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Areal Distribution and Concentration of Contaminants of Concern in Surficial Streambed and Lakebed Sediments, Lake St. Clair and Tributaries, Michigan, 1990-2003

Scientific Investigations Report 2006-5189

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

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By Cynthia M. Rachol and Daniel T. Button

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	**By**	**To obtain**
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic yard (yd^3)	0.7646	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28,350	milligram (mg)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

ABBREVIATIONS USED IN THIS REPORT

AMLE	Adjusted Maximum Likelihood Estimation
AOC	Area of Concern
ATSDR	Agency for Toxic Substances and Disease Registry
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
HCB	Hexachlorocyclobenzene
HCH	Hexachlorocyclohexane
LEL	Lowest Effect Level
MCHD	Macomb County Health Department
MDEQ	Michigan Department of Environmental Quality
NIOSH	National Institute for Occupational Safety and Health
OME	Ontario Ministry of the Environment
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PEC	Probable Effect Concentration
PEC-Q	Probable Effect Concentration Quotient
SEL	Severe Effect Level
TEC	Threshold Effect Concentration
US	United States
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Areal Distribution and Concentration of Contaminants of Concern in Surficial Streambed and Lakebed Sediments, Lake St. Clair and Tributaries, Michigan, 1990–2003

By Cynthia M. Rachol and Daniel T. Button

Abstract

As part of the Lake St. Clair Regional Monitoring Project, the U.S. Geological Survey evaluated data collected from surficial streambed and lakebed sediments in the Lake Erie-Lake St. Clair drainages. This study incorporates data collected from 1990 through 2003 and focuses primarily on the U.S. part of the Lake St. Clair Basin, including Lake St. Clair, the St. Clair River, and tributaries to Lake St. Clair. Comparable data from the Canadian part of the study area are included where available. The data are compiled into 4 chemical classes and consist of 21 compounds. The data are compared to effects-based sediment-quality guidelines, where the Threshold Effect Level and Lowest Effect Level represent concentrations below which adverse effects on biota are not expected and the Probable Effect Level and Severe Effect Level represent concentrations above which adverse effects on biota are expected to be frequent.

Maps in the report show the spatial distribution of the sampling locations and illustrate the concentrations relative to the selected sediment-quality guidelines. These maps indicate that sediment samples from certain areas routinely had contaminant concentrations greater than the Threshold Effect Concentration or Lowest Effect Level. These locations are the upper reach of the St. Clair River, the main stem and mouth of the Clinton River, Big Beaver Creek, Red Run, and Paint Creek. Maps also indicated areas that routinely contained sediment contaminant concentrations that were greater than the Probable Effect Concentration or Severe Effect Level. These locations include the upper reach of the St. Clair River, the main stem and mouth of the Clinton River, Red Run, within direct tributaries along Lake St. Clair and in marinas within the lake, and within the Clinton River headwaters in Oakland County.

Although most samples collected within Lake St. Clair were from sites adjacent to the mouths of its tributaries, samples analyzed for trace-element concentrations were collected throughout the lake. The distribution of trace-element concentrations corresponded well with the results of a two-dimensional hydrodynamic model of flow patterns from the Clinton River into Lake St. Clair. The model was developed independent from the bed sediment analysis described in this report; yet it showed a zone of deposition for outflow from the Clinton River into Lake St. Clair that corresponded well with the spatial distribution of trace-element concentrations. This zone runs along the western shoreline of Lake St. Clair from L'Anse Creuse Bay to St. Clair Shores, Michigan and is reflected in the samples analyzed for mercury and cadmium.

Statistical summaries of the concentration data are presented for most contaminants, and selected statistics are compared to effects-based sediment-quality guidelines. Summaries were not computed for dieldrin, chlordane, hexachlorocyclohexane, lindane, and mirex because insufficient data are available for these contaminants. A statistical comparison showed that the median concentration for hexachlorobenzene, anthracene, benz[*a*]anthracene, chrysene, and pyrene are greater than the Threshold Effect Concentration or Lowest Effect Level.

Probable Effect Concentration Quotients provide a mechanism for comparing the concentrations of contaminant mixtures against effects-based biota data. Probable Effect Concentration Quotients were calculated for individual samples and compared to effects-based toxicity ranges. The toxicity-range categories used in this study were nontoxic (quotients < 0.5) and toxic (quotients > 0.5). Of the 546 individual samples for which Probable Effect Concentration Quotients were calculated, 469 (86 percent) were categorized as being nontoxic and 77 (14 percent) were categorized as being toxic. Bed-sediment samples with toxic Probable Effect Concentration Quotients were collected from Paint Creek, Galloway Creek, the main stem of the Clinton River, Big Beaver Creek, Red Run, Clinton River towards the mouth, Lake St. Clair along the western shore, and the St. Clair River near Sarnia.

Introduction

The waterway formed by the St. Clair River, Lake St. Clair, and the Detroit River connects Lake Huron with Lake Erie and is part of the international boundary between the United States and Canada (fig. 1). Within this waterway, the Detroit River is one of 14 rivers nationwide designated as a National Heritage River because of its historically strategic importance for navigation in the Great Lakes. The waterway provides a water supply for about 4 million people, critical habitat for maintaining biodiversity in the aquatic environment and supporting fisheries, and major recreational opportunities for southeastern Michigan and southern Ontario. Major streams that discharge to the waterway upstream from Belle Isle in Detroit River are the Black, Belle, Pine, and Clinton Rivers in the United States and the Thames and Sydenham Rivers in Ontario, Canada.

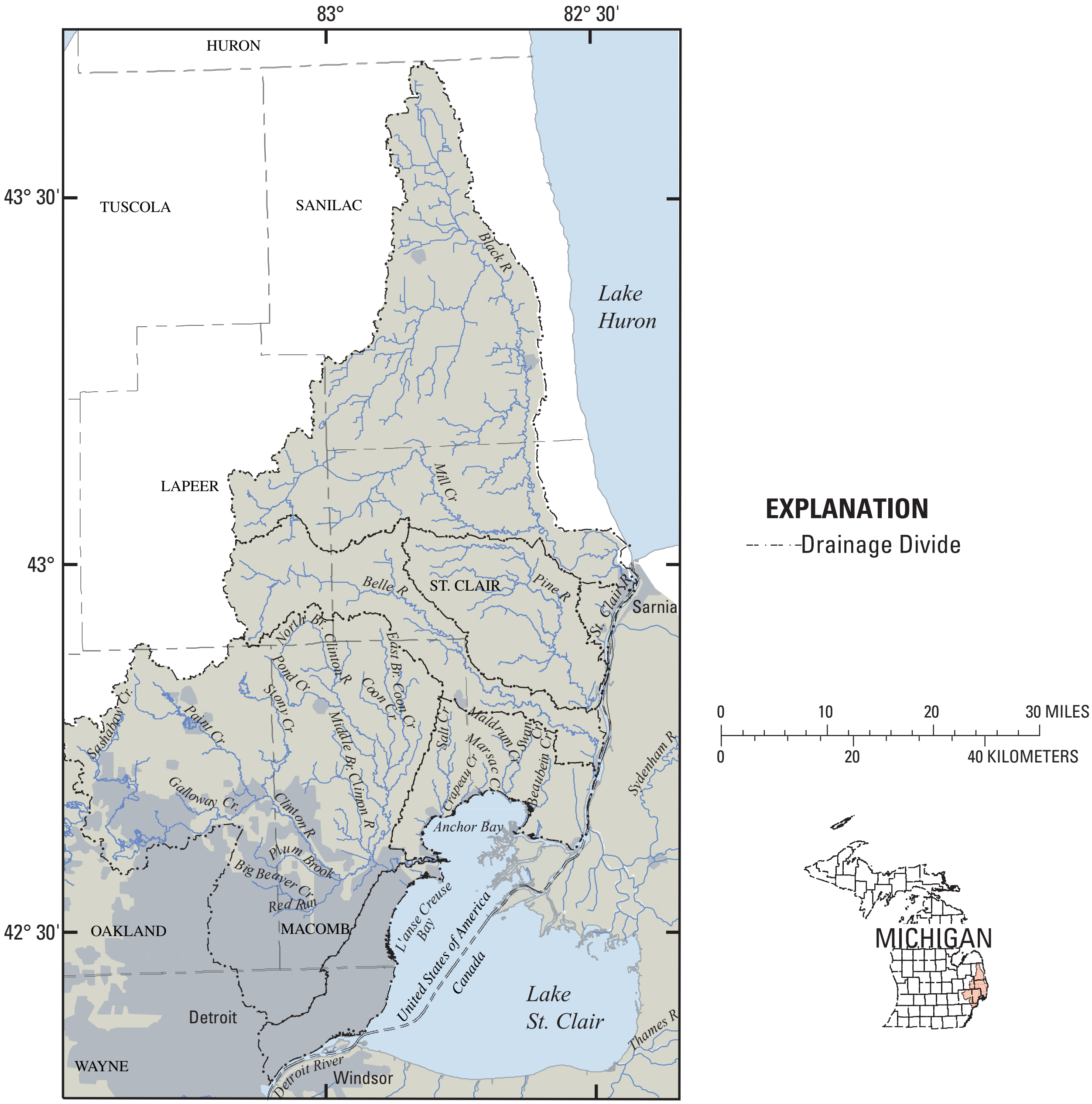


Figure projection is Albers, False_Easting: 0.000000, False_Northing: 0.000000, Central_Meridian: -83.000000, Standard_Parallel_1: 29.500000, Standard_Parallel_2: 45.500000, Latitude_Of_Origin: 23.000000, GCS_North_American_1983.
County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 1. Location of Lake St. Clair, St. Clair River, Clinton River, Belle River, Pine River, and Black River drainage basins, Mich.

In an effort to clean up the most polluted areas in the Great Lakes, the Great Lakes Water-Quality Board of the International Joint Commission has designated drainages to the St. Clair River as an Area of Concern (AOC). The AOC designation commits state and provincial governments to developing and implementing Remedial Action Plans (RAPs) as part of their watershed planning efforts. In 2003, as part of the ongoing monitoring, assessment, and remediation efforts in this region, the Lake St. Clair Regional Monitoring Project partners (Macomb County Health Department, Oakland County Drain Commissioner, St. Clair County Health Department, Wayne County Department of Environment, Macomb County Public Works Department, Michigan Department of Environmental Quality, Environmental Consulting and Technology, Inc., and U.S. Geological Survey) developed plans for a 3-year water-quality assessment and monitoring of the basins within the United States that drain to Lake St. Clair (fig. 1). The Lake St. Clair Regional Monitoring Project is a comprehensive assessment of the hydrological, chemical, and physical state of the surface water of the study area. The plan includes water-quality monitoring, collection of discrete (grab) and automatic water-quality samples, and monitoring of bacteria.

To support the water-quality assessments conducted under the Lake St. Clair Regional Monitoring Project, the U.S. Geological Survey (USGS) compiled sediment-quality data from international, federal, state, and local databases for Lake St. Clair, and the St. Clair, Black, Pine, Belle, and Clinton Rivers. Contaminant concentrations were summarized and compared with selected freshwater bed-sediment-quality guidelines that are commonly used in the Great Lakes area.

Sediments act as a sink or storage medium for contaminants released to the water column or deposited from atmospheric loads, and they provide a mechanism for the transport and storage of contaminants in the environment (Prosser and others, 2001). By understanding the distribution of contaminated sediments, identifying critical hot spots, and locating potential sources of contaminants, strategies can be developed towards isolating or remediating contaminated sediments and improving the surrounding water quality and aquatic habitat.

Purpose and Scope

This report describes the spatial distribution and concentrations of contaminants of concern in streambed and lakebed sediments in the U.S. part of the Lake St. Clair Basin, including tributaries to Lake St. Clair, the St. Clair River, and Lake St. Clair. Where available, data on sediment-quality conditions in the Canadian part of the watershed also were compiled and evaluated. Summary statistics were calculated and compared to sediment-quality guidelines for aquatic macroinvertebrates.

This compilation relied on available bed-sediment-quality data collected as part of numerous studies from 1990 to 2003. The classes of compounds discussed in this report are organochlorine pesticides, total polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and trace elements, including mercury. Compounds from these classes have been identified by the International Joint Commission as critical contaminants that merit primary emphasis in remediation activities because of their effect on aquatic organisms and aquatic-dependent wildlife (International Joint Commission, 1998).

Although one of the purposes of this report is to describe the spatial extent and ranges of contaminant concentrations in streambed and lakebed sediments in the Lake St. Clair Basin, it is important to note that numerous dredging activities may have influenced some of the results discussed. Ongoing navigational and (or) remedial dredging programs remove contaminated lakebed and streambed sediments; it is fully conceivable that this dredging may remove some, but not all, of the contaminated sediments within a particular area. The overall effect reduces the mass of specific contaminants, resulting in certain areas that may be less contaminated than shown in this report. Also, it should be apparent that dredging activities meant to remove contaminated materials that have been buried through natural riverine processes may expose these materials and induce oxidizing reactions, thereby releasing the contaminants to the water column.

Additionally, this report does not directly address the effect of contaminant mixtures on biota. Current literature on bed-sediment quality suggests that the bioavailability of contaminants may be limited by synergistic and antagonistic relations between various contaminants. Aquatic biota data matching the sediment-quality data analyzed for this study were not available; therefore, the data used in this study were compared to toxicity ranges established as part of other studies of contaminated sediments in freshwater environments.

Description of Study Area

The St. Clair River and Lake St. Clair are part of a waterway that connects Lake Huron to Lake Erie along the international border between the United States and Canada (fig. 1). The St. Clair River originates at the outlet of Lake Huron and empties into Lake St. Clair through a large delta. Lake St. Clair has an estimated drainage area of 228,800 mi^2 at its outlet into the Detroit River, including the upper Great Lakes. The main U.S. tributaries and their U.S. drainage areas within the Lake St. Clair Basin are the St. Clair (1,157 mi^2), Clinton (797 mi^2), Belle (227 mi^2), Pine (195 mi^2), and Black Rivers (710 mi^2). Bed-sediment chemistry data collected from these tributaries and parts of the St. Clair River and Lake St. Clair were included as part of this analysis.

The study area covers parts of Sanilac, Lapeer, Wayne, and Oakland Counties and all of Macomb and St. Clair Counties in southeastern Michigan. These counties contain 23 percent of the Michigan population (U.S. Census Bureau, 2002) and are some of the fastest growing counties in the State. Land use within the study area is a mix of urban areas, agricultural land, forests, and wetlands. Land-cover data collected between

1997 and 2000 show that the northern part of the study area is dominated by agricultural land and forest, whereas the southern part is mostly urban and forest, generally in the form of parkland (fig. 2; Pacific Meridian Resources, 2001).

Study Analysis

This study relied on digital and hardcopy data for surficial bed-sediment samples collected between 1990 and 2003 from streams and lakes across the U.S. part of the Lake St. Clair Basin. Sources of the data include federal, state, provincial, and local agencies. Bed-sediment data were compiled from projects and studies by the Ontario Ministry of the Environment (OME), U.S. Army Corps of Engineers (USACE), USGS, Michigan Department of Environmental Quality (MDEQ), St. Clair County Drain Commission, and Macomb County Health Department (MCHD). The data collected by these agencies were used to support dredging programs and routine assessments of sediment quality and to assist in contaminant-plume characterization and source identification. Although the data included both core and grab samples, the core samples were included in this study only if the sampling interval was less than 12 in. from the sediment-water interface or contained subsamples comprising intervals less than 12 in.

Comparison with Sediment-Quality Guidelines

For this report, bed-sediment data were compared to sediment-quality guidelines developed by MacDonald and others (2000) and Persaud and others (1993, table 1). The guidelines of MacDonald and others (2000) — Threshold Effect Concentration (TEC) and Probable Effect Concentration (PEC) — are more conservative than those of Persaud and others (1993). The TEC and PEC guidelines were developed through a consensus-based analysis of other published sediment-quality guidelines. The guidelines developed by Persaud and others (1993) specify Lowest Effect Level (LEL) and Severe Effect Level (SEL) concentrations for three organochlorine insecticides not addressed by MacDonald and others (2000). The LEL and SEL guidelines were generated by means of a screening-level concentration approach, which consists of matching data on whole-sediment chemistry and benthic-invertebrate community structure.

Although most sediment-quality guidelines are related to concentrations in marine and estuarine sediments (Long and Morgan, 1991), the guidelines of MacDonald and others (2000) and Persaud and others (1993) were developed through studies of freshwater sediments and are frequently used to assess the possible effects of contaminants in surficial bed sediments on populations of benthic macroinvertebrates in the Great Lakes Basin. For the sediment-quality guidelines used, the TECs represent concentrations below which adverse effects on biota are not expected; the PECs represent concentrations above which adverse effects on biota are expected to be frequent. Most organochlorine insecticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and trace elements discussed in this report were evaluated using PECs and TECs. However, for hexchlorobenzene, total hexachlorocyclohexane, and mirex, PEC and TEC guidelines were not available. As a substitute, the LEL and SEL were used.

These guidelines serve as screening tools for estimating the potential toxicity of streambed sediments in freshwater streams; however, they do not replace the need for toxicity testing or aquatic-community assessments to determine specific adverse effects on native aquatic organisms at a particular site. These guidelines provide no measure or assumption of biological uptake to fish species or human exposure. Site-specific evaluations of fish and benthic communities provide an indication of the effect of contaminant biomagnification within the food chain and of the subtle effects of contaminants on the reproduction, growth, and behavior of aquatic organisms.

Depiction of Areal Distribution of Contaminants

The available sediment-chemistry data were plotted on base maps of the study area using latitude and longitude coordinates associated with each sampling location (figs. 3–24). Symbology applied to each map is based on the sediment-quality guidelines used for each constituent: green indicates that the concentration was not detected (for detection limits less than the TEC or LEL) or that the concentration was less than the TEC or LEL; yellow indicates that the concentration was between the TEC or LEL and PEC or SEL; orange indicates that the concentration was greater than the PEC or SEL; and red indicates that the concentration was greater than 10 times the PEC or SEL. A mapping order was used to ensure that pertinent data were not obscured by unavoidable overlapping of symbols. This mapping order set the priority of the visible data as follows:

1. For locations where more than one sample was collected (the site was sampled over a number of years or conditions), the most recent concentration supersedes the former concentrations, and its value is visible on top.

2. Higher concentrations are symbolized by larger circles. On the map, these larger symbols will plot behind symbols representing lower concentrations so as not to obscure them. The higher concentrations will cover the lower concentrations if they are more recent. For multiple samples collected on the same day (such as the case with subsampled core sections all less than 12 in. deep) the highest concentrations supersede the lower concentrations, the idea being that the chances of a false positive are much less than chances of a false negative.

3. The same symbology is applied to sample concentrations that were less than the TEC or LEL and sample

Table 1. Selected sediment-quality guidelines for freshwater bed sediment that have been observed or predicted to be associated with adverse effects on benthic macroinvertebrates.
[Sediment concentrations are dry weight; µg/kg, microgram per kilogram; mg/kg, milligram per kilogram; --, no guideline available; *, guideline used in contaminant maps in figures 3–24 of this report.]

Constituent	U.S. Environmental Protection Agency Great Lakes Sediment-Quality Guidelines[1]		Ontario Ministry of the Environment Provincial Sediment-Quality Guidelines[2]	
	Threshold Effect Concentration (TEC)	Probable Effect Concentration (PEC)	Lowest Effect Level (LEL)	Severe Effect Level (SEL)
Organochlorine insecticides or biocides				
Chlordane, total (µg/kg)	3.24*	17.6*	7	60
DDT, total (µg/kg)	5.28*	572*	7	120
Dieldrin plus aldrin (µg/kg)	1.9*	61.8*	2	910
Hexcachlorobenzene (µg/kg)	--	--	20*	240*
Hexachlorocyclohexane, total (µg/kg)	--	--	3*	120*
Lindane (µg/kg)	2.37*	4.99*	--	--
Mirex, total (µg/kg)	--	--	7*	1,300*
Industrial organochlorine compounds				
PCBs, total (µg/kg)	59.8*	676*	70	5,300
Polycyclic aromatic hydrocarbons				
Anthracene (µg/kg)	57.2*	845*	220	3,700
Benz[*a*]anthracene (µg/kg)	108*	1,050*	320	14,800
Benzo[*a*]pyrene (µg/kg)	150*	1,450*	370	14,400
Chrysene (µg/kg)	166*	1,290*	340	4,600
Phenanthrene (µg/kg)	204*	1,170*	560	9,500
Pyrene (µg/kg)	195*	1,520*	490	8,500
PAHs, total (µg/kg)	1,610*	22,800*	4,000	100,000
Trace elements				
Arsenic (mg/kg)	9.79*	33*	6	33
Cadmium (mg/kg)	0.99*	4.98*	0.6	10
Copper (mg/kg)	31.6*	149*	16	110
Lead (mg/kg)	35.8*	128*	31	250
Mercury (mg/kg)	.18*	1.06*	.2	2
Zinc (mg/kg)	121*	459*	120	820

[1] MacDonald and others, 2000.
[2] Persaud and others, 1993.

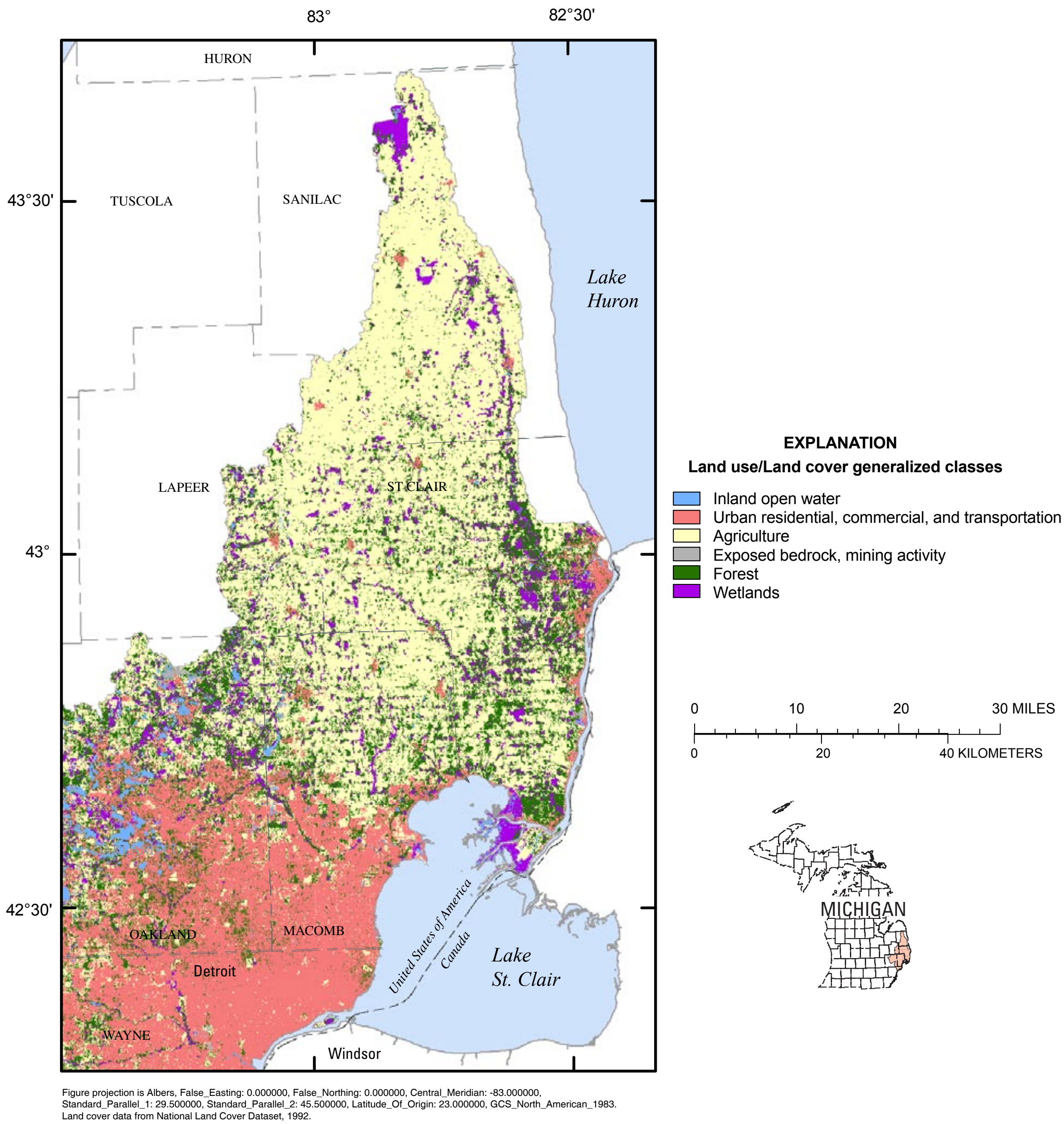


Figure 2. Land cover in the Clinton River, Belle River, Pine River, and Black River drainage basins, Mich.

concentrations that were censored by a detection limit that was less than the TEC or LEL. Because the censored sample concentrations and limits were below the levels of interest, they are considered to be innocuous.

4. Also included in the maps are sample locations where the concentration was less than the detection limit, but the detection limit was greater than the TEC or the LEL. The interest for these points shifts from knowing how high above the TEC or LEL the detection limits were to knowing the location of these sites and their usefulness to this evaluation. Because the detection limits were greater than the level of interest and the analytical methods used did not detect the presence of a specified constituent, the amount of interpretation that can be done for these sites is limited. Constituents with detection limits greater than the TEC or LEL provide minimal information as to the biological effects of the constituents. These locations are identified as small, gray circles.

5. Additionally, sample locations in which the concentration was censored by detection limits but the detection limits were not provided with the data are included in the maps. For the same reason as those constituents for which the analytical detection limits were greater than the TEC and LEL, the interest for these sites is in knowing their locations, and their usefulness in evaluating biological effects. These locations are identified as small, open circles.

Statistical Analysis

Summary statistics of the data were calculated for each constituent by use of the adjusted maximum likelihood estimation (AMLE) method (Helsel and Hirsch, 2002). In the application of this method, it is assumed that the data follow a known distribution; typically, environmental data are most often characterized by a lognormal distribution (Helsel, 2005). For each constituent, observed data were used to define a lognormal curve representing a hypothetical overall data distribution. Summary statistics were estimated from the hypothetical distribution and are assumed to describe the population as a whole. The AMLE method yields unbiased statistics if the observed data fit an exact lognormal distribution and if the sample size is large (25 or more concentration values greater than the detection limit; Helsel and Hirsch, 2002). If the data did not fit well to a lognormal distribution, the mean and standard deviation contained large estimation errors; in addition, transforming the data in order to fit into a lognormal distribution resulted in a bias. This bias is reflected in the mean and standard deviation as the estimates were transformed for the lognormal distribution and retransformed back to the original units. For data with a small number of detections, the mean and standard deviation tend to be overestimated (Helsel, 2005).

Because the AMLE relies on an assumed distribution based on the observed data, the overall dataset may contain values censored at more than one detection limit. The data for all constituents except copper used in this study has been censored at multiple detection limits. The ranges of detections limits are listed in table 2. For five of the constituents evaluated as part of this study, concentrations were greater than the detection limits in fewer than 25 samples. These constituents were chlordane, dieldrin plus aldrin, hexachlorocyclohexane, lindane, and mirex. Summary statistics were not calculated for these constituents.

Calculation of Probable Effect Concentration Quotients

Data describing the effects of the contaminants contained in the sediment samples analyzed in this report on biota were not available. In its place, this study relied on the findings of a study conducted by Ingersoll and others (2000), where the predictability of sediment-quality guidelines was tested against effects-based data for the amphipod *Hyalella azteca* and the midge *Chironomus tentans*. The effects-based data used by Ingersoll and others (2000) provided comparisons with 10- to 28-day toxicity tests for *Hyalella azteca* and 10- to 14-day toxicity tests for *Chironomus tentans.* A straight-forward comparison of the toxicity data with the matching sediment-quality data only provided a means for evaluating individual sediment-quality guidelines and classifying samples as toxic or nontoxic. Ingersoll and others (2000) proposed a sediment quality screening tool which may be used to determine sediment toxicity where mixtures of several contaminants are present. Their method, Probable Effect Concentration Quotients (PEC-Qs), provide a mechanism for comparing the concentrations of contaminant mixtures against effects-based biota data (MacDonald and others, 2000; Ingersoll and others, 2000). Overall, a consistent increase in toxicity was observed at mean PEC-Qs of >0.5. For this study, 0.5 was used as the breakpoint between toxic and nontoxic mean PEC-Qs.

PEC-Qs were calculated by dividing the sample concentration by its respective PEC concentration. In order to calculate a mean PEC-Q for each sample, the PEC-Qs for individual contaminants were summed and divided by the number of contaminants in the analysis. For PAHs, these calculations included only total PAH and not individual PAH compounds so that certain compounds were not included twice. In addition, constituent concentrations that were below the reported detection limit were included in the analysis and assigned values equal to half of the detection limit. The AMLE method described in the previous section is not applicable to this phase of the analysis; it is a means for estimating statistics descriptive of a population of data, but it is limited when estimating values for a specific sample.

Table 2. Number of samples collected for analysis of each chemical constituent, number of samples with detections, and range of detected concentrations. [Sediment concentrations are dry weight; µg/kg, microgram per kilogram; mg/kg, milligram per kilogram; --, no concentration range.]

Constituent	Total number of samples	Range of detected concentrations	Range of detection limits for non-detected samples	Number of samples not detected			Number of samples less than the TEC*	Number of samples between TEC* and PEC*	Number of samples greater than PEC*	Number of samples greater than 10 x PEC*
				Detection limit unknown	Detection limit greater than TEC*	Detection limit less than TEC*				
Organochlorine insecticides or biocides										
Chlordane, total (µg/kg)**	293	0.8-120	1-520	49	198	42	2	0	2	0
DDT, total (µg/kg)	291	2.3-22,000	1.4-130	48	119	54	4	65	0	1
Dieldrin plus aldrin (µg/kg)**	293	--	1-130	48	241	4	0	0	0	0
Hexachlorobenzene (µg/kg)	254	2-1,100	1-19,000	0	149	8	17	71	9	0
Hexachlorocyclohexane, total (µg/kg)**	293	2-40	1-162	48	192	42	1	10	0	0
Lindane (µg/kg)**	293	2-40	0.7-130	48	146	97	1	0	1	0
Mirex, total (µg/kg)**	52	--	1-130	0	8	44	0	0	0	0
Industrial organochlorine compounds										
PCBs, total (µg/kg)	494	20-8,520	20-3,300	45	210	55	31	128	23	2
Polycyclic aromatic hydrocarbons										
Anthracene (µg/kg)	390	20-13,000	20-4,100	43	105	90	38	95	18	1
Benz[*a*]anthracene (µg/kg)	390	16-36,000	20-4,100	39	93	33	85	108	29	3
Benzo[*a*]pyrene (µg/kg)	382	34-23,000	40-4,000	38	81	79	54	106	22	2
Chrysene (µg/kg)	390	14-28,000	20-4,000	38	75	27	101	109	36	4
Phenanthrene (µg/kg)	244	11-35,000	46-4,000	38	69	21	31	53	28	4
Pyrene (µg/kg)	208	20-57,000	46-4,000	36	58	14	31	62	38	5
PAHs, total (µg/kg)	246	81-317,500	40-4,000	35	5	54	56	77	17	2

*For hexachlorobenezene, hexachlorocyclohexane, and mirex, the LEL and SEL were used in place of the TEC and PEC.

**Summary statistics were not calculated for contaminants with less than 25 samples.

Magnitude and Areal Distribution of Sediment Contaminants in the Lake St. Clair Basin

Data from surficial bed-sediment samples collected from the Lake St. Clair Basin were analyzed for 21 USEPA-designated contaminants of concern. These contaminants are those for which sufficient data were available for analysis and for which bed-sediment-quality guidelines have been established. Four chemical classes comprise these contaminants: organochlorine pesticides, PCBs, PAHs, and trace elements. The number of samples collected for analysis of each chemical constituent, the number of samples with detections, and the range of the detected concentrations used in this report are listed in table 2. Maps showing the spatial distribution and concentration relative to the selected sediment-quality guidelines for each of the 21 constituents accompany the discussion of the chemical classes (figs. 3–24).

Organochlorine Insecticides or Biocides

Organochlorine compounds analyzed for this report are organochlorine pesticides and polychlorinated biphenyls (PCBs). Many organochlorine pesticides are no longer manufactured or sold for use in the United States or Canada because of environmental and human-health concerns. An exception is lindane, which is sold by prescription for control of head lice. Organochlorine pesticides and PCBs are still manufactured and used in certain parts of the world. Organochlorine compounds are characterized by their great persistence in the environment and are considered highly toxic to fish and other aquatic organisms. These compounds have a high affinity for lipids, resulting in their biomagnification in the food chain. Chlorinated organic compounds are hydrophobic; they tend to adsorb to organic carbon and other fine particles in suspended and bed sediments. Because of this behavior, these compounds can be present in sediments in concentrations that are orders of magnitude greater than those in water. Therefore, sediments can serve as a mechanism by which environmentally persistent organochlorine compounds remain in a surface-water system many years after their initial input (Smith and others, 1988).

Total chlordane (sum of chlordane, oxychlordane, cis-nonachlor, and trans-nonachlor)

Chlordane is a wide-spectrum insecticide that was introduced in 1947 for urban and agricultural uses. Chlordane consists of gamma and alpha isomers and technical chlordane. Oxychlordane, cis-nonachlor, and trans-nonachlor are formed when chlordane degrades in the environment. Chlordane has been used for the control of mosquitoes, cockroaches, ants, and termites. According to the Agency for Toxic Substances and Disease Registry (ATSDR; 2005), chlordane was used in agricultural and residential applications (lawns and gardens), and for control of termites. USEPA restricted its agricultural use in 1976, banned all uses except termite control in 1983, and discontinued all uses in 1988. According to the National Institute for Occupational Safety and Health (NIOSH; 1999), chlordane is toxic to aquatic organisms and is an environmental hazard because of its persistence. Moreover, it degrades slowly in the environment, strongly adheres to soil, and is hydrophobic (Agency for Toxic Substances and Disease Registry, 2005).

Detected concentrations of chlordane in the Lake St. Clair Basin ranged from 0.8 to 120 µg/kg. The detection limits for censored data ranged from 1 to 520 µg/kg. The dataset contained four samples with detected chlordane concentrations (table 2), which is an insufficient number for calculation of summary statistics. The highest concentrations of chlordane were measured in Lake St. Clair at the mouths of the Clinton River (120 µg/kg) and Crapeau Creek (104 µg/kg, fig. 3); both samples exceeded the PEC of 17.6 µg/kg. The other two detected values were measured in samples collected from the Clinton River (0.8 µg/kg) and Paint Creek (3.0 µg/kg).

Total DDT (sum of isomers of DDT, DDD, and DDE)

Dichlorodiphenyltrichloroethane (DDT) degrades to dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD), which also are toxic and highly resistant to further chemical decomposition. DDT and its isomers are the most persistent of all contact insecticides because of their insolubility in water and low vapor pressure (Gessner and Griswold, 1978). The ATSDR (2005) indicated that DDT, DDE, and DDD are rapidly broken down by sunlight; they strongly adhere to soil and are hydrophobic. Widespread use of DDT in the United States began in 1939, peaked in the 1960s, continued until about 1970, and greatly declined when DDT was discontinued in 1972. The degradate DDE has no commercial uses; however, DDD has been used as a pesticide and, in one form, has been used medically to treat cancer of the adrenal gland. According to NIOSH (1999), DDT is highly toxic to aquatic organisms and has the ability to bioaccumulate. DDT tends to accumulate in plants and in fatty animal tissues.

Detected concentrations of DDT in the Lake St. Clair Basin ranged from 2.3 to 22,000 µg/kg. The detection limits for censored data ranged from 1.4 to 130 µg/kg. Concentrations of DDT greater than the TEC were found in the main stem of the Clinton River; in Big Beaver Creek and Red Run; along the western shore of Lake St. Clair at the mouths of Swan Creek, Crapeau Creek, Salt Creek, and Pitts Drain; and along the southeastern shore of Lake St. Clair (fig. 4). All of the sample concentrations that were greater than the TEC were below the PEC, except for one sample concentration that was 22,000 µg/kg, which is more than 10 times the PEC.

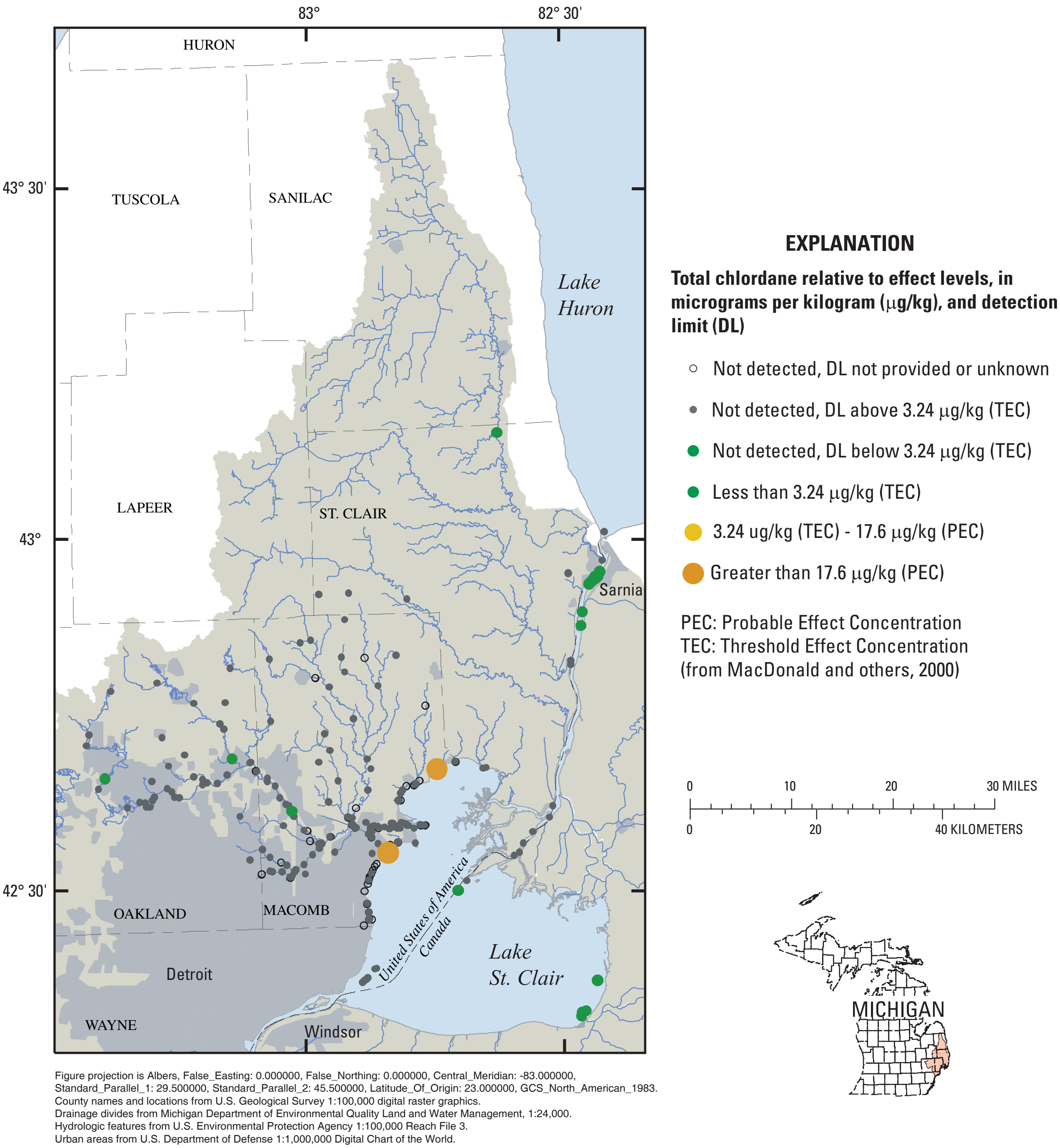
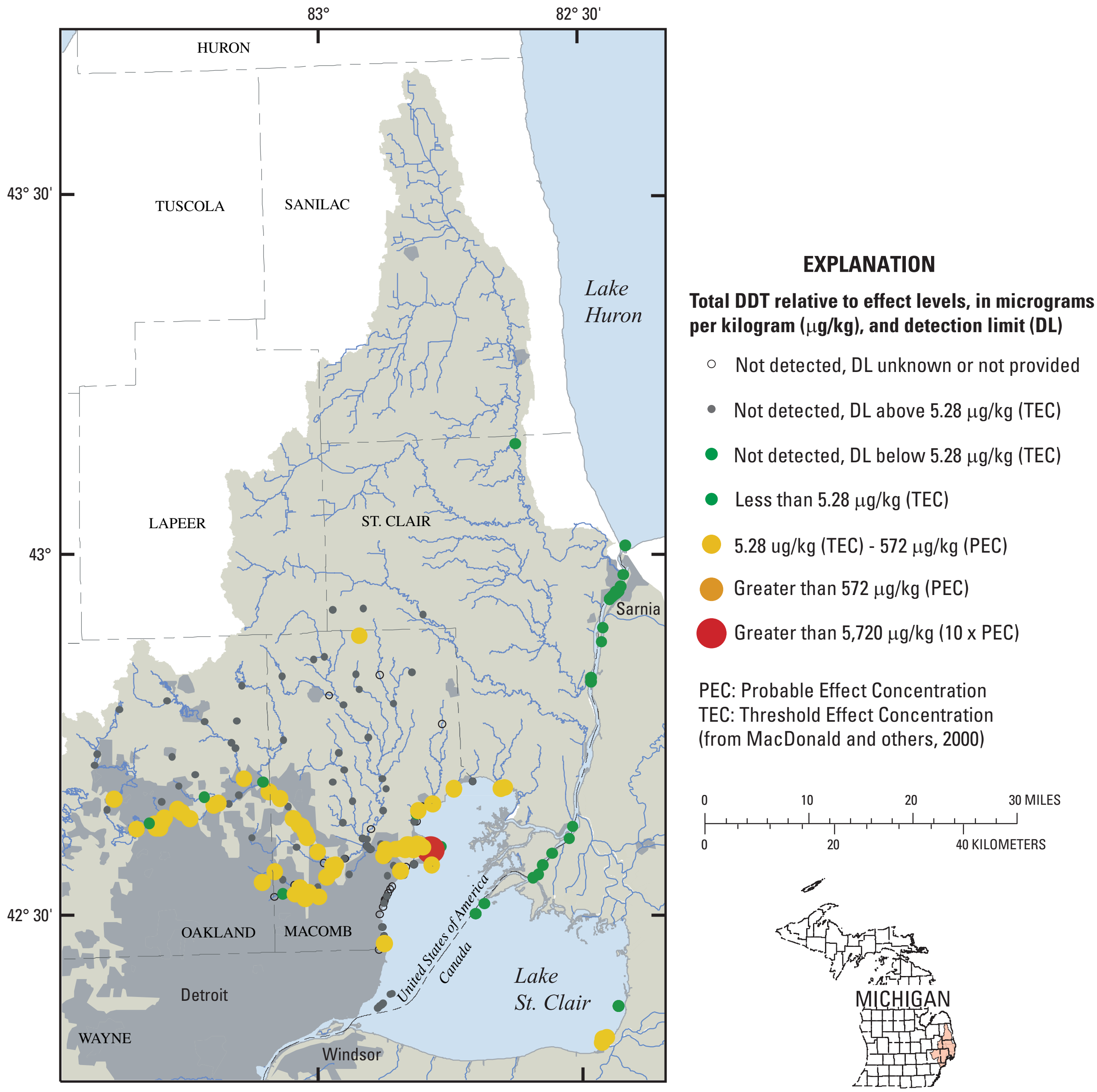


Figure 3. Total chlordane concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.



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County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 4. Total DDT concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

Total dieldrin (sum of dieldrin plus aldrin)

Dieldrin and aldrin were two of the most widely used chlorinated hydrocarbon pesticides prior to 1974. In 1974, all pesticide uses of these chemicals were canceled except for in-ground termite control, mothproofing, and application onto nonfood roots. Most remaining uses for aldrin were banned in the United States by 1987, and the last product was discontinued in 1991 (Binational Toxic Strategy, 1998). Both chemicals were used primarily in agricultural areas to control insect pests, originally on corn and later on citrus fruits (U.S. Environmental Protection Agency, 1993). These substances also were used in urban areas for control of termites, cockroaches, and fire ants into the 1980s.

According to NIOSH (1999), both dieldrin and aldrin are very toxic to aquatic organisms, have the ability to bioaccumulate, and are environmentally persistent. Aldrin is metabolically converted to dieldrin by bacteria and sunlight. Aldrin rapidly degrades to dieldrin in plants and animals, whereas dieldrin is stored in fatty tissues and tends to leave the body slowly (Agency for Toxic Substances and Disease Registry, 2005).

All 293 sediment samples from the Lake St. Clair Basin had concentrations of total dieldrin below their respective detection limits, which ranged from 1 to 130 µg/kg (table 2). Concentrations in four of the samples were censored at detection limits that were less than the TEC concentration of 1.90 µg/kg, and concentrations in 241 of the samples were censored at detection limits that were greater than the TEC. The detection limit of dieldrin in analysis of 48 of the samples were not provided or are unknown. Most of the samples analyzed for total dieldrin were from locations spread across the Clinton River Basin, in the upper and lower reaches of the St. Clair River, and along the western shore of Lake St. Clair (fig. 5). Because all dieldrin concentrations were censored, summary statistics were not calculated for this constituent.

Hexachlorobenzene

Hexachlorobenzene (HCB) was used until 1965 as a fungicide to protect seeds of onions and of sorghum, wheat, and other grains. Additionally, it was used in the making of fireworks, ammunition, and synthetic rubber (Agency for Toxic Substances and Disease Registry, 2005). Commercial uses for HCB have been discontinued in the United States. According to NIOSH (1999), HCB is very toxic to aquatic organisms and has the ability to bioaccumulate. It is also hydrophobic and strongly adheres to sediment, giving it the ability to persist for long periods in the environment (Agency for Toxic Substances and Disease Registry, 2005). HCB has been known to build up to high concentrations in plants and animals.

Detected concentrations of HCB in the Lake St. Clair Basin ranged from 2 to 1,100 µg/kg. The detection limits for censored data ranged from 1 to 19,000 µg/kg. Of the 254 samples, HCB was detected in 97 (table 2). Seventy-one of these samples had concentrations that were greater than the LEL of 20 µg/kg and were less than the SEL of 240 µg/kg; nine samples had concentrations greater than the SEL, ranging from 260 to 1,100 µg/kg. These samples were clustered in the upper reaches of the St. Clair River nearshore to Sarnia (fig. 6).

Total hexachlorocyclohexane (sum of α, β, δ, and γ isomers)

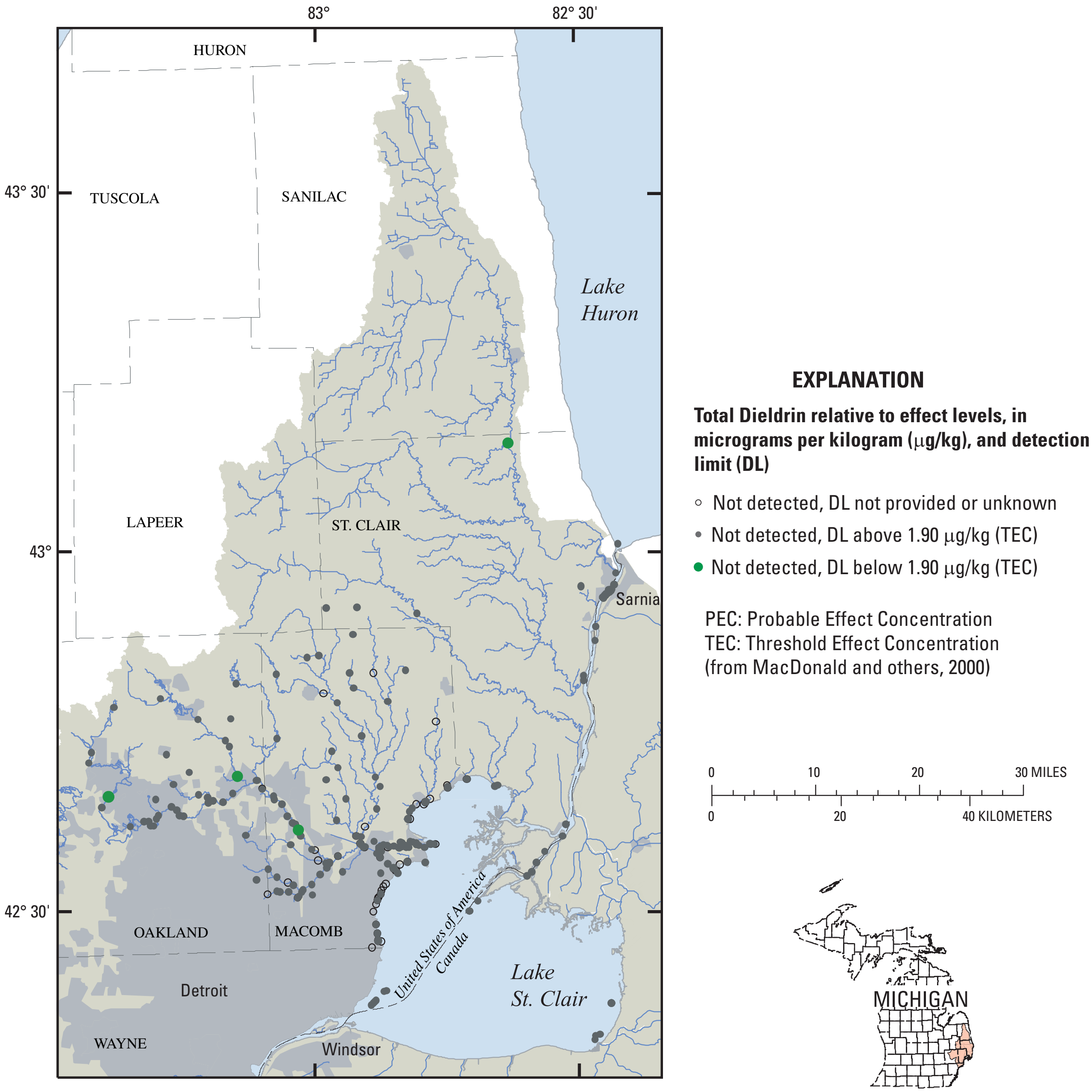
Hexachlorocyclohexane (HCH) and its isomers are agricultural and topical insecticides (Parker, 1984). Technical-grade HCH was a mixture of the α, β, δ, ε, and γ isomers and was used as an insecticide. This form of HCH has not been used in the United States for more than 20 years (Agency for Toxic Substances and Disease Registry, 2005). Although degradation of HCH can take a long time, it can be broken down by algae, fungi, and bacteria into less toxic substances. HCH has the ability to accumulate in the fatty tissues of fish.

Detected concentrations of hexachlorocyclohexane ranged from 2 to 40 µg/kg. The detection limits for censored data ranged from 1 to 162 µg/kg. Concentrations of HCH in 11 of the 293 samples were greater than detection limits (table 2). These samples ranged in concentration from 2 to 40 µg/kg; only one sample had a concentration less than the LEL of 3 µg/kg. The detections were in samples from the upper reach of the St. Clair River, along the main stem of the Clinton River, in Paint Creek, in Big Beaver Creek, and in Red Run (fig. 7). Because of the small number of samples with detected concentrations, summary statistics were not calculated for this constituent.

Lindane (γ-hexachlorocyclohexane)

Lindane is the gamma isomer of HCH and is an organochlorine insecticide registered for commercial and home use. It is an active ingredient in several prescription lotions, creams, and shampoos used for the elimination of head and body lice and scabies (Shelton, 1990; Agency for Toxic Substances and Disease Registry, 2005).

Detected concentrations of lindane ranged from 2 to 40 µg/kg. The detection limits for censored data ranged from 0.7 to 130 µg/kg. Concentrations of lindane in 2 of the 293 samples were greater than detection limits (table 2). The detected concentrations, 2 and 40 µg/kg, were found in the upper reaches of the St. Clair River and in Paint Creek, respectively (fig. 8). At 40 µg/kg, the Paint Creek sample was 8 times the PEC of 4.99 µg/kg. The majority of sample concentrations were below detection limits that were greater than the TEC of 2.37 µg/kg. Because of the small number of samples with detected concentrations, summary statistics were not calculated for this constituent.



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County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 5. Total dieldrin concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

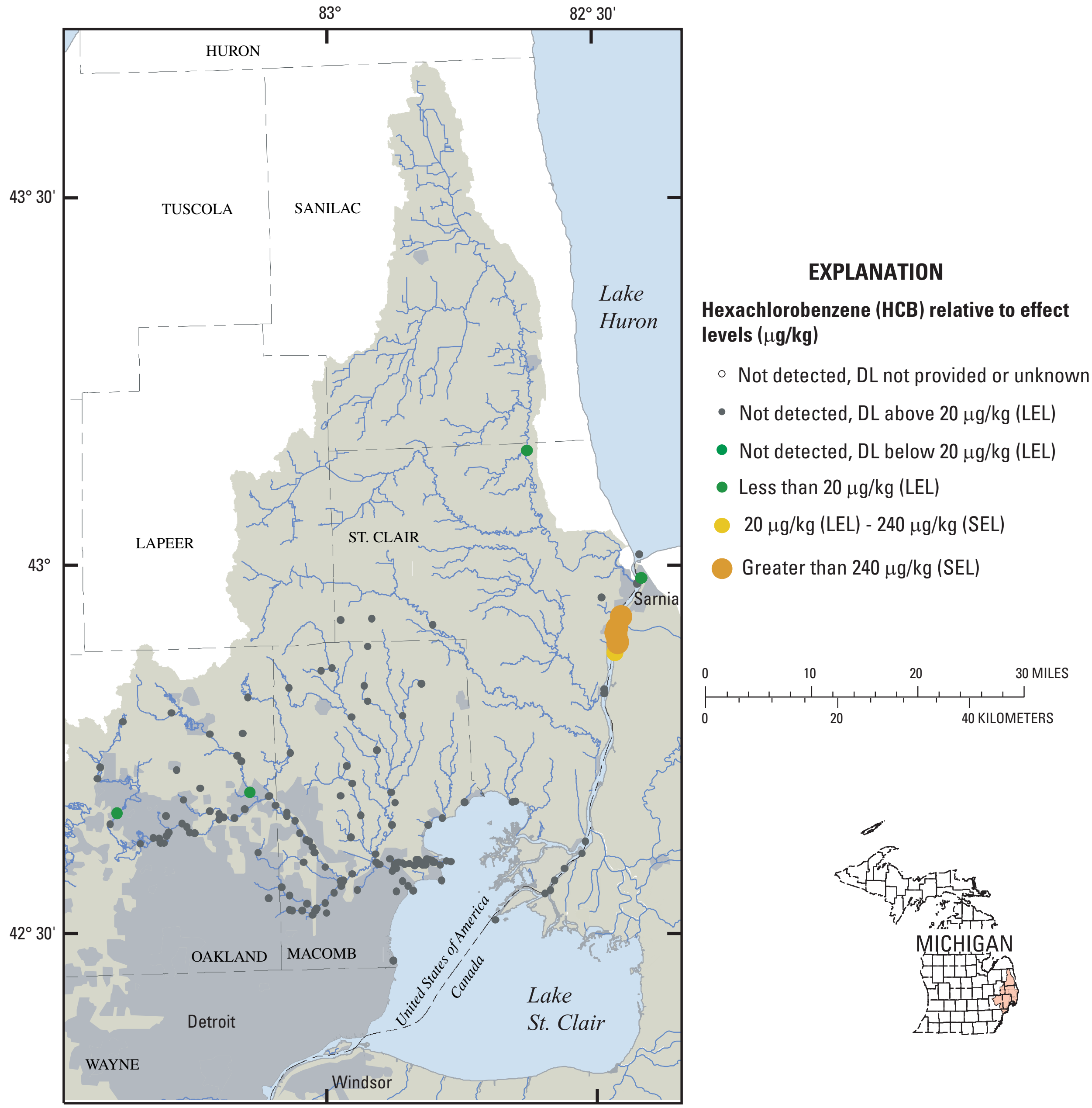

Figure 6. Hexachlorobenzene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

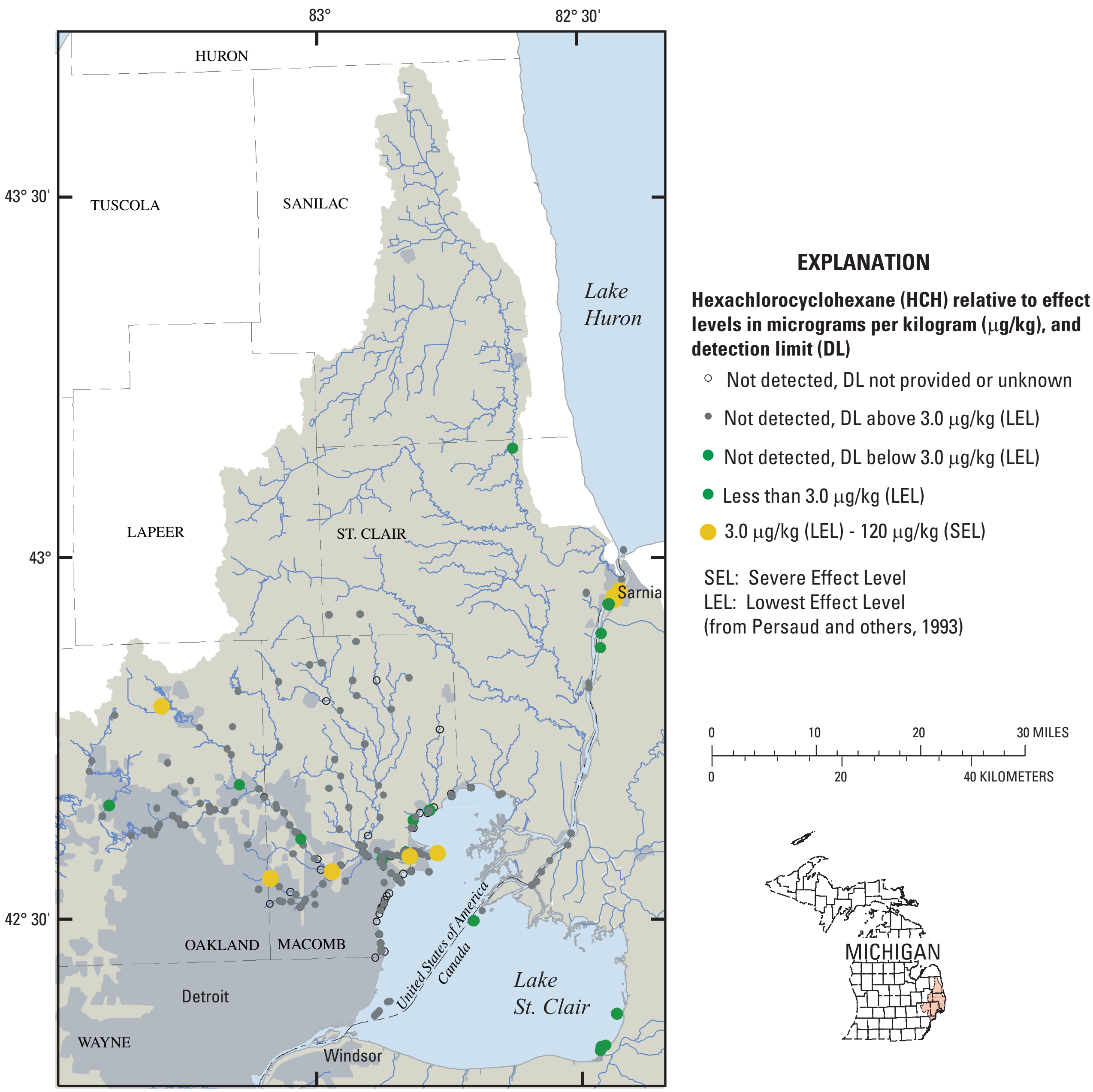

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Figure 7. Hexachlorocyclohexane concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basins, Mich.

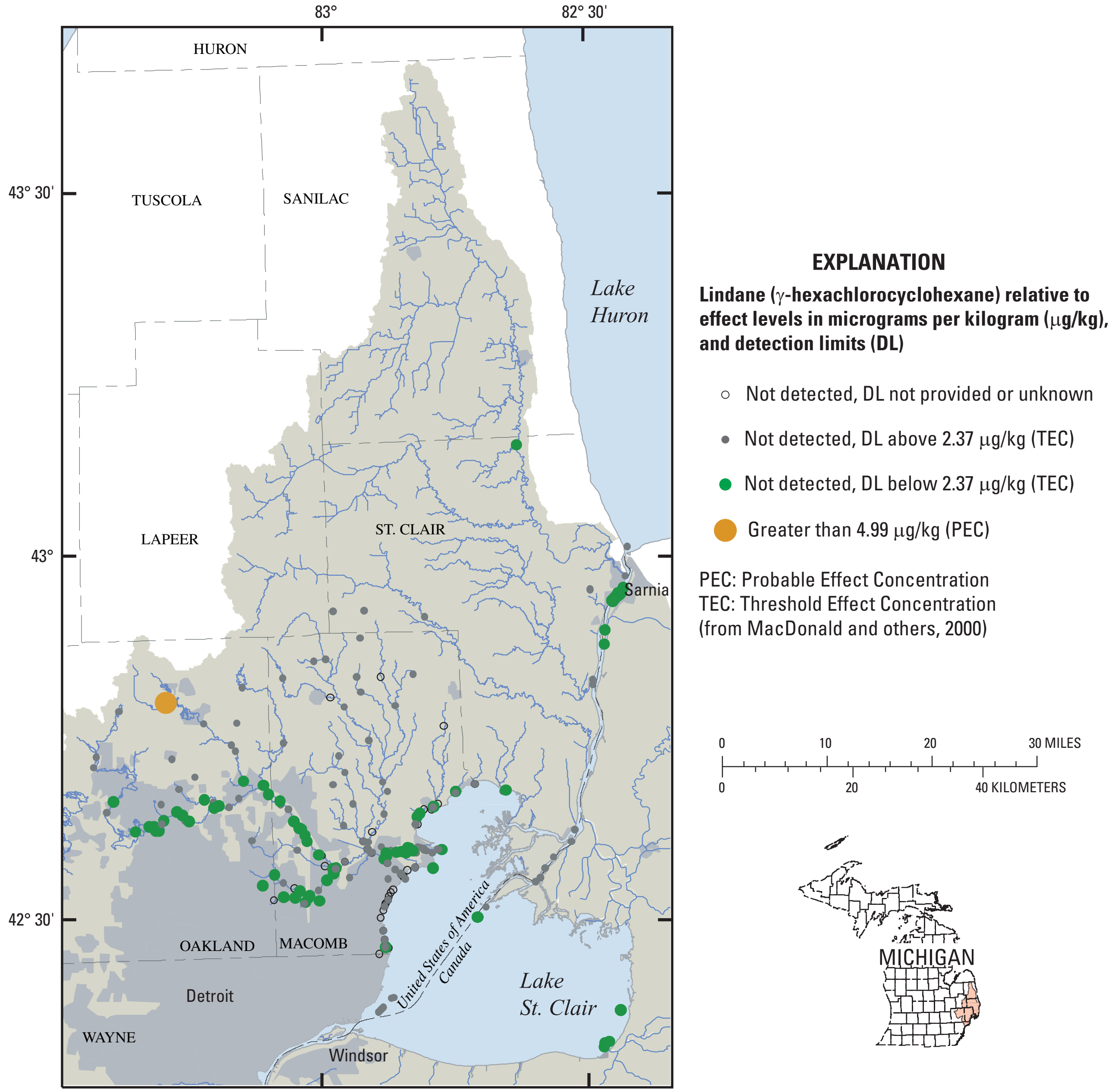

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Figure 8. Lindane concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

Total mirex (sum of mirex plus photomirex)

Mirex (trade name Dechlorane) was used in the Great Lakes area in the 1960s and 1970s, primarily as a fire-retardant additive in plastics, rubber, paint, paper, and electrical goods (Agency for Toxic Substances and Disease Registry, 2005). Mirex may still be used as a color-enhancing agent in fireworks (Binational Toxic Strategy, 1998). Mirex was used extensively in the southeastern United States to control fire ants. All pesticide uses of mirex in the United States were canceled in 1977. Mirex breaks down slowly in the environment; it is hydrophobic and tends to adhere to sediments. Additionally, it has the ability to bioaccumulate. Photomirex is the degradation product of mirex.

None of the 52 samples analyzed for mirex contained concentrations greater than the detection limits, which ranged from 1 to 130 µg/kg (table 2). Forty-four of the sample detection limits were below the LEL concentration of 7 µg/kg, and eight of the sample detection limits were greater than the LEL. Detection limits were provided for all 52 of the samples used in this study. Most of the samples analyzed for mirex were from locations within the upper reaches of streams in the Clinton River Basin, in the upper reaches of the St. Clair River, and along the eastern shore of Lake St. Clair (fig. 9). Because of the small number of samples with detected concentrations, summary statistics were not calculated for this constituent.

Industrial Organochlorine Compounds

Total PCB (sum of Aroclors 1016, 1221, 1232, 1242, 1248, 1254, and 1260 or as total PCBs)

Polychlorinated biphenyls (PCBs) are complex mixtures containing up to 209 individual chlorinated compounds (congeners). Arochlor is the tradename of PCB formulations , each formulation representing a particular commercial mixture. PCBs are constituents of various industrial products such as hydraulic fluids and coolants in electrical transformers. Although PCB use in the United States was banned in 1977 (Binational Toxic Strategy, 2004) industries in Canada such as utilities, iron/steel, pulp and paper, school/care facility/food processing, governments, and mining/smelting continue to use high-level PCBs. These industries have been working with the Toxic Strategy PCB Workgroup to phase out PCB uses voluntarily. PCBs do not easily break down in the environment, and they easily develop strong adherences to organic matter in sediments (Agency for Toxic Substances and Disease Registry, 2005). PCBs have the ability to accumulate in fish and animals, which have been known to build up concentrations of these compounds that are many times greater than those observed in water.

Detected concentrations of PCBs in the Lake St. Clair Basin ranged from 20 to 8,520 µg/kg. The detection limits for censored data ranged from 20 to 3,300 µg/kg. Concentrations of PCBs greater than the TEC were found along the main stem of the Clinton River, in Big Beaver Creek and Red Run, along the western shore of Lake St. Clair downstream from the mouth of the Clinton River in L'anse Creuse Bay, and in the upper reaches of the St. Clair River (fig. 10). Detectable concentrations of PCBs were found in 184 of the 494 samples (table 2). PCB concentrations greater than the TEC of 59.8 µg/kg and less than the PEC of 676 µg/kg were found in 128 of the samples; 23 were greater than the PEC, and 2 were greater than 10 times the PEC.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are formed during the incomplete burning of fossil fuels, garbage, and other organic substances (Agency for Toxic Substances and Disease Registry, 2005). Atmospheric loads of PAHs result from the incomplete combustion of organic carbon in materials such as wood, municipal solid waste (through incineration), tobacco, and fossil fuels. Even natural occurrences, such as forest fires, can result in the introduction of some PAHs into bed sediments (National Research Council, 1983). PAHs are considered to be the most acutely toxic component of petroleum products, and they also are associated with chronic toxicity and carcinogenic effects (Irwin and others, 1997). Acute toxicity is rarely reported in humans, fish, or wildlife as a result of exposure to low concentrations of a single PAH compound. PAHs are more frequently associated with long-term chronic toxicity. Exposure to PAHs in bed sediment has been implicated in liver and skin tumors in fish such as brown bullheads and white suckers, and in the disruption of cellular or subcellular processes within organs or tissue of other organisms (Baumann and others, 1982; International Joint Commission, 1993; Smith and others, 1994). PAHs have the ability to break down by reacting with sunlight and other chemicals in the air, and they can be degraded by microorganisms in sediments; PAHs are not soluble in water and tend to adhere to sediment (Agency for Toxic Substances and Disease Registry, 2005).

Anthracene

Anthracene is used in industry as a source of dyestuffs and in coating applications (Parker, 1984). According to NIOSH (1999), anthracene has the ability to bioaccumulate in aquatic organisms and plants.

Detected concentrations of anthracene in the Lake St. Clair Basin ranged from 20 to 13,000 µg/kg. The detection limits for censored data ranged from 20 to 4,100 µg/kg. Concentrations of anthracene greater than the TEC were found predominantly in the Clinton River Basin, within L'anse Creuse Bay, at the mouth of Crapeau Creek, and in the upper reaches of the St. Clair River (fig. 11). Sites along the Clinton River with concentrations greater than the TEC include the main stem, Paint Creek, the Middle Branch, Plum Brook, Big

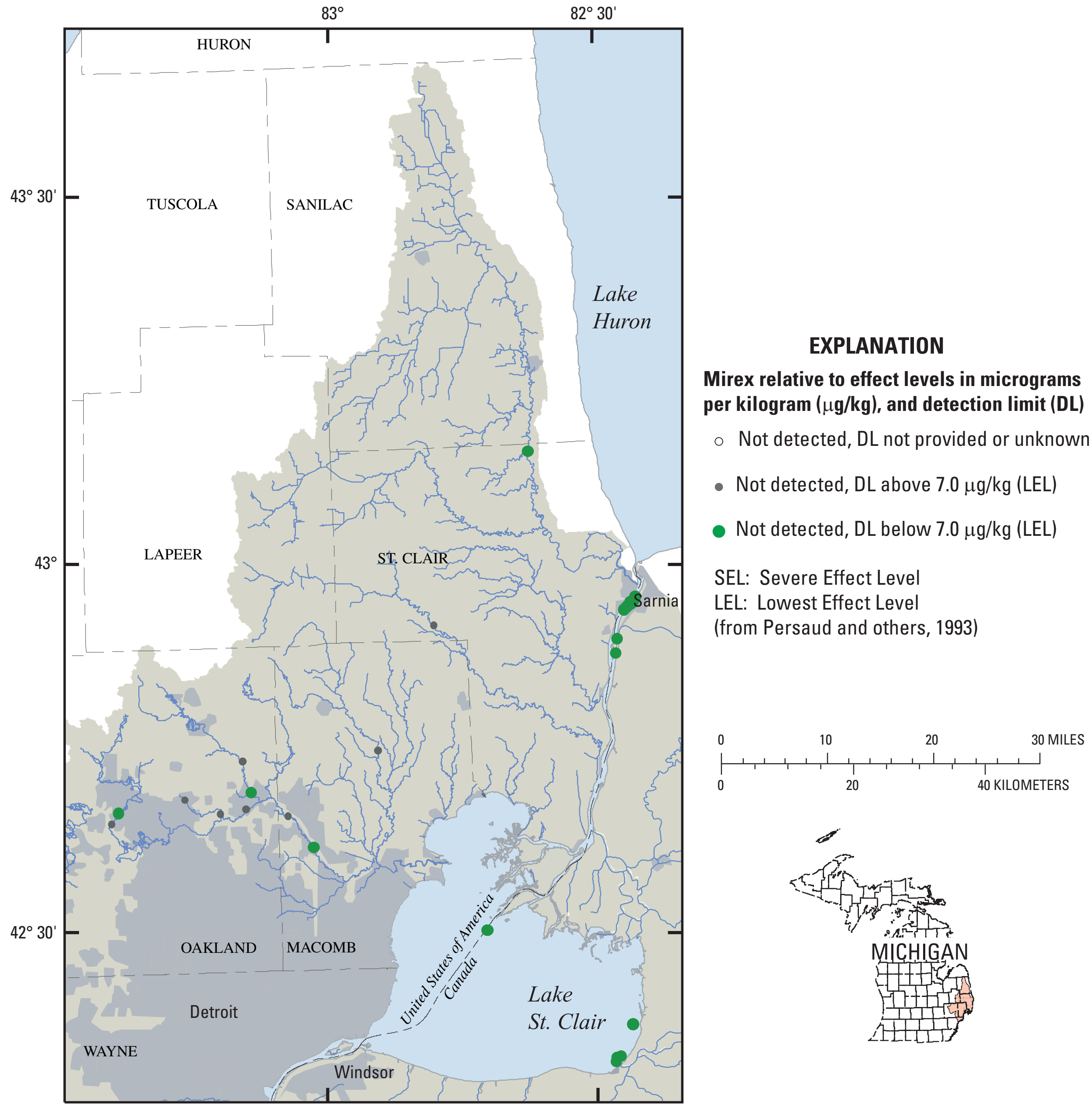

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Figure 9. Mirex concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

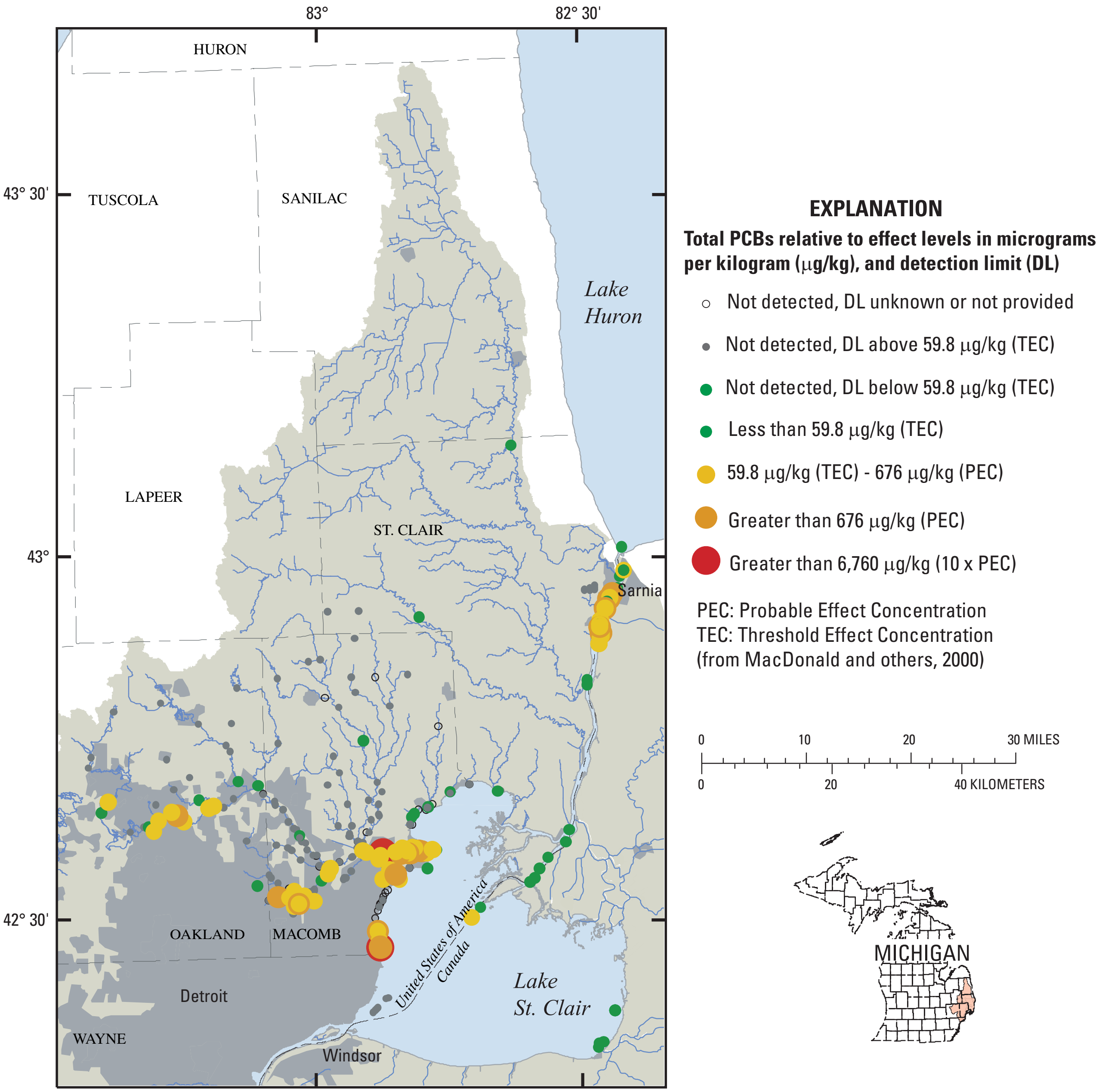

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Figure 10. Total PCB concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

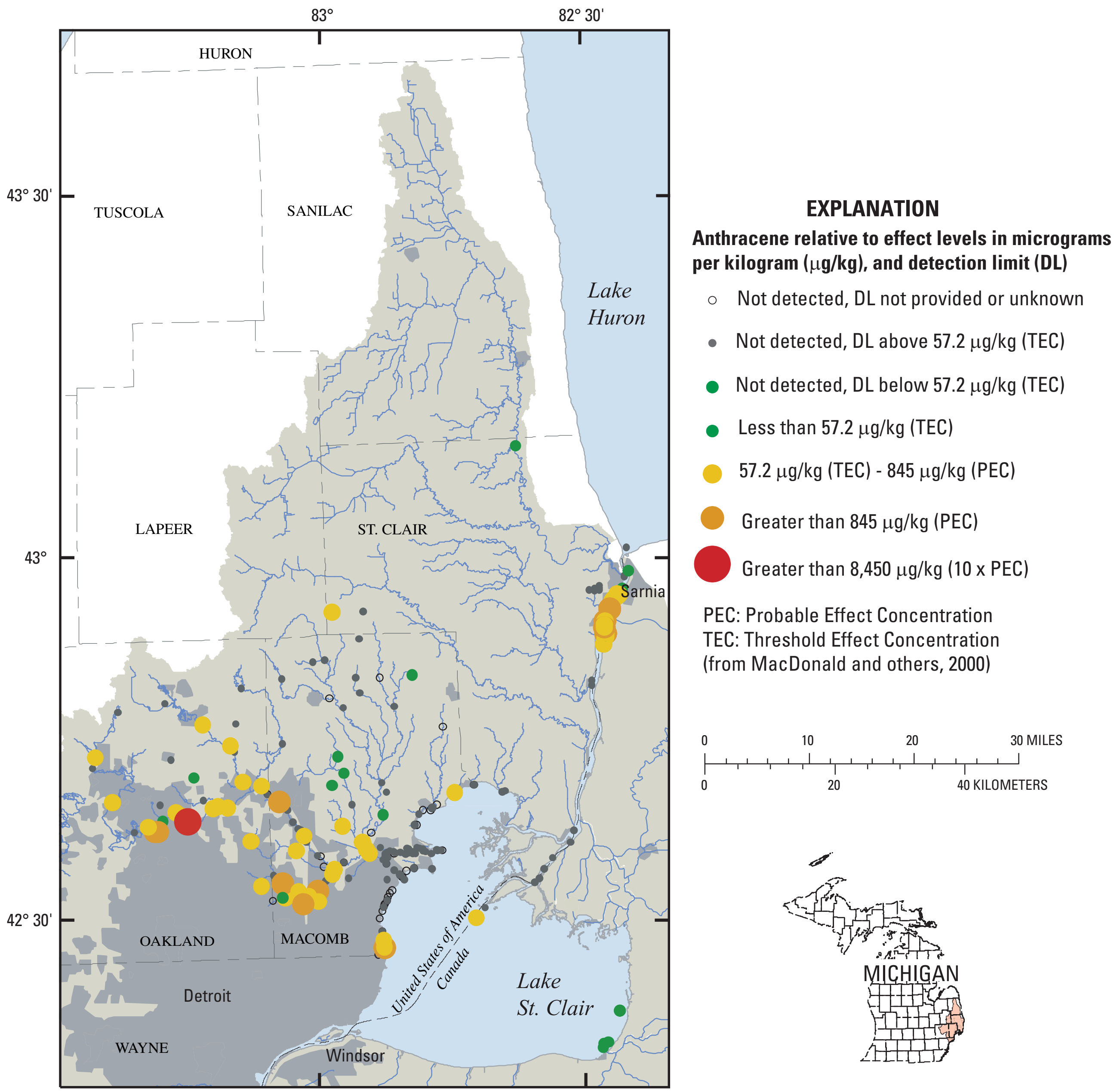

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Figure 11. Anthracene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

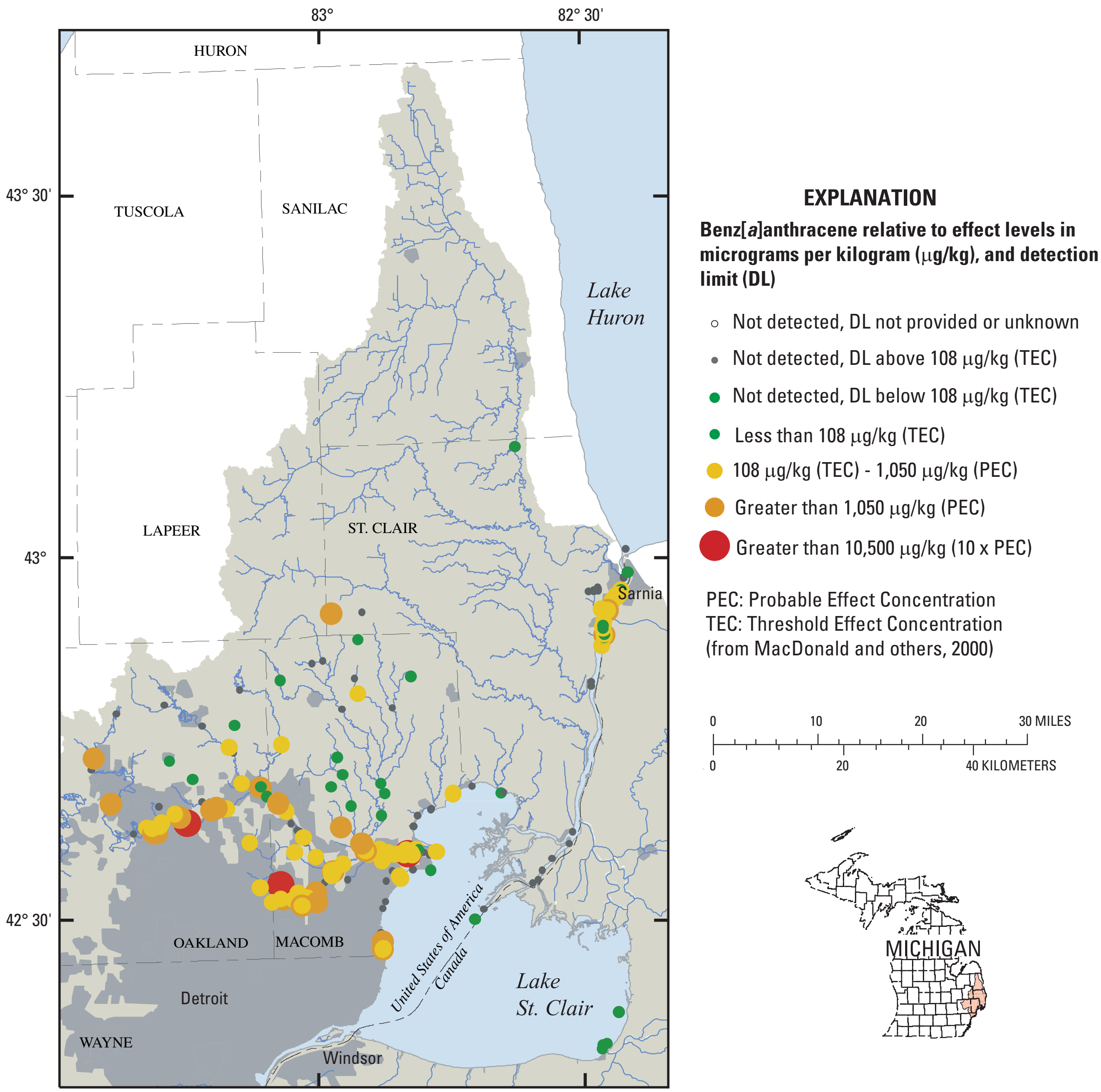

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Figure 12. Benz[*a*]anthracene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

Beaver Creek, and Red Run. Of the 390 sediment analysis results, concentrations of anthracene were detected in 152 samples (table 2). Anthracene concentrations greater than the TEC of 57.2 µg/kg and less than the PEC of 845 µg/kg were found in 95 samples. Eighteen samples contained concentrations greater than the PEC, and one concentration was greater than 10 times the PEC.

Benz[*a*]anthracene

Benz[*a*]anthracene is formed when gasoline, garbage, or any animal or plant materials are burned, and it is usually found in smoke and soot. Benz[*a*]anthracene is also found in creosote (Irwin and others, 1997). Sources of benz[*a*]anthracene are mainly urban and industrial. Neither NIOSH (1999) nor ATSDR (2005) provides specific environmental impact data for benz[*a*]anthracene.

Detected concentrations of benz[*a*]anthracene in the Lake St. Clair Basin ranged from 16 to 36,000 µg/kg. The detection limits for censored data ranged from 20 to 4,100 µg/kg. Concentrations of benz[*a*]anthracene greater than the TEC were found in the Clinton River Basin on the main stem, in Coon Creek, in Paint Creek, in Stony Creek, in Plum Brook, in Big Beaver Creek, and in Red Run; along the western shore of Lake St. Clair in L'anse Creuse Bay and at the mouth of Crapeau Creek; and in the upper reaches of the St. Clair River (fig. 12). Detectable concentrations of benz[*a*]anthracene were found in 225 of the 390 samples (table 2). Benz[*a*]anthracene concentrations greater than the TEC of 108 µg/kg and less than the PEC of 1,050 µg/kg were found in 108 samples. Twenty-nine samples contained concentrations greater than the PEC, and three concentrations were greater than 10 times the PEC.

Benzo[*a*]pyrene

Benzo[*a*]pyrene is a ubiquitous product of incomplete combustion and is widespread in the environment (Irwin and others, 1997). Its sources are mainly industrial: coal-tar processing, petroleum refining, shale refining, coal and coke processing, kerosene processing, heat and power generation, and combustion of fuels. Benzo[*a*]pyrene is found in runoff containing greases and oils, and it is a potential roadbed and asphalt leachate (Verschueren, 1977). Neither NIOSH (1999) nor ATSDR (2005) provides specific environmental data for benzo[*a*]pyrene.

Detected concentrations of benzo[*a*]pyrene in the Lake St. Clair Basin ranged from 34 to 23,000 µg/kg. The detection limits for censored data ranged from 40 to 4,000 µg/kg. Concentrations of benzo[*a*]pyrene greater than the TEC were found predominantly in the Clinton River Basin along the main stem, in Coon Creek, in Paint Creek, in Plum Brook, in Big Beaver Creek, and in Red Run; along the western shore of Lake St. Clair in L'anse Creuse Bay and at the mouth of Crapeau Creek; and in the upper reaches of the St. Clair River (fig. 13). Detectable concentrations of benzo[*a*]pyrene were found in 184 of the 382 samples (table 2). Benzo[*a*]pyrene concentrations greater than the TEC of 150 µg/kg and less than the PEC of 1,450 µg/kg were found in 106 samples. Twenty-two samples contained concentrations greater than the PEC, and two concentrations were greater than 10 times the PEC.

Chrysene

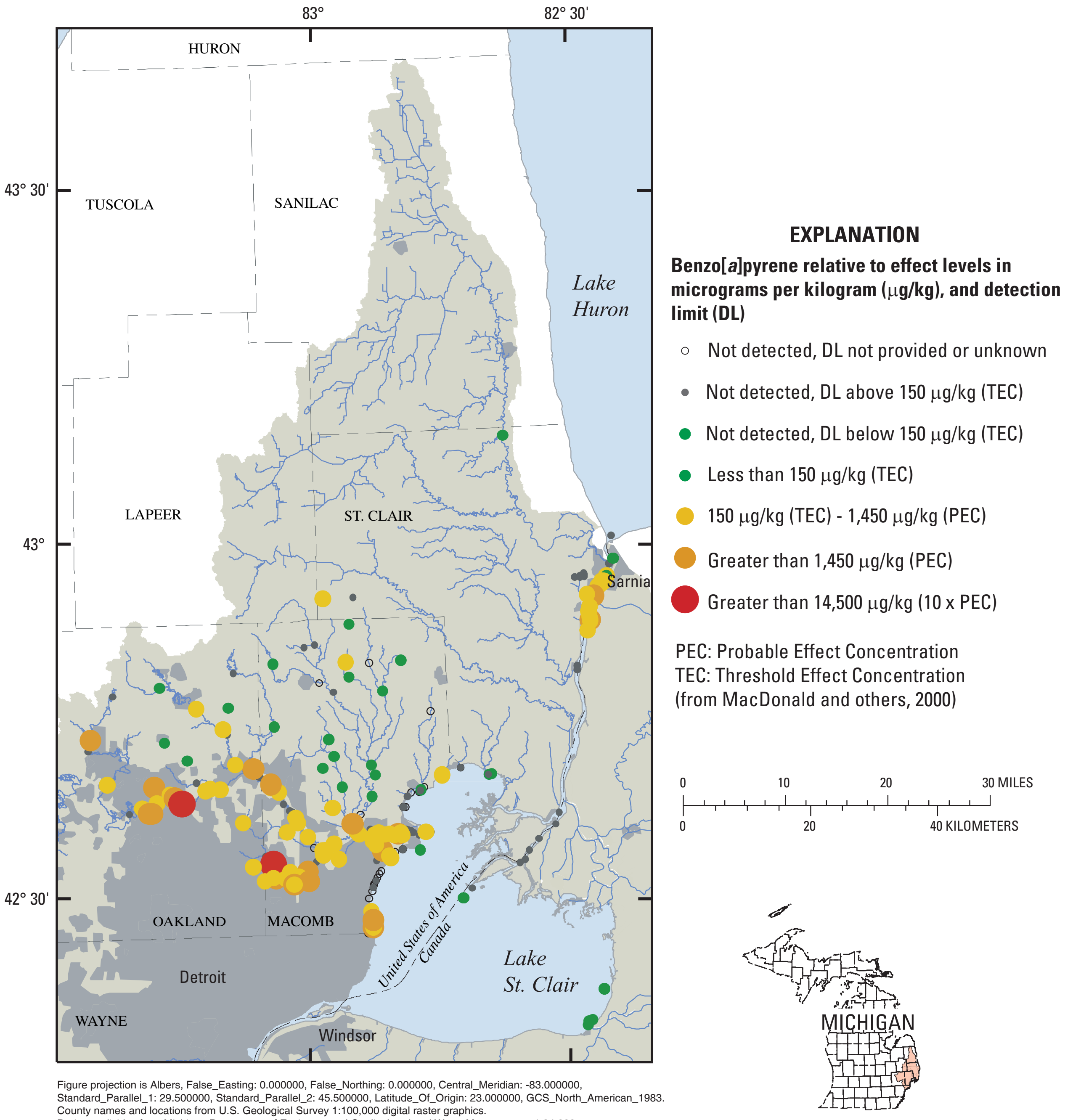
Chrysene is a component in coal tar and is present in exhaust from gasoline engines (Verschueren, 1977). Chrysene is usually found in smoke (including cigarette smoke), soot, coal tar, and coke-oven emissions (U.S. Environmental Protection Agency, 1997). Neither NIOSH (1999) nor ATSDR (2005) provides specific environmental data for chrysene.

Detected concentrations of chrysene in the Lake St. Clair Basin ranged from 14 to 28,000 µg/kg. The detection limits for censored data ranged from 20 to 4,000 µg/kg. Concentrations of chrysene greater than the TEC were found predominantly in the Clinton River Basin along the main stem, in Coon Creek, in Stony Creek, in Paint Creek, in Big Beaver Creek, and in Red Run; along the western shore of Lake St. Clair in L'anse Creuse Bay and at the mouth of Crapeau Creek; and in the upper reaches of the St. Clair River (fig. 14.). Detectable concentrations of chrysene were found in 250 of the 390 samples (table 2). Chrysene concentrations greater than the TEC of 166 µg/kg and less than the PEC of 1,290 µg/kg were found in 109 samples (28 percent). Thirty-six samples (10 percent) contained concentrations greater than the PEC, and four concentrations were greater than 10 times the PEC.

Phenanthrene

Phenanthrene is naturally present in coal and petroleum and is a high-temperature combustion byproduct (U.S. Environmental Protection Agency, 1993). It is used in industry and in the synthesis of dyes and drugs (Parker, 1984). Neither NIOSH (1999) nor ATSDR (2005) provides specific environmental data for phenanthrene.

Detected concentrations of phenathrene in the Lake St. Clair Basin ranged from 11 to 35,000 µg/kg. The detection limits for censored data ranged from 46 to 4,000 µg/kg. Concentrations of phenanthrene greater than the TEC were found predominantly in the Clinton River Basin along the main stem, in Stony Creek, in Paint Creek, in Plum Brook, in Big Beaver Creek, and in Red Run; along the western shore of Lake St. Clair in L'anse Creuse Bay and at the mouth of Crapeau Creek; and in the upper reaches of the St. Clair River (fig. 15). Detectable concentrations of phenanthrene were found in 116 (48 percent) of the 244 samples (table 2). Phenanthrene concentrations greater than the TEC of 204 µg/kg and less than the PEC of 1,170 µg/kg were found in 53 samples. Twenty-eight samples contained concentrations greater than the PEC, and four concentrations were greater than 10 times the PEC.



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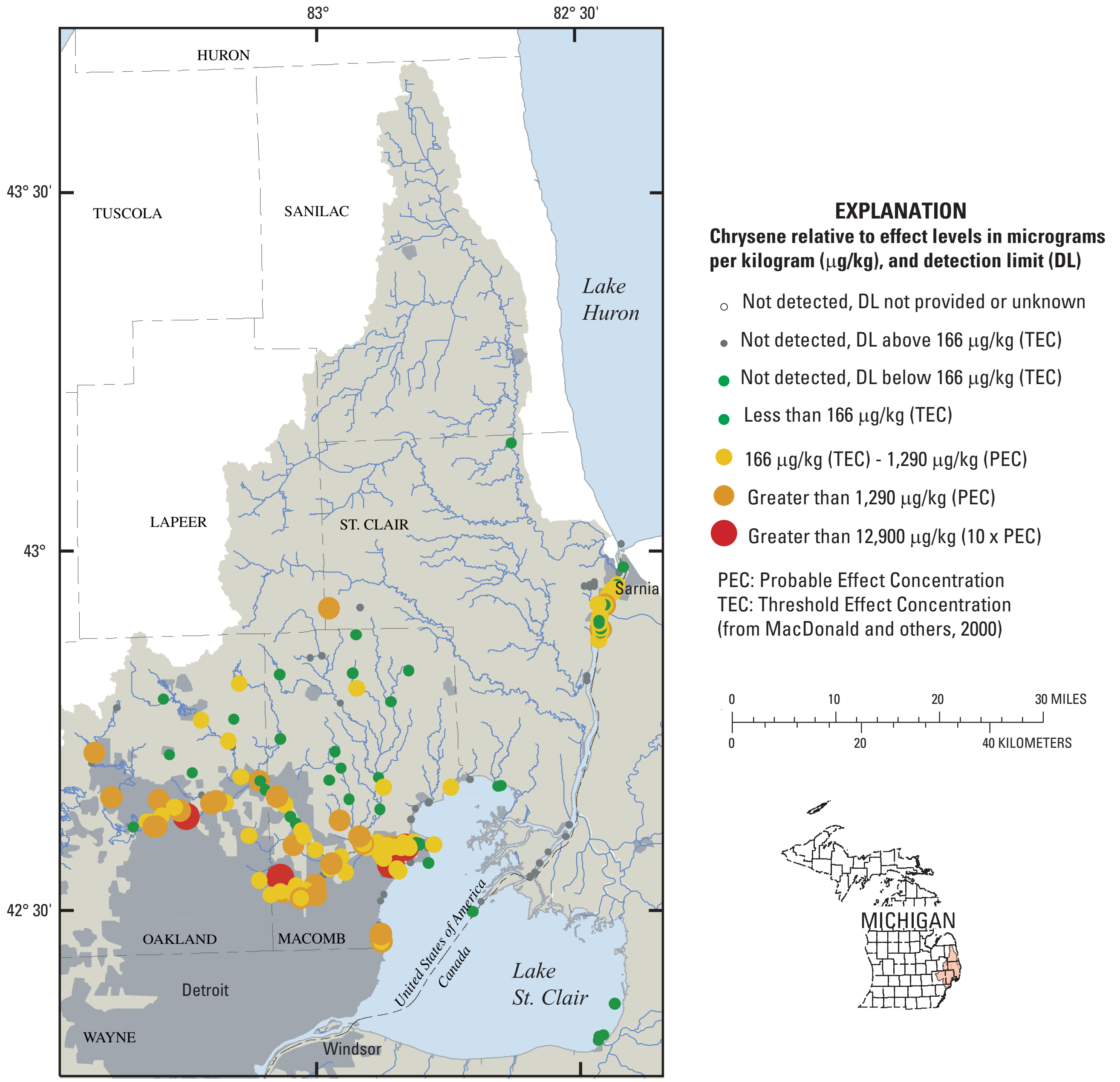
County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 13. Benzo[*a*]pyrene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.



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Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 14. Chrysene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

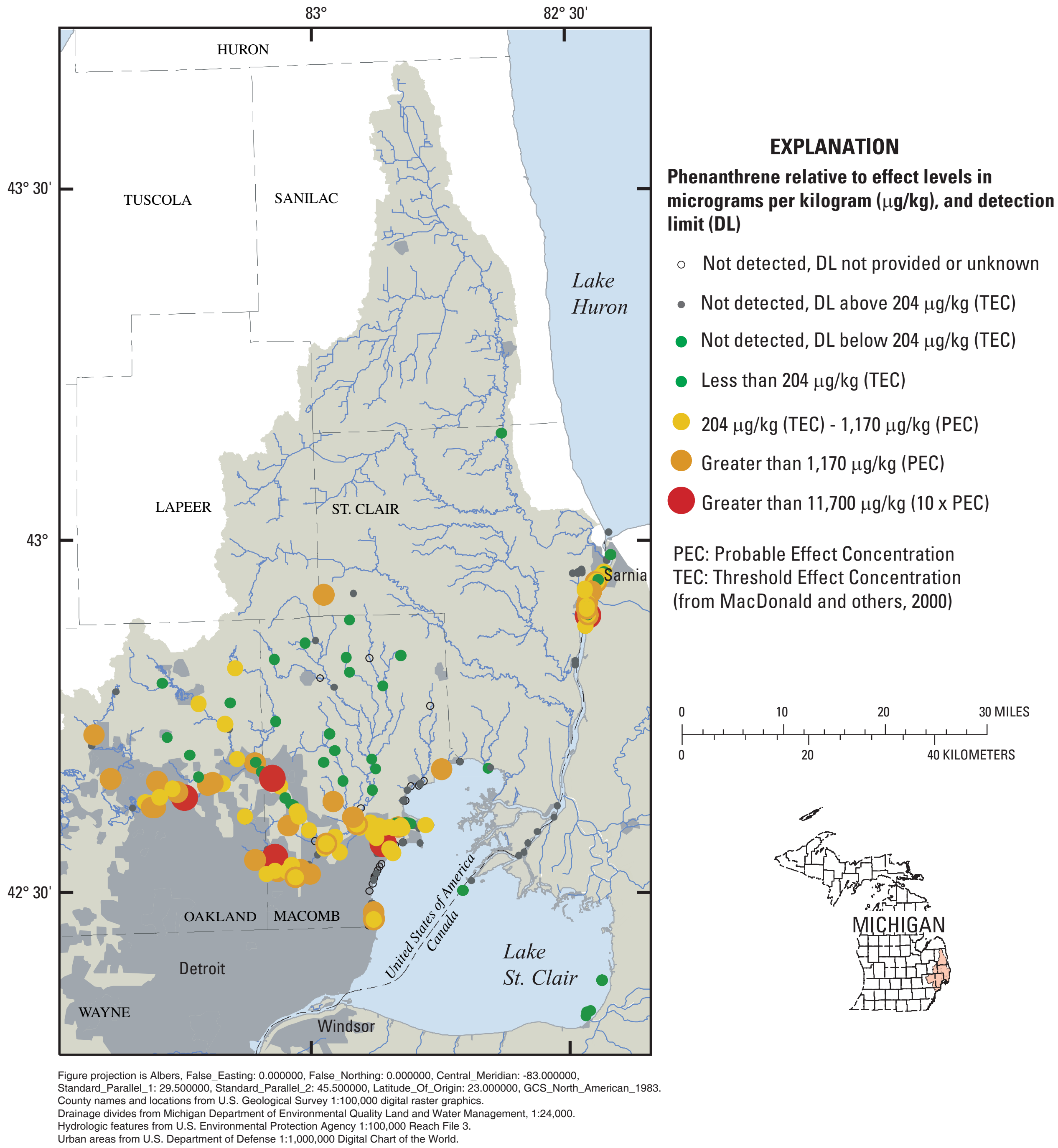
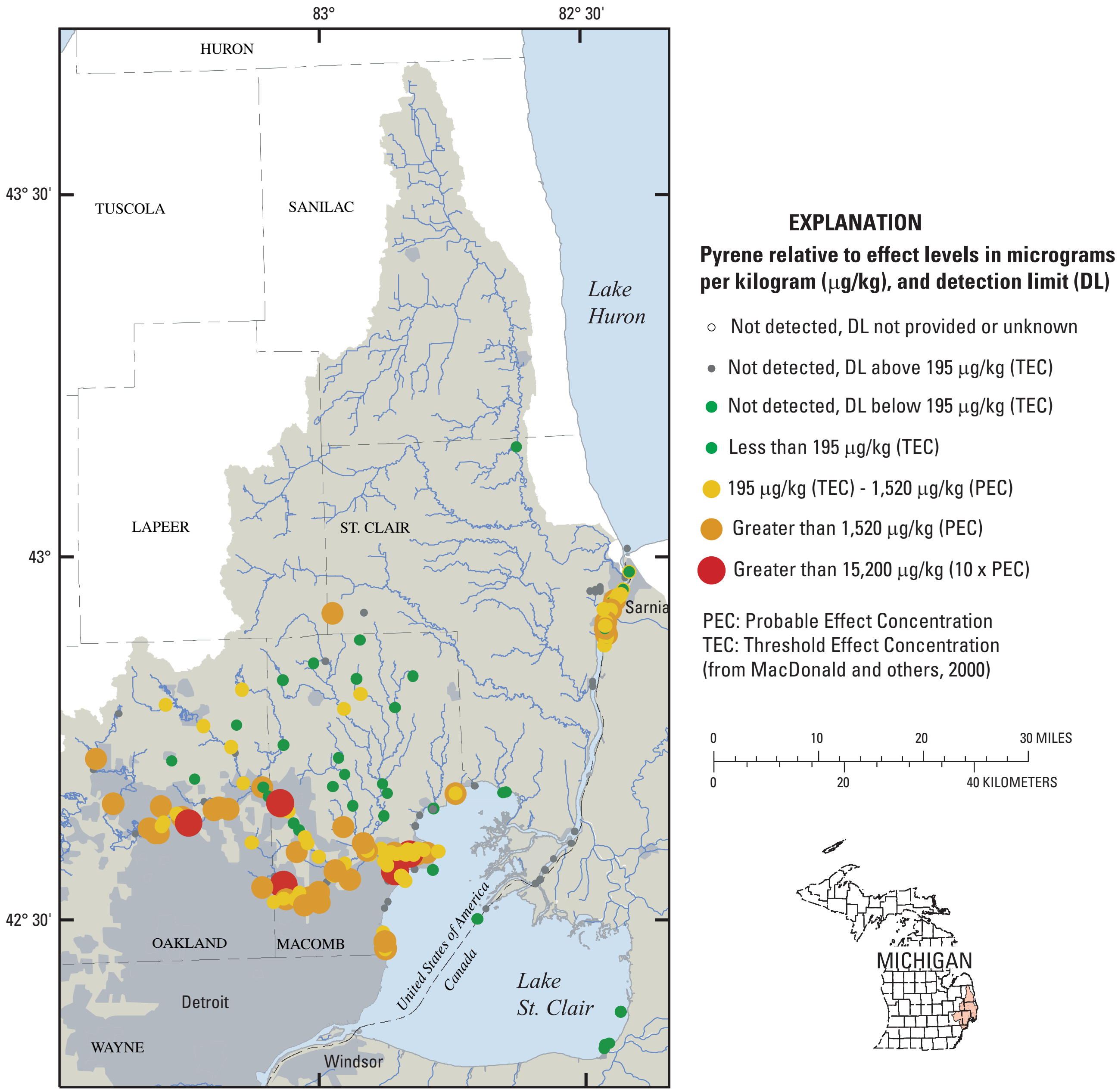


Figure 15. Phenanthrene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.



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County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 16. Pyrene concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

Pyrene

Pyrene occurs in coal tar and can be produced by hydrogenation of anthracite coal (Budavari and others, 1989). Pyrene is used to make plastics and dyes and has been used as a pesticide. Neither NIOSH (1999) nor ATSDR (2005) provides specific environmental data for pyrene. According to Budavari and others (1989), pyrene is insoluble in water.

Detected concentrations of pyrene in the Lake St. Clair Basin ranged from 20 to 57,000 µg/kg. The detection limits for censored data ranged from 46 to 4,000 µg/kg. Detectable concentrations of pyrene were found in 136 of 208 bed-sediment samples (table 2). Pyrene concentrations greater than the TEC of 195 µg/kg and less than the PEC of 1,520 µg/kg were found in 61 samples. Thirty-seven samples contained concentrations greater than the PEC and five concentrations were 10 times the PEC. Concentrations of pyrene greater than the PEC were found in the upper reaches of the St. Clair River, in Sashabaw Creek, along the main stem of the Clinton River, in Big Beaver Creek, in Red Run, in Plum Brook, in the Middle Branch Clinton River, at the mouth of the Clinton River, along the western shore of Lake St. Clair in L'anse Creuse Bay, and at the mouth of Crapeau Creek (fig. 16).

Total PAH

Sediment samples analyzed for total PAH consisted of the sum of concentrations for acenaphthene, acenaphthylene, anthracene, benzo[*a*]anthracene, benzo[*a*]pyrene, benzo[*b*]fluoranthene, benzo[*ghi*]perylene, benzo[*k*]fluoranthene, chrysene, dibenz[*a,h*]anthracene, fluoranthene, fluorine, indeno[*1,2,3-cd*]pyrene, naphthalene, phenanthrene, and pyrene. Although many of these contaminants were discussed individually in the preceding sections, some sediment samples were analyzed for overall PAH content. For use in this study, the concentrations of total PAH were calculated by the sum of concentrations of 16 individual PAHs for each location.

Detected concentrations of total PAH in the Lake St. Clair Basin ranged from 81 to 317,500 µg/kg. The detection limits for censored data ranged from 40 to 4,000 µg/kg. Concentrations of total PAH greater than the TEC were found predominantly in the Clinton River Basin along the main stem, in Stony Creek, in Paint Creek, in Plum Brook, in Big Beaver Creek, and in Red Run; along the western shore of Lake St. Clair in L'anse Creuse Bay and at the mouth of Crapeau Creek; and in the upper reaches of the St. Clair River (fig. 17). Detectable concentrations of total PAH were found in 152 of the 246 samples (table 2). Total PAH concentrations greater than the TEC of 1,610 µg/kg and less than the PEC of 22,800 µg/kg were found in 77 samples. Seventeen samples contained concentrations greater than the PEC, and two concentrations were greater than 10 times the PEC.

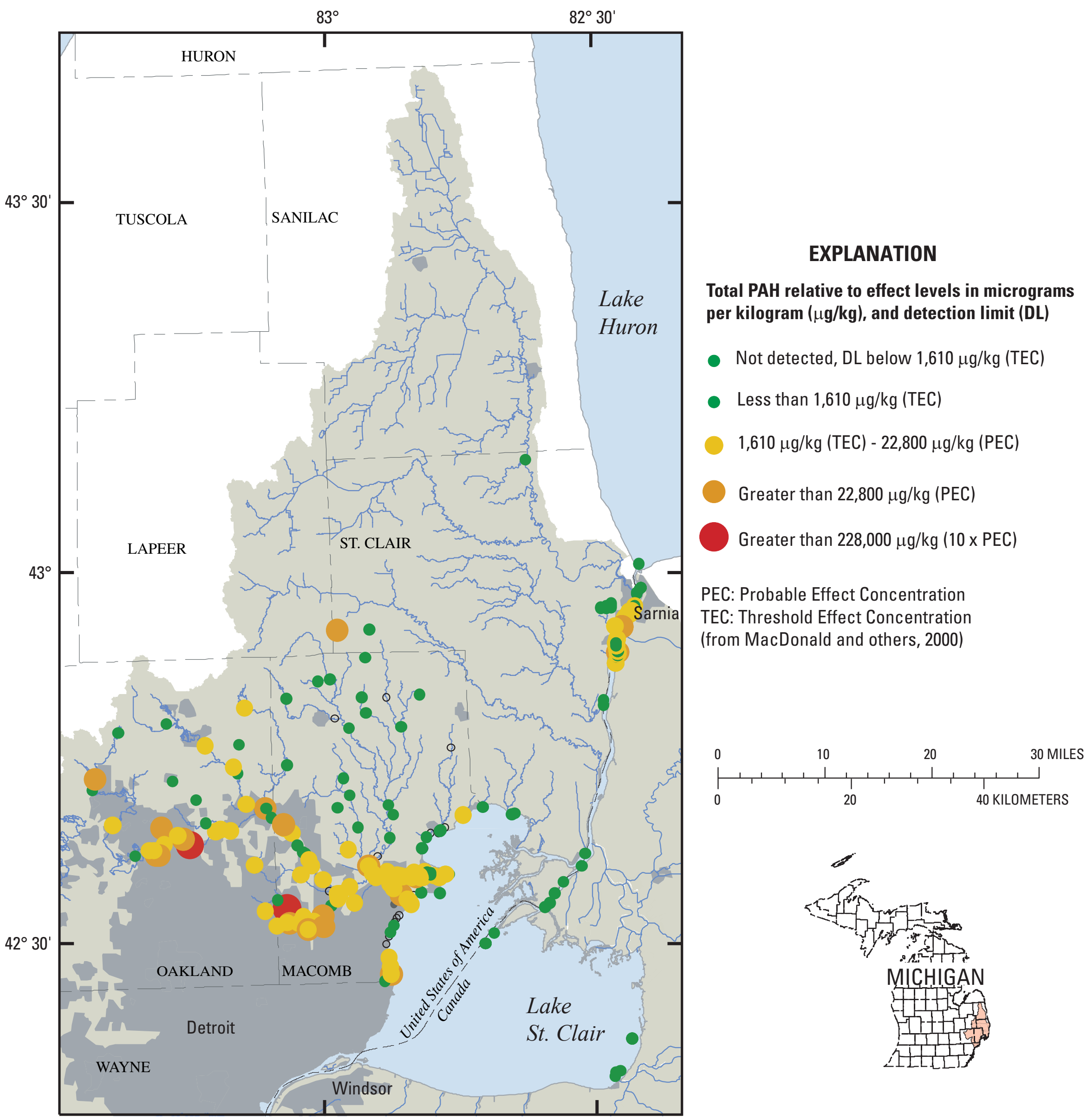
Trace Elements

Trace elements in bed sediment are derived from a variety of sources, including weathering of rocks and soils and input from anthropogenic sources. Trace elements at naturally occurring concentrations generally are not harmful to aquatic life; however, the high end of the natural concentration range typically falls in the lower range of the various sediment-quality guidelines, an overlap that can confound interpretation of the data. Out of the four contaminant classes analyzed in this report, trace elements were the most frequently detected class in streambed and lakebed sediments. Avenues by which trace elements are introduced into bed sediments include atmospheric deposition (such as from automobile exhaust), industrial emissions (especially from activities such as plating, smelting, and refining), wastewater discharges, seepage from landfills, and stormwater runoff. The extensive use of trace elements in industry commonly results in concentrations far greater than natural levels (Armitage, 1995). Certain trace elements are known to be highly toxic and bioaccumulative in food chains, but little is known about the occurrence and biological significance of others.

Arsenic

Arsenic sources include wood preservatives, herbicides, and insecticides. Lead arsenate and calcium arsenate have been applied extensively as miticides and pesticides on orchard crops. Additional uses include metal-ore processing, glassware, ceramics, leather tanning, chemical industries, pigmentation in paints, and additives in medical treatments (Michigan Water Resources Commission, 1972). Arsenic also occurs naturally in water. A study of the occurrence of arsenic in ground water in southeastern Michigan noted that arsenic concentrations were commonly elevated in wells that were completed in the Marshall Sandstone (Haack and Rachol, 2000). The Marshall Sandstone is in direct contact with the overlying glacial deposits and is underlain by the Coldwater Shale. The Michigan Basin is a bowl-shaped depression in which many of the bedrock layers thin outwards along their outer extents. Much of the upper reaches and northern tributaries of the Clinton River are in an area where the Coldwater Shale is the local bedrock (fig. 18) and where the glacial deposits are influenced by the underlying bedrock chemistry. Arsenic is persistent in the environment, and cannot be destroyed; however, its form can change (National Institute for Occupational Safety and Health, 1999; Agency for Toxic Substances and Disease Registry, 2005). Many arsenic compounds are soluble in water, and fish and shellfish have the ability to accumulate arsenic.

Arsenic was detected in all 526 samples of bed sediment from the Lake St. Clair Basin, at concentrations ranging from 0.7 to 50 mg/kg (table 2). Concentrations of arsenic greater than the TEC were found in the East Branch Coon Creek, in Coon Creek, in the North Branch Clinton River,



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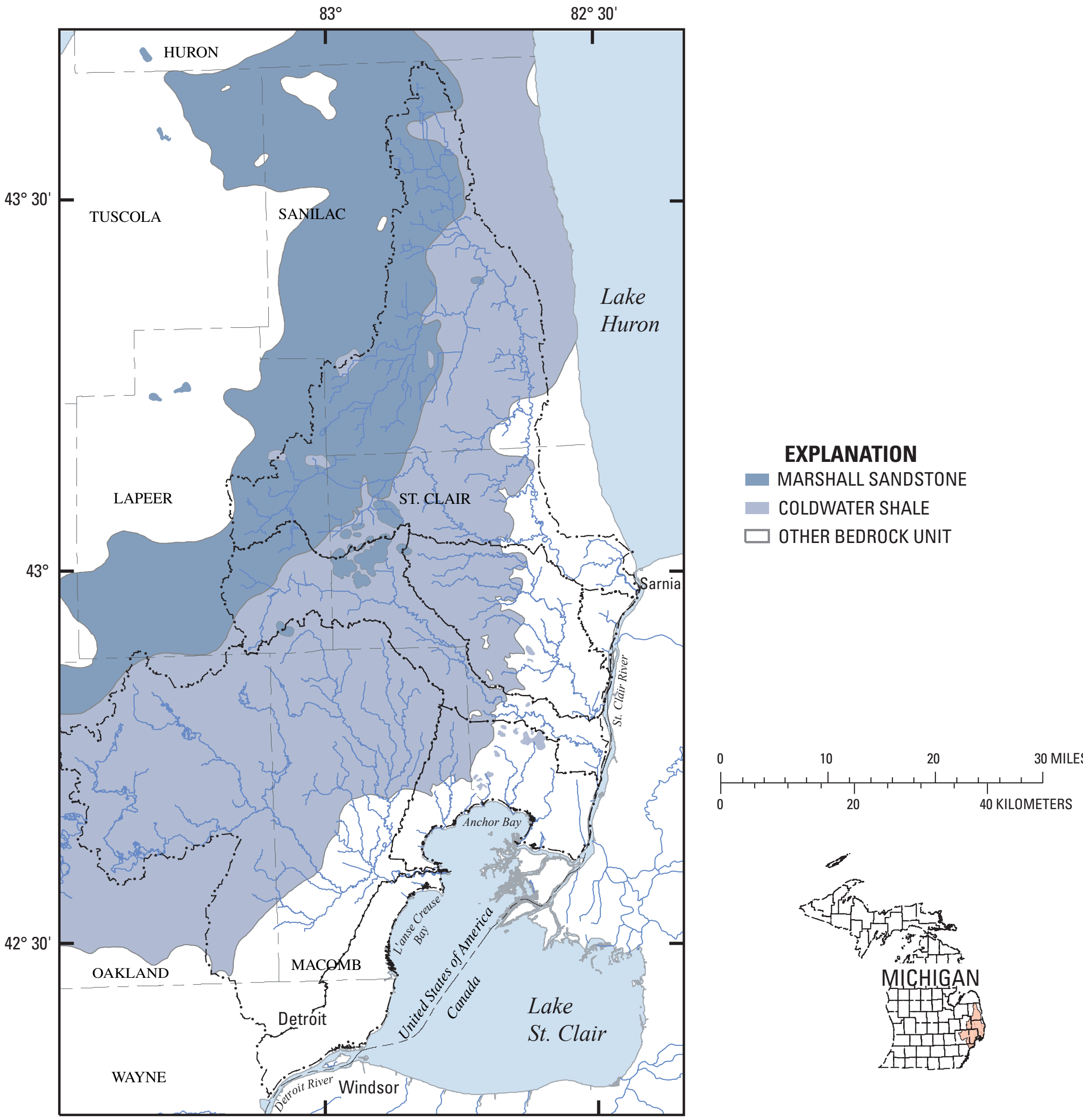
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 17. Total PAH concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.



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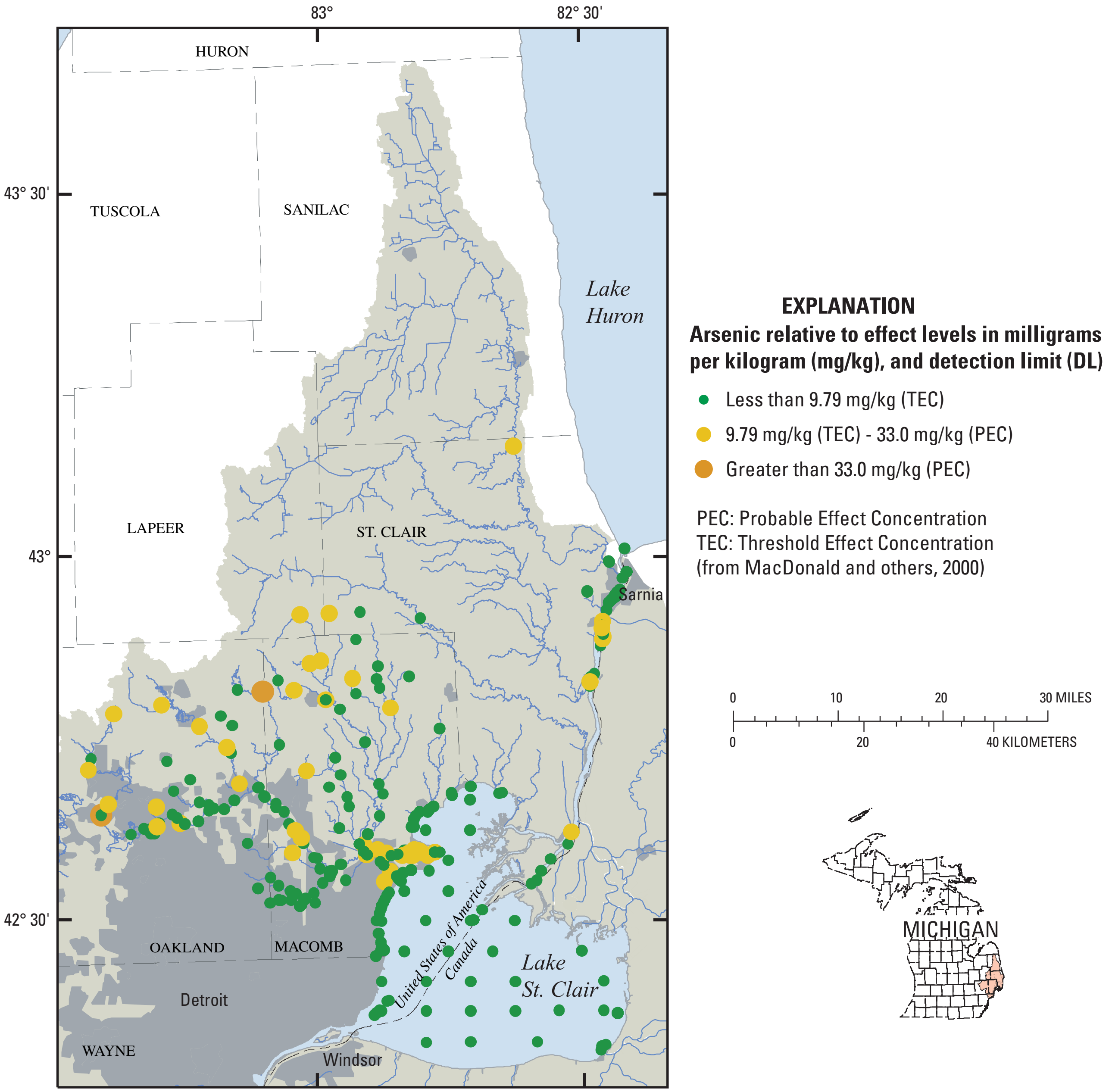
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Bedrock geologic units from Michigan Department of Environmental Quality Geological Survey Division, 1:500,000.

Figure 18. Location of Marshall Sandstone and Coldwater Shale in southeastern Mich.



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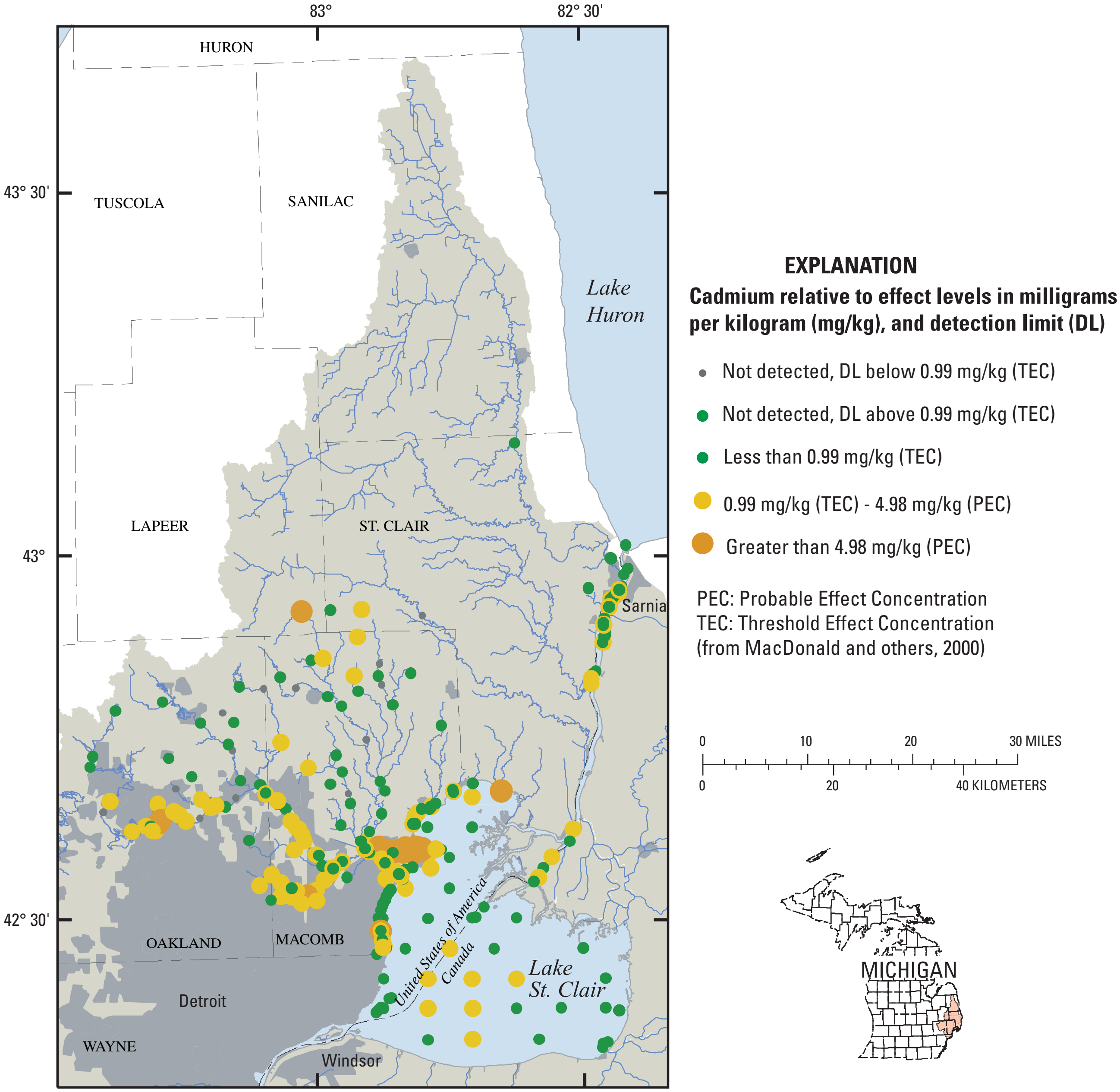
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 19. Arsenic concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.



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County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 20. Cadmium concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

in Pond Creek, in Stony Creek, in Paint Creek, in Sashabaw Creek, and along the main stem and towards the mouth of the Clinton River, and in the upper reaches of the St. Clair River (fig. 19). Arsenic concentrations greater than the TEC of 9.79 mg/kg and less than the PEC of 33 mg/kg were found in 49 samples. Two samples contained concentrations greater than the PEC.

Cadmium

Major industrial use of cadmium has been in alloys with copper, lead, silver, aluminum, and nickel. Cadmium also is used in electroplating, ceramics, pigmentation, photography, batteries, and nuclear reactors. Cadmium salts are sometimes used as insecticides and antihelminthics (Michigan Water Resources Commission, 1972). Other sources of cadmium emissions are releases to the environment from fossil-fuel use, fertilizer applications, and sewage-sludge disposal (Shelton, 1990). Trace amounts of cadmium occur naturally, chiefly as a sulfide salt. Cadmium is found in very low concentrations in most rocks, coal, and petroleum, often in combination with zinc. According to ATSDR (2005), cadmium binds strongly to sediments. Fish, plants, and animals are able to take up cadmium and, over many years of exposure to low environmental concentrations, they tend to retain cadmium for long periods (Agency for Toxic Substances and Disease Registry, 2005).

Detected concentrations of cadmium in the Lake St. Clair Basin ranged from 0.04 to 28 mg/kg. The detection limits for censored data ranged from 0.05 to 2 mg/kg. Concentrations of cadmium greater than the TEC were found throughout the Clinton River Basin along the main stem, in Coon Creek, in Stony Creek, in Plum Brook, in Big Beaver Creek, in Red Run, and towards the river's mouth; in the upper and lower reaches of the St. Clair River; and within Lake St. Clair, particularly along its western shoreline (fig. 20). Samples analyzed for cadmium contained concentrations greater than detection limits in 457 out of the 532 samples (table 2). Cadmium concentrations greater than the TEC of 0.99 mg/kg and less than the PEC of 4.98 mg/kg were found in 129 samples. Twenty-seven samples contained concentrations greater than the PEC.

Copper

Metallic copper is used extensively in the electrical industry, in many alloys for cooking utensils, and for water pipes and roofing. Copper salts are used in textile processes, pigmentation, tanning, photography, engraving, electroplating, insecticides, fungicides, control of algae and other aquatic growths, and many other industrial processes. Copper is a known contaminant in urban stormwater runoff (Michigan Water Resources Commission, 1972). In the environment, copper compounds can break down and release free copper, which tends to bind to organic matter, clay, soil, or sand (Agency for Toxic Substances and Disease Registry, 2005).

All of the 519 samples of sediment from the Lake St. Clair Basin contained concentrations of copper greater than the detection limit of 1 mg/kg (table 2). Ten samples contained concentrations greater than the PEC of 146 mg/kg; these samples were collected from the upper reaches of the St. Clair River, and in the Clinton River Basin along the main stem, in East Branch Coon Creek, in Coon Creek, in Plum Brook, in Big Beaver Creek, in Red Run, and towards the Clinton River's mouth (fig. 21). In 134 samples, concentrations of copper were between the TEC of 31.6 mg/kg and the PEC. These samples were spread throughout the Clinton River Basin, along the western shoreline of Lake St. Clair, and in the upper reaches of the St. Clair River.

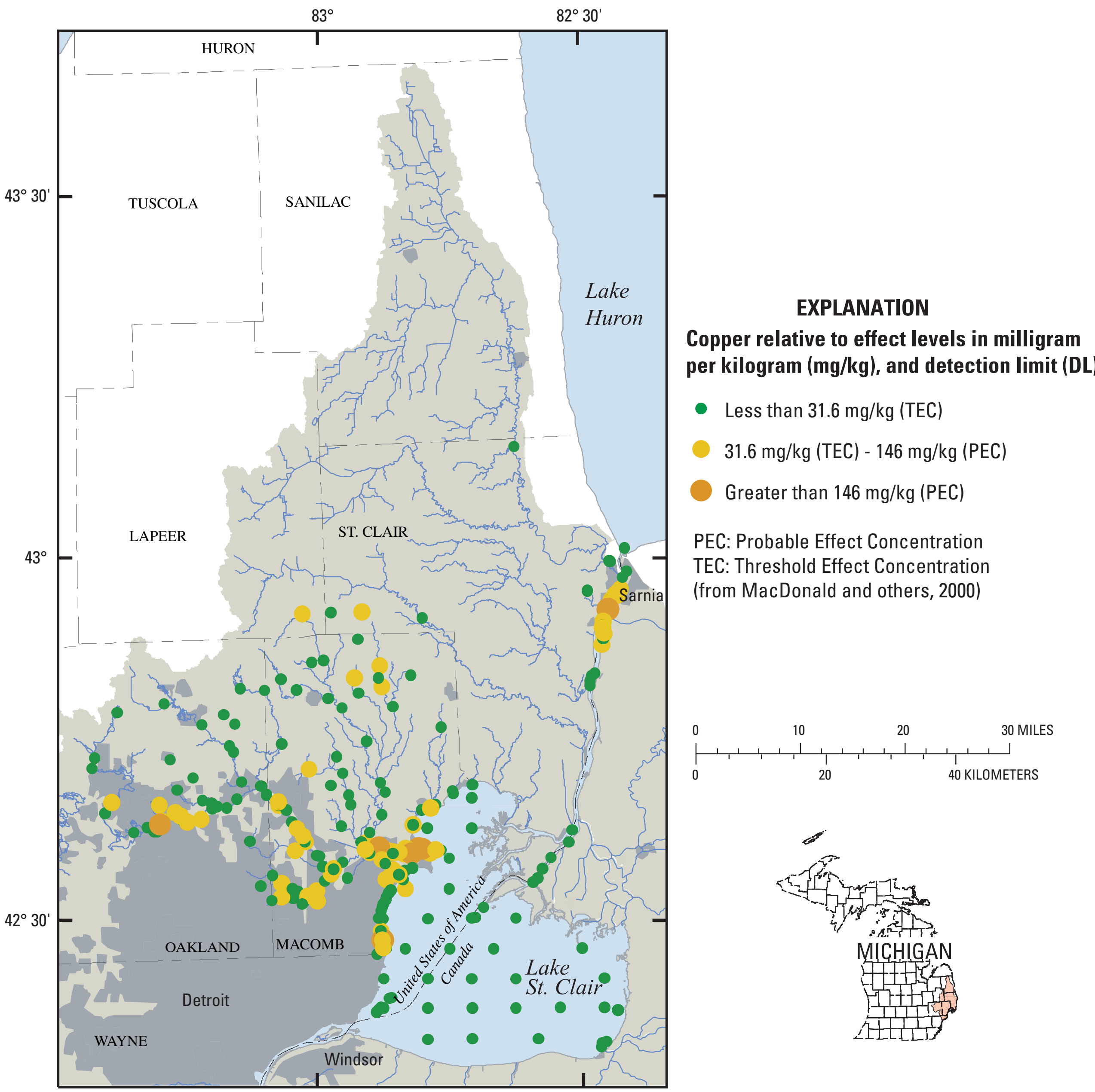
Lead

In the past, a major use of lead was the antiknock agent tetraethyl lead (also known as alkyl lead) in gasoline. Other uses include leaded glass, storage batteries, plumbing, and lead oxides and pigments in paint. Lead is released as a waste byproduct of coal and oil combustion, metal refining and fabrication, cement manufacture, and waste incineration. Lead is a known contaminant in urban stormwater runoff and in landfill leachate (Michigan Water Resources Commission, 1972). According to ATSDR (2005), lead compounds can break down by exposure to sunlight, air, and water. Lead tends to adhere to sediment and has the ability to move from sediment into ground water, depending on the type of lead compound and the sediment. Lead can bioaccumulate in plants and aquatic organisms, particularly shellfish (National Institute for Occupational Safety and Health, 1999).

Detected concentrations of lead in the Lake St. Clair Basin ranged from 1.4 to 800 mg/kg. Six of the 540 samples analyzed for lead content contained concentrations below detection limits that ranged from 1 and 5 mg/kg (table 2). Thirty-one samples contained concentrations greater than the PEC of 128 mg/kg and were found in the upper reaches and mouth of the Clinton River Basin; in the upper reaches of the St. Clair River; and along the western shoreline of Lake St. Clair in L'anse Creuse Bay and at the mouth of Pitts Drain (fig. 22). There were 124 samples containing concentrations between the TEC of 35.8 mg/kg and the PEC. These samples were found throughout the Clinton River Basin along the main stem, in East Branch Coon Creek, in Coon Creek, in Stony Creek, in Sashabaw Creek, in Plum Brook, in Big Beaver Creek, in Red Run, and towards the Clinton River's mouth; in the upper reaches of the St. Clair River; and along the shoreline of Lake St. Clair in L'anse Creuse Bay and at the mouths of Swan Creek, Crapeau Creek, Salt River, and Pitts Drain.

Mercury

Mercury is a volatile metal that can exist in elemental, inorganic-salt, and organic-compound forms. Methylmercury is an example of the latter. These various forms have different



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Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
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Figure 21. Copper concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

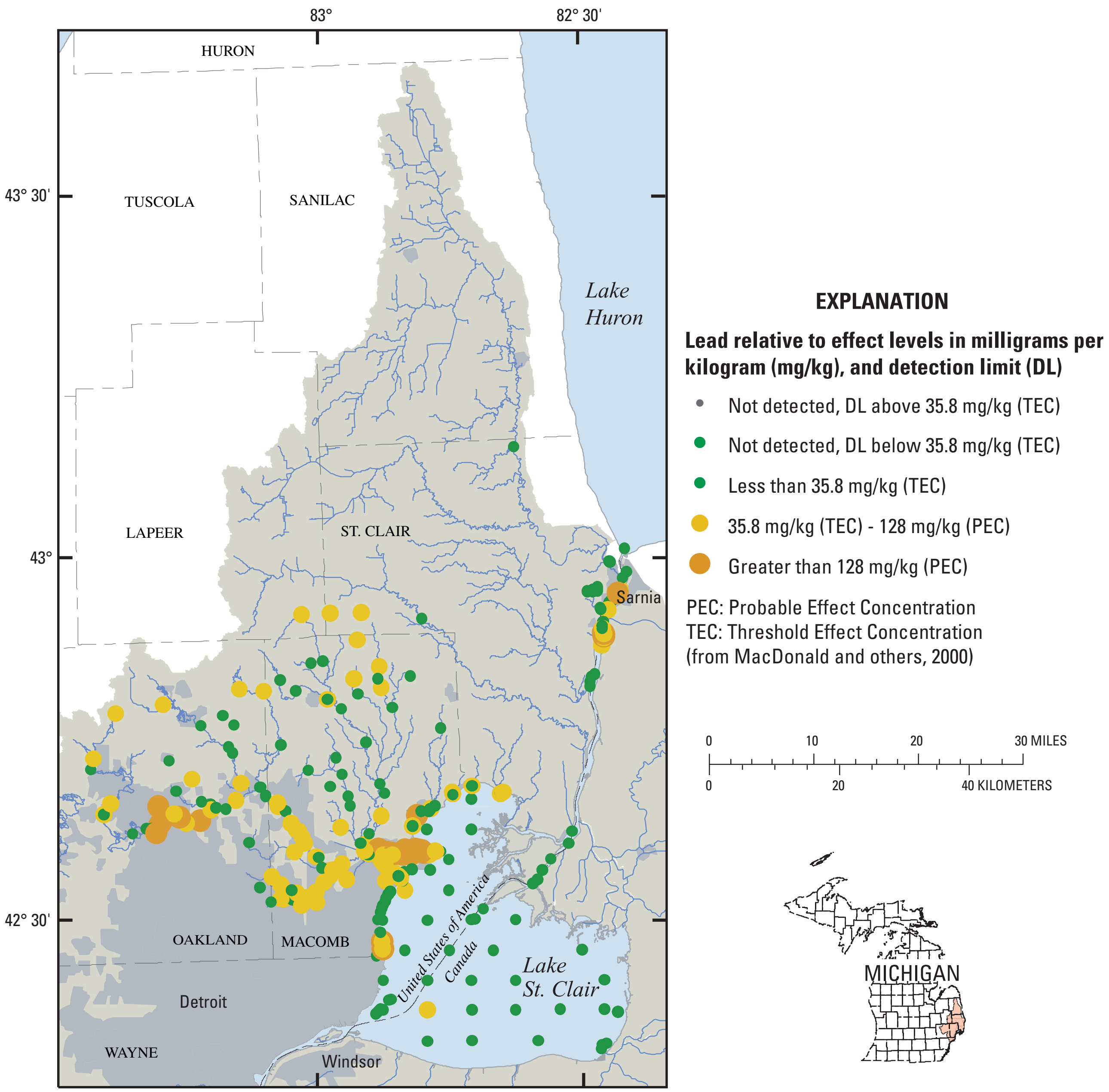

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Figure 22. Lead concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

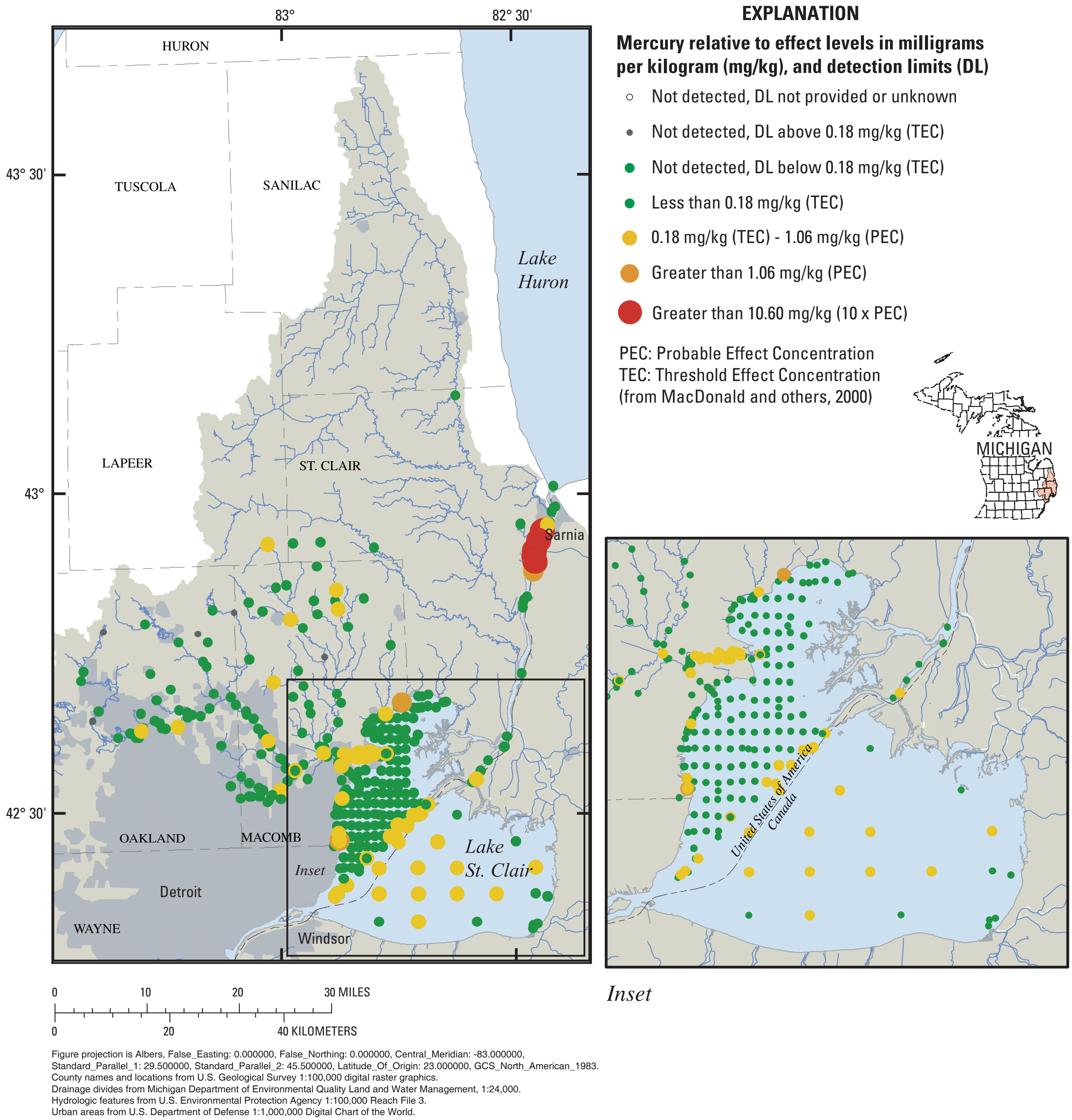
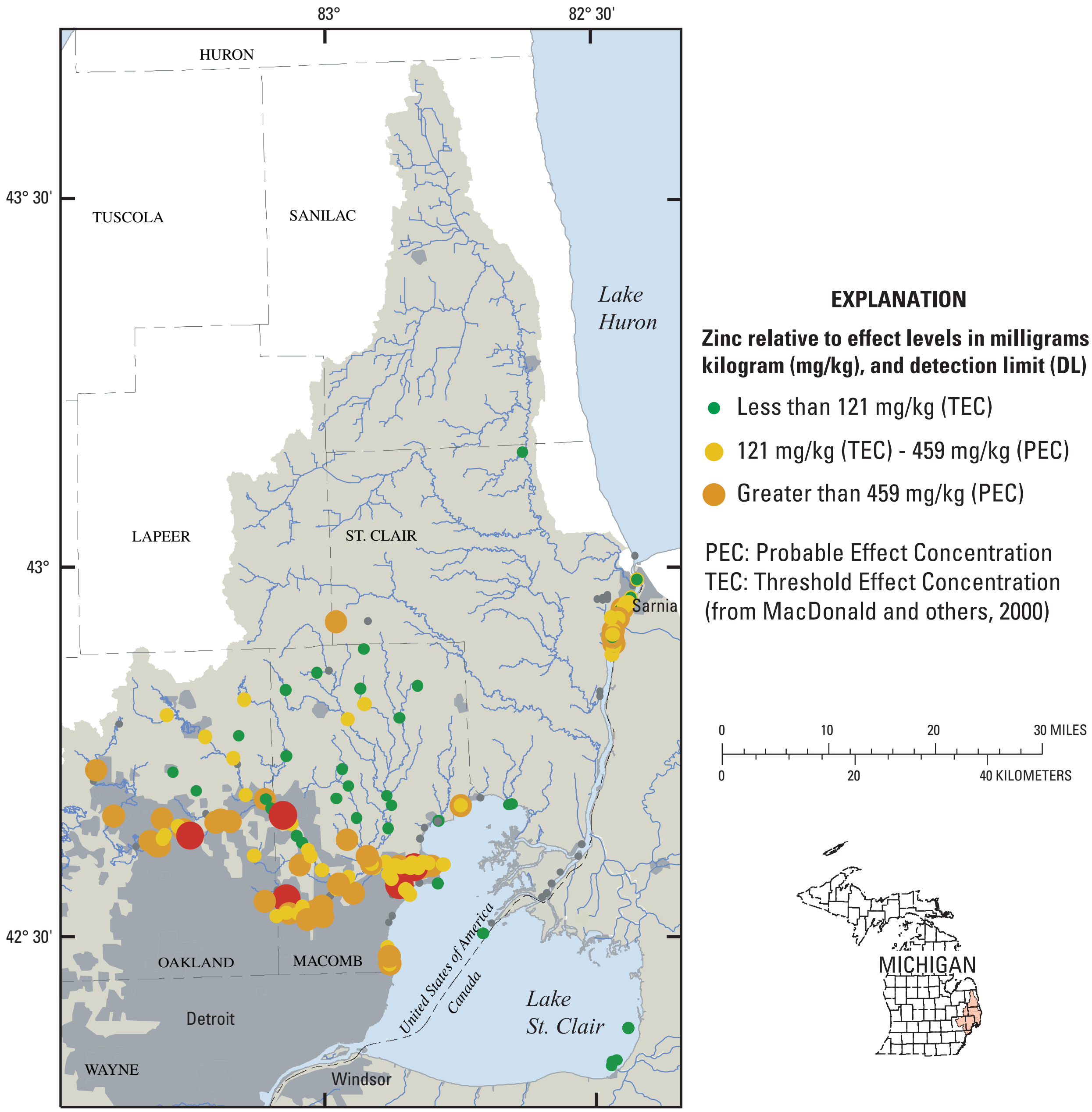


Figure 23. Mercury concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.



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County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 24. Zinc concentrations in streambed and lakebed sediments relative to effect levels, Lake St. Clair Basin, Mich.

properties and toxicities. Mercury is widely used within the industrial, medical, agricultural, and consumer sectors; more than 2,000 applications have been identified. Coal combustion and municipal and medical-waste incineration are the major anthropogenic sources to the atmosphere (Irwin and others, 1997). Most biocidal and fungicidal uses and mercury use in paints have been discontinued. Mercury is released as a waste byproduct in metal smelting and battery manufacturing, waste incineration, and disposal of batteries and other consumer goods. Implementation of pollution controls and closures of chlorine and caustic soda manufacturing plants have reduced releases of mercury to the environment (International Joint Commission, 1993). Global atmospheric transport of mercury through rainfall is a common source. According to NIOSH (1999) and ATSDR (2005), mercury has the ability to bioaccumulate in aquatic organisms, specifically in fish.

Detected concentrations of mercury in the Lake St. Clair Basin ranged from 0.01 to 48 mg/kg. The detection limits for censored data ranged from 0.01 to 5 mg/kg (table 2). Ninety of the samples contained concentrations greater than the PEC of 1.06 mg/kg; of these, 15 contained concentrations greater than 10 times the PEC. These highest concentrations were found in the upper reaches of the St. Clair River and in Lake St. Clair at the mouth of Crapeau Creek and in L'anse Creuse Bay (fig. 23). In all, 129 samples with concentrations between the TEC of 0.18 mg/kg and the PEC were found throughout the Clinton River Basin on the main stem, in East Branch Coon Creek, in the North Branch Clinton River, in Pond Creek, and in Red Run; at the mouth of the Clinton River to Lake St. Clair; along the western shore of Lake St. Clair in L'anse Creuse Bay and at the mouth of Pitts Drain; in the upper reaches of the St. Clair River; and towards the center and eastern part of Lake St. Clair.

Zinc

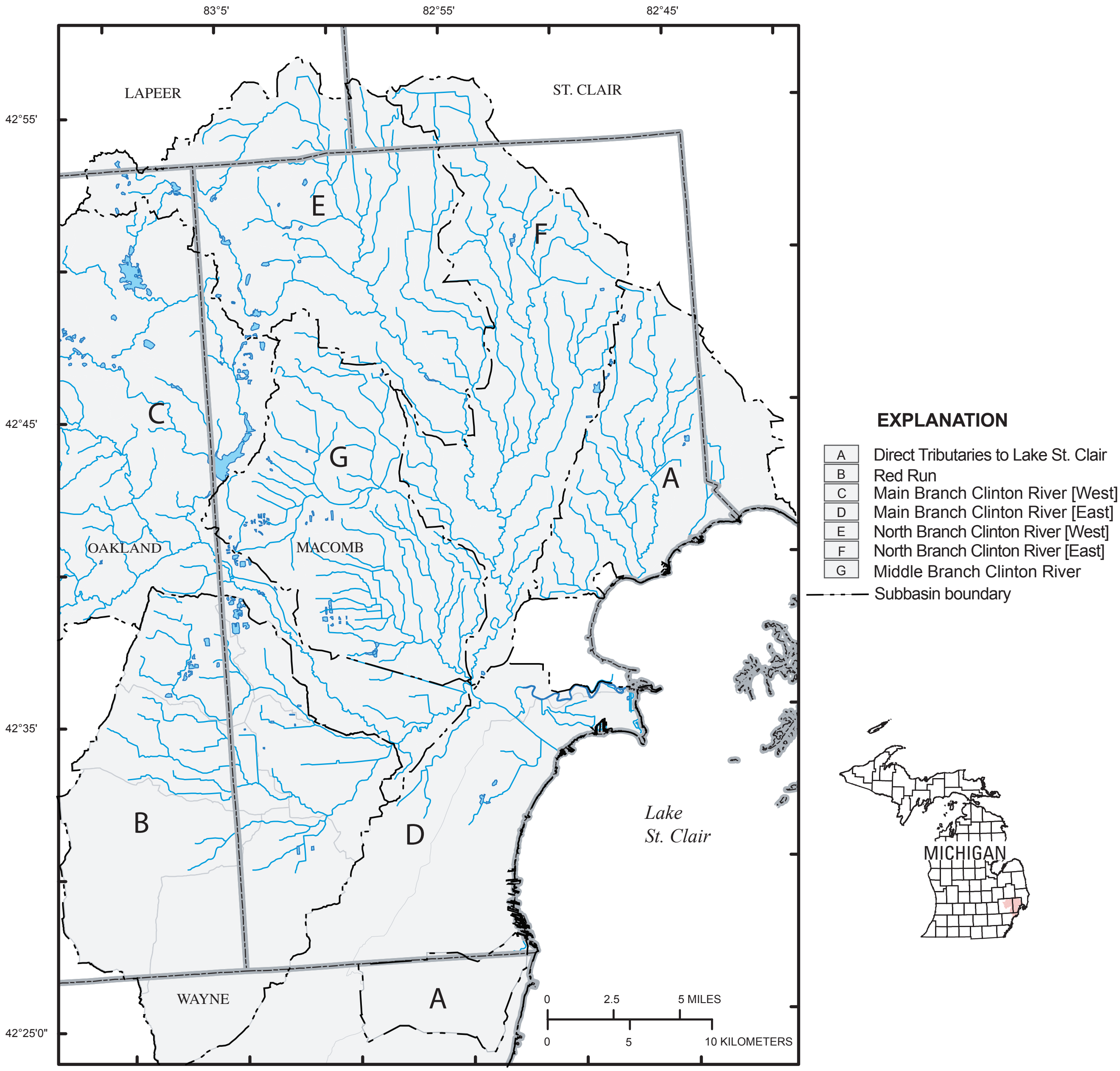
Elemental zinc has been used extensively for galvanizing, alloys, electrical purposes, printing plates, dye manufacture, dyeing processes, and many other industrial processes. Zinc salts are used in paint pigments, cosmetics, pharmaceuticals, dyes, pesticides, and fertilizers. Industrial wastes sometimes contain high concentrations of zinc, and common salts include zinc oxide, zinc sulfate, and zinc sulfide (Michigan Water Resources Commission, 1972; Agency for Toxic Substances and Disease Registry, 2005). Zinc is a known contaminant in urban stormwater runoff and in landfill leachate, and it is leachable from galvanized pipes used as culverts. Zinc tends to attach to sediments and has the ability to bioaccumulate in fish and animals.

All samples analyzed for zinc in the Lake St. Clair Basin contained concentrations greater than detection limits and ranged from 1 to 860 mg/kg (table 2). Eleven of the 366 samples contained zinc concentrations greater than the PEC of 459 mg/kg, and all were in the main stem of the Clinton River and in Red Run (fig. 24). Samples containing concentrations between the TEC of 121 mg/kg and the PEC were located throughout the Clinton River Basin along the main stem, in East Branch Coon Creek, in Coon Creek, in Stony Creek, in Paint Creek, in Plum Brook, in Big Beaver Creek, and in Red Run; in the upper reaches of the St. Clair River; and along the western shoreline of Lake St. Clair in L'anse Creuse Bay. Samples containing concentrations below the TEC were located throughout the study area and ranged in concentration from 1 to 120 mg/kg.

Sediment Categories with Respect to the Probable Effect Concentration

Owing to the large amount of available data within the Clinton River, Lake St. Clair, and smaller direct tributary basins along Anchor Bay and L'Anse Creuse Bay, sediment concentration categories were developed. These categories provide a summary of specific locations where samples containing high concentrations of contaminants were collected. The categories were developed using subbasin definitions that is similar to those for a water quality sampling program of the Macomb County Health Department. Locations of the subbasins are show in figure 25 and the categorical data are listed in table 3. In this report, "Direct Tributaries" refers to smaller drainages that flow directly into Lake St. Clair along Anchor Bay and L'Anse Creuse Bay, including Beaubein Creek, Swan Creek, Maldrum Creek, Marsac Creek, Crapeau Creek, Salt Creek, Auvase Creek, and the Milk River. "Lake St. Clair" refers to the main body of the lake itself, including areas along its shoreline within the United States border. The "Main Branch Clinton River [East]" subbasin is drained by the main stem of the Clinton River and its tributaries from its confluence with the North Branch Clinton River to its mouth into Lake St. Clair. The "Main Branch Clinton River [West]" subbasin is drained by the main stem of the Clinton River and its tributaries from its headwaters in Oakland County to its confluence with the North Branch Clinton River. The "Middle Branch Clinton River" subbasin is drained by the Middle Branch Clinton River and its tributaries from its headwaters in the middle of Macomb County to its confluence with the North Branch Clinton River. The "North Branch Clinton River [East]" subbasin is drained by the North Branch Clinton River and tributaries from its headwaters in northern Macomb County and southern Lapeer County to its confluence with Coon Creek. The "North Branch Clinton River [West]" subbasin is drained by Coon Creek and tributaries from its headwaters in southern St. Clair County and northern Macomb County to its confluence with the main stem of the Clinton River. The "Red Run" subbasin is drained by Red Run Drain and its tributaries.

Within the organochlorine insecticides or biocides contaminant class, at least one sample exceeded the PEC for chlordane and lindane. These samples were collected near the mouth of Crapeau Creek, a direct tributary to Lake St. Clair, and within Lake St. Clair marinas along the shoreline of St.



County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.

Figure projection is Hotine Oblique Mercator, Type 2, Scale factor at the projection's center 0.9996; longitude of the projection's center 86 00 00 W; latitude of the projection's center 45 18 33 N; Azimuth at the projection's center 337.25555555556.

Figure 25. Subbasins of the Clinton River and direct tributaries into Lake St. Clair used for comparions by sediment-concentration category.

Table 3. Level and frequencies of bed-sediment contamination in Lake St. Clair and seven subbasins in the Clinton River Basin. [Categories based on the degree and frequency that bed-sediment samples exceed Probable Effect Concentration (PEC) guidelines: ◆, concentration in at least one sample exceeded 10 times the contaminant's PEC; ●, concentration in at least one sample exceeded the contaminant's PEC; and ○, concentration in all samples were less than the contaminant's PEC; and –, no samples were analyzed for the contaminant.]

Class and constituent	Direct tributaries	Lake St. Clair	Main Branch [East]	Main Branch [West]	Middle Branch	North Branch [East]	North Branch [West]	Red Run
Organochlorine insecticides or biocides								
Chlordane	●	●	○	○	○	○	○	○
Total DDT	○	○	◆	○	○	○	○	○
Dieldrin plus aldrin	○	○	○	○	○	○	○	○
Hexachlorobenzene	○	○	○	○	○	○	○	○
Hexachlorocyclohexane	○	○	○	○	○	○	○	○
Lindane	○	○	○	●	○	○	○	○
Mirex	–	○	–	○	–	–	○	–
Industrial organochlorine compounds								
Total PCBs	◆	○	◆	●	○	○	○	●
Polycyclic aromatic hydrocarbons								
Anthracene	●	○	○	◆	○	○	○	●
Benz[*a*]anthracene	●	●	◆	◆	●	○	●	◆
Benzo[*a*]pyrene	●	●	●	◆	●	○	○	◆
Chrysene	●	●	◆	◆	●	○	●	◆
Phenanthrene	●	●	◆	◆	●	○	●	◆
Pyrene	●	●	◆	◆	●	○	●	◆
Total PAH	●	●	●	◆	●	○	●	◆
Trace elements								
Arsenic	○	○	○	●	○	○	○	○
Cadmium	●	●	●	●	○	○	●	●
Copper	○	●	●	●	○	○	○	○
Lead	●	●	●	●	○	○	○	○
Mercury	●	○	○	○	○	○	○	○
Zinc	○	○	●	●	○	○	○	○

Clair Shores. In addition, at least one sample collected near the mouth of the Clinton River exceeded 10 times the PEC for total DDT.

With respect to PCBs (the only compounds evaluated in the industrial organochlorine compound contaminant class), at least one sample exceeded the PEC within Main Branch Clinton River [West] and Red Run subbasins and at least one sample exceeded 10 times the PEC within a direct tributary to Lake St. Clair and the Main Branch Clinton River [East] subbasin. Within the Main Branch Clinton River [West] subbasin, the sample exceeding the PEC was collected near the river's headwaters in Oakland County. For the Red Run subbasin, two samples exceeding the PEC were collected within Red Run Drain and Bear Creek. At least one sample exceeded 10 times the PEC within the Milk River, a direct tributary to Lake St. Clair, and along the Main Branch Clinton River [East] subbasin, downstream from its confluence with the North Branch Clinton River.

For the polycyclic aromatic hydrocarbons contaminant class, at least one sample exceeded the PEC in all subbasins except the North Branch Clinton River [East]. Within the direct tributaries, at least one sample exceeded the PEC for all of the PAHs summarized in this report near the mouth of Milk River and for phenanthrene near the mouth of Crapeau Creek. Samples collected within Lake St. Clair marinas along St. Clair Shores exceeded the PEC for benz[*a*]anthracene, benzo[*a*]pyrene, chrysene, phenanthrene, and pyrene. Within the Main Branch Clinton River [East] subbasin, samples exceeded 10 times the PEC for chrysene, phenanthrene, and pyrene at locations within and near the Clinton River mouth and spillway; and samples exceeded the PEC for benzo[*a*]pyrene and total PAH at locations within and near the Clinton River mouth and spillway. Within the Main Branch Clinton River [West] subbasin, samples exceeded 10 times the PEC for all PAHs. These samples were all collected near the river's headwaters in Oakland County. Within the Middle Branch Clinton River subbasin, at least one sample exceeded the PEC for all of the PAHs except anthracene. These samples were collected within tributaries to the Middle Branch Clinton River and near its confluence with the North Branch Clinton River. Within the North Branch Clinton River [West] subbasin, at least one sample exceeded the PEC for benz[*a*]anthracene, chrysene, phenanthrene, pyrene, and total PAH; specifically, samples were collected within tributary drains east of Almont. Within the Red Run subbasin, at least one sample exceeded ten times the PEC for all PAHs except anthracene; these samples were collected within Big Beaver Creek. Additionally, three samples exceeded the PEC along Red Run and Big Beaver Creek.

For the trace-element class, at least one sample was collected within the direct tributaries that exceeded the PEC for cadmium, lead, and mercury in Milk River, Auvase Creek, Swan Creek, and Crapeau Creek. Within Lake St. Clair, at least one sample exceeded the PEC for cadmium, copper, and lead; however, these samples were collected within marinas along the shoreline of St. Clair Shores rather than the open lake. Within Main Branch Clinton River [East] subbasin, at least one sample exceeded the PEC for cadmium, copper, lead, and zinc; the samples were collected at several locations between the confluence with the North Branch Clinton River and the river's mouth. Within Main Branch Clinton River [West] subbasin, at least one sample exceeded the PEC for each of the trace elements except mercury. These samples were collected near the river's headwaters in Oakland County. The PEC for cadmium was exceeded by at least one sample within the North Branch Clinton River [West] and Red Run subbasins. One sample was collected in the headwaters of the North Branch Clinton River in southern Lapeer County; and the other sample was collected along Red Run Drain.

Spatial Trends of Contaminants of Concern in Surficial Bed Sediments

Spatial trends of the contaminants of concern can be interpreted by considering the hydrology of the Lake St. Clair Basin. The hydrodynamics of the St. Clair River-Lake St. Clair-Detroit River waterway has been the subject of several modeling efforts (Ibrahim and McCorquodale, 1985; Schwab and others, 1989; Holtschlag and Koschik, 2002; Holtschlag and Koschik, 2004). In particular, a two-dimensional hydrodynamic model was developed for source-water assessment in the St. Clair-Detroit River Waterway (Holtschlag and Koschik, 2002). Model simulations indicated that variations in wind conditions, rather than variations of inflows from St. Clair River, are the primary determinant of changing current patterns on Lake St. Clair (Holtschlag and Koschik, 2004). In particular, the 2004 report describes the partitioning of wind data from a weather station on Lake St. Clair into 24 adjoining sectors, each having an angular width of 15 degrees. The expected wind speed was calculated for each sector and was used to specify a set of wind boundary conditions for model simulations needed to identify source areas to public water intakes on Lake St. Clair.

In this analysis, the same 24 hydrodynamic simulations were used to investigate depositional areas of Clinton River outflows into Lake St. Clair. In particular, a hypothetical, massless (neutrally buoyant) particle was located near the mouth of Clinton River at an easting of 13,554,455 (International) ft and a northing of 402,721 ft based on the Michigan South (zone 2113) State Plane Coordinate System of 1983. This location corresponds to a latitude of 42.59383 degrees north and a longitude of 82.76551 degrees west based on the North American Datum of 1983. The hypothetical particle was tracked forward in time for a period of up to 168 hours, so that the particle could reach the outlet of Lake St. Clair, which is the Detroit River. The traces of the particle tracks from the 24 simulations are shown on figure 26. The traces were used to delineate a depositional zone in which real particles, having mass, would be expected to settle within Lake St. Clair from outflows of the Clinton River. In general,

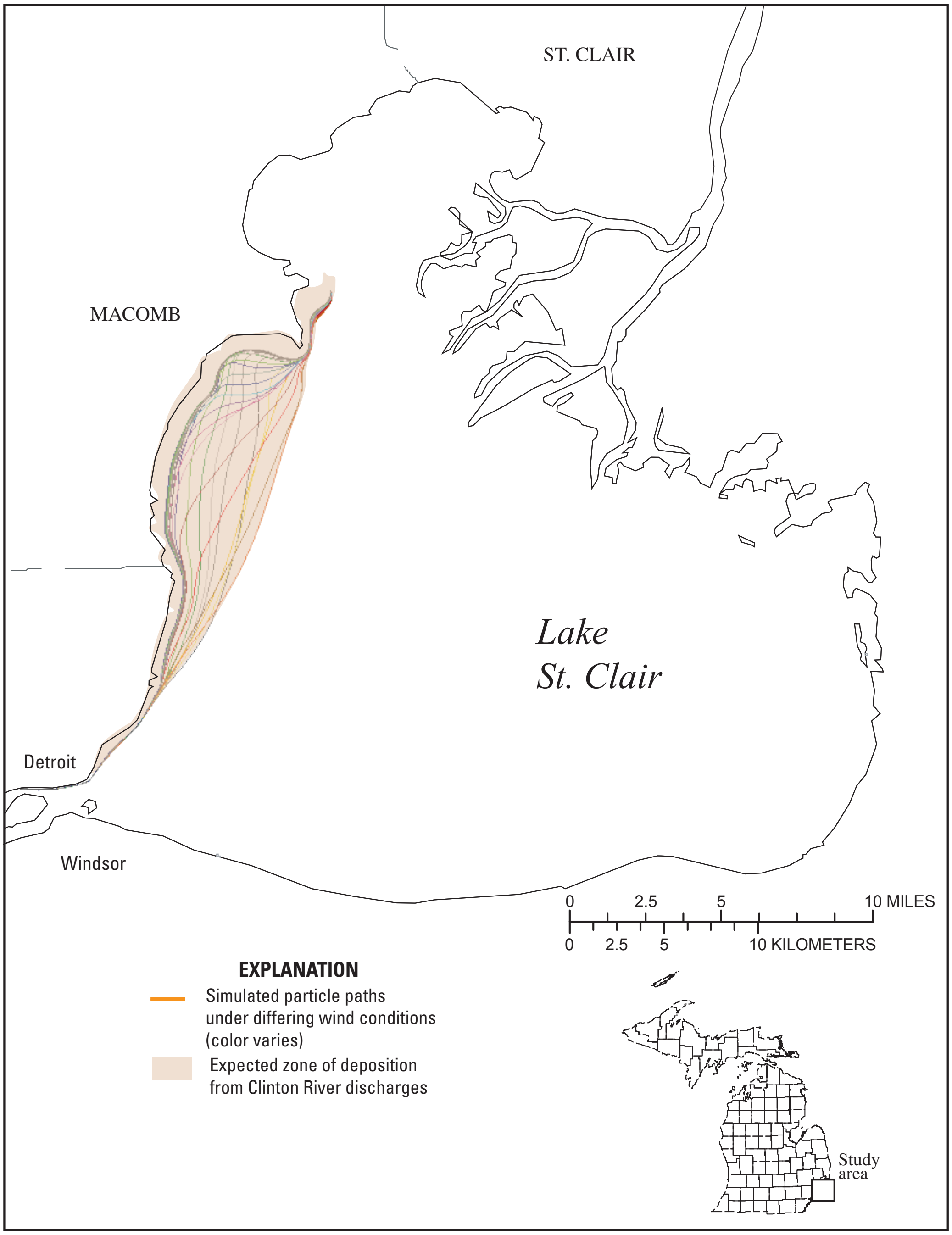


Figure 26. Particle paths and zone of deposition delineated from 24 simulations of a two-dimensional hydrodynamic model of outflows from the Clinton River into Lake St. Clair, Mich.

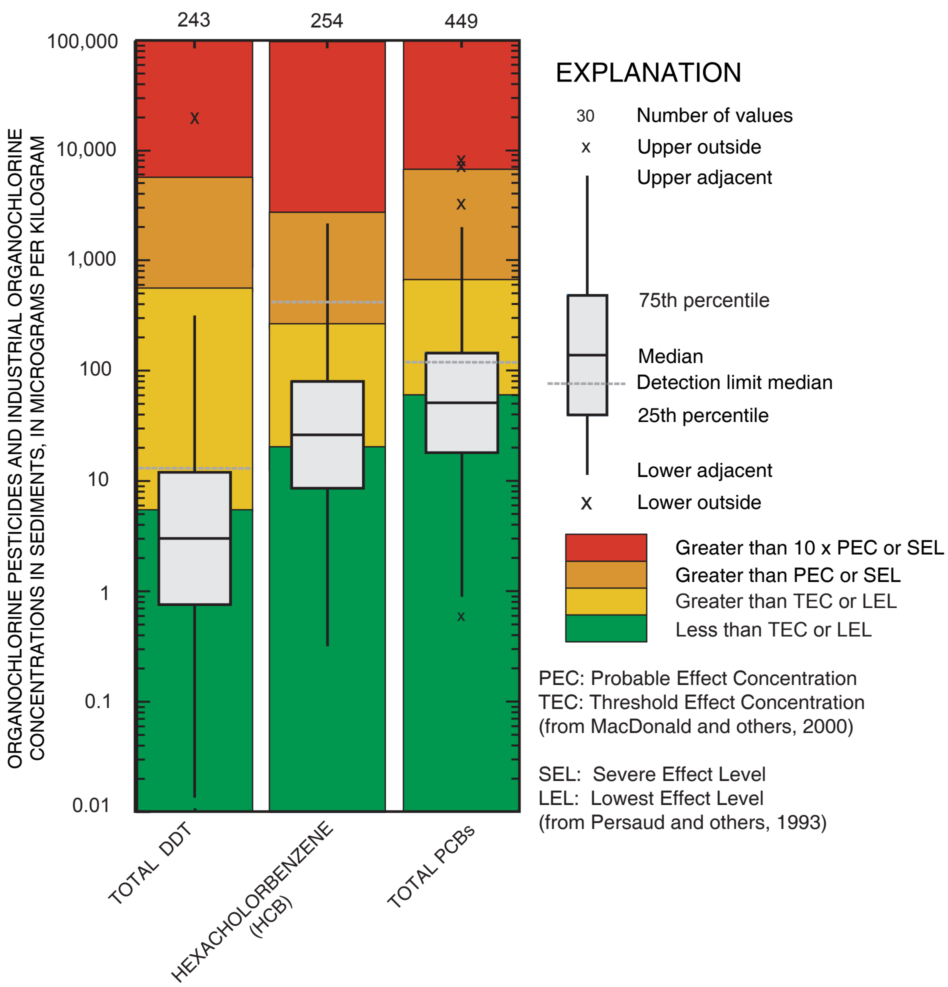


Figure 27. Organochlorine pesticides and industrial organochlorine concentrations in streambed and lakebed sediments, Lake St. Clair Basin, Mich.

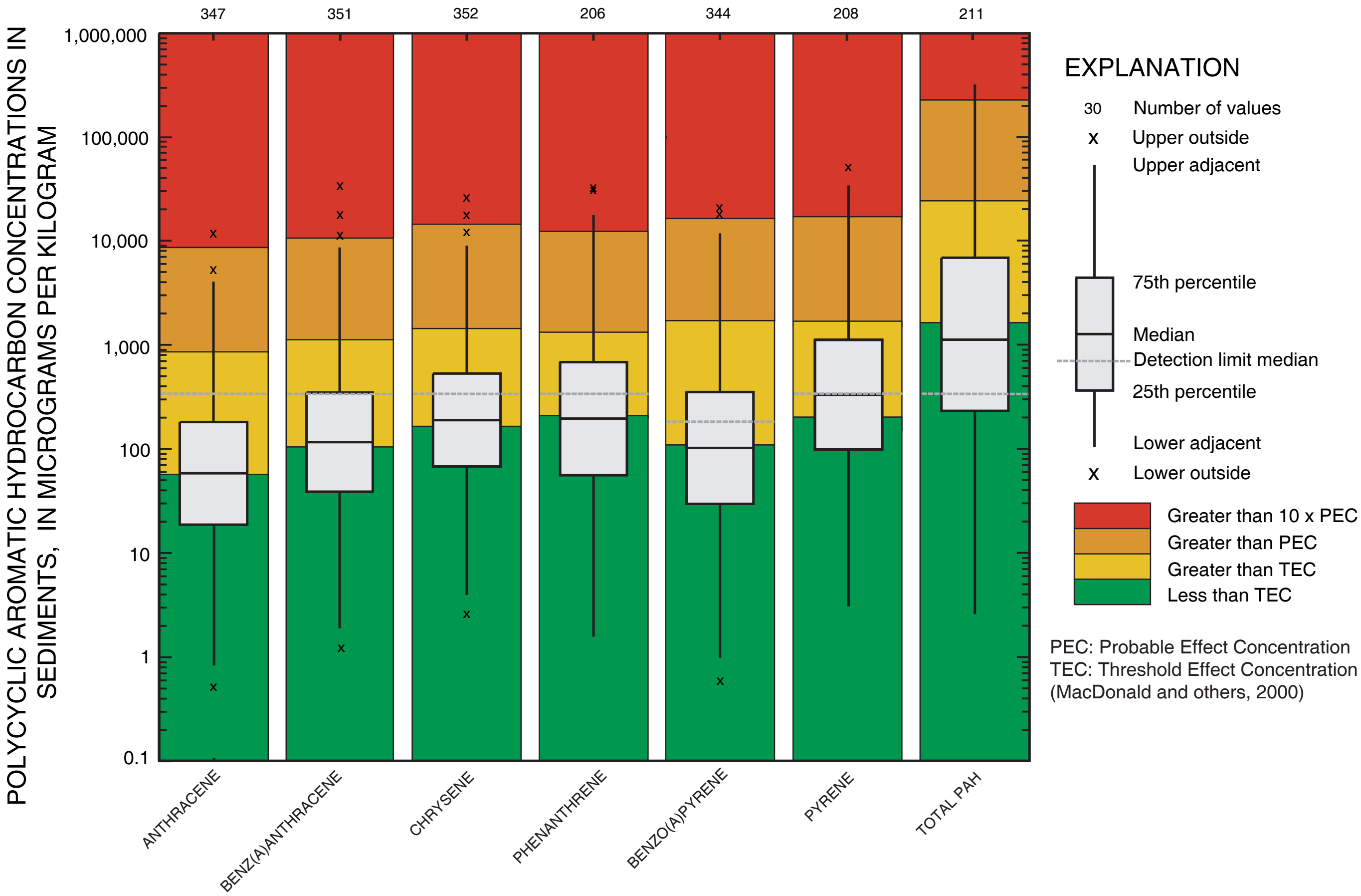


Figure 28. Polycyclic aromatic hydrocarbon concentrations in streambed and lakebed sediments, Lake St. Clair Basin, Mich.

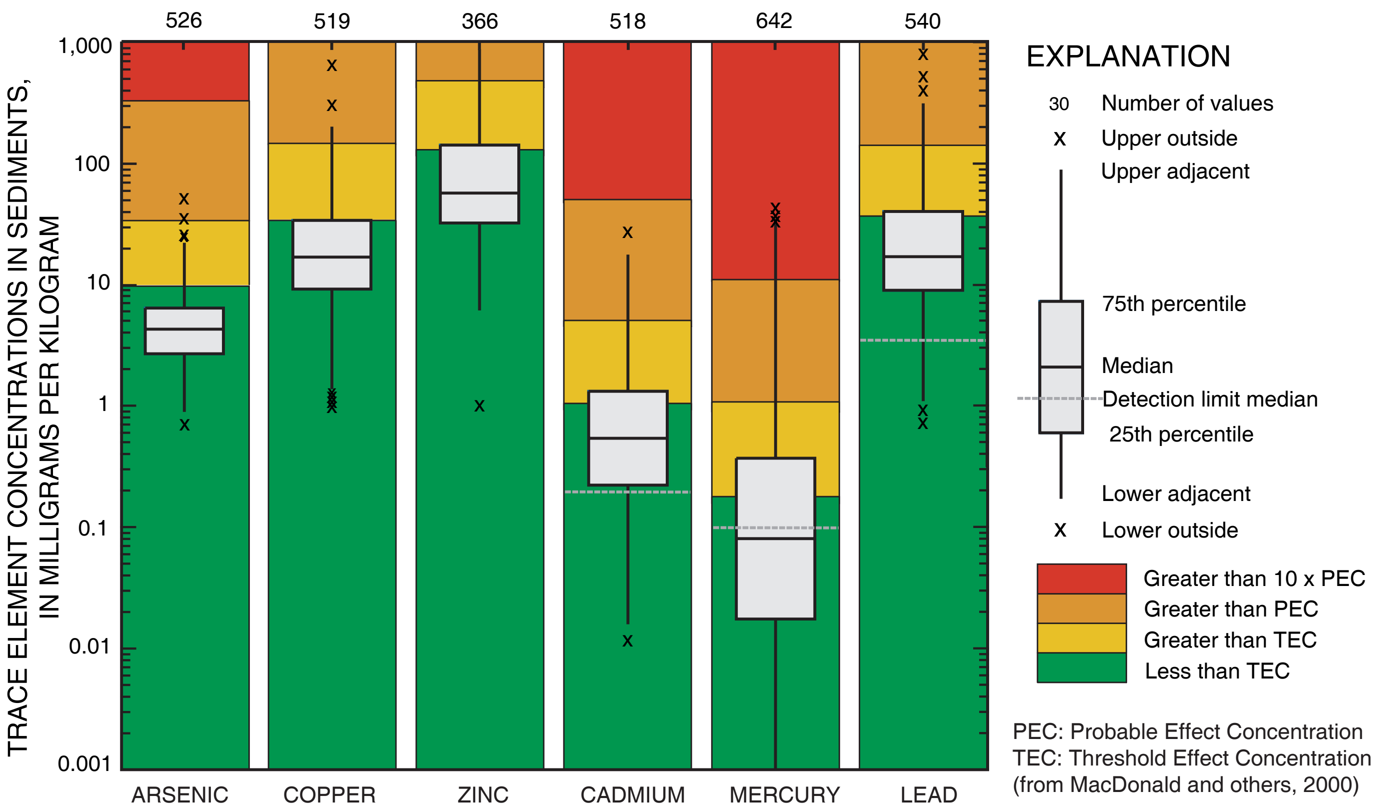


Figure 29. Trace element concentrations in streambed and lakebed sediments, Lake St. Clair Basin, Mich.

Table 4. Selected summary statistics and effect-level concentrations for contaminants of concern.
[Sediment concentrations are dry weight; µg/kg, microgram per kilogram; mg/kg, milligram per kilogram; TEC and PEC, Threshold Effect Concentration and Probable Effect Concentration (from MacDonald and others, 2000); LEL and SEL, Lowest Effect Level and Severe Effect Level (from Persaud and others, 1993)]

Class and constituent	Median	75th percentile	TEC or LEL	PEC or SEL
Organochlorine insecticides or biocides				
Total DDT (µg/kg)	3.02	12.03	5.28	572
Hexachlorobenzene (µg/kg)	25.47	77.47	20	240
Industrial organochlorine compounds				
Total PCBs (µg/kg)	51.32	145.84	59.8	676
Polycyclic aromatic hydrocarbons				
Anthracene (µg/kg)	58.63	182.69	57.2	845
Benz[*a*]anthracene (µg/kg)	119.54	357.58	108	1,050
Chrysene (µg/kg)	190.26	534.9	166	1,290
Phenanthrene (µg/kg)	196.93	694.16	204	1,170
Benzo[*a*]pyrene (µg/kg)	102.79	355.91	150	1,450
Pyrene (µg/kg)	340.35	1,162.43	195	1,520
Total PAH (µg/kg)	1,115.87	6,830	1,610	22,800
Trace elements				
Arsenic (mg/kg)	4.3	6.4	9.79	33
Cadmium (mg/kg)	0.55	1.34	.99	4.98
Copper (mg/kg)	17	34	31.6	149
Lead (mg/kg)	17	40	35.8	128
Mercury (mg/kg)	.08	.37	.18	1.06
Zinc (mg/kg)	56	140	121	459

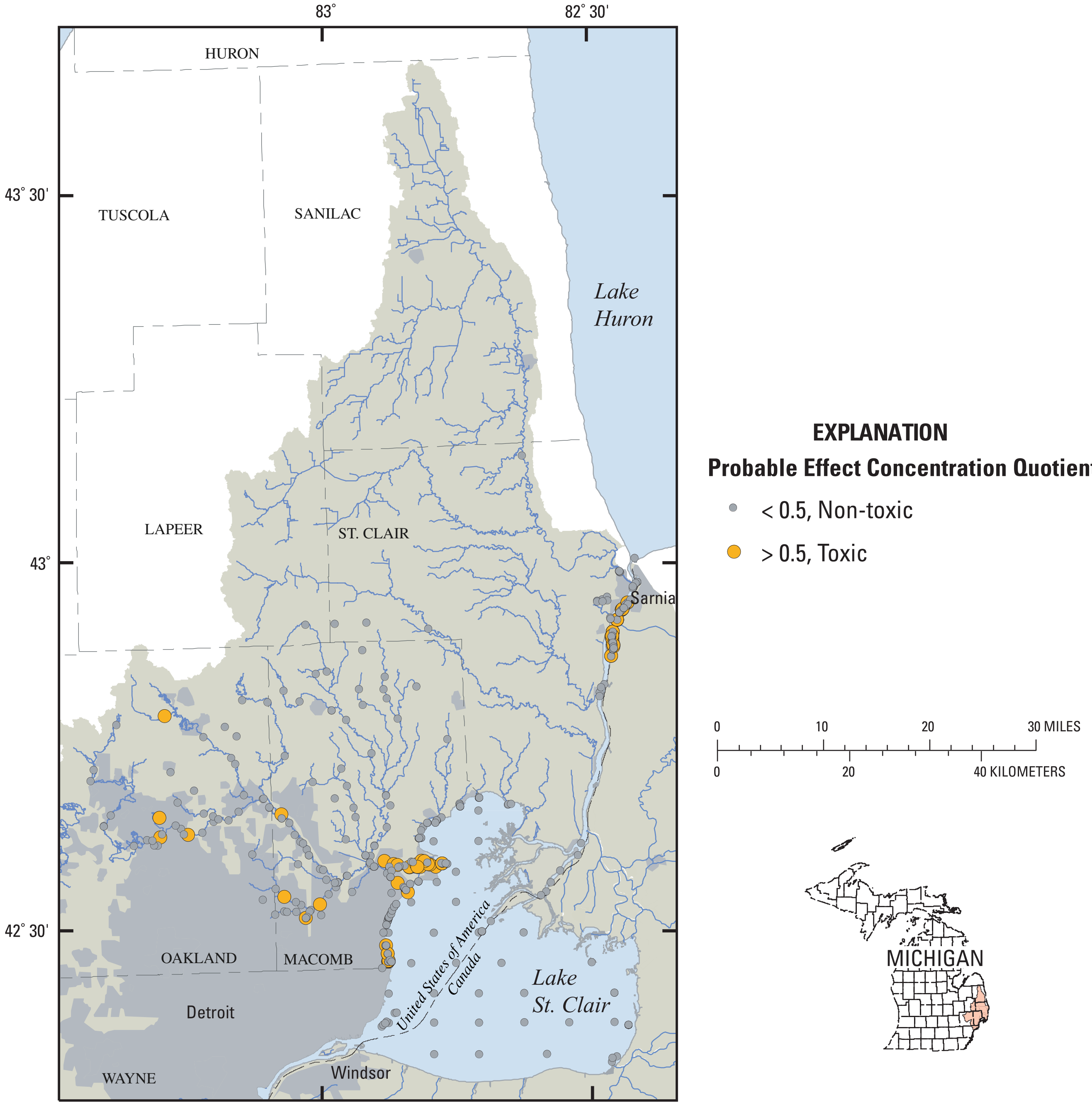


Figure projection is Albers, False_Easting: 0.000000, False_Northing: 0.000000, Central_Meridian: -83.000000, Standard_Parallel_1: 29.500000, Standard_Parallel_2: 45.500000, Latitude_Of_Origin: 23.000000, GCS_North_American_1983.
County names and locations from U.S. Geological Survey 1:100,000 digital raster graphics.
Drainage divides from Michigan Department of Environmental Quality Land and Water Management, 1:24,000.
Hydrologic features from U.S. Environmental Protection Agency 1:100,000 Reach File 3.
Urban areas from U.S. Department of Defense 1:1,000,000 Digital Chart of the World.

Figure 30. Probable effect concentration quotients calculated from bed-sediment sample analysis results, Lake St. Clair Basin, Mich.

this zone occurs within an area south from L'Anse Creuse Bay to St. Clair Shores, Mich., along the western edge of Lake St. Clair.

The zone of deposition described above is consistent with the areal distribution maps of selected trace elements, which were the only class of contaminants collected throughout Lake St. Clair examined in this report. Sediment samples analyzed for mercury concentrations, in particular, were collected in a network of locations that covered the western portion of Lake St. Clair. The areal distribution map for mercury (fig. 23) shows two fairly distinct zones within Lake St. Clair. Samples containing mercury concentrations between the TEC and PEC were found in central and eastern Lake St. Clair; however, samples from western Lake St. Clair generally yielded mercury concentrations lower than the TEC. Based on the results of hydrodynamic simulations, it is not likely that the Clinton River is the source of the higher mercury concentrations observed in the middle and eastern portions of Lake St. Clair. Similar observations could be made for cadmium (fig. 20).

Statistical Analysis of Contaminants of Concern in Surficial Bed Sediments

As discussed previously, summary statistics of the data, by compound, were calculated by use of the AMLE method (Helsel and Hirsch, 2002). Boxplots of the summary statistics allow for comparison of the constituents within each chemical class and relate the statistics to the corresponding sediment-quality criteria (figs. 27-29). Values for the principal summary statistics are listed in table 4. The data were insufficient to develop summary statistics for dieldrin (plus aldrin), chlordane, HCH, lindane, and mirex; therefore, these compounds are not represented with boxplots.

Summary statistics for organochlorine insecticides or biocides and total PCBs relate similarly to effect-level concentrations (fig. 27; table 4). The median and 75^{th} percentile of total DDT concentrations are less than the TEC and the PEC, respectively. For total PCBs, the median and 75^{th} percentile were also less than the TEC and PEC, respectively. For HCB, the median and 75^{th} percentile are both between the LEL and the SEL.

Summary statistics for polycyclic aromatic hydrocarbon compounds are shown in figure 28 and table 4. For anthracene, benz[*a*]anthracene, chrysene, and pyrene, the median and 75^{th} percentile are both between the TEC and PEC. For phenanthrene, benzo[*a*]pyrene, and total PAH, the median and the 75^{th} percentile are less than the TEC and PEC, respectively.

Summary statistics for trace element constituents are shown in figure 29 and table 4. For all of the trace element constituents analyzed, the median and the 75^{th} percentile are less than the TEC and PEC, respectively.

Categorizing Bed-Sediment Data by Means of Probable Effect Concentration Quotients

Probable Effect Concentration Quotients (PEC-Qs) were computed and used to categorize the bed-sediment-quality data as toxic or nontoxic to the amphipod *Hyalella azteca* and the midge *Chironomus tentans*. Of the 546 individual samples analyzed, 469 (86 percent) were categorized as being nontoxic, and 77 (14 percent) were categorized as being toxic. Bed-sediment samples with toxic PEC-Qs were collected from Paint Creek, Galloway Creek, the main stem of the Clinton River, Big Beaver Creek, Red Run, the Clinton River towards the mouth, Lake St. Clair along the western shore, and the St. Clair River near Sarnia (fig. 30).

Summary and Conclusions

To support the water-quality assessments conducted under the Lake St. Clair Regional Monitoring Project, the U.S. Geological Survey (USGS) compiled sediment-quality data from international, federal, state, and local databases for Lake St. Clair, and the St. Clair, Black, Pine, Belle, and Clinton Rivers. Contaminant concentrations were summarized and compared with selected freshwater bed-sediment-quality guidelines that are commonly used in the Great Lakes area.

The extent to which contaminant concentrations exceed the selected sediment-quality guidelines indicates the potential for impairment of aquatic life. The link between the organisms most at risk for impairment and exposure to surficial sediments is strong because benthic macroinvertebrates and fish live in or forage near the surface of these sediments. This study examined the areal distribution of 21 contaminants of concern in streambed and lakebed sediments relative to current sediment-quality guidelines. Pertinent conclusions include the following:

- Maps indicated areas that routinely contained sediment contaminant concentrations that were greater than the Threshold Effect Concentration or Lowest Effect Level. These locations include the upper reach of the St. Clair River, the main stem and mouth of the Clinton River, Big Beaver Creek, Red Run, and Paint Creek.

- Maps indicated areas that routinely contained sediment contaminant concentrations that were greater than the Probable Effect Concentration or Severe Effect Level. These locations include the upper reach of the St. Clair River, the main stem and mouth of the Clinton River, Red Run, within direct tributaries along Lake St. Clair and in marinas within the lake, and within the Clinton River headwaters in Oakland County.

- Statistical summaries show that the median concentrations of hexachlorobenzene, anthracene, benz[*a*]anthracene, chrysene, and pyrene were greater than the Threshold Effect Concentrations or Lowest Effect Levels for these substances.

- Twenty-four simulations of a two-dimensional hydrodynamic model were used to investigate depositional areas of Clinton River outflows into Lake St. Clair. This model delineated a zone of deposition that occurs along the western edge of Lake St. Clair, within an area south from L'Anse Creuse Bay to St. Clair Shores, Mich. Based on the results of these simulations, it is not likely that the Clinton River is the source of the higher mercury and cadmium concentrations observed in the middle and eastern portions of Lake St. Clair.

- Calculation of Probable Effect Concentration Quotients from individual sample analysis shows that the majority of the sample concentrations (86 percent) were categorized as nontoxic to amphipods and midges. Samples that were categorized as toxic were collected from Paint Creek, Galloway Creek, the main stem of the Clinton River, Big Beaver Creek, Red Run, the Clinton River towards the mouth, Lake St. Clair along the western shore, and the St. Clair River near Sarnia.

Acknowledgments

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