concentrations in common carp and walleye at each site on the St. Croix, Minnesota, and Mississippi Rivers were determined for the three time periods. Upon visual inspection of figures 3 and 4, median PCB concentrations in common carp and walleye appear greatest in 1975-79 and 1980-87, and least during 1988-95 at most sites. Declines in median PCB concentration for common carp at individual sites are most evident in the TCMA. This trend is not as clear for walleye. The absence of a clear temporal trend in PCB concentrations for walleye may be attributed to small data set sizes and the relatively low PCB concentrations in walleye.

There was a significant temporal decrease in LNPCB concentrations in common carp among the three time periods within UMR-1,2,3 and 5 and MN-2. There was no difference among time periods for SC-2 and MN-1, and there were not enough data to determine difference for UMR-4 and SC-1 (table 4, Supplemental Information section). Median LNPCB concentrations in common carp were highest from 1975-79, lower during 1980-87, and least from 1988-95 with the exception of SC-2, which had the greatest median LNPCB concentration during 1980-87, and MN-1 which had a greater LNPCB concentration in 1988-95 than in 1980-87 (table 4, Supplemental Information section, and fig. 5). Most of the stream segments exhibited over 80 percent decline in median PCB concentrations in common carp between 1975-79 and 1988-95. The percent change in median LNPCB concentration between 1975-79 and 1988-95 ranged from a 52 percent decline in the MN-1 to 93 percent decline in UMR-3.

There was a significant decrease over time of LNPCB concentrations in walleye among time periods at UMR-5, which was the only segment with a large enough data set size for statistical analyses. Median non-normalized and LNPCB concentrations were generally greatest during 1975-79, less during 1980-87, and least during 1988-95, with the exception of UMR-1 where the medians where greatest during 1988-95, less in 1975-79, and least during 1980-87. The percent change in median LNPCB concentration for walleye could be computed for only four river segments. The values ranged from a 12 percent increase at UMR-1 to a 94 percent decline at MN-2.

The results from these temporal analyses were similar to those of other studies in the United States and in the UMIS. In a nationwide survey, the USFWS (Schmitt and others, 1990) reported a significant downward trend in PCB concentrations in fish, including concentrations in common carp at a USFWS station in Lake Pepin between the 1976-77 and the 1984 sampling periods. Sullivan (1988) also reported that PCB concentrations in common carp tissue decreased 49 percent between the 1975-76 and 1979-80 time periods in the UMIS. Biedron and Helwig (1991) reported a decrease in concentrations in common carp between a 1975-76 and a 1987-88 sampling period.

Factors Affecting Polychlorinated Biphenyl Distribution

The spatial distribution of non-normalized PCB and LNPCB concentrations in common carp and walleye correspond with historical and current point- and non point-source PCB inputs in the densely populated TCMA. Moody and Battaglin (1995) reported that there was more population stress (defined as the number of people in a drainage basin per river discharge in cubic meter/second) in the Mississippi (> 10,000) than in the Minnesota (7,500-9,999), or in the St. Croix Rivers (0-2,499). Greater population density is associated with greater numbers of electrical transformers, industrial effluent, wastewater sewage inputs, and runoff from impervious surfaces.

Greater population density and associated PCB sources could account for greater median and individual PCB and LNPCB concentrations in fish in the Mississippi River segments within and downstream of the TCMA (UMR-3,4 and 5) than in fish from sites upstream of the TCMA. The similarity of PCB and LNPCB concentrations in common carp and walleye in SC-2 and MN-2 with concentrations in the TCMA may also be related to greater urbanization. The St. Croix River primarily drains forested land except in the area below St. Croix Falls where there is more urbanization and the Minnesota River drains primarily agricultural land except in the area below Mankato where population density increases. Other possible reasons for greater PCB concentrations in SC-2 and MN-2 are fish migrations upstream from the Mississippi River.

PCB distribution is also related to sediment movement and deposition. PCB concentrations in fish were greater in areas that historically had elevated PCB concentrations in bed sediment (Degurse and Ruhland, 1972; Interagency Task Force, 1976). Fish in pooled areas, where they are potentially exposed to greater PCB concentrations deposited with sediment, exhibit greater concentrations of PCBs in their tissues. Pooled areas such as Spring Lake (UMR-3) and Lake Pepin (UMR-5) on the Mississippi River, and Lake St. Croix on the St. Croix River near its confluence with the Mississippi (part of SC-2) historically had elevated PCB concentrations in bed sediments (Interagency Task Force, 1976). More recently, Rostad and others (1995) reported that PCB concentrations in bed sediment in UMR-2 of the Mississippi River were lower (between 0 and 0.05 mg/kg) than concentrations in UMR-3 and 4 (0.10 to 0.15 mg/kg), and greatest in UMR-5 (0.20 to 0.30 mg/kg). In addition to factors related to the environmental setting, other factors such as small data set sizes and differences in collection and laboratory procedures between agencies may also influence the observed spatial distribution of PCBs.

Although PCB concentrations have decreased during 1975-95, low concentrations of PCBs still remain in the aquatic environment despite the fact that PCBs were banned over 20 years ago. The decrease in PCB concentrations over the 20 year period evaluated in this report can be attributed to termination of PCB production and reduction in PCB discharges into these rivers. However, improvements in laboratory procedures over the 20 year period could also contribute to a portion of the decrease, because earlier methods may have overestimated PCB concentrations in the early 1970's (Hora, 1984). PCB concentrations in walleye decreased more gradually over the 20-year time period, and were low enough that the variability in the data often masked any trend. In addition, data set sizes were small, which may influence the results.

Summary and Conclusions

The U.S. Geological Survey (USGS) analyzed previously collected data from 1975-95 on polychlorinated biphenyl (PCB) concentration data in common carp and walleye fillets in 3 rivers draining the Upper Mississippi River Basin upstream from the outlet of Lake Pepin. Data were analyzed for the Upper Mississippi River (UMIS) study unit of the USGS National Water-Quality Assessment Program. The UMIS study unit is a 47,000-square-mile basin that includes the drainage of the Mississippi River upstream from Lake Pepin and includes the Twin Cities Metropolitan Area (TCMA) containing most of the population of Minnesota. PCB data from common carp and walleye fillets collected from rivers in the UMIS study unit were obtained from the Metropolitan Council Environmental Services (MCES), the Minnesota Fish Contaminant Monitoring Program (MFCMP), the U.S. Fish and Wildlife Service (USFWS), and the Wisconsin Department of Natural Resources (WDNR).

PCBs in fish tissue are of concern because PCBs are potentially toxic, teratogenic, and have been linked to poor fetal development and endocrine disruption in fish and other animals, including humans, that consume fish. Because of the potential effects of PCBs on environmental and human health, it is important to develop strategies of management of PCBs. An understanding of PCB spatial and temporal trends is necessary to develop these strategies.

During 1975-87 and 1980-87, 10 and 4 percent of walleye samples and 45 and 36 percent of common carp samples, respectively, exceeded the USFDA guideline of 2 milligrams per kilogram (mg/kg) PCB in fish tissue. Individual PCB concentrations in common carp and walleye tissues were below the 2 mg/kg commercial USFDA limit set for commercial fisheries by the USFDA after 1987.

Median PCB concentrations at individual sites and within stream segments were generally greatest in common carp and walleye from Mississippi River segments in the TCMA during 1975-79 and 1980-87. Median PCB concentrations were generally lower in walleye than in common carp during 1975-79 and 1980-87 except in river segment UMR-4 during 1975-79. Median non-normalized and LNPCB concentrations in walleye were greatest in UMR-4 during 1975-79, and in UMR-5 in 1980-87, in contrast to PCB concentrations in common carp, which were greatest in UMR-3 during those time periods.

There was a significant difference ($P < 0.05$) among LNPCB concentrations in common carp considering all river segments combined during all three time periods. Common carp in UMR-3 and 4 in the TCMA had greater LNPCB concentrations than in other river segments. LNPCB concentrations in common carp and walleye at UMR-1, SC-1 and MN-1 (those segments upstream or outside the TCMA) were lower than those UMR segments within the TCMA (UMR-2,3,4,5). Median non-normalized and LNPCB concentrations in common carp in MN-2 and SC-2 were lower than those in UMR-3, but similar to other UMR segments within and downstream of the TCMA.

The spatial distribution of non-normalized PCB and LNPCB concentrations in common carp and walleye correspond with historical and current point- and non point-source PCB inputs in the densely populated TCMA. Greater population density and associated PCB sources could account for greater median and individual PCB and LNPCB concentrations in fish in the Mississippi River segments within and downstream of the TCMA (UMR 3,4 and 5) than in fish tissues from sites upstream of the TCMA. Greater PCB and LNPCB concentrations in common carp and walleye in SC-2 and MN-2 may also be related to greater urbanization which is associated with both point- and non point-source PCB contamination. PCB distribution is also related to sediment movement and deposition. PCB concentrations in fish were greater in areas that historically had elevated PCB concentrations in bed sediment. In addition to factors related to the environmental setting, other factors such as small data set sizes, differences in collection and laboratory procedures between agencies, and fish migration may also influence the spatial distribution of PCBs observed in this study.

Temporal trend determination included graphic analyses of sites and statistical analyses of river segments. Median PCB concentrations in common carp and walleye at individual sites were greatest in 1975-79 and 1980-87, and least during 1988-95 at most sites. Median PCB concentration declines at individual sites are most evident in the TCMA. There was a significant decrease in LNPCB concentration in common carp between 1975-79 and 1988-95 in UMR-1,2,3 and 5 and MN-2. Median LNPCB concentrations in common carp were highest from 1975-79, lower during 1980-87, and least from 1988-95, with the exception of SC-2 which had the highest median LNPCB concentration during 1980-87, and MN-1 which had a greater LNPCB concentration during 1988-95 than 1980-87. There was a significant decrease over time of LNPCB concentrations in walleye among time periods at UMR-5.

The results from these temporal analyses were similar to those of other studies in the United States and in Minnesota and Wisconsin that reported a significant downward trend in PCB concentrations in fish tissues. Although PCB concentrations have decreased during 1975-95, low concentrations of PCBs still remain in the aquatic environment despite the fact that PCBs were banned nearly 20 years ago. The decrease in PCB concentrations over the 20 year period evaluated can be attributed to termination of PCB production and reduction in PCB discharges into these rivers. However, improvements in laboratory procedures over the 20 year period could also contribute to a portion of the decrease, because earlier methods may have overestimated PCB concentrations in the early 1970's. PCB concentrations in walleye decreased more gradually over the 20-year time period, and were low enough that the variability in the data often masked any trend. In addition, data set sizes were small, which may influence the results.

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Supplemental Information

Table 3. Site numbers, rivers, segments, river miles, site names, and samplling agencies for sites sampled by the Minnesota Fish Contaminant Monitoring Program, Metropolitan Council Environmental Services, U.S. Fish and Wildlife Service, and Wisconsin Department of Natural Resources

Site No.[1]	River[2]	Segment[3]	River mile	Site name	Sampling agency[4]
1	UMR	UMR-1	UMR-1365	Mississippi River by Lake Itasca	MFCMP
2	UMR	UMR-1	UMRR-1172	Mississippi River in Blandin Reservoir at Grand Rapids	MFCMP
3	UMR	UMR-1	UMR-1171	Mississippi, Grand Rapids, downstream of Blandin Dam to Prairie River	MFCMP
4	UMR	UMR-1	UMR-1003.5	Mississippi River downstream of Dam at Brainerd	MFCMP
5	UMR	UMR-1	UMR-974	Mississippi River upstream of Little Falls Dam	MFCMP, USFWS
6	UMR	UMR-1	UMR-973.6	Mississippi River downstream of Little Falls Dam- upstream of RR bridge	MFCMP
7	UMR	UMR-1	UMR-966-965	Mississippi River downstream of Little Falls Dam (965.5)	MFCMP
8	UMR	UMR-1	UMR-933.2-953	Mississippi River Royalton to Sartell (943)	MFCMP
9	UMR	UMR-1	UMR-930	Mississippi River at Sauk Rapids	MFCMP
10	UMR	UMR-1	UMR-926	Mississippi River downstream of St. Cloud Dam	MFCMP
11	UMR	UMR-1	UMR-895	Mississippi River at Monticello	MFCMP
12	UMR	UMR-1	UMR-872	Mississippi River at Anoka USH-169	MFCMP, MCES
13	UMR	UMR-2	UMR-866	Mississippi River downstream of Coon Rapids Dam	MFCMP
14	UMR	UMR-2	UMR-859	Mississippi River at Fridley	MFCMP
15	UMR	UMR-2	UMR-853.5	Mississippi River in Minneapolis (downstream of upper SAF lock)	MFCMP
16	UMR	UMR-2	UMR-850	Mississippi River, Lock and Dam 1 to St. Anthony Falls	MFCMP
17	UMR	UMR-3	UMR-840	Mississippi River near St. Paul at Wabasha	MFCMP, MCES
18	UMR	UMR-3	UMR-830	Mississippi River near St. Paul	MFCMP
19	UMR	UMR-3	UMR-826	Mississippi River at Grey Cloud Island	MFCMP, MCES

Table 3. Site numbers, rivers, segments, river miles, site names, and samplling agencies for sites sampled by the Minnesota Fish Contaminant Monitoring Program, Metropolitan Council Environmental Services, U.S. Fish and Wildlife Service, and Wisconsin Department of Natural Resources--Continued

Site No.[1]	River[2]	Segment[3]	River mile	Site name	Sampling agency[4]
20	UMR	UMR-3	UMR-821	Mississippi River at Spring Lake near Sedil	MFCMP
21	UMR	UMR-3	UMR-819.6	Mississippi, Pool 2, 2 miles from St. Paul Park	MFCMP
22	UMR	UMR-3	UMR-817	Mississippi River near Hastings (upstream of Lock and Dam 2)	MFCMP
23	UMR	UMR-4	UMR-815	Mississippi river at Hastings (downstream of Lock and Dam 2)	MFCMP, MCES
24	UMR	UMR-4	UMR-811.5	Mississippi River by confluence with St. Croix River	MFCMP
25	UMR	UMR-4	UMR-802	Mississippi River near Diamond Bluff	MFCMP, MCES
26	UMR	UMR-4	UMR-797	Mississippi River near Red Wing	MFCMP, MCES
27	UMR	UMR-5	UMR-796	Mississippi River near Red Wing	MFCMP
28	UMR	UMR-5	UMR-790.5	Mississippi River near Red Wing	MFCMP, WDNR
29	UMR	UMR-5	UMR-760-785	Mississippi River - Pool 4 - Lake Pepin	MFCMP, USFWS, WDNR
30	SC	SC-1	SC-128	St. Croix River (St. Croix Rapids at St. Croix State Forest)	MFCMP
31	SC	SC-1	SC-118	St. Croix River 1 mile upstream of Hwy 48	MFCMP
32	SC	SC-1	SC-111	St. Croix River near Danbury	MFCMP
33	SC	SC-1	SC-108	St. Croix River at Clam River	MFCMP
34	SC	SC-1	SC-92	St. Croix River at Snake River Mouth	MFCMP
35	SC	SC-1	SC-87	St. Croix River near HWY 70	MFCMP
36	SC	SC-1	SC-83	St. Croix River near Steven's Creek	MFCMP
37	SC	SC-1	SC-52	St. Croix River upstream of St. Croix Falls	MFCMP
38	SC	SC-2	SC-50	St. Croix River at Interstate Park	MFCMP
39	SC	SC-2	SC-31	St. Croix River near Marine on the St. Croix	MFCMP, MCES, WDNR

Table 3. Site numbers, rivers, segments, river miles, site names, and samplling agencies for sites sampled by the Minnesota Fish Contaminant Monitoring Program, Metropolitan Council Environmental Services, U.S. Fish and Wildlife Service, and Wisconsin Department of Natural Resources--Continued

Site No.[1]	River[2]	Segment[3]	River mile	Site name	Sampling agency[4]
40	SC	SC-2	SC-17	St. Croix River near Hudson	MFCMP, WDNR
41	SC	SC-2	SC-11	St. Croix River at Afton	MFCMP
42	MN	MN-1	MN-305	Minnesota River at Big Stone Reservoir	MFCMP
43	MN	MN-1	MN-260	Minnesota River upstream of Granite Falls Dam	MFCMP
44	MN	MN-1	MN-252	Minnesota River at Granite Falls (downstream of dam)	MFCMP
45	MN	MN-1	MN-242	Minnesota River at Renville County Park	MFCMP
46	MN	MN-1	MN-196	Minnesota River at Morton	MFCMP
47	MN	MN-1	MN-155.5	Minnesota River near New Ulm	MFCMP
48	MN	MN-1	MN-120	Minnesota River near Judson	MFCMP
49	MN	MN-2	MN-112	Minnesota River near Mankato (downstream of Blue Earth River)	MFCMP
50	MN	MN-2	MN-99	Minnesota River neat Seven Mile Creek	MFCMP
51	MN	MN-2	MN-94	Minnesota River near Northstar	MFCMP
52	MN	MN-2	MN-88	Minnesota River at St. Peter	MFCMP
53	MN	MN-2	MN-64	Minnesota River near Henderson	MFCMP
54	MN	MN-2	MN-39	Minnesota River near Jordan	MFCMP, MCES
55	MN	MN-2	MN-35	Minnesota River at the Carver Rapids Area	MFCMP
56	MN	MN-2	MN-25	Minnesota River at Shakopee	MFCMP
57	MN	MN-2	MN-5	Minnesota River upstream of Fort Snelling	MFCMP, MCES
58	MN	MN-2	MN-3.5	Minnesota River at Fort Snelling Park	MFCMP

[1]Refers to numbers on figures 2, 3, and 4

[2]UMR- Mississippi River, SC- St. Croix River, MN- Minnesota River

[3]Refers to segments on figure 2

[4]MFCMP- Minnesota Fish Contaminants Monitoring Program, WDNR- Wisconsin Department of Natural Resources, MCES- Metropolitan Council Environmental Services, USFWS- U.S. Fish and Wildlife Service.

Table 4. Number of analyses and minimum, median, and maximum polychlorinated biphenyl and lipid-normalized polychlorinated biphenyl concentrations (in milligrams per kilogram) in common carp for each river segment within three time periods: 1975-79, 1980-87, and 1988-95 (Minnesota Fish Contaminants Monitoring Program 1975-95; Wisconsin Department of Natural Resources, 1975-95)
[na, not applicable; --, no data]

		1975-1979		1980-1987		1988-1995		P-value among time periods	Percent change between 1975-79 and 1988-95 medians
Segment	Statistic	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Lipid-normalized	Lipid-normalized
UMR-1	Number	11	11	22	22	6	6	0.000	-81
	Minimum	0.07	2.0	0.07	1.2	0.07	0.7		
	Median	**0.4**	**15.7**	**0.2**	**6.3**	**0.07**	**2.9**		
	Maximum	4.2	144.8	2.6	45.7	0.2	6.6		
UMR-2	Number	19	19	15	15	10	10	0.001	-90
	Minimum	0.07	4.7	0.1	2.6	0.07	1.1		
	Median	**1.2**	**46.7**	**0.7**	**14.3**	**0.1**	**4.5**		
	Maximum	20.8	1350.0	5.5	167.0	0.3	10.9		
UMR-3	Number	19	19	23	23	6	6	0.000	-93
	Minimum	0.5	16.1	0.6	4.8	0.07	4.4		
	Median	**5.9**	**151.3**	**3.4**	**49.8**	**0.2**	**10.6**		
	Maximum	33.0	406.2	8.2	342.0	0.7	47.3		
UMR-4	Number	5	5	15	15	--	--	na	--
	Minimum	0.5	30.7	0.7	7.3	--	--		
	Median	**3.0**	**73.8**	**2.4**	**35.4**	**--**	**--**		
	Maximum	6.7	1000.0	5.8	82.2	--	--		

Table 4. Number of analyses and minimum, median, and maximum polychlorinated biphenyl and lipid-normalized polychlorinated biphenyl concentrations (in milligrams per kilogram) in common carp for each river segment within three time periods: 1975-79, 1980-87, and 1988-95 (Minnesota Fish Contaminants Monitoring Program 1975-95; Wisconsin Department of Natural Resources, 1975-95)--Continued

[na, not applicable; --, no data]

		1975-1979		1980-1987		1988-1995		P-value among time periods	Percent change between 1975-79 and 1988-95 medians
Segment	Statistic	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Lipid-normalized	Lipid-normalized
UMR-5	Number	28	28	21	21	9	9	0.000	-91
	Minimum	0.4	11.4	0.1	1.2	0.07	2.6		
	Median	**2.4**	**39.0**	**1.2**	**19.0**	**0.2**	**3.4**		
	Maximum	12.0	285.7	7.2	85.7	0.9	48.3		
SC-1	Number	--	--	--	--	6	6	--	--
	Minimum	--	--	--	--	0.07	0.9		
	Median	**--**	**--**	**--**	**--**	**0.07**	**1.3**		
	Maximum	--	--	--	--	0.07	3.5		
SC-2	Number	10	10	9	9	7	7	0.084	-74
	Minimum	0.1	4.1	0.2	3.9	0.07	1.2		
	Median	**0.5**	**18.6**	**1.3**	**25.5**	**0.1**	**4.8**		
	Maximum	3.6	62.1	7.2	100.3	1.2	60.0		
MN-1	Number	8	8	4	4	6	6	0.441	-52
	Minimum	0.07	0.9	0.07	0.9	0.07	2.0		
	Median	**0.3**	**12.3**	**0.3**	**3.4**	**0.07**	**6.0**		
	Maximum	6.9	203.9	0.5	8.2	0.1	35		

Table 4. Number of analyses and minimum, median, and maximum polychlorinated biphenyl and lipid-normalized polychlorinated biphenyl concentrations (in milligrams per kilogram) in common carp for each river segment within three time periods: 1975-79, 1980-87, and 1988-95 (Minnesota Fish Contaminants Monitoring Program 1975-95; Wisconsin Department of Natural Resources, 1975-95)--Continued

[na, not applicable; --, no data]

		1975-1979		1980-1987		1988-1995		P-value among time periods	Percent change between 1975-79 and 1988-95 medians
Segment	Statistic	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Lipid-normalized	Lipid-normalized
MN-2	Number	15	15	12	12	7	7	0.020	-80
	Minimum	0.07	3.5	0.1	3.2	0.07	1.9		
	Median	**1.7**	**23.0**	**0.9**	**15.5**	**0.07**	**4.7**		
	Maximum	12.3	164.8	4.9	248.0	0.2	16.7		
P-value among segments within each time period			0.000		0.000		0.012		

Table 5. Number of analyses and minimum, median, and maximum polychlorinated biphenyl and lipid-normalized polychlorinated biphenyl concentrations in walleye for each river segment within three time periods: 1975-79, 1980-87, and 1988-95 (data from Minnesota Fish Contaminants Monitoring Program and Wisconsin Department of Natural Resources)

[na, not applicable; --, no data]

		1975-1979		1980-1987		1988-1995		P-value among time periods	Percent change between 1975-79 and 1988-95 medians
Segment	Statistic	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Lipid-normalized	Lipid-normalized
UMR-1	Number	2	2	2	2	6	6	na	+12
	Minimum	0.07	7.0	0.07	5.4	0.07	2.4		
	Median	**0.07**	**10.5**	**0.07**	**7.1**	**0.07**	**12.0**		
	Maximum	0.07	14.0	0.07	8.8	0.07	70.0		
UMR-2	Number	1	1	3	3	--	--	na	--
	Minimum	0.8	114.9	0.2	14.6	--	--		
	Median	**0.8**	**114.9**	**0.3**	**16.7**	**--**	**--**		
	Maximum	0.8	114.9	0.3	38.6	--	--		
UMR-3	Number	2	2	2	2	2	2	na	-88
	Minimum	0.3	37.5	0.2	22.9	0.1	6.7		
	Median	**0.4**	**64.6**	**0.2**	**24.6**	**0.1**	**7.2**		
	Maximum	0.6	91.7	0.2	26.2	0.2	7.7		
UMR-4	Number	2	2	12	12	--	--	na	--
	Minimum	6.5	282.6	0.1	16.0	--	--		
	Median	**8.2**	**374.6**	**0.4**	**44.5**	**--**	**--**		
	Maximum	9.8	466.7	3.8	230.0	--	--		

Table 5. Number of analyses and minimum, median, and maximum polychlorinated biphenyl and lipid-normalized polychlorinated biphenyl concentrations in walleye for each river segment within three time periods: 1975-79, 1980-87, and 1988-95 (data from Minnesota Fish Contaminants Monitoring Program and Wisconsin Department of Natural Resources)--Continued

[na, not applicable; --, no data]

		1975-1979		1980-1987		1988-1995		P-value among time periods	Percent change between 1975-79 and 1988-95 medians
Segment	Statistic	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Lipid-normalized	Lipid-normalized
UMR-5	Number	12	12	16	15	7	7	0.000	-77
	Minimum	0.3	50.0	0.1	12.5	0.2	16.7		
	Median	**1.0**	**118.3**	**0.6**	**63.2**	**0.5**	**26.9**		
	Maximum	1.6	180.0	3.6	100.0	1.1	84.6		
SC-1	Number	--	--	--	--	11	11	na	--
	Minimum	--	--	--	--	0.07	4.1		
	Median	**--**	**--**	**--**	**--**	**0.07**	**7.0**		
	Maximum	--	--	--	--	0.07	11.7		
SC-2	Number	--	--	5	4	2	2	na	--
	Minimum	--	--	0.07	14.0	0.2	20.0		
	Median	**--**	**--**	**0.3**	**33.7**	**0.4**	**35.0**		
	Maximum	--	--	0.7	55.0	0.6	50.0		
MN-1	Number	--	--	--	--	3	3	na	--
	Minimum	--	--	--	--	0.07	8.8		
	Median	**--**	**--**	**--**	**--**	**0.07**	**14.0**		
	Maximum	--	--	--	--	0.07	14.0		

Table 5. Number of analyses and minimum, median, and maximum polychlorinated biphenyl and lipid-normalized polychlorinated biphenyl concentrations in walleye for each river segment within three time periods: 1975-79, 1980-87, and 1988-95 (data from Minnesota Fish Contaminants Monitoring Program and Wisconsin Department of Natural Resources)--Continued

[na, not applicable; --, no data]

		1975-1979		1980-1987		1988-1995		P-value among time periods	Percent change between 1975-79 and 1988-95 medians
Segment	Statistic	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Non-normalized	Lipid-normalized	Lipid-normalized	Lipid-normalized
MN-2	Number	2	2	5	5	2	2	na	-94
	Minimum	0.6	130.0	0.1	20.0	0.07	10.0		
	Median	**1.1**	**165.6**	**0.2**	**35.0**	**0.07**	**10.9**		
	Maximum	1.6	201.2	0.5	58.8	0.1	11.8		
P-value among segments within each time period			0.019		0.044		0.005		

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