2 Remedial Investigation Summary

This section provides a summary of information from the Remedial Investigation (RI) report for the Lower Fox River and Green Bay that is relevant to the human health and ecological risk assessment. This includes the hydrologic, physical, chemical, fate and transport and important habitat and ecological characteristics of the system and biological characteristics of the river and bay. Specifically, this summary of the RI report will:

- Define the historical setting, including sources of chemicals of concern in the Lower Fox River;
- Describe the physical characteristics of the Lower Fox River and Green Bay along areas of impacted sediment deposits;
- Estimate the occurrence, volume, and mass of sediments containing identified chemical compounds, particularly polychlorinated biphenyls (PCBs);
- Discuss the fate and transport of contaminants within the Lower Fox River and Green Bay;
- Describe the biological distribution of observed species, the shoreline habitat types, and habitat quality of the Lower Fox River and Green Bay; and
- Present the results of an analysis of time trends within the Lower Fox River for changing sediment and fish tissue concentrations.

2.1 Environmental Setting and Background

2.1.1 Site History

The Lower Fox River and Green Bay regions have long been important transportation corridors within the state of Wisconsin. Abundant and reliable food, as well as other natural resources in the area, have fostered development since prior to arrival of Europeans to the region. By the early 1800s, timber, agriculture, fishing and fur trading, and other commercial activities were either well established or beginning to be developed, based on the availability of the local resources. During the 1820s and 1830s, Green Bay was a key entrance into the American west and large-scale migration to the area and development occurred (Burridge, 1997). In 1839–40, representatives of the U.S. federal government (the Topographical Engineers office) recommended the construction of a series of dams, locks, canals, and other improvements in order to make the Lower Fox River navigable between Green Bay and Lake Winnebago (Burridge, 1997). Channelization of the Lower Fox River began as part of this effort, as did construction of the locks and dams at each of the river's rapids. Along with development came utilization, exploitation, and degradation of the local resources, including the water quality of the river and bay.

Currently, the Lower Fox River and Green Bay areas support a population of approximately 595,000, about 10 percent of the state's population. The Lower Fox River valley, especially in the Appleton and Neenah-Menasha area, may still contain the largest concentration of pulp and paper industries in the world (20 mills in approximately 60 kilometers (km) [37 miles]). The paper industry remains active within the valley and plays a vital role in the local and state economy. Other industries important to the region include metal working, printing, food and beverages, textiles, leather goods, wood products, and chemicals. In addition to heavy industrial land use, the region also supports a mixture of agricultural, residential, light industrial, conservancy, and wetland areas.

2.1.2 Chemicals of Potential Concern in the Lower Fox River

COPCs, representing potential risks to human and ecological health, were identified in the Screening Level Risk Assessment (SLRA) (RETEC, 1998b). These compounds include the chlorinated organic compounds PCBs and dioxins/furans, the chlorinated pesticides dichlorodiphenyltrichloroethane (DDT), DDD, and DDE, and dieldrin, and the inorganic compounds mercury, lead, and arsenic. The SLRA determined that risks were primarily associated with PCBs, mercury, and DDE.

Polychlorinated Biphenyls (PCBs)

From the early 1950s through the early 1970s, the manufacture of carbonless copy paper used a PCB emulsion. In 1954, Fox River valley paper mills began manufacturing, de-inking, and recycling of carbonless copy paper. Aroclor 1242 was the PCB mixture used in the manufacture of carbonless copy paper and approximately 20.4 million kilograms (kg) (45 million pounds) of this emulsion were reportedly used in the Lower Fox River valley between about 1954 and 1971. The use of PCBs was unregulated and the potential health effects were unknown during this time period.

The use of PCBs in carbonless paper manufacturing ceased in 1971. The Wisconsin Department of Natural Resources (WDNR) estimated that approximately 313,600 kg (691,370 pounds) of PCBs were released to the environment during this time (1954 to 1971), although the discharge estimates range from 126,450 to 399,450 kg (278,775 to 880,640 pounds) based on the percentages of PCBs lost during production or recycling of carbonless copy paper (WDNR, 1999a). Further, WDNR (1999a) estimated that 98 percent of the total PCBs released into the Lower Fox River had occurred by the end of 1971. In addition, WDNR (1999a) indicated that five facilities, including the Appleton Papers-Coating Mill, P. H. Glatfelter Company and associated Arrowhead Landfill, Fort James-Green Bay West Mill (formerly Fort Howard), Wisconsin Tissue, and Appleton Papers-Locks Mill contributed over 99 percent of the total PCBs discharged to the river. A portion of these PCBs settled into river sediments.

The companies discussed above have been named as potentially responsible parties (PRPs) under the CERCLA statute. Fort James Corporation, P. H. Glatfelter, Riverside Paper Company, U.S. Paper Mills Corporation, and Wisconsin Paper Mills, Inc. were identified as PRPs by the U.S. Fish and Wildlife Service in 1994, and NCR Corporation and Appleton Papers, Inc. in 1996. These parties refer to themselves as the Fox River Group (FRG).

Point source discharges of the COPCs have decreased significantly since implementation of the Clean Water Act and other environmental regulations in the early 1970s. As a result, input of PCBs into the Lower Fox River from regulated discharges is essentially eliminated. However, residual sources for PCBs and other detected compounds remain in the river sediments, continuing to affect water quality, fish, wildlife, and potentially humans. PCBs have also been detected in many fish and bird species in the Lower Fox River and Green Bay. Due to the continued elevated levels of PCBs present within the Lower Fox River and Green Bay, WDNR issued consumption advisories in 1977 and 1987 for fish and waterfowl, respectively; Michigan issued fish consumption advisories for Green Bay in 1977. Most of these advisories are still in place.

Sediments are the most significant source of PCBs entering the water column (Fitzgerald and Steuer, 1996) and over 95 percent of the PCB load into Green Bay is derived from the Lower Fox River (WDNR, 1998c). PCBs from sediment deposits are discharged into Green Bay at the mouth of the Lower Fox River through sediment transport and PCB dissolution in the water column. Up to 280 kg (620 pounds) of PCBs were transported from the Lower Fox River into Green Bay during a 1-year period in 1989–1990 (Velleux and Endicott, 1994). Approximately 122 kg (270 pounds) of PCBs are transported from Green Bay to Lake Michigan annually (EPA, 1998a). Based on the data included in the Fox

River database, the estimated mass of PCBs in sediments of the Lower Fox River and Green Bay is approximately 100,000 kg (220,000 pounds).

Mercury and DDE

Sediments from upstream of the Kaukauna dam to Green Bay contain elevated mercury concentrations. Elevated mercury levels in Lower Fox River sediments are attributed to mercuric slimicides (phenyl mercuric acetate) used in paper manufacturing. This practice was discontinued in 1971. Studies completed in the 1990s indicate that mercury concentrations remain elevated more than 20 years after mercury use was discontinued (WDNR, 1996b).

Few identifiable point sources exist for the other compounds of potential concern in the Lower Fox River. Dioxin is not a manufactured compound; rather it is a byproduct of various chlorinated organic compounds, such as PCBs. The pesticides DDT and dieldrin once had widespread use in agriculture, but there is no point source associated with these compounds. However, DDE in sediments below the De Pere dam and Green Bay are of risk to fish and birds. Similarly, the metals lead and arsenic, even now, have widespread uses and are not associated with any specific point sources.

2.2 Physical Characteristics

2.2.1 Total Organic Carbon

Total organic carbon (TOC) affects the bioavailability and toxicity of some substances and influences the composition and abundance of benthic communities. Some chemicals (particularly low-solubility organic compounds) strongly adsorb onto organic coatings over the surfaces of inorganic particles. As a result, sediment with high TOC content tends to accumulate higher concentrations of organic compounds than sediment with lower TOC content. TOC was analyzed in over 1,600 sediment samples from the Lower Fox River, Green Bay, and select tributaries to assist in the interpretation of the sediment organics data. TOC concentrations in sediments are extremely variable.

Average TOC value in Lake Winnebago is 7.8 percent (78,000 milligrams per kilogram [mg/kg]), suggesting that significant background TOC levels are present within the system. Moving downstream, the TOC average in each reach shows a general decline. The river-wide TOC average is 4.91 percent. The average TOC concentrations in Green Bay range from 0.14 to 2.33 percent. In comparison, the Lake Michigan TOC average is 0.35 percent.

2.2.2 Lower Fox River

The Lower Fox River flows northeast approximately 63 km (39 miles) from Lake Winnebago to Green Bay. The Lower Fox River is the primary tributary to lower Green Bay, draining approximately 16,395 square kilometers (km^2) (6,330 square miles [mi^2]) with a mean discharge of 122 cubic meters [m^3] (4,300 cubic feet per second [cfs]) (USGS, 1998a, 1998b, 1998c, 1998d, 1998e, 1998f). The change in river elevation between Lake Winnebago and Green Bay is approximately 51 meters (168 feet).

Bathymetry and Currents

The Lower Fox River is relatively narrow, generally less than 305 meters (1,000 feet) wide over much of its length, and ranges up to approximately 6.1 meters (20 feet) deep in some areas. Where the river widens significantly, water depths generally decrease to less than 3 meters (10 feet) deep. In Little Lake Butte des Morts, water depths range between 0.61 and 1.53 meters (2 and 5 feet) except in the main channel. In general, however, the main channel of the river ranges from approximately 1.8 to 6.1 meters (6 to 20 feet) deep. Figure 2-1 presents the elevation profile of the Lower Fox River.

Navigation

There are 17 locks and 12 dams located on the Lower Fox River between Lake Winnebago and the De Pere dam. The river is still navigable to recreational boats, but the Rapide Croche lock is permanently closed to restrict sea lamprey migration. Navigation for ocean-bound vessels extends from Green Bay, upriver approximately 4.8 km (3 miles) to the Fort James Paper Company (formerly Fort Howard) turning basin via a shipping channel maintained to a water depth of approximately 7.3 meters (24 feet). Flow in this section of the river is sometimes reversed by wind-driven increases in Green Bay water levels, commonly known as seiche events.

Sediment Composition and Deposition

Soils and river sediments in the region are predominantly silt and clay units with varying amounts of sand and gravel due to past glacial events. The glacial deposits also affect the surficial soils in the vicinity of the Lower Fox River, many of which are described as silty clay loam, silty clay, and clay. Sediment is typically deposited on the inside portion of a meander bend, while the outer part of the meander bend (the cut bank) usually is erosional due to increased stream flow velocities. Between the Little Rapids and De Pere dams, the river is again relatively straight, although not as wide or as shallow as Little Lake Butte des Morts.

Reach Designations

To facilitate modeling activities and identification of specific points along the river, the Lower Fox River was divided into the following four separate reaches in sequential order going downstream:

- Little Lake Butte des Morts (LLBdM),
- Appleton to Little Rapids,
- Little Rapids to De Pere, and
- De Pere to Green Bay (also Green Bay Zone 1).

These four reaches were based on similar water depths, current velocities, contaminant concentrations and distribution, and dam/lock structures (Table 2-1 and Figure 1-1). These reach designations were used during the RI to streamline the evaluation and reporting of sediment, water, and biological tissue data. Specific sediment deposits were identified in the first three reaches (Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere). These deposits were labeled A through HH and POG. Deposits were originally designated based on physical attributes, then later the chemical nature and extent of each deposit was determined. The De Pere to Green Bay Reach was divided into 96 Sediment Management Units (SMUs) to support the modeling efforts of the 1989 Green Bay Mass Balance Study. Table 2-1 summarizes the 35 sediment deposits (labeled A through HH) upstream of the De Pere dam and 96 Sediment Management Units (SMUs 20 through 115) downstream of the De Pere dam.

2.2.3 Green Bay

Green Bay is a narrow, elongated bay, approximately 190 km (119 miles) in length and an average of 37 km (23 miles) in width. The bay is bounded by the City of Green Bay at the south end and by both Big and Little Bays de Noc, in Michigan's Upper Peninsula (UP), on the north end. Wisconsin's Door Peninsula separates the majority of Green Bay from Lake Michigan. Urban areas located along the west shore of Green Bay include the cities of Marinette, Peshtigo, and Oconto, Wisconsin; and Escanaba and Menominee, Michigan. The city of Sturgeon Bay, Wisconsin, is the only urban area located on the east shore of Green Bay.

The Green Bay watershed drains approximately 40,000 km^2 (15,625 mi^2) or about one-third of the Lake Michigan drainage basin. Two-thirds of the Green Bay drainage is in Wisconsin and one-third in Michigan. The Lower Fox River is the largest tributary to Green Bay, contributing approximately 42 percent of the total drainage, over 95 percent of the PCB load, and 70 percent of the suspended sediments (WDNR, 1999a; Smith *et al.*, 1988). Other significant tributaries, located along the west and north sides of the bay, include Duck Creek and the following rivers: Suamico, Pensaukee, Oconto, Peshtigo, Menominee, Cedar, Ford, Escanaba, Tacoosh, Rapid, Whitefish, Sturgeon, and Fishdam.

Bathymetry and Currents

The bathymetry in Green Bay is controlled by its geologic history. Based on the eastern dip of the bedrock units along its lengthwise axis and the glacial scouring of the basin, the bay gently slopes to mid-bay moving from west to east. Eastward of this mid-bay, the bottom is a relatively flat sediment plain that rises abruptly near the east shore. Within this framework, the bathymetry for each Green Bay zone has unique characteristics. The bathymetry for the De Pere to Green Bay Reach (Zone 1) has been described above. The bathymetry of Zone 2 is more complicated than the bathymetry of either Zone 3 or Zone 4, due to the numerous shallow areas located within Zone 2. Zones 3 and 4 comprise a large, relatively deep body of water which only have areas with depths less than 9 meters (30 feet) located along the shoreline.

At the south end, the bay is a freshwater estuary due to the shallow water depths, while the northern end is a deep-water lake. The mean depth of the bay is approximately 20 meters (65 feet), with much shallower water depths near the shoreline. Few areas of the bay have depths exceeding 40 meters (131 feet). Green Bay covers an area of approximately 4,150 km^2 (1,600 mi^2) and has a volume of about 83 cubic kilometers (km^3) (20 cubic miles [mi^3]). The long-term average Lake Michigan and Green Bay elevation is 176.49 meters (579.02 feet), according to the International Great Lakes Data (USACE, 1996).

The dominant currents in Green Bay flow counterclockwise. In addition, the bay waters are subject to seiches, which may temporarily change water levels from several centimeters up to 1 foot or more, and reverse the flow of the Lower Fox River up to the De Pere dam. The combination of these factors results in relatively rapid mixing of sediment-rich tributary waters, and therefore contaminant loads, with those of Green Bay.

Sediment Composition and Deposition

In the northern portion of Green Bay, especially along the west side of the bay, outwash and glacial lake plains (typically dominated by sands) developed and ultimately affected soil formation, while on the Door and Garden peninsulas, clay till deposits are predominant. Superimposed on the glacial deposits are modern fluvial and alluvial sediments associated with slopewash, river, and floodplain deposits. Discharge at the mouth of the Lower Fox River is directed easterly by the counterclockwise currents. This can result in plumes of sediment-rich water up to 20 to 40 km (12 to 24 miles) along the east shore of the bay. Sediment initially deposited in the southern end of the bay can become resuspended due to seiche action and redeposited further to the north along the eastern shore. Consequently, the majority of river-related sediment in Green Bay is present along the southern and eastern portions.

Zone Designations

The Green Bay Mass Balance Study (EPA, 1989d, 1989e) divided the bay into four morphometric zones based on physical/chemical/biological characteristics observed in the bay (Table 2-2 and Figure 1-2). Observations included eutrophication, chemical contaminants, foraging areas, habitat gradients, and distribution of fish populations. Green Bay Zone 1 is the same as the De Pere to Green Bay Reach of the Lower Fox River. Zones 2 and 3 are further divided into A and B segments by a center line extending out from the mouth of the Lower Fox River to Chambers Island. Zones 2A and 3A are located on the west side of this line, while zones 2B and 3B are located on the east side of this line.

2.3 Nature and Extent of Contaminants of Potential Concern

2.3.1 Estimation of PCB Distributions

This section discusses: 1) data interpolation methods for determining PCB spatial distributions, 2) occurrence of sediment, 3) PCB sediment volume and mass distribution, and 4) riverbed maps showing the occurrence of PCBs in the sediments of the Lower Fox River and Green Bay. These bed maps were prepared from surface and subsurface sediment profile data contained within the Fox River database (FRDB), and originating at specific points along the river and in the bay. Specific details of the bed mapping procedure may be found in the Remedial Investigation Report (RETEC, 2002a). A summary specific to the BLRA is presented below.

In order to view the spatial distribution of PCBs across the study area, a methodology was developed to predict, or interpolate, sediment concentrations between known data collection points. An interpolation grid was necessary to resolve discrepancies between samples with different detection limits, depth intervals, and sample collection and compositing methods from numerous studies conducted over a 10-year period. From the interpolated PCB concentration points, a map of the overall concentrations as sediment isopleths could be produced. The methodology for mapping property distributions was developed jointly by WDNR and the Fox River Group, and is further described in the RI Report.

Data Interpolation for the Lower Fox River

The interpolations for the Lower Fox River are based on the results included in the FRDB as of March 1, 2000, consisting of about 900 sample results and locations in the Lower Fox River from nine studies conducted between 1989 and 1999.[2] The 1999 data set included post-dredge sampling data from the Deposit N sediment removal demonstration project. Data for the Lower Fox River were first screened to remove older data that were geographically too close to locations with newer data. Sediment data for the Lower Fox River has been collected in various studies since 1989. In order to use the most recent data available, the data were assigned to three different time periods: 1989 through 1992, 1993 through 1995, and 1996 through 1998. All of the data from the period 1996 through 1998 were used in the interpolation. A relationship was developed between similar ranges of PCB concentrations and the distances between data points in each range. From this analysis, a distance of less than 133 meters (436 feet) was determined to indicate that an older sample location was too close to a newer sample location. In this case, the older data were not used in the interpolations. This analysis was conducted first on the 1993 through 1996 data set to create a new data set for the 1993 through 1998 period. The analysis was then repeated using the 1989 through 1992 data set. In this way, the entire data set from 1989 through 1998 was used, but older data were superseded by newer data.

The interpolation used the revised 1989 through 1998 data set. The entire area of the Lower Fox River was superimposed with a square grid containing cells 10 meters by 10 meters (33 feet by 33 feet). The screened data were used to interpolate the parameter value at each grid point.

Interpolations used the inverse distance method, whereby grid point values were more strongly affected by the sampling location(s) closest to the grid point. The inverse distance method gives more weight to closer points by using an inverse distance to the fifth power, meaning that points farther away have significantly less effect on the interpolated value at a point. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes 32 times more to the interpolation than does the second point.

In addition to inverse weighting, a maximum set distance was selected for which data points may influence grid point results. Erroneous interpolations can occur if data are extrapolated over excessive distances. To prevent this condition, grid point values were computed using data within a certain distance or radius of the grid point location. Data points located further from the grid point than the

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[2] The specific sediment studies used in the BLRA are discussed in Section 4.

established radius were not used in the interpolation. If there were no data points within the interpolation radius of a grid point, then no value was interpolated for that grid point.

The interpolation radius for computing sediment thickness was set at 100 meters (328 feet). For all other parameters, the interpolation radius varied among the river reaches. In the Little Lake Butte des Morts Reach, complete coverage of the river required a radius of 400 meters (1,312 feet). For the Appleton to Little Rapids Reach, the river is more narrow and linear. For this reach, the interpolation radius was computed as one-third of the average river width, or 79 meters (259 feet), to minimize the influence of separate deposits on the interpolation. The Little Rapids to De Pere and De Pere to Green Bay reaches used an interpolation radius of 1,000 meters (3,280 feet), as specified in Technical Memorandum 2e and in the Technical Memorandum 2e Addendum (WDNR, 1999c, 2000c).

Data interpolations for the Lower Fox River were conducted for nine different layers of sediment depth: 0 to 10 centimeters (cm) (0 to 4 inches), 10 to 30 cm (0.33 to 1 foot), 30 to 50 cm (1 to 1.6 feet), 50 to 100 cm (1.6 to 3.3 feet), 100 to 150 cm (3.3 to 4.9 feet), 150 to 200 cm (4.9 to 6.6 feet), 200 to 250 cm (6.6 to 8.2 feet), 250 to 300 cm (8.2 to 9.8 feet), and greater than 300 cm (9.8 feet). These sediment depths were selected based on previous and current modeling efforts as well as being defined by WDNR (1998b).

Data Interpolation for Green Bay

Interpolation of sediment data from Green Bay followed the same methods as used in the Lower Fox River. The data set for the Green Bay interpolations included approximately 240 sample results and locations from three studies conducted between 1989 and 1998.

For the interpolation, Green Bay was divided into a square grid with 100 meters (328 feet) between points. The same inverse distance approach was used on both the Lower Fox River and Green Bay, but the analysis on Green Bay used the distance squared rather than distance raised to the fifth power. Therefore, interpolated results in Green Bay were more affected by data points farther way from the grid point than in the Lower Fox River interpolation. For instance, for two data points, where the first point is half as far from the grid point as the second point, the first point contributes four times more to the interpolation than does the second point.

The maximum interpolation radius for Green Bay was set at 8,000 meters (26,250 feet). This means that data points more than 8,000 meters (26,250 feet) from a grid point were not used in the interpolation for that grid point. Conversely, grid points more than 8,000 meters (26,250 feet) from any data point have no interpolated value, and this is evidenced by the lack of data in some areas of the bay, particularly along the west shore of Zone 3A and in Zone 4.

Green Bay data were integrated for four different layers of sediment depth: 0 to 2 cm (0 to 0.8 inches), 2 to 10 cm (0.8 to 4 inches), 10 to 30 cm (0.33 to 1 foot), and greater than 30 cm (1 foot). In addition to these four sediment layers, a composite sediment layer was developed for a thickness of 0 to 10 cm (0 to 4 inches). This layer was computed as a thickness-weighted average of the 0- to 2- and 2- to 10-cm layers (0- to 0.8- and 0.8- to 4-inch). The 0- to 10-cm (0- to 4-inch) layer was developed for use in the RA and food web modeling because the top 10 cm (4 inches) is considered to be the biologically active zone (Ecology, 1995). The other two layers were selected to coincide with layering developed for the river.

PCB Bed Maps

Maps showing the distribution of PCBs in sediment were constructed directly from the interpolated grids using ArcView and Spatial Analyst. The interpolated grid was displayed and color contoured into different ranges based on PCB concentration. Areas where sediment is absent were not included in the color contouring. Similarly, areas outside the interpolation radius are not included in the color contouring. The concentration intervals selected for the bed maps were based upon a combination of observed concentration ranges, cleanup level evaluations, the 50 ppb PCB detection limit, variability of the data collection, and criteria for bed mapping. The total PCB concentration ranges and mapping intervals used for the Lower Fox River and Green Bay (in micrograms per kilogram [μg/kg]) are:

- 0 to 50;
- 50 to 125;
- 125 to 250;
- 250 to 500;
- 500 to 1,000;
- 1,000 to 5,000;
- 5,000 to 10,000;
- 10,000 to 50,000;
- Greater than 50,000 (Lower Fox River); and
- Greater than 5,000 (Green Bay).

Sediment bed maps for total PCBs are shown on Figures 2-2 through 2-6, and are discussed further below.

2.3.2 Extent of PCB Chemical Impacts

Approximately 96,800 kg (213,400 pounds) of PCBs in the Lower Fox River and Green Bay system are distributed in about 474 million m^3 (620 million cy). Review of the PCB mass and contaminated sediment volume herein considers sediments which contain more than 50 μg/kg PCBs. The results are summarized below and indicate that the De Pere to Green Bay Reach and Green Bay Zone 2, combined, contain almost 60 percent of the total PCB mass in the system in less than 10 percent of the total contaminated sediment volume. The PCB mass and volume of contaminated sediment for each river reach and bay zone are listed below.

Location	PCB Mass and Percent in System*	Contaminated Sediment Volume and Percent in System*
Little Lake Butte des Morts Reach	1,540 kg (1.6%)	1.35 million m^3 (0.29%)
Appleton to Little Rapids Reach	94 kg (0.1%)	0.18 million m^3 (0.04%)
Little Rapids to De Pere Reach	980 kg (1.0%)	1.71 million m^3 (0.36%)
De Pere to Green Bay Reach	25,984 kg (26.8%)	5.52 million m^3 (1.16%)
Green Bay Zone 2	32,013 kg (33.1%)	39.5 million m^3 (8.33%)
Green Bay Zone 3	35,243 kg (36.4%)	397 million m^3 (83.72%)
Green Bay Zone 4	925 kg (1.0%)	28.9 million m^3 (6.10%)
Total	**96,784 kg**	**474.16 million m^3**

Note:
* Includes sediments containing PCB concentrations greater than 50 μg/kg.

As shown above, over 96 percent of the total PCB mass within the Lower Fox River and Green Bay is located between the De Pere dam and the northern boundary of Zone 3, which is bounded by Chambers Island. The magnitude and extent of PCB-impacted sediments for each river reach and zone of Green Bay are summarized below.

Little Lake Butte des Morts Reach

PCB distribution in the surface sediments of Little Lake Butte des Morts is shown on Figure 2-2. The nine sediment deposits in this reach (deposits A through H and POG) contain about 1,540 kg (3,395 pounds) of PCBs in about 1.35 million m^3 (1.77 million cy) of sediment with concentrations greater than 50 μg/kg PCBs. These deposits cover about 314 hectares (775 acres) and thicknesses range up to approximately 1.9 meters (6.2 feet) thick. The highest detected total PCB concentration in sediment was 222,722 μg/kg (average 15,043 μg/kg). Upstream deposits A, B, and POG have the highest PCB mass-to-sediment volume ratios in this reach. These three deposits contain 952 kg (2,100 pounds) of the PCBs in about 252,000 m^3 (329,600 cy) of sediment. About 910 kg (2,000 pounds) of the PCBs in these three deposits are present in the upper 100 cm (3.3 feet) of sediment. Deposits A/B, E, and POG contain over 1,400 kg (3,086 pounds) of PCBs, or about 91 percent of the PCBs present in this reach. About 53 percent of the mass in the deposits listed above are present in the upper 30 cm (1 foot) of sediment.

Appleton to Little Rapids Reach

Sediment accumulation in the Appleton to Little Rapids Reach is more localized compared with the other three reaches. The 22 sediment deposits in this reach (deposits I through DD) contain about 94 kg (207 pounds) of PCBs in about 184,790 m^3 (241,700 cy) of sediment with concentrations greater than 50 μg/kg PCBs (Figure 2-3). These deposits cover approximately 153 hectares (378 acres) and generally occur in areas of slower stream flow velocities (e.g., where the river widens, in the vicinity of dams/locks, eddy pools along the banks, etc.). Sediment thicknesses range up to approximately 100 cm (3.3 feet) thick. The highest detected total PCB concentration in sediment was 77,444 μg/kg (average 6,406 μg/kg). Only deposits W, X, and DD have a volume exceeding 30,000 m^3 (39,240 cy) of sediment and these are located where the river widens and/or upstream of a dam. The average sediment volume in each of the remaining 19 deposits in this reach is about 3,780 m^3 (4,944 cy). Approximately 32 kg (71 pounds) of PCBs remain in deposits N and O following completion of the 1999 sediment remediation demonstration project and no future attempt to remove this mass is currently under consideration. The total surface area of this reach is approximately 7,000,000 square meters (m^2) (2.7 mi^2), while deposits with measurable PCBs are only 870,000 m^2 (0.3 mi^2) (12.6 percent). In general, surface sediment PCB concentrations are less than 1,000 μg/kg in this section.

Little Rapids to De Pere Reach

Sediment accumulation in this reach extends over a long distance and large area. The four sediment deposits in this reach (deposits EE through HH) contain 980 kg (2,160 pounds) of PCBs in approximately 1.71 million m^3 (2.24 million cy) of sediment with concentrations greater than 50 μg/kg PCBs (Figure 2-4). The four deposits in this reach are essentially a single sediment unit covering about 266 hectares (657 acres). Sediment thicknesses range up to 2.3 meters (7.5 feet) thick in select areas, especially near the De Pere dam. The highest detected total PCB concentration in sediment was 54,000 μg/kg (average 6,292 μg/kg). Concentrations exceeding 5,000 μg/kg exist at the southernmost limit to Deposit EE, and at the northernmost part of the reach behind the De Pere dam. Almost all of the PCBs are contained in the upper 100 cm (3.3 feet) of sediments, with 535 kg (1,180 pounds) contained in the upper 0 to 30 cm (0 to 1 foot).

De Pere to Green Bay Reach

This reach contains the largest volume and areal extent of impacted sediments in the Lower Fox River (Figure 2-5). Ninety-one (91) percent of the PCB mass for the entire river is present in this reach. The 96 SMUs in this reach contain 25,984 kg (57,285 pounds) of PCBs in over 5.5 million m^3 (7.2 million cy) of sediments with concentrations greater than 50 μg/kg PCBs. Almost the entire sediment bottom contains soft sediment covering about 524 hectares (1,295 acres) and ranging in thickness up to 4 meters (13 feet). The highest detected total PCB concentration in sediment was 710,000 μg/kg (average 21,722 μg/kg) before completion of the SMU 56/57 demonstration project.

Approximately 636 kg (1,400 pounds) of PCBs and 31,000 m^3 (40,550 cy) of sediment were removed from SMUs 56–61 during the SMU 56/57 sediment remediation demonstration project. Further, removal of additional sediment and PCBs from SMU 56/57 started in August 2000, but the final mass and volume estimates are not expected to be known until early 2001. Excluding SMUs 56–61, six SMU groups (SMUs 20–25, 32–37, 38–43, 62–67, 78–73, and 80–85) contain almost 11,000 kg (24,250 pounds) of PCBs, or about 37 percent of the total mass in the Lower Fox River. These SMU groups also exhibit the highest PCB concentrations or greatest PCB mass-to-sediment volume ratios in the river.

The mass of PCBs increases significantly with depth. Approximately 16,150 kg (35,530 pounds) of PCBs, or about 55 percent of the total PCB mass in the Lower Fox River, occurs in the upper 100 cm (3.3 feet) of sediment. Approximately 10,600 kg (23,370 pounds) of PCBs (36 percent of the PCBs in the river) are buried below 100 cm (3.3 feet).

PCBs are fairly evenly distributed in the surface sediments within this reach. Of the 5.2 million m^2 (2 mi^2) of sediment surface within this reach, 4.5 million m^2 (1.7 mi^2) (87 percent) have PCB concentrations greater than 1,000 μg/kg.

Green Bay Zone 2

This zone contains approximately 32,000 kg (70,550 pounds) of PCBs in 39.5 million m^3 (51.6 million cy) of sediment with concentrations greater than 50 μg/kg (Figure 2-6). Sediments with the highest PCB concentrations have accumulated adjacent to the navigation channel and between the mouth of the river and Point Au Sable. The PCB distribution reflects the influence of Green Bay current patterns, as higher concentrations are located along the east side of the bay. Sediments in Zone 2A cover about 5,930 hectares (14,650 acres) and have an average thickness of about 0.34 meter (1.1 feet). In Zone 2B, the sediments cover about 5,150 hectares (12,725 acres) and have an average thickness of about 0.38 meter (1.25 feet). The highest total PCB concentration in sediment was 17,000 μg/kg (average 324 μg/kg).

Considering only sediments with more than 1,000 μg/kg PCBs reduces the mass and volume estimates to 27,470 kg (60,430 pounds) and 17.8 million m^3 (23.3 million cy). This represents slightly more than 45 percent of the PCBs, but less than 3 percent of the estimated volume of impacted sediment in the bay.

Approximately 14,500 kg (31,900 pounds) of PCBs are contained in about 29.8 million m^3 (39 million cy) of sediment in the upper 30 cm (1 foot). Sediments with the highest PCB concentrations have accumulated adjacent to the navigation channel and between the mouth of the river and Point Au Sable. The distribution shows the influence of Green Bay current patterns, as higher PCB concentrations are located along the east side of the bay.

Green Bay Zone 3

This zone contains approximately 35,240 kg (77,700 pounds) of PCBs in 397 million m^3 (519 million cy) of sediment with concentrations greater than 50 μg/kg (Figure 2-6). PCB distribution results show that sediments with the highest concentrations have accumulated along the east shore of Green Bay, extending from Dyckesville to Egg Harbor, reflecting the influence of Green Bay current patterns. Sediments in Zone 3A cover about 85,890 hectares (212,240 acres) and have an average thickness of just 21 cm (0.7 foot). In Zone 3B, the sediments cover about 69,340 hectares (171,340 acres) and have an average thickness of about 31 cm (1 foot). The highest detected total PCB concentration in sediment was 1,320 μg/kg (average 448 μg/kg).

Considering sediments with more than 1,000 μg/kg PCBs reduces the mass and volume estimates to 1.65 kg (3.64 pounds) and 8,800 m^3 (11,510 cy), respectively. This represents less than 0.003 percent of both the PCB mass and sediment volumes in the bay.

Considering the upper 30 cm (1 foot) of sediments, approximately 30,000 kg (66,000 pounds) of PCBs are contained within about 355.9 million m^3 (465.5 million cy). However, as indicated above, a large majority of this mass is located in sediments with concentrations below 1,000 μg/kg PCBs. Surface sediment PCB concentrations are generally higher in the southern part of the zone (greater than 500 μg/kg), and lower (less than 125 μg/kg) just below Chambers Island.

Green Bay Zone 4

The estimated PCB mass and sediment volume results indicate that Zone 4 is relatively unaffected by PCBs compared to zones 2 and 3. However, fewer soft sediment locations were noted and sampled in this zone than in either zones 2 or 3 during 1989 and 1990 sampling activities. Zone 4 contains less than 925 kg (2,040 pounds) of PCBs, or only about 1 percent of the total mass in the system (Figure 2-6). Total PCB concentrations detected in sediment within Zone 4 are all less than 500 μg/kg with an average of 54 μg/kg.

Findings regarding the presence and distribution of other COPCs identified in the Screening Level Risk Assessment are fully described in the Lower Fox River and Green Bay RI Report (RETEC, 2002a).

2.3.3 Extent of Other COC Impacts

Major findings regarding the distribution of other chemical parameters in sediments include the following:

- Mercury was used in a number of pulp and paper production activities to reduce slime. The SLRA identified mercury concentrations exceeding 0.15 mg/kg as a potential concern. Mercury concentrations in Lake Winnebago sediments averaged 0.14 mg/kg, while average concentrations in each reach of the Lower Fox River ranged from 1.26 to 2.42 mg/kg. The elevated mercury concentrations are widespread in the Lower Fox River sediments and are not associated with any specific deposit or point source discharge.

- Mercury concentrations in Green Bay are much lower than levels in the river. The average concentration in Zone 2 was 0.593 mg/kg, but averages in zones 3 and 4 range only up to 0.19 mg/kg, which is just above the Lake Winnebago background concentration.

- The spatial distribution of dioxin/furan compounds cannot be evaluated because only 22 samples were collected from deposits D/E/POG, deposits EE/HH, and SMUs 56/57. Concentrations of 2,3,7,8-TCDD/TCDF detected in sediments ranged from 0.23 to 170 nanograms/kilogram (ng/kg) (parts per trillion [ppt]).

- Sixteen (16) chlorinated pesticides, generally associated with agricultural non-point source activities, were detected in river sediments at concentrations up to 67 μg/kg. Additional non-point pesticide sources may include atmospheric deposition and stormwater runoff from pesticides used at parks, golf courses, and other institutional facilities; however, these sources are likely to be small compared with agricultural activities. Only seven compounds, DDT, DDD, DDE, endrin aldehyde, endrin ketone, gamma-BHC (lindane), and heptachlor, were detected in more than four sediment samples. Distribution of these compounds was generally sporadic. Only DDT and dieldrin were identified by the SLRA as being chemicals of potential concern. The SLRA identified DDT (total) concentrations above 1.6 μg/kg as a potential concern. DDT was detected at 10 widely-distributed locations within the Lower Fox River above this concentration. There is no established concentration of concern for dieldrin, which was detected in only one sample from Little Lake Butte des Morts, suggesting that dieldrin distribution is very limited. Neither DDT nor dieldrin were detected within Green Bay.

- Lead is a naturally-occurring element in soil and sediment. Background lead concentrations in Lake Winnebago sediments averaged 35 mg/kg while average concentrations in each reach of the Lower Fox River ranged from 75.6 to 167.8 mg/kg. The SLRA identified lead concentrations above 47 mg/kg as a potential concern. While some deposits detected lead concentrations as high as 1,400 mg/kg, lead occurrence is widespread in the Lower Fox River sediments and cannot be related to any specific point source discharge. In Green Bay, the average lead concentration ranged from 1.5 to 29.9 mg/kg, which is lower than the Lake Winnebago background concentration.

- Arsenic is also naturally occurring in soil and sediment. Background arsenic concentrations in Lake Winnebago sediments averaged 5.33 mg/kg. The SLRA identified arsenic concentrations above 8.2 mg/kg as a potential concern. An elevated arsenic concentration was detected in only one location (SMU 38) at 385 mg/kg. Excluding this arsenic detection, average concentrations in both the river and the bay were below the Lake Winnebago background concentration of 8.2 mg/kg.

- SVOCs, which result from both point and non-point sources in urban and rural areas, were detected throughout the Lower Fox River at concentrations exceeding the background levels observed in Lake Winnebago. The SVOCs detected at higher concentrations included PAHs and also occurred in widespread areas of the river. Total PAH concentrations below 4,000 μg/kg typically do not warrant further assessment. Total PAH concentrations along the Lower Fox River ranged non-detectable to 60,000 μg/kg. A number of locations from Little Lake Butte des Morts to the mouth of the river exceeded 4,000 μg/kg with the highest values frequently observed downstream of more urbanized areas. None of the sediment samples collected within Green

Bay Zone 2 exceeded 4,000 μg/kg, and PAHs were not detected in zones 3 or 4.

2.4 Contaminant Fate and Transport

Contaminant fate and transport in the Lower Fox River and Green Bay is largely a function of suspension, deposition, and redeposition of the chemicals of concern that are bound to sediment particles. The organic compounds of concern, including PCBs and pesticides, exhibit strong affinities for organic material in the sediments. The suspension and fate and transport of these organic compounds absorbed onto the sediments is largely controlled by moving water in the Lower Fox River and Green Bay. Greater volumes of sediments become suspended and are transported during high-flow events (such as storms and spring snowmelt). The Lower Fox River has an average discharge of 122 m^3/s (9,605 cfs) 10 percent of the time. Previous investigators have estimated that these high-flow events transport more than 50 to 60 percent of the PCB mass that moves over the De Pere dam and into Green Bay.

Other modes of contaminant transport such as volatilization, atmospheric deposition, and point-source discharges are negligible when compared to the river transport. Figures 2-7 and 2-8 each present a conceptual model of PCB fate and transport in the Lower Fox River and Green Bay system by volume and mass, respectively.

2.4.1 Lower Fox River Sediment Deposition

Sediment deposition and resuspension processes are primarily a function of particle size and water velocity. Transport of sediments occurs as particles are suspended in the water or moved along the base of the river as bed load. The system is dynamic and areas of sediment accumulation may become erosional areas, or vice versa, based on changes in water velocity (e.g., storm events), river bathymetry (e.g., shoreline erosion), and other factors.

TSS data have been evaluated to estimate the movement of sediment through the system. Distinct deposits of accumulated sediment occur throughout the Lower Fox River in areas of low stream flow velocity. These areas are generally in the vicinity of the locks, dams, shoreline coves, and back eddies, or in areas where the river widens. However, estimates of net deposition or net erosion only reflect an average accumulation or loss over time for an entire reach and do not explain finer-scale deposition/erosion events occurring within a reach. Net deposition does not imply a purely depositional environment and vice versa.

Over 75,000 metric tons (MT) (82,700 tons) of TSS enters Little Lake Butte des Morts from Lake Winnebago annually. However, the TSS load at the Appleton gauging station is lower than this figure by approximately 8,000 MT (8,800 tons). Based on the net loss of TSS load, the slow water velocity, shallow bathymetry, and extensive sediment deposits, the Little Lake Butte des Morts Reach is subject to sediment accumulation.

The Appleton to Little Rapids Reach experiences a net loss of sediment. Between Appleton and Kaukauna, the river shows a marginal increase of approximately 2,500 MT (2,750 tons) in the TSS load. However, between Kaukauna and Little Rapids, the river experiences a net erosion as the TSS load doubles from approximately 67,000 MT (77,000 tons) to approximately 142,000 MT (154,000 tons) (Figure 2-7). The lack of soft sediment between Rapide Croche dam and Little Rapids suggest that resuspended sediments are likely transported to Little Rapids (Deposit DD) or further downstream. Based on the net increase of TSS load, the fast stream velocities (as high as 0.3 m/s), narrow river sections, and the lack of many sediment deposits, the Appleton to Little Rapids Reach is subject to a net loss of sediment.

The TSS load within the Little Rapids to De Pere Reach declines by about 61,500 MT (68,000 tons), a 43 percent decrease from upstream inputs. Deposit EE, the largest sediment deposit upstream of the De Pere dam, extends approximately 8.5 km (5.3 miles) upstream of the dam. Based on the significant net decrease of TSS load, the large number of sediment deposits, and the slow stream flow velocities (average of 0.12 m/s), the Little Rapids to De Pere Reach experiences net sediment deposition and accumulation.

In the De Pere to Green Bay Reach, TSS loads coming over the De Pere dam range between approximately 80,000 and about 100,000 MT (90,000 and 110,000 tons) annually. At the river mouth, the TSS load was only 20,000 MT (22,000 tons), indicating that the TSS load declined by approximately 75 to 80 percent. The average stream flow velocity in this reach was less than 0.08 m/s, which is the lowest value for any of the four river reaches. Results of the Green Bay Mass Balance Study show that at a typical discharge rate of 105 m^3/s (3,700 cfs), approximately 272 MT (300 tons) per day of TSS flows over the De Pere dam; however, only approximately 54 MT (60 tons) per day are discharged at the mouth. Based on the significant net decrease of TSS load, the large number of thick sediment deposits, and the slow stream flow velocities, the De Pere to Green Bay Reach experiences net sediment deposition.

For storm events with flows around 280 m^3/s (9,900 cfs), the TSS load over the De Pere dam increases to 1,800 MT (2,000 tons) per day, while storm events with flows of 430 m^3/s (15,250 cfs) have a TSS load of about 7,100 MT (7,850 tons) per day. Quadrupling the stream flow rate in the river results in an approximately 26 times greater TSS load.

2.4.2 Green Bay Sediment Deposition

Estimated annual sediment accumulation in Green Bay varies from about 20,000 MT to about 150,000 MT (22,050 to 165,350 tons). The USGS estimated the average annual sediment load from the Fox River into Green Bay is approximately 82,500 MT (90,940 tons) to 136,000 MT (150,000 tons). Recent 1998 data suggests that about 153,000 MT (168,800 tons) of sediment were discharged into the bay during 1998.

Sediment is not deposited uniformly across the bottom of the bay. Water current patterns determine the distribution of sediments, and ultimately, that of PCBs and other chemical compounds in Green Bay. The primary depositional zone in Green Bay extends along the east shore for a distance of approximately 25 km (15.5 miles) north of the Lower Fox River mouth.

Approximately 17,500 MT (19,290 tons) of sediment is transported from the inner bay to the outer bay along the east side of Chambers Island. However, about 19,000 MT (20,943 tons) of sediment is transported from the outer bay to the inner bay along the west side of the island, following dominant circulation patterns (Figure 2-7). Therefore, there is a net sediment gain in the inner bay of approximately 2,400 MT (2,645 tons). Approximately 10 to 33 percent of the inner bay tributary sediment load (the majority of which is from the Lower Fox River) is transported to the outer bay.

Sediments that have been deposited can be re-entrained and transported. A number of different studies and models have evaluated sediment resuspension, and it has been shown that most sediment transport within the bay occurs during large storms. A large volume of sediment was transported from the inner bay to the outer bay as a result of a September 1989 storm. Erosion of shore and nearshore sediments was found to be directly related to the magnitude, direction, and duration of winds within the bay, which effected currents and wave action. Within the bay, sediment deposits are located in areas where the stress ratios were less than about five to nine, in comparison with the Lower Fox River ratios of three to five. Sediments within the bay settle in a far less turbulent environment than those of the Lower Fox River; therefore, the uppermost layer of sediment was found to have consolidated in 7 to 14 days, rather than less than 3 hours. Moderate to strong winds, which are the single most important factor for bay sediment resuspension, occur on average every 7 days on the Great Lakes.

2.4.3 PCB Transport

Review of sediment transport through the river reaches and bay zones was evaluated to assess where PCB transport is occurring with all movement. The conceptual models show the PCB mass/volume contained with each reach/zone (greater than 50 μg/kg PCB) and how much PCBs are transported from one reach/zone into the next annually (Figures 2-7 and 2-8).

Fox River

Approximately 1,540 kg (3,395 pounds) of PCBs are present within the Little Lake Butte des Morts Reach. The sediments of the lake have long acted as a continuing source of PCBs to the river/bay system. WDNR (1995) estimates are that less than 1 kg per year are annually transported from Lake Winnebago into Little Lake Butte des Morts (Figure 2-8). Approximately 40 kg (88 pounds) of PCBs are resuspended and transported from Little Lake Butte des Morts to the Appleton to Little Rapids Reach, even though Little Lake Butte des Morts is a net depositional area.

The Appleton to Little Rapids Reach exhibits increased stream flow velocities compared with the rest of the river. Only about 94 kg (207 pounds) of PCBs are located within sediments in this reach. These data show that little of the sediment or PCBs are deposited permanently within this reach.

Within the Little Rapids to De Pere Reach, the De Pere dam acts as a sediment trap. Approximately 64 kg (141 pounds) per year of PCBs enter the reach and 77 kg (169 pounds) per year are transported over the De Pere dam. Although net sediment deposition occurs in this reach (Figure 2-8), dissolution of PCBs from sediment into the water column becomes more important than does actual transport of sediment to which PCBs are sorbed.

The De Pere to Green Bay Reach experiences net sediment deposition and over 25,900 kg (57,100 pounds) of PCBs are present in this reach. On a mass and volume basis, this reach has the most significant sediment load in the river. Sediments in this reach act as the major continuing source of PCBs into Green Bay.

Green Bay and Lake Michigan

Based on river water sample results, approximately 220 to 280 kg (485 to 617 pounds) of PCBs were transported from the Lower Fox River into Green Bay annually in 1989 through 1990 and 1994 through 1995. These results suggested that roughly 1 percent of the PCB mass within the river is discharged into the bay annually. However, recent 1998 data suggest that the PCB load into Green Bay may be decreasing and only about 125 kg (275 pounds) of PCBs were discharged from the river into the bay based on the 1998 data, which is just over 0.4 percent of the river mass. The average estimates of the PCB mass entering Green Bay from the Lower Fox River annually range between 125 and 220 kg (275 and 485 pounds) per year. Based on peak flow conditions within the river, the highest estimated PCB load into Green Bay is about 550 kg (1,212 pounds) per year. Approximately 120 kg (264 pounds) of PCBs are transported from Green Bay into Lake Michigan annually (Figure 2-8). However, the results of these studies suggest that the PCB mass located between the De Pere dam (in the Lower Fox River) and Chambers Island (in Green Bay) is so large that, at these low rates of loss, a large mass of PCBs will remain in these sediments far into the future.

Other PCB Pathways

In addition to PCB input to the river and bay from contaminated sediments, other PCB sources and sinks exist. Approximately 3 to 5 kg (6 to 11 pounds) of PCBs are introduced into the river from other discharge locations where PCBs remain in effluent lines or from continued carbonless paper recycling. Due to the ubiquitous and resilient nature of PCBs, low concentrations of PCBs have been detected at discharge locations that continue to contribute PCBs to the system. Estimates of atmospheric deposition of PCBs into Green Bay range from 2 to 35 kg (4 to 77 pounds) annually. Based on a 1987 and 1988 USGS PCB mass-loading study of major tributaries into Green Bay, more than 90 percent of the PCB load into Green Bay was attributable to the Lower Fox River. The other Green Bay tributaries contributed only about 10 kg (22 pounds) annually to the bay (Figure 2-8).

In addition to accumulation of PCBs in river and bay sediments, PCBs do exit the system through volatilization (Figure 2-8). A number of studies have indicated that PCB volatilization from the water exceeds atmospheric deposition. PCB losses through volatilization to the atmosphere range between 0 and 5 kg (0 and 11 pounds) per year for the Lower Fox River, whereas volatilization losses in Green Bay range between 130 and 500 kg (286 to 1,102 pounds) annually. The surface area for Green Bay is a significant volatilization pathway (Figure 2-8).

2.5 Ecological Characteristics (Habitats and Species)

The Lower Fox River basin and Green Bay varies considerably in its potential to provide and support different kinds of wildlife habitat and this variability affects the wildlife diversity and populations. While the BLRA focuses primarily on aquatic, or aquatic-dependent species, the RI discusses the two major types of habitat; terrestrial (on land) and aquatic (within or near the water). The two main terrestrial habitats within the Lower Fox River and Green Bay area are open land and woodland. Aquatic habitats within the area are wetland, riverine, and lacustrine. Aquatic habitats are generally much more complex than terrestrial habitats. All five of these habitats are described below. Cities and villages represent an urban environment that most wildlife typically avoid, except certain passerines that nest almost anywhere (i.e., select species of wrens, swallows, sparrows, robins, blackbirds, etc.) and scavengers (i.e., racoons, squirrels, vermin, etc.).

The significant groups of wildlife found within these habitats include the following:

- Both pelagic and benthic aquatic invertebrate species form the primary prey in the food webs of the river and bay. Species of oligochaetes and chironomids (worms and midges) are typically most abundant and are found throughout the Lower Fox River and Green Bay. Amphipods, crayfish, snails, and mussels are also present in the river and bay. Zebra mussels, an exotic species, are present throughout Green Bay and in parts of the river.

- Fish of the region include salmon/trout; game fish, including walleye, yellow perch, and northern pike; and pelagic and benthic non-game fish. A discussion of the significant fish species within the study area is presented later in this section.

- Birds of the region include raptors, gulls/terns, diving birds, migratory waterfowl, passerines, shorebirds, and wading birds. A listing of the significant bird species within the study area is presented later in this section. These animals are found nesting, feeding, and living in both terrestrial and aquatic habitat environments.

- Mammals of the region include large and small game animals that generally live in open or wooded habitat, as well as fur-bearing animals that may forage or live within or near aquatic environments. The small and large game animals include rabbits, squirrels, bear, and deer. The fur-bearing animals include beaver, red fox, mink, raccoon, muskrat, and otter. Additionally, bats feed on insects in the vicinity of Lake Winnebago and along the Lower Fox River near the Fox Cities. Few of the mammals will be discussed in detail within this document. Mink are the principal species discussed in the BLRA.

- Reptiles and amphibians, including snakes, turtles, frogs, and toads are present in the region (Exponent, 1998). Typically, the frogs and turtles confine themselves to the wetland and nearshore areas while several snake species and toads are found in association with both terrestrial and aquatic habitats. Frogs and toads that dwell in wetlands or nearshore areas are fed upon by wading birds of the region.

A series of habitat and species area use maps were compiled and presented in the Remedial Investigation. Only the results of those compilations are presented below.

Within the Lower Fox River valley, the terrestrial habitats are generally located adjacent to the river from a point downstream of Kaukauna to just upstream of De Pere. In the vicinity of the Fox Cities Metropolitan Statistical Area (MSA) and Green Bay MSA, much of the river shoreline and associated wildlife habitat has been developed (Figures 2-9 through 2-12). Natural habitats have retreated from the river and exist only in less developed areas, usually as cultivated lands for agriculture, open meadows, or small localized woodlands. The aquatic habitat is wetland and riverine, and is comprised of and confined to the Lower Fox River and its tributaries.

Green Bay represents a lacustrine habitat, one of several habitats found in the area surrounding the bay. The land surrounding Green Bay is much less developed than the Lower Fox River valley. Open, agricultural land and forests/woodlands comprise between 65 and 94 percent of the land use outside of Brown County, while residential and commercial/industrial land use is less than 5 percent. Wetlands also account for up to 20 percent of county land use in these areas (Table 2-3). The communities located along the shores of Green Bay are much smaller and less populated than the cities of the Lower Fox River valley. Excluding the city of Green Bay, approximately 255,000 people inhabit the Green Bay tributary watersheds (Table 2-4). While individual residences or structures may be located along the shores of Green Bay, shoreline development is much less concentrated than in the Lower Fox River valley and extensive open land or forested tracts may be present along or in close proximity to the shore.

2.5.1 Open Lands

Open land habitat in the Lower Fox River and Green Bay area is largely agricultural and characterized as cropland, orchards, pastures, and meadows with grasses, herbaceous shrubs, and vines. The Fox Cities and Brown County land use maps (East Central Wisconsin Regional Planning Commission, 1996 and Brown County Planning Commission, 1990, respectively) indicate this is the largest habitat present within 0.8 km (0.5 mile) of the Lower Fox River.

Along the east side of Green Bay, from the Lower Fox River mouth to Little Sturgeon Bay, open land is the predominant habitat (Exponent, 1998). Use of the land for agricultural purposes along the east shore of Green Bay is responsible for the presence of this habitat in this area. Review of Door County SCS soil survey maps (1978) and land use information (see RI Section 3.1.2) indicates that open land habitat is prevalent north of Little Sturgeon Bay and throughout the Door Peninsula. Approximately 50 percent of the land in Door County is classified as agricultural, in part due the large number of orchards and other agricultural land located inland from the bay.

Dominant wildlife in open land areas are waterfowl (at rest or feeding), Hungarian partridge, pheasant, songbirds (meadowlark, field sparrows, horned lark, etc.), white-tailed deer, rabbits, red fox, coyote, and various livestock, including Holstein and brown Swiss cattle.

2.5.2 Woodlands

Woodland habitat is characterized as hardwood and conifer forest land and wood lots with an associated understory of grasses, legumes, and wild herbaceous plants. Woodland habitat originally covered a vast majority of the land in eastern Wisconsin and Michigan's upper peninsula. Due to development and growth of urban areas and agricultural activities in the Lower Fox River valley, few significant tracts (16.2 hectares [40 acres] or more) of woodland habitat are present within 1.6 km (1 mile) of either bank of the river. Those areas that are present are usually thin, elongated areas which border roads or farm fields.

Typical vegetative cover includes oak, maple, poplar, cherry, apple, hawthorn, dogwood, hickory, blackberry, hazelnut, viburnum, and blueberry. Conifers include pine, spruce, cedar, juniper, fir, and tamarack. Birds and wildlife eat the nuts, fruits, buds, catkins, twigs, bark, and foliage that the vegetation provides, as well as using the vegetation for nesting sites and when seeking protective cover from predators. Woodlands are inhabited by upland game birds and passerines, small and large game, as well as other non-game animals that include the invertebrates, insects, reptiles, and amphibians typical of the upper Midwest. Dominant species in these areas include whitetail deer, squirrel, raccoon, ruffed grouse, songbirds, thrushes, and woodpeckers. Many of the species that utilize the open land habitats will seek food and protection within woodlands when necessary.

Within the state of Michigan, significant tracts of woodlands and forests are designated as state or federal lands. Parcels of the Escanaba River State Forest stretch from just north of the city of Menominee to just outside the city of Escanaba, a distance of approximately 45 km (28 miles). Some of this land is located on the shores of the bay, but most of it is inland about 1.2 to 2.4 km (0.75 to 1.5 miles). Smaller tracts of the Escanaba River State Forest are located along the shores of Little Bay de Noc north of Gladstone and throughout Delta

County. Altogether, the Escanaba River State Forest comprises 168,350 hectares (416,000 acres) of land. The Hiawatha National Forest comprises 348,000 hectares (860,000 acres) and is located in the central portion of the UP, running from the north end of Big Bay de Noc to the shores of Lake Superior. Large tracts of land within the Stonington Peninsula are designated as part of the Hiawatha National Forest. Finally, the Lake Superior State Forest comprises over 404,700 hectares (1 million acres) of forested land in the central and eastern UP. The northern portion and eastern side of the Garden Peninsula, as well as much of Summer Island are designated as Lake Superior State Forest land. In addition to these state and federal forests, the J. W. Wells State Park and Beach is located along the west shore of Green Bay between Menominee and Escanaba. Fayette State Park is located on the west side of the Garden Peninsula, just off of Sand Bay on the east shore of Big Bay de Noc.

There is no state or federally designated forest land located along the shores of Green Bay in Wisconsin. However, three forested Wisconsin state parks are located on the Door Peninsula. The largest of these is Peninsula State Park, which is comprised of about 1,520 hectares (3,760 acres) of forest and includes about 32 km (20 miles) of shoreline along the east side of Green Bay. Potawatomi State Park is located on the south side of Sturgeon Bay and comprises about 456 hectares (1,127 acres). Finally, Rock Island is a designated state park and comprises approximately 510 hectares (1,260 acres).

2.5.3 Wetlands

Areas identified and mapped as wetlands by the WDNR along the Lower Fox River are shown on Figures 2-9 through 2-12. Wetland areas along Green Bay, which were identified and mapped by WDNR, USFWS (1981), and Bay Lake Regional Planning Commission (BLRPC), are shown on Figures 2-13 and 2-14.

Wetland habitat is probably the most critical habitat within the Lower Fox River and Green Bay area, providing an important habitat for all wildlife groups. Wetlands provide nesting and feeding areas for many migratory birds, including waterfowl, shorebirds, wading birds, and passerines. Many of these birds feed in or over wetlands. Dominant species include geese and mallards, blue-winged teal, wood ducks, scaup, goldeneye, common and hooded mergansers, bald eagles, osprey, and great blue and black-crowned night herons. Some species of fish seek out wetlands for spawning or foraging purposes, including northern pike, bass, sunfish, yellow perch, carp, alewife, rainbow smelt, and shiners (Brazner and Beals, 1997). Small game and fur-bearing mammals that inhabit wetlands include muskrat, mink, otter, and bats, which utilize wetlands habitat for nesting, feeding, and protective cover (Exponent, 1998). Numerous insects, amphibians, snakes, turtles, and invertebrates live within wetlands.

Both the USFWS (1979) and the Michigan Natural Features Inventory (MNFI) (Minc and Albert, 1998) have developed wetland classifications. The classifications used by Exponent (1998) in the Lower Fox River and the southern portion of Green Bay are, more or less, those of the USFWS (1979), while many of the descriptions for Green Bay are those of the MNFI. Therefore, an effort has been made to identify the wetlands in Green Bay using both classification systems in order to facilitate an understanding of the habitat.

According to the MNFI, there are six types of coastal wetlands found within the Great Lakes, including Green Bay, based on floristic variability (Minc and Albert, 1998). The descriptions are generally similar to those above and, moving from deeper water to the shore, these wetland types include the following:

- **Submergent Marsh:** contains submerged aquatic vegetation (SAV) and/or floating vegetation.

- **Emergent Marsh:** characterized by shallow water or saturated soils with rushes, cattails, and other emergent species.

- **Shoreline or Strand Zone:** located at or just above the waterline and are typically thin zones, usually dominated by herbs.

- **Wet Meadow (herbaceous):** characterized by saturated or periodically flooded soils dominated by sedges, grasses, and other herbs.

- **Shrub Swamp and Swamp Forest:** characterized by periods of standing water and are dominated by woody species adapted to a variety of flooding regimes, including dogwood, cottonwood, tamarack, and spruce.

These are general wetland types and not all types are found within each wetland or wetland complex (Minc and Albert, 1998). These can also be lacustrine (associated with lakes), riverine (associated with rivers and streams), and palustrine (isolated or connected wet areas such as marshes, swamps, and bogs). The wetlands located within Green Bay are primarily lacustrine followed by palustrine and then riverine. The wetland descriptions used by Exponent (1998) are presented below, as well as information pertaining to the typical flora of each wetland type.

Wetlands are characterized by seasonally-flooded basins and swales, as well as open, marshy, swampy, or shallow water areas with water-tolerant vegetation.

Lower Fox River and Green Bay wetland types observed by Exponent (1998) included the following:

- **Emergent/Wet Meadow Wetlands.** These wetlands/wetland complexes are typically present along the west shore and tributary mouths of Green Bay, as well as in the backwater covers of Little Lake Butte des Morts and the Lower Fox River (Exponent, 1998). These wetland areas are a combination of the emergent, shoreline, and wet meadow types defined by MFNI (above). Typical emergent vegetation in these wetlands include cattails, bulrush, arrowhead, assorted rushes, sedges, and reeds (Exponent, 1998). Smartweed, wild millet, wild rice, saltgrass, purple loosestrife, cordgrass, reed canary grass, phragmites, and sagittaria are also common within these wetland complexes. The submergent and floating aquatic vegetation within these marshes primarily consists of water-milfoil, coontail, wild celery, pondweeds, and water lilies (Exponent, 1998).

- **Scrub/Shrub Wetlands.** These wetlands are often found in conjunction with emergent/wet meadow wetland complexes in the Lower Fox River and the southern portion of Green Bay (Exponent, 1998). Shrub willows, small cottonwoods, dogwoods, and small ash, as well as elderberry and buttonbush are typical vegetation. These wetlands are located primarily along the west shore of Green Bay, in association with the emergent/wet meadow wetlands located near tributary deltas, shallows, reefs, and spits. Small and large game utilize the wetlands, as do waterfowl, passerines, and select heron species (Exponent, 1998).

- **Forested Wetlands.** These wetlands occur along the banks of the Lower Fox River and the shorelines of Green Bay throughout the habitat characterization zones (Exponent, 1998). These wetlands are forested with numerous deciduous species, including elm, cottonwood, willow, ash, maple, box elder, dogwood, and sumac (Exponent, 1998). Red and white oaks and large cottonwood typically dominate the canopy of more mature forested areas while white oak, maple, and ash usually dominate the canopy of upland wetland complexes (Exponent, 1998).

Exponent (1998) determined that emergent/wet meadow wetland complexes accounted for 43 percent of all wetlands observed in the assessment area. Shrub/scrub wetlands comprised approximately 27 percent of the wetlands and were located mainly along the west shore of Green Bay, while forested wetlands accounted for 25 percent of the area and were predominantly located in the northern portion of the assessment area (Exponent, 1998). Open water within designated wetland areas accounted for 2 percent of the total area and aquatic beds, excavated ponds, and wetlands smaller than 0.8 hectare (2 acres) in size comprised the remaining 3 percent of the area assessed (Exponent, 1998).

Within the Lower Fox River valley, Exponent (1998) identified only 135 hectares (334 acres) of wetlands within 0.4 km (0.25 mile) of the shore. Of these identified wetlands, 119 hectares (294 acres) or 88 percent were located between Little Lake Butte des Morts and the De Pere dam, in the upper three reaches of the river (Figures 2-9 through 2-11). The wetlands in this part of the river were predominately forested wetland (68.9 hectares or 170 acres) and emergent/wet meadow wetlands (32 hectares or 81 acres). The largest wetland areas are associated with the Stroebe Island Marsh and backwater areas in Little Lake Butte des Morts, the 1,000 Islands wetlands (adjacent to Kaukauna/mouth of Kankapot Creek), and the Little Rapids dam, and account for approximately 87 percent of the wetlands upstream of the De Pere dam (Exponent, 1999). Exponent (1998) only identified 16 hectares (40 acres) of wetlands in the De Pere to Green Bay Reach (Green Bay Zone 1), and these were predominantly emergent/wet meadow and forested wetlands (Figure 2-12). Approximately 60 percent of these wetlands (9.5 hectares/23.4 acres) are associated with marsh at the mouth of the Lower Fox River (Exponent, 1998).

In addition to the wetland analysis, Exponent (1998) documented the presence and areal extent of SAV within each portion of the Lower Fox River, even though it appears that these areas were not classified as wetlands. Approximately 350 hectares (865 acres) of SAV are present in the Lower Fox River, with only about 8 hectares (20 acres) located downstream of the De Pere dam. Approximately 260 hectares (642 acres) of SAV is present within Little Lake Butte des Morts and is likely associated with the Stroebe Island marsh and the other backwater wetlands of Little Lake Butte des Morts. Another 62 hectares (153 acres) of SAV are present in the same part of the river as the 1,000 Islands wetlands; therefore, it is assumed that the SAV is again associated with these wetlands. Only 26 hectares (64 acres) of SAV are present in the Lower Fox River downstream of the Rapide Croche dam (Exponent, 1998). This is likely due to the fact that the river is narrower with faster stream flow velocities; conditions that are not favorable for the establishment of SAV.

In 1981, the USFWS completed a study of the fish and wildlife resources of the Great Lakes coastal wetlands. This study found that there are at least 17,098 hectares (42,250 acres) of wetlands located along the shores of Green Bay (Table 2-3). The wetland/wetland complexes included in Table 2-3 are those over 40.5 hectares (100 acres) in size. According to Dr. Dennis Albert (MNFI), the

40.5-hectare (100-acre) criterion is typically used by MNFI when conducting wetland studies (Albert, 2000). Dr. Albert indicated that although there are a number of fully functioning wetlands under 20.2 hectares (50 acres) along the shores of Green Bay, physical constraints generally keep these wetland areas from expanding. Therefore, controlling losses in the larger wetlands or wetland complexes is the important factor in maintaining the overall wetland area in a given region (Albert, 2000).

Approximately 42 percent of the significant wetland areas are located in Wisconsin while about 58 percent of the wetlands are located in Michigan. As discussed previously, bathymetry and the physical environment of the bay have a significant influence on the size and location of coastal wetlands. Based on these factors, the distribution of wetlands along the east shore of Green Bay is very limited compared to the west shore of the bay and in both Big and Little Bays de Noc (Table 2-3; Figures 2-13 and 2-14).

Slightly more than 569 hectares (1,400 acres) of wetlands are located along the east shore of Green Bay. This represents only 3.3 percent of all the wetland areas larger than 40.5 hectares (100 acres) in the area (Table 2-3). Wetlands along the east side of Green Bay are generally classified as palustrine (marsh or swamp) (USFWS, 1981). Palustrine wetlands generally lack flowing water and have water depths less than 1.8 meters (6 feet) deep. Exponent (1998) described the largest east shore wetlands (from the Lower Fox River to Little Sturgeon Bay) as emergent/wet meadow wetlands. Based on the information provided by Exponent (1998) and the USFWS (1981) descriptions, many of the wetlands along the east shore of Green Bay are emergent/wetland meadow complexes.

The west shore of Green Bay has about 8,000 hectares (19,770 acres) of wetlands (Table 2-3), approximately 47 percent of the Green Bay wetlands greater than 40.5 hectares (100 acres). This includes all shoreline from the mouth of the Lower Fox River to the city of Escanaba, Michigan. From the mouth of the Lower Fox River to the city of Oconto, Exponent (1998) classified slightly more than 50 percent of the wetlands as emergent/wet meadow, while approximately 31 percent were shrub/scrub wetlands. The information provided by USFWS (1981) and Minc and Albert (1998) suggest that wetlands further north of the city of Oconto are similar, as palustrine wetlands are usually found with the lacustrine areas (Table 2-3). Almost all of the west shore wetlands were primarily classified as lacustrine systems by the USFWS (1981). These wetlands are affected by littoral currents, storm-driven wave action, wind action, and ice scour, which are the primary causes of shoreline sediment deposition and erosion (Minc and Albert, 1998). These lacustrine systems have developed in the shallows of the bay and many of them in Wisconsin water are associated with the Green Bay tributary spits or deltas. Only wetlands associated with river deltas are classified as riverine systems (Table 2-3). These include select portions of the Atkinson Marsh (Duck Creek), Oconto Marsh (Oconto River), Peshtigo River Wetland, Cedar River Wetland complex, and Ford River Wetland complex. Other riverine wetlands are associated with the other tributaries; however, these wetlands are usually very small and are not included in Table 2-3.

Wetlands found in both Bays de Noc are predominantly lacustrine systems and are generally similar to the west shore wetlands. Approximately 8,527 hectares (21,070 acres) of wetlands are located in these two bays. This is slightly under 50 percent of the wetlands within Green Bay (Table 2-3). These wetlands have extensive emergent vegetation development (Minc and Albert, 1998). Also, the wet meadow complexes, shrub swamp, and swamp forest wetlands in the UP are typically larger and more areally extensive than further south in Green Bay, primarily due to less development in this region of the bay.

The state of Wisconsin has a number of designated wetlands/wildlife areas located in the Green Bay area (Table 2-4). The largest of these is the Green Bay West Shores Wildlife Area (W.A.), which is comprised of 11 units. The 11 units, along with the area, are listed below, starting near the mouth of the Lower Fox River and moving north along the west shore. The status of an area as either a designated state W.A. or National Wildlife Refuge (N.W.R.) is also indicated.

Currently, 3,015.8 hectares (7,452.1 acres) of land are designated as part of the Green Bay West Shores W.A. However, the WDNR desires to expand this area to a total of 5,639 hectares (13,933 acres) in the future (WDNR, 2000a).

The Gardner Swamp State W.A. lies along the east side of the bay in Door County, located approximately 2.4 km (1.5 miles) south of Little Sturgeon Bay, and covers 478 hectares (1,181 acres) (WDNR, 2000a). In addition, the WDNR is currently planning to establish the Red Banks Glades W.A. in Brown County. This planned W.A. would be approximately 204 hectares (503 acres) and would be located just inland from the bay, like the Gardener Swamp W.A. (WDNR, 2000a).

The city of Green Bay owns and operates the Bay Beach Wildlife Sanctuary, which is located approximately 1.9 km (1.2 miles) east of the Lower Fox River and just south of Green Bay's historic Bay Beach. The sanctuary is approximately 283 hectares (700 acres), of which 24.3 hectares (60 acres) are standing water and lagoon. Wet meadow, emergent, and shrub/scrub wetland areas are all present within the area (Baumann, 2000).

2.5.4 Riverine Habitat of the Lower Fox River

Riverine aquatic systems refer to the rivers and tributaries of the Great Lakes whose water quality, flow rate, and sediment loads are controlled in large part by their drainage basins. Tributary rivers typically have a low flow volume, although the flow volume may vary significantly due to seasonal influences. Tributaries such as the Lower Fox River are also influenced by the amount of the development immediately adjacent to the riverbanks or within the drainage basin. A summary of Green Bay tributaries is shown on Table 2-5.

The Habitat Characterization Assessment (Exponent, 1998) divided the Lower Fox River into two parts, upstream and downstream of the De Pere dam. The upstream portion is comprised of the Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere reaches, while the downstream portion is comprised of the De Pere to Green Bay Reach. Eight different aquatic habitats were identified within the Lower Fox River (Exponent, 1998). These habitat types, along with the percentage of each type within the river, are listed in Table 2-6 and shown for each reach on Figures 2-9 through 2-12.

The largest category described by Exponent (1998) was the island/peninsula habitat (Table 2-6). Most of the areas where island/peninsula habitat was observed are small, unnamed outcroppings and areas within the Lower Fox River which were formed during lock and dam construction and channelization of the river in the 1800s. A few notable areas for this type of habitat are Stroebe and James Islands in Little Lake Butte des Morts (Figure 2-9), the 1,000 Islands Nature Conservancy near Kaukauna (Figure 2-10), and the unnamed islands associated with the Cedar, Combined, Rapide Croche, and Little Kaukauna locks (Exponent, 1998).

Backwater, cuts, and coves are the second largest habitat category observed within the Lower Fox River (Table 2-6). These areas are relatively undisturbed by human activities and thus are very desirable for wildlife and fish (Exponent, 1998). Additionally, these habitat areas are generally small and scattered throughout the river, making them an important habitat for maintenance of current fish and wildlife populations that use them. These areas are shown on Figures 2-9 through 2-12.

Other habitat types that are important are the dam riffles, submerged rock, piling or ruin environments, and sandbars or silt deposited areas (Nikolai, 1998). Although these two habitats constitute just over 12 percent of the Lower Fox River, game fish are often associated with these areas. Also, fish like walleye prefer rocky substrates with fast-running water for spawning purposes. Based on the fact that the walleye are an important game fish of the Lower Fox River, this habitat is significant.

Besides reviewing the aquatic habitat, Exponent (1998) evaluated the riverbanks and substrate characteristics. The river shoreline was divided into both developed and natural riverbank, with subcategories of each. About 44.6 percent of the river shoreline is protected with either riprap or bulkheads while the remaining 55.4 percent of the river is natural bank (Table 2-7). The shoreline delineation, as classified by Exponent (1998) is shown on Figures 2-9 through 2-12. Slightly more than 22.4 km (13.9 miles) of the 28 km (17.4 miles) of developed shoreline is protected with riprap (Table 2-7). This is about 36 percent of the total shoreline. Exponent (1998) indicated that riprap protection is preferred to bulkheads because the riprap tends to offer some habitat possibilities to fish and wildlife within the river, as some fish will find protection and feeding opportunities and some birds will nest in the crevices and gaps of riprap. Bulkheads offer little in the way of habitat due to the smooth surfaces and vertical walls.

The Lower Fox River has about 34.8 km (21.6 miles) of natural shoreline (Table 2-7). The largest category of natural shoreline was riparian canopy, which includes tree-lined and forested banks of the river. Almost 44 percent of the entire river shoreline was described as riparian canopy (Table 2-7), with about 15.9 km (9.9 miles) of this shoreline situated between the Cedars and Little Kaukauna locks (Figure 2-10). This is one of the least developed portions of the Lower Fox River, with steep banks that inhibit significant agricultural or urban development. Shorelines with either groundcover or wetland comprised almost 6.8 km (4.2 miles) while sand/gravel beaches comprised less than 1 percent of the shore (Table 2-7).

2.5.5 Lacustrine Habitat of Green Bay

The lacustrine habitat of Green Bay is very different than the riverine habitats of the Lower Fox River. Lacustrine systems, like Green Bay, have deeper water, allowing temperature stratifications (thermoclines) to develop (Belonger, 2000). A thermocline is a thin layer of water that has a significant temperature gradient, separating warmer water above from colder water below. The presence of a thermocline provides large water bodies the ability to host many different species of fish and other aquatic organisms that may prefer a warmer or colder temperature environment. Numerous fish species can be found within different areas and at various depths of lacustrine habitat based on the water depth, currents, and temperature. Additionally, water temperature is a significant biological factor and indicator for many aquatic organisms.

Other unique aspects of lacustrine environments are related to water currents, sediment deposition and erosion, and the wetland complexes that develop therein. Unlike rivers, which basically have a unidirectional current (gravitational), lacustrine currents are more complex, variable, and weaker (Maitland and Morgan, 1997). Also, sediment erosion within Green Bay is largely confined to shore and nearshore areas, where wind, wave action, and ice scour are the primary causes for erosion and redeposition. Bottom sediments transported from the Lower Fox River and other tributaries into Green Bay are typically deposited nearby the source mouth. This is evidenced by the thick sediment deposits and shallow water depths at the southern end of the bay (Lower Fox River/Duck Creek mouths) and the spits, shoals, and shallows located near the mouths of the other significant tributaries along the west side of the bay. Lacustrine environments typically develop larger wetlands than riverine systems, especially in areas of extensive shallow water and low current velocities, as described above.

Lacustrine environments are generally categorized based on the biological conditions of the system and the three classifications are eutrophic, oligotrophic, and dystrophic. Lower Green Bay is eutrophic and the northern end is generally oligotrophic. Eutrophic lakes are nutrient rich, usually shallow, turbid waters that may experience oxygen deficiencies under the ice or in deeper areas at certain times of the year (Maitland and Morgan, 1997). Oligotrophic lakes are typically deep, clear waters that are nutrient poor and rarely, if ever, have oxygen deficiencies (Maitland and Morgan, 1997). In addition, Green Bay is also mesotrophic in areas; the mesotrophic classification is an intermediate between eutrophic and oligotrophic conditions.

Inner Bay Water Quality

The southern end of Green Bay is a lacustrine estuary, which is a zone of transition from a riverine to lacustrine environment. An estuary is typically defined as a submerged river mouth, which may extend for some distance into a large body of water. Water depths in Zone 2 are generally less than 1.8 meters (6 feet). This area ranges from eutrophic to hypereutrophic (Sager and Richman, 1991) and it has a long history of being a eutrophic water body.

The silty substrates, shallow water depths, extensive wetlands, and green color were all observed by the earliest explorers of the region. The process of eutrophication is natural and generally occurs over an extended period of time, as fresh waters naturally tend to silt up. The availability of potential nutrients within bottom sediments is typically only released when the water becomes shallow enough that macrophytes utilize them (Maitland and Morgan, 1997). This was the general state of the inner bay (particularly the southern end) when European settlers arrived in the region. The hypereutrophic conditions of the lower bay were likely brought on by development, which greatly accelerated eutrophication. The Lower Fox River served as the primary disposal system for domestic and industrial wastes, which contributed significant quantities of nutrients (particularly phosphorous and nitrogen), to the bay through much of the twentieth century. Also, intense farming with heavy application of fertilizers, especially in the lowland areas of the rivers and lakes, leads to enrichment of runoff waters with nutrients (Maitland and Morgan, 1997), and this has occurred in the Lower Fox River and Green Bay area (Harris, 1993).

The fish die-offs on the east side of the bay in 1938 through 1939 (Wisconsin State Committee on Water Pollution) indicated the impacts of poor water quality and the lack of dissolved oxygen (D.O.) on the inner bay. Water quality and benthic community studies throughout the mid-1900s showed low D.O. and degraded water quality. The results of the benthic community studies will be discussed below. Since waste treatment practices reduced the loads of organic wastes in the 1970s, D.O. concentrations have generally remained above the standard of 5 mg/L (Harris, 1993). However, D.O. concentrations have dropped below 5 mg/L during summer months when algal blooms occur (Harris, 1993). Recurring algal blooms are one sign that the eutrophic conditions of the southern bay continue today.

The shoal extending from Point Au Sable to Long Tail Point reduces the mixing ability within this part of the bay; water south of the shoal is hypereutrophic while water north of this area is classified as eutrophic (McAllister, 1991). There is also a trophic gradient within the inner bay that results from the currents described previously (Section 3.4). Satellite images from 1984 indicated that eutrophic water conditions extended along the east shore of the bay from the mouth of the Lower Fox River to Sturgeon Bay (Sager, 1986). Water along the east shore of the bay was more eutrophic than was the water flowing along the west side of the bay (McAllister, 1991). However, following the reduction of phosphorous and other chemical loadings during the 1980s, the water clarity north of the Long Tail Point improved, allowing reestablishment of wild celery in some west shore wetland areas (Harris, 1990; McAllister, 1991).

Outer Bay Water Quality

The northern half of Green Bay (the outer bay) is generally oligotrophic to mesotrophic (Sager and Richman, 1991). Much of the outer bay, especially in the deep-water areas of the eastern half, is oligotrophic, while conditions become mesotrophic moving south towards and past Chambers Island. Eutrophic conditions may be present in the shallow areas of Big Bay de Noc during the summer, as waters within both Bays de Noc are well mixed (Schneeberger, 2000). Conditions along the northwest shore of Green Bay, from Menominee, Michigan, to the north end of Little Bay de Noc, are suitable areas for mesotrophic conditions. The wetland areas, shallow waters, and bay tributaries located on the western shore likely foster eutrophic conditions, while the cold, oligotrophic waters of Lake Michigan flow along the shoreline. Therefore, depending on the time of year and the local weather conditions, the north and northwest sides of the bay may experience all three water conditions.

2.5.6 Benthic Communities

In the Lower Fox River and Green Bay environment, the benthic macroinvertebrates are primarily bottom-dwelling invertebrates that include adult and larval insects, mollusks, crustaceans, and worms. Given the predominance of fine-grained silt/clay sediments in the river, the predominant species are sediment dwelling and burrow directly into the substrate for most of their life cycle. The benthic macroinvertebrate community plays a vital role in ecosystem functions such as nutrient cycling and organic matter processing, and is an important food resource for the benthic and pelagic fish communities, as well as semi-aquatic organisms such as birds and mammals.

Historical macroinvertebrate surveys completed between 1938 and 1978 examined populations and taxa richness near the mouth of the Lower Fox River and in southern Green Bay. The 1938 through 1939 pollution survey found that oligochaetes and chironomids dominated the benthic communities within this area, although very small numbers of leeches, sowbugs, scuds, clams, and snails were observed at various locations. The oligochaetes and chironomids are thought to be tolerant of organic enrichment and/or degraded habitats like that of the Lower Fox River and southern Green Bay, whereas other species are less tolerant of enriched/degraded habitats. In addition, oligochaetes and chironomids were completely absent in a few locations in the southern bay, suggesting that water quality in this portion of the bay did not support such pollution-tolerant species (Surber and Cooley, 1952). However, the burrowing mayfly (*Hexagenia*) was detected at 16 of 51 stations sampled in 1938 through 1939 (Markert, 1978). *Hexagenia* are considered to be pollution-sensitive or intolerant taxa and their presence was indication that water quality conditions had not reached their worst.

Water quality, as measured by the benthic community populations, deteriorated significantly between 1938 through 1939 and 1952. Comparison of the 1938 through 1939 and 1952 sampling data indicated that both the oligochaete and chironomid populations had increased. Additionally, established populations of both groups were observed at locations as far north as Oconto and Little Surgeon Bay, indicating that the water quality in the southern bay was progressively worsening (Surber and Cooley, 1952). Similar results were noted in 1978 (Markert, 1978). In 1978, the density of oligochaetes and midges was greater than in 1938 through 1939, while the burrowing mayfly (*Hexagenia*) was not observed at all. These results indicated that further degradation of water quality had continued since 1938 through 1939. However, comparison of the 1952 and 1978 sample results indicated that there was some improvement in water quality since the 1950s (Markert, 1978).

A number of studies completed in the late 1980s and 1990s evaluated the macroinvertebrate taxa richness and diversity in the Lower Fox River and Green Bay (Call *et al.*, 1991; Integrated Paper Services [IPS], 1993a, 1993b, 1994, 1995; WDNR, 1996b). Similar to the historic surveys, these studies generally found that the benthic infauna of the Lower Fox River and Green Bay were dominated principally by oligochaetes and chironomids with roundworms, flatworms, scuds, caddisflies, leeches, and sowbugs completing the inventory (IPS, 1993a, 1993b). These studies showed that the benthic macroinvertebrate communities from upstream reference sites and locations in Green Bay far from the mouth of the river were higher in taxa richness than the Lower Fox River sites. Similar to the historical results, mayflies were not found in the Lower Fox River or lower Green Bay, but were found in both the reference sites (WDNR, 1996a [*Caenis* sp.]; Call *et al.*, 1991 [*Hexagenia*]). However, it remains inconclusive if these lower infaunal and species counts were a result of organic enrichment, chemical contamination, poor physical conditions, or other factors.

The 1992 and 1993 results reflect recovery from the severely impaired conditions found in the 1960s and 1970s (IPS, 1994). These results were bolstered in 1994 by the presence of snails, clams, and mussels at the Little Lake Butte des Morts sites in deposits D and POG (IPS, 1995). The results of these early 1990s studies indicated that the density of the benthic community populations had increased significantly compared with studies completed during the 1980s in Little Lake Butte des Morts (IPS, 1995). Downstream of Little Lake Butte des Morts, in deposits N and EE/FF, the 1992 through 1994 benthic community results indicated that benthic community populations increased; however, oligochaetes and chironomids were still dominant and there was no corresponding increase in community diversity to accompany the population increase. Similarly, conditions in the middle and outer portions of Green Bay seemingly reflected an improvement in general water quality due to an increase in scuds and sowbugs, which were typically observed in more northern reaches of the bay (IPS, 1995). However, the presence of zebra mussels probably signals future difficulty for the benthic communities of the Lower Fox River and Green Bay due to the ability of this exotic species to out-compete the local benthic species for food and habitat (IPS, 1995).

2.5.7 Fish

Through the mid-1970s the population levels of fish species, such as walleye and perch, were low within the Lower Fox River and southern Green Bay ecosystems. Contaminants, along with low D.O. conditions brought about by uncontrolled and untreated wastewater dumped into the river, were believed to be a contributing factor causing low population levels. Principal species found within the system were those that could tolerate these conditions, especially bullhead and carp.

With the institution of water quality controls in the mid-1970s, contaminants and D.O. conditions improved. The WDNR undertook a program to reintroduce walleye into the river and bay through a stocking program beginning in 1973. That program was wholly successful; self-sustaining populations of walleye now exist within the river and bay. Recent electrofishing catch data for walleye from De Pere dam to the mouth of the Lower Fox River are shown on Figure 2-15.

In addition to walleye, a number of other species became reestablished in the Lower Fox River and Green Bay, including white and yellow perch, alewife, shad, bass, and other species. Historical anecdotal data from the Oneida tribe and more recent creel survey data from the WDNR indicate that Duck Creek and Suamico tributaries to southern Green Bay were used by numerous fish species (Nelson, 1998).

The WDNR has completed extensive fish surveys in the Lower Fox River and inner Green Bay. However, due to the numerous factors which may effect fish populations, simply reviewing and comparing the population survey results from various years is not valid. Year-to-year fish populations do not necessarily indicate whether conditions within the river/bay are degraded or improving because other environmental, physical, or biological factors may be impacting select fish species at any given time. Select fish surveys for the Lower Fox River have been reviewed to provide data on the types of fish present within the system at given points in time. However, no in-depth analysis of whether these population surveys indicate declining or improving conditions is included. No Green Bay fish surveys are included in this discussion. Rather, the personal observations from WDNR and MDNR personnel familiar with both the commercial and sport fisheries of Green Bay are used.

Due to the fact that environmental degradation of the Lower Fox River and Green Bay either directly or indirectly impacts the resources of the Oneida and Menominee Nation Trust Lands, issues of concern to both tribes are addressed herein. The fisheries of the Lower Fox River and Green Bay are important to the Oneida and Menominee Indian Nations for cultural and historical purposes. The fish supply was historically a major source of protein for many tribal members, as the fish could be dried, canned, salted, or smoked for use throughout the year (Stratus Consulting, 1999b). Fish have historically been a staple part of the diet of the Oneida. When the Oneida came to Wisconsin from New York, a primary reason they chose the land around Duck Creek was because of the abundant waterfowl and fish associated with the creek. Therefore, the fish of Duck Creek became an important resource for the tribe. Duck Creek lies within the Oneida Reservation and PCBs have been found within fish caught in Duck Creek. Therefore, the results of the 1998 Duck Creek fish assessment, completed cooperatively by the USFWS, WDNR, and Oneida Nation, has been summarized and included herein.

Similarly, the Menominee Nation historically celebrated the return of the lake sturgeon ("*Namä'o*" in Menominee) at Keshena Falls on the Wolf River, a tributary of the Lower Fox River (Beck, 1995). The Menominee Indians have lived in Wisconsin longer than any other tribe, and the annual return of the lake sturgeon (*Namä'o*) was a cause for religious celebration and for sustenance after winter, when the availability of food was typically at its lowest (Beck, 1995). Due to the cultural and religious importance of the lake sturgeon to the Menominee, a description of the habitat, spawning, and life cycle of the lake sturgeon is also included.

Lower Fox River/Duck Creek Fish Surveys

In association with water quality studies, the WDNR has conducted multiple fish population surveys of the Lower Fox River, as well as Duck Creek. The surveys were completed during several time periods with a variety of survey gear and for several purposes and are listed in Table 2-8.

The fish catch results from these studies are summarized in Tables 2-9 and 2-10. Table 2-9 summarizes the fish survey results for the Lower Fox River upstream of the De Pere dam while Table 2-10 summarizes fish surveys in the De Pere to Green Bay Reach. The fish observed in Duck Creek during 1995 and 1996 are indicated on Table 2-10 because both these rivers/river reaches are connected directly with Green Bay.

At least 43 different fish species were identified in the Lower Fox River upstream of the De Pere dam (Table 2-9). Twenty-four (24) were game fish and 19 species were non-game fish (as defined by state statute). The 1983 Little Lake Butte des Morts fish survey indicates that approximately 60 percent of the species captured were game fish, and that black bullhead and black crappie were the predominant fish (Table 2-9). More recent surveys in 1998 for Little Lake Butte des Morts showed a more diverse assemblage of species than observed in 1983 (Exponent, 1999). Species captured in 1998 that were absent in the 1983 surveys included bass (both smallmouth and largemouth), longnose gar, shiner (rosyface and golden), and pumpkinseed.

Population results for Little Lake Butte des Morts to the De Pere dam indicate that game fish typically comprise about 30 to 40 percent of the fish captured (Table 2-9). Yellow perch, walleye, white bass, and bullheads have all been the dominant game fish species at one point or another. Carp was the most prevalent fish observed in the Lower Fox River upstream of the De Pere dam. Carp typically accounted for 50 to 90 percent of non-game fish and approximately 50 to 60 percent of the all fish captured in the surveys.

Annual fyke net studies of fish populations have been completed for the De Pere to Green Bay Reach since 1987 (Table 2-10). Due to differences in the lengths of the studies conducted, only the data from April of each year has been summarized on Table 2-10. Game fish account for 70 to 90 percent of the total captured fish population. The dominant game fish typically include yellow perch, one of the primary commercial species in the bay, as well as walleye, white bass, and white perch. Furthermore, walleye is the only other game fish that generally comprises more than 10 percent of the total fish population (Table 2-10). Non-game fish below the De Pere dam are predominantly carp, white sucker, drum, and quillback.

As indicated on Table 2-10, 21 fish species (7 non-game and 14 game fish) that have been observed in the De Pere to Green Bay Reach were also observed in Duck Creek (Cogswell and Bougie, 1998). In addition to the species identified in Table 2-10, 34 other fish species were also observed in Duck Creek. However, many of these were small non-game fish like shiners, chubs, and darters. Cogswell and Bougie (1998) found that the fish-supporting capacity of Duck Creek is limited by several factors, including low water flow, low D.O., high water temperatures, and degraded water quality. Duck Creek is an intermittent stream and has been significantly impacted by the agricultural activities of the watershed. Sediment erosion from tilled fields has been found to account for over 75 percent of the total phosphorous load in the creek (WDNR, 1997). The assessment results indicated that the walleye and northern pike of Green Bay frequented several tributaries during their life. Walleye and northern pike originally tagged within the Lower Fox River were found in Duck Creek, and 46 percent of the northern pike tagged in Duck Creek were recaptured at several locations in Green Bay (Cogswell and Bougie, 1998). Also, the age and size range of the walleye captured in Duck Creek was similar to those in the Lower Fox River during spring (Cogswell and Bougie, 1998). These results indicate that there is fish migration between Green Bay and its tributaries. Similarly, Terry Lychwick, WDNR, indicated that tagging studies in the De Pere to Green Bay Reach (Green Bay Zone 1) and Green Bay Zone 2 revealed that fish migrate between the bay and river (Lychwick, 2000). These study results suggest that there are not separate river and bay fish populations in this area, rather, the fish move to locations where food and habitat characteristics are favorable.

Green Bay Fishery Observations and Habitat

The fish of Green Bay have been categorized in four groups (Table 2-11). These groups include the salmon/trout, benthic, pelagic, and game fish groups. Many of the salmon and trout of the region are found in cold-water fisheries of the northern part of Green Bay. The benthic fish are those that generally feed or live near the bottom of the bay while the pelagic fish are those which typically feed or live in the water column. The game fish listed in Table 2-11 are those fish typically sought by sport or commercial fisherman. The state of Michigan has listed the lake sturgeon and the sauger as threatened species (Table 2-11).

The general spawning areas in Green Bay for each of these groups of fish is shown on Figures 2-16 and 2-17 (NOAA, 1999). As expected, the spawning areas for the salmon/trout species are in the vicinity of the tributaries. The spawning areas for the pelagic and benthic fish are very similar and concentrated mainly in the areas of significant wetlands (Figures 2-13 and 2-14). The game fish spawning areas are similar, but also include additional areas on the east side of Green Bay, indicative that some species, like walleye, prefer gravel beds to the SAV that is associated with the wetlands (Figure 2-17). The spawning areas obtained from the Great Lakes Commission (2000) for large portions of Zone 4 were not identified as specific species and are simply shown as points on Figures 2-16 through 2-20 to indicate locations where fish either spawn or have been observed.

As indicated in Table 2-11, most of the fish being evaluated as part of the food web models are pelagic fish (shiners, gizzard shad, smelt, and alewife). The yellow perch and walleye are the only two game fish included while the carp is the only benthic species included. The Green Bay spawning areas for the food web model fish are shown on Figures 2-18 through 2-20 (NOAA, 1999). As mentioned above, walleye prefer gravel beds for spawning. Such habitat is typically associated with the increased stream flows near the tributary mouths on both the east and west side of the bay. Yellow perch, gizzard shad, alewife, smelt, and carp spawning areas are all associated with the extensive west shore wetlands. The emerald shiner is the only species whose spawning habitat is limited to the east shore of the bay.

The fishery habitat of Green Bay varies considerably based on the water characteristics and bay bathymetry. Green Bay zones 2 and 4 are quite different in terms of their physical characteristics, which affects species distribution and trophic complexity. Green Bay Zone 2 is hypereutrophic (warm and highly productive), while Zone 4 is meso-oligotrophic (cooler and less productive). Related distinguishing characteristics of Zone 4 include lower population densities of fish, less trophic complexity, clearer water, and less human development as compared to Zone 2 (Brazner and Beals, 1997; Sager and Richman, 1991).

The following summary is based on the observations and personal communications of Mike Toneys and Brian Belonger (WDNR) and Phil Schneeberger (MDNR).

Green Bay south of the Peshtigo Reef (west side) and Sturgeon Bay (east side) is generally a warm-water fishery, with eutrophic water conditions, significant plankton populations, and numerous fish species (Toneys, 1999; Belonger, 2000). This fishery is separated from the cold-water fishery to the north by the circular, counterclockwise water currents, one of which runs west from the Peshtigo Reef to Sturgeon Bay on the east side. North of Peshtigo Reef and Sturgeon Bay, the fishery is a cold-water, meso-oligotrophic system with reduced plankton populations and fewer fish species (Schneeberger, 1999).

The general observations of the Green Bay fisheries are described below. Fish with each of these fisheries tend to remain in one area or the other. Tagging studies of yellow perch and smallmouth bass indicate that these fish tend to stay within the area where they were caught (i.e., yellow perch in the warm, south bay waters do not typically migrate to the cold-water fishery of the north bay) (Toneys, 1999). Similarly, the Sturgeon Bay Canal is prone to seiche effects and water temperature changes of 5.5 to 11 degrees centigrade (˚C) (10 to 20 degrees Fahrenheit [˚F]) in a single day. Therefore, fish within Green Bay may move into Lake Michigan and vice-versa, but this is not a significant migration route (Toneys, 1999).

South of the Sturgeon Bay-Peshtigo line, heavily-pursued sport fish include walleye, yellow perch, northern pike, and spotted muskellunge (muskie). North of Sturgeon Bay-Peshtigo, smallmouth bass, brown trout, and salmonids are also pursued (Toneys, 1999; Belonger, 2000). The yellow perch and alewife are the predominant commercial species in the southern area, especially during the summer. During the winter, the lake whitefish become an important commercial species. The whitefish prefer cold waters and are fished in the northern bay year-round. However, when water temperatures decrease south of Sturgeon Bay-Peshtigo, these fish migrate south in pursuit of food (Toneys, 1999; Belonger, 2000). A thermocline has been observed in this area, which tends to form and stay near a depth of 3 to 12 meters (10 to 40 feet), based on weather conditions.

If a consistent northeast wind is experienced, this may push the thermocline down to depths of approximately 18 meters (60 feet) (Belonger, 2000).

In northern Green Bay, walleye, yellow perch, northern pike, splake, chinook salmon, smallmouth bass, white bass, and carp are all sought by sport fishermen. In Michigan, the annual sport catch of walleye may range between 30,000 and 90,000 kg (66,100 and 198,400 pounds) while the yellow perch catch is on the order of 10,000 to 80,000 kg (22,050 to 176,400 pounds) (Schneeberger, 1999). Commercially, the lake whitefish and rainbow smelt are the main species pursued. The annual whitefish catch ranges from 1 million to 1.5 million kg (2.2 million to 3.3 million pounds) while the smelt catch is on the order of 50,000 to 200,000 kg (110,230 to 440,900 pounds) (Schneeberger, 1999).

The commercial fishery for lake whitefish has increased significantly over the last 20 years, and the catches are near an all-time high (Belonger, 2000; Schneeberger, 1999, 2000). In the northern half of Green Bay, the walleye fishery has also increased in the number of fish caught for each hour of fishing and the total numbers of walleyes taken (Schneeberger, 2000).

In addition to these observations, Brazner and Magnuson (1994) found that more fish preferred the nearshore wetland habitats to beaches, which have fewer plants and stronger wave action. In 1997, Brazner indicated that fish populations in the vicinity of undisturbed wetlands were greater than those in disturbed wetlands or beach areas. More forage species and the majority of the game fish captured, including yellow perch and bluegills, were taken in the vicinity of undisturbed wetlands. The highly productive (eutrophic) southern bay provided a better forage base for fishes than did the meso-oligotrophic northern end (Brazner, 1997). This is very important for young fish, which almost all forage on zooplankton at some point during maturation (Brazner, 1997).

The overall patterns of fish abundance, species distribution, and habitat use by fish in Green Bay have been recently well characterized by Brazner and colleagues at the University of Wisconsin (Brazner, 1997; Brazner and Beals, 1997; Brazner and Magnuson, 1994). Each of these papers summarized data collected from 24 stations extending the whole length of Green Bay: eight stations in Zone 2, eight stations in Zone 3, and eight stations in Zone 4. All of these stations were along the western side of Green Bay except for one station on the eastern side of Zone 2, Point Sable. The two habitats targeted for sampling were wetlands (12 stations) and sandy beaches (12 stations). Additionally, half of the stations for each of these two habitats were selected because they were developed, and the other half were selected because they were undeveloped.

These stations were sampled in the summer and fall of 1990 and 1991, and in the spring of 1991. Almost 42,000 fish, representing 54 species and 20 families, were caught and analyzed over these sampling periods. Most of these fish (86 percent) were immature (younger than 2 years old) likely because of the small mesh sampling gear used which favored selection of younger age classes of fish.

The data collected by Brazner and colleagues were analyzed to determine to what degree fish preferentially used different regions of the bay, habitats within those regions, and to what degree human development impacted habitat use. Statistical analyses including cluster analysis, ordination, and discriminant analysis indicated that regional differences most strongly influenced fish assemblages, followed by habitat differences, and the least determining factor was development status.

Approximately half (49 percent) of all the fish collected came from Zone 2, most of them captured in undeveloped wetlands, and only 16 percent came from Zone 4. Not only was abundance greater in Zone 2, but also species richness. Of the regional characteristics measured, turbidity was determined to be the best predictor of fish abundance. Other important regional characteristics included water temperature, conductivity, and pH (Brazner and Beals, 1997).

Habitat differences adequately defined fish assemblages for Green Bay zones 3 and 4, but they were not a good predictor for Zone 2 (Brazner and Beals, 1997). Macrophyte level was the habitat characteristic that best predicted fish assemblages. When macrophyte cover and richness is high, the same is generally true of fish richness and abundance (Brazner and Beals, 1997). An exception to this is where macrophyte cover is so dense that it has limited utility for fish.

Turbidity, in addition to being a primary regional characteristic, is a key limiting factor to macrophyte growth and, therefore, habitat differences (Brazner and Beals, 1997). Areas that are highly turbid, such as Green Bay Zone 2, have less developed macrophytes, whereas Zone 4, which has clear waters, has well developed macrophytes. Overall, these differences have resulted in lower biomass and vegetation-dependent fish in Zone 4 (centrarchids, northern pike, golden shiners) and higher biomass, more turbidity-tolerant fish communities in Zone 2 (gizzard shad, white bass, common carp) (Brazner and Magnuson, 1994). Turbidity in Zone 2 is assumed to be equally influenced by biotic (phytoplankton production) and abiotic (erosion, runoff, and resuspension) factors (Brazner and Beals, 1997). It has been estimated that 70 percent of the water in Zone 2 (Long Tail Point to Point Sable) is composed of Lower Fox River water (Brazner and Beals, 1997).

In terms of trends in individual species, spottail shiners were the most abundant fish, with over 122,000 individuals caught in the spring of 1991 (Brazner, 1997). Catch of this species was not dependent on habitat type, but was dependent on region; 93 percent of the catch was obtained from Zone 2. Excluding these spottail data, spottail shiners were still one of the top five most abundant species caught; the remaining top five species were yellow perch, alewife, spotfin shiner, and bluntnose minnow. Yellow perch represented about 25 percent of the approximately 42,000 fish caught, and spottail shiner represented approximately 22 percent.

For 21 of the 54 fish species caught, either more than 80 percent of the individuals or at least a significant number of them were caught in one zone. These results demonstrate that regional differences were stronger determining factors of fish assemblage than habitat or development. Of these 21 fish species, freshwater drum, white bass, and gizzard shad were caught almost exclusively in Zone 2, and golden shiners, pumpkinseeds, and logperch were most often caught in Zone 4 (Brazner, 1997). The three species that were dominantly caught in Zone 3 (rainbow smelt, trout perch, and banded killfish) were not the most abundant fish caught in this zone.

Specifically, for receptors selected for risk evaluation of the Lower Fox River and Green Bay, the following information was obtained from the Brazner (1997) study:

- Yellow Perch
  - Dominantly found in Green Bay Zone 2 (74 percent)
  - Dominantly found in wetland habitat (74 percent)

- Spottail Shiner
  - Dominantly found in Green Bay Zone 2
  - Dominantly found in beach habitat

- Alewife
  - Dominantly found in beach habitat

- Gizzard Shad
  - Dominantly found in Green Bay Zone 2

- Emerald Shiner
  - Dominantly found in Green Bay Zone 2

- Common Shiner
  - Dominantly found in wetland habitat

- Golden Shiner
  - Dominantly found Green Bay Zone 4
  - Dominantly found in undeveloped wetland habitat

- Common Carp
  - Dominantly found Green Bay Zone 2
  - Dominantly found in undeveloped wetland habitat

- Rainbow Smelt
  - Dominantly found Green Bay Zone 3
  - Dominantly found in beach habitat

Note: trends for brown trout ($n = 2$) and walleye ($n = 9$) were not evaluated because an insufficient number of individuals were collected.

Life Histories of Fish Species in the Lower Fox River and Green Bay

The remainder of this section details receptor species descriptions, life history, and food preferences for the important receptor species identified in the Risk Assessment

Shiners (Minnows). Shiner species found in the Lower Fox River and Green Bay include golden shiner (*Notemigonus crysoleucas*), emerald shiner (*Notropis atherinoides*), and common shiner (*Notropis cornutus*). Like carp, shiners are in the family Cyprinidae.

All shiner species are relatively small forage fish that average 5 to 10 cm (2 to 3.9 inches) in length. Golden shiners are silver with a dusky stripe along their side and a small, almost vertical mouth. Common shiners are olive on top with a dark stripe running down the middle of their back, and one or two stripes along their upper sides. Emerald shiners are light olive on top with a dusky stripe along their back, a silver stripe with emerald reflections along their side, and a large mouth.

Shiners generally inhabit shallow areas with limited current and rarely are found in riffles, but common shiners can tolerate some turbidity (Becker, 1983). Frequently these fish are found over similar substrates (sand, mud, gravel), but common and golden shiners are more dependent on vegetation than emerald shiners (Becker, 1983). Water temperatures can strongly influence the distribution of these fish; the preferred temperature is 25 °C (77 °F), but common and golden shiners have been shown to tolerate temperatures up to 34 °C (93 °F)

(Becker, 1983). These open-water fish rarely go below the thermocline (11 to 15 meters [36 to 49 feet]). Interestingly, golden shiners have a remarkable ability to survive under low dissolved oxygen conditions. In Michigan lakes when oxygen levels were between 0 and 0.2 mg/kg, golden shiners have survived where other fish have not (Becker, 1983).

Due to the number of species present in Wisconsin, spawning occurs between May and August (Becker, 1983). Shiners are typically stream-spawning fish (USFWS, 1983a), and prefer to spawn over gravel shoals and bottoms or other silt-free, firm substrates where water currents are prevalent and sufficient to supply much-needed dissolved oxygen to the eggs. However, the golden shiner is an exception to this rule, since this species spawns over beds of submerged vegetation and have even been noted to fail to spawn within pools in which aquatic vegetation was absent (Becker, 1983). Most species of shiners will spawn in the nests of other fish. The most important factor affecting spawning is water temperature, with different species' spawning instinct reacting to different water temperature regimes (Becker, 1983). The number of eggs that develop within the female is largely related to age and body weight and dependent upon the species of concern.

Most species of shiners are omnivorous, feeding equally on plant and animal matter (USFWS, 1983a). They are known to feed at the bottom of streams or lakes, in the water column, and near the surface. Males typically grow faster and larger than females, and they range in lengths from about 8.9 to 20.3 cm (3.5 to 8 inches), depending on the age, sex, and species of shiner observed (USFWS, 1983a; Becker, 1983).

Due to their relatively small size, shiners are preyed upon by many game fish, including bass, crappies, walleye, northern pike, and muskellunge. Birds such as pied-billed grebes, mergansers, bitterns, green herons, night herons, kingfishers, and bald eagles also prey on shiners (Becker, 1983).

Gizzard Shad. Gizzard shad (*Dorosoma cepedianum*) is an abundant omnivore in many central and southern United States lakes (Shepherd and Mills, 1996), and are found throughout the Lower Fox River and the southern half of Green Bay. Gizzard shad, along with alewife, are members of the herring family Clupeidae. Adults are generally 28 cm (11 inches) in length. Gizzard shad have a distinctive whip-like dorsal ray. They are silver-blue colored above, silver-white on the sides, and they have six to eight dark stripes on their top and upper sides.

Gizzard shad thrive in warm, fertile, shallow water bodies with soft, muddy bottoms and high turbidity (USFWS, 1985), which essentially describes lower

Green Bay. If few predators abound, gizzard shad populations can quickly explode and become a nuisance. Additionally, gizzard shad are often abundant in large sluggish rivers, lakes, swamps, and bayous (USFWS, 1985), and they often travel in schools close to the surface. Spawning typically occurs between late April/early May through August (Becker, 1983) in shallow rivers and streams, and spawning may extend over a period of 2 weeks for any given female. Females may produce upwards of 380,000 eggs (Becker, 1983) although some researchers have found mean egg production to be about 13,000 eggs per individual (USFWS, 1985). However, after age 2, egg production generally declines, sometimes rapidly.

Gizzard shad typically live less than 6 years, reaching lengths of 28 to 41 cm (11 to 16 inches) and weighing around 0.91 kg (2 pounds). However, specimens ranging up to 52.1 cm (20.5 inches) and weighing 1.6 kg (3.5 pounds) (Becker, 1983) and other specimens age 10 or 11 have been recorded (USFWS, 1985).

Gizzard shad feed in both the limnetic zone and along bottom sediment, with diet being controlled largely by the local environment. Shad captured in open water have been observed to feed on free-floating plankton, whereas shad captured in streams were found to feed on littoral vegetation and small aquatic insect larvae (USFWS, 1985). In lakes, young fish feed almost exclusively on zooplankton while larger fish feed on zooplankton, phytoplankton, insect larvae, and detritus (USFWS, 1985).

An essentially open-water species, living at or near the water surface (Becker, 1983; USFWS, 1985), gizzard shad are preyed on by numerous species. Young-of-the-year (YOY) shad are important to sport fish and waterfowl because of their rapid growth rates, making them a "short and efficient link in the food chain that directly connects basic plant life with sport fish" (Becker, 1983). They are also an important food source for numerous waterfowl and wading birds (Becker, 1983).

Rainbow Smelt. Rainbow smelt (*Osmerus mordax*) are widespread and abundant non-indigenous pelagic planktivores in the Great Lakes (Jones *et al.*, 1995). Smelt are an important prey species for Green Bay, but are not found above the De Pere dam in the Upper Fox River. These fish average 15 to 20 cm (5.9 to 7.9 inches) in length, but despite their small size, they have comparatively large mouths. Rainbow smelt are olive colored on top, and silver with blue or pink iridescence on their sides. They also have a silver stripe on their sides.

Spawning occurs on sandy beaches near river mouths in the Great Lakes between late March and early May when the water temperatures reach 4 °C (39 °F), and lasts approximately 2 weeks. Specifically, in Lake Michigan, spawning in Green Bay may be a week or two behind spawning in northern Lake Michigan because Green Bay remains covered with ice longer (Becker, 1983). Female smelt typically release no more than 50 eggs during each spawning session and, once released, the eggs sink immediately to the bottom of the stream, where they become attached to the substrate (Becker, 1983). Development of the eggs takes about 20 to 30 days. Once hatched, smelt fry are transparent and about 5.5 to 6 millimeters (mm) (0.22 to 0.24 inches) long (Becker, 1983).

While YOY fish are pelagic, as they age they move towards a bottom existence. The fish often school offshore, prefer cool clear water, and are most abundant in water depths of 18 to 26 meters (59 to 85 feet), although they can be found in water depths of 14 to 64 meters (46 to 210 feet) (Becker, 1983). Optimum temperatures range from 6.1 to 13.3 ˚C (43 to 56 ˚F) and feeding is at a peak at 10 ˚C (50 ˚F). Rainbow smelt reach sexual maturity in approximately 2 years (approximately 170 mm [6.7 inches]) and can live up to 8 years (Becker, 1983). Males live approximately 5 years, reaching a length of about 21.8 cm (8.6 inches), while females typically live about 7 years and reach a length around 310 cm (12.2 inches) (Becker, 1983).

Full-grown smelt subsist principally on larger crustaceans (like opossum shrimp). However, in the inshore waters they may consume large numbers of fishes, including YOY alewife, YOY smelt, and sticklebacks, while other researchers have found them to feed on smelt, shiners, yellow perch, burbot, and rock bass, as well as mayfly larvae and chironomid (Becker, 1983). Smelt have supplanted chubs as the principal food of Lake Superior's trout population and their importance in the food chain in Lake Michigan may be similar. Brook trout, brown trout, lake trout, whitefish, herring, walleye, yellow perch, northern pike, and burbot all prey on smelt.

Rainbow smelt are an exotic species in the Great Lakes, belonging to the family Osmeridae, which is essentially a marine family (Becker, 1983). Smelt were likely introduced into the Great Lakes as forage fish for salmon and trout. The first recorded smelt catch was off the coast of Michigan in 1923 (Becker, 1983). Originally, these fish were regarded as a nuisance species, with hordes of them invading and becoming entangled in nets (UWSGI, 2000). However, in the 1930s, smelt runs up the small streams and tributaries of Lake Michigan developed into an avid sport using dip-nets or seining. The cities of Oconto and Marinette, Wisconsin attracted 20,000 to 30,000 people to festivities scheduled to coincide with these runs (UWSGI, 2000; Becker, 1983). Smelt are only found within the Lake Michigan and Lake Superior basins.

Smelt have suffered occasional die-offs that have significantly reduced the populations. According to local Green Bay fisherman, smelt runs typically last only 1 night, when previously these runs might have lasted anywhere from 1 week to 10 days (Stiller, 1998).

The decline in the commercial smelt catch and the shorter smelt runs in the Green Bay tributaries may be due to a number of factors, including the following:

- Increased predation of smelt by burbot, trout, and salmon (Belonger, 2000), or

- Spawning occurring within the shallow waters and nearshore habitat of Green Bay rather than in the tributaries (Belonger, 2000).

Alewife. Alewife (*Alosa pseudoharengus*) are non-indigenous small anadromous pelagic planktivores that prefer open water and sandy habitats. Alewife, along with shad, sardines, and menhaden, are members of the herring family Clupeidae, which are predominantly marine species. Individuals of these landlocked populations are generally half the size (averaging approximately 16 cm [6 inches] in length) of the marine alewife (approximately 36 cm [14 inches] in length) (Scott and Crossman, 1973). Alewife are blue-green colored on top and silver on the sides, with thin dark stripes on their top and upper sides.

Alewife are abundant in Lake Michigan and Green Bay, and Becker (1983) indicated that alewife constituted 70 to 90 percent of the fish biomass in Lake Michigan. Alewife inhabit all levels of the lake and bay over all bottom types. However, they avoid cold water when possible, and during winter they migrate to the deepest and warmest water of the lake/bay (Becker, 1983). Alewife swim in dense schools and are the major prey of trout, salmon, and other fish in the lake (UWSGI, 2000). In 1974, it was estimated that coho salmon consumed approximately 36 to 45 million kg (80 to 100 million pounds) of alewife, which was about 5 percent of the total alewife biomass (Becker, 1983). Also, more than 8.16 million kg (18 million pounds) have been caught and processed primarily as poultry feed since 1966 (Becker, 1983).

Alewife populations in Lake Michigan have varied widely. In the 1920s in Lake Michigan, sea lampreys were introduced and greatly reduced the number of large predatory fish. Therefore, when the alewife were introduced in the 1940s, they had few predators and populations had an opportunity to increase. In the 1960s and early 1970s, alewife were the dominant forage fish accounting for 70 to 90 percent of fish by weight in Lake Michigan. Lamprey populations peaked in the 1950s, but in the late 1950s lamprey population control methods were found.

Since then, lamprey populations have been markedly reduced. In the early 1980s, alewife populations in Lake Michigan began to decline dramatically (Mason and Brandt, 1996). This decline, and the continued lower levels of alewife, are believed to be related to predation by trout and salmon which are primary predators (Flath and Diana, 1985), and walleye and perch which also prey on alewife. Additionally, alewife die-offs are believed to occur because of rapid temperature changes and wide fluctuations in temperature (Hewett and Stewart, 1989). Severely cold winters and the spring and summer return of alewife to shallow warmer waters can initiate die-offs (Scott and Crossman, 1973). This species is likely more temperature-sensitive than other species because it is naturally adapted to marine conditions where temperature variations are not as dramatic.

Alewife travel in dense schools, move towards nearshore waters in the spring (mid-March and April), and spawn during the early summer. Spawning occurs from June to August. In Lake Michigan, peak spawning occurs in the first 2 weeks of July (Becker, 1983). Preferred temperatures for spawning have been estimated at 13 to 16 ˚C (55 to 61 ˚F) in Lake Ontario, although they can also vary widely from 5 to 22 ˚C (41 to 72 ˚F).

Spawning typically occurs in water less than 3.05 meters (10 feet) deep with no preference concerning bottom type (Becker, 1983). Females produce from 11,000 to 22,000 eggs. In Lake Michigan, schools of 5,000 to 6,000 spawning fish have been observed densely packed in areas of 4.5 to 6 meters (15 to 20 feet) in diameter (Becker, 1983). Alewife typically live less than 8 years, generally reaching lengths of 15.2 to 20.3 cm (6 to 8 inches) and weighing 113 to 227 grams (4 to 8 ounces) (UWSGI, 2000; Becker, 1983). Alewife fry are both phototropic and pelagic, feeding on zooplankton. However, as they grow, the water depth in which the fish feed largely controls the diet. Zooplankton predominate for fish which feed nearshore, while amphipods are consumed in water depths over 9 meters (29.5 feet) deep (Becker, 1983). Additionally, gastropods have been found in alewife captured in the littoral zone, indicating the alewife feed on the bottom to some extent. Researchers have found that alewife consume *Daphnia* preferentially in the southern portion of Green Bay (Becker, 1983). Brandt and Magnuson (1980) found that the distribution of juvenile and adult alewife differs with temperature. YOY alewife reach maximum abundance when daytime water temperatures exceed 17 ˚C (62.5 ˚F) while adult alewife prefer water temperatures of 11 to 14 ˚C (52 to 57 ˚F).

The alewife is an exotic species, first noted in Lake Erie in 1931; by 1953 these fish had made their way throughout the Great Lakes system and were observed in Lake Superior. Although the presence of the alewife has had some positive aspects, there are significant negative consequences associated with this exotic species. Alewife have reduced the number of perch, herring, chubs, and minnows through direct competition with the young of those species for plankton and other small aquatic organisms which comprise the diet of these fish (UWSGI, 2000). Alewife also prey on the young of the species (Becker, 1983). Additionally, annual die-offs litter the beaches, resulting in aesthetically displeasing odors. Alewife have also been known to clog the intake pipes of power plants and municipal water filtration plants (Becker, 1983).

Yellow Perch. Yellow perch (*Perca flavescens*) are native to the Lower Fox River and Green Bay, and are one of the most important fish of Wisconsin and Michigan in terms of both the commercial and sports fishing industries. Along with the walleye, the yellow perch is a member of the perch family Percidae. Yellow perch average 15 to 25 cm (6 to 10 inches) in length. They are green colored on top, whitish on the underside, and they have distinct green-brown vertical bands extending down their yellow sides.

The preferred habitat of yellow perch is found along shoreline areas and in clear lakes with depths of less than 10 meters (33 feet), temperatures of 18 to 21 ˚C (64 to 70 ˚F), sand, gravel, or muddy sediments, and modest to moderate amounts of aquatic vegetation (Becker, 1983; Scott and Crossman, 1973, USFWS, 1983b). A study examining the frequency of litoral fishes in a Wisconsin lake determined that yellow perch (YOY and adults) were highly associated with complex macrophyte beds (Weaver *et al.*, 1997). Of the sites examined, the only locations where yellow perch were not caught were two sites having the lowest abundance of vegetation. Turbidity adversely affects growth of juveniles and temperatures of 32 ˚C (90 ˚F) can be lethal, but yellow perch are tolerant of low oxygen levels. In Lake Michigan, oxygen levels of 0.1 to 0.3 ppm killed numerous yellow perch, but many survived (Becker, 1983). Bluegill, largemouth bass, and walleye are fish species that cannot survive low oxygen concentrations.

Perch are a schooling species that feed during the day and rest on the bottom at night. Schools of yellow perch may range from 50 to 200 fish and usually are associated with feeding activities conducted during daylight hours.

Yellow perch normally spawn shortly after ice-out in April or early May, when water temperatures range between 7.2 and 11.1 ˚C (45 and 52 ˚F), and may continue for 8 to 19 days (Becker, 1983). During spawning, the eggs are usually deposited in sheltered areas and are frequently draped over emergent and submergent vegetation or submerged brush in water depths of 0.6 to 3 meters (2 to 10 feet). Rocks, sand or gravel may be used if submergent vegetation is not available (USFWS, 1983b). The fish may travel long distances prior to spawning. Lake Winnebago perch may swim from 48 to 81 km (30 to 50 miles) up the Fox River before they reach suitable spawning habitat (Becker, 1983). Egg production in the female yellow perch is extremely variable with the individual based on the size of the fish; researchers have observed anywhere from less than 1,000 to 210,000 eggs in select fish in Minnesota and Wisconsin (Becker, 1983), with greater fecundity in larger individuals. Eggs are released in strands up to 2.15 meters (7 feet) in length and up to 10 cm (4 inches) in width (Becker, 1983).

Similar to walleye, yellow perch provide no protection for the eggs or fry (Becker, 1983), which hatch anywhere from 8 to 27 days following spawning. The speed with which hatching occurs depends on water temperature (Becker, 1983). Shorter hatching periods are typically associated with warm water while 27-day hatching periods have been observed in 8.5 to 12 ˚C (47 to 53 ˚F) water (Becker, 1983). Larvae are approximately 0.5 cm (0.2 inch) upon hatching and swim to the surface, where they remain in the upper 0.9 to 1.2 meters (3 to 4 feet) of water for the first 3 to 4 weeks. Microscopic zooplankton are important to the survival of perch fry. If the zooplankton are too large, the young fry perish (Becker, 1983). Young-of-the-year perch continue to consume zooplankton and other aquatic insects until they are quite large. Perch do not typically begin to feed on other fish until they have reached a length of about 18 cm (7 inches) or more, sometime between age 3 and 4 years (Becker, 1983). Mature yellow perch generally range in length from 15 to 25 cm (6 to 10 inches) and weigh 170 to 454 grams (6 to 16 ounces) (UWSGI, 2000). Males reach maturity in about 1 year while females mature in 2 years in Green Bay (Belonger, 2000). In Wisconsin waters, yellow perch generally live about 7 to 10 years (USFWS, 1983b). Brandt and Magnuson (1980), found that the distribution of juvenile and adult perch differs with temperature. Juvenile perch catches are highest in waters 15 to 20 ˚C (59 to 68 ˚F) while catches of adult perch are greatest in waters which are 7 to 8 ˚C (44.5 to 46.5 ˚F).

Young yellow perch are preyed upon by all fish-eating species, including muskie, northern pike, burbot, smallmouth and largemouth bass, bowfins, bullheads, and lampreys (Becker, 1983). However, walleye and yellow perch have a special relationship. Each species preys on the other at different times in the life cycle: large walleye feed on yellow perch, while yellow perch feed on walleye fry. Additionally, perch eggs are eaten by aquatic birds and other animals and the fish are eaten by gulls, terns, mergansers, herons, grebes, ospreys, and kingfishers (Becker, 1983).

Populations of yellow perch in Lake Michigan have widely fluctuated. As previously discussed, yellow perch year-class strength may be inversely related to abundance of alewife (Brandt *et al.*, 1987; Mason and Brandt, 1996). Between 1889 and 1970, average catch rates were 1.1 million kg (2.4 million pounds) per year from Green Bay, but because of the dramatic decline in perch since 1990 (a loss of 80 percent of the population), beginning in January 1997, Wisconsin banned commercial fishing in Lake Michigan and reduced daily recreational limits to five individuals per day. Additional factors that possibly adversely affect the yellow perch populations include the following:

- Increase in white perch populations, which feed on the YOY perch and also compete with adult perch for food; and

- Introduction of zebra mussels into the benthic community, which aggressively compete for the zooplankton species which yellow perch fry and YOY also consume (Belonger, 2000).

Carp. Carp (*Cyprinus carpio*) is an abundant bottom-dwelling species found in southern Green Bay. Along with shiners, carp belong to the minnow and carp family Cyprinidae. Adult carp have been found to range in length from 41 to 58 cm (16 to 23 inches) and weigh from 1 to 10 kg (2 to 22 pounds) (Weber and Otis, 1984). Carp have two distinct barbles on each side of the upper jaw. These fish are gray/gray-green colored on top, have a dark edge on the upper side, and are white to yellow on the underside.

Carp are tolerant of turbidity, low dissolved oxygen, pollution, and rapid temperature changes better than most other fish in North America (Becker, 1983). Part of their ability to tolerate low oxygen is because they can use atmospheric oxygen. Although they are tolerant of a wide range of conditions, they prefer shallow lakes and streams that have abundant aquatic vegetation (Becker, 1983). Carp prefer warm temperatures of close to 32 ˚C (90 ˚F), but this is within the range of temperatures that have been found to be lethal (31 and 34 ˚C [88 to 93 ˚F]), and above a temperature at which carp spawning could occur (Becker, 1983).

Carp have the ability to range widely; some tagged fish have traveled 1,090 km (677 miles), and a carp tagged in Lake Winnebago was recaptured 148 km (92 miles) away (Becker, 1983). Most tagging studies of carp have found that they are generally recaptured within a few kilometers (Becker, 1983). Generally, carp are wary and bolt for vegetation and cover or deeper water with little provocation. The exception to this behavior is during spring, when spawning occurs (Becker, 1983).

Spawning occurs from April to August in Wisconsin and peaks in late May to early June when temperatures range from 18 to 28 ˚C (64 to 82 ˚F) (Becker, 1983; Scott and Crossman, 1973). An investigation of spawning carp in Lake Winnebago and nearby lakes determined that preferred spawning areas were shallow vegetated waters (0.15 to 1.2 meters [0.5 to 3.9 feet] deep) (Weber and Otis, 1984). These preferences have also been supported by other authors (Becker, 1983; Scott and Crossman, 1973). A single female carp may release 50,000 to 620,000 eggs during the primary spawning period (Becker, 1983). Carp eggs float through the water and, due to an adhesive coating surrounding the egg, attach themselves to underwater vegetation, debris, or any other object to which the egg will adhere (USFWS, 1982). Spawning over areas with dense vegetation will increase the success of reproduction, but some studies have indicated that carp will not spawn in water cooler than 16 ˚C (60 ˚F).

Incubation lasts for 3 to 16 days depending on the temperature (Becker, 1983). Four to five days after hatching, young move off vegetation and go to the bottom (Becker, 1983). Through their first summer, carp fry are strongly associated with vegetation as protective cover in 15 to 30 cm (6 to 12 inches) of water (Weber and Otis, 1984). Young carp leave this shallow weedy habitat when they are 76 to 102 mm (3 to 4 inches) and generally too large for predators to consume (Becker, 1983). After the first season of growth, carp are generally 13 to 19 cm (7 to 7.5 inches) long (Scott and Crossman, 1973). Although young carp are food for both birds and other fish, when they reach 1.4 to 1.8 kg (3 to 4 pounds), they are too large to be a prey item. Carp are generally mature at age 2 (males) or 3 (females) and usually live for 9 to 15 years (Becker, 1983).

Carp are omnivorous, feeding equally on plant and animal matter (USFWS, 1982). The fry initially feed on zooplankton, but will also feed on phytoplankton if necessary. As young fish grow, they feed on littoral and later bottom fauna, taking in worms and the larvae of insects as well as vegetation, such as seeds, algae, and detritus (USFWS, 1982). Adult carp are opportunistic feeders, which are able to utilize any available food source (USFWS, 1982; Becker, 1983). Male carp generally mature between 2 and 4 years while female carp take about 3 to 5 years to mature. Typically, carp grow to be about 38 to 56 cm (15 to 22 inches) in length and weigh up to 3.2 kg (7 pounds) (UWSGI, 2000). However, the maximum weight reported for carp in north America is 42.1 kg (93 pounds) (USFWS, 1982).

Carp have been harvested commercially from the Great Lakes since the first recorded catch in 1893 until contaminants closed the fisheries, which occurred in the early 1980s in Green Bay. Carp, especially young carp, are preyed upon by many game fish, including bass, crappies, northern pike, bowfin, turtles, snakes, loons, grebes, and mergansers, and carp eggs are preyed upon by minnows, catfish, and sunfish (Becker, 1983).

Walleye. Walleye (*Stizostedion vitreum*) is a popular, year-round game and commercial fish found in Lake Michigan, generally in areas less than 7 meters (23 feet) deep (Magnuson and Smith, 1987). The walleye is the largest member of the perch family (Percidae—a group that includes sauger, darters, and yellow perch) in North America. It is not a member of the pike family as commonly believed. These fish range in length from 33 to 64 cm (12 to 24 inches) and weigh from 0.45 to 2.3 kg (1 to 5 pounds). Walleye have huge mouths that extend past the eye and strong canine teeth (Becker, 1983). Walleye are yellow-olive/brown colored on top and brassy yellow-blue along the sides. They have 5 to 12 dusky saddles that become less visible as they age (Becker, 1983).

Walleye are found throughout the Fox and Wolf River basins and their connecting lakes, as well as Green Bay (Becker, 1983). Walleye are tolerant of a range of environmental conditions, particularly turbidity and low light, but they are not tolerant of low oxygen levels. Winter kills, because of low oxygen, have occurred in Wisconsin (Becker, 1983). Walleye prefer quiet waters over sand, gravel, and mud substrates (Becker, 1983). They generally rest in deep dark waters during the day and migrate to rocky shoals and weed beds to feed at night, but they may be active during the day if it is cloudy or the waters are turbid (Becker, 1983). Young-of-the-year fish can be found near the sediments in 6 to 10 meters (20 to 33 feet) of water (Scott and Crossman, 1973), but can be caught in surface waters up to lengths of approximately 35 mm (1.3 inches) (WDNR, 1970). Larger fish are generally found in depths of 14 meters (46 feet) or less and form loose schools (Scott and Crossman, 1973). Schooling is common during feeding and spawning.

Between mid-April and early May, walleye migrate to wind-swept, rocky shorelines, flooded wetlands or inlet streams with gravel bottoms to spawn. Preferred spawning habitats are shallow shoreline areas, shoals, riffles, and dam faces with rocky substrate and good water circulation from wave action and currents (USFWS, 1984). The fish may travel long distances during the migration. Lake Winnebago walleye, for instance, may swim 161 km (100 miles) up the Wolf River before they reach suitable spawning habitat (Becker, 1983). The female walleye will lay an average of 50,000 eggs and generally spawns out completely in 1 night. Summer territories and spawning grounds are distinct areas, and walleye may have a homing instinct for spawning grounds. The range of summer area is generally limited to 3 to 8 km (2 to 5 miles), but the recorded range has varied from 0.8 to 110 km (0.5 to 68 miles). A study of walleye in Lake

Poygan found that walleye traveled an average distance 47 km (29 miles) (Becker, 1983).

Walleye spawn soon after ice melts and temperatures reach 3 to 7 ˚C (37 to 44 ˚F) and spawning peaks when temperatures are 6 to 10 ˚C (43 to 50 ˚F) (Becker, 1983). In Lake Winnebago, the timing of spawning has been recorded as a 2- to 3-week period between the first week in April and the first week in May (WDNR, 1970). Walleye from Green Bay move upstream into the Fox River to spawn; however, their movement is restricted by the De Pere dam (Magnuson and Smith, 1987). Walleye do not build nests and after releasing eggs, they offer no parental care. Spawning occurs at night generally on gravel bottoms, but they can spawn on vegetation. In Lake Winnebago, flooded marsh areas are preferred spawning grounds (Becker, 1983). Continuous flowing water over the eggs is important for hatching success. The time for eggs to hatch is dependent on the water temperature: at 14 ˚C (57 ˚F), eggs hatch in about 7 days and when water temperatures are 4 ˚C (39 ˚F), eggs hatch in about 26 days (Becker, 1983). Adult walleye provide no protection for the eggs (USFWS, 1984).

Fry move off wetlands a day or two after hatching and obtain an open-water existence. They stay in open water until they are about 30 mm (1.2 inches) and then return to shore around June (Becker, 1983). By the end of July, walleye in Lake Winnebago are about 75 mm (3 inches) or larger. At this size, walleye shift their diet from zooplankton only to include fish and invertebrates, and by fall they are generally 130 mm (5 inches) (Becker, 1983). Female walleye grow faster and become larger than males. Mature walleye generally range in length from 33 to 64 cm (13 to 25 inches) and from 0.5 to 2.3 kg (1 to 5 pounds) (UWSGI, 2000). Males reach maturity in 2 or 3 years, when they are 30 to 34 cm (12 to 13.5 inches) long while females mature in 4 to 5 years at lengths of 38 to 43 cm (15 to 17 inches). In Wisconsin waters, walleye generally live about 7 to 10 years (UWSGI, 2000), but walleye can live more than 20 years (Lychwick, 2000) in Green Bay. However, growth of the walleye is dependent upon the food supply, temperature, and population density (USFWS, 1984).

Brown Trout. Brown trout (*Salmo trutta*) is a popular, seasonally-caught game fish in Green Bay. These fish range in length from 41 to 61 cm (16 to 24 inches) and weigh from 0.9 to 3.6 kg (2 to 8 pounds). Brown trout are light brown to brown-black in color with red and black spots, but on the lower sides and stomach, they are silvery. Brown trout have large jaws.

As compared to other species of trout, brown trout grow faster, live longer, and better tolerate degraded habitats, warm temperatures (up to 29 ˚C [84 ˚F]), and turbidity (Becker, 1983). They are fairly common in cold waters of Wisconsin and self-sustaining populations in Lake Michigan are enhanced with stocking. In Green Bay, this species is generally limited to the northern two-thirds of the bay, which contains deeper and colder waters. Preferred temperatures are 10 to 18 °C (50 to 64 °F) (Becker, 1983).

Brown trout are most often found along the shore in waters no deeper than 15 meters (49 feet) (Becker, 1983) and they have been known to inhabit waters along the west shore of Green Bay from the towns of Oconto and Marinette (Magnuson and Smith, 1987). Wild brown trout fingerlings that were tagged have been found to travel an average of 16 km (10 miles) in 1 year. Hatchery-reared trout released in Wisconsin waters generally remained within 24 km (15 miles) of the release point, but some tagged fish after 1 year were found to range up to 323 km (201 miles) (Becker, 1983).

Spawning occurs when waters are close to 8 °C (46 °F), in autumn and early winter (October to December). Spawning areas are shallow waters with gravel bottom substrate, generally stream headwaters rather than rocky shores, but spawning does occur in lakes along rocky reefs. Females build nests and males defend them. Unlike salmon, these fish do not die after they spawn and most individuals spawn more than once. During spawning, these fish may school, but when not spawning, crowding is not tolerated (Becker, 1983). Generally, brown trout are sexually mature at 2 years old and live for approximately 7 years.

Brown trout tend to be nocturnal feeders, and food items can include aquatic and terrestrial insects, crustaceans, molluscs, frogs, shrimp, salamanders, and other fish. Zooplankton are an important food source for small brown trout (Becker, 1983). Up to about 229 mm (9 inches), they are insect feeders and past this length they dominantly consume (70 percent of the diet) fish such as young trout, sculpins, minnows, darters, and lampreys (Becker, 1983). Magnuson and Smith (1987) found that brown trout collected in the spring from Green Bay Zone 3 dominantly consumed alewife (73 percent of the diet); rainbow smelt were the other 27 percent of the identified forage fish consumed. Half of the brown trout collected in the fall in this region of the bay had empty stomachs and, therefore, prey consumption was not evaluated (Magnuson and Smith, 1987). Presumably, this was about the same time as their spawning. It is suspected that over the summer, brown trout, like walleye, increase their consumption of rainbow smelt (Magnuson and Smith, 1987).

2.5.8 Birds

The terrestrial and aquatic habitats of the Lower Fox River and Green Bay provide food, protective cover, nesting areas, and resting locations for both regional and migratory birds and waterfowl. Birds associated with the river and bay are divided into seven groups, and include the following:

- Passerines,
- Gulls and terns,
- Diving birds,
- Shorebirds,
- Wading birds,
- Waterfowl, and
- Raptors.

A listing of the common or important birds within each group, along with its status as a threatened or endangered species, is included in Table 2-12. A brief description of each group of birds is presented below. Figure 2-21 shows the general distribution of the birds within these groups throughout Green Bay (NOAA, 1999). As with the fish data in Zone 4, bird data obtained from the Great Lakes Commission (2000) did not differentiate specific species. Therefore, locations where birds of concern either nest or have been observed are simply shown as points.

Passerine Birds

A large number of passerine birds exist within the Lower Fox River and shorelines of Green Bay. Common passerine species include blackbirds, wrens, sparrows, and swallows (Table 2-12). These birds typically feed on insects, seeds, and small invertebrates found through foraging along the ground. A large number of blackbirds, wrens, sparrows, and swallows feed on the insects or insect larvae which are found in and above the surface water of the Lower Fox River and Green Bay. Additionally, typical habitat for these birds include wetlands, open meadows, and grasslands (Exponent, 1998; Harrison and Greensmith, 1993). The blackbirds tend to nest in loose colonies while sparrows and wrens typically nest individually (Harrison and Greensmith, 1993). These birds are migrant to partially migrant, dependent on local winter weather conditions and the supply of food (Harrison and Greensmith, 1993). None of the passerines are listed on state or federal endangered/threatened species lists (Table 2-12).

The red-winged blackbird (*Agelaius phoeniceus*) is the most common bird within this group found in Wisconsin. The annual probability of sighting this bird is well over 95 percent and they typically are found in Wisconsin from late February through late November (Temple *et al.*, 1997). The likelihood of sighting the five other birds in this group ranges from approximately 35 to 55 percent, and these species are usually sighted between April and October (Temple *et al.*, 1997).

Tree swallows (*Tachycineta bicolor*) are also common migratory songbirds that breed in and migrate through the Lower Fox River and Green Bay. Tree swallows nest in semi-colonial groups in natural cavities (trees, posts, streambanks) near water. Tree swallows feed exclusively on insects, predominately aquatic insects. Tree swallow population data is not available from the Lower Fox River and Green Bay because studies of these birds in this region have used artificial nest boxes rather than relying on naturally-nesting populations (Ankley *et al.*, 1993; Custer *et al.*, 1998).

Both the red-winged blackbird and the tree swallow are protected under the Migratory Bird Treaty Act.

Gulls/Terns

The gulls/terns group for the Green Bay area includes two species of gulls and four species of terns (Table 2-12). All six of these species feed on fish, insects, and eggs, and as well as scavenging for other food over open water or in wetland areas (Exponent, 1998; Harrison and Greensmith, 1993). These birds tend to nest in large colonies (Harrison and Greensmith, 1993). The black (*Chilidonias niger*) and Forster's (*Sterna forsteri*) terns prefer to nest in marsh areas while the other four species prefer to nest on the ground, often on remote islands or in areas protected from predators (Exponent, 1998). The annual probability of sighting the tern species in Wisconsin ranges from approximately 25 to 45 percent, while the likelihood of sighting the two gulls is about 65 percent (Temple *et al.*, 1997). The two gulls remain in the area throughout the year, while the terns are migratory and are typically present in Green Bay from April through October (Temple *et al.*, 1997).

Forster's tern, common tern (*Sterna hirundo)*, and the Caspian tern (*Sterna caspia*) are migratory species of colonial waterbirds that breed in the Great Lakes and generally winter in more southern coastal areas. Wisconsin listed the Caspian, common, and Forster's terns as endangered species, while the state of Michigan lists the Caspian and common terns as threatened species (Table 2-12). All three of these terns are protected under the Migratory Bird Treaty Act. Due to their endangered status within Wisconsin, the locations of tern nesting areas in the Lower Fox River and Green Bay area are presented as blocks on the maps, similar to sturgeon, on Figures 2-12 and 2-21.

Based on the protected status of these three terns, a number of studies have been conducted to evaluate the remaining Green Bay populations, as well as the effects of PCB uptake through the consumption of bay fish. These birds typically nest on islands, where they are generally safe from predators. Primary nesting areas for the Forster's tern are Bay Port and Kidney Island, Long Tail Point, and

Oconto Marsh. The primary nesting areas for the common terns are on Kidney Island, while the Caspian tern nesting colonies are located on Gravelly and Gull islands, located just south of Summer Island, between Green Bay and Lake Michigan (Stratus Consulting, 1999c).

Tern populations have generally been increasing over the past 20 years. From 1978 and 1987 the nesting pairs of Forster's tern observed in the state of Wisconsin increased from 136 pairs to 435 pairs, while the population of common terns increased from 60 pairs to 600 pairs between 1979 and 1986. Similarly, the number of Caspian tern nests located on Gravelly and Gull islands increased from about 600 to over 1,000 between 1977–78 and 1991. This increase is reflective of the overall Great Lakes Caspian tern population, which has grown by at least 90 percent since the 1970s (Stratus Consulting, 1999c). These results suggest that the tern populations are recovering within the bay area and should continue to expand to a level which the region can support (Stratus Consulting, 1999c).

Both common and Forster's tern were listed in 1979 as endangered in the state of Wisconsin. To enhance population success, Forster's tern platforms have been placed at several locations in the state, including Green Bay. The six monitored island platforms in Green Bay indicated feeding, but not nesting activity. The use of nesting platforms was discontinued because of challenges associated with their placement and maintenance. For the common tern, fencing and ring-billed gull control have been used to enhance breeding success.

Around the Green Bay area, nesting Forster's terns have been reported since the late 1930s, although they were likely nesting without record prior to this period. The Forster's tern preferred habitat is around wetlands and terns feed mainly on small fish (alewife, emerald shiner, and rainbow smelt) and on some aquatic invertebrates. The uncertain population status for the Forster's tern is further supported by the variability present in historical data (Figure 2-22). Forster's tern population levels are generally believed to have declined over the past 100 years in Wisconsin due in part to marsh draining and other habitat disturbance, plume hunting, and potential chemical contamination (Mossman, 1988). For example, nesting at the Duck Creek Delta was abandoned in 1973, likely because of high water and loss of emergent vegetation; nesting pairs moved to the Bay Port Industrial Tract (Mossman, 1988). In 1987, Kidney Island was the only known nesting location in Green Bay.

Population data reported in June 1997 for the previous year indicates that for both species, population status is uncertain and requires additional study (Matteson, 1998). For the common tern, of the six colony sites recorded in the state, two are in Green Bay within the study area for this report: Kidney Island and Pensaukee Dredge Spoil Island, with an estimated number of breeding pairs of 16 and 75, respectively, for each location. For the Forster's tern, of the nine colony sites recorded in the state, two are within the study area for this report: Long Tail Point and South Oconto Marsh, with an estimated number of breeding pairs of 70 and 45, respectively, for each location.

As with the Forster's tern, both inland and coastal populations of common terns have faced recent historical population declines during the period of the 1950s to the 1980s. It is believed that these declines were due to nesting site competition with ring-billed gulls, decreased adequate habitat, high water levels, human disturbance, predation, and organochlorine contamination (Matteson, 1988). For the Great Lakes region, some of the highest population levels were measured in the 1980s. In southern Green Bay, there were 135 recorded nesting pairs in 1976, 427 in 1985, 577 in 1986, and 280 in 1987. In 1997, one common tern nesting pair was recorded at Kidney Island and 74 nesting pairs were recorded at Pensaukee (Cuthbert, 1998).

Diving Birds

Diving birds include the horned and pied-billed grebes, double-crested cormorants, common loon, and belted kingfisher. All of these birds feed on fish, diving beneath the water to capture their prey; the two grebes also feed on aquatic insects (Exponent, 1998; Harrison and Greensmith, 1993). All of the birds tend to nest along the shore or in wetlands, with the two grebes preferring shallow-water nests, while the cormorant may also nest slightly off the ground (Exponent, 1998; Harrison and Greensmith, 1993). Both the loon and kingfisher are listed as migrant birds, while the other three species are listed as partial migrants (Harrison and Greensmith, 1993).

The annual probability of sighting most of the birds ranges from 50 to over 80 percent in Wisconsin, and the best times are between March and November (Temple *et al.*, 1997). The exception is the horned grebe, which only migrates through the area to locations further north; therefore, the likelihood of sighting this bird is less than 30 percent, and chances are best between March and May and again between September and December (Temple *et al.*, 1997). None of the diving birds are listed on state or federal endangered/threatened species lists.

Double-crested Cormorants. Double-crested cormorants (*Phalacrocorax auritus*) are a migratory species of colonial waterbird that breed in the Great Lakes and generally winter in coastal areas, including Alaska. These birds nest in large communities in a variety of habitats including cliffs, grassy slopes, low bushes, or dead trees. Cormorants consume approximately 20 percent of their body weight each day and on average weigh 1.7 kg (3.7 pounds). The primary food consumed is small fish such as rainbow smelt and alewife and, as available, perch.

Numerous studies have been conducted to evaluate double-crested cormorant populations and the effects of PCBs. Prior to the 1960s, it is estimated that at least several hundred nesting pairs of cormorants were located throughout the state. During the 1960s and 1970s, the population of double-crested cormorants declined significantly and the bird was placed on the Wisconsin Endangered and Threatened Species List in 1972. At this time, only 66 nesting pairs of cormorants were present statewide, and even fewer along the Lower Fox River and into Green Bay. Beginning in 1973, state, academic, and federal agencies (WDNR, USFWS, National Parks Service, University of Wisconsin, Wisconsin Society of Ornithology) combined efforts to catalog the colony location, size, and reproductive success of the double-crested cormorant throughout Wisconsin. Following aggressive measures to protect the bird, cormorant populations recovered dramatically through the late 1970s and 1980s, and in 1986 the cormorant was removed from the Wisconsin Endangered and Threatened Species List. In 1997, 81 percent of the state breeding population, which now numbers more than 10,000 birds, nests in the vicinity of Green Bay (Matteson *et al.*, 1998; Weseloh *et al.*, 1994) which may be due in part to a decrease in commercial fishing and a resulting increase abundance of prey fish. Cormorant nesting locations along Green Bay are shown on Figure 2-21.

Prior to 1979, inland breeding populations exceeded the number of nesting birds on the Great Lakes. Since 1990, however, the Great Lakes population of double-crested cormorants has exceeded the inland population levels by approximately five times (Matteson, 1998). The nesting population in the Green Bay and Lake Michigan region, as of 1997, accounted for 81 percent of the total breeding population. The largest colonies were found in the following four locations: Spider Island, Cat Island, Hat Island, and Jack Island (Stratus Consulting, 1999c) as indicated on Figure 2-23. Of these islands, Cat Island is located closest to the mouth of the Fox River and contains the second highest density of double-crested cormorants.

Shorebirds

The shorebirds group for the Green Bay area includes eight species of plovers, sandpipers, and snipe (Table 2-12). As indicated by the name, birds within this group feed and nest along the shore, typically foraging for small crustaceans, insects, worms, and other invertebrates (Harrison and Greensmith, 1993). These birds nest along the ground, sometimes on rocky or sandy shores and others within marsh or wetland areas.

The common snipe and spotted sandpiper are the most sighted birds within this group in Wisconsin. These birds are generally present from April/May through September/October and have an annual sighting probability of about 50 percent (Temple *et al.*, 1997). The likelihood of sighting the other birds within this group ranges from approximately 15 to 25 percent as these species generally migrate further north. Therefore, these birds generally are present around May, and then may be sighted between late June and October (Temple *et al.*, 1997). The piping plover is very uncommon in the region and it is listed as an endangered species by both states as well as federally (Table 2-12).

Wading Birds

The wading birds group for the Green Bay area includes 13 species of heron, woodcock, rail, egret, bittern, and crane (Table 2-12). As indicated by the name, birds within this group typically feed in shallow, nearshore waters and emergent wetland areas. They typically forage for small fish and crustaceans, amphibians, insects, worms, and other invertebrates (Harrison and Greensmith, 1993).

Within this group, the bitterns, rails, and woodcock are generally small birds, ranging in height from 18 to 51 cm (7 to 20 inches). These birds, along with the sandhill crane, generally nest on the ground. The herons, egrets, and cranes are much larger birds, ranging from 61 to 122 cm (24 to 48 inches). The herons and egrets generally prefer to nest in trees, but will nest in marshes and lowlands if suitable habitat is not available (Harrison, 1979). Rookeries for both the great blue and black-crowned night herons are located in the 1,000 Islands Nature Conservancy as well as in Green Bay (Nikolai, 1998). Herons, woodcock, and cranes are common in Wisconsin and the UP from mid-spring through mid-fall (Temple *et al.*, 1997), as these are all migratory birds. However, the likelihood of sighting a bittern is less than 30 percent while both egrets and rails are very uncommon in the area (Temple *et al.*, 1997). The king rail, least bittern, snowy egret, and yellow rail are all included on one of the state or federal threatened or endangered species lists (Table 2-12). However, yellow rail habitat is maintained in the Seney National Wildlife Refuge, located north of Lake Michigan in the central portion of the UP, where these birds have been consistent summer residents since the 1800s (De Vore, 1999).

Waterfowl

The waterfowl of the Green Bay area includes 21 different species (Table 2-12). These birds typically feed in the water on plants, insects, aquatic organisms, shellfish, crustaceans, and occasionally on small fish (Exponent, 1998; Harrison and Greensmith, 1993). Waterfowl tend to nest in or very near water, generally preferring swamps and marshes to open-water habitat (Exponent, 1998). Some of these birds may nest in loose colonies while others nest individually.

Waterfowl are typically migratory birds; however, the location of their summer and winter destinations plays a significant role of when particular species are present in the Green Bay area. Mallard and black ducks as well as Canada geese are present in the area year-round and the annual probability of sighting for these species ranges from 50 up to about 95 percent (Temple *et al.*, 1997). Coot, teal, ruddy, and wood ducks are all present in the bay from early spring through late fall and are somewhat common, with sighting probabilities ranging from 50 to 75 percent (Temple *et al.*, 1997). A number of species migrate further north into Canada during the summer; some winter in the Green Bay region, while others migrate further south, spending only a short time in the area. The species that winter in the area include mergansers, goldeneye, the greater scaup, and bufflehead. These species are fairly common in the area, with sighting probabilities of 30 to 60 percent (Temple *et al.*, 1997). Species which pass through the region, typically found anywhere between March and May and again in October/November, include the canvasback, redhead, and ring-necked ducks, as well as the lesser scaup, northern shoveler, and whistling swan. These species area also fairly common, with sighting probabilities ranging from 35 to 55 percent (Temple *et al.*, 1997). Being migratory in nature, waterfowl are generally protected under the Migratory Bird Act. However, many of the ducks and geese included in this group are game species, with an established hunting period that occurs during October in Wisconsin and Michigan.

Since at least 1975, WDNR has completed a mid-winter waterfowl survey to evaluate the numbers of migratory waterfowl wintering along the Lower Fox River. The results from these surveys indicate that, overall, the number of migratory waterfowl in the region have increased from between 1,000 to 2,000 individuals in the 1970s to well over 4,000 individuals recently. These populations are controlled by many factors, including the severity of the winter weather and access to an adequate supply of food. However, increases in bird populations, especially among the primarily piscivorus birds, like the goldeneye and the mergansers, suggests that the populations are recovering to some degree (Nikolai, 1998).

Raptors

The raptors included in this group are the bald eagle, osprey, peregrine falcon, and merlin. The bald eagle and the osprey tend to be piscivorus, feeding on suckers, northern pike, muskellunge, bullheads, as well as small mammals, waterfowl, other birds, and carrion (Exponent, 1998; Harrison and Greensmith, 1993). Eagles and ospreys prefer open-water areas, but, when necessary, eagles will hunt in open meadow and light woodlands (Harrison and Greensmith, 1993). The two falcon species typically hunt other birds or small mammals, preferring open land, and are not generally found in heavily-forested areas (MDNR, 2000).

Typically, these birds nest in high places such as the tops of trees or rock ledges (Exponent, 1998; Harrison and Greensmith, 1993). The eagle and osprey are the most common species in Wisconsin, with an annual probability of sighting these two birds around 55 and 45 percent, respectively (Temple *et al.*, 1997). Known active and inactive bald eagle and osprey nesting locations in Green Bay are presented on Figure 2-24. The likelihood of sighting the two falcons is less than 25 percent, as both are uncommon in the area. The eagle will winter within the Green Bay/Lake Michigan area, simply moving as necessary in order to find open water for hunting (MDNR, 2000). However, the osprey and the falcons are migratory birds and generally return to the region from March through October (Temple *et al.*, 1997). The peregrine falcon is listed as an endangered species in both states and federally (Table 2-12). The bald eagle, osprey, and merlin are listed threatened species in Michigan and federally, while in Wisconsin only the osprey is listed as a threatened species (Table 2-12). These birds are also protected under the Migratory Bird Treaty Act.

Bald Eagles. Of the raptors within the Lower Fox River and Green Bay, bald eagles are of special concern because of their federally-protected status, and their known sensitivity to chlorinated hydrocarbons. Eagle populations around the Great Lakes were virtually eliminated in the 1960s—an occurrence believed to be mostly the result of chlorinated hydrocarbon toxicity (Bowerman, 1993). This correlation is supported by the fact that as DDE and PCBs were banned from use in the United States in the mid-1970s, evidence of bald eagle nesting success increased, although there was a lag time of approximately 10 years before bald eagle nesting success noticeably increased.

Bald eagles (*Haliaeetus leucocephalus*) are one of the largest raptors in North America. Their preferred habitat is one in which there is a large water-to-land edge area and where there are large areas of unimpeded view (Palmer, 1988). Eagles are not generally found in areas of high human use (EPA, 1993a). Within the Great Lakes area, some eagles are present on a year-round basis, while others are transient and winter in more southern locations (Palmer, 1988). The Green Bay region contains on of the largest number of nesting eagles in the United States, excluding Alaska (Palmer, 1988).

The return and recovery of bald eagles has been well documented in both Wisconsin and Michigan (Bowerman, 1993; Dykstra and Meyer, 1996), and includes surveys along the Lower Fox River and Green Bay. These studies have been summarized by the USFWS in the Avian Injury report (Stratus Consulting, 1999c). The following section summarizes the information taken principally from those reports.

Bald eagle populations have generally been increasing throughout the Great Lakes (Stratus Consulting, 1999c). However, despite population increases, the eagles nesting on the shores of Lake Michigan still exhibit reproductive rates lower than those of neighboring birds in inland Wisconsin and Michigan (Colborn, 1991; Bowerman, 1993). The overall productivity of Green Bay/Lake Michigan eagles was reported at more than 60 percent below the normal rate of inland Wisconsin eagles (Dykstra and Meyer, 1996).

The return of the bald eagle to Green Bay began in 1974, when a single pair of nesting eagles was observed. Both the WDNR and the MDNR initiated annual surveys, and between 1974 and 1986 only one to two pairs of nesting eagles were observed in Green Bay and the eastern side of the Door Peninsula. Beginning in 1987, nesting pairs increased and by 1997 there were 14 nesting pairs (Figure 2-25) (Stratus Consulting, 1999c). Bald eagles returned much later to the Lower Fox River. The number of breeding pairs of eagles nesting along the Lower Fox River went from one in 1986 to three in 1994 to two since 1995 (Stratus Consulting, 1999c).

Bald eagles arrive back at their nesting territories in the assessment area in February, and the young fledge between early June and July. Depending upon ice conditions, bald eagles may remain in the assessment area during the winter; up to 12 have been recorded in December on the Lower Fox River (Howe *et al.*, 1993). Thus, breeding bald eagles spend a substantial part of the year in the assessment area.

Figures 2-9, 2-10, and 2-24 show the nesting locations within the Lower Fox River and Green Bay. There are two active nests within the Lower Fox River: one within the Little Lake Butte des Morts Reach (Figure 2-9), and one at Kaukauna in the Appleton to Little Rapids Reach (Figure 2-10). Within the bay (Figure 2-24), there is one nest active in Green Bay Zone 2, two nests in Zone 3A, and nine nests were active in Green Bay Zone 4. There are no reported nests in Zone 3B along the Green Bay side of the Door Peninsula, but there is a single active nest at the northernmost tip on the Lake Michigan side.

Overall, nesting success for Wisconsin bald eagles remains high. The most recent census for Wisconsin was conducted by WDNR in 1997, and showed that of the 632 active nests throughout Wisconsin, a total of 739 young were produced. However, productivity within Green Bay bald eagle nests remained significantly reduced, relative to nests in inland Wisconsin and Michigan (Figure 2-26) (Dykstra and Meyer, 1996). Mean annual production rates for the inland nests has been at, or exceeded one young per nesting annually; a rate necessary to maintain a healthy, self-reproducing population (Kubiak and Best, 1991). In contrast, Green Bay nests have oscillated considerably between no to few young in the late 1970s to 1994, to only recently achieving at, or above one per nest (Stratus Consulting, 1999c). By contrast, the nests within the Lower Fox River produced greater than one young per active nest, with the nest at Kaukauna producing two to three per nest since 1988, and the Mud Creek nest (near Little Lake Butte des Morts) between one and three per nest since 1994 (Table 2-13).

Mammals

Important small mammals that utilize the aquatic resources of the Lower Fox River/Green Bay basin include beaver, mink, muskrat, raccoon, and river otter. Beaver is found in several of the feeder streams to the river and bay, and may be an incidental user, but is not considered to be resident. Both muskrat and otter are found in Green Bay. Muskrat are principally habitat-limited to backwater sloughs or marshes. Raccoons are ubiquitous throughout the basin. Otter returned to the Lower Fox River area sometime in the mid-1980s and mink slides and scat are observed during mid-winter surveys; however, populations of both animals are low (Nikolai, 1998).

There is only anecdotal information concerning mink populations along the Lower Fox River (Patnode, 1998). WDNR trapping records show mink upstream of Little Lake Butte des Morts, but there are no records downstream of the lake (WDNR, unpublished data). This information may indicate that the mink population is restricted by lack of appropriate habitat or due to high contaminant levels in this part of the river. A review of studies in which PCB uptake in mink were studied will be included in the BLRA.

A study to evaluate possible impacts to bat populations may also be undertaken by WDNR (Rezabeck, 1998). Like tree swallows and other birds mentioned in the previous section, bats also feed on insects found in and above the waters of the Lower Fox River and Lake Winnebago. A bat colony located in the bluffs of the Niagara escarpment east of the Lower Fox River may be studied as part of such an effort. In addition, there is a likely bat colony in the Red Bank Glades Scientific Area just north of the mouth of the Fox River (Nikolai, 2000).

2.5.9 Mink

A summary of suitable and preferred mink habitat is presented below. In addition, information regarding the domestic production of mink in Wisconsin is also presented because it was mink ranchers and associated researchers who first found that PCBs had a detrimental influence on mink reproduction and mortality. Therefore, a brief summary of the mink farming operations in Wisconsin is included.

Mink Habitat

Mink are semi-aquatic, predatory mammals associated with lakes, streams, rivers, and marshes. Mink are generally nocturnal creatures that feed on fish, crayfish, waterfowl, muskrat, rabbits, and rodents. The availability of prey greatly influences the density and distribution of mink populations in a given area. Mink are active throughout the year, feeding on whatever prey is available (USFWS, 1986). Their dens are generally located near the water's edge and studies suggest mink typically remain within 200 meters (660 feet) of open water. In Michigan, studies indicated that mink are most commonly associated with brushy or wooded areas adjacent to aquatic habitats. Preferable foraging and den areas in wetland environments include dense vegetation and irregular shorelines, while the preferred lacustrine habitat include small oligotrophic lakes with stony shores. Streams or rivers surrounded by either marsh vegetation or abundant downfall/debris provide cover and pools for foraging. Studies in Quebec, Canada show that mink activity decreases as stream flow increases. Additionally, the channelization of rivers in Mississippi and Alabama caused a decline in mink populations as it was accompanied by a decrease in shoreline configuration diversity, loss of aquatic vegetation, and reductions in prey availability and habitat quality (USFWS, 1986).

Channelization of the Lower Fox River has contributed to a general decline of mink habitat in the region. The habitat suitability, as determined by Exponent (1998), was based on shoreline characteristics included in WDNR wetland maps and WISCLAND GIS maps of the project area and are shown for the Lower Fox River on Figures 2-27 through 2-32. The suitability definitions are as follows:

- **Good:** forest shrub/scrub, forest wetland, broadleaf deciduous, or lowland wetland areas;
- **Moderate:** emergent wetland, meadow, or wetland less than 0.8 hectares (2 acres);
- **Marginal:** grassland or agricultural areas;
- **Poor:** golf course, low-intensity urban (obtained from land use maps only); and
- **Unsuitable:** aquatic beds/flats, open water, barren, or high-intensity urban.

As previously discussed, much of the shoreline has been developed between Neenah and Kaukauna and between De Pere and Green Bay. Most of the shoreline in the Little Lake Butte des Morts Reach and between Appleton and Kaukauna is characterized by Exponent as either “poor” or “unsuitable” on Figures 2-27 and 2-28, respectively. This reflects the development of these areas. However, in the less developed areas of the Appleton to Little Rapids and Little Rapids to De Pere reaches, large tracts of the shoreline are characterized as “marginal” to “good” habitat (Figures 2-28 and 2-29, respectively). Mink habitat suitability in the De Pere to Green Bay Reach is largely characterized as “unsuitable” (Figure 2-30), which is similar to the Little Lake Butte des Morts Reach.

Mink habitat suitability for Green Bay zones 2 and 3 is presented on Figures 2-31 and 2-32, respectively. In Zone 3, mink habitat suitability characterization efforts in Green Bay extended only just beyond Marinette on the west side and Sturgeon Bay on the east side. The shoreline in Green Bay zones 2A and 3A, on the west side, are generally characterized as “marginal” to “good” (Figures 2-31 and 2-32, respectively). The habitat in Zone 2B is generally characterized as “poor” to “unsuitable,” although “moderate” to “good” habitat is present with increasing distance from the mouth of the Lower Fox River (Figure 2-31). The habitat suitability in Zone 3B is generally characterized as “moderate” to “good” except in areas where development has occurred, such as the cities of Dyckesville and Sturgeon Bay (Figure 2-32).

Domestic Mink Production in Wisconsin

Due to demand, mink have been raised domestically to provide a reliable source of pelts. Wisconsin has long been a leader in the production of domesticated mink. According to NASS (2000) data, the 82 mink farms in Wisconsin produced the most mink pelts (almost 732,000) in the United States during 1999. Additionally, the NASS (2000) data for Michigan indicate that 13 farms produced 51,000 pelts in 1999.

In the late 1950s and early 1960s, mink ranchers in Wisconsin and other areas bordering the Great Lakes faced a crisis as production rapidly decreased due to the mortality of mink kits and infertility of female mink (Gilbertson, 1988). In the 1960s and 1970s, researchers concluded that PCBs in Great Lakes fish (specifically coho salmon from Lakes Michigan and Erie) adversely affected domestic mink production, causing reproductive failure in the females and mortality in both kits and adults. Female mink that were fed fish containing PCBs often failed to mate, and when they did, the mortality rate of the kits often approached 100 percent (Gilbertson, 1988). PCBs accumulate in the brain, liver, and kidneys of the mink and concentrations of about 5 to 11 ppm were present in these organs following death. Further, a wild mink found in a marsh located along Green Bay had a similar kidney PCB concentration as those observed during laboratory studies (Gilbertson, 1988). These results suggest that PCBs affect both wild and domesticated mink populations.

Wild Mink in the Study Area

Wild mink population estimates for Wisconsin and Michigan are not available. Approximately 22,600 mink were trapped in the state of Wisconsin in 1998 through 1999 (WDNR, 1999b). However, these records do not indicate how many were collected in the counties along the Lower Fox River or Green Bay.

WDNR has approximately 40 laboratory reports (unpublished data) from analysis of mink tissue and organ samples from specimens trapped in 1992 and 1994. The results indicate that PCBs, as well as mercury and other metals, are present in these wild mink tissues/organs. The majority of the mink were trapped within Marinette County, but others were taken in Brown, Oconto, and Winnebago counties as well. Typically, these reports include only general trapping location information. Because these mink were collected more than 6 years ago, assessing the current health and stability of wild mink populations in the area is not practical from these analytical results.

2.5.10 Otter

WDNR harvest records for 1998 through 1999 suggest that otter are present in the counties along the Lower Fox River and west side of Green Bay, but not in counties along the east side of the bay. This may either be due to habitat requirements or it may reflect the influence of chemical contamination. Because the WDNR records do not indicate where selected fur-bearing species are trapped (other than a specific county) it is difficult to assess which factor (habitat or chemical contamination) is more restrictive. WDNR (1999b) records show that a combined 26 otters were collected in Outagamie and Winnebago counties while 56 otters were collected in Marinette and Oconto counties separately in 1998 through 1999. However, only one otter was taken in Brown County (WDNR, 1999b). According to Gilbertson (1988), no otters were trapped in Door and Kewaunee counties in 1984 and the 1998 through 1999 harvest records suggest that this trend continues (WDNR, 1999b).

Endangered and Threatened Species

A number of different animals have been or are currently on the Wisconsin, Michigan, or Federal Endangered and Threatened Species lists. Listed animals which have historically been found in the vicinity of the Lower Fox River or Green Bay include: osprey, common tern, Forster's tern, Caspian tern, and great egret (Matteson *et al.*, 1998). The osprey, common tern, and Forster's tern have nested along the Lower Fox River as well as at upstream locations in Lake Winnebago, Little Lake Butte des Morts, and Lake Poygan. Osprey have been sighted near

Kaukauna and have attempted to nest in the vicinity of Combined locks, while terns have been observed farther upstream. Additionally, Caspian tern and great egret have nested on some of the islands located in Green Bay. Very few nesting pairs have been observed over the past few years and recovery of these populations is slow (Matteson *et al.*, 1998).

In addition to these birds, the WDNR reported a bed of clams or mussels which may be threatened. The sediment bed which these clams/mussels inhabit is approximately 6 meters (20 feet) wide and 30.5 meters (100 feet) long and is located near the mouth of Mud Creek in the Lower Fox River (Szymanski, 1998, 2000).

As mentioned above, populations of both eagles and the double-crested cormorants have recovered to the point where both birds have been removed from the Wisconsin endangered species list. Other populations, specifically, wild mink and otter, have been found to be declining around the Lower Fox River and Green Bay, yet they are not currently listed by state or federal agencies. The endangered and threatened fish and birds of the region were listed on Tables 2-11 and 2-12. The endangered and threatened mammals of the region are listed in Table 2-14.

2.6 Time Trends of Contaminants in Sediment and Fish

A time trends analysis was conducted on sediments and fish tissue within the Lower Fox River and Zone 2 of Green Bay in order to assess whether statistically significant changes in PCB concentrations were occurring. For the purposes of the BLRA, it was important to understand if apparent or implied decreases in PCB concentrations in sediments and fish tissue were real, and if so, determine if the rate of change could be estimated. A brief description of the methods and results is given below. The detailed analysis may be found as Appendix G of the Remedial Investigation (RETEC, 2002a).

2.6.1 Sediment Methods

For sediments, the overall approach was to first review the data for usability, then explore relevant groupings of the data both horizontally and vertically to conduct regression-type analyses for increases or decreases in PCB concentrations over time. All data used in these analyses were from the Fox River database.

Exploratory analysis demonstrated that PCB concentrations varied across locations in the river. To adequately conduct the analysis of time trends, it was necessary to undertake a separate evaluation of the spatial layout; a horizontal evaluation within the river bed and a vertical evaluation with each depth stratum.

The deposit designations used in the RI/FS (e.g., A, POG, EE, or SMU 26, shown on Figures 2-2 through 2-5) were found to be unsuited to defining spatially-cohesive subsets, as many samples had no deposit designation and some deposit designations spanned stretches of a river reach too long to allow adequate assessment and control of spatial structure. Based upon analysis of the spatial layout, 23 distinct geographic "deposit groups" were determined, forming data subsets with spatial structures far more amenable to statistical analysis. These were given designations that reflected the general deposit designations in the RI/FS, with the added benefit that these groups designated non-overlapping spatial sets. The statistical groups analyzed are shown on Figures 2-33 through 2-35.

Depth strata within each deposit group were consistent with the RI/FS: 0 to 10 cm (0 to 4 inches), 10 to 30 cm (0.33 to 1 foot), 30 to 50 cm (1 to 1.6 feet), 50 to 100 cm (1.6 to 3.3 feet), and 100+ cm (3.3+ feet). Sample groups defined by a specific deposit and depth stratum were analyzed separately for the time trends. Depth strata within some deposits were excluded due to either inadequate sample size or lack of time variation. After averaging samples from a common sediment core within a particular stratum, 1,618 observations in 46 combinations of deposit and depth were included in the sediment time trends analysis. PCBs were analyzed as the logarithm of PCB concentration (in μg/kg) due to the approximately lognormal distribution of these values.

Spatial correlation among observations was determined using semivariograms, a common technique in geostatistics. In order to avoid overstating statistical significance of time trends in the presence of spatially-correlated observations, the Window Subsampling Empirical Variance (WSEV) (Heagerty and Lumley, 2000) estimation method was used. WSEV is analogous to averaging observations within cells of a grid, where the grid size is specified such that sample subsets falling into different cells of the grid are approximately independent of each other. The WSEV method yields a proper estimate of variance that can be used to calculate statistical significance.

The WSEV method for handling spatial dependence was used in conjunction with a standard method for estimating time trends; regression analysis. Regression models for log PCB concentration versus time, depth, and linear and quadratic spatial coordinates were fitted using the method of maximum likelihood, which readily incorporates the observations below detection limit without imputation of a value such as half the detection limit. Throughout the analysis, significance levels of $p < 0.05$ from regression analysis or from any other analysis were designated as "statistically significant."

2.6.2 Fish Methods

Like sediments, the approach for examining time trends in fish tissue PCB concentrations was to first review the data, then explore relevant groupings of the data on which to conduct regression-type analyses. In addition to the four reaches of the Lower Fox River, fish time trends were examined in Green Bay Zone 2. This was undertaken to determine whether PCB exposure in Zone 1 and Zone 2 were identical (i.e., represent a single exposure unit), or if there were distinct trends in these two zones for the target fish species. Fish tissue data from those two zones were explored first to ascertain whether they represented a single or separate exposure units (i.e., have different time trends for PCBs). This was conducted to determine whether the data should be combined for a single analysis, or to conduct separate time trends analyses for the two zones.

All data used in these analyses were from the Fox River Database. A total of 1,677 fish samples were available for analysis, divided into three main sample types: fillet without skin, fillet with skin, and whole body. Inadequate sample size presented the greatest obstacle to analysis. There were several cases where there were substantial data, but there was inadequate spread in the years between collections. It should be noted that within the Little Rapids to De Pere Reach, there with no fish groups with both sufficient sample size and time spread. There were over a hundred combinations of reach, species, and sample type with at least one observation, but only 19 of these had sufficient numbers of samples and a sufficient time spread for analysis of time trends. Carp and walleye provided the largest number of observations of any species. These 19 combinations represent 867 samples—over half of all samples of whole body, fillet with skin, and fillet without skin. In addition to the 19 combinations, there were four analyses which could statistically combine samples from the fillet and whole body categories (within a single reach and single species) to come up with a single time trend estimate.

Data on PCBs in fish were analyzed as the logarithm of PCB concentration in micrograms per kilogram. The percent lipid content of samples was significantly associated with PCB concentration in most species and sample types, and was thus used as a normalization term in all analyses.[3]

Regression models for PCB concentrations versus time were fitted using the logarithm of percent lipid content and time as independent variables. A linear spline function was included in some time trends analyses to accommodate

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[3] Note that fish concentrations of PCBs were not normalized by dividing by lipid content of samples. Thus, the concentrations are expressed as log micrograms of PCBs per kilogram of tissue rather than per kilogram of lipid.

different rates of change in PCB concentrations during earlier versus later periods. The maximum likelihood method was used to accommodate observations below detection limit. A test for changing trends was also carried out.

The difference in fish PCB concentrations between Green Bay Zone 1 (De Pere to Green Bay Reach) and Green Bay Zone 2 was analyzed using both cross-sectional data (five analyses) and time trends data (three analyses), again controlling for percent lipid content of samples in regression models. All regression models for the fish analysis were fitted using the maximum likelihood method to accommodate the small fraction of observations below the detection limit.

2.6.3 Results

Results of the sediment time trends are presented in Table 2-15, and are represented graphically on Figures 2-33 through 2-35. Seventy percent of all calculated slopes (32 out of 46) were negative. However, only 13 out of the 46 slopes were statistically significant, such that a hypothesis of no change in PCB concentration over time could be rejected. Of those, 10 were negative,[4] and within that subset eight were in the 0- to 10-cm (0- to 4-inch) segment.

Conducting a meta-analysis on the surface sediment data showed a negative trend in all reaches except Appleton to Little Rapids (Table 2-16). A meta-analysis of time trends in surface sediments yielded an average rate of decrease in PCB concentration per year of -18 percent in Little Lake Butte des Morts, +0.6 percent in the Appleton Reach, -10 percent in the Little Rapids Reach, and -15 percent in the De Pere Reach. These trends were statistically significant except for the Appleton Reach.

While those data suggest an overall decline in PCBs in the Lower Fox River, a more careful analysis of the subsurface data suggest that these declines are restricted to the upper 0 to 10 cm (4 inches). While 32 out of the 46 analyses were negative, there is a strong trend toward fewer and weaker negative slopes at increasing depth. Table 2-15 and Figure 2-33 show in general that the subsurface deposits do not show a significant decline in PCB concentrations. For Little Lake Butte des Morts, the figures suggest that there is a generally increasing trend in subsurface PCBs, and an indeterminate mixture of trends that is not distinguishable from zero in the Appleton and De Pere reaches. For Little Rapids to De Pere, there are consistently negative trends in the 10- to 30-cm (0.33- to 1-foot) strata, but in the lower strata, the data are consistent with either zero trend

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[4] A negative slope indicates decreasing PCB concentrations; a positive slope indicates increasing PCB concentrations over time.

(30 to 50 cm [1 to 1.6 feet]), or an increasing trend (50 to 100 cm [1.6 to 3.3 feet]).

These results suggest that over time, the surface sediment concentrations of PCBs have been steadily decreasing. However, numerically this was difficult to define, and depended upon the specific deposits or sediment management units. PCB concentrations in sediment suggest declines, but a large fraction of analyses provided little useful trend information. A large fraction of sediment analyses yielded imprecise or inconclusive trends such that positive, negative, or zero trends are consistent with the data.

Like sediment PCB concentrations, fish tissue PCB concentrations showed a significant but slow rate of change throughout the lower Fox River and lower Green Bay (Table 2-17). Initial exploration of the data demonstrated that there were statistically significant declines in tissue PCB concentrations in all species in all reaches. More detailed analyses were then conducted to determine if there had been a constant linear rate of decline, or if significant changes in the rate of decline, or "breakpoints," could be identified. Among fish time trends analyzed, nine out of 19 combinations of reach, species, and sample type showed a statistically significant change in slope during earlier and later periods. In all of the reaches of the river, and in Zone 2, there were steep declines in fish tissue PCB concentrations from the 1970s, but with significant breakpoints in declines beginning around 1980. After the breakpoint, depending upon the fish species, the additional apparent declines were either not significantly different from zero, or were relatively low (5 to 7 percent annually). However, for two species there were increases in PCB concentrations after the breakpoint; walleye in Little lake Butte des Morts and carp in Green Bay Zone 1.

Most slopes were negative, and all statistically significant slopes were negative. Over the period of analyzed data, percentage rates of decrease were usually between -5 and -10 percent per year (compounded). Percent lipid content of tissue was significantly related to PCB concentration in 16 out of the 19 analyses. Specific trends in sediment and fish by reach are discussed below.

Little Lake Butte des Morts

Time trend results for sediments in Little Lake Butte des Morts are presented in Table 2-15 and on Figures 2-33 through 2-35. With the exception of two strata at 10 to 30 cm (0.33 to 1 foot) in two separate deposit groups, slopes are negative (9 out of 11 analyses). However, statistically significant negative slopes (decreasing PCB concentration over time) was found only in surface sediments (0 to 10 cm [0 to 4 inches]) of four deposit groups (AB, D, F, GH). The estimated rates of decrease ranged from 8 to 24 percent per year, with wide confidence intervals for these rates of change; a rate of decrease of as little as 1 to 5 percent and as much as 15 to 43 percent per year. While the slopes were negative, there were no significant trends at deposits C or POG. In fact, for POG the estimated annual slope was -18.6 percent per year, but the upper and lower confidence bound on the estimate ranged from -43.3 to +16.9 percent per year.

When pooled across all deposits, there was an estimated significant ($p < 0.001$) average annual decrease of -15 percent of surface concentrations (Table 2-16) within the period supported by the data. It is important to note that on a reach basis, the 95 percent confidence intervals around the estimated average were 22 percent, up to 8 percent annual rate of decrease.

The only statistically significant increasing trend of PCB concentrations occurs at 10 to 30 cm (0.33 to 1 foot) in Deposit Group D, where the rate of increase is 108 percent per year. The confidence interval for the significantly increasing slope at 10 to 30 cm (0.33 to 1 foot) in Deposit Group D indicates a rate as low as 59 percent and as high as 171 percent per year. The Time Trends Analysis Report noted that this must represent a temporary positive trend because a projection of the PCB concentration even at the minimum of 59 percent per year would yield an absurd 10,000-fold increase in PCB concentration after 20 years.

Caution needs to be used in the interpretation of the estimated average decrease within this reach. As noted previously, there were wide confidence intervals around all estimates for the sediment deposit groups. While the mass-weighted time trend for surface sediments indicated a significant decrease, the fact that the estimate did not include Deposit E, the largest depositional area within the reach, must be considered. There were insufficient data to conduct the analysis for Deposit E, and thus the sediment time trend is somewhat skewed by the lack of inclusion here.

For the fish examined in this reach, an early rapid decline was observed until around 1987, followed by either a slower decline or a flattening without further decline, depending upon the species (Table 2-17). Within this reach, time trends were conducted on carp and walleye (skin-on fillet and whole body), and northern pike and perch (skin-on fillet). For carp, the breakpoints identified for the skin-on fillet and whole body were 1979 and 1987, respectively. Walleye data fillet and whole body data show that the breakpoint occurs between 1987 and 1990. The fillet data suggests no change in concentration after the breakpoint, while the whole body data showed a sharp rate of increase (22 percent per year). However, the latter analysis, when tested, was not significantly different from zero. For northern pike skin-on fillets, the analysis showed no breakpoint, but a constant rate of decline of 12 percent per year. By contrast, yellow perch skin-on fillets declined sharply until 1981, and have since remained at constant levels. A meta-analysis conducted on all fish data combined yields a statistically significant, but slow rate of decline of 4.9 percent (range 2.1 to 7.5 percent decrease) per year.

Appleton to Little Rapids

For this reach, there were only sufficient data to evaluate Deposit Group IMOR, Deposit N (pre-demonstration dredging), and Deposit Group VCC. For these three groupings, surface sediments at IMOR showed an estimated annual increase of 9.9 percent, while the other two showed decreases in total PCB concentrations. While Deposit N surface sediments were found to be significant, there were non-significant increases observed in the subsurface sediments. Again, confidence limits around the estimated mean for all deposits was wide. Meta-analysis for the reach showed a non-significant increase of 0.6 percent per year.

For fish in this reach, the only tissue type with sufficient numbers and time spread of data were walleye skin-on fillet. Analysis of those data showed a relatively constant rate of decline of 10 percent (range 5.6 to 17.9 percent decrease) per year.

Little Rapids to De Pere

Time trends in sediments for this reach have a majority of negative slopes; but two of only three significant slopes were negative and occur in the 0- to 10-cm (0- to 4-inch) and 10- to 30-cm (0.33- to 1-foot) depth strata. One large, positive, statistically significant slope occurs at the 30- to 50-cm (1- to 1.6-foot) depth (Table 2-15, Figure 2-34).

The surface sediment (0 to 10 cm [0 to 4 inches]) in the Lower EE Deposit Group has a significantly negative slope ($p = 0.04$), implying a rate of decrease of 15 percent per year with a 95 percent confidence interval of 2 to 26 percent rate of decrease per year. In the same deposit group, the deeper 30- to 50-cm (1- to 1.6-foot) stratum shows a significantly positive slope, indicating a rate of increase of 23 percent per year and a 95 percent confidence interval of 4 to 46 percent per year. In Deposit Group FF, the 10- to 30-cm (0.33- to 1-foot) layer has a significantly negative slope with a rate of PCB concentration decrease of 20 percent per year with a 95 percent confidence interval of 1 to 35 percent. Again, while the estimates speak to significant decreasing or increasing PCB concentrations over time in these strata and deposit group combinations, the analysis showed wide confidence intervals. For surface sediments, the annual change ranged from an increase of 19.1 percent per year to a decrease of 33 percent per year.

Although only one surface sediment has a statistically significant decline, the mass-based meta-analysis found an overall statistically significant combination of declining PCB concentrations in the reach, with a slope of -0.046 per year ($p = 0.01$), implying a 10 percent per year rate of decrease (95 percent confidence interval: -17 to -2 percent). While some uncertainty may persist in the individual surface deposits, the PCB mass in the surface of this reach appears to be generally declining as of the mass estimation date, 1989 through 1990.

As noted previously, there were not sufficient fish tissue data for analysis of time trends.

De Pere to Green Bay (Zone 1)

The time trends analysis for surface sediments in this reach showed primarily negative slopes (Table 2-15). Statistically significant negative slopes were found in only three combinations of deposit group and depth. SMU Group 2649 showed a significantly negative slope ($p < 0.001$) in the surface deposit (0 to 10 cm [0 to 4 inches]), with a rate of decrease of 13 percent per year (95 percent confidence interval of 8 to 17 percent decrease per year). SMU Group 5067, 0 to 10 cm (0 to 4 inches), also has a significantly negative slope ($p = 0.01$) implying an annual rate of decrease of 21 percent (95 percent confidence interval of 5 to 33 percent). In the same SMU group (5067), at a greater depth of 50 to 100 cm (1.6 to 3.3 feet), a significant ($p = 0.003$) and large positive slope with a rate of increase of 133 percent per year (95 percent confidence interval of 56 to 250 percent) was observed.

It is important to note that an exceptionally high value of PCB concentration in SMU Group 5067 was excluded from the analysis. Sample A3_0-4 had a concentration of 99,000 ppb, whereas all other samples in the 0- to 10-cm (0- to 4-inch) stratum in this deposit ranged from 400 to 7,800 ppb. In a statistical sense, the sample is an "outlier," but that does not imply error in the value of 99,000.

For fish, Green Bay Zone 1 and Zone 2 PCB exposures were found to be significantly different. This difference was determined using two methods: 1) cross-sectional analyses, which compared fish PCB concentrations within a single year (e.g., 1989 data only) between the zones; and 2) estimating the significant differences between time trend slopes calculated separately for the two zones. Four out of five cross-sectional analyses showed statistically significant differences, either in the relationship of lipid content and PCB concentration or in the mean PCB concentration, while controlling for lipid content. All three time trend analyses comparing the two zones showed significantly different trends in the two reaches. Thus, the time trends in the two zones were handled separately.

For Zone 1, there appears to be a significant but slow rate of decline for most fish species tested with no breakpoint identified. The exception to this pattern were carp, which showed a breakpoint in 1995, and steep significant increases in PCB concentrations of 22 percent per year. Other fish tested within the reach included gizzard shad, northern pike, walleye (fillet and whole body), white bass, and white sucker. With the exception noted for carp, all species showed a rate of decline in PCB concentrations of between 5 and 10 percent annually. Combining all data showed that there is an average rate of decline of 7 percent per year.

Green Bay Zone 2

Zone 2 shows decreasing trends with no significant breakpoints in most species tested, including carp. Significant decreases of between 4 and 15 percent annually were found in alewife, carp, and yellow perch. The exception to this was gizzard shad, which showed a significant increasing trend of 6 percent PCBs in tissues per year.

2.6.4 Conclusion

The objective of the time trends analysis was to determine if PCB concentrations in the Lower Fox River were decreasing over time. For PCB concentrations in surface sediment, the data suggest an overall decline. PCB concentrations in surface sediments in the Lower Fox River are generally decreasing over time, but apparent detectable loss is limited to the top 10 cm (4 inches) of sediment. The apparent declines observed in surface sediments is consistent with the continued observed transport of PCBs from the river to Green Bay, as discussed in Section 2.4. The rate of change in surface sediments is both reach- and deposit-specific. The change averages an annual decrease of 15 percent, but ranges from an increase of 17 percent to a decrease of 43 percent. A large fraction of analyses provided little useful information for projecting future trends because of the lack of statistical significance and the wide confidence limits observed. This is especially true for sediments below the top 10 cm (4 inches); changes in the sediment PCB concentrations cannot be distinguished from zero, or no change.

PCB concentrations in fish are also generally decreasing over the analysis period. The changes in PCBs in the sediments are reflected in the significant but slow declines in fish tissue concentrations of between 5 and 7 percent annually. Exceptions to the general overall decline were noted with walleye in Little Lake Butte des Morts, carp in Green Bay Zone 1, and gizzard shad in Zone 2 where significant increases in PCB concentrations were observed. In all reaches, a breakpoint was observed in the fish tissue declines. The presence of an earlier slowing of rates of decrease in fish, along with a more recent phenomenon of changing trends in some species and sample types, suggests that fish time trends are changeable. Since PCBs in fish are derived from PCBs in sediment, the sediment rates of change may also be changeable.

It is important to note that the trends discussed are limited to the period of time for which data existed. These analyses are not suitable for projecting trends; the data do not provide the assurance of a future steady or rapid decline in PCB concentrations. Even though there are a number of negative time trends that suggest PCB declines, future projections of PCB concentrations in sediments and fish are highly uncertain. Over the period of data collection, surface sediments and fish species have, on the average, declined in PCB concentrations. Yet the presence of increases in PCB concentrations in deeper sediments, and of breakpoints and other non-linear phenomena in fish PCB time trends (on the log scale), suggest that the river, its sediment, and its species may be experiencing an arrest or reversal of such a decline. The analyzed data do not assure continued PCB decreases over time.

The time trends analysis dealt strictly with the testing of changes in PCB concentrations over time, and not with the mechanisms that could control changes in sediment and tissue loads. As discussed in Section 2.4, studies have shown that PCBs are being transported out of the Lower Fox River into Green Bay, while PCBs in Green Bay migrate into Lake Michigan. Therefore, PCB dispersal is one factor in the observed PCB declines. In addition, some of the variability observed in the data may be accounted for by changes in river profile, burial, scour by flood or ice, and propeller wash in the lower reaches of the river. As the analysis focused solely on the existing data, these potential mechanisms could not be adequately controlled or accounted for.

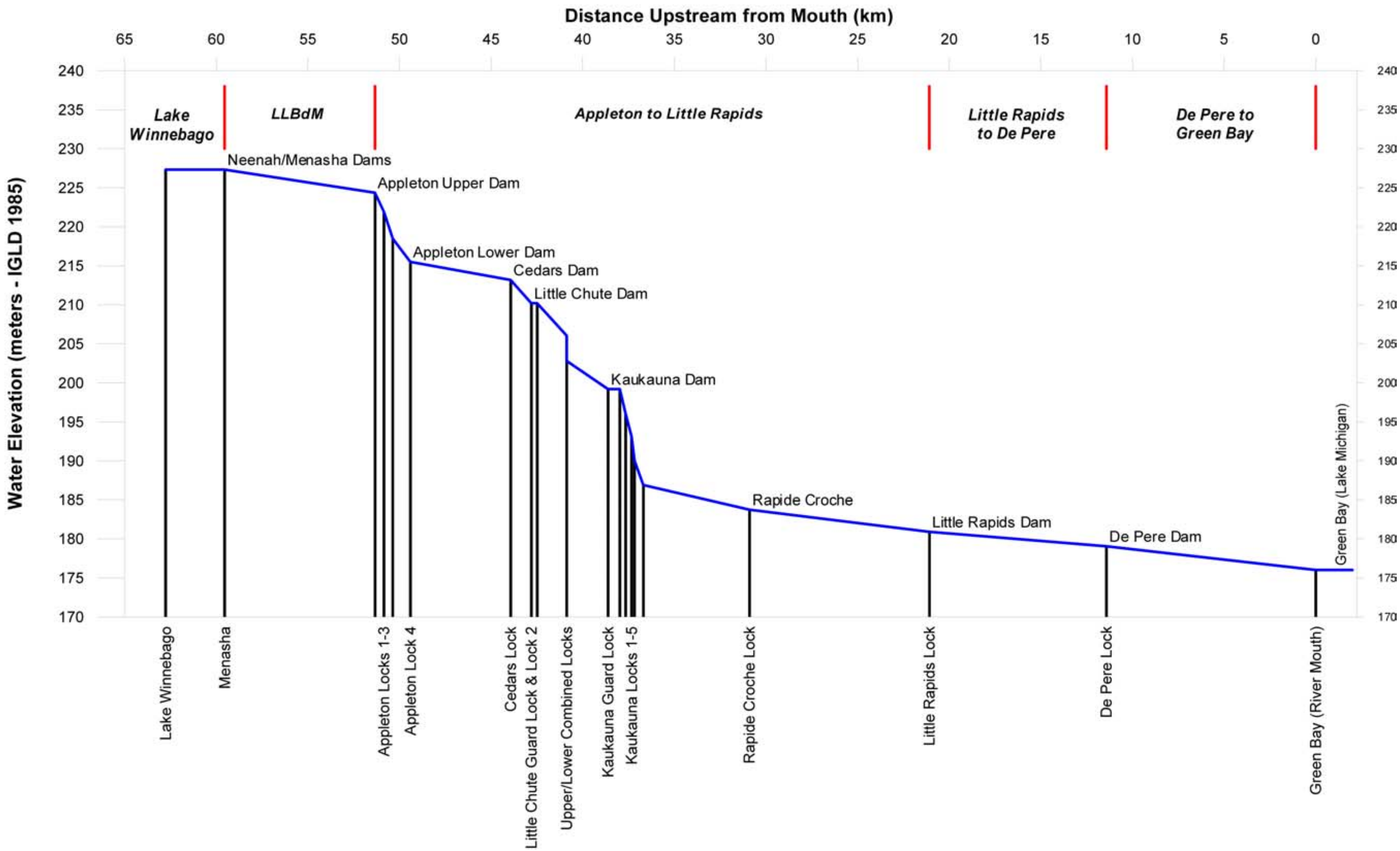
The conclusions of a general decrease in PCB burdens in sediments and fish of the Lower Fox River and in Zone 1 of Green Bay are consistent with findings by other researchers in the Great Lakes. Deceases in PCB concentrations have been observed in Lake Michigan (Offenberg and Baker, 2000; DeVault *et al.*, 1996; Lamon *et al.*, 1998), Lake Ontario (DeVault *et al.*, 1996; Gobas *et al.*, 1995) and Lake Superior (Smith, 2000). The yearly rate of decline for PCBs in biota and sediment of Lake Superior has been estimated at 5 to 10 percent per year (Smith, 2000), which is generally consistent with the trends observed in the Lower Fox River. However, several other researchers have also noted breakpoints, or constant levels of PCBs beginning in the mid- to late 1980s. Lake trout and smelt are reported to have been relatively constant in Lake Ontario since 1985 (Gobas *et al.*, 1995). PCB body burdens in Lake Erie walleye were shown to be declining between the periods of 1977 and 1982, but after that period remained constant through 1990 (DeVault *et al.*, 1996). Time tends analysis for salmonids in Lake Michigan showed generally decreasing tissue concentrations, but upper-bound forecast estimates for lake trout and chinook indicated that there would be a steady, or slightly increasing annual average PCB concentration. These findings are consistent with the time trends analysis for the Lower Fox River, and suggest that there may continue to be slow, gradual declines, or steady-state concentrations for many years to come.

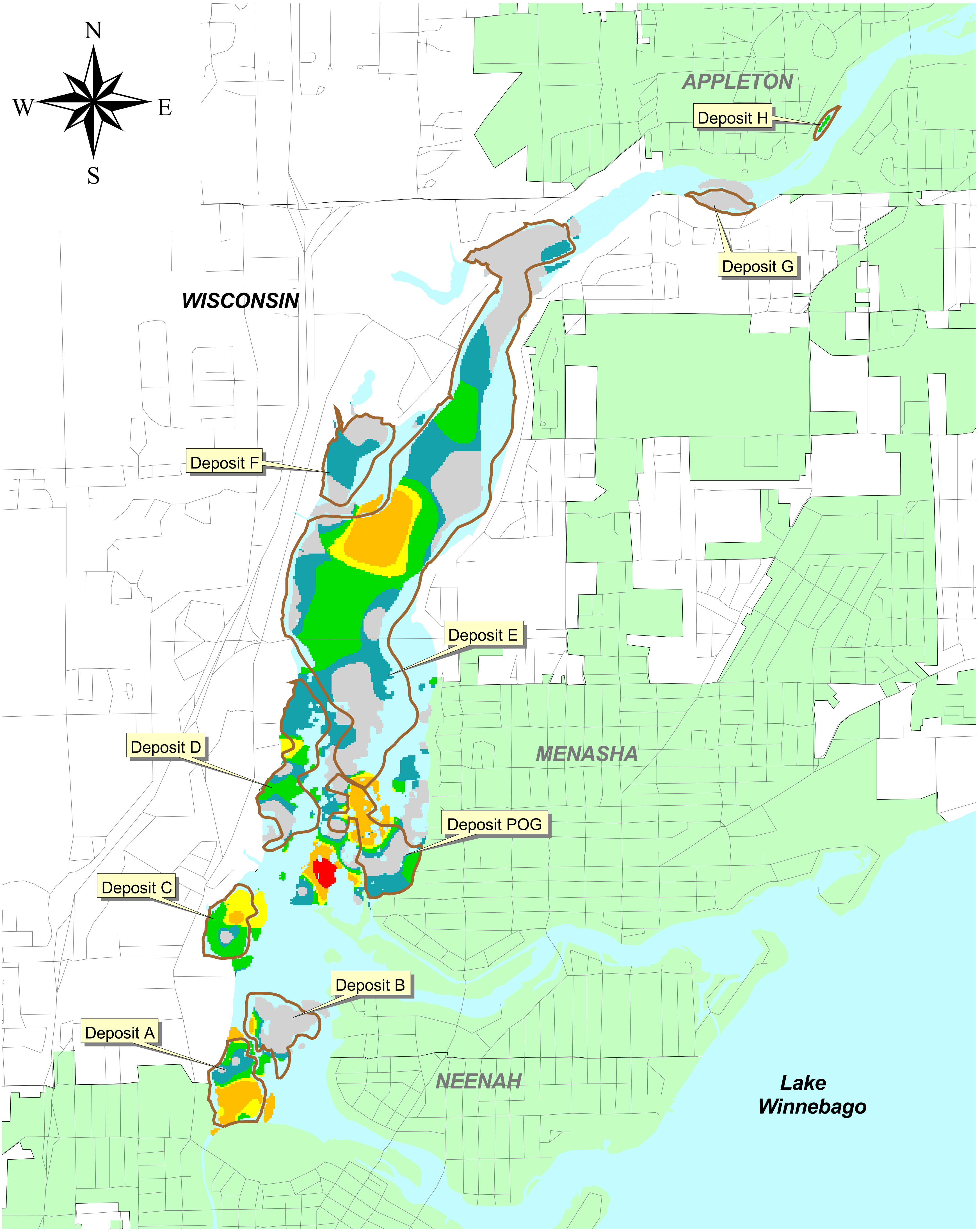
Given the potential for disturbance and redistribution of sediments, which has been observed in the past due to scouring, there is a high degree of uncertainty in projecting future PCB concentrations in sediments and fish. Given this, coupled with similar observations for sediments and fish on other Great Lakes systems, there is too much uncertainty to apply the information to human health or ecological risk analysis. The current Fox River data shows wide confidence limits on slopes. Some important game fish such as walleye or carp, as well as forage fish (gizzard shad) show increasing PCB levels.

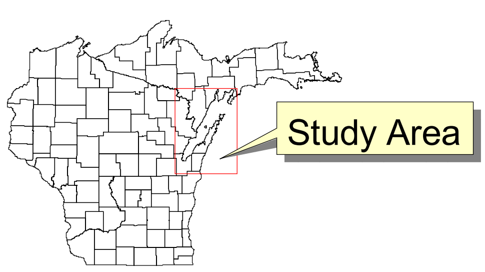
2.7 Section 2 Figures and Tables

Section 2 figures and tables follow page 2-84 and include:

Figure 2-1 Lower Fox River Elevation Profile

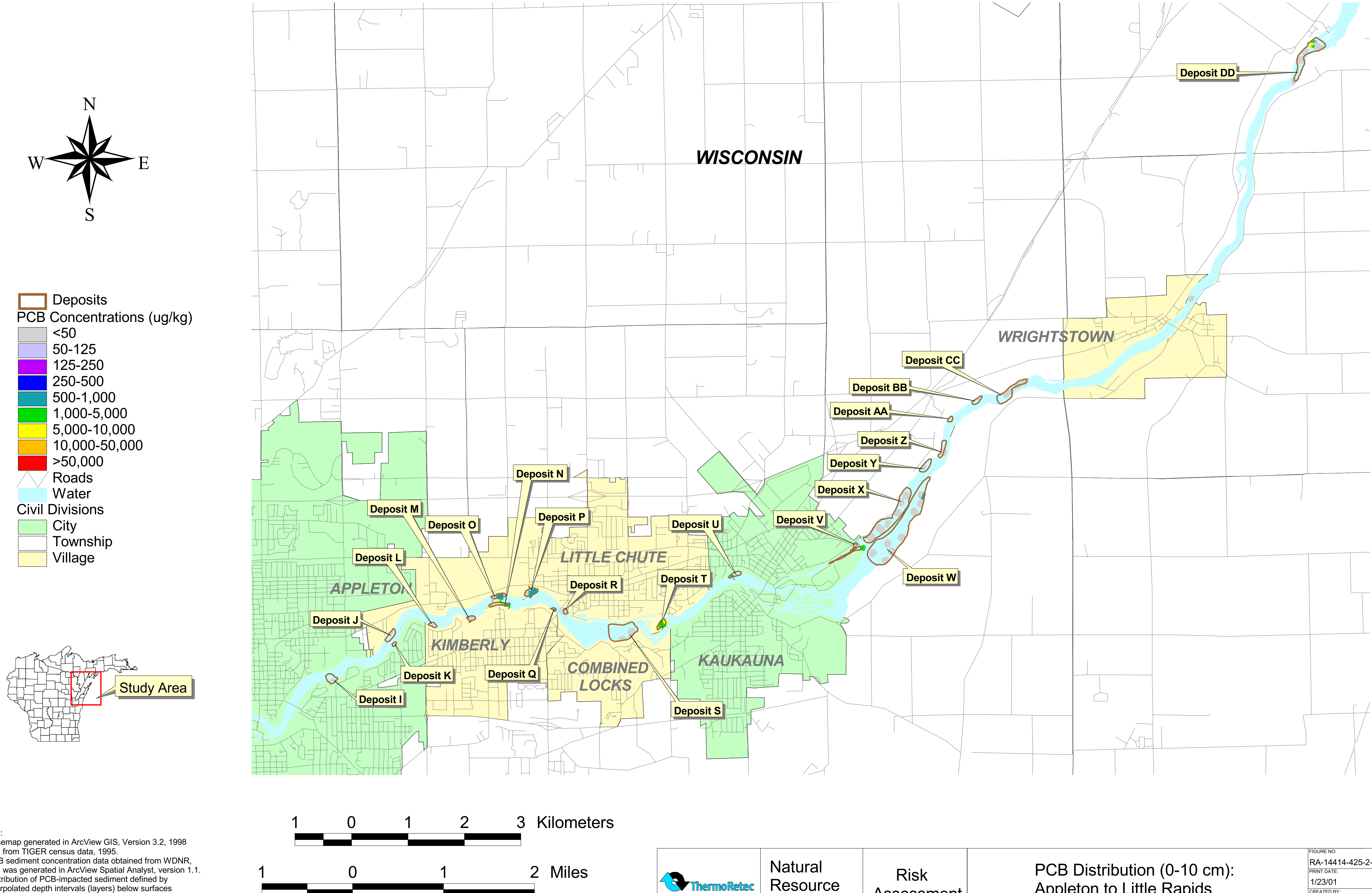






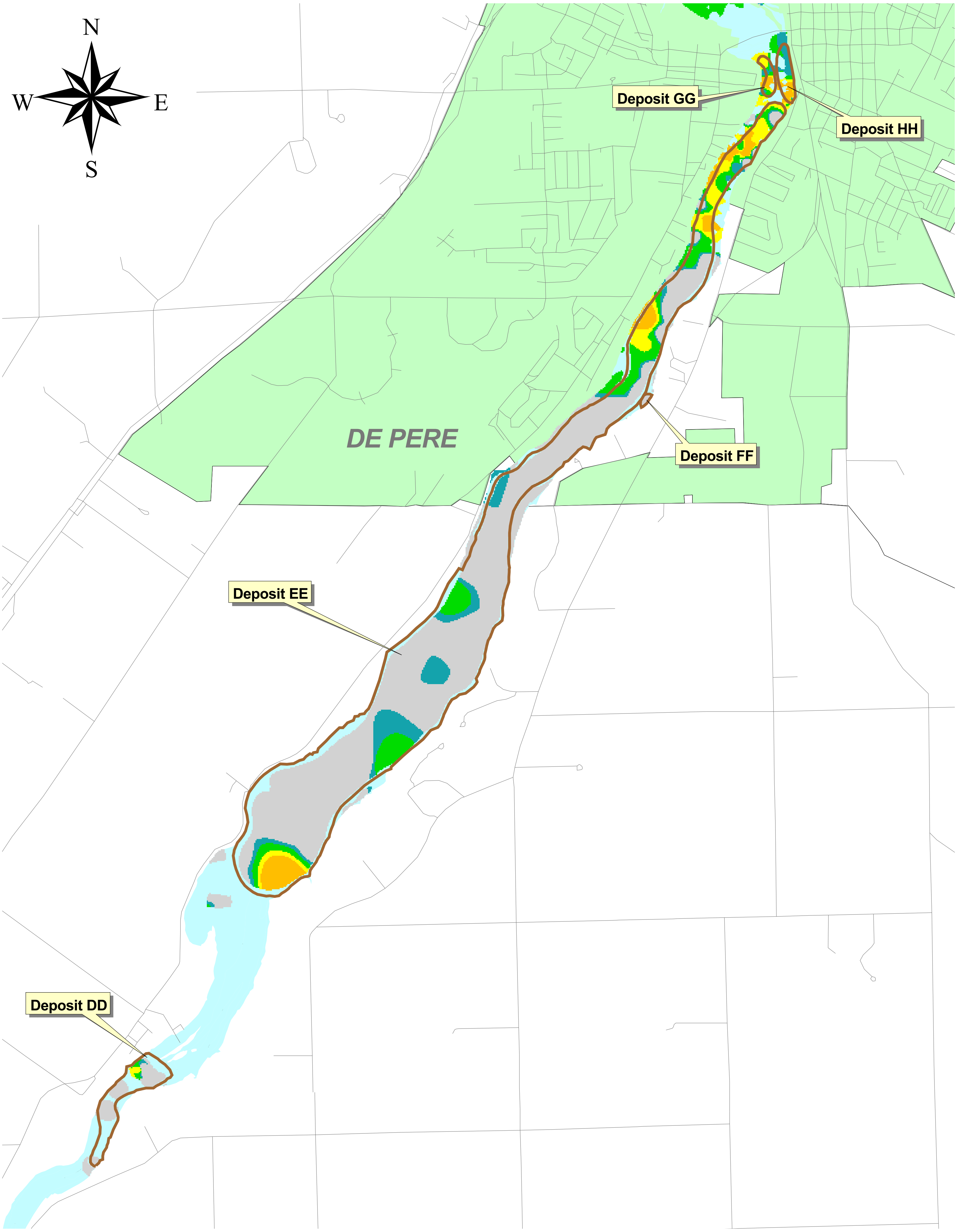
NOTE:
1. Basemap generated in ArcView GIS, Version 3.2, 1998 and from TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.

ThermoRetec	Natural Resource Technology	Risk Assessment	PCB Distribution (0-10 cm): Little Lake Butte des Morts	FIGURE NO: RA-14414-425-2-2
				PRINT DATE: 1/23/01
				CREATED BY: SCJ
			FIGURE 2-2	APPROVED: AGF



NOTE:
1. Basemap generated in ArcView GIS, Version 3.2, 1998 and from TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.

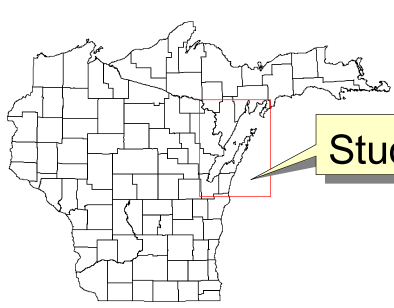
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	PCB Distribution (0-10 cm): Appleton to Little Rapids FIGURE 2-3	FIGURE NO: RA-14414-425-2-3 PRINT DATE: 1/23/01 CREATED BY: SCJ APPROVED: AGF



Deposits
PCB Concentrations (ug/kg)
- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- 5,000-10,000
- 10,000-50,000
- >50,000

Roads
Water

Civil Divisions
- City
- Township
- Village

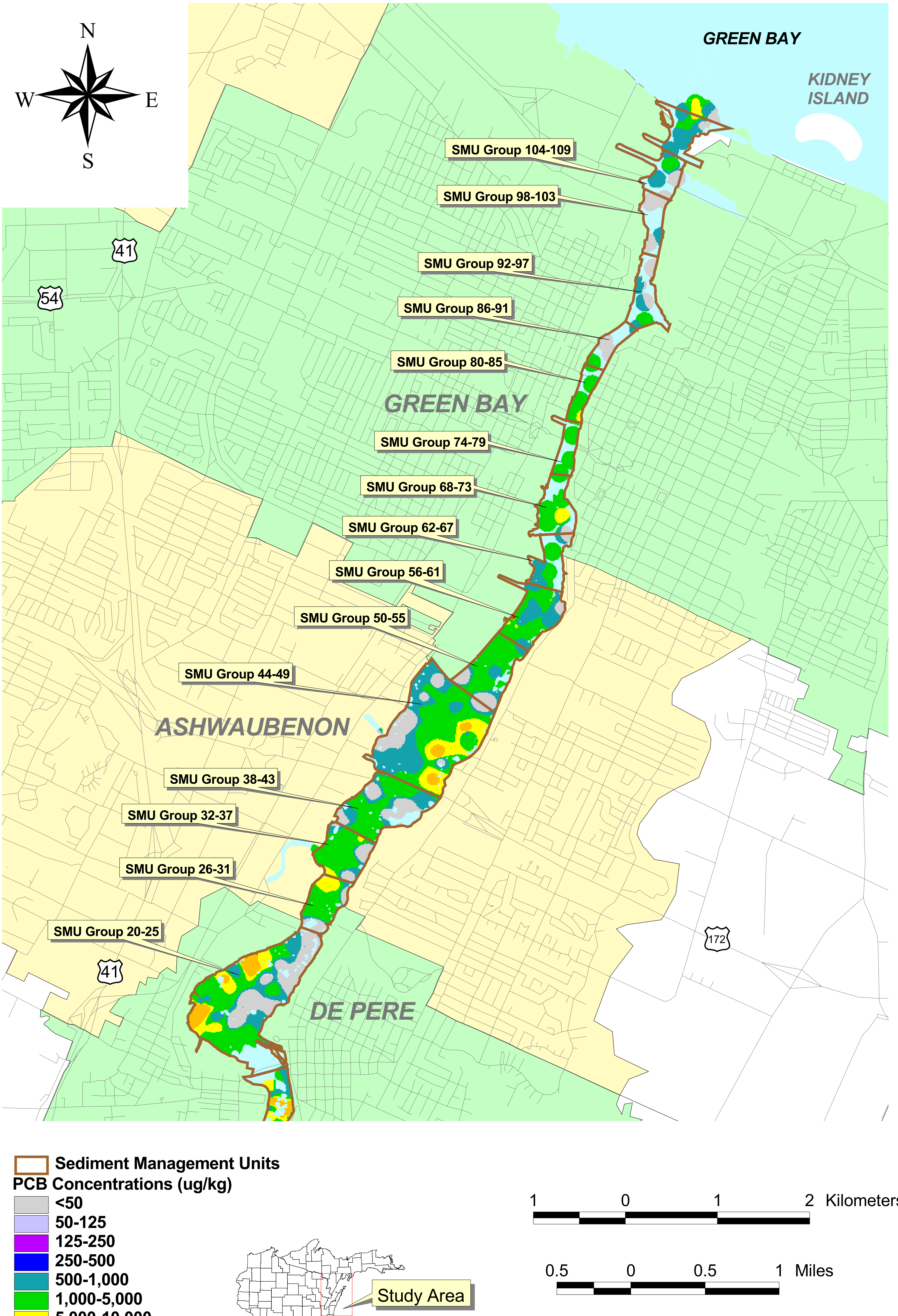


0.5 0 0.5 1 1.5 Kilometers

0.5 0 0.5 1 Miles

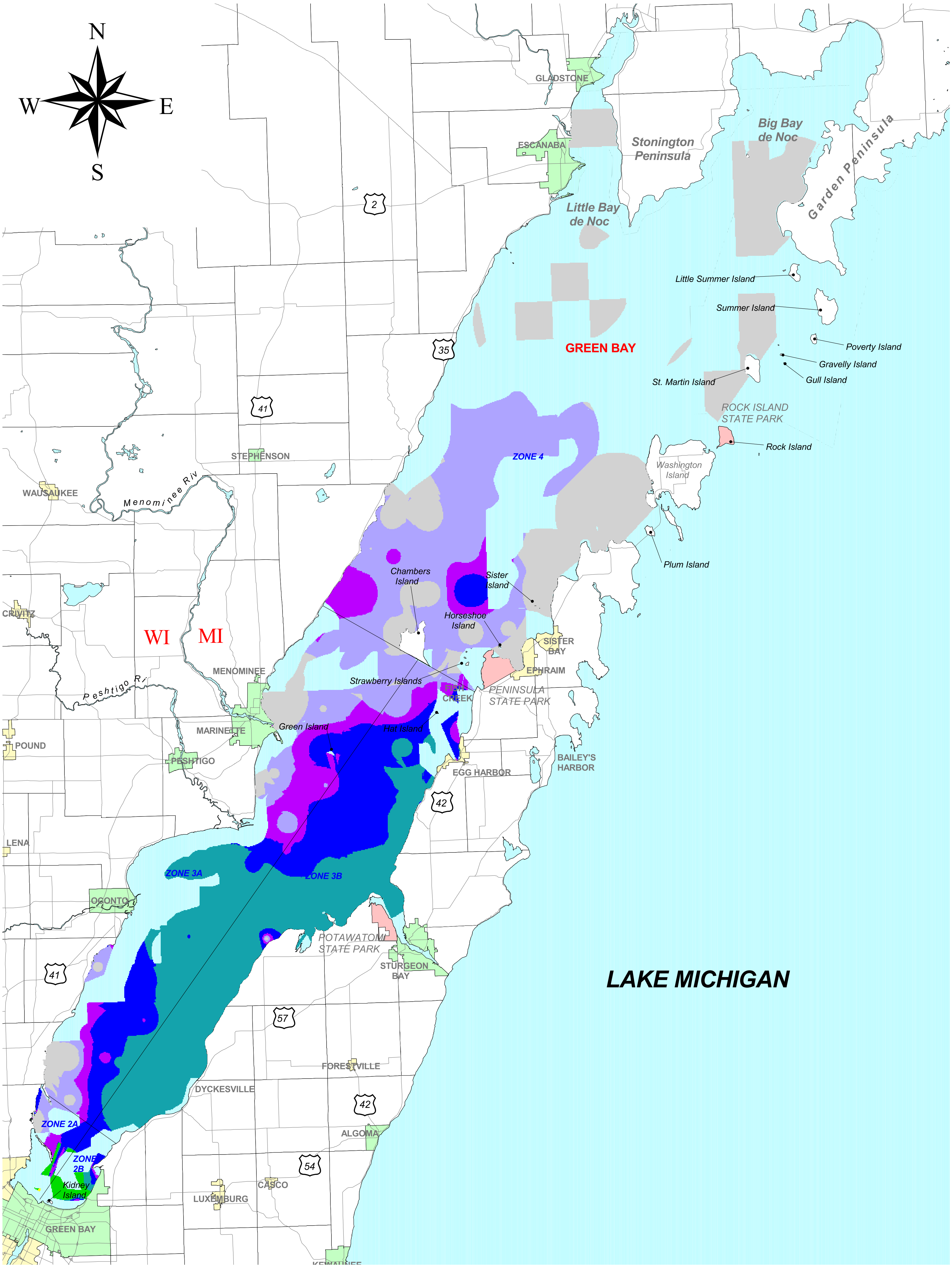
NOTE:
1. Basemap generated in ArcView GIS, Version 3.2, 1998 and from TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.

ThermoRetec	Natural Resource Technology	Risk Assessment	PCB Distribution (0-10 cm): Little Rapids to De Pere	FIGURE NO: RA-14414-425-2-4
				PRINT DATE: 1/23/01
				CREATED BY: SCJ
			FIGURE 2-4	APPROVED: AGF



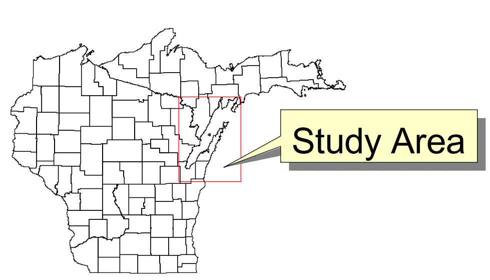
NOTE:
1. Basemap generated in ArcView GIS, Version 3.2, 1998 and from TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.

ThermoRetec	Natural Resource Technology	Risk Assessment	PCB Distribution (0-10 cm): De Pere to Green Bay	FIGURE NO: RA-14414-425-2-5
				PRINT DATE: 1/23/01
				CREATED BY: SCJ
			FIGURE 2-5	APPROVED: AGF



PCB Concentrations (ug/kg)
- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- > 5,000
- Roads
- State Parks
- Water

Civil Divisions
- City
- Township
- Village



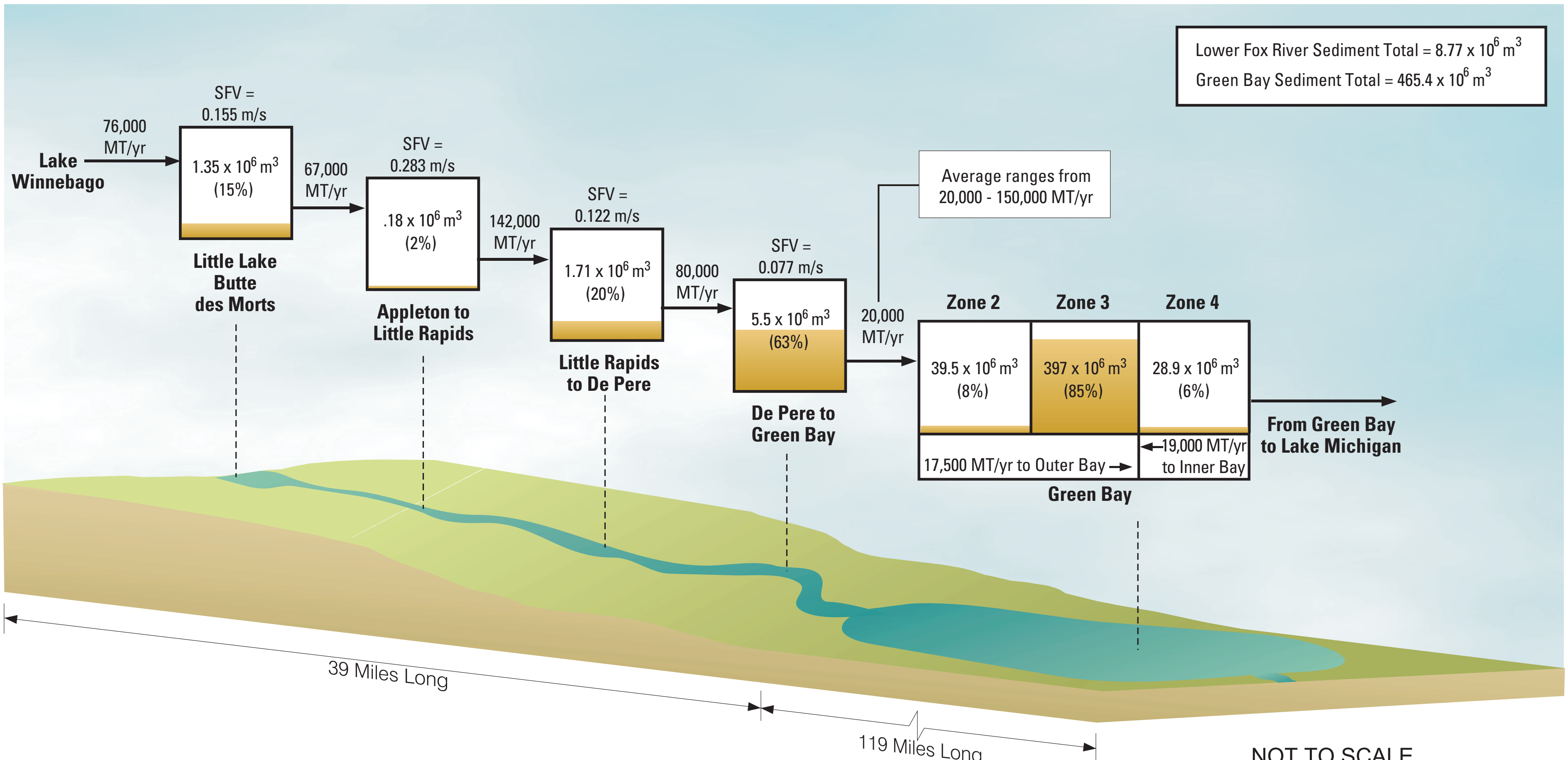
10 0 10 20 Kilometers

10 0 10 Miles

NOTE:
1. Basemap generated in ArcView GIS, Version 3.2, 1998 and from TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 30 cm depths. Assume no exceedences beyond depths shown.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	PCB Distribution (0-10 cm): Green Bay	FIGURE NO: RA-14414-425-2-6
				PRINT DATE: 1/23/01
				CREATED BY: SCJ
			FIGURE 2-6	APPROVED: AGF

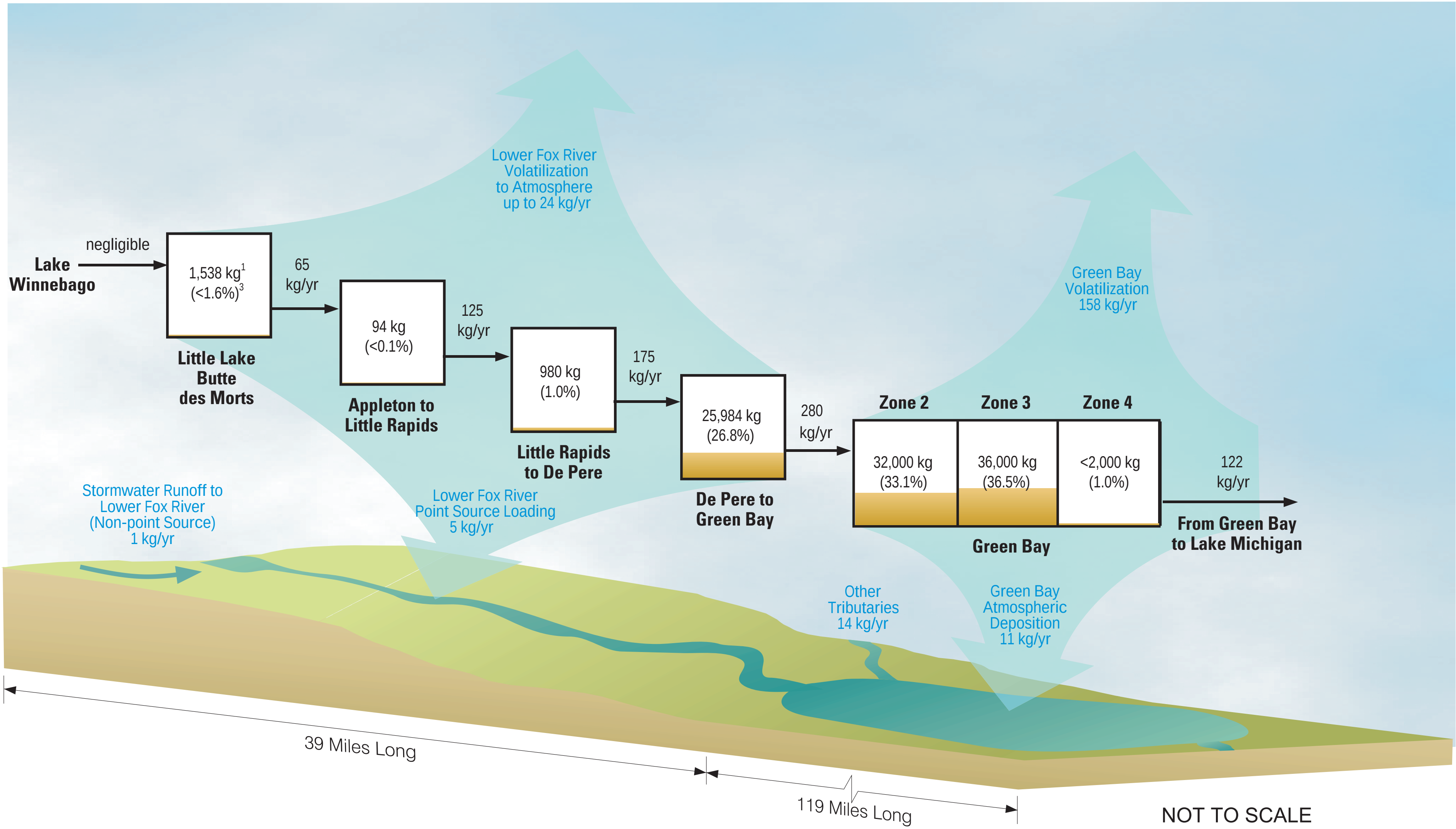
Figure 2-7 Estimated Annual Sediment Transport Rates and Stream Flow Velocities



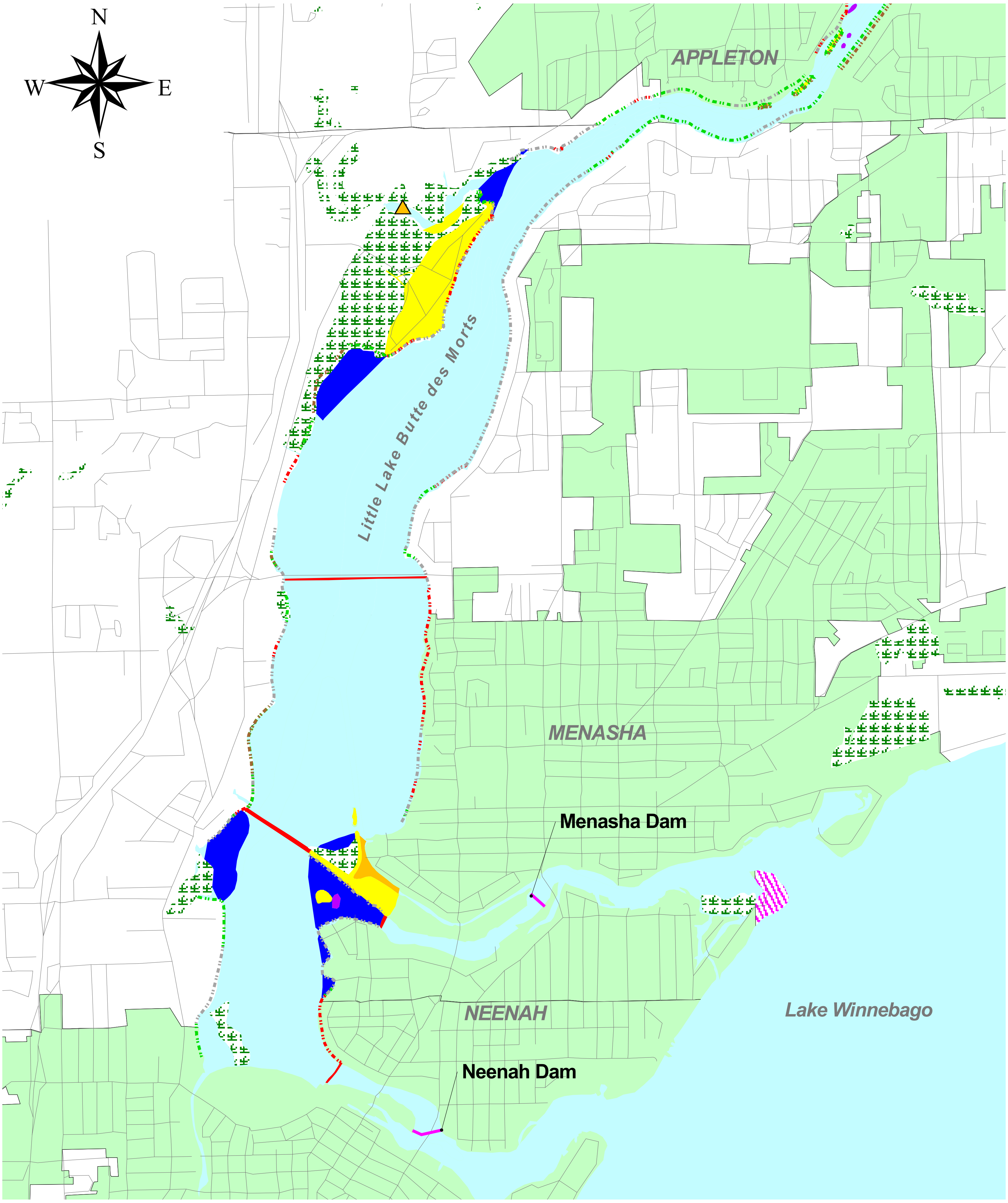
Notes: 1.Sediment volumes contain PCB concentrations > 50 µg/kg PCBs.
2. MT/yr = metric ton per year.
3. Data source for discharge rates is Steuer et al, 1995.
4. Percentages correspond to fraction of total sediment volumes residing in each river reach or bay zone. Volume estimates obtained from tables 5-13, 5-14 and 5-15.
5. SFV = Stream Flow Velocity.
6. The average Stream Flow Velocity for the entire Lower Fox River is 0.137 m/s.
7. 1 x $10^6 m^3$ = one million cubic meters of sediment

F:\PROJECTS\DOCS\4414\DOC\BLRA\DRAFT\FIGS\SEC2FIGS.PDF

Figure 2-8 Lower Fox River and Green Bay System Estimated PCB Mass and Major PCB Flux Pathways



Notes:
1. PCB mass in sediments with PCB concentrations of 50 µg/kg or more.
2. Flux rates are average estimated loading rates per year.
3. Percentages correspond to fraction of total PCB mass in project area residing in each reach or zone. PCB mass estimates obtained from Tables 5-13, 5-14 and 5-15 in the Remedial Investigation.
4. Estimate of PCB loads from WDNR 1995 and www.epa.gov/med/images/gbmassbal.gif



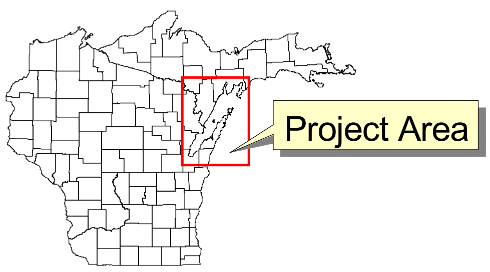
Physical Habitat Features
- Bridge
- Cuts, Coves, Backwaters
- Dam Riffles
- Island
- Lock Channel
- Submerged piling, ruin, rock
- Tributary

Shoreline Features
- Bulkhead
- Grass
- Gravel Cobbles
- Riprap
- Sand
- Sandy beach
- Soft Sediments
- Trees

- Wetlands
- Bald Eagle Nesting Sites

Threatened or Endangered Resources
- Lake Sturgeon
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village

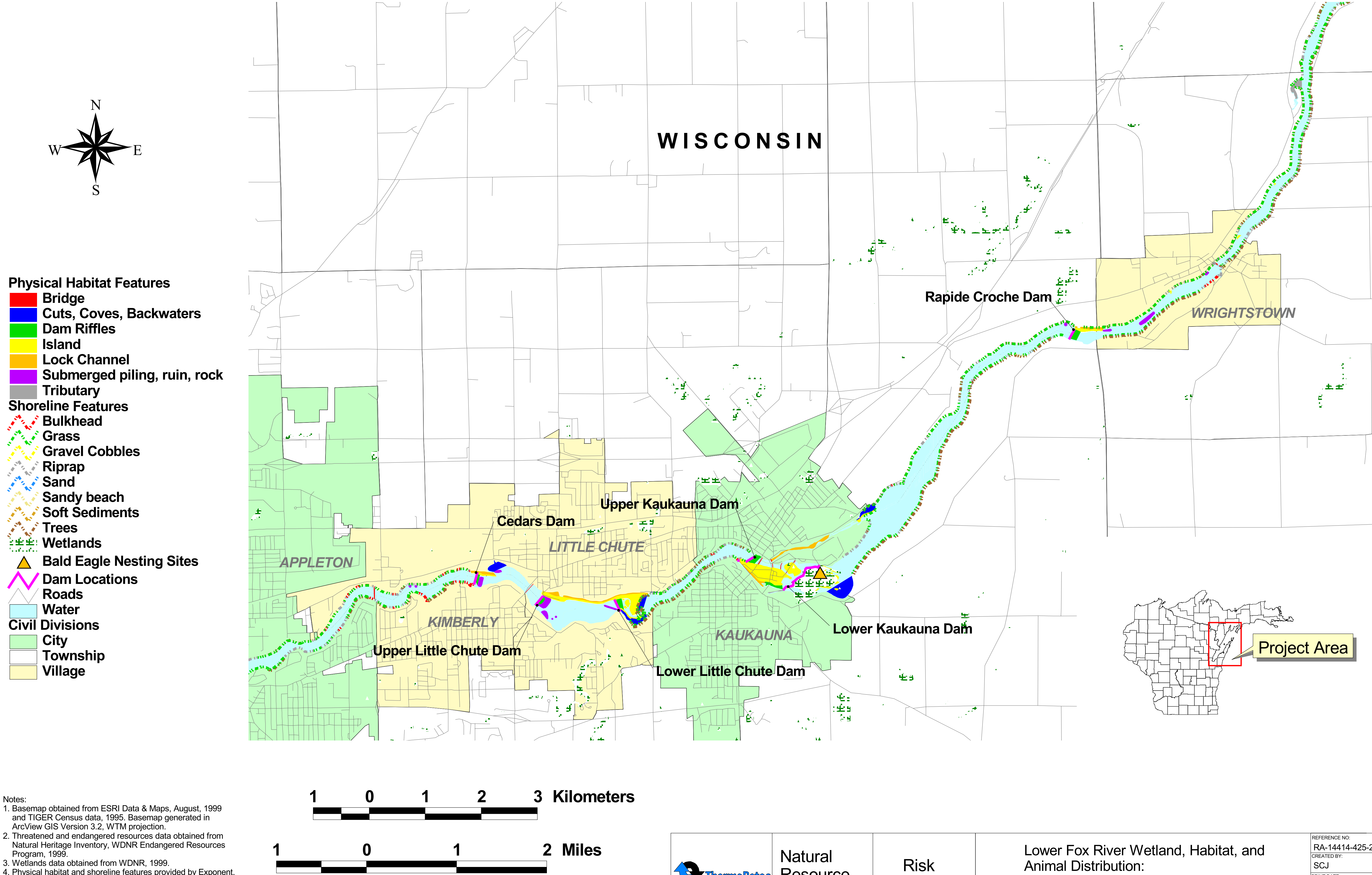


0.5 0 0.5 1 Kilometers

0.5 0 0.5 1 Miles

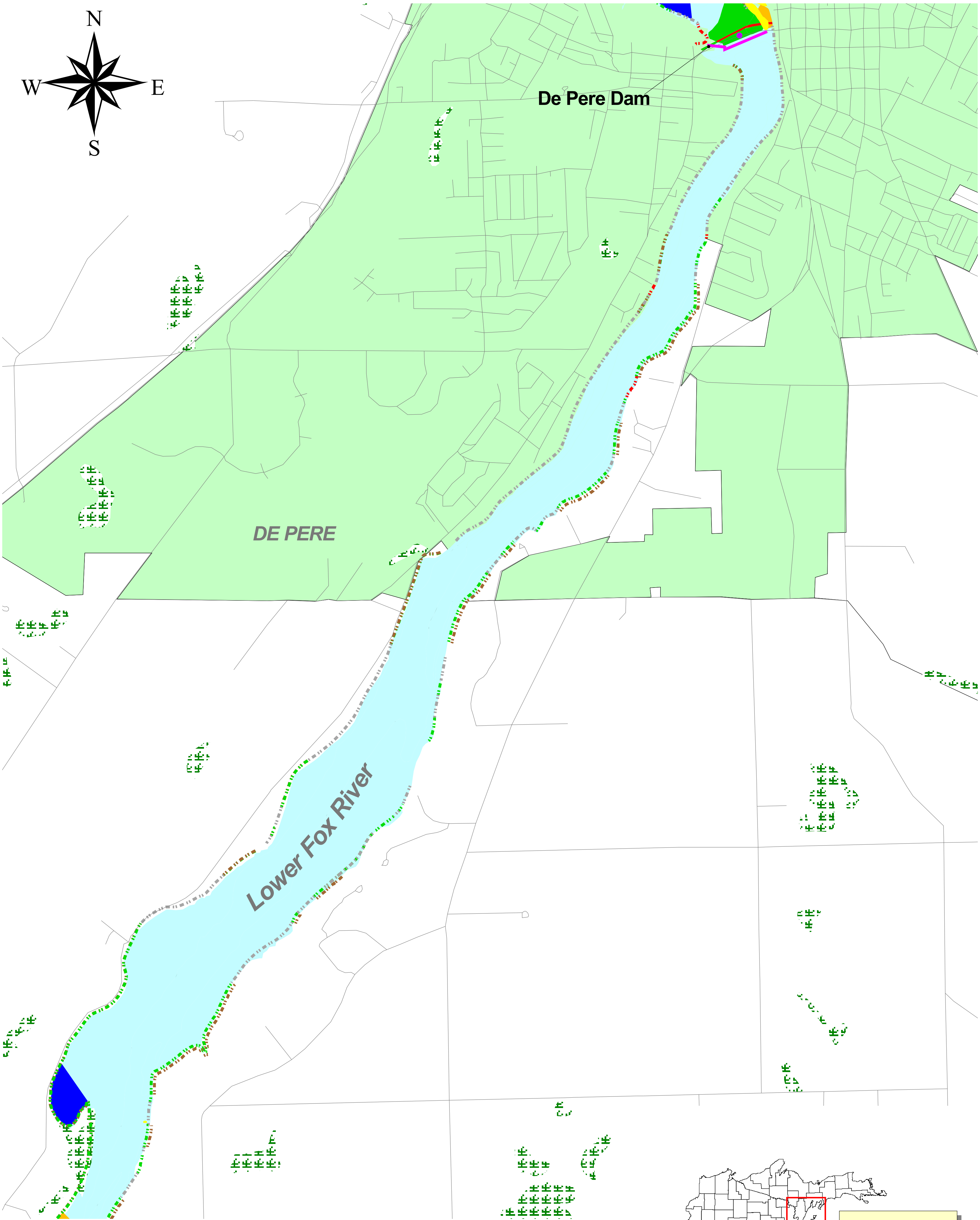
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Threatened and endangered resources data obtained from Natural Heritage Inventory, WDNR Endangered Resources Program, 1999.
3. Wetlands data obtained from WDNR, 1999.
4. Physical habitat and shoreline features provided by Exponent, 1999.

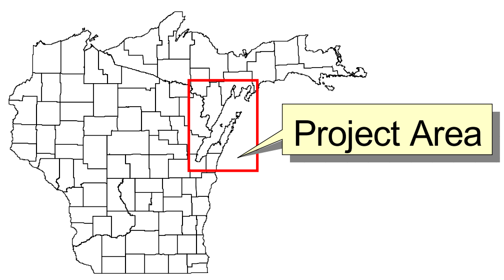
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Lower Fox River Wetland, Habitat, and Animal Distribution: Little Lake Butte des Morts Reach	REFERENCE NO: RA-14414-425-2-9
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-9	APPROVED: AGF



Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Threatened and endangered resources data obtained from Natural Heritage Inventory, WDNR Endangered Resources Program, 1999.
3. Wetlands data obtained from WDNR, 1999.
4. Physical habitat and shoreline features provided by Exponent, 1999.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Lower Fox River Wetland, Habitat, and Animal Distribution: Appleton to Little Rapids Reach	REFERENCE NO: RA-14414-425-2-10
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-10	APPROVED: AGF





Physical Habitat Features
- Bridge
- Cuts, Coves, Backwaters
- Dam Riffles
- Island
- Lock Channel
- Submerged piling, ruin, rock
- Tributary

Shoreline Features
- Bulkhead
- Grass
- Gravel Cobbles
- Riprap
- Sand
- Sandy beach
- Soft Sediments
- Trees

- Wetlands
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village

0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Threatened and endangered resources data obtained from Natural Heritage Inventory, WDNR Endangered Resources Program, 1999.
3. Wetlands data obtained from WDNR, 1999.
4. Physical habitat and shoreline features provided by Exponent, 1999.

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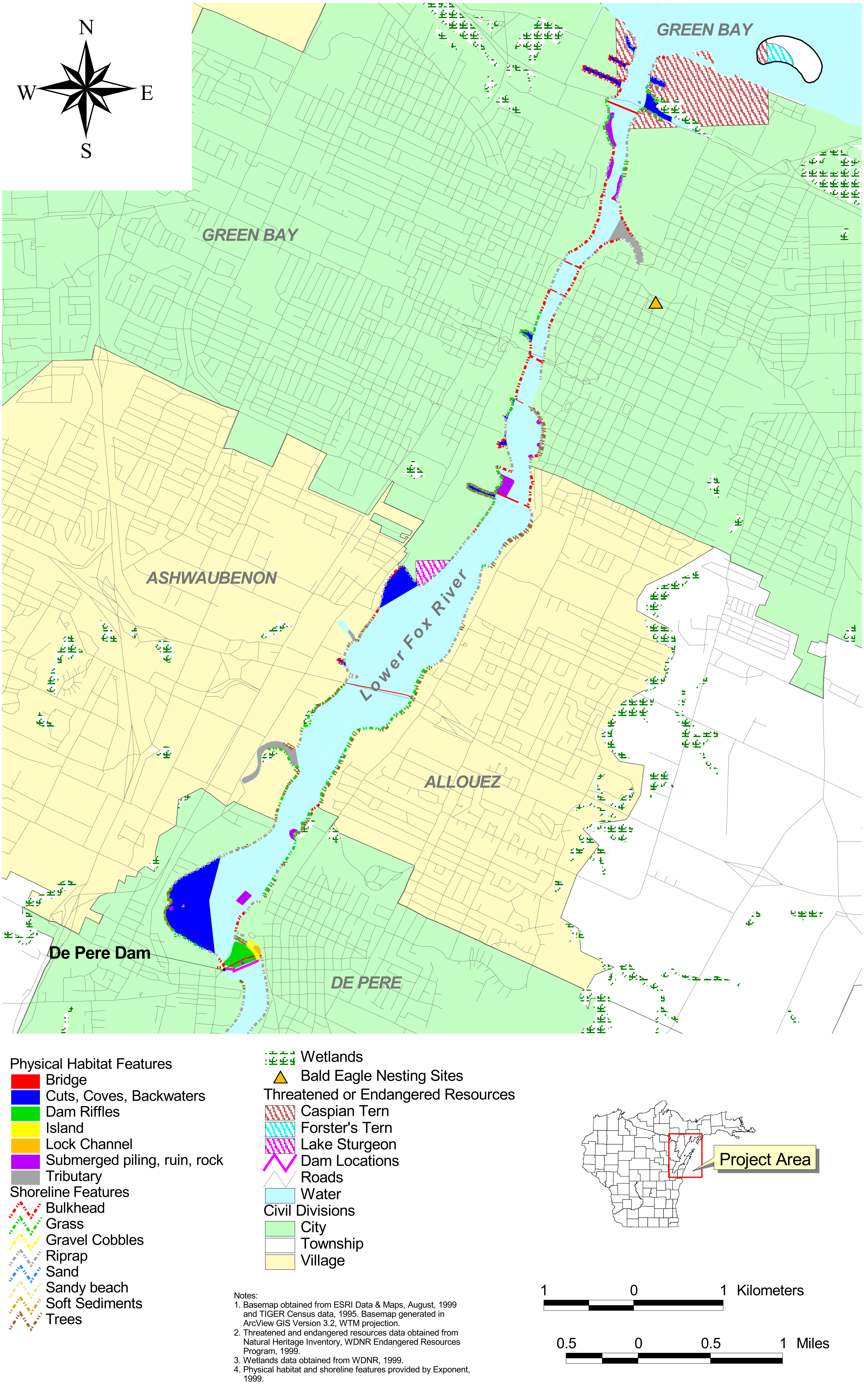
Natural Resource Technology

Risk Assessment

Lower Fox River Wetland, Habitat, and Animal Distribution: Little Rapids to De Pere Reach

FIGURE 2-11

REFERENCE NO: RA-14414-425-2-11
CREATED BY: SCJ
PRINT DATE: 3/14/01
APPROVED: AGF



Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Threatened and endangered resources data obtained from Natural Heritage Inventory, WDNR Endangered Resources Program, 1999.
3. Wetlands data obtained from WDNR, 1999.
4. Physical habitat and shoreline features provided by Exponent, 1999.

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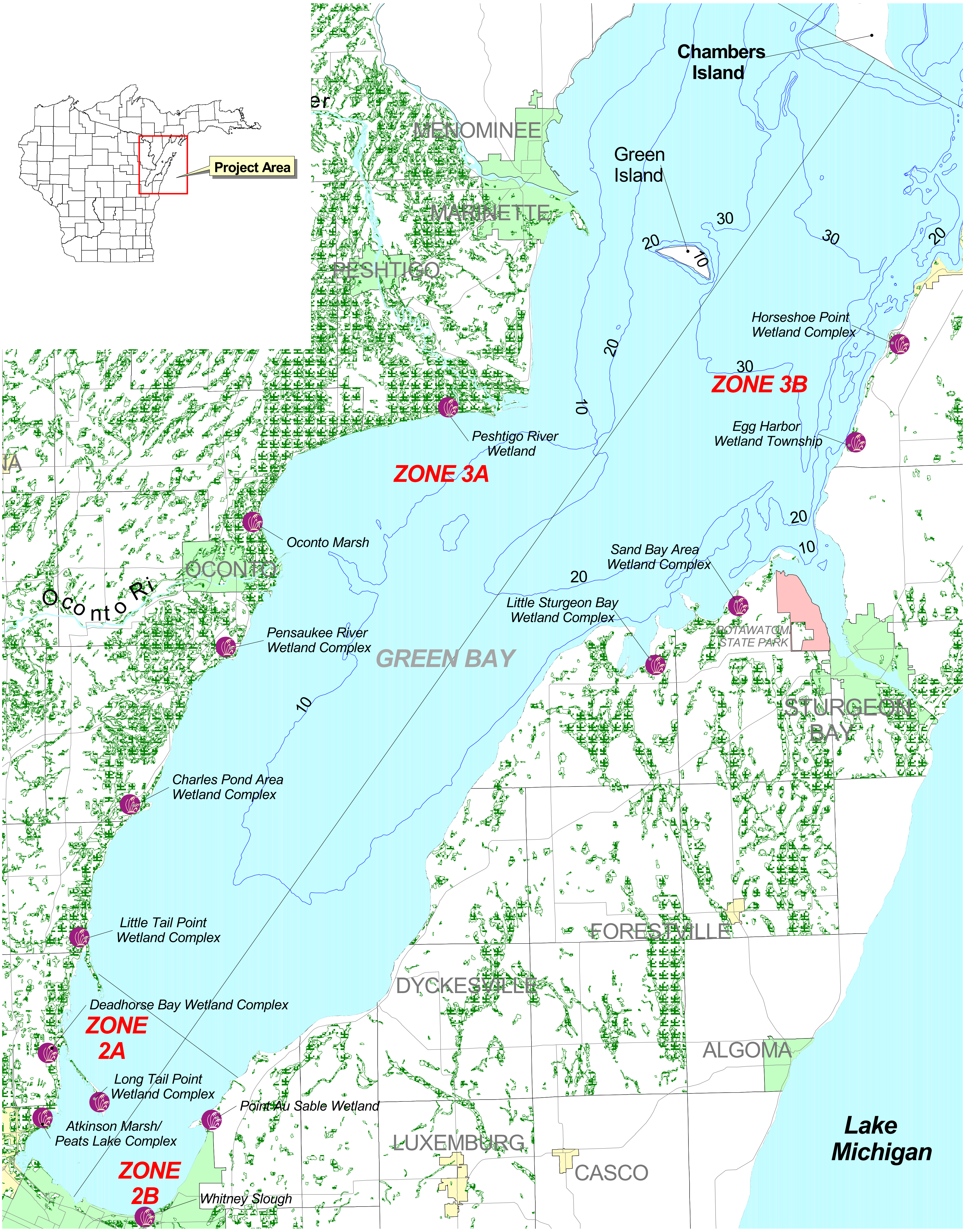
Natural Resource Technology

Risk Assessment

Lower Fox River Wetland, Habitat, and Animal Distribution: De Pere to Green Bay Reach

FIGURE 2-12

REFERENCE NO: RA-14414-425-2-12
CREATED BY: SCJ
PRINT DATE: 3/14/01
APPROVED: AGF



Wetland Areas > 40 Hectares (100 acres)
Bathymetry Contours (10 m)
Roads
Wetlands
Wisconsin State Parks
Water

Civil Divisions
City
Township
Village

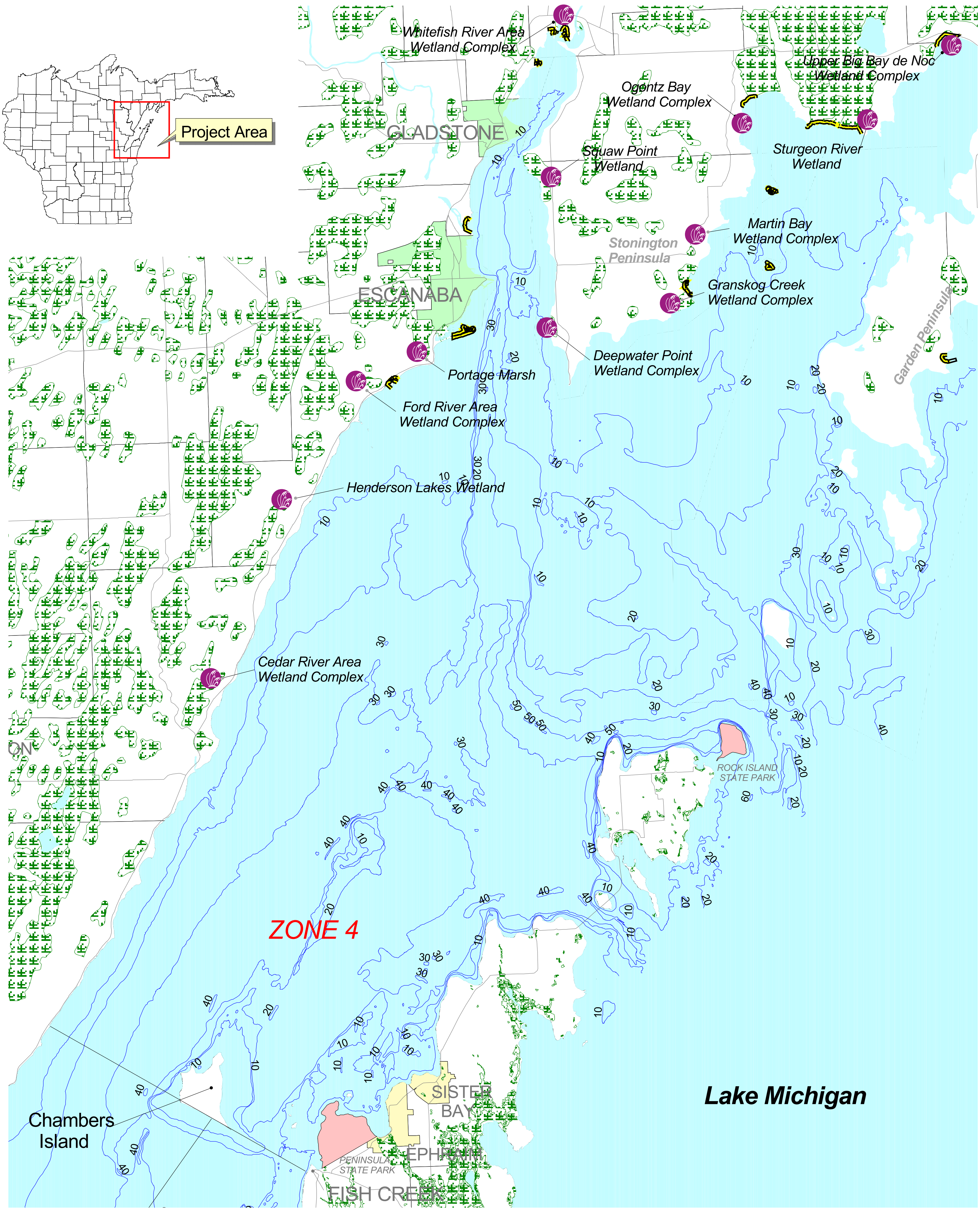
5 0 5 10 Kilometers

5 0 5 Miles

N
W E
S

NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, from ESRI data and maps on CD-ROM and TIGER census data.
2. Aerial ground surveys and survey resource data collected in 1991 and 1992. Data compiled from USFWS, WDNR, Michigan DNR, Bureau of Endangered Resources, Bay-Lake Regional Planning Commission, USACE, and several historical societies.
3. Bathymetry contours in meters, obtained from NOAA, 1999.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Wetland Distribution: Green Bay Zones 2 & 3	DRAWING NO: RA-14414-425-2-13
			FIGURE 2-13	PRINT DATE: 1/23/01
				CREATED BY: SCJ
				APPROVED: AGF



Wetland Areas > 40 Hectares (100 acres)
Bathymetry Contours (10 m)
Roads
Delta County Environmental Areas
Water
Wetlands
Area Parks
Civil Divisions
City
Township
Village

5 0 5 10 15 Kilometers

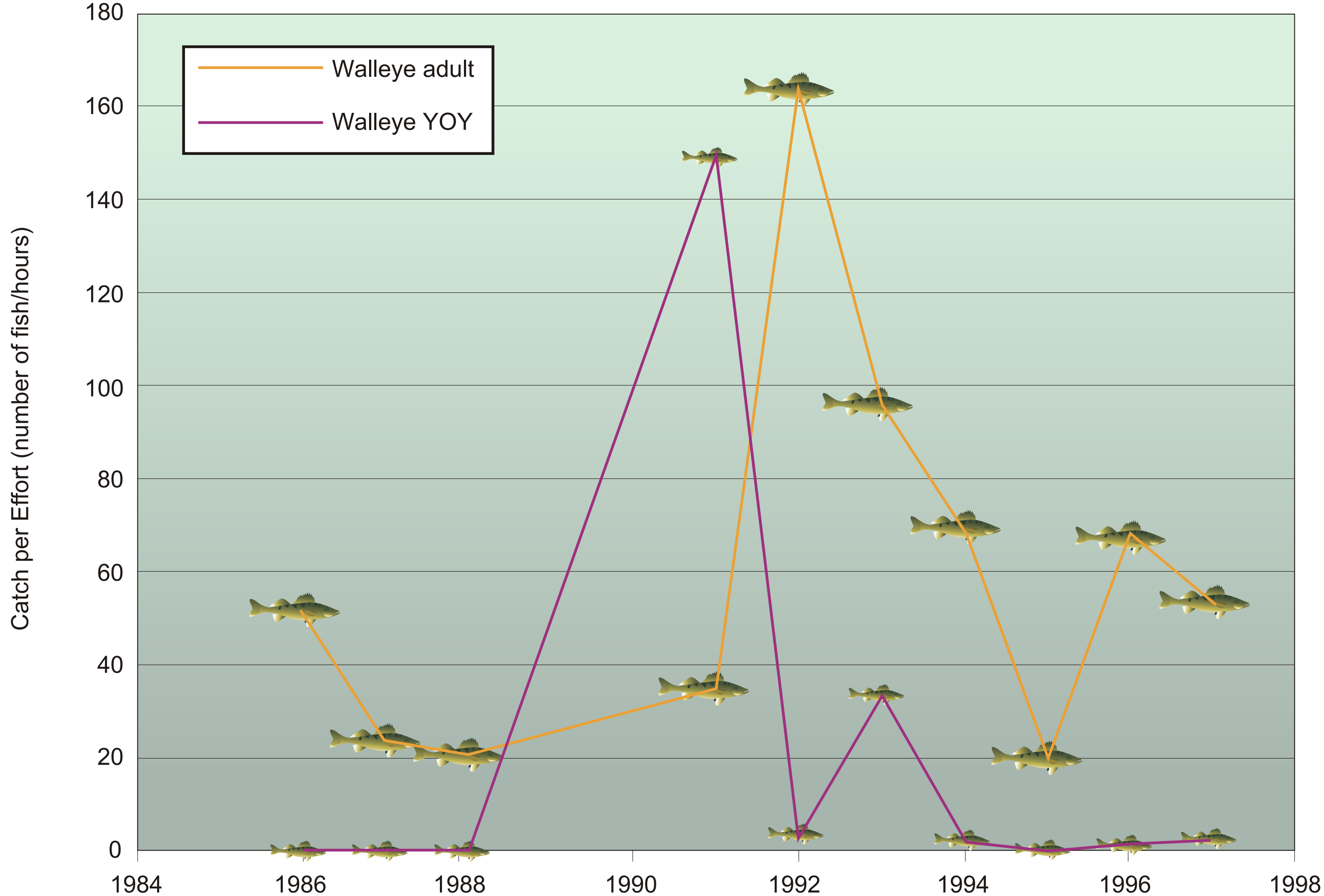
5 0 5 10 Miles

N E S W

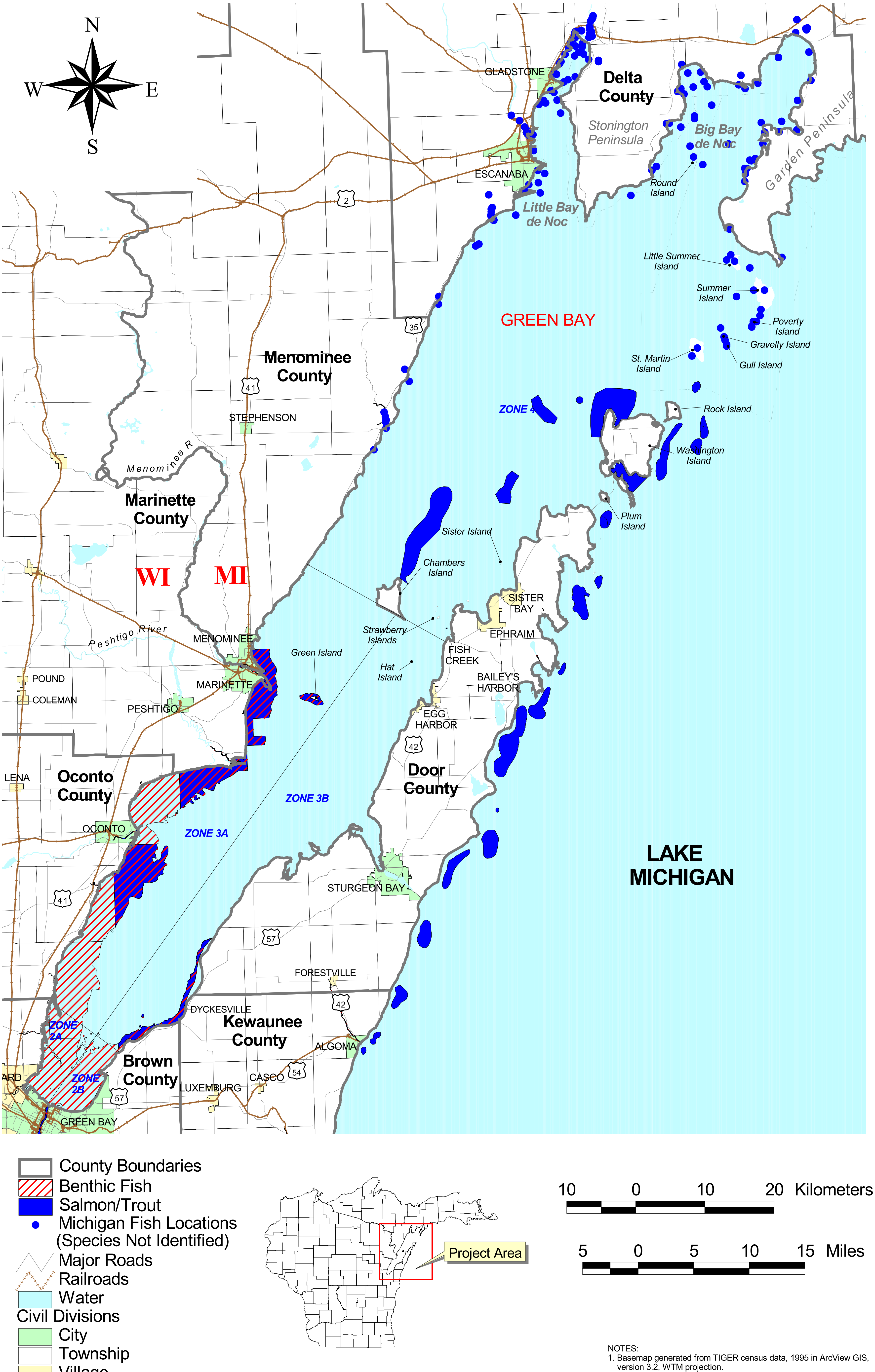
NOTES:
1. Basemap generated in ArcView GIS, version 3.2, from ESRI Data & Maps on CD-ROM and TIGER census data.
2. Aerial ground surveys and survey resource data collected in 1991 and 1992. Data compiled from USFWS, WDNR, Michigan DNR, Bureau of Endangered Resources, USACE, Bay-Lake Regional Planning Commission, and several historical societies.
3. Bathymetry contours in meters, obtained from NOAA, 1999.
4. Delta County Environmental Area Boundaries provided by Michigan Dept. of Environmental Quality.
These are sensitive areas established by MDEQ.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Wetland Distribution: Green Bay Zone 4	DRAWING NO: RA-14414-425-2-14
				PRINT DATE: 1/23/01
				CREATED BY: SCJ
			FIGURE 2-14	APPROVED: AGF

Figure 2-15. Electrofishing Walleye Catch Data in Green Bay Zone 1

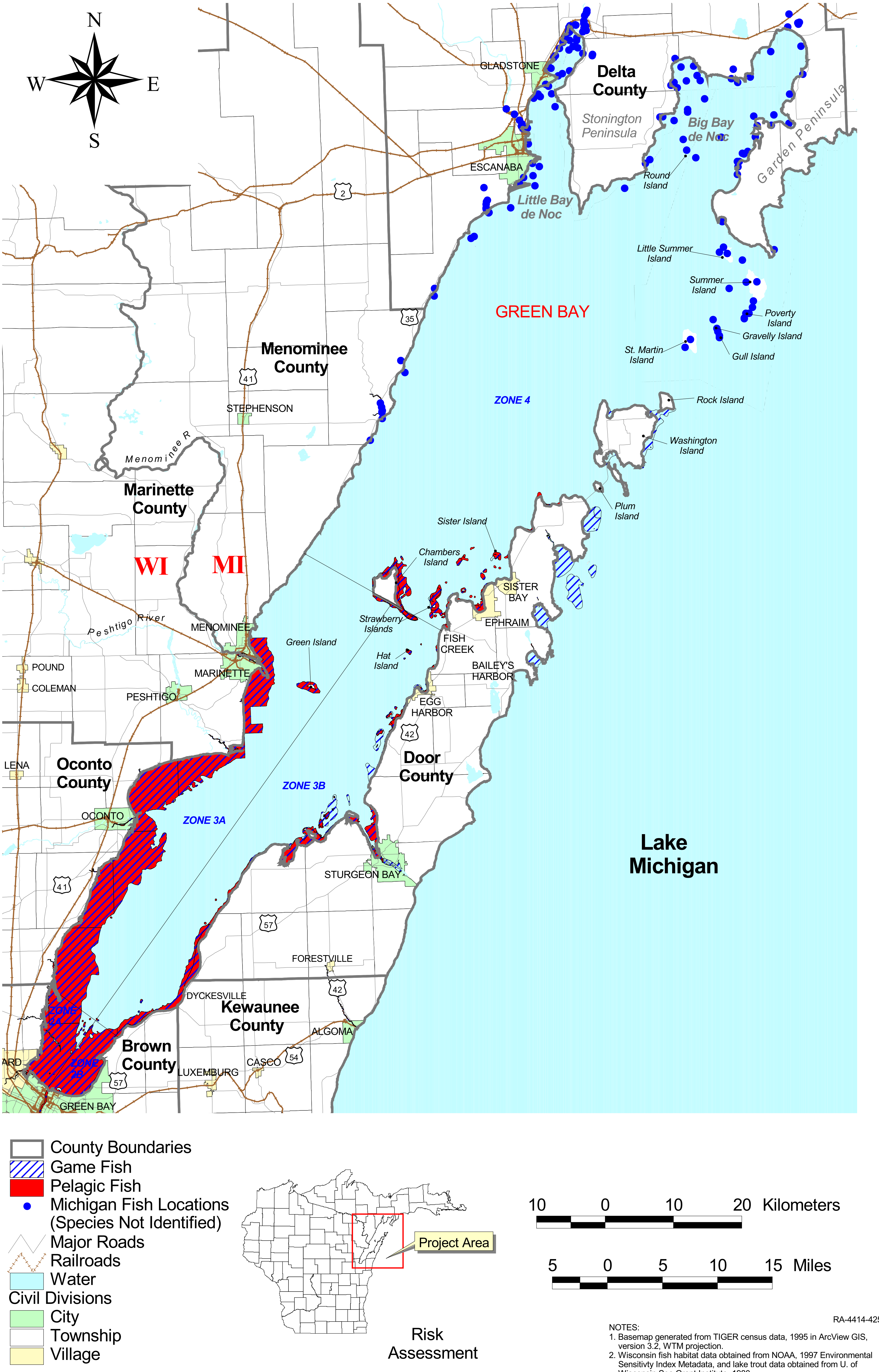


ThermoRetecJanuary2001Figure2_15



NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin fish habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and lake trout data obtained from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan fish locations provided by Great Lakes Commission, 1980.

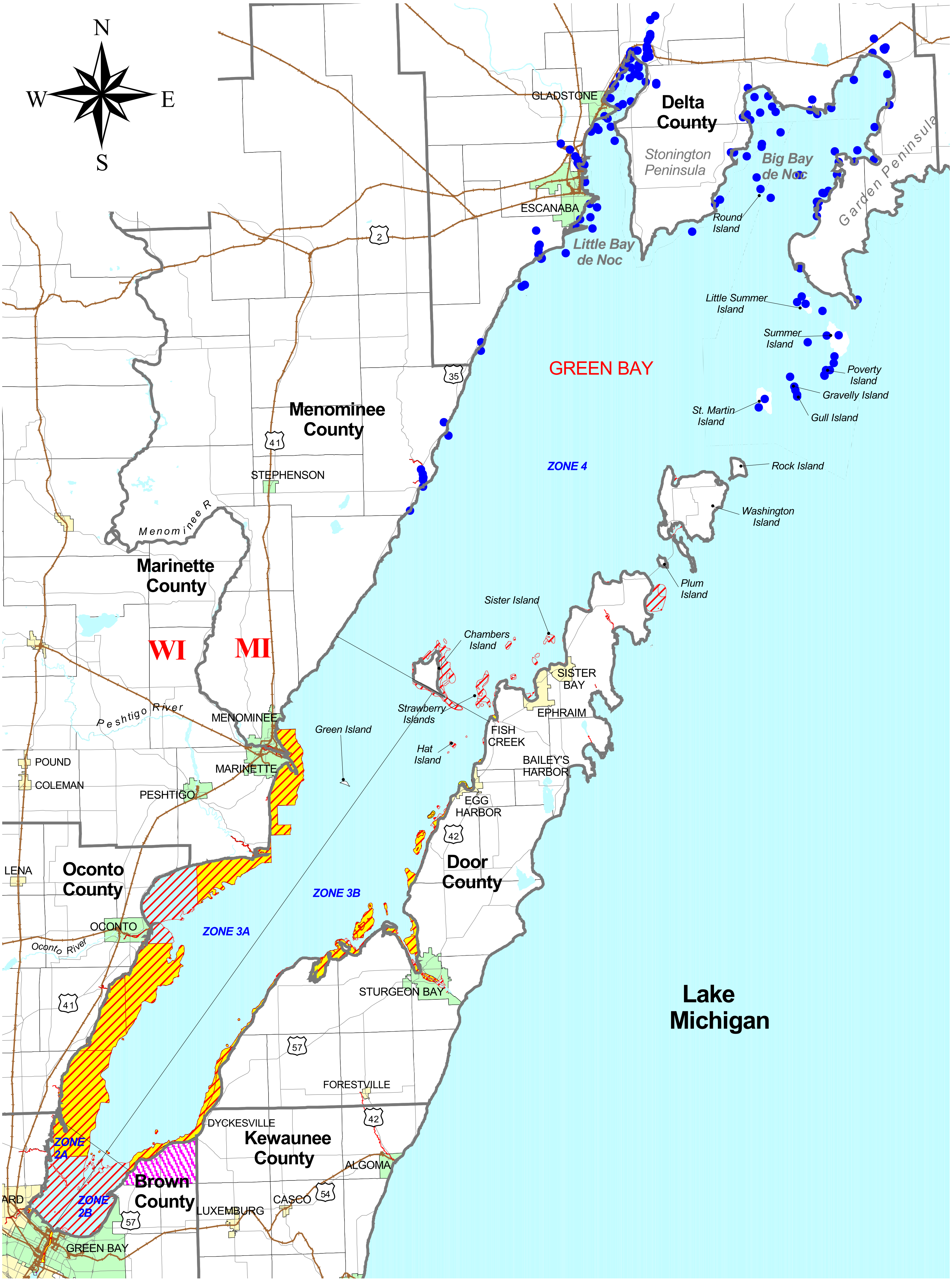
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Spawning Areas by Fish Types: Salmon/Trout and Benthic Fish	DRAWING NO: RA-4414-425-2-16 PRINT DATE: 3/14/01 CREATED BY: SCJ
			FIGURE 2-16	APPROVED: AGF

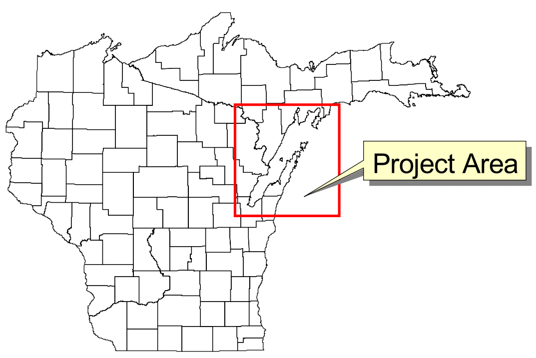


RA-4414-425-2-17

NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin fish habitat data obtained from NOAA, 1997 Environmental Sensitivity Index Metadata, and lake trout data obtained from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan fish locations provided by Great Lakes Commission, 2000.

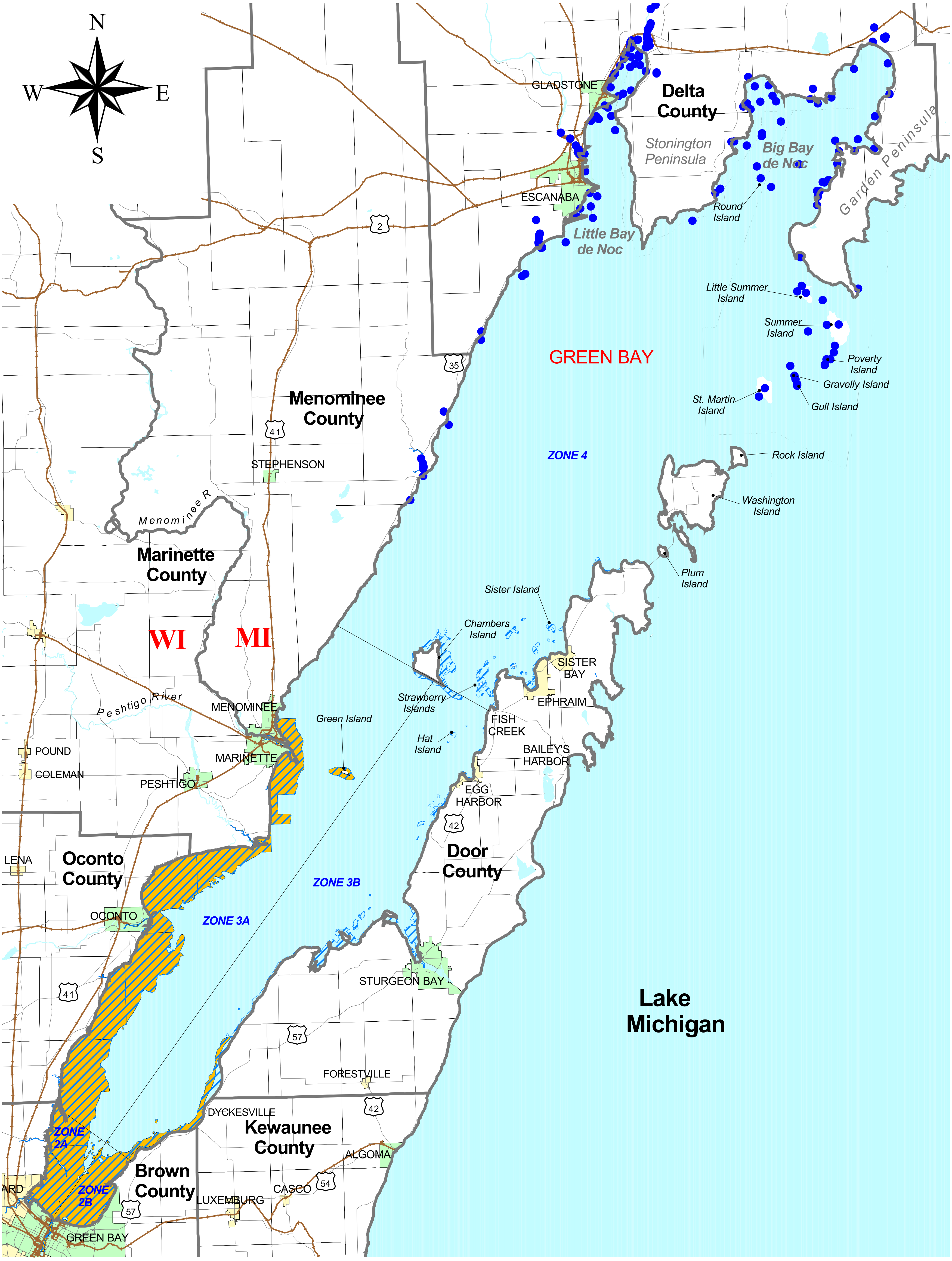
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Spawning Areas by Fish Species: Pelagic and Game Fish	DRAWING NO: RA-4414-425-2-17
				PRINT DATE: 3/14/01
				CREATED BY: SCJ
			FIGURE 2-17	APPROVED: AGF





NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin fish habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and lake trout data obtained from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan fish locations provided by Great Lakes Commission, 2000.
4. Door Peninsula fish habitat data obtained from U. of Wisconsin Sea Grant Institute, 1980.
5. According to Phillip Schneeberger of MDNR (telecon 1999), Walleye commonly spawn in the Whitefish, Escanaba, Ford, Cedar, and Menominee tributary rivers. Yellow Perch commonly use the shallow waters of both bays De Noc.

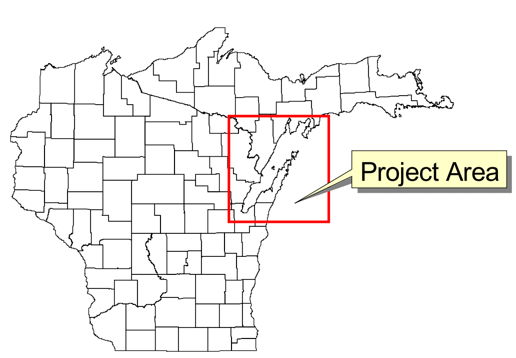
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Spawning Areas by Fish Species: Walleye, Yellow Perch, and Sturgeon	DRAWING NO: RA-4414-425-2-18
				PRINT DATE: 3/14/01
				CREATED BY: SCJ
			FIGURE 2-18	APPROVED: AGF



- County Boundaries
- Alewife
- Carp
- Michigan Fish Locations (Species Not Identified)
- Major Roads
- Railroads
- Water

Civil Divisions

- City
- Township
- Village

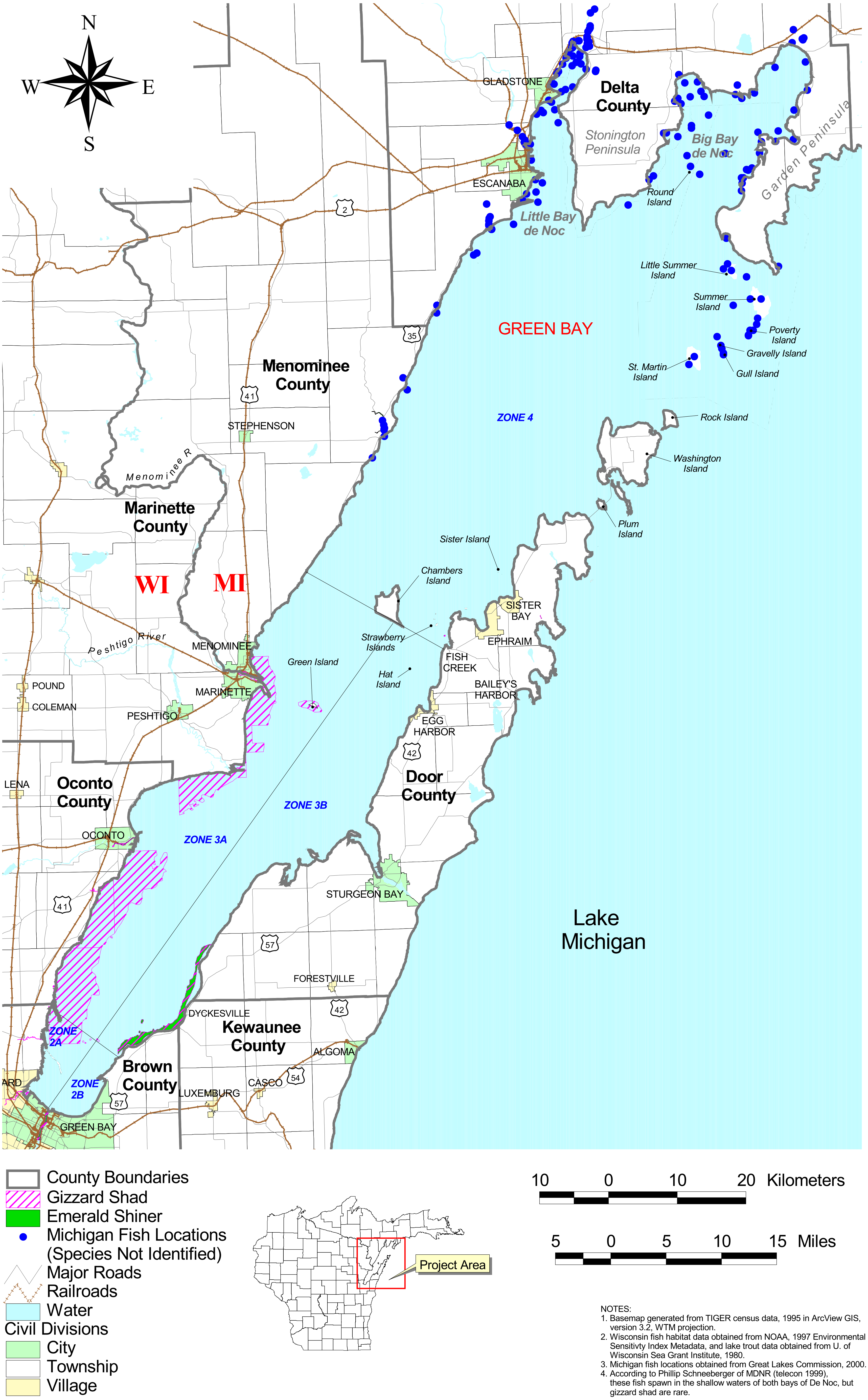


10 0 10 20 Kilometers

5 0 5 10 15 Miles

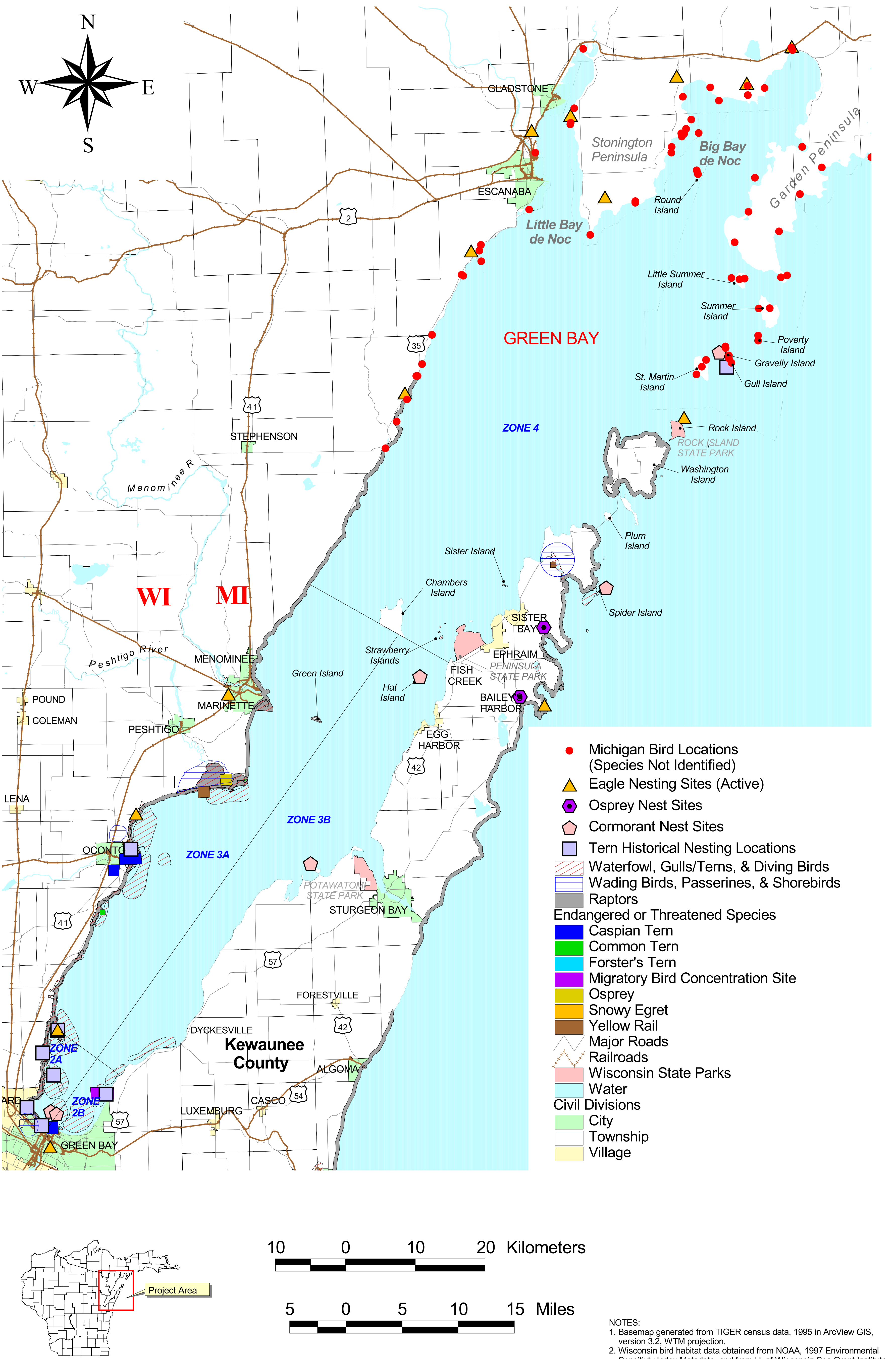
NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin fish habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan fish locations obtained from Great Lakes Commission, 2000.
4. According to Phillip Schneeberger of MDNR (telecon 1999), carp spawning is concentrated in the northern end of Little Bay de Noc, and along the shorelines of Big Bay de Noc.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Spawning Areas by Fish Species: Carp and Alewife	DRAWING NO: RA-4414-425-2-19
				PRINT DATE: 3/14/01
				CREATED BY: SCJ
			FIGURE 2-19	APPROVED: AGF



NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin fish habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and lake trout data obtained from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan fish locations obtained from Great Lakes Commission, 2000.
4. According to Phillip Schneeberger of MDNR (telecon 1999), these fish spawn in the shallow waters of both bays of De Noc, but gizzard shad are rare.

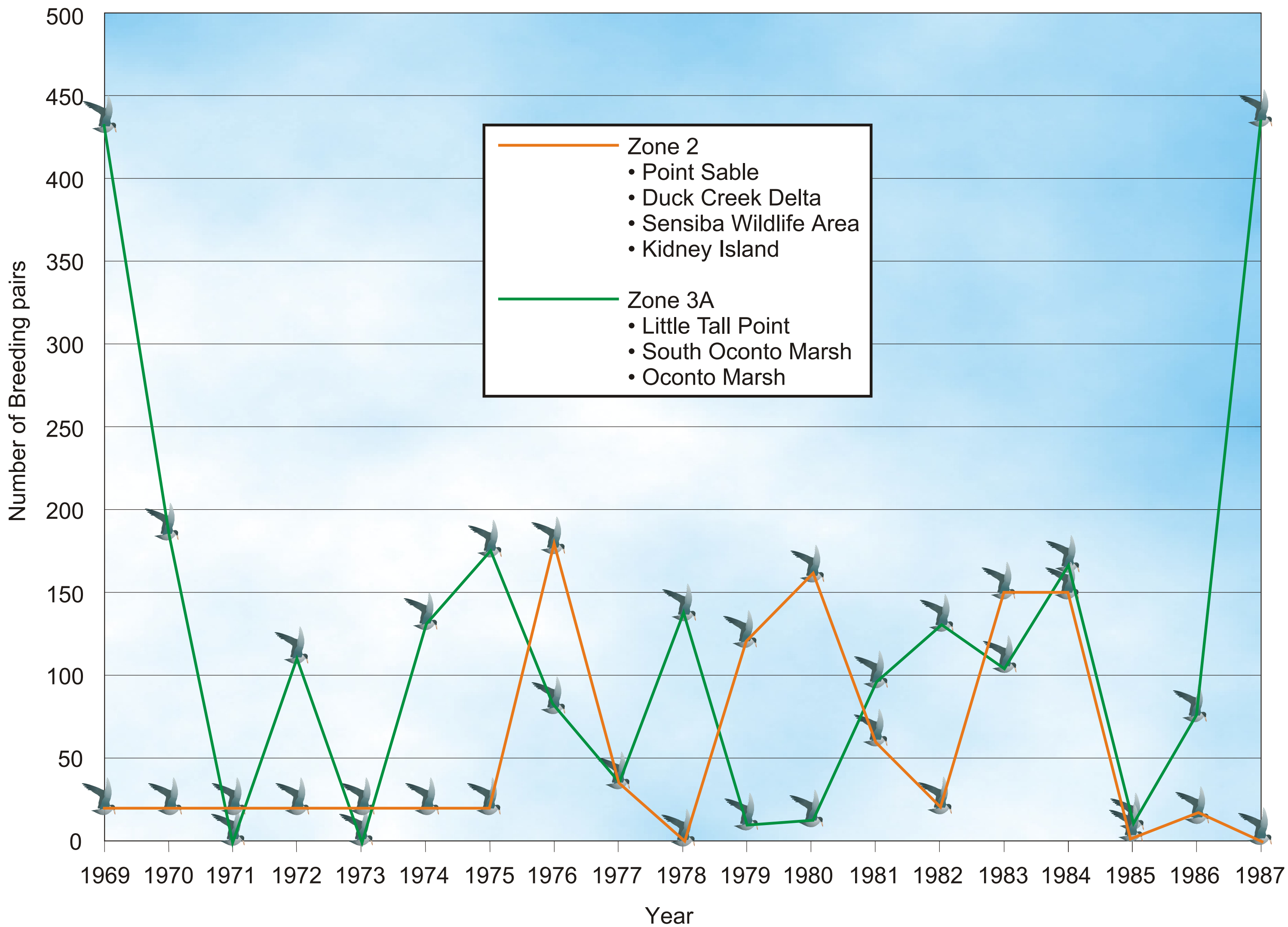
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Spawning Areas by Fish Species: Emerald Shiners and Gizzard Shad	DRAWING NO: RA-4414-425-2-20 PRINT DATE: 3/14/01 CREATED BY: SCJ
			FIGURE 2-20	APPROVED: AGF



NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin bird habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan bird locations obtained from Great Lakes Commission, 2000.
4. Bird nesting sites obtained from USFWS/Stratus, 1999 Bird Injury Report and S. Stubevoll of WDNR, 1998.
5. Threatened and endangered resources provided by Natural Heritage Inventory, WDNR Endangered Resources Program, 1999.

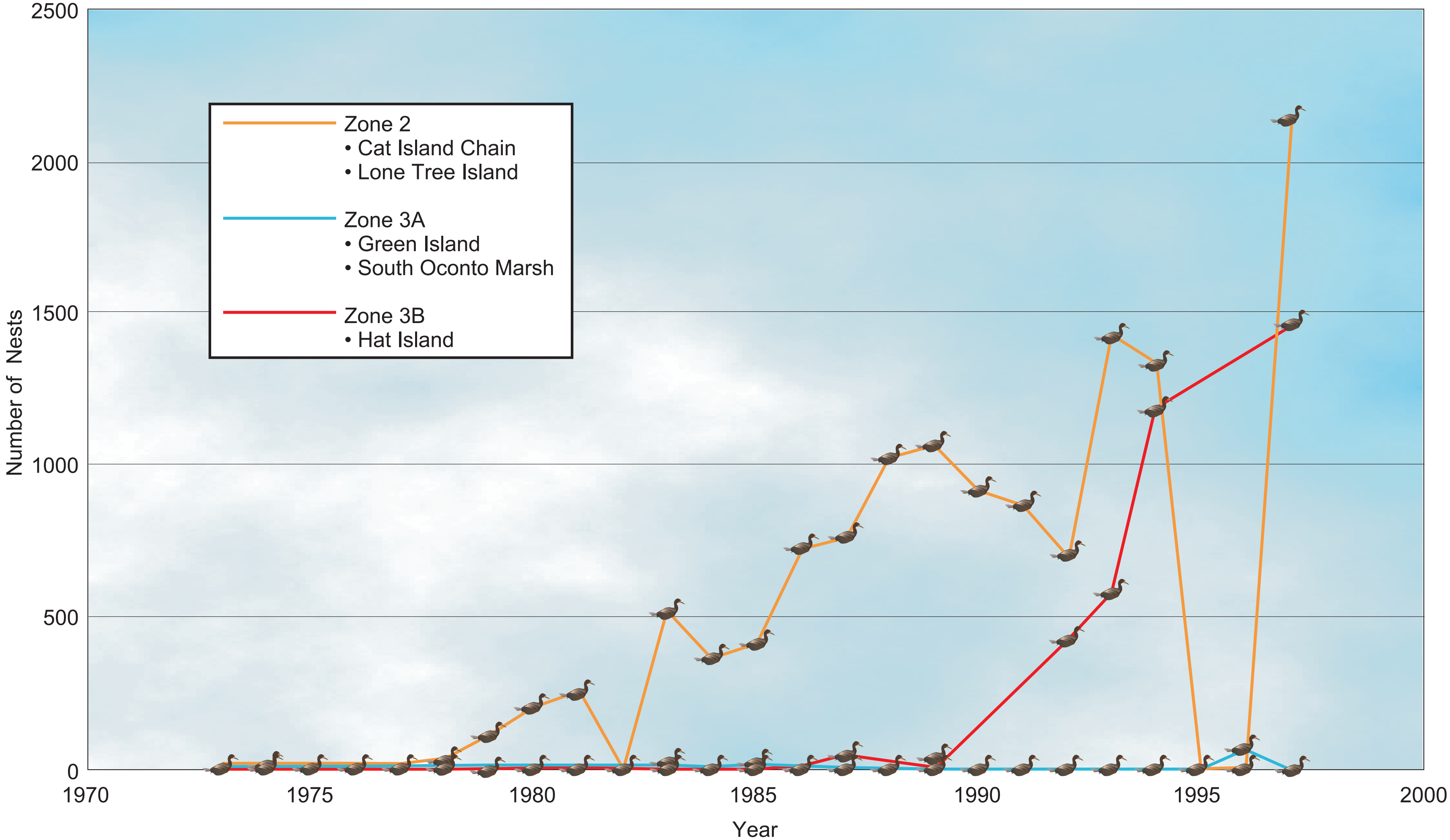
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Distribution of Birds in Green Bay: Select Species and Groups	DRAWING NO: RA-4414-425-2-21
			FIGURE 2-21	PRINT DATE: 3/14/01
				CREATED BY: SCJ
				APPROVED: AGF

Figure 2-22. Forster's Tern Population Data in Green Bay

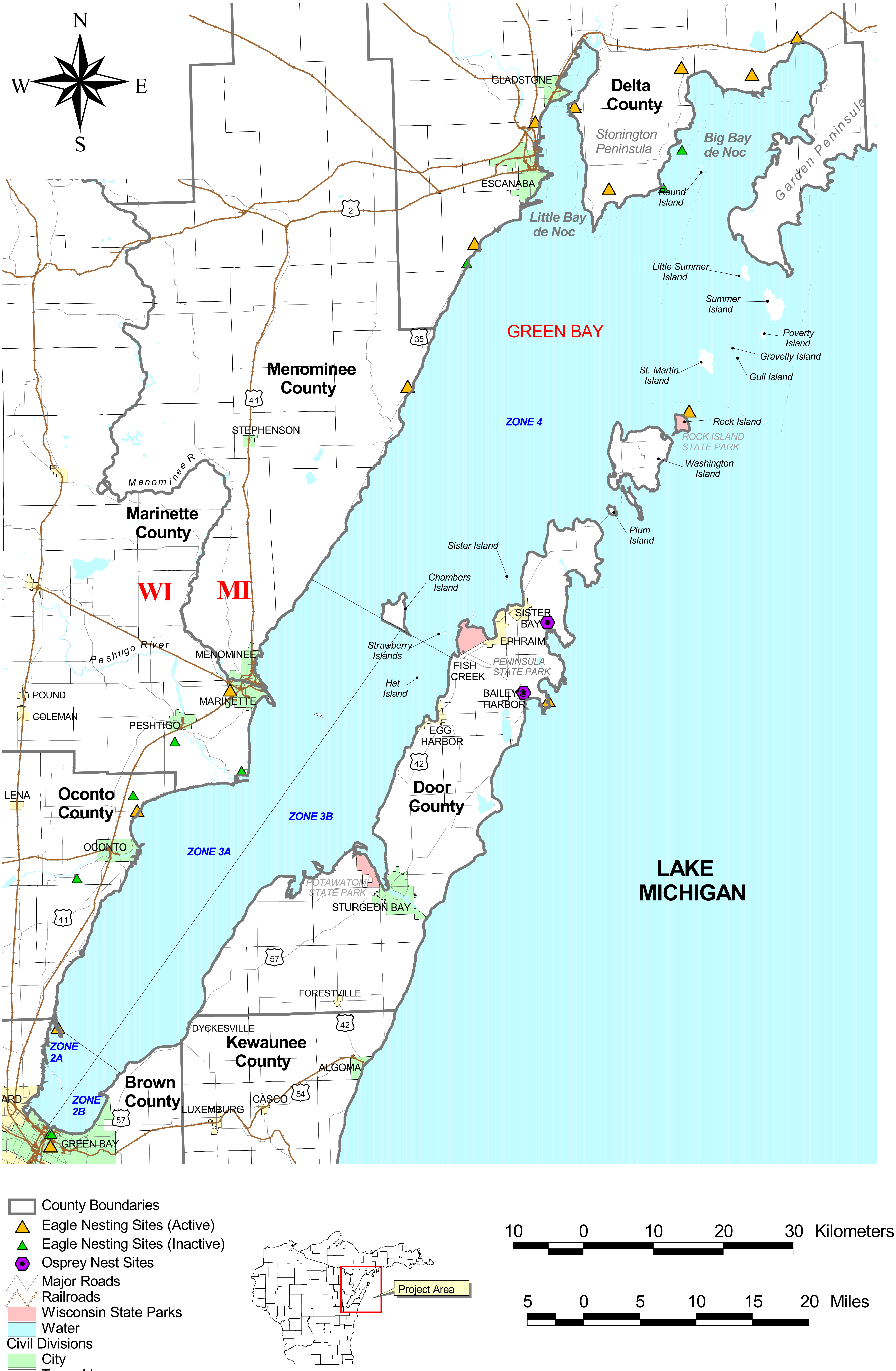


ThermoRetecJanuary2001Figure2_22

Figure 2-23. Number of Double-Crested Cormorant Nests in Zones 2 and 3 of Green Bay



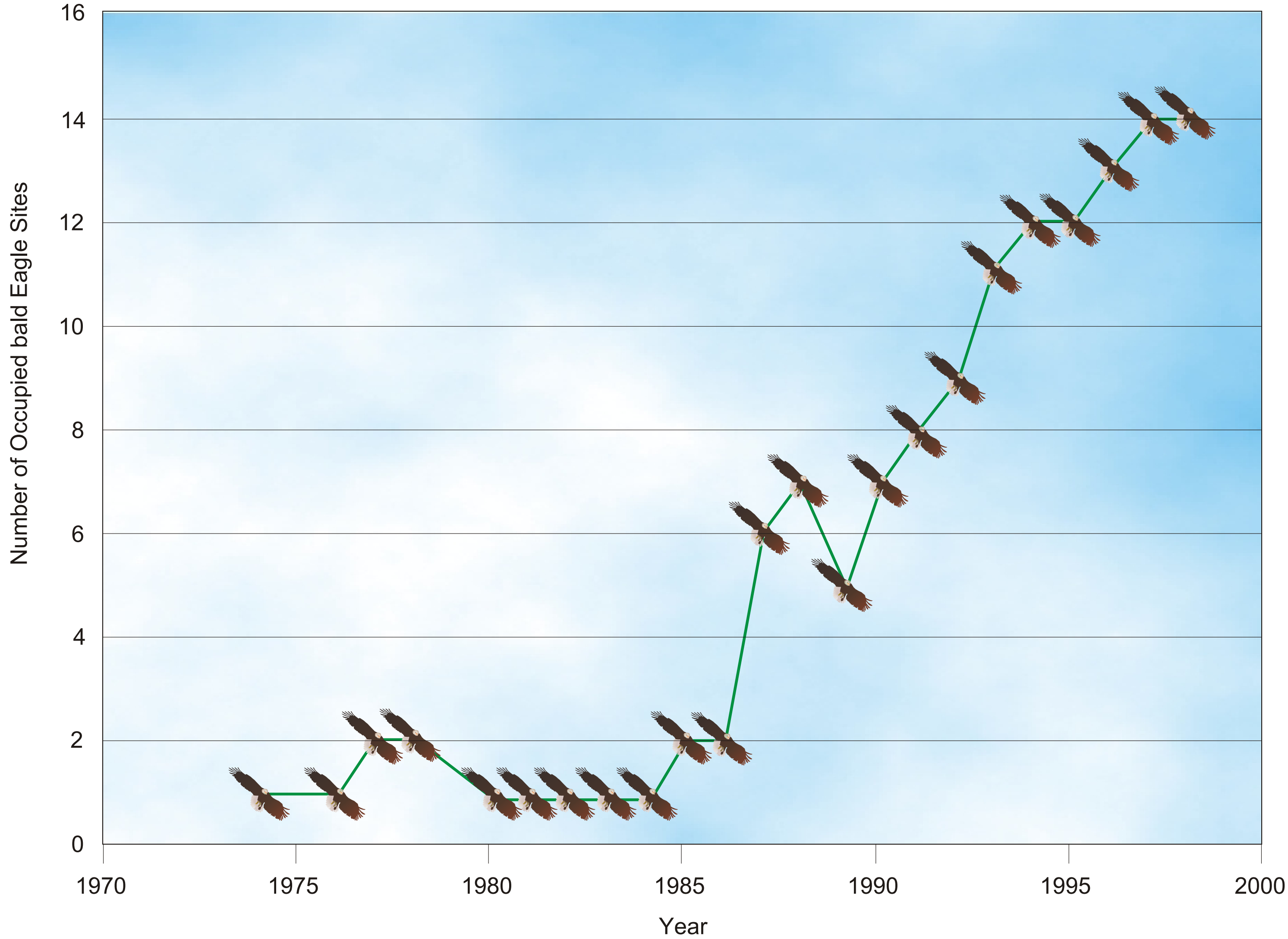
ThermoRetecJanuary2001Figure2_23



NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin data provided by S. Stubenvoll, WDNR.
3. Michigan data from USFWS, 1999.

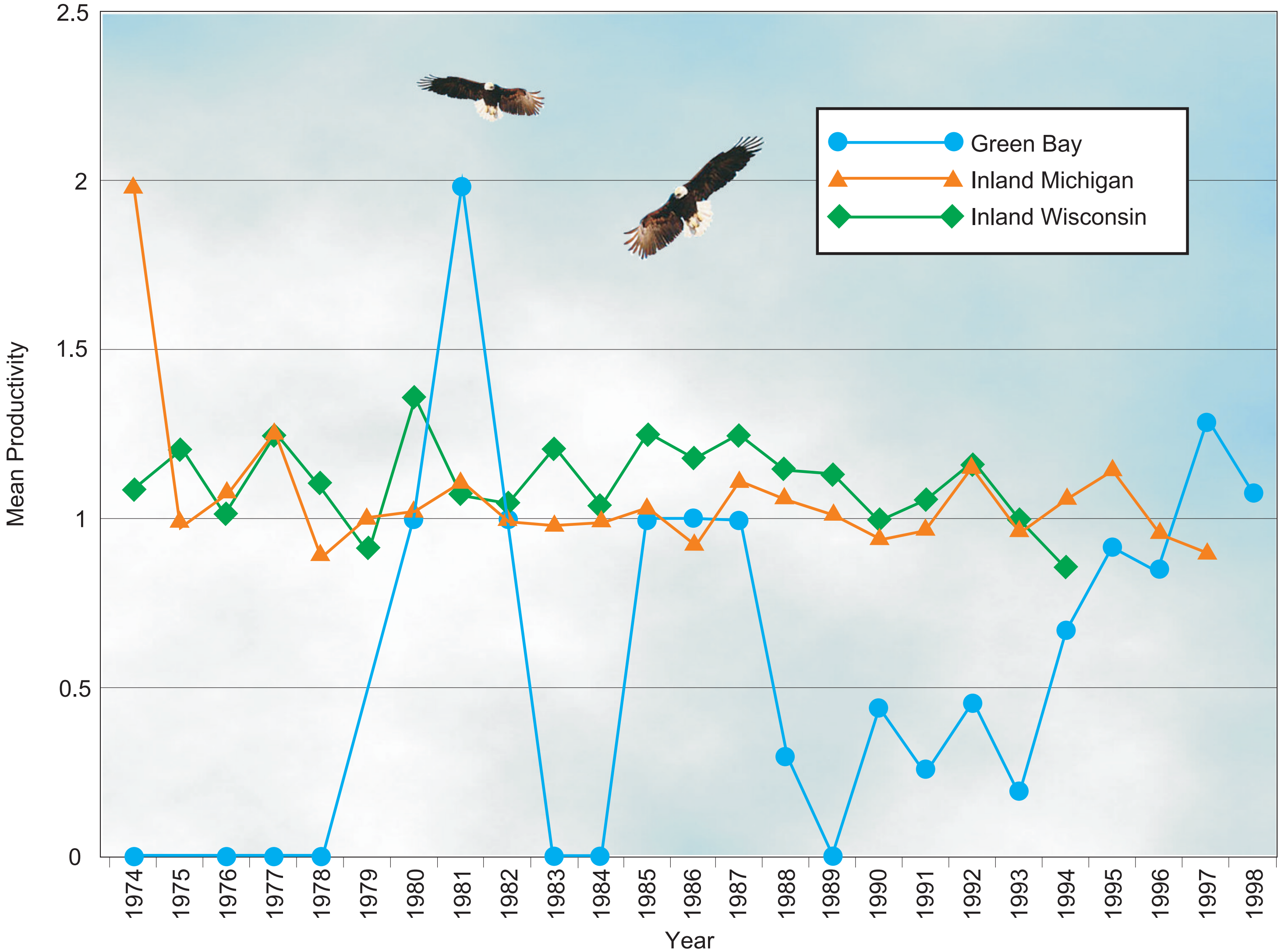
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Distribution of Birds in Green Bay: Eagle and Osprey Locations	DRAWING NO: RA-4414-425-2-24 PRINT DATE: 3/14/01 CREATED BY: SCJ APPROVED: AGF
			FIGURE 2-24	

Figure 2-25. Number of Occupied Bald Eagle Nesting Sites on Green Bay



ThermoRetecJanuary2001Figure2_25

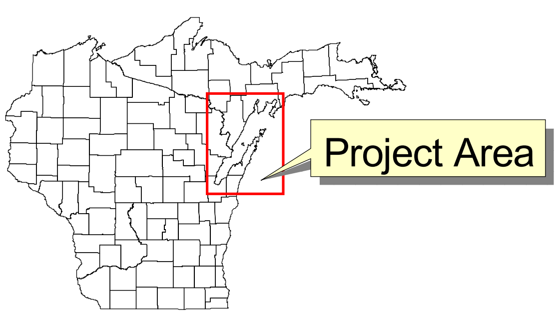
Figure 2-26 Mean Annual Productivity of Bald Eagles Nesting on Green Bay, Inland Michigan, and Inland Wisconsin



Note: Adapted from USFW 1999.

Mink Habitat (100m Buffer)
- Good
- Moderate
- Marginal
- Poor
- Unsuitable
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village

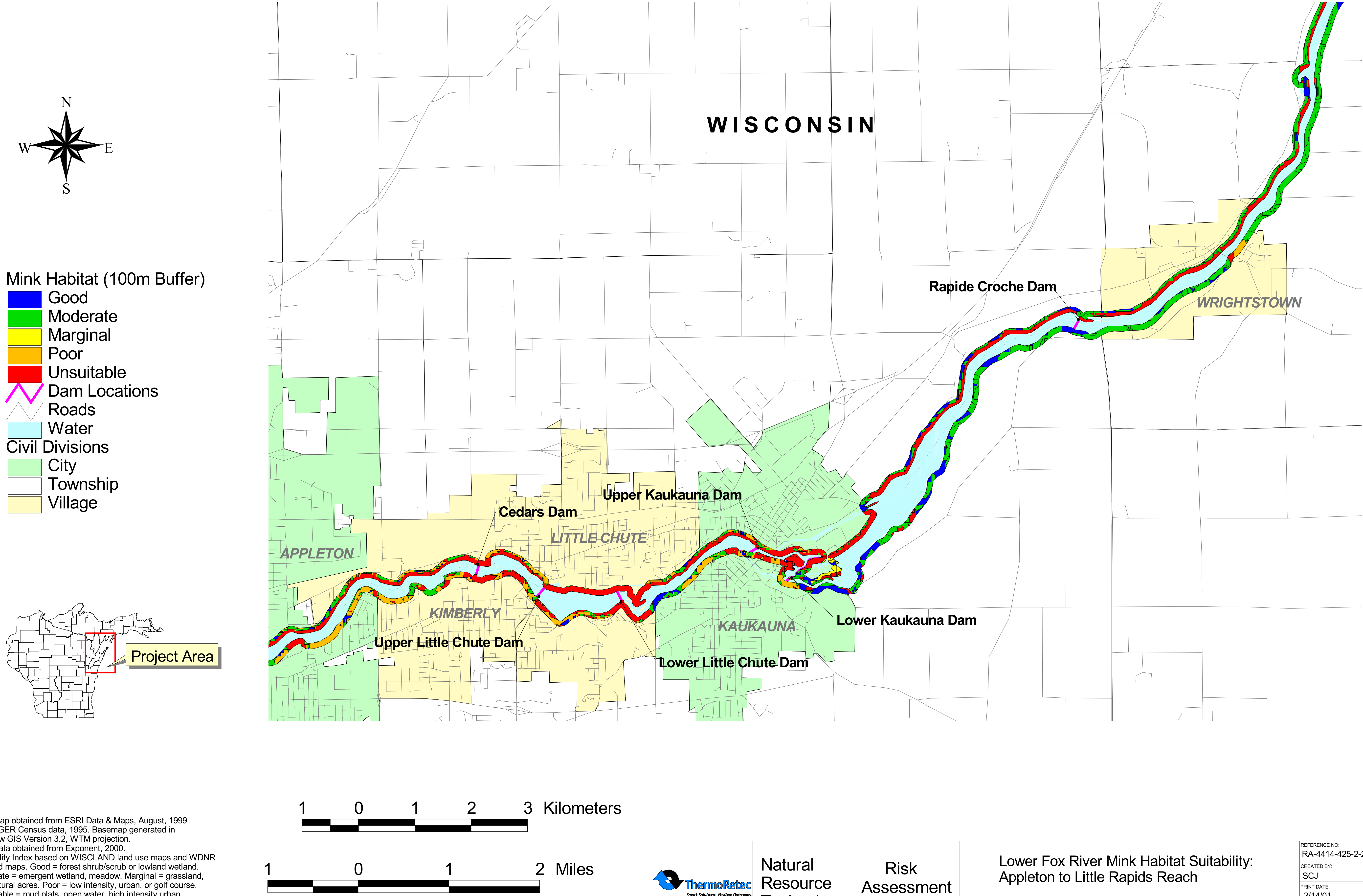


0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

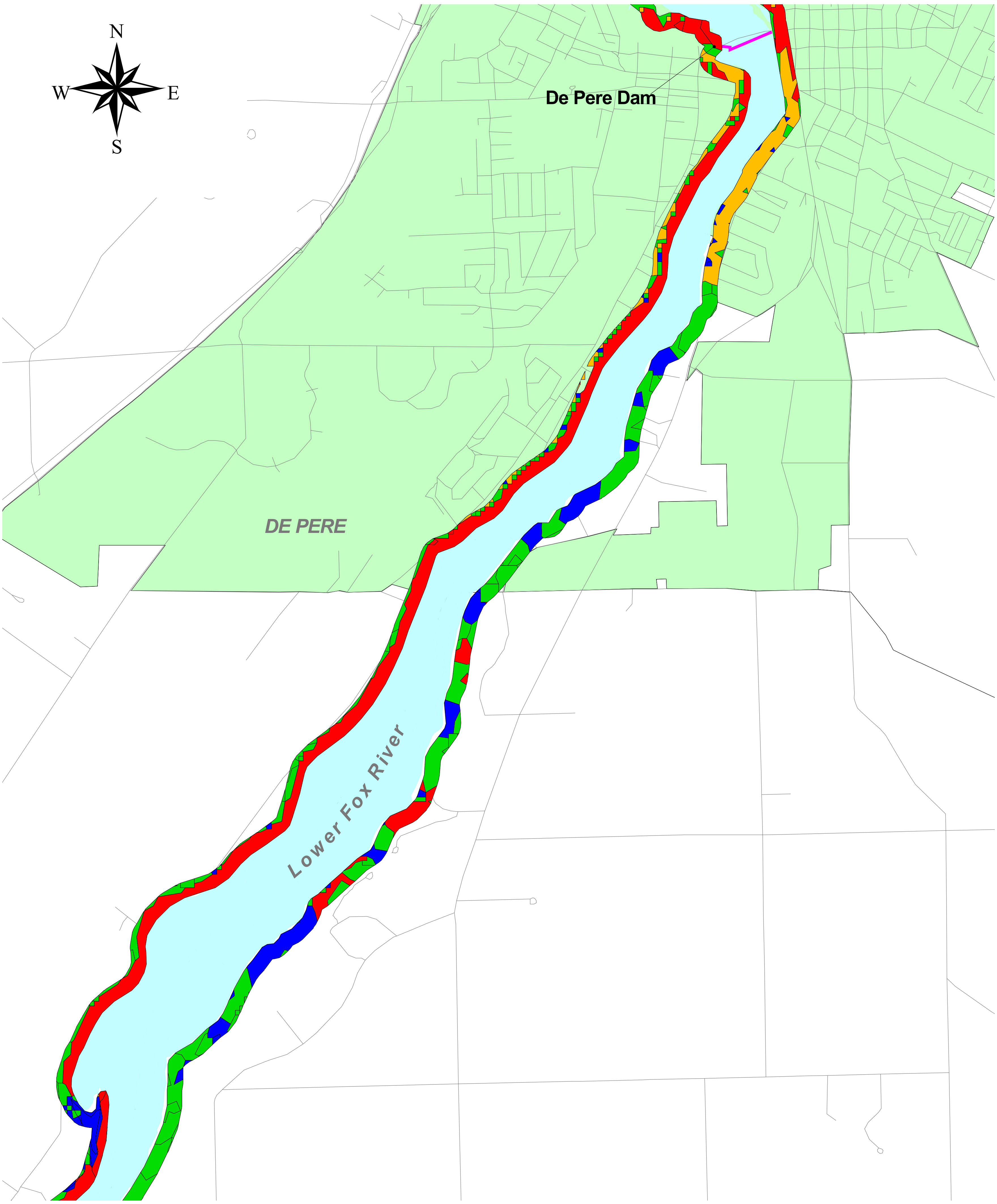
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or lowland wetland. Moderate = emergent wetland, meadow. Marginal = grassland, agricultural acres. Poor = low intensity, urban, or golf course. Unsuitable = mud plats, open water, high intensity urban.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Lower Fox River Mink Habitat Suitability: Little Lake Butte des Morts Reach	REFERENCE NO: RA-4414-425-2-27
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-27	APPROVED: AGF



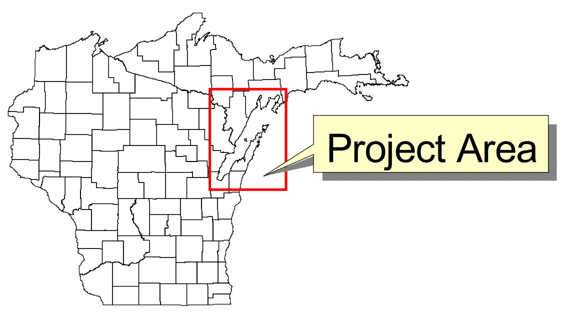
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or lowland wetland. Moderate = emergent wetland, meadow. Marginal = grassland, agricultural acres. Poor = low intensity, urban, or golf course. Unsuitable = mud plats, open water, high intensity urban.

ThermoRetec	Natural Resource Technology	Risk Assessment	Lower Fox River Mink Habitat Suitability: Appleton to Little Rapids Reach	REFERENCE NO: RA-4414-425-2-28
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-28	APPROVED: AGF



Mink Habitat (100m Buffer)
- Good
- Moderate
- Marginal
- Poor
- Unsuitable
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village

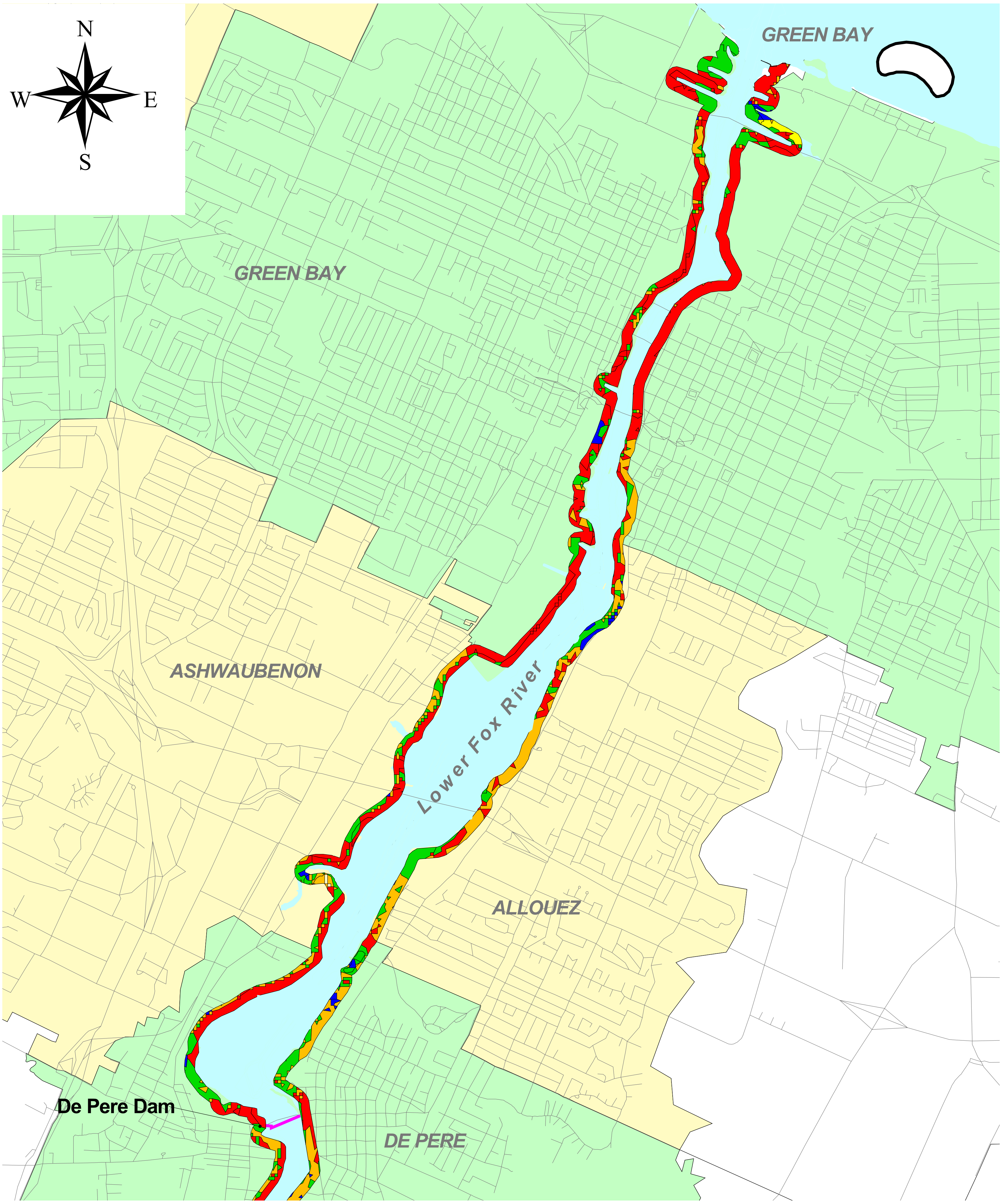


0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

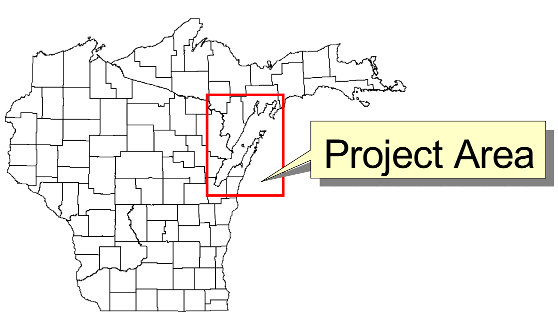
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or lowland wetland. Moderate = emergent wetland, meadow. Marginal = grassland, agricultural acres. Poor = low intensity, urban, or golf course. Unsuitable = mud plats, open water, high intensity urban.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Lower Fox River Mink Habitat Suitability: Little Rapids to De Pere Reach	REFERENCE NO: RA-4414-425-2-29
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-29	APPROVED: AGF



Mink Habitat (100m Buffer)
- Good
- Moderate
- Marginal
- Poor
- Unsuitable
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village

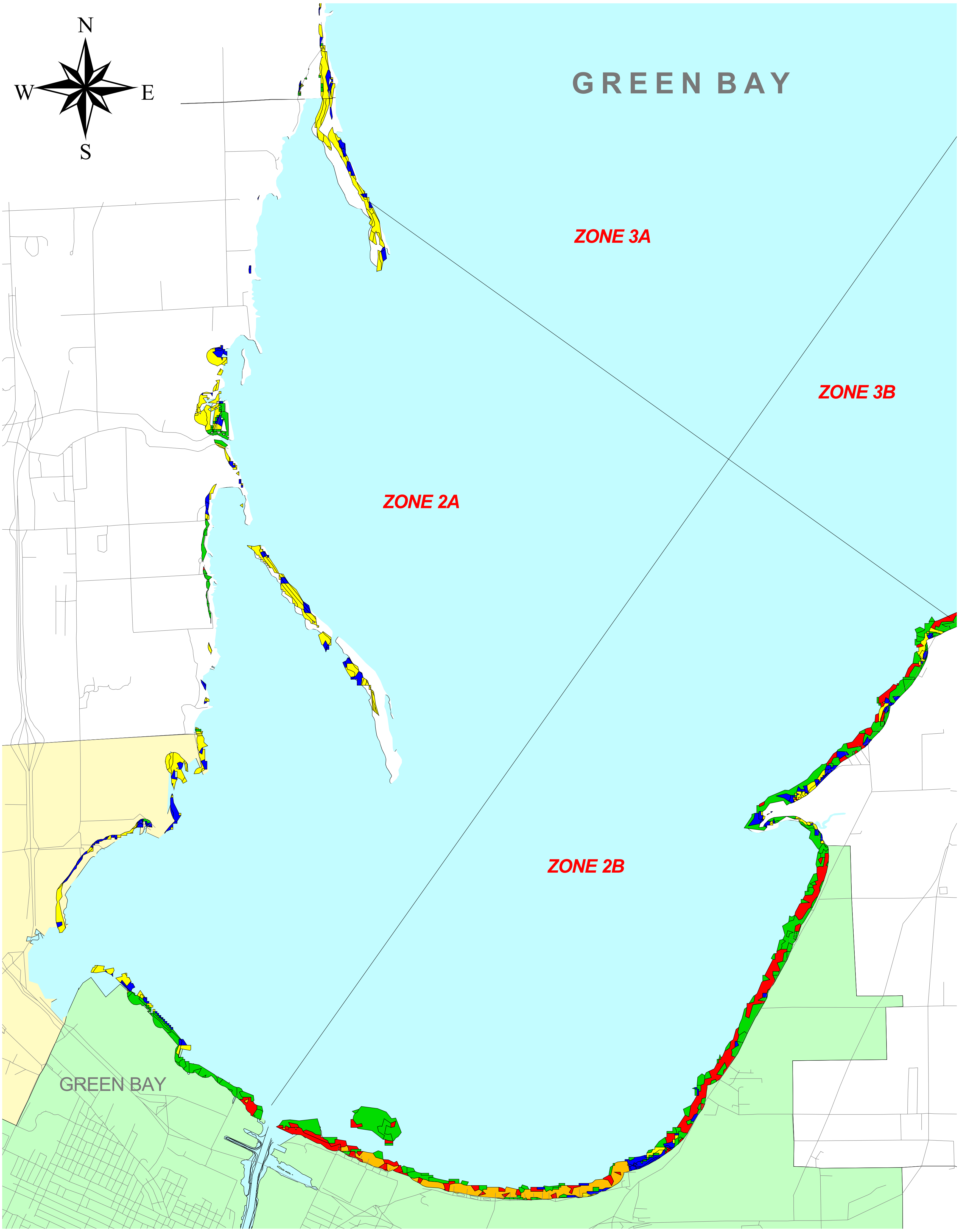


0.5 0 0.5 1 1.5 Kilometers

0.5 0 0.5 1 Miles

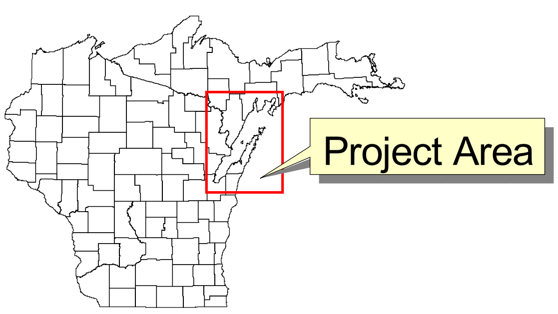
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or lowland wetland. Moderate = emergent wetland, meadow. Marginal = grassland, agricultural acres. Poor = low intensity, urban, or golf course. Unsuitable = mud plats, open water, high intensity urban.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Lower Fox River Mink Habitat Suitability: De Pere to Green Bay Reach	REFERENCE NO: RA-4414-425-2-27
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-30	APPROVED: AGF



Mink Habitat (100m Buffer)
- Good
- Moderate
- Marginal
- Poor
- Unsuitable
- Roads
- Water

Civil Divisions
- City
- Township
- Village

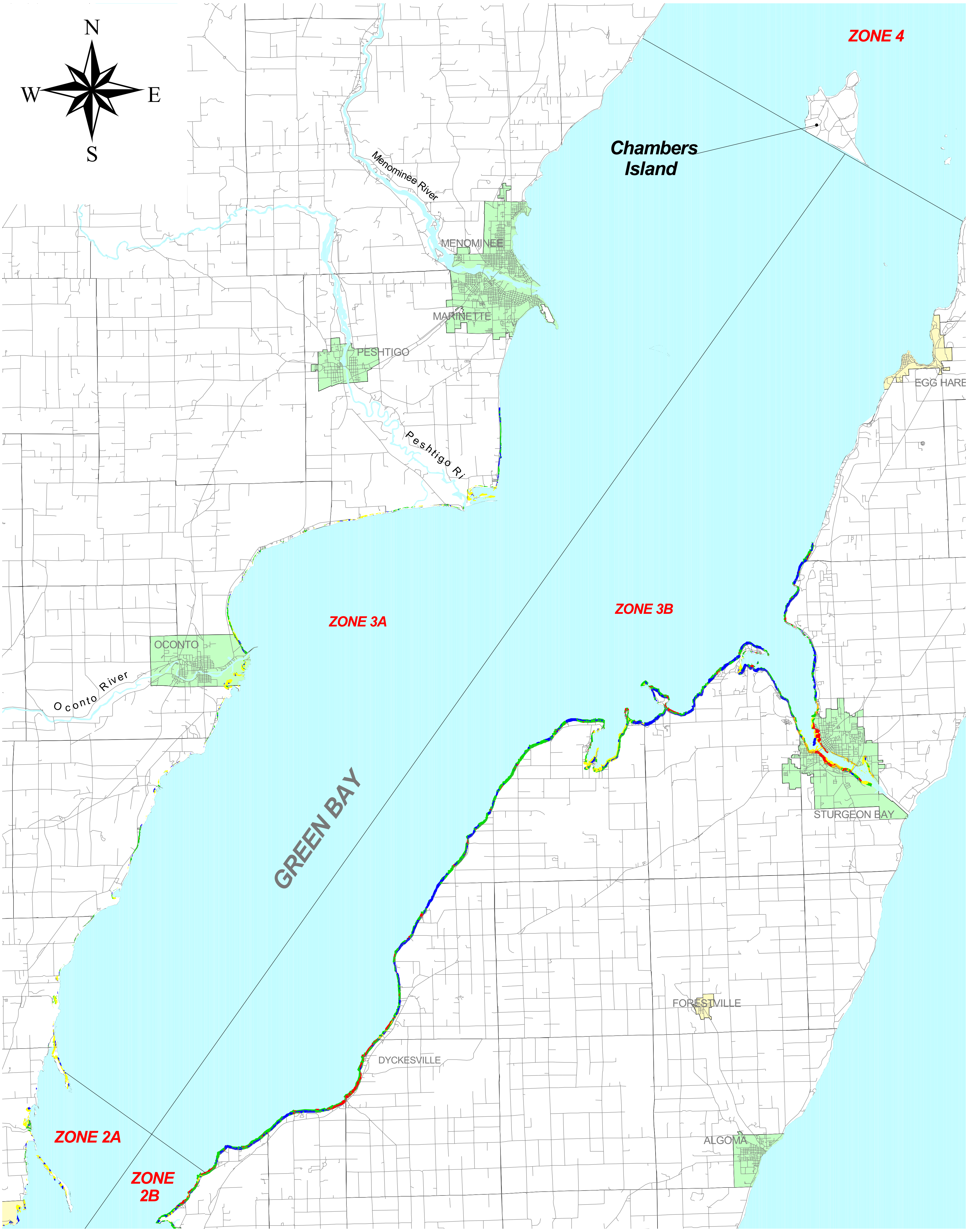


1 0 1 2 Kilometers

1 0 1 Miles

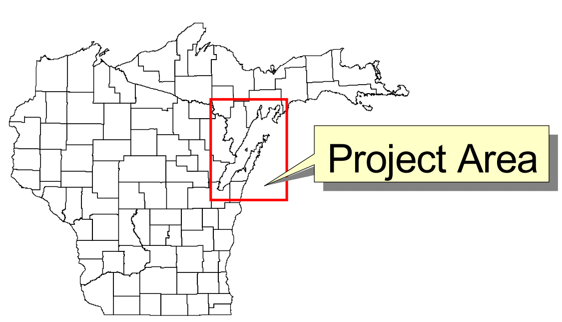
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or lowland wetland. Moderate = emergent wetland, meadow. Marginal = grassland, agricultural acres. Poor = low intensity, urban, or golf course. Unsuitable = mud plats, open water, high intensity urban.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Mink Habitat Suitability: Zone 2	REFERENCE NO: RA-4414-425-2-31
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-31	APPROVED: AGF



Mink Habitat (100m Buffer)
- Good
- Moderate
- Marginal
- Poor
- Unsuitable
- Roads
- Water

Civil Divisions
- City
- Township
- Village



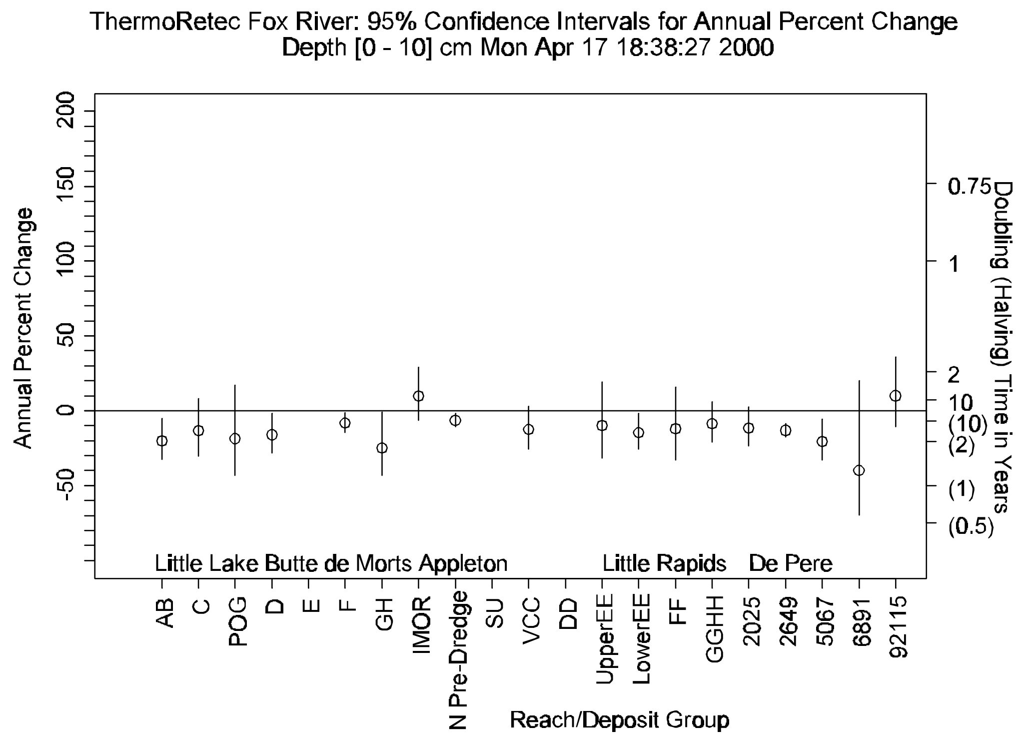
3 0 3 6 9 Kilometers

3 0 3 6 Miles

Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or lowland wetland. Moderate = emergent wetland, meadow. Marginal = grassland, agricultural acres. Poor = low intensity, urban, or golf course. Unsuitable = mud plats, open water, high intensity urban.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Risk Assessment	Green Bay Mink Habitat Suitability: Zone 3	REFERENCE NO: RA-4414-425-2-32
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 2-32	APPROVED: AGF

Figure 2-33 Time Trends of PCBs in Sediments for Depths from 0 to 10 cm and from 10 to 30 cm



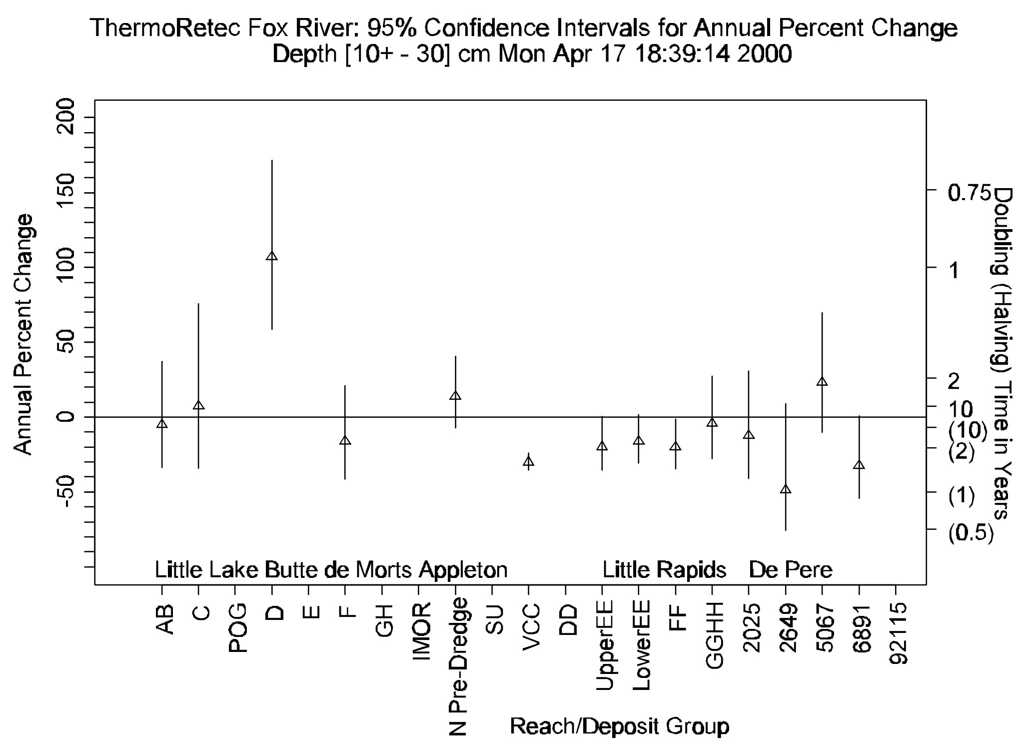
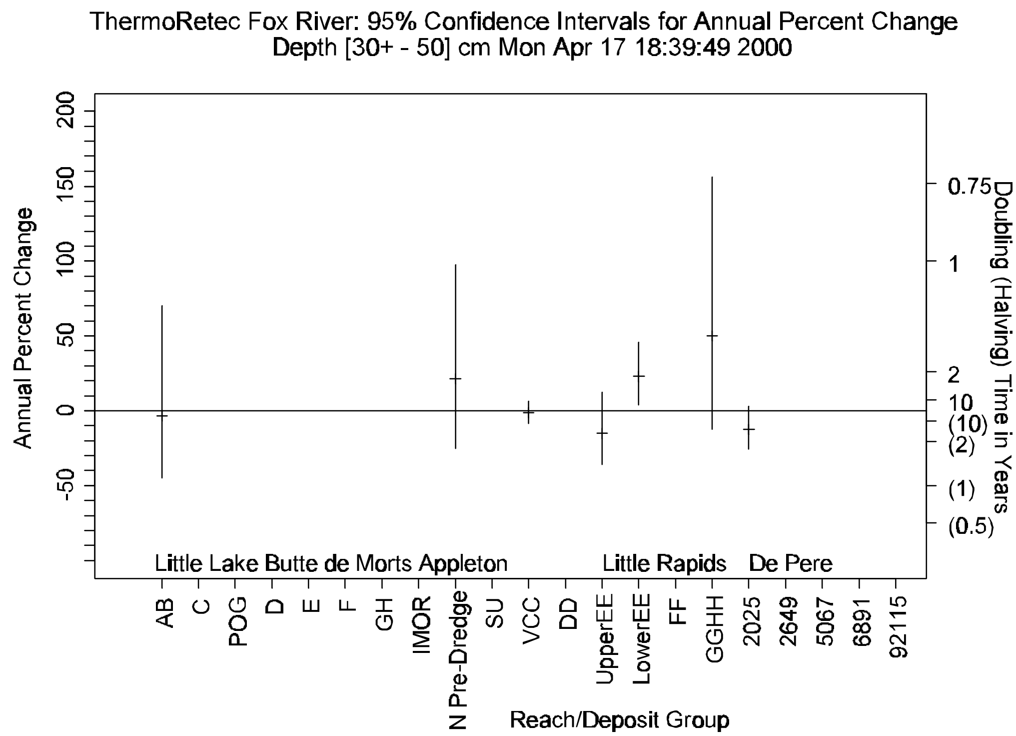


Figure 2-34 Time Trends of PCBs in Sediments for Depths from 30 to 50 cm and from 50 to 100 cm



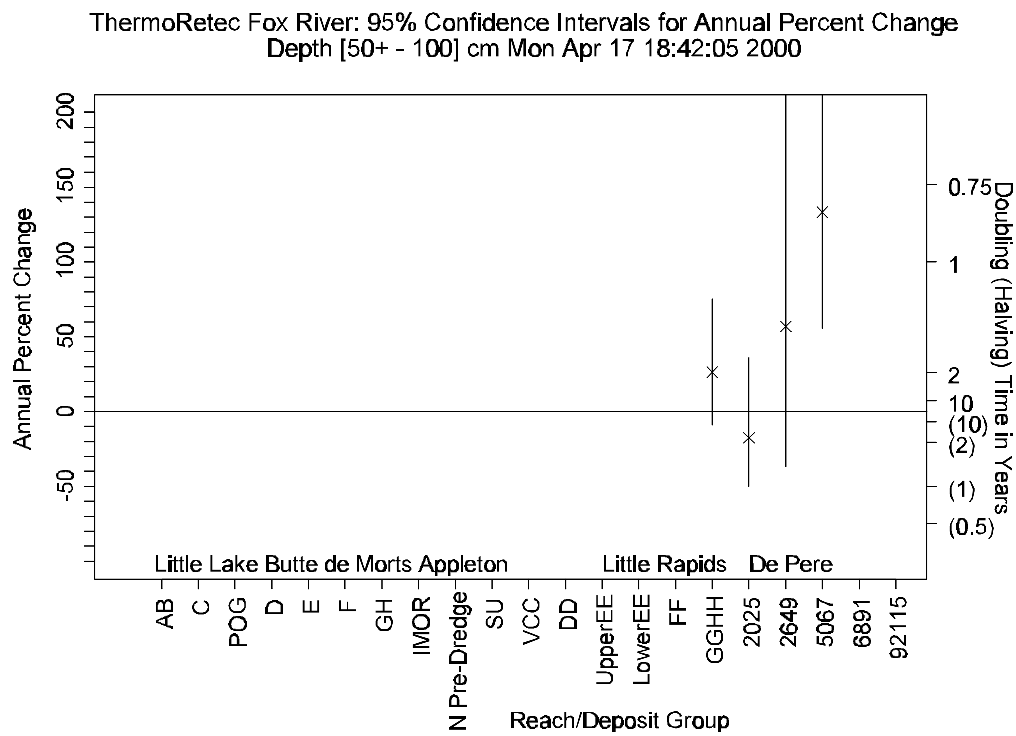


Figure 2-35 Time Trends of PCBs in Sediments for Depths over 100 cm

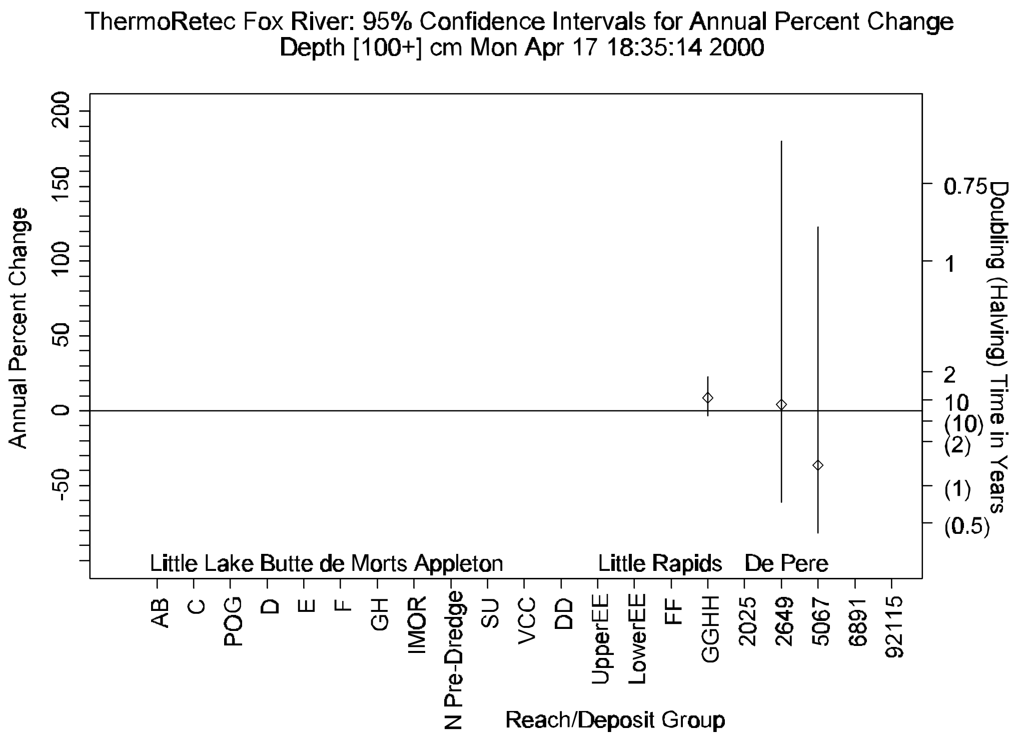


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Table 2-1 Reach and Contaminant Deposit Designations for the Lower Fox River

Reach	Description	Deposits or Sediment Management Units (SMUs)
Little Lake Butte des Morts	Little Lake Butte des Morts from Neenah and Menasha dams to outlet	Deposits A–H and POG
Appleton to Little Rapids	Little Lake Butte des Morts outlet to Little Rapids (Little Kaukauna dam)	Deposits I–DD
Little Rapids to De Pere	Little Rapids (Little Kaukauna dam) to De Pere dam	Deposits EE–HH
De Pere to Green Bay	De Pere dam to river mouth into Green Bay	SMUs 20–115

Table 2-2 Zone Designations for Green Bay

Green Bay Zone Description
Zone 1 is identical to, and will be referred to hereinafter as, the De Pere to Green Bay Reach of the Fox River, discussed above.
Zone 2 extends from the mouth of the Lower Fox River to a line about 12.2 km (7.6 miles) from the mouth of the river. This line crosses the bay near Little Tail Point on the west side of the bay and near Red Banks/Point Vincent on the east side of the bay, approximately 10 km (6.2 miles) south of Dyckesville, Wisconsin.
Zone 3 extends from the northern boundary of Zone 2 to a line just south of Chambers Island. The northern boundary of Zone 3 is located about 86.7 km (53.9 miles) north of the mouth of the Lower Fox River. Therefore, Zone 3 extends for a distance of approximately 74.5 km (46.3 miles). The boundary line of Zone 3 connects Beattie Point, in the Michigan UP to Fish Creek, Wisconsin on the Door Peninsula.
Zone 4 (Figure 1-2) includes the remainder of Green Bay north of Chambers Island, including both Big and Little Bays de Noc. The distance from the south side of Chambers Island to the northern shores of Big Bay de Noc is approximately 101 km (63 miles).

Table 2-3 Major Green Bay Wetland Areas/Complexes

Wetland Area or Complex	State	Areal Extent		Wetland Type
		Acres	Hectares	
East Shore of Green Bay				
Horseshoe Point Wetland Complex	WI	272	110.1	P
Egg Harbor Township Wetland	WI	130	52.6	P
Sand Bay Area Wetland/Complex	WI	120	48.6	L
Little Sturgeon Bay Wetland Complex	WI	315	127.5	P
Point Au Sable Wetland	WI	112	45.3	L/P
Whitney Slough	WI	457	184.9	P
West Shore of Green Bay				
Atkinson Marsh/Peats Lake Complex	WI	509	206.0	L/P/R
Deadhorse Bay Wetland Complex	WI	322	130.3	L/P
Long Tail Point Wetland Complex	WI	163	66.0	L/P
Little Tail Point Wetland Complex	WI	210	85.0	P/L
Charles Pond Area Wetland Complex	WI	170	68.8	L/P
Pensaukee River Wetland Complex	WI	490	198.3	L
Oconto Marsh	WI	9,370	3,791.9	L/P/R
Peshtigo River Wetland	WI	5,040	2,039.6	L/P/R
Cedar River Area Wetland Complex	MI	1,556	629.7	L/P/R
Henderson Lakes Wetland	MI	253	102.4	P
Ford River Area Wetland Complex	MI	389	157.4	L/R
Portage Marsh	MI	1,302	526.9	L
North Shore of Green Bay				
Whitefish River Area Wetland Complex	MI	641	259.4	L
Squaw Point Wetland	MI	729	295.0	L/P
Deepwater Point Wetland Complex	MI	265	107.2	L
Granskog Creek Wetland Complex	MI	729	295.0	L
Sand Bay Wetland Complex	MI	181	73.2	P
Martin Bay Wetland Complex	MI	514	208.0	L
Ogontz Bay Wetland Complex	MI	1,759	711.8	L
Sturgeon River Wetland	MI	6,697	2,710.2	L
Upper Big Bay de Noc Wetland Complex	MI	9,555	3,866.8	L
Wetland Areal Total		**Acres**	**Hectares**	**Sq. Miles**
East Shore Wetland Totals		1,406	569	2.2
West Shore Wetland Totals		19,774	8,002	30.9
North Shore Wetland Totals		21,070	8,527	32.9
Wisconsin Wetland Total		17,680	7,155	27.6
Michigan Wetland Total		24,570	9,943	38.4
Total Wetlands Area		**42,250**	**17,098**	**66**

Notes:

[1] This table only includes wetlands and complexes larger than 100 acres in 1981 (USFWS, 1981).

L - Lacustrine wetland.

P - Palustrine wetland.

R - Riverine wetland.

Table 2-4 Green Bay West Shore Wildlife Area Units

Unit	Hectares (Acres)	Unit	Hectares (Acres)
Peats Lake/South Shore	163.6 (404.3)	Pensaukee W.A.	164.1 (405.6)
Long Tail Point N.W.R.	52.3 (129.3)	Pecor Point	35.3 (87.1)
Sensiba W.A.	317.8 (785.4)	Oconto Marsh	362.7 (896.2)
Little Tail	86.0 (212.4)	Rush Point	74.2 (183.3)
Tibbet-Suamico	106.7 (263.6)	Peshtigo Harbor W.A.	1,609.4 (3,976.9)
Charles Point	43.7 (108.0)	**Total Area**	**3,015.8 (7,452.1)**

Table 2-5 Summary of Green Bay Tributaries

Tributary	State	Drainage Area km^2 (mi^2)	Mean Discharge m^3/s (cfs)	Population Total
Lower Fox	WI	16,394 (6,330)	149 (5,262)	306,360
Duck-Pensaukee	WI	780 (301)	2.9 (101.6)	66,890
Suamico	WI	157 (60.7)	0.95 (33.4)	N/A
Oconto	WI	2,416 (933)	15.9 (560)	25,650
Peshtigo	WI	2,991 (1,155)	20 (704)	30,770
Menominee	WI/MI	10,748 (4,150)	78 (2,750)	57,320
Door - Kewaunee	WI	N/A	N/A	47,410
Cedar - Ford	MI	2,199 (849)	N/A	18,250
Escanaba	MI	2,383 (920)	23 (828)	7,570
Tacoosh	MI	75 (29)	N/A	N/A
Rapid	MI	352 (136)	N/A	N/A
Whitefish	MI	811 (313)	N/A	N/A
Fishdam - Sturgeon	MI	766 (296)	5.3 (188)	2,170
			Total:	**562,390**

Note:
N/A - Not available.

Table 2-6 Lower Fox River Habitats

Habitat Type	Description	Upstream of De Pere Dam	Downstream of De Pere Dam	River Totals
Lock Channels	These border the dams and provide habitat for fish, birds, and wildlife.	9.74%	0.38%	10.12%
Bridge Abutments	These create eddies which attract forage fish feeding on plankton. Swallows also nest beneath bridges.	0.01%	< 0.01%	0.01%
Backwaters, cuts, & coves	These serve as refuge and foraging sites for fish and wildlife. Piscivorous birds feed in these areas.	20.93%	6.91%	27.84%
Islands & Peninsulas	These provide habitat for birds and wildlife. The shores and shallows provide spawning grounds.	43.16%	0.48%	43.64%
Tributaries	Wetlands often develop at the mouths and provide habitat for fish, birds, and wildlife.	2.10%	4.09%	6.19%
Dam Riffles	Turbulent water is preferred spawning habitat of walleye and other fish. These areas attract many fish to feed, which attracts piscivorous birds.	4.22%	1.56%	5.78%
Submerged rock, piling, or ruins	Outcroppings, rocky shallows, and abandoned former piers and pilings provide excellent habitat for aquatic organisms and nesting or roosting sites for birds.	3.49%	2.93%	6.42%
Deadfall and overhang	Features vegetated shoreline, offering favorable habitat for fish, wildlife, and piscivorous birds and nesting sites for passerines. Habitat density upstream of De Pere dam was generally moderate to high while downstream it was generally low.			

Note:

Prepared from information compiled by Exponent (1998).

Table 2-7 Lower Fox River Shoreline and Substrate Types

Shoreline Type & Distance (km)	Upstream of De Pere Dam						Downstream of De Pere Dam					LFR Shoreline Totals	
	Area 1	Area 2	Area 3	Area 4	Area 5	Totals	Area 1	Area 2	Area 3	Area 4	Totals	Distance	Percent
Developed Shoreline													
Riprap	5.99	1.85	3.12	1.73	4.46	**17.15**	1.44	1.46	0.66	1.67	**5.24**	**22.39**	**35.7%**
Bulkhead	1.88	1.18	0.00	0.20	0.19	**3.46**	0.08	0.17	0.61	1.33	**2.18**	**5.64**	**9.0%**
Total	7.87	3.03	3.12	1.94	4.65	**20.61**	1.52	1.63	1.28	2.99	**7.42**	**28.03**	**44.6%**
Natural Shoreline													
Riparian Canopy	1.48	2.89	7.93	7.96	3.91	**24.16**	1.79	0.72	0.43	0.41	**3.35**	**27.51**	**43.8%**
Groundcover/wetland	2.17	1.48	1.95	0.20	0.47	**6.27**	0.55	0.02	0.00	0.00	**0.57**	**6.84**	**10.9%**
Sand/gravel	0.00	0.00	0.00	0.10	0.28	**0.38**	0.00	0.02	0.00	0.00	**0.02**	**0.41**	**0.6%**
Total	3.65	4.37	9.88	8.26	4.65	**30.81**	2.34	0.77	0.43	0.41	**3.94**	**34.75**	**55.4%**
Total Shoreline (km)	**11.51**	**7.40**	**13.00**	**10.20**	**9.30**	**51.41**	**3.86**	**2.40**	**1.70**	**3.40**	**11.36**	**62.78**	**100.0%**
River Substrate Types and Area (km^2)													
Type 1	1.62	0.00	1.85	0.01	3.23	**6.70**	1.89	1.62	0.49	0.95	**4.95**	**11.65**	**53.3%**
Type 2	2.70	0.15	0.37	0.05	0.15	**3.43**	0.11	0.09	0.00	0.00	**0.19**	**3.62**	**16.6%**
Type 3	1.08	1.35	1.85	1.71	0.23	**6.21**	0.06	0.00	0.00	0.01	**0.07**	**6.28**	**28.8%**
Type 4	0.00	0.00	0.00	0.00	0.15	**0.15**	0.04	0.00	0.01	0.04	**0.09**	**0.24**	**1.1%**
Type 5	0.00	0.00	0.02	0.01	0.02	**0.05**	0.00	0.00	0.00	0.00	**0.00**	**0.05**	**0.2%**
Total Coverage (km^2)	**5.40**	**1.50**	**4.08**	**1.78**	**3.78**	**16.54**	**2.10**	**1.70**	**0.50**	**1.00**	**5.30**	**21.84**	**100.0%**

Notes:

Prepared from information compiled by Exponent (1998).

Descriptions of the Areas (Exponent, 1998).

Area 1 - Little Lake Butte des Morts to Appleton lock 1.
Area 2 - Appleton lock 1 to Cedars lock.
Area 3 - Cedars lock to Rapide Croche lock.
Area 4 - Rapide Croche lock to Little Kaukauna lock.
Area 5 - Little Kaukauna Lock to De Pere dam.

Area 1 - De Pere dam to Highway 172 bridge.
Area 2 - Highway 172 bridge to Ft. Howard (Ft. James) RR trestle.
Area 3 - Ft. Howard RR trestle to E. Mason Street bridge.
Area 4 - E. Mason Street bridge to mouth of the Fox River.

Descriptions of Substrate Types (Exponent, 1998).

Type 1 - Soft, aqueous, silty sediments.
Type 2 - Semicompact to compact sands and/or clay.
Type 3 - Compact sand, gravel, or cobble deposits.
Type 4 - Combination of Types 1 and 2.
Type 5 - Cobble/boulder-size rocks.

Table 2-8 Lower Fox River/Duck Creek Fish Surveys

Study Area	Time Period	Reference	Purpose
Little Lake Butte des Morts to De Pere	1976	Marinac & Coble	Determine species present and relative abundance
Rapide Croche to Wrightstown	1976	Langhurst	Evaluate stocks as water quality improves in the future
Little Lake Butte des Morts to Wrightstown	1977	Meyers	Community and populations
Little Lake Butte des Morts	1983	Meyers	Evaluate northern pike populations and spawning areas
Little Lake Butte des Morts to Wrightstown	1993/94	Brook & Lychwick	Fisheries and habitat status
Little Rapids to De Pere	1994/95	Lychwick	Population surveys
De Pere to Green Bay	1987/98	Lychwick	Evaluate early spring spawning populations
Duck Creek Assessment	1995/96	Cogswell/Bougie	Populations survey spring through fall

Table 2-9 Lower Fox River Fish Species Composition

Species	Little Lake Butte des Morts		Little Lake Butte des Morts to Little Rapids			
	1983		1976–1977		1993–1994	
	Total Catch	Percent of Catch	Total Catch	Percent of Catch	Total Catch	Percent of Catch
Non-Game Fish [A]						
Alewife	0	0.0%	0	0.0%	0	0.0%
Bowfin	0	0.0%	0	0.0%	0	0.0%
Burbot	77	1.4%	2	0.0%	0	0.0%
Carp	1,995	36.1%	2,997	52.9%	533	54.1%
Creek Chub	0	0.0%	1	0.0%	0	0.0%
Drum (freshwater)	0	0.0%	137	2.4%	73	7.4%
Gizzard Shad	0	0.0%	11	0.2%	4	0.4%
Shortnose Gar	0	0.0%	5	0.1%	2	0.2%
Longnose Gar	0	0.0%	1	0.0%	0	0.0%
Redhorse	0	0.0%	0	0.0%	0	0.0%
Silver Lamprey	0	0.0%	0	0.0%	0	0.0%
Emerald Shiner	0	0.0%	82	1.4%	7	0.7%
Golden Shiner	0	0.0%	6	0.1%	1	0.1%
Spotfin Shiner	0	0.0%	4	0.1%	0	0.0%
Spottail Shiner	0	0.0%	1	0.0%	0	0.0%
White Sucker	180	3.3%	527	9.3%	3	0.3%
Quillback Carpsucker	1	0.0%	157	2.8%	15	1.5%
Log Perch	0	0.0%	42	0.7%	0	0.0%
Trout Perch	0	0.0%	43	0.8%	38	3.9%
Total: Non-game fish	**2,253**	**40.8%**	**4,016**	**70.9%**	**676**	**68.6%**
Game Fish						
Bluegill	2	0.0%	1	0.0%	0	0.0%
Rock Bass	0	0.0%	27	0.5%	3	0.3%
Largemouth Bass	0	0.0%	0	0.0%	0	0.0%
Smallmouth Bass	0	0.0%	6	0.1%	1	0.1%
White Bass	8	0.1%	46	0.8%	189	19.2%
Yellow Bass	1	0.0%	0	0.0%	0	0.0%
Black Bullhead	1,407	25.5%	933	16.5%	0	0.0%
Brown Bullhead	83	1.5%	0	0.0%	0	0.0%
Yellow Bullhead	0	0.0%	11	0.2%	0	0.0%
Channel Catfish	0	0.0%	1	0.0%	0	0.0%
Flathead Catfish	0	0.0%	0	0.0%	1	0.1%
Black Crappie	1,540	27.9%	96	1.7%	7	0.7%
White Crappie	0	0.0%	0	0.0%	0	0.0%
Spotted Muskie	0	0.0%	0	0.0%	0	0.0%
Northern Pike	171	3.1%	59	1.0%	12	1.2%
White Perch	0	0.0%	0	0.0%	0	0.0%
Yellow Perch	22	0.4%	360	6.4%	18	1.8%
Pumpkinseed	0	0.0%	15	0.3%	0	0.0%
Sauger	0	0.0%	0	0.0%	7	0.7%
Green Sunfish	2	0.0%	0	0.0%	0	0.0%
Brook Trout	0	0.0%	0	0.0%	0	0.0%
Lake Trout	0	0.0%	0	0.0%	0	0.0%
Rainbow Trout	0	0.0%	0	0.0%	0	0.0%
Walleye	34	0.6%	94	1.7%	72	7.3%
Total: Game Fish	**3270**	**59.2%**	**1649**	**29.1%**	**310**	**31.4%**
Totals	**5,523**	**100%**	**5,665**	**100%**	**986**	**100%**

Table 2-9 Lower Fox River Fish Species Composition (Continued)

Species	Little Rapids to De Pere					
	1975–1976		1983–1985		1994–1995	
	Total Catch	Percent of Catch	Total Catch	Percent of Catch	Total Catch	Percent of Catch
Non-Game Fish [A]						
Alewife	221	3.4%	0	0.0%	46	0.5%
Bowfin	1	0.0%	0	0.0%	1	0.0%
Burbot	0	0.0%	156	0.8%	4	0.0%
Carp	3,425	53.1%	12,570	65.1%	2,611	28.2%
Creek Chub	1	0.0%	0	0.0%	0	0.0%
Drum (freshwater)	156	2.4%	1,661	8.6%	928	10.0%
Gizzard Shad	3	0.0%	2,903	15.0%	1,081	11.7%
Shortnose Gar	5	0.1%	0	0.0%	6	0.1%
Longnose Gar	1	0.0%	2	0.0%	0	0.0%
Redhorse	0	0.0%	36	0.2%	76	0.8%
Silver Lamprey	0	0.0%	0	0.0%	0	0.0%
Emerald Shiner	1	0.0%	1	0.0%	71	0.8%
Golden Shiner	1	0.0%	0	0.0%	0	0.0%
Spotfin Shiner	0	0.0%	0	0.0%	55	0.6%
Spottail Shiner	0	0.0%	0	0.0%	77	0.8%
White Sucker	648	10.0%	545	2.8%	24	0.3%
Quillback Carpsucker	15	0.2%	92	0.5%	208	2.2%
Log Perch	0	0.0%	0	0.0%	37	0.4%
Trout Perch	1	0.0%	4	0.0%	315	3.4%
Total: Non-game fish	**4,479**	**69.4%**	**17,970**	**93.0%**	**5,540**	**59.8%**
Game Fish						
Bluegill	2	0.0%	5	0.0%	38	0.4%
Rock Bass	7	0.1%	69	0.4%	110	1.2%
Largemouth Bass	0	0.0%	1	0.0%	1	0.0%
Smallmouth Bass	0	0.0%	10	0.1%	493	5.3%
White Bass	174	2.7%	85	0.4%	293	3.2%
Yellow Bass	0	0.0%	0	0.0%	1	0.0%
Black Bullhead	1,024	15.9%	61	0.3%	0	0.0%
Brown Bullhead	0	0.0%	9	0.0%	0	0.0%
Yellow Bullhead	0	0.0%	11	0.1%	1	0.0%
Channel Catfish	2	0.0%	34	0.2%	411	4.4%
Flathead Catfish	0	0.0%	8	0.0%	11	0.1%
Black Crappie	188	2.9%	290	1.5%	269	2.9%
White Crappie	0	0.0%	0	0.0%	2	0.0%
Spotted Muskie	0	0.0%	0	0.0%	1	0.0%
Northern Pike	46	0.7%	228	1.2%	57	0.6%
White Perch	0	0.0%	0	0.0%	327	3.5%
Yellow Perch	396	6.1%	112	0.6%	535	5.8%
Pumpkinseed	59	0.9%	2	0.0%	1	0.0%
Sauger	1	0.0%	19	0.1%	9	0.1%
Green Sunfish	2	0.0%	0	0.0%	10	0.1%
Brook Trout	0	0.0%	0	0.0%	0	0.0%
Lake Trout	0	0.0%	0	0.0%	0	0.0%
Rainbow Trout	0	0.0%	0	0.0%	0	0.0%
Walleye	74	1.1%	404	2.1%	1,153	12.4%
Total: Game Fish	**1975**	**30.6%**	**1348**	**7.0%**	**3723**	**40.2%**
Totals	**6,454**	**100%**	**19,318**	**100%**	**9,263**	**100%**

Notes:

[A] As Listed in Wisconsin State Statute Chapter 29.01.

[B] No differentiation made between shortnose/longnose gar. Value listed for shortnose gar represents both species.

[C] No differentiation made between bullheads (black, brown, yellow). Value listed for black bullhead represents all three species.

Table 2-10 Lower Fox River Fish Populations in the De Pere to Green Bay Reach

Species	1987 Catch	1987 % Catch	1988 Catch	1988 % Catch	1989 Catch	1989 % Catch	1990 Catch	1990 % Catch	1991 Catch	1991 % Catch	1992 Catch	1992 % Catch
Non-Game Fish												
Alewife*	3	0.0%	-	0.0%	-	0.0%	-	0.0%	1	0.0%	-	0.0%
Burbot	19	0.1%	25	0.1%	12	0.1%	12	0.1%	12	0.1%	12	0.1%
Carp*	1,220	5.4%	659	3.7%	1,322	6.6%	886	9.6%	863	4.6%	1,382	8.7%
Drum (freshwater)*	259	1.1%	210	1.2%	998	5.0%	652	7.1%	391	2.1%	1,242	7.8%
Gar	28	0.1%	20	0.1%	35	0.2%	17	0.2%	9	0.0%	58	0.4%
Gizzard Shad*	2	0.0%	8	0.0%	4	0.0%	104	1.1%	13	0.1%	34	0.2%
Longnose Sucker	4	0.0%	2	0.0%	6	0.0%	-	0.0%	3	0.0%	12	0.1%
Mooneye	-	0.0%	-	0.0%	1	0.0%	-	0.0%	-	0.0%	8	0.1%
Quillback	30	0.1%	7	0.0%	72	0.4%	176	1.9%	280	1.5%	866	5.4%
Redhorse*	16	0.1%	12	0.1%	17	0.1%	11	0.1%	22	0.1%	17	0.1%
Trout-perch*	2	0.0%	5	0.0%	10	0.1%	7	0.1%	-	0.0%	32	0.2%
White Sucker*	1,554	6.9%	1,002	5.6%	2,071	10.4%	724	7.9%	852	4.5%	817	5.1%
Total Non-Game Fish	**3,137**	**13.9%**	**1,950**	**10.9%**	**4,548**	**22.8%**	**2,589**	**28.2%**	**2,446**	**13.0%**	**4,480**	**28.1%**
Game Fish												
Black Bullhead*	274	1.2%	608	3.4%	960	4.8%	599	6.5%	64	0.3%	18	0.1%
Black Crappie*	413	1.8%	181	1.0%	602	3.0%	427	4.6%	730	3.9%	255	1.6%
Bluegill*	4	0.0%	2	0.0%	29	0.1%	53	0.6%	10	0.1%	17	0.1%
Brook Trout	1	0.0%	-	0.0%	1	0.0%	-	0.0%	-	0.0%	1	0.0%
Brown Bullhead	5	0.0%	10	0.1%	13	0.1%	1	0.0%	-	0.0%	1	0.0%
Channel Catfish	52	0.2%	55	0.3%	125	0.6%	315	3.4%	74	0.4%	238	1.5%
Flathead Catfish	-	0.0%	2	0.0%	10	0.1%	22	0.2%	8	0.0%	35	0.2%
Hydrid Muskie	-	0.0%	39	0.2%	4	0.0%	4	0.0%	2	0.0%	12	0.1%
Largemouth Bass*	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Muskie*	1	0.0%	-	0.0%	-	0.0%	2	0.0%	1	0.0%	1	0.0%
Northern Pike*	94	0.4%	116	0.6%	222	1.1%	79	0.9%	127	0.7%	192	1.2%
Pumpkinseed*	2	0.0%	3	0.0%	3	0.0%	4	0.0%	-	0.0%	1	0.0%
Rainbow Trout*	-	0.0%	-	0.0%	-	0.0%	13	0.1%	9	0.0%	1	0.0%
Rock Bass*	26	0.1%	13	0.1%	49	0.2%	46	0.5%	13	0.1%	23	0.1%
Sauger	1	0.0%	-	0.0%	-	0.0%	1	0.0%	5	0.0%	12	0.1%
Smallmouth Bass*	6	0.0%	3	0.0%	4	0.0%	14	0.2%	19	0.1%	13	0.1%
Walleye	3,017	13.4%	1,531	8.6%	1,781	8.9%	635	6.9%	1,392	7.4%	1,957	12.3%
White Bass*	723	3.2%	534	3.0%	357	1.8%	419	4.6%	962	5.1%	766	4.8%
White Perch*	-	0.0%	-	0.0%	3	0.0%	137	1.5%	5	0.0%	212	1.3%
Yellow Bullhead*	6	0.0%	7	0.0%	20	0.1%	7	0.1%	2	0.0%	-	0.0%
Yellow Perch*	14,763	65.5%	12,797	71.7%	11,220	56.2%	3,817	41.6%	12,889	68.7%	7,718	48.4%
Total Game Fish	**19,388**	**86.1%**	**15,901**	**89.1%**	**15,403**	**77.2%**	**6,595**	**71.8%**	**16,312**	**87.0%**	**11,473**	**71.9%**
Total Fish	**22,525**	**100.0%**	**17,851**	**100.0%**	**19,951**	**100.0%**	**9,184**	**100.0%**	**18,758**	**100.0%**	**15,953**	**100.0%**

Table 2-10 Lower Fox River Fish Populations in the De Pere to Green Bay Reach (Continued)

Species	1993 Catch	1993 % Catch	1994 Catch	1994 % Catch	1995 Catch	1995 % Catch	1996 Catch	1996 % Catch	1997 Catch	1997 % Catch	1998 Catch	1998 % Catch
Non-Game Fish												
Alewife*	2	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Burbot	38	0.2%	35	0.3%	38	0.8%	16	0.4%	23	1.0%	34	0.4%
Carp*	216	0.9%	866	6.7%	102	2.2%	161	3.6%	129	5.6%	218	2.8%
Drum (freshwater)*	156	0.7%	533	4.1%	86	1.9%	63	1.4%	55	2.4%	420	5.3%
Gar	7	0.0%	25	0.2%	5	0.1%	-	0.0%	-	0.0%	8	0.1%
Gizzard Shad*	1	0.0%	84	0.6%	5	0.1%	1	0.0%	-	0.0%	-	0.0%
Longnose Sucker	3	0.0%	3	0.0%	1	0.0%	-	0.0%	2	0.1%	1	0.0%
Mooneye	1	0.0%	3	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Quillback	554	2.4%	239	1.8%	54	1.2%	72	1.6%	8	0.3%	72	0.9%
Redhorse*	55	0.2%	73	0.6%	10	0.2%	41	0.9%	17	0.7%	107	1.4%
Trout-perch*	7	0.0%	1	0.0%	27	0.6%	-	0.0%	1	0.0%	-	0.0%
White Sucker*	824	3.6%	1,807	13.9%	204	4.4%	256	5.7%	121	5.3%	848	10.8%
Total Non-Game Fish	**1,864**	**8.2%**	**3,669**	**28.2%**	**532**	**11.5%**	**610**	**13.6%**	**356**	**15.5%**	**1,708**	**21.7%**
Game Fish												
Black Bullhead*	21	0.1%	51	0.4%	2	0.0%	12	0.3%	8	0.3%	8	0.1%
Black Crappie*	33	0.1%	281	2.2%	35	0.8%	20	0.4%	2	0.1%	22	0.3%
Bluegill*	1	0.0%	1	0.0%	2	0.0%	2	0.0%	-	0.0%	1	0.0%
Brook Trout	1	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Brown Bullhead	-	0.0%	2	0.0%	2	0.0%	-	0.0%	-	0.0%	-	0.0%
Channel Catfish	44	0.2%	369	2.8%	46	1.0%	27	0.6%	10	0.4%	227	2.9%
Flathead Catfish	3	0.0%	23	0.2%	1	0.0%	4	0.1%	3	0.1%	21	0.3%
Hydrid Muskie	1	0.0%	9	0.1%	-	0.0%	-	0.0%	-	0.0%	1	0.0%
Largemouth Bass*	-	0.0%	-	0.0%	1	0.0%	-	0.0%	-	0.0%	-	0.0%
Muskie*	1	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%	8	0.1%
Northern Pike*	19	0.1%	135	1.0%	24	0.5%	17	0.4%	37	1.6%	120	1.5%
Pumpkinseed*	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Rainbow Trout*	-	0.0%	6	0.0%	-	0.0%	-	0.0%	-	0.0%	-	0.0%
Rock Bass*	16	0.1%	4	0.0%	8	0.2%	17	0.4%	4	0.2%	18	0.2%
Sauger	16	0.1%	25	0.2%	2	0.0%	8	0.2%	2	0.1%	25	0.3%
Smallmouth Bass*	6	0.0%	20	0.2%	22	0.5%	27	0.6%	21	0.9%	40	0.5%
Walleye	3,442	15.1%	3,952	30.4%	1,024	22.1%	1,539	34.4%	1,509	65.9%	3,821	48.6%
White Bass*	333	1.5%	267	2.1%	60	1.3%	219	4.9%	11	0.5%	140	1.8%
White Perch*	159	0.7%	1,450	11.2%	327	7.1%	325	7.3%	55	2.4%	866	11.0%
Yellow Bullhead*	1	0.0%	-	0.0%	2	0.0%	1	0.0%	-	0.0%	-	0.0%
Yellow Perch*	16,843	73.9%	2,729	21.0%	2,546	54.9%	1,647	36.8%	272	11.9%	829	10.6%
Total Game Fish	**20,940**	**91.8%**	**9,324**	**71.8%**	**4,104**	**88.5%**	**3,865**	**86.4%**	**1,934**	**84.5%**	**6,147**	**78.3%**
Total	**22,804**	**100.0%**	**12,993**	**100.0%**	**4,636**	**100.0%**	**4,475**	**100.0%**	**2,290**	**100.0%**	**7,855**	**100.0%**

Note:

* Indicates that this fish species was observed in Duck Creek during the 1995/1996 survey assessment (Cogswell and Bougie, 1998).

Table 2-11 Green Bay - Common and Important Fish Species

Common Name	Species Name	Food Web	Wisconsin Listing	Michigan Listing	Federal Listing
Salmon and Trout					
Atlantic salmon	*Salmo salar*				
Brown trout	*Salmo trutta*				
Chinook salmon (king)	*Oncorhynchus tshawytscha*				
Coho salmon (silver)	*Oncorhynchus kisutch*				
Pink salmon (humpy)	*Oncorhynchus gorbuscha*				
Rainbow trout (steelhead)	*Salmo gairdneri*				
Brook trout	*Slavelinus fontinalis*				
Lake trout	*Slavelinus namaycush*				
Benthic Fish					
Black bullhead	*Ictaluras melas*				
Brown bullhead	*Ictalurus nebulosus*				
Carp	*Cyprinus carpio*	✓			
Channel catfish	*Ictalurus punctatus*				
Yellow bullhead	*Ictalurus natalis*				
Shorthead redhorse	*Moxostoma macrolepidotum*				
Silver redhorse	*Moxostoma anisurum*				
White sucker	*Catostomus commersoni*				
Pelagic Fish					
Common shiner	*Notropis cornutus*	✓			
Emerald shiner	*Notropis atherinoides*	✓			
Gizzard shad	*Dorosoma cepedianum*	✓			
Lake sturgeon	*Acipenser fulvescens*			▼	
Rainbow smelt	*Osmerus mordax*	✓			
Redfin shiner	*Notropis umbratilis*	✓			
Spottail shiner	*Notropis hudsonius*	✓			
Alewife	*Alosa pseudoharengus*	✓			
Game Fish					
Lake whitefish	*Coregonus clupeaformis*				
Muskellunge	*Esox masquinongy*				
Northern pike	*Esox lucius*				
Sauger	*Stizostedion canadense*			▼	
Walleye	*Stizostedion vitreum*	✓			
Yellow perch	*Perca flavescens*	✓			
Black crappie	*Pomoxis nigromaculatus*				
Bluegill	*Lepomis macrochirus*				
Largemouth bass	*Micropterus salmoides*				
Pumpkinseed	*Lepomis gibbosus*				
Rock bass	*Ambloplites rupestris*				
Smallmouth bass	*Micropterus dolomieui*				
White bass	*Morone chrysops*				

Notes:

◆ - Delisted.
▼ - Threatened.
✚ - Endangered.
✓ - Included in Risk Assessment food web models.

Table 2-12 Lower Fox River and Green Bay - Common and Important Bird Species

Common Name	Species Name	Food Web	Wisconsin Listing	Michigan Listing	Federal Listing
Raptors					
Bald eagle	*Haliaeetus leucocephalus*	✓	◆	▼	▼
Merlin	*Falco Columbarius*			▼	
Osprey	*Pandion haliaetus*		▼	▼	
Peregrine falcon	*Falco peregrinus*		✚	✚	✚
Gulls and Terns					
Black tern	*Chilidonias niger*				
Caspian tern	*Sterna caspia*		✚	▼	
Common tern	*Sterna hirundo*	✓	✚	▼	
Forster's tern	*Sterna fosteri*	✓	✚		
Herring gull	*Larus argentatus*				
Ring-billed gull	*Larus delawarensis*				
Diving Birds					
Belted kingfisher	*Megaceryle alcyon*				
Common loon	*Gavia immer*				
Double-crested cormorant	*Phalacrocorax auritus*	✓			
Horned grebe	*Podiceps auritus*				
Pied-billed grebe	*Podilymbus podiceps*				
American white pelican	*Pelecanus erythrorhynchos*				
Passerine Bird					
Brewer's blackbird	*Euphagus cyanocephalus*				
Marsh wren	*Cistothorus palustris*				
Red-winged blackbird	*Agelaius phoeniceus*				
Sedge wren	*Cistothorus platensis*				
Swamp sparrow	*Melospiza georgiana*				
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*				
Shorebird					
Common snipe	*Capella gallinago*				
Dunlin	*Calidris alpina*				
Least sandpiper	*Calidris minutilla*				
Pectoral sandpiper	*Calidris melanotos*				
Piping plover	*Charadrius melodus*		✚	✚	✚▼
Sanderling	*Calidris alba*				
Semipalmated sandpiper	*Calidris pusilla*				
Spotted sandpiper	*Actitis macularia*				

Table 2-12 Lower Fox River and Green Bay - Common and Important Bird Species (Continued)

Common Name	Species Name	Food Web	Wisconsin Listing	Michigan Listing	Federal Listing
Wading Birds					
American bittern	*Botaurus lentiginosus*				
American woodcock	*Philohela minor*				
Black-crowned night heron	*Nycticorax nycticorax*				
Cattle egret	*Bubulcus ibis*				
Great blue heron	*Ardea herodias*				
Green-backed heron	*Butorides striatus*				
King rail	*Rallus elegans*			✚	
Least bittern	*Ixobrychus exilis*			▼	
Sandhill crane	*Grus canadensis*				
Snowy egret	*Egretta thula*		✚		✚
Sora rail	*Porzana carolina*				
Virginia rail	*Rallus limicola*				
Yellow rail	*Coturnicops noveboracensis*		▼	▼	
Waterfowl					
American coot	*Fulica americana*				
Black duck	*Anas rubripes*				
Blue-winged teal	*Anas discors*				
Bufflehead	*Bucephala albeola*				
Canada goose	*Branta canadensis*				
Canvasback	*Aythya valisineria*				
Common goldeneye	*Bucephala clangula*				
Common merganser	*Mergus merganser*				
Common moorhen	*Gallinula chloropus*				
Greater scaup	*Aythya marila*				
Green-winged teal	*Anas crecca*				
Lesser scaup	*Aythya affinis*				
Mallard	*Anas platyrhynchos*				
Northern shoveler	*Anas clypeata*				
Oldsquaw	*Clangula hyemalis*				
Red-breasted merganser	*Mergus serrator*				
Redhead	*Aythya americana*				
Ring-necked duck	*Aythya collaris*				
Ruddy duck	*Oxyura jamaicensis*				
Whistling swan (tundra swan)	*Olor columbianus*				
Wood duck	*Aix sponsa*				

Notes:

◆ - Delisted.
▼ - Threatened.
✚ - Endangered.
✓ - Included in Risk Assessment food web models.

Table 2-13 Productivity (large young raised per active nest) of Fox River Bald Eagles from 1988 to 1998

Nest Name	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Kaukauna, Wisconsin	2	1	0	3	3	3	1	3	2	2	3
Mud Creek, Wisconsin							2	3	1	2	3
East River, Wisconsin							0				
Productivity Summary, All Nests											
Number of active nests	1	1	1	1	1	1	3	2	2	2	2
Number of young reared	2	1	0	3	3	3	3	6	3	4	6
Young/active nest	2	1	0	3	3	3	1	3	1.5	2	3

Note:
A blank cell indicates that the nesting territory was unoccupied in that year.
Source:
USFWS and WDNR bald eagle productivity databases.

Table 2-14 Endangered and Threatened Mammal Species of the Lower Fox River and Green Bay

List	Endangered	Threatened
Wisconsin	Timber wolf and pine marten	None
Michigan	Timber wolf, cougar, lynx, prairie vole, and Indiana bat	Least shrew
Federal	Timber wolf, gray bat, Indiana bat, and Ozark big-eared bat	Lynx

Table 2-15 Results of Sediment Time Trends Analysis for the Lower Fox River

Deposit Group	Depth Range (cm)	Log_{10} (PCB) Time Trend Slope Estimate	WSEV Standard Error	WSEV *p*-Value	Statistically Significant Slopes	Estimated Annual Compound Percent Increase in PCB Level	Estimated Annual Compound Percent Increase in PCB Level	
							95% Confidence Interval Lower-bound	95% Confidence Interval Upper-bound
Little Lake Butte des Morts								
AB	0–10	-0.0970	0.0348	0.0131	*	-20.03	-32.52	-5.22
	10–30	-0.0213	0.0647	0.7535		-4.78	-33.86	37.09
	30–50	-0.0144	0.1113	0.8995		-3.26	-44.95	70.02
C	0–10	-0.0612	0.0342	0.1481		-13.15	-30.22	8.09
	10–30	0.0317	0.0770	0.7018		7.57	-34.24	75.95
POG	0–10	-0.0893	0.0567	0.1900		-18.59	-43.33	16.95
D	0–10	-0.0755	0.0317	0.0307	*	-15.96	-28.06	-1.83
	10–30	0.3168	0.0454	0.0009	***	107.39	58.51	171.33
F	0–10	-0.0373	0.0136	0.0252	*	-8.23	-14.62	-1.37
	10–30	-0.0760	0.0749	0.3246		-16.06	-41.67	20.81
GH	0–10	-0.1244	0.0541	0.0443	*	-24.91	-43.12	-0.88
Appleton								
IMOR	0–10	0.0412	0.0255	0.1810		9.95	-6.57	29.38
N Pre-dredge	0–10	-0.0281	0.0065	0.0233	*	-6.26	-10.64	-1.65
	10–30	0.0572	0.0440	0.2061		14.08	-7.48	40.67
	30–50	0.0846	0.0932	0.3877		21.50	-25.22	97.40
VCC	0–10	-0.0582	0.0275	0.0878		-12.53	-25.65	2.90
	10–30	-0.1537	0.0164	0.000001	***	-29.81	-35.42	-23.72
	30–50	-0.0060	0.0151	0.6984		-1.37	-8.71	6.55

Table 2-15 Results of Sediment Time Trends Analysis for the Lower Fox River (Continued)

Deposit Group	Depth Range (cm)	Log_{10} (PCB) Time Trend Slope Estimate	WSEV Standard Error	WSEV *p*-Value	Statistically Significant Slopes	Estimated Annual Compound Percent Increase in PCB Level	Estimated Annual Compound Percent Increase in PCB Level	
							95% Confidence Interval Lower-bound	95% Confidence Interval Upper-bound
Little Rapids								
Upper EE	0–10	-0.0447	0.0435	0.3618		-9.79	-31.68	19.13
	10–30	-0.0944	0.0429	0.0554		-19.53	-35.64	0.62
	30–50	-0.0712	0.0536	0.2173		-15.11	-35.80	12.25
Lower EE	0–10	-0.0682	0.0193	0.0387	*	-14.53	-25.81	-1.53
	10–30	-0.0759	0.0390	0.0695		-16.03	-30.58	1.58
	30–50	0.0900	0.0330	0.0213	*	23.02	3.86	45.72
FF	0–10	-0.0549	0.0557	0.3400		-11.87	-32.94	15.82
	10–30	-0.0962	0.0390	0.0389	*	-19.87	-34.86	-1.43
GGHH	0–10	-0.0394	0.0231	0.1643		-8.66	-21.23	5.90
	10–30	-0.0182	0.0596	0.7631		-4.10	-27.73	27.25
	30–50	0.1762	0.1008	0.1188		50.02	-12.18	156.27
	50–100	0.1012	0.0700	0.1586		26.23	-9.16	75.42
	100+	0.0365	0.0249	0.1587		8.76	-3.50	22.57

Table 2-15 Results of Sediment Time Trends Analysis for the Lower Fox River (Continued)

Deposit Group		Depth Range (cm)	Log_{10} (PCB) Time Trend Slope Estimate	WSEV Standard Error	WSEV *p*-Value	Statistically Significant Slopes	Estimated Annual Compound Percent Increase in PCB Level	Estimated Annual Compound Percent Increase in PCB Level: 95% Confidence Interval Lower-bound	Estimated Annual Compound Percent Increase in PCB Level: 95% Confidence Interval Upper-bound
De Pere									
SMU Group	2025	0–10	-0.0528	0.0231	0.0838		-11.45	-23.58	2.61
		10–30	-0.0556	0.0750	0.4796		-12.02	-40.91	31.01
		30–50	-0.0580	0.0322	0.1016		-12.50	-25.81	3.20
		50–100	-0.0847	0.1058	0.4306		-17.72	-50.17	35.85
	2649	0–10	-0.0608	0.0109	0.00001	***	-13.06	-17.41	-8.48
		10–30	-0.2882	0.1440	0.0764		-48.50	-75.68	9.04
		50–100	0.1957	0.1419	0.2399		56.93	-36.65	288.69
		100+	0.0177	0.1548	0.9146		4.15	-61.29	180.26
	5067	0–10	-0.0998	0.0345	0.0136	*	-20.53	-33.17	-5.49
		10–30	0.0912	0.0649	0.1800		23.37	-10.26	69.61
		50–100	0.3677	0.0684	0.0030	**	133.17	55.54	249.55
		100+	-0.1963	0.2223	0.4112		-36.36	-81.81	122.65
	6891	0–10	-0.2208	0.0944	0.1013		-39.86	-69.89	20.11
		10–30	-0.1685	0.0765	0.0550		-32.16	-54.45	1.03
	92115	0–10	0.0413	0.0426	0.3493		9.97	-10.91	35.75

Notes:

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Table 2-16 Mass-weighted Combined Time Trend for 0 to 10 cm Depth by Reach

Deposit Group	Log_{10}(PCB) Time Trend Slope Estimate	WSEV Standard Error	PCB Mass (kg)	*p*-value	Annual Percent Change in PCB Concentration	Percent Change 95% Lower-bound	Percent Change 95% Upper-bound
Little Lake Butte des Morts							
AB	-0.09705	0.034798	71.7				
C	-0.06124	0.03423	25.4				
POG	-0.08935	0.056669	113.5				
D	-0.07554	0.031669	32.1				
F	-0.0373	0.013582	142.5				
GH	-0.12443	0.054119	15.7				
Reach, Combined	**-0.07071**	**0.01831**	**400.9**	**0.0001*** **	**-15.0**	**-21.8**	**-7.7**
Appleton							
IMOR	0.041186	0.025457	13.7				
N Pre-dredge	-0.02805	0.006544	6.9				
VCC	-0.05816	0.02746	5.2				
Reach, Combined	**-0.01135**	**0.01217**	**25.9**	**0.9**	**0.6**	**-5.9**	**7.5**
Little Rapids							
Upper EE	-0.04473	0.043487	85.0				
Lower EE	-0.06819	0.019322	25.4				
FF	-0.05486	0.055669	36.7				
GGHH	-0.03936	0.023149	131.6				
Reach, Combined	**-0.04567**	**0.018764**	**278.7**	**0.01***	**-10.0**	**-17.3**	**-2.0**
De Pere							
SMU Group 2025	-0.05279	0.02305	225.6				
SMU Group 2649	-0.06078	0.010894	356.8				
SMU Group 5067	-0.09978	0.034549	92.4				
SMU Group 6891	-0.22081	0.094396	72.1				
SMU Group 92115	0.041293	0.042639	37.1				
Reach, Combined	**-0.07296**	**0.012829**	**784.0**	**<0.0001*** **	**-15.5**	**-20.2**	**-10.4**

Notes:

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

Table 2-17 Results of Fish Time Trends Analysis on the Lower Fox River

Species	Type	Sample Size	Year of Breakpoint	Percent Change per Year	95% Confidence Interval		*p*-Value
					LCL	UCL	
Little Lake Butte des Morts							
Carp	fillet on skin	55	1979	-6.15	-10.9	-1.1	0.0177
Carp	whole fish	40	1987	0.71	-12.3	15.6	0.9172
Northern Pike	fillet on skin	19		-11.83	-16.7	-6.7	0.0003
Walleye	fillet on skin	63	1990	3.44	-7.8	16.0	0.5576
Walleye	whole fish	18	1987	21.47	-3.5	52.9	0.0874
Yellow Perch	fillet on skin	34	1981	0.73	-5.0	6.8	0.8025
Combined				**-4.86**			**0.0055**
Appleton to Little Rapids							
Walleye	fillet on skin	30		-9.97	-15.7	-3.9	0.0028
De Pere to Green Bay (Zone 1)							
Carp	whole fish	90	1995	21.76	2.2	45.0	0.0277
Gizzard Shad	whole fish	19		-5.07	-7.2	-2.9	0.0002
Northern Pike	fillet on skin	40		-9.95	-13.0	-6.8	<0.0001
Walleye	fillet on skin	120		-7.19	-8.7	-5.6	<0.0001
Walleye	whole fish	58		-8.11	-10.4	-5.8	<0.0001
White Bass	fillet on skin	58		-4.72	-7.5	-1.8	<0.0001
White Sucker	fillet on skin	44		-7.90	-10.3	-5.5	<0.0001
Combined				**-6.89**			**<0.0001**
Green Bay Zone 2							
Alewife	whole fish	44		-3.96	-7.8	0.0	0.0497
Carp	fillet on skin	28		-5.06	-11.8	2.2	0.1557
Carp	whole fish	57	1983	-15.54	-19.5	-11.4	0.0000
Gizzard Shad	whole fish	32		5.91	1.2	10.8	0.0144
Yellow Perch	fillet on skin	19		-10.75	-16.8	-4.2	0.0038
Combined				**-5.11**			**0.0000**