3 Physical Characteristics

This chapter provides a historical description of the anthropogenic impacts to the river and bay system and a description of the current physical and ecological characteristics of the Lower Fox River valley and Green Bay. Specifically, this chapter describes the Lower Fox River and Green Bay land use, meteorological, geological, and hydrological characteristics. Hydrologic characteristics include flow and currents within both the river and bay, as well as information pertaining to sediment deposition and transport, which are important factors in the movement of chemicals that have been detected in the river system.

3.1 Land Use

The abundance of natural resources in the region has had a significant impact on the current environmental conditions and land use. This section describes the historical and current land use as well as the important role which wood pulping and paper manufacturing has played in the region. In addition, other commercial activities have been impacted by historical and current environmental degradation conditions within the region.

3.1.1 Historical Land Use

The Lower Fox River valley has long been home to many different Native Americans (Menominee, Winnebago, Fox, and other tribes) before European settlers arrived in the area. In the late 1600s, Europeans had entered the region and used the river system for fur trading and as a route for exploration and transportation. Early settlements in the area included Fort Howard, which eventually became the city of Green Bay. By the early 1800s, timber, agriculture, fishing, fur trading, and other commercial activities were either well established or beginning to be developed based on the availability of the local resources. The historical settlement of the Lower Fox River valley has resulted in numerous present-day cultural and historic landmarks.

This region has long been used by humans for transportation, commerce, energy, food (fish and waterfowl), and recreation, and by wildlife for habitat and migration. Industries developed rapidly in the Lower Fox River valley due to the availability of water from Lake Winnebago, the Lower Fox River, and Green Bay. Beginning in about 1820, lumber and flour industries came to the Lower Fox River valley. The year 1850 marked the peak of the flour industry, which was followed by flour mill conversion to saw mills and/or pulp and paper mills. The earliest paper mill in Outagamie County was established in Appleton in 1853.

Fourteen hydropower sites were also located along the river from Lake Winnebago to Green Bay.

By the mid-1800s, saw mills were using dam-generated power. As these facilities developed and economic changes occurred, some of these mills converted to paper production and wood pulping. Today, industries and municipalities use the river for waste assimilation, industrial processing, cooling water, and power generation, while individuals use the river for recreation and as a food source (WDNR, 1995).

Green Bay is the largest city in the region, with a population of approximately 185,000 people (Brown County Planning Department, 1999). Historical development of the Green Bay region has been similar to that of the Lower Fox River valley. The city was originally founded as a fort and center of trade and transport at the mouth of the Lower Fox River. First under French control, the area later was commanded by the British, and finally by the Americans following the War of 1812. In 1816, Fort Howard was erected just west of the mouth of the Lower Fox River to consolidate American power and deter British and Canadian interests in the region, which had been predominant since the 1730s. The city of Green Bay developed around fishing, commerce, manufacturing, transportation, and as a general cargo port. It continues to be an important port, exporting paper, lumber, and wood products, and importing general bulk cargo. The Port of Green Bay operates from April 1 through December 31 and typically handles about 1.8 million tons of bulk cargo annually (Haen, 2000).

The cities of Oconto, Peshtigo, and Marinette, Wisconsin and Menominee, Michigan developed around the timber industry in the 1820s and 1830s. Timber and lumber mills in these cities helped supply the burgeoning cities of Milwaukee and Chicago, both of which were rapidly building and growing during this time. Whereas mills in the Lower Fox River valley were able to switch from flour and lumber processes to paper manufacturing, most of the mills located north of the city of Green Bay eventually closed as the need for these mills could not be sustained and the source of timber moved further west.

The city of Sturgeon Bay, Wisconsin, developed as a center for ship building, fishing, and agriculture. The first permanent residents arrived in the area during the 1850s and the city took its name from the huge sturgeon that once populated the waters of the bay. The Sturgeon Bay canal connects the waters of Sturgeon Bay (Green Bay) with Lake Michigan, thus shortening the trip for vessels carrying cargo between the city of Green Bay and the cities of southern Lake Michigan, including Milwaukee and Chicago. The canal was completed in 1882.

The city of Escanaba, Michigan, developed along with the iron mining industry in Michigan's Upper Peninsula (UP) and served as an important export and transportation center. Similar to the decline of the timber industry in the other cities along Green Bay, the city of Escanaba eventually experienced a decline in port activities as the iron mining industry in the UP declined. Today, approximately 7 to 8 million long tons of iron ore and taconite pellets are shipped out of Escanaba annually, compared with 12 to 14 million long tons annually in the early 1980s (Rodgers, 2000).

Tourism has also become an important commercial activity in the cities located along Green Bay in recent years. As each of the major manufacturing/commercial industries discussed above has declined, the percentage of income generated through tourism has increased. Therefore, tourism remains an important economic activity for the region, due in large part to the natural harbors, scenic views, and wildlife areas located in and around the shores of Green Bay.

3.1.2 Current Land Uses

The Green Bay and Lower Fox River areas support a population of approximately 595,300. The Lower Fox River valley is the second largest urbanized region in the state of Wisconsin and supports a population of approximately 412,900, about 8.1 percent of the state population. The Lower Fox River valley includes the Fox Cities, which include all the cities from Neenah/Menasha through Kaukauna, as well as the Green Bay Metropolitan Statistical Area (MSA), which includes much of Brown County. The population of the other counties surrounding Green Bay is approximately 119,100 in Wisconsin and about 63,300 in Michigan.

The Lower Fox River valley, from the Fox Cities to Green Bay, may still contain the largest concentration of pulp and paper industries in the world (20 mills in approximately 59.5 km [37 mi]). The paper industry remains active within the valley and plays a vital role in the local and state economy. The paper industry employs approximately 26,000 in the Lower Fox River valley and over 53,000 people at pulp, paper, and allied firms throughout the state (Wisconsin Paper Council, 2000). 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.

Regional land use along the Lower Fox River was compiled by planning commissions in both the Fox Cities and Brown County. The Fox Cities Area Existing Land Use Map (East Central Wisconsin Regional Planning Commission

[ECWRPC], 1996) extends from the outlet of Lake Winnebago to a point about 5 km (3 mi) downstream of Kaukauna. The Fox River Corridor Land Use Map (Brown County Planning Commission, 1990) covers the entire length of the Lower Fox River within Brown County. There is stretch of river about 1.5 km (1 mi) not covered by these two maps; however, land-use details on these maps provide a general description of development in the river vicinity. The approximated land use percentages for areas within about 0.4 km (0.25 mi) of the bank of the Lower Fox River are summarized below.

Land Use Summary - Lower Fox River Valley

Land Use	Fox Cities (1996)	Brown County (1990)	Entire River
Residential	32.9%	25.5%	29.2%
Industrial/Commercial	26.2%	25.3%	25.8%
Woodlands	14.6%	17.9%	16.2%
Parks	11.6%	6.8%	9.3%
Agricultural	0.5%	11.4%	5.8%
Public	7.2%	1.3%	4.3%
Wetlands	5.1%	1.6%	3.4%
Vacant	2.0%	10.2%	6.0%

Notes: Percentages are approximate and are intended to provide a general indication of land use along the Lower Fox River. The Fox Cities includes all communities between Neenah/Menasha and Kaukauna. Public land includes school properties.

The largest category of land use along the Lower Fox River is residential. In addition, about 40 percent of land use along the river not classified as residential or industrial/commercial represents potential wildlife habitat.

Land use in the vicinity of Green Bay was collected from available county records for Brown, Door, Kewaunee, Marinette, and Oconto counties in Wisconsin and for Delta and Menominee counties in Michigan. Except for Kewaunee County, a large percentage, if not all of the land within these counties, lies in the Green Bay watershed. Much of Kewaunee County, as well as portions of Door County, Wisconsin and Delta County, Michigan, lie in the Lake Michigan watershed. Additionally, land use further inland may have as significant impact on water quality in Green Bay as do near- or on-shore land uses. A summary of the land use in the counties bordering Green Bay is presented on Table 3-1.

Counties located along Green Bay are largely undeveloped (Table 3-1). Brown County, Wisconsin, is the only county where more than 5 percent of the total land is used for residential or industrial/commercial purposes. Between 65 percent and 85 percent of all land in these counties is classified as either agricultural or forested lands, reflecting the overall rural nature of this area. Wetlands comprise 3 percent to 20 percent of the land in these counties (Table 3-1). The largest wetland areas are located in Brown, Oconto, and Marinette counties, all located along the western side of Green Bay. Door and Kewaunee counties on the eastern side of the bay have less than 3.3 percent wetlands.

3.2 Meteorology

Meteorological data for the region provide background on weather patterns that are considered in the evaluation and design of possible sediment remedy technologies. Temperature and precipitation extremes influence long-term planning and remedial management considerations.

Northeastern Wisconsin and the applicable portions of the Michigan UP are characteristic of continental climate with distinct changes in weather over the region. Summers are warm and occasionally hot and humid while the winters are cold and snowy. Spring and autumn are transitional seasons, with gradual to abrupt changes in weather. Weather fronts, moving from west to east and southwest to northeast, account for the abrupt changes in weather and usually occur every two to four days. Lake Michigan and Green Bay provide a modifying influence on local weather, creating the "lake effect" of cooler temperatures near the lakes during the summer and slightly warmer temperatures during the winter (Wisconsin State Climatology Office [WSCO], 2000).

The average monthly and annual temperature and precipitation data for the cities of Green Bay, Appleton, Marinette, and Sturgeon Bay, Wisconsin, along with information for Fayette, Michigan (located on Big Bay de Noc) from 1961 through 1990 are summarized on Tables 3-2 through 3-6, respectively. Between the late spring and summer months of May through September, the average monthly temperature ranges from a low of 10°C to a high of 21°C (50°F to 70°F). Temperatures are highest during July, with an average of approximately 21°C (70°F). Both Sturgeon Bay, Wisconsin and Fayette, Michigan (located on the Door and Garden Peninsulas, respectively), are the coolest locations. These two locations are cooler than cities on the south or west sides of Green Bay due to the lake effect, the prevailing southwest winds, and their proximity to Lake Michigan. From June through August, Green Bay, Appleton, and Marinette typically have about five to seven days per year with temperatures exceeding 32°C (90°F). However, during this same period, Sturgeon Bay only has one to two days annually and Fayette, Michigan, has only one day every 10 years where temperatures exceed 32°C (90°F). Conversely, during the winter months of December through February, the average temperature ranges from -10°C to -4°C (14°F to 24°F). January temperatures are coldest with an average of approximately -8°C (16°F). It is also typical to have between 15 and 23 days in January where the average temperature is below 0°C (32°F). Frost usually occurs from mid-October through very early May (WSCO, 2000) and soils in the region are seasonally frozen.

The average annual precipitation in the study area ranged from 0.73 to 0.82 meters (28.8 to 32.2 inches). Most of the precipitation occurs as rain and snow with occasional episodes of sleet and hail. Over half the annual precipitation (from about 53 percent to 57 percent) falls from May through September. August is typically the wettest month with at least 8.1 centimeters (3.2 inches) of rain and significant precipitation also occurs during both June and September (Tables 3-2 through 3-6). February is typically the driest month with just over 2.5 centimeters (1 inch) of precipitation. Snowfall is extremely variable year to year; the mean annual snowfall is approximately 1.2 meters (44 to 48 inches) at Green Bay, Appleton, and Sturgeon Bay, while both Marinette and Fayette, Michigan, typically receive about 1.34 meters (53 inches) of snowfall. The highest snowfall amounts recorded range from 2.3 to 3.3 meters (90 to 130 inches), with snowfall generally increasing to the north, reflecting lake effect snows (WSCO, 2000). Most of the streams and lakes are ice-covered from late November to late March and flooding is most frequent and serious during the month of April, when melting snow and spring run-off are greatest (WSCO, 2000).

Prevailing winds are from the northwest in winter and from the southwest in summer. However, wind from the northeast is common in the vicinity of Green Bay. A windrose diagram, developed from the NOAA weather station at the city of Green Bay, is included in Appendix C. The wind rose diagram and accompanying table indicate that prevalent winds are out of the west and south-southwest directions. The table indicates that winds are out of this west to south-southwesterly direction 37 percent of the time and range between 10 and 30 km/hr (6 to 19 mph) 27 percent of the time. The wind rose diagram also indicates that winds from the northeast and northwest are about evenly distributed while easterly and southeasterly winds are the least common. As previously discussed, the winds from the northeasterly direction are significant due to the seiche effect on currents and water levels in Green Bay and the Lower Fox River.

3.3 Geologic Characteristics

This section discusses the regional geology, soils, hydrogeologic characteristics, and water use in the region. These factors affect the physical characteristics of sediments, migration of chemicals of concern, possible sediment remedies, and on-land disposal options of PCB impacted material.

3.3.1 Regional Geologic Setting

The Lower Fox River and Green Bay basins lie in the ridges and lowlands province of eastern Wisconsin and western Michigan. The eastern ridges and lowlands generally trend north-south across Wisconsin from northeastern Illinois to the Michigan shores of Lake Superior. This province is a southwest-northeast trending area underlain by Paleozoic Rocks. The bedrock does not entirely control surface geomorphology, as the glacial advances and retreats planed off the bedrock highs and filled in bedrock valleys with till and outwash deposits (Krohelski and Brown, 1986). Stratigraphic cross-sections and other pertinent information concerning the regional geology of the area are included in Appendix D.

3.3.1.1 Bedrock Geology

The Lower Fox River valley and Green Bay is underlain by a sequence of Precambrian undifferentiated granite overlain by Paleozoic sandstones dolomite, and shale (Appendix D). The Paleozoic bedrock units, from oldest to youngest, are Cambrian sandstones, Ordovician dolomite, sandstone, and shale units and undifferentiated Silurian dolomites. The Paleozoic rocks range from 61 to 488 m (200 ft to 1,600 ft) thick on the western and eastern sides of Brown County, respectively. The bedrock surface slopes east approximately 5.7 to 7.6 m/km (30 to 40 ft/mi), toward and beneath Lake Michigan (Krohelski and Brown, 1986). This regional dip has resulted in the most prominent surface expression of the bedrock, the Silurian Niagara Escarpment. The escarpment lies east of and parallel to the Lower Fox River lowlands. In addition, the Ordovician Maquoketa Shale has also been eroded in the western part of the study area due to the regional dip of the bedrock strata. Where present, the Maquoketa Shale serves as an aquitard that hydraulically separates the shallow Niagara dolomite from the deeper sandstone and dolomite aquifers.

In the Lower Fox River valley, the Silurian Niagara Dolomite is only present in the eastern portion of Brown County; it is entirely absent in Outagamie and Winnebago counties. Around Green Bay, the Niagara dolomite comprises the surface bedrock in both the Door and Garden Peninsulas (Bosley, 1976; Sinclair, 1960).

Similar to the Niagara Dolomite, the Maquoketa Shale has also been eroded east of (and parallel to) the Lower Fox River. In Wisconsin, the Maquoketa Shale is only present in the very southeastern corner of Outagamie County (Krohelski and Brown, 1986) and as thin outcroppings along the very western edge of Door County (USGS, 1992). In Michigan, the contemporaneous Ordovician Shale unit is the Richmond Group/Collingwood Formation, which comprises the surface bedrock of the Stonington Peninsula. The contact between Silurian age units and Ordovician age units within Michigan is just east of Stonington Peninsula, at the north end of Big Bay de Noc.

Due to the erosion of the dolomite and shale bedrock units, the uppermost bedrock in the Lower Fox River valley (from the city of Green Bay to Little Bay de Noc) are Ordovician age limestone/dolomite units. Within Wisconsin, these are the Sinnipee Group, composed of the Galena and Platteville formation dolomites, and the Decorah Formation shale. The Sinnipee Group subcrops just east and west of the Lower Fox River, along the axis of the river valley. Additionally, bedrock units of the western shore of Green Bay are comprised of the Galena and Platteville formations (Krohelski and Brown, 1986). Within Michigan, these are the Trenton and Black River formation, and they are contemporaneous with the Galena and Platteville units (Sinclair, 1960; Vanlier, 1963).

3.3.1.2 Glacial Geology

Unconsolidated Quaternary glacial deposits cover the bedrock and consist of silty clay to clay loam tills with associated sand and gravel outwash and lacustrine units. In the Lower Fox River valley the glacial deposits range in thickness from approximately 15 m (50 ft) over much of the area to over 61 m (200 ft) in the area around Wrightstown. The surficial units were deposited by the Green Bay and Lake Michigan lobes of the Wisconsinan glaciation, approximately 10,000 to 13,000 years ago (Attig, *et al.,* 1988). The associated till and outwash units are of the Kewaunee and Horicon formations (Appendix D). Superimposed on the glacial deposits are modern fluvial and alluvial sediments associated with slopewash, river, and floodplain deposits (Krohelski and Brown, 1986).

At least 10 separate tills of the Kewaunee Formation (Mickelson, *et al.,* 1984) have been described in the Lower Fox River valley, Green Bay, and the surrounding region (Appendix D). In addition to the Kewaunee Formation till units, there are silty and clayey lacustrine sediments of several ages, as well as sand and gravel proglacial outwash sediments of several ages. According to Mickelson, *et al.* (1984), an arbitrary vertical cut-off at the Lower Fox River (and hence on each side of the bay) has been used because the correlative units differ significantly on both sides of the river. In general, the Kewaunee Formation is comprised of fine grained units usually having a predominance of silt rather than clay with approximately one-third sand. The Kewaunee Formation tills were deposited by both the Green Bay and Lake Michigan lobes.

Glenmore Member (Kewaunee Formation) deposits underlie the stream bed and overbanks from Lake Winnebago to the tip of Door County on the east side of the Lower Fox River valley and Green Bay. Along the west side, deposits of the Middle Inlet and Kirby Lake Members (Kewaunee Formation) underlie the stream bed and overbank of both the river and bay. The Kirby Lake Member extends from south of Lake Winnebago to just upstream of Wrightstown and the Middle Inlet Member extends from this point well into Michigan (Mickelson, *et al.,* 1984). The Kewaunee unconsolidated deposits are overlain by undifferentiated alluvium, lacustrine sediments, and peat or muck.

Following deposition of the till units above, the Lower Fox River valley and Green Bay basin were modified by proglacial lakes. The southern Fox River valley was occupied by proglacial Lake Oshkosh while areas of Lake Michigan and the Lower Fox River valley were occupied by proglacial Nipissing Lake. These lakes deposited significant volumes of largely fine-grained materials, consisting of very fine sand, silt, and clay and differing from modern river sediments by a lack of organic material (Need, 1983). These lakes also affected the western shore of Green Bay but only flooded the southern portion of Door County. The northern portion of the Door Peninsula and the Garden Peninsula do not exhibit proglacial lake sediments.

Due to the glacial events which occurred in the Lower Fox River valley and Green Bay basins, soils and river sediments in the region are predominantly silt and clay units with varying amounts of sand and gravel. Soils in the vicinity of the Lower Fox River are generally described as silty clay loam and silty clay. In the northern portion of Green Bay, especially along the west side, the outwash and glacial lake plains are typically dominated by sands while clay till deposits are predominant on the Door and Garden Peninsulas (Soil Conservation Service [SCS], 1972; 1978; 1988; 1989; 1991; 1994). Due to the easterly dip of the bedrock, the thickness of the glacial deposits is as great as 15 m (50 ft) on the west side of Green Bay. However, these deposits are generally less than 3 m (10 ft) thick on the Door and Garden Peninsulas, and thinner along the eastern shore of Green Bay.

3.3.2 Regional Soils

Soils in the Lower Fox River valley are largely comprised of tills and lacustrine unconsolidated sediments which range in age from approximately 10,000 to 13,000 years old (Mickelson, *et al.,* 1984). These soils are the Hortonville, Kewaunee, and Manawa soils, which were formed in till, and the Winneconne and Oshkosh soils, which were formed in proglacial lake sediments (SCS, 1972).

Soils in Winnebago County belong to the Kewaunee-Manawa-Hortonville soil association. These soils are generally well to somewhat poorly drained silt loam with loamy or clayey subsoil underlain by loamy or clayey glacial till (SCS, 1972). Soils between the Winnebago County line and Wrightstown, within Outagamie County, are classified in the Winneconne-Manawa Soil Association. These soils are well to somewhat poorly drained, medium to fine textured, slowly permeable soils underlain by silty clay glacial till or lacustrine sediments (SCS, 1972). These soils were deposited in glacial Lake Oshkosh.

Soils along the lowest reaches of the Lower Fox River lowlands from Wrightstown north to Green Bay belong to the Oshkosh-Manawa Soil Association (SCS, 1972). Oshkosh soils are well drained to somewhat poorly drained with a clayey subsoil; these soils formed in glacial lake plains (SCS, 1972). Along the Green Bay shoreline at the mouth of the Lower Fox River is an extensive area of Carbondale-Cathro-Marsh soils, which are very poorly drained organic soils and marsh approximately 1.2 m (4 ft) thick (SCS, 1972). Other areas along the shoreline are described as filled land, indicating that soils were placed in their present locations through construction or other activities.

Soils along the west side of Green Bay are generally more sandy than soils along the east side of the bay. Soils immediately inland of the southwest side of the bay belong to the Tedrow-Roscommon Soil Association and are comprised of deep, nearly level, somewhat poorly to poorly drained sandy soils of lacustrine origin. These sands were likely derived from Upper Cambrian sandstones and transported by upland streams and re-worked by longshore currents (SCS, 1972). Soils located immediately adjacent to the bay are the organic Carbondale-Cathro-Marsh soils, described above.

Shoreline soils in Oconto and Marinette counties, Wisconsin and in Menominee County, Michigan are dominated by nearly level to gently sloping, somewhat poorly to very poorly drained, sandy soil on flats and in depressions of outwash and glacial lake plains (SCS, 1988; 1989; 1991). In Oconto and Marinette counties, these soil are of the Wainola-Cormant and Wainola-Deford Associations; in Menominee County they are of the Deford-Wainola-Rousseau Association. In the upland areas of Oconto and Marinette counties, the soils are loamy, nearly level to very steep, and well drained to somewhat poorly drained soils; these belong to the Onaway-Solona and Emmet-Charlevoix Associations, respectively.

In Michigan, loamy soil of the Charlevoix-Ensley-Cathro Association and organic soils of the Roscommo-Tawas Association are present along the west shore of the bay in Menominee and Delta counties (SCS, 1989 and 1994). Soils along the west and east shores of Little Bay de Noc are dominantly sandy soils of outwash and lake plains origin of the Rubicon Soil Association. The predominant soils of the Stonington Peninsula are loamy, nearly level, poorly drained loamy and organic soils of the Nahma-Ensley-Cathro Association. The Garden Peninsula is comprised of loamy soils of the Summerville-Limestone rock Landongrie Association. These soils are loamy and organic soils poorly to very poorly drained (SCS, 1994).

Along the east shore of Green Bay in Wisconsin, the dominant soils of southern Door County are deep, well to somewhat poorly drained, nearly level to somewhat steep silty clay soils of the Kewaunee-Kolberg-Manawa Association over silty clay till or dolomite bedrock (SCS, 1978). Soils of the Summerville-Longrie-Omena association extend from just north of Little Sturgeon Bay through the Garden Peninsula. These soils are shallow to deep, well drained, nearly level to moderately steep soils that have sandy loam to loam subsoil over sandy loam, till or dolomite bedrock (SCS, 1978).

3.3.3 Hydrogeology

3.3.3.1 Regional Hydrogeology

Three aquifer systems are present in the Lower Fox River (LFR) valley and Green Bay watershed. These aquifer systems generally consist of more than one geologic unit conducive to the movement and migration of water and they generally extend from the southern part of Wisconsin north into the UP (Krohelski and Brown, 1986; USGS, 1992). These aquifer systems include the following:

1. The Upper Aquifer of unconsolidated Quaternary deposits, Galena/Platteville Formations, and, where present, the Niagara dolomite

2. The St. Peter aquifer in the Ordovician age sandstones

3. The Elk Mound aquifer in the deeper Cambrian age sandstones

In addition, there are two general confining units (aquitards), which separate the aquifers and limit vertical groundwater movement. These units are the Maquoketa Shale/Sinnipee Dolomite and the St. Lawrence, a silty dolomite. The Precambrian basement granite also forms an aquitard at the base of the Elk Mound aquifer (Krohelski and Brown, 1986). As stated above, these geologic units continue north into the UP.

The upper aquifer in the region includes the Silurian Niagara dolomite above the Maquoketa Shale on the east side of the area and the upper Ordovician sandstone formations on the west side of the area. The Niagara dolomite is the upper bedrock unit in both the Door and Garden Peninsulas. Although the aquifer is not extensive, it can supply up to 50 gallons per minute (gpm) in areas where it is present and where secondary porosity has increased water movement (USGS, 1992). West of the Niagara Escarpment in Wisconsin, the Galena/Platteville Formations form the upper bedrock units. In the UP, the Trenton/Black River Formations comprise the upper bedrock units. The Galena/Platteville/Trenton/Black River formations typically yield only enough water to be used for domestic supply wells (USGS, 1992). These bedrock units are generally hydraulically connected to the overlying Quaternary deposits wherever present. The aquitards beneath the Upper Aquifer are either the Maquoketa or Glenwood shale or Sinnipee dolomite, depending on the region of the state and the surface bedrock units (USGS, 1992).

The St. Peter aquifer includes the St. Peter Formation, the Prairie du Chien Group, and the Jordan Formation (Au Train Formation in the UP). It is underlain by the St. Lawrence aquitard (Krohelski and Brown, 1986; USGS, 1992). Most of the St. Peter aquifer units are sandstones which readily yield water, but significant amounts of dissolved minerals within this and underlying aquifers may make the water aesthetically unpleasing (USGS, 1992). The St. Lawrence confining unit consists of the St. Lawrence Formation and Tunnel City Group, and is composed of silty, shaly dolomites.

The underlying Elk Mound aquifer consists of sandstone units of the Elk Mound Group, and is hydraulically similar to the St. Peter aquifer. In Wisconsin, the Elk Mound Group consists of the Wonowoc, Eau Claire, and Mount Simon Formations (Krohelski and Brown, 1986). The Eau Claire and Mount Simon Formations extend, with the Mount Simon formation being the more productive of the two units in the UP (USGS, 1992). The basement complex is Precambrian, composed of igneous, crystalline rock that limits the vertical movement of groundwater. Primary water production is from the St. Peter aquifer, and the Elk Mound aquifer, both are bedrock aquifers and located at depth.

Prior to development in the Fox River Valley in the 1900s, the St. Peter aquifer was confined and existed under artesian conditions throughout most of the area. However, significant demands placed upon the aquifer have caused a well-known and studied drop in the potentiometric surface of the St. Peter aquifer. The cone of depression was centered on the city of Green Bay until 1950s when the city built a pipeline to Lake Michigan to supply the city's water needs. The St. Peter aquifer rebounded somewhat in the city of Green Bay, however, additional deep water wells were built along the Lower Fox River from De Pere to Lake Winnebago to supply growing population and industry needs and the cone of depression migrated south along the Lower Fox River, and is currently most dramatic in the De Pere area (Conlon, 1998; Axness, et. al., 2002). The potentiometric surface in the St. Peters has fallen between 100 and 400 feet from pre-development levels.

Hydrogeologic Setting Lower Fox River

The Lower Fox River occupies a lowland area approximately 10 miles wide, commonly described as the Fox River Valley. The Lower Fox River generally flows across relatively low permeability Quaternary deposits of lacusterine clay and silts and glacial till (Krohelski and Brown, 1986). These low permeability units underlie operable units OU1, OU3 & OU4 and sections of OU2. The clay, silt and till vary in thickness from less than 50 feet to over 100 feet (Need, 1985).

Under sections of OU2 in the Lower Fox River, the Sinnipee dolomite sub crops in the riverbed. Evidence of bedrock sub crop includes the rapids that exist along OU2, and limited soft sediment deposits. The river is classically narrow due to the bedrock riverbed. Rocks of this formation form the first major confining unit in the area and are considered to be relatively impermeable - or of low permeability (Krohelski and Brown, 1986; Conlon, 1998). The primary water supply aquifers for the Lower Fox River Valley are located beneath this confining unit.

Because shallow groundwater flow generally follows the ground surface topographic contours, groundwater flow in the Upper Aquifer is toward the Lower Fox River from the northwest and southeast (Plate 1, Krohelski and Brown, 1986).

Prior to development in the 1900s and significant pumping from the St. Peter aquifer, many springs and seeps existed in the Fox Valley as a result of the artesian conditions of the St. Peter aquifer. It is thought that the St. Peter aquifer also likely discharged to the Upper Aquifer and the Lower Fox River (Krohelski and Brown, 1986). Since water levels have been drawn down as much as 400 feet in the St. Peter aquifer, it no longer discharges to the Lower Fox River (Conlon, 1998). The significant cone of depression in the St. Peter aquifer induces vertical flow from the Upper Aquifer to the St. Peter aquifer reducing the amount of discharge to local streams including the Lower Fox River (USGS, 1998).

If water use in the valley changes, and the St. Peter aquifer rebounds to predevelopment levels, it may once again discharge to the Lower Fox River along certain reaches (Batten and Bradbury, 1996; Krohelski, 2002).

Lower Fox River/Groundwater Interaction

The Upper Aquifer in the area is composed of Silurian dolomites east of the Lower Fox River, and the unconsolidated glacial tills and lake sediments that cover the entire area. Groundwater movement in the Upper Aquifer is part of the local flow system and controlled by local topographic features. Because the Lower Fox River lies in a wide low valley, trending southwest to northeast, groundwater movement is toward the river (Krohelski and Brown, 1986; USGS, 1998). There have been no detailed studies of the Upper Aquifer to quantify the amount of ground water discharging to the Lower Fox River. Draw down in the St. Peter aquifer since development in 1900s has caused an increase in discharge from the Upper Aquifer downward to the St. Peter, reducing the volume of ground water discharging to the Lower Fox River (Conlon, 2002). However, it is likely that groundwater from the Upper Aquifer discharges to the Lower Fox River during periods of low or base flow. Discharge to the river is limited due to the following factors:

- Relatively impermeable tills and lake bed deposits, 50 - 100 feet thick, in which the river bed flows
- Relatively impermeable dolomite which sub crops in stretches of the river bed in OU2 (Conlin, 2002; Krohelski, 2002)
- Moderate to low head conditions between the Lower Fox River and the Upper Aquifer
- High surface run-off after storm events, reducing recharge to the Upper Aquifer
- Increased pumping rates for municipal and industrial use, and consequential drawdown

In a water supply modeling study (USGS, 1998), the volume of water in the Lower Fox River was measured at several points along the river from LLBdM to river mouth at Green Bay in order to estimate the contribution of groundwater to the river. For rivers with significant groundwater contributions, the expectation is that flow volume will increase downstream even after taking into account tributaries and other sources. In the case of the Lower Fox River, there was relatively minor unaccounted for change in volume over the 39 miles, supporting the case of limited groundwater discharge. For the same study, an inspection of a dolomite quarry in Kaukauna, approximately 100 feet from the Lower Fox River, revealed limited groundwater discharge into the quarry several hundred feet below the water level of the river, further supporting the case of limited ground water movement through this formation to the river (Conlin, 2002; Krohelski, 2002). In addition, caliper logs in the Sinnipee show no borehole enlargement, indicating relatively dense, and impermeable material. Due to the lack of detailed local studies of the Upper Aquifer, the discharge volumes to the Lower Fox River have not been quantified.

Although the majority of the Upper Aquifer is less impermeable material, lens of sand and gravel are present (Krohelski and Brown, 1986), and may produce locally significant discharge to the Lower Fox River where the sand and gravel lens intersect the river bed. Individual lens have not been specifically identified in the study area.

3.3.3.2 Water Use (1995)

Water use data (USGS, 1995a and 1995b) for the Lower Fox River watershed and the other significant Green Bay tributaries are summarized on Table 3-7. Approximately 595,300 people live in the Lower Fox River and Green Bay watersheds. Over 381,000 people are served by public water supply systems, which provide over 62.8 million gallons per day (MGD) (USGS, 1995a and 1995b). The source of water supplied by public systems is about equal between groundwater and surface water sources. Private wells and well systems supply about 11.1 MGD to the remaining population in the watersheds listed (Table 3-7).

The Lower Fox River watershed (Fox Cities MSA through Green Bay MSA) uses about 46.5 MGD, or 74 percent of the water consumed in the region daily. About 92 percent of this 46.5 MGD is supplied via public water supply systems. Further, only about 17.8 MGD of groundwater is pumped from the regional aquifers in the Lower Fox River area. According to water supply well records, the wells which supply the 17.8 MGD range in depth from 500 to over 1,000 ft below land surface (WDNR, 1985). Based on these well depths, it is unlikely that contaminated sediments would impact the groundwater sources that supply these municipal water wells. The remaining 28.7 MGD of water provided by public water supply systems are obtained from surface water sources. Many of the larger municipalities in the region, including Neenah, Menasha, Appleton, and Green Bay, use surface water for municipal water supply. Neenah, Menasha and Appleton pump water from Lake Winnebago while the city of Green Bay pumps water from Lake Michigan through a 42-mile pipeline that is located approximately four miles offshore of the city of Kewaunee.

Based on the fine-grained glacial deposits which underlie the Lower Fox River and the absence of regional groundwater extraction, there is little groundwater recharge from the Lower Fox River into the upper aquifer. Therefore, it is unlikely that contaminated river sediments are adversely impacting groundwater quality beneath the Lower Fox River. According to Krohelski and Brown (1986), only two streams within Brown County (Duck Creek and Suamico River) were identified as losing streams. These Green Bay tributaries recharge the upper aquifer in different reaches due to the absence of glacial material beneath the riverbed.

Water use in the other watersheds are significantly lower than that in the Lower Fox River watershed and is much more dependent on private water supplies (Table 3-7). Of the remaining 16.33 MGD of water consumed in the region, only the Menominee (Marinette/Menominee area) and Door/Kewaunee watersheds consume more than 1.57 MGD (Table 3-7). Approximately 6.7 MGD are consumed in the Menominee watershed while about 3.13 MGD are consumed in the Door/Kewaunee watershed. Within the Menominee watershed about 38.5 percent of the population is supplied by private wells/systems. Between 42 percent and 75 percent of the population is served by private wells/systems in the remaining watersheds. This breakdown of the population served by public versus private water supply systems reflects the rural nature of the remaining watersheds, especially when compared with the urban centers located throughout the Lower Fox River valley and at Marinette/Menominee.

The generation of electrical power uses the greatest volume of water in the Lower Fox River and Green Bay area. Over 398 MGD is used for thermoelectric power generation at the Wisconsin Public Service Corporation (WPSC) Pulliam power plant, which is located at the mouth of the Fox River. In addition, hydroelectric power (from dams on the river) uses almost 11.5 billion gallons per day. However, this water use is not included in the Total Water Use column (Table 3-7) because this water only represents river flow. No pumping or other efforts are required to obtain this water. In addition, water use for the Point Beach Nuclear power plant in Kewaunee County is not included in Table 3-7 because this water is obtained from Lake Michigan.

Over 146 MGD are used for industrial/commercial purposes, with about 80 percent of the total consumed in the Lower Fox River and Menominee watersheds. Additionally, over 93 percent of the water used for industrial/commercial purposes is obtained from surface water sources. Mining, irrigation, and livestock consume about 18.7 MGD (Table 3-7). Therefore, of the 625 MGD of water consumed in the region, about 92 percent of the water (574 MGD) is obtained from surface water sources. Due to the historic problems with water pollution in the Lower Fox River and Green Bay, the main surface water sources for human consumption are Lakes Winnebago and Michigan.

3.4 Lower Fox River Surface Water Hydrology

This section discusses the factors that influence or control flow in the Lower Fox River. Current velocities, high, low, and average flow characteristics, and river bathymetry all influence the movement of impacted sediments and consideration of possible remedial alternatives.

The slope of the bedrock and the pre-glacial bedrock valleys control the topography and drainage of the Lower Fox River valley. A pre-glacial bedrock valley lies along the axis of the Lower Fox River and was filled with glacial sediments from glacial Lake Oshkosh (around Lake Winnebago) and Nipissing Lake (from De Pere to Green Bay). The Lower Fox River and its tributaries have flowed over and cut through these relatively flat glacial lake plain sediments (Olcott, 1968).

3.4.1 Surface Water Flow Controls

3.4.1.1 Dams in Wisconsin and on the Lower Fox River

Dams in Wisconsin and on the Lower Fox River are subject to state and federal regulations and most of the dams are regulated for energy production. Most existing dams are not primarily flood control structures and there are no plans to remove any of the existing dams on the Lower Fox River. However, there are concerns about the release of upstream contaminated sediment in the event of a dam removal or failure. Inspection and dam stability information on the dams owned and operated by the USACE reveals that the dams are regularly inspected, have post inspection maintenance conducted and have no significant stability concerns.

Regulatory History of Wisconsin Dams. The first dam built in Wisconsin was built in 1809 to provide power for a sawmill on the Fox River at De Pere. Black River saw it's first sawmill in 1819, and in 1831 one was built on the Wisconsin River. These early dams aided people in providing flowages for transporting goods, and for powering lumber and grain mills. The first state regulation of dams began with the Milldam Act, a part of the Wisconsin Territorial Laws of 1840, No. 48. The purpose of this act was to encourage the construction of mill-powering dams, by permitting the flooding of the land of others without acquiring easements for millponds. These early dams provided for and encouraged settlement in Wisconsin.

In 1841, dams on navigable streams were required to obtain legislative permission, as a part of the Wisconsin Territorial Laws of 1841, No. 9. This helped encourage economic development, as well as protect the public interest in waterways. The Milldam Act was repealed in 1849 (ch. 157), as the constitutionality of preventing compensation by flooded landowners was challenged at the Wisconsin Supreme Court. The impoundments created by dams were viewed as a public resource, and therefore it was argued that private land, such as the land being flooded by these dams, could not be taken from its landowners for public use without compensation being given to the landowner. In 1857 the Milldam Act was revived under Chapter 62, Laws of 1857, but was repealed and recreated in 1858. In a court case in 1860, it was stated by the court that the Milldam Act would be overruled if it were not for precedent and economic benefits, and therefore the Milldam Act was constitutional.

In 1863, it was declared that navigable waterways are public highways. In the following years, the "sawlog" test was developed to determine navigability. In 1909, the legislature decided they no longer had the time or expertise to issue permits for dams, and that responsibility was given to state agencies.

For much of the early 1900s, the Rail Road Commission and then the Public Service Commission (PSC) had jurisdiction over dams. Laws changed over the years, to address issues such as the rights of upstream and downstream landowners, the debate over navigable and non-navigable rivers, and public safety rights. In 1967, the Wisconsin Department of Natural Resources was created, and jurisdiction over dams was handed over from the PSC to the WDNR. In the early 1980s, the WDNR developed standards for design, construction and reconstruction of large dams, enacted Warning Sign and Portages for Dams rules for public safety. In 1991, procedures for implementation of dam maintenance, repair, modification or abandonment grant program were put into place.

The WDNR currently deals with permitting for new dam construction, repairs, reconstruction, ownership transfers, and abandonment. Many dams in the state have been in place since the late 1800s, and a great deal of time must be invested in inspecting aging dams and making sure they comply with public safety requirements, and environmental regulations.

Wisconsin Dams. There are approximately 3,700 dams inventoried in the state of Wisconsin. An additional 700 dams have been built and washed out or removed since the late 19th century. The federal government has jurisdiction over large dams that produce hydroelectricity - approximately 5 percent of the dams in Wisconsin. The WDNR regulates most of the rest of the dams. Approximately 50 percent of the dams in Wisconsin are owned by private individuals, 19 percent by the state of Wisconsin, 16 percent by municipalities such as townships or county governments, and 15 percent by other ownership types.

A dam with a structural height of over 6 feet and impounding 50 acre-feet or more, or having a structural height of 25 feet or more and impounding more than 15 acre-feet is classified as a large dam. There are approximately 1,200 large dams in the state of Wisconsin. Dams are classified as High Hazard when their failure would put lives at risk. The "hazard" rating is not based on the physical attributes, quality or strength of the dam itself, but rather the possibility of loss of life and property should the dam fail.

The Public Trust Doctrine emanates from Article IX, Section 1 of the Wisconsin Constitution. It states that all rivers, lakes and navigable waterways are under the jurisdiction of the state of Wisconsin. Any structure which is built on a waterway impacts the public rights to that waterway, and needs to be monitored by the state of Wisconsin to assure safety, water quality, public access and monitor its impact on Wisconsin wildlife.

Dam Safety Program. Chapter 31, created in 1917 under the Water Power Law, was developed to ensure that dams are safely built, operated and maintained. NR 333 provides design and construction standards for large dams and NR 335 covers the administration of the Municipal Dam Repair and Removal Grant Program. WDNR is responsible for administration of these regulations. Chapter 31 covers:

- Dam permitting
- Dam construction
- Dam safety, operation and maintenance
- Alteration or repair of dams
- Dam transfer and dam removal
- Water level and flow control

In regards to dam safety inspections, Chapter 31.19 requires the department to inspect all of the large dams on navigable waterways once every 10 years. However, WDNR does not typically inspect dams that are regulated by a federal agency.

Dam Removal. Dams have been built and removed in Wisconsin for almost 200 years. In the early years, when a dam no longer provided and functional or economic purpose it was removed from the stream. Many of the dams in the state today have been in place for years. While many of these no longer provide their original function they have become a part of the communities identity. This can make decisions about whether to perform costly upgrades to dams or remove them very difficult.

The WDNR is required to review and approve all applications for dam abandonment and removal. Consideration of abandonment/removal has usually come about because of a failure incident or as the result of a WDNR inspection that found significant defects that requires major repairs to correct. Economic, social, and environmental factors all play a significant role in the decision to remove dams.

In recent decades, Wisconsin has seen a large number of its historic dams aging and falling into disrepair. In most cases the Department has remained neutral in the decision making process, only seeking to correct safety deficiencies at dams. As dam removals have been accomplished over the last 20 years, significant improvements have been noted in water quality, habitat and bio-diversity at many of these sites. In light of this, in recent years, the WDNR has advocated for the removal of certain dams for the purpose of stream and habitat restoration.

In all cases, the Department's activities related to dam removal included assuring that the project meets the statutory requirements of Chapter 31 and is completed in a manner that protects the public rights in navigable waters and public safety. In cases where WDNR advocated dam removal, they participated in public information meetings to explain the benefits of dam removal to the surrounding ecosystem, and assisted with funding to accomplish removal and restoration activities. In the future these types of efforts will probably continue on a selective basis, driven by watershed plans that identify dams which are most detrimental to the ecosystem. Without willing dam owners, dams cannot be removed or property operated and maintained.

Almost 100 dams have been removed from Wisconsin streams since 1967. The dam inventory lists over 900 dams that have been built and removed since the 1800s. Removed dams have ranged in size from small dams on trout streams, such as the Cartwright Dam on Shell Creek, medium size dams such as the Ontario Dam on the Kickapoo River and fairly large dams on warm water streams such as the North Avenue Dam on the Milwaukee River.

The three major reasons for dam removals in Wisconsin are:

- Removal of an unsafe structure under Chapter 31.19 of our state statutes. Under Chapter 31.19 the WDNR is required to inspect "large" dams at least once every 10 years to ensure their safety.

- Chapter 31.187 charges the WDNR with removing "abandoned" dams when either no owner is found or the owner or owners are not able to fund repairs.

- In a few cases, WDNR has removed or proposed to remove dams that have a significant environmental impact. Many of those are on WDNR properties.

The normal process in which a removal might be considered would involve a dam that has been identified as deficient through a failure or an inspection. If the dam owner can be identified, the owner would then be notified of the problems and given a timeline to correct all deficiencies. An official order may be given, ordering the dam owner to either perform the needed repairs or remove the structure - repair or removal is their choice. If the dam owner is considering removal, or if it is not economically feasible for the dam owner to repair the dam (dam removal generally costs one-third of estimated reconstruction costs), the owner submits an application to abandon the permit of the dam and a plan for removal of the structure. At this point, a public information meeting is often held, in which the WDNR explains the situation and gains public input. If the owner chooses to pursue dam removal, an Environmental Assessment may then be prepared, followed by public notice, which provides the opportunity for a contested case hearing. Once these steps are complete, a permit to abandon the dam will be issued with conditions for removal.

With regard to resource management, the most significant benefits of dam removal include:

- Re-connection of important seasonal fish habitat
- Normalized temperature regimes
- Improved water clarity (in most cases)
- Improved dissolved oxygen concentrations
- Normalized sediment and energy transport
- Improved biological diversity

In general, carp prefer the warm waters of an impoundment, yet when a dam is removed the cool water species such as trout and bass, generally preferred by anglers, can move back into the river and re-populate.

Dams on the Lower Fox River. Table 3-8 presents a summary of the location and pertinent information on the dams for the lower Fox River from Lake Winnebago to Green Bay. In that stretch of the river there are 13 existing dams and one dam that was abandoned. Of the existing dams, all are classified as large. Nine of these dams have a high hazard potential while four have a significant hazard rating. A majority of these dams (11) are licensed by the Federal Energy Regulatory Commission, suggesting that the dams primary purpose is energy related, not flood control. While all of the dams have some potential for the release of contaminated sediments from upstream sediment deposits, the database maintained by the WDNR's Dam Safety program specifically lists the releases of contaminated sediments as a concern relative to dam failure scenarios or immediate need for draw downs for six of these dams.

Joint dam ownership is quite common for the dams along the Fox River. Eight dams have at least partial ownership by the U.S. Army Corps of Engineers. Sections of some of these dams are also under private ownership. Negotiations are continuing on the transfer of the "transportation locks" portion from the USACE to the state. The USACE (and co-owners) will retain the ownership of the dams. At this time, the WDNR is not aware of any plans to remove any of these dams. Of the Lower Fox River dams, WDNR Dam Safety staff has indicated that the De Pere dam may be in need of repairs, however, they do not believe that there is a concern of a catastrophic failure.

Eight of the dams on the lower Fox River from Lake Winnebago to the mouth of the Fox River at Green Bay are either fully or partially owned by the U.S. Army Corps of Engineers. The WDNR reviewed past periodic inspection and the conclusions of stability analysis for each of these dams. The results of this review are presented in Table 3-9. The USACE is not identified as a co-owner of Kaukauna dam.

In general, the stability analysis indicated that the spillway and sluiceway sections of the dams have adequate compression to resist overturning and the have adequate bearing capacity to support the maximum base pressure. While inspections did reveal various potential problems, such as the need for concrete repairs, the overall conclusion of the reports were that dams were found to be in good condition overall and no structural deficiencies were found which would affect the operation of the dam. Many of the inspection reports recommended development of a plan to prioritize repairs for the dams on the Fox River over a subsequent five-year period. The USACE has stated that maintenance recommended by the routine inspection is conducted. This information is from WDNR's Dam Safety, Floodplain, Shoreland program's webpage (http://www.dnr.state.wi.us/org/water/wm/dsfm/dams/index.html) concerning dam safety. In addition, the web page provides more information such as frequently asked questions about the dams in Wisconsin.

3.4.1.2 Lower Fox River Dams and Navigational Controls

There are 17 locks and 13 existing dams and one abandoned dam located along the Lower Fox River between Lake Winnebago and the De Pere dam. There is one abandoned dam. The locks are an important aspect of navigation on the Lower Fox River. The Neenah and Menasha dams control discharge from Lake Winnebago. Similarly, the other dams located between LLBdM and De Pere control flow in the lower portion of the river. These dams are used to control water levels throughout the river to provide a continued source of power for the hydroelectric plants located along the river and to allow navigation.

The locks serve approximately 7,400 boats and barges annually and, according to the ECWRPC, boaters generate between $5 million to $6 million in revenues to the area annually. Additionally, the locks save many area property owners thousands of dollars annually on maintenance costs because marine contractors that utilize the locks can move equipment to project sites much more cheaply by water than by land.

In 1984, the navigation portion of the Lower Fox River project was placed in "caretaker status" by the USACE. Under this status, the USACE performs minimal maintenance, and only three of the 17 navigation locks are in operational condition: the De Pere, Little Rapids, and Menasha locks. With the exception of the Rapide Croche Lock (which is permanently closed to restrict the movement of sea lampreys), all the other locks would require maintenance and renovation before operational status could be restored.

In June 1998, the United States House of Representatives passed a bill which would allow control and maintenance of the Lower Fox River locks to pass from the federal government to state and local governments in Wisconsin. The state of Wisconsin and the USACE signed a memorandum of agreement in September 2000 for the transfer of the Fox River locks (WDNR, 2000d). This agreement does not actually transfer the control or property yet, but it establishes the framework for the transfer to occur in the future. A number of general provisions of the agreement include the following:

- The Rapide Croche Lock will be maintained as a sea lamprey barrier

- The federal government will provide funding for the repair and rehabilitation of the land, locks, and appurtenant features prior to transfer

- The locks and dams will be inspected to evaluate which features require immediate attention

- The state of Wisconsin will be responsible for the operation, maintenance, repair, replacement, and rehabilitation of the locks and appurtenant features after the transfer is complete

3.4.1.3 Neenah-Menasha (Lake Winnebago)

Lake Winnebago is a controlled waterway with specific water level targets, depending on the season of the year. The USACE oversees and maintains discharge from Lake Winnebago to the Lower Fox River. The information contained within this section was obtained from the Lake Winnebago Facts Book (USACE, 1998a).

In the early 1980s, water level targets were established to provide water usage for hydropower and navigation while preserving or enhancing fish, wildlife, and wetland habitat, as well as water quality in the Lower Fox River and the Lake Winnebago pool. The Lake Winnebago pool consists of the other large water bodies upstream of Lake Winnebago. The local water level datum for Lake Winnebago is the Oshkosh datum. The water level in Lake Winnebago has been established at or above the crest of the Menasha Dam (51 centimeters or 1.68 ft Oshkosh datum) during the navigation season.

Lake Winnebago seasonal water level targets have a range of less than 107 cm (3.5 ft) between the allowable low (5.5 cm or 0.18 ft Oshkosh) and high (105 cm or 3.45 ft Oshkosh) water levels. The water level targets are divided into five segments based on seasonal water level objectives. The regulation periods and objectives are briefly described below (USACE, 1998a).

Winter Drawdown: Following formation of solid ice cover in the Lake Winnebago pool, the water level in Lake Winnebago is slowly lowered to the winter drawdown level of 21 cm (0.68 ft) Oshkosh. This drawdown level of 21 cm (0.68 ft) Oshkosh provides capacity needed to contain spring runoff. If the capacity is insufficient, flooding in the Lower Fox River is likely during snow melt. However, if the lake level is drawn down too low, spring outflows from Lake Winnebago may have to be restricted in order to achieve the required navigation stage when the pool is refilled.

Typically, drawdown commences at a rate designed to achieve a target level by about March 1.

Between Drawdown and Ice-out: Once the target drawdown level has been achieved, the stage is held constant until ice cover in the Lake Winnebago pool breaks up and starts moving out, which usually occurs in late March or early April. Maintenance of these water levels is important because water level increases can cause ice damage to wetlands and the Lake Winnebago shoreline.

After Ice-out: Following breakup of the ice, the Lake Winnebago pool is refilled. The target navigation stage, 91 cm (3.0 ft) Oshkosh, is to be achieved by the beginning of May, typically the start of the navigation season. To achieve this, the pool is allowed to fill in early April.

Navigation Season: During the navigation season, the Lake Winnebago water level is held as close as possible to the target stage. However, since the year's lowest inflows occur during this time, it is not always possible to maintain the target level throughout the navigation season. The navigation season extends through approximately mid-October.

Between Navigation Season and Freeze-up: When the navigation season ends, the water level in Lake Winnebago is decreased to approximately 61 to 76 cm (2.0 to 2.5 ft) Oshkosh by December 1. The only outflow constraint is to observe a maximum safe discharge of about 510 m^3/s (18,000 cfs), while allowing only gradual changes in stage to minimize impacts on wildlife. Following this, the winter drawdown water levels are implemented in accordance with the plan.

3.4.2 Lower Fox River Surface Elevation

The Lower Fox River decreases about 48.2 m (158 ft) between the Menasha and De Pere dams and approximately 3.3 m (11 ft) between the De Pere dam and the mouth of the river. The overall gradient for the Lower Fox River is 51.5 m (169 ft) over 63 km (39 miles) or 8.2×10^{-4} m/m. Gradient information obtained from the NOAA Recreational Chart (1992) is summarized on Table 3-10 and the river profile is shown on Figure 3-1.

Three areas exist where the water level elevation decline approaches or exceeds 9.1 m (30 ft). These three sections are located within the Appleton to Little Rapids Reach, between the outlet of LLBdM and the Rapide Croche dam (Figure 3-1 and Table 3-10). The first section is located between the Upper and Lower Appleton dams, where the river elevation declines about 8.5 m (28 ft) in just 1.9 km (1.2 miles). The other two sections are located adjacent to one another. These extend from the Little Chute dam to the Kaukauna dam and from the Kaukauna dam to the Rapide Croche dam. The gradients for each of these river sections is approximately an order of magnitude higher than the gradients for the remaining sections of the river (Table 3-10). These three sections of the river contain limited soft sediment deposits because of increased flow velocities. The only two locations with a large areal extent of sediment in these sections are deposits W and X. Deposits W and X are located between the Kaukauna and Rapide Croche dams, in an area where the river width increases to approximately 640 m (2,100 ft), and flow velocities decrease. Additionally, the elevation decline in the Appleton to Little Rapids Reach exceeds 42.8 m (140 ft), whereas the elevation decreases in the other three reaches are all approximately 3 m (10 ft) or less.

3.4.3 Low-Flow and Flood Frequencies

The flow of the Lower Fox River, from Lake Winnebago to the mouth at Green Bay, has been historically monitored by as many as six stream gauging stations operated by the USGS. Most recently, the USGS operated two automated acoustical velocity meter (AVM) stream gauging stations on the Lower Fox River. The first AVM gauge was located at the south end of Lutz Park, approximately 0.8 km (0.5 mile) upstream of Memorial Drive bridge in Appleton (Hydrologic Station # 04084445). The other AVM gauge was located about 1.3 km (0.8 mile) upstream from the mouth in Green Bay, or about 0.8 km (0.5 mile) upstream of Interstate 43 bridge (Hydrologic Station # 040851385). The former gauging stations and the years for which data are available from each are listed below.

The historical river discharge information from the Rapide Croche Dam station (#04084500) is presented on Table 3-11. This gauging station has been recording discharge and stream flow since October 1917. The Water Year (WY) extends from October 1 through September 30 of the following year. The summarized Rapide Croche results (Table 3-11) show that daily discharge volumes ranged from a low of 4 m^3/s (138 cfs) to a maximum of 680 m^3/s (24,000 cfs). The month of April typically exhibits the highest discharge volumes, due to winter snow melt and spring rains. Four months, March through June, have average daily discharge volumes exceeding the annual average of 122 m^3/s (4,300 cfs). Conversely, the late summer months of August and September generally have the lowest flows. These results are similar to the shorter records of other Lower Fox River gauges.

Fox River Gauging Stations and Years of Available Data

Station Location	Hydrologic Station #	Drainage Area km^2 (mi^2)	Years of Data Available
Fox River at Appleton	04084445	15,410 (5,950)	7/1/86 to 9/30/97
Fox River at State Highway 55 at Kaukauna	04084475	15,488 (5,980)	10/1/88 to 9/30/90
Fox River at Rapide Croche Dam near Wrightstown	04084500	15,565 (6,010)	10/1/17 to 9/30/97
Fox River at Little Rapids	04085054	15,800 (6,100)	10/1/88 to 9/30/90
Fox River at De Pere	04085059	15,825 (6,110)	10/1/88 to 9/30/90
Fox River at Oil Tank Depot, Green Bay	040851385	16,395 (6,330)	10/1/88 to 9/30/99

Note: The historical stream flow data for each of the gauges listed is available through the Internet from the USGS (http://waterdata.usgs.gov/nwis-w/WI/) and are USGS, 1998a, 1998b, 1998c, 1998d, 1998e and 2000, respectively.

In 1980, the WDNR developed a waste load allocation for the Lower Fox River, based on the seven-day average low stream flow with a ten-year frequency ($Q_{7,10}$) of 26.9 m^3/s (950 cfs). Discharge records by the Appleton water department used in this study indicated that stream discharge volumes exceeding 96 m^3/s (3,400 cfs) were far more frequent than were any of the other volumes evaluated (WDNR, 1980). Based on the stream gauge records for the Rapide Croche gauge, the average discharge volume in the upper portion of the river (between LLBdM and the De Pere dam) is approximately 122 m^3/s (4,300 cfs) (USGS, 1998c).

A similar flood frequency evaluation at the Rapide Croche gauging station was completed by USGS (Krug, *et al.,* 1992). The 10-year flood discharge is 544 m^3/s (19,200 cfs) while the 100-year flood flow is over 685 m^3/s (24,200 cfs). These volumes are 5 to 6 times greater than the average discharge of 122 m^3/s (4,300 cfs).

3.4.4 Measured and Estimated Stream Flow Velocities

Stream flow velocity is an important factor in evaluating areas where sediment deposition or erosion is likely to occur. The average stream flow velocity in each river reach was estimated using discharge measurements collected from USGS gauges along the river (Table 3-12). These estimates were completed using the river cross-sections determined for the GBMBS modeling efforts (WDNR, 1995).

The cross-sections listed on Table 3-12 are the area estimated at the boundary between each water column segment in the transport models (Velleux and Endicott, 1994; WDNR, 1995). The cross-sectional areas listed are for the boundary of each model segment and the deposits within each segment are listed

(Table 3-12). Some deposits lie in more than one model segment and these have been listed accordingly. Water column segments 4 and 5 lie adjacent to each other and are only separated by the Menasha Channel; therefore, these two segments share the boundary with water column segment 6, which Table 3-12 reflects. Also, because the De Pere dam separates water column segments 27 and 28, there was no listing for this boundary, so deposits GG and HH have been listed as though they fall in segment 26. In general, stream flow velocities in the river average approximately 0.14 meter per second (m/s) (0.45 feet per second [ft/s]).

The average stream flow velocity in the LLBdM Reach is 0.15 m/s (0.51 ft/s) and velocities range from 0.08 to 0.35 m/s (0.26 to 1.15 ft/s). However, in LLBdM itself (water column segments 2 through 9), the average steam flow velocity is just under 0.13 m/s (0.42 ft/s) and overall velocities range from 0.08 to 0.20 m/s (0.26 to 0.65 ft/s) (Table 3-12). This lower average for LLBdM is due to the fact that LLBdM is a wide, generally shallow lake in comparison with the rest of the river. This is evident by the increased stream flow velocity (exceeding 0.30 m/s) in water column segments 10 and 11. These segments (10 and 11) are located at the outlet of LLBdM and the cross-sectional area decreases significantly compared to the other portions of LLBdM (Table 3-12).

The average stream flow velocity in the Appleton to Little Rapids Reach is 0.24 m/s (0.78 ft/s), approximately 65 percent higher than the LLBdM Reach and almost double the velocity found in LLBdM proper. This reach had the highest estimated stream flow velocities in the river, ranging from 0.15 m/s (0.48 ft/s) to 0.37 m/s (1.23 ft/s) (Table 3-12). Two of the three highest stream flow velocities in this reach are found in water column segments 19 through 21, a part of the river where no sediment deposits were found.

The average stream flow velocity in the Little Rapids to De Pere Reach is 0.12 m/s (0.40 ft/s), approximately half of the average velocity for the Appleton to Little Rapids Reach (Table 3-12). Flow velocities in this reach range from 0.11 m/s (0.37 ft/s) to 0.13 m/s (0.42 ft/s), the smallest variation in flow velocities noted in any reach (Table 3-12). The largest sediment deposit located upstream of the De Pere dam, Deposit EE, is located in this reach.

The De Pere to Green Bay Reach has an average stream flow velocity of 0.08 m/s (0.25 ft/s), the lowest found in the river (Table 3-12). Due to these overall low stream flow velocities, the largest volume of deposited sediment occurs in this reach.

3.4.5 Lower Fox River Bathymetry

The Lower Fox River is relatively narrow, generally less than 305 m (1,000 ft) wide over much of its length, and ranging up to approximately 6.1 m (20 ft) deep in some areas. Where the river widens significantly, the depth generally decreases to less than 3 m (10 ft) deep and, in the case of LLBdM, water depths range between 0.61 to 1.53 m (2 to 5 ft) except in the main channel. In general, the main channel of the river ranges from approximately 1.8 to 6.1 m (6 to 20 ft) deep. Bathymetry information available from the NOAA recreational charts for Lake Winnebago and the Lower Fox River (NOAA, 1992) are included in Appendix E.

3.4.5.1 LLBdM Reach

Water depths in the LLBdM Reach are generally less than 1.8 m (6 ft) (NOAA, 1992). Water depths on the south end of the lake, near sediment deposits A and B, are less than 1.2 m (4 ft). The main flow channel, which starts near the edge of sediment Deposit C, is approximately 2.4 m (8 ft) deep on the south end and increases to approximately 5.8 m (19 ft) near the lake outlet. Downstream of Deposit E, the water depth in the main channel ranges between 1.8 and 3.4 (6 and 11 ft) with depths between 0.6 and 1.2 m (2 and 4 ft) along the banks of the river.

3.4.5.2 Appleton to Little Rapids Reach

This reach of the river meanders more than any other reach and is comprised of a series of large contiguous pools. Similar to the LLBdM Reach, water depth in the main channel ranges between 1.8 and 3 m (6 and 10 ft) throughout much of the reach. This reach is marked by sections of the river with varied widths and, as such, the river depth decreases to as little as 0.3 m (1 ft) just downstream of Kaukauna. Near the Rapide Croche dam, the river depth increases to as great as 16 ft in the main channel. Between the Rapide Croche and Little Rapids dams, the river is generally narrow and main channel water depths are usually between 1.4 to 3.7 m (8 to 12 ft).

3.4.5.3 Little Rapids to De Pere Reach

The width is greatest at the upstream end and decreases downstream. The main channel depth is usually greater than 2.7 m (9 ft) and increases to 5.5 m (18 ft) approaching the De Pere dam. Along the banks of the river the depth is generally less than 1.8 m (6 ft) deep throughout this reach.

3.4.5.4 De Pere to Green Bay Reach

Water depths in this reach range between 1.8 and 7.3 m (6 and 24 ft) deep in the main channel. The lower 4.8 km (3 mil) of the reach are dredged by the USACE in order to maintain the navigation channel. Prior to 1982, the navigation channel was maintained from the mouth of the river to the De Pere dam, but since 1982 this upper portion of the channel has been maintained to a depth of 1.8 m (6 ft). Between De Pere and the Fort James-West turning basin (formerly Fort Howard), the depth of water is generally less than 1.8 m (6 ft) outside of the navigation channel. Downstream of the Fort James-West turning basin, the river narrows so that the navigation channel almost encompasses the entire width of the river. Dredging of sediments from the navigation channel is discussed in more detail in Section 3.6.1.3 below.

3.5 Green Bay Surface Water Hydrology

This section discusses the factors that influence water currents, bathymetry, and mixing in Green Bay. These factors control the migration of impacted sediments from the Lower Fox River in the bay. The occurrence and movement of ice in the bay will also influence the feasibility and costs of removing and treating or storing impacted sediments. A number of studies concerning Green Bay water circulation, currents, and mixing patterns were recently summarized by the USFWS (Stratus, 1999a). Portions of the information included in this section were derived from the USFWS document.

3.5.1 Green Bay Water Level Elevations

Water level elevations within Green Bay reflect the water level within the Lake Michigan-Huron basin. These two lakes are connected through the Straits of Mackinac and are a single lake basin.

Water levels within the Great Lakes are measured according to the International Great Lakes Datum 1985 (IGLD 1985), which has its zero reference elevation point located at Rimouski, Quebec, Canada (USACE, 1996). The bench mark elevation for Lake Michigan is 178.065 m (584.203 ft) IGLD 1985 at Calumet Harbor, at the south end of the lake. The overall annual long-term average (LTA) elevation for the Lake Michigan-Huron basin is 176.485 m (579.02 ft) IGLD 1985 (USACE, 1998b). The monthly LTA elevation ranges from a low of 176.34 m (578.54 ft) IGLD 1985 in February to a high of 176.64 m (579.53 ft) IGLD 1985 in July (USACE, 1998b).

Historically, the lowest and highest monthly water elevation levels were recorded in March 1964 and October 1986, respectively. In March 1964, the Lake

Michigan-Huron basin had a water level elevation of 175.58 m (576.05 ft) IGLD 1985. In October 1986, the measured water level elevation was 177.50 m (582.35 ft) IGLD 1985. The basin has an overall range of approximately 1.92 m (6.3 ft) (USACE, 1998b).

Water levels within the Great Lakes are currently decreasing. During 1996 and 1997, water levels were significantly above average, and the winters of 1995-96 and 1996-97 experienced snowfall accumulations which provided recharge for the Great Lakes. However, staring in late 1998, water levels within the lakes begin to decline, falling to near average or below average water levels. The Lake Michigan-Huron basin began 1999 at 176.281 m (578.35 ft), about 7.6 cm (3 in) below the January LTA and the 1999 elevations peaked in mid-July at 176.41 m (578.77 ft), which is about 22.9 cm (9 in) below the July LTA (USACE, 2000a). During the rest of 1999 water level elevations declined even further to about 175.96 m (577.30 ft), or about 43.2 cm (17 in) below the December LTA (USACE, 2000a).

Data collected between March 1999 and February 2000 indicate that only 68 percent of the normal annual precipitation fell in the Lake Michigan-Huron basin during this time frame. Snowmelt runoff is responsible for about 40 percent of the annual water supply into the Great Lakes (USACE, 2000b). Snow cover in the Lake Michigan-Huron basin in March 2000 was drastically lower compared to March 1997 USACE (2000b). In March 1997, large portions of the UP had snow pack with a snow-water equivalent (SWE) exceeding 30 cm (12 in) and the lower peninsula of Michigan had a SWE of >0 to 20 cm (>0 to 8 in) (USACE, 2000b). However, in March 2000, the snow cover SWE was less than 10 cm (4 in) throughout in Michigan and in Wisconsin (USACE, 2000b). In addition to less snow fall, the warmer winters of 1998, 1999, and 2000 have reduced ice cover over the lakes and increased evaporation (USACE, 2000b). Combined, these factors have contributed to lakes levels which are approaching the record low for the Lake Michigan-Huron basin (USACE, 2000b).

3.5.2 Green Bay Water Circulation, Currents, and Mixing Patterns

PCBs and other contaminants in the Lower Fox River are either adsorbed onto suspended sediment particles or dissolved within the water column. Therefore, current patterns in Green Bay are important for evaluating the spatial distribution of PCBs and other contaminants in both the sediments and water column derived from the river.

Complex water currents and circulation patterns are present in Green Bay. However, there is an overall general counterclockwise movement of water in the bay. Water from Lake Michigan moves into the bay and flows south along the west shore (Smith, *et al.,* 1988). Water from the Lower Fox River is generally transported north along the east shore of the bay, carrying suspended sediment as well as contaminants in dissolved and particulate phases. In addition, the inner bay and outer bay each have their own general counterclockwise currents (or gyres), which are effected by the presence of spits and shoals on the west side of the bay. Based on modeling results, it was estimated that monthly average residual currents exceeding 5.0 cm/s were common in most of the bay during August 1989 (Blumberg, 2000).

Water circulation in Green Bay is controlled by a number of different factors:

- Wind speed and direction
- Surface water elevation changes induced by wind and barometric pressure
- River discharge
- Upwelling of the thermocline in Lake Michigan
- Thermal and density gradients between the bay and Lake Michigan
- Ice cover
- The Coriolis effect (Gottlieb, *et al.,* 1990)

HydroQual, Inc. (HydroQual) completed a modeling analysis of current patterns in Green Bay based on data collected during the 1989-90 GBMBS. The monthly mean surface and bottom circulation patterns as calculated by a three dimensional circulation model (HydroQual, 1999) for August 1989 are shown in Figures 3-2 and 3-3, respectively. The USFWS also recently completed a summary of previous flow studies in the Lower Fox River and Green Bay system. Portions of the following sections concerning water circulation in Green Bay have been derived from this summary (Stratus, 1999a).

Shallow bays and lakes, especially like the inner bay of Green Bay, respond rapidly to the transient forces listed above, which tend to dominate over steady, low-frequency forces for short time intervals. Long term averaging of currents reveals steady, residual circulation patterns responsible for the net mass transport (Blumberg, 2000). Miller and Saylor (1985) noted that the monthly averaging of currents shows a relatively consistent circulation pattern, with the magnitude of the currents varying from month to month. Figures 3-2 and 3-3 show the formation of several gyres in the bay, resulting in a complex residual circulation pattern in Green Bay. This circulation pattern affects mixing, flushing, and mass transport.

The formation of small-scale gyres, in both the inner and outer bays, causes localized entrapment of water masses and associated constituents. Due to the localized gyres, the flushing time for Green Bay is estimated to be on the order of 1,000 days (Blumberg, 2000). Estimated flushing times for the inner portion of Green Bay (HydroQual, 1999) are much lower than for the entire bay. The areas within 10 km and 25 km of the mouth of the Fox River flush in about 25 days and about 100 days, respectively (Blumberg, 2000).

3.5.2.1 Lower Fox River Discharge into Green Bay

As mentioned above, the USGS has an AVM gauge located at the mouth of the Fox River to record discharge into Green Bay. The Fox River is the largest tributary to Green Bay, with an average discharge of 122 m^3/s (4,300 cfs) (USGS, 1998c). A summary of observed flow measurements at the mouth of the river are listed in Table 3-13. Discharge during WY 1999 was about 106 m^3/s (3,753 cfs) while the average discharge over the past 11 years (WY 1989-1999) was 141 m^3/s (4,999 cfs) (USGS, 2000) (Table 3-13). In addition, data from WY 1989-99 indicate that river discharge exceeds 272 m^3/s (9,605 cfs) 10 percent of the time and 114 m^3/s (4,040 cfs) 50 percent of the time (Table 3-13).

Negative discharge values result from seiche events, when flow in the Lower Fox River is reversed and water moves from Green Bay into the river. The seiche is produced when northeast winds push water in Green Bay to the south end of the bay (Smith, *et al.,* 1988). The seiche occurs daily and, as evidenced by the AVM data, results in reversed stream flows in the lower reach of the river. Water levels in the south end of the bay often fluctuate between 0.15 and 0.3 m (0.5 and 1 ft), although water levels have increased more due to storm events. The seiche also results in the general counterclockwise flow in Green Bay, which facilitates mixing of the river and bay water. The flow reversal can be significant, with recorded reversed discharge volumes of 92 m^3/s (3,250 cfs), which is 75 percent of the Lower Fox River average discharge of 122 m^3/s (4,300 cfs).

Even greater flow reversals have been recorded for individual storm events. The USGS hydrographs for two storm events in November 1998 are included in Appendix F. On November 10, 1998, the gauging station hydrograph recorded a significant reversal of flow in the Lower Fox River. Over an approximate 6- to 12-hour period the, following conditions were observed at the mouth of the Lower Fox River:

- Streamflow volume reversed from a high of about 710 m^3/s (25,000 cfs) to about -1,840 m^3/s (-64,900 cfs)

- Water levels dropped from approximately 176.63 m (579.5 ft) IGLD 1985 prior to the storm to 175.01 m (574.2 ft) IGLD 1985 immediately following the storm

- The stream flow velocities decreased from about 0.15 m/s (0.5 ft/sec) to -1.52 m/s (-5 ft/s).

A similar storm on November 23, 1998, produced a stream flow volume reversal of -566 m^3/s (-20,000 cfs) with a drop in water levels of approximately 0.37 m (1.2 ft), and a decrease from a positive stream flow velocity to about -0.49 m/s (-1.6 ft/s) (Appendix F). The records for these two storm events indicate that significant changes in water level and flow are possible at the southern end of Green Bay.

An intense storm event in April 1973 was responsible for severe flooding near the mouth of the river. This storm lifted a 1,000,000-gallon oil tank off of its foundation and removed the last small remnants of the Cat Island Chain which were present above the surface water at that time (Erdman, 1999a). The Cat Island Chain, which had been experiencing continued erosion following the development and rip-rapping activities associated with construction of the Bay Port confined disposal facility (CDF) in the former Atkinson Marsh, disappeared following this storm event. However, at the time of this RI, small portions of the chain were visible in the bay due to low water levels. Development of the Bay Port CDF and loss of large areas of wetlands in the southern end and west shore of the bay are discussed further (Section 4.2.3.2).

3.5.2.2 Fox River Plume Studies

The Fox River is the dominant tributary to Green Bay and, based on USGS gauging station data for the eight largest tributaries (the Fox, Pensaukee, Oconto, Peshtigo, Menominee, Ford, Escanaba, Fishdam-Sturgeon basins) its accounts for over 40 percent of the total tributary inflows into the bay (Bertrand, *et al.,* 1976). Historical analysis of water movement in Green Bay was initiated by Harrington in 1895 (Bertrand, *et al.,* 1976). Fisherman and sailors around Green Bay noted that Fox River water moved from the mouth of the river along the southeastern and eastern shore of the bay on a general line from the mouth of the river towards Point Au Sable (Erdman, 1999a). On the 1845 chart of Green Bay, water depths between the mouth of the river and Point Au Sable, east of Grassy Island, generally range from 3 to 4.9 m (10 to 16 ft) (Bosley, 1976). Water levels west of the river mouth and Grassy Island range from 1.2 to 3 m (4 to 10 ft), indicating that the main channel from the river into the bay was located east of Grassy Island. Originally, navigators had to tack around Point Au Sable and Grassy Island in order to sail into the Fox River. The navigation channel opened in 1867 cut through Grassy Island and the sand bar located near the mouth of the Lower Fox River (University of Wisconsin Sea Grant Institute [UWSGI], 1979). Dredging of the navigation channel thus diverted some of the Fox River discharge from the southeast corner of Green Bay straight into the bay from the river mouth.

Historically, low DO concentrations detected along the east shore of the inner bay were blamed for massive fish die-offs. Studies were conducted by the Wisconsin State Board of Health - Committee on Water Pollution in 1938-39, 1948, and 1956, the Sulphite Pulp Manufacturer's Committee on Waste Disposal in 1944 (Wiley, 1944), and the WDNR in 1966-67 (WDNR, 1968). These four studies indicated that low DO conditions were present on the east side of Green Bay just downstream from the mouth of the Lower Fox River, especially during winter months when ice-cover was greatest.

In 1966, Schraufnagel presented a general summary of the counterclockwise water currents in the bay (Bertrand, *et al.,* 1976). Although Schraufnagel's summary of water currents within the bay was fairly accurate, it was not based on actual plume delineation studies. Rather, this evaluation of Fox River water movement through the bay was based more on empirical observations, like those described above and the fish die-offs noted on the east side of the bay during winter.

Water entering Green Bay from the Fox River is typically warmer and more sediment laden than the rest of the bay water, thus, allowing the river plume to be tracked within the bay. Studies conducted since the late 1960s of the Fox River plume in Green Bay show that river water moves up the east shore of the bay. The plume has been observed and detected up to 40 km (25 mi) from the mouth of the river (Gottlieb, *et al.,* 1990).

In July 1968 and August 1969, Modlin and Beeton (1970) used specific conductance measurements to trace the Fox River plume in Green Bay. They traced the Fox River plume for distances of 14 to 34 km (8.7 to 21.1 mi) from the river mouth and they noted that the plume moved north along the eastern shore of the bay. Additionally, they detected a plume of lower conductivity water along the western shore of the inner bay and ascertained that this was either outer bay or Lake Michigan water moving south along the western shore. Similarly, in late 1969, Ahrnsbrak and Ragotzie (1970) used conductivity and light transmissivity measurements to observe the distribution of Fox River water in the bay and their conclusions were similar to those of Modlin and Beeton (1970). Ahrnsbrak and Ragotzie (1970) tracked the Lower Fox River plume up to 20 km (12.4 mi) from the river mouth along the eastern shore during the prevailing southerly winds. Their results also suggested that Long Tail Point limited the mixing of water in the southernmost portion of the bay. Long Tail Point is located along the west shore of Green Bay and it extends approximately 5.5 km (3.4 mi) into the bay. Both studies concluded that movement of the Fox River plume north along the east side of the bay is part of an overall counterclockwise circulation pattern in the bay.

More recently, Lathrop, *et al.* (1990) used remote sensing techniques to observe and track the Fox River plume along the east shore of Green Bay. Lathrop, *et al.* (1990) observed that the Fox River plume moved along the east shore from 20 to 40 km (12.4 to 25 mi) north of the river mouth. These findings were based on satellite and other remote sensing data collected on July 18, 1984, July 24, 1986, and June 9 and July 27, 1987. These study results supported the conclusion by Ahrnsbrak and Ragotzkie (1970) that Long Tail Point forms a mixing barrier in the southernmost portion of Green Bay, allowing Lower Fox River water to move farther north into the bay before becoming thoroughly mixed with other water.

Similarly, the Fox River plume was discernible in the water column chloride data collected as part of the GBMBS in 1989 (HydroQual, 1999). A plume of higher chloride concentrations extended from the mouth of the river along the east shore of the bay for a distance of approximately 42 km (26 miles), which is consistent with other observations of the plume. The surface and bottom water currents in August 1989 (Figures 3-2 and 3-3) indicate that northward flow occurs immediately adjacent to the east shore of the bay, from the mouth of the river to about the location of Little Sturgeon Bay. North of Little Sturgeon Bay, the flow patterns become much more varied and complicated.

3.5.2.3 Inner Bay/Outer Bay Mixing Studies

Chambers Island is the boundary between inner and outer Green Bay and several studies have examined the circulation pattern and exchange of water between the inner and outer bay around the island. Flow around Chambers Island is an important aspect of circulation in Green Bay and the USFWS recently summarized a number of studies documenting these patterns (Stratus, 1999a). Generally, these studies have found that net flow is from the inner to the outer bay. As shown on Figures 3-2 through 3-3, flow around Chambers is complex. The prevailing winds are from the south-southwest in Green Bay (Appendix C) and during such events, circulation patterns in the bay are generally counterclockwise and flow from the inner to outer bay occurs along the east side of the island (Miller and Saylor, 1985). However, when the wind shifts from south-southwest (SSW) to north-northeast (NNE), the currents in Green Bay also change, with flow from the inner to outer bay occurring along the west shore of Green Bay (Miller and Saylor, 1985). Using modeling results, Heaps *et al.* (1982) determined that the circulation patterns in the bay became steady within about 12 hours of the onset of wind from any particular direction. Based on the wind induced current patterns, PCB transport from the inner to outer bay generally occurs on the east side of Chambers Island. However, this current and PCB transport pattern is disrupted and reversed during strong northeasterly winds (Miller and Saylor, 1985).

Surface water investigations found that DO concentrations were much higher along the west side of Chambers Island than the east side in 1982 (Stratus, 1999a). These results suggested that the higher DO water of the outer bay and/or Lake Michigan was moving along the west side of the bay while lower DO water of the inner bay was moving along the east side. Similarly, in 1985, Miller and Saylor measured current and temperature on the west and east sides of Chambers Island. They observed that at a depth of approximately 12 m (39 ft), cold water from the outer bay generally flows southward along the west shore while warm water from the inner bay flows northward along the east shore. The remote sensing studies completed by Lathrop, *et al.* (1990) showed a thermal difference between the surface waters on the west and east sides of Chambers Island, with colder water extending farther south on the west side, and warmer water farther north on the east side.

In 1993, Miller and Saylor showed that water flow around Chambers Island is more complex than a simple counterclockwise motion. During the summer months, the colder and deeper water tends to flow south into the inner bay to the west of Chambers Island, and the shallow, warmer water layer flows north out of the inner bay on both the west and east sides (Miller and Saylor, 1993). These results are shown on Figures 3-2 and 3-3 (HydroQual, 1999). During the summer, surface currents are stronger east of the Oconto River, with two clockwise gyres between the Oconto and Menominee Rivers. These gyres merge along the northern shore, downstream of the Peshtigo River. Around Chambers Island, surface currents are clockwise northwest of the island and counterclockwise southeast of the island (Figure 3-2) (Blumberg, 2000). The combined surface currents are then directed northeast towards Washington Island (Blumberg, 2000). In addition, the formation of many small-scale gyres causes localized entrapment of water masses and their constituents, implying that the mass crossing the Chambers Island transect is not directly transported to the mouth of Green Bay and into Lake Michigan (Blumberg, 2000). During the winter, water tends to flow north out of the inner bay on the east side of the island and the eastern half of the western passage. These flow patterns result in a lesser, separate counterclockwise flow pattern in both the inner and outer bay (HydroQual, 1999).

In addition to the current evaluation, Miller and Saylor (1993) estimated water exchange between the inner and outer portions of Green Bay. They concluded that net flow for the study period was from the inner to the outer bay at approximately 130 m^3/s (4,591 cfs). Additionally, Gottlieb, *et al.* (1990) measured current velocities around Chambers Island, in the inner bay, and in the passages connecting Green Bay with Lake Michigan. Current velocities were greatest on the east of Chambers Island, sometimes ranging as high as 0.35 m/s (1.1 ft/s). West of Chambers Island the velocities typically ranged from 0.12 m/s to 0.24 m/s (0.4 ft/s to 0.8 ft/s). Current velocities in the inner bay typically ranged up to 0.12 m/s (0.4 ft/s) (Gottlieb, *et al.,* 1990).

In addition to the current and volume measurements, Hawley and Niester (1993) used water transparency data and information collected at the same time as Miller and Saylor's data to estimate sediment transport. Hawley and Niester (1993) concluded that approximately 17,500 metric tonnes (MT) (19,290 tons) of sediment were transported from the inner bay to the outer bay, generally along the east side of Chambers Island, during May through October 1989. However, they also found that approximately 19,900 MT (21,940 tons) of sediment were transported from the outer bay to the inner bay along the west side of Chambers Island. Therefore, there was a net increase of approximately 2,400 MT (2,650 tons) of sediment transported into the inner bay. However, as bay sediments are often subjected to a repeating cycling of suspension-transport-deposition, movement of sediment between the inner and outer bays may occur a number of times before sediment is ultimately transported further north into the bay and Lake Michigan.

3.5.2.4 Green Bay/Lake Michigan Mixing Studies

Similar to current flow within Green Bay, USFWS also summarized the exchange of water between Green Bay and Lake Michigan (Stratus, 1999a). Miller and Saylor (1985) and HydroQual (Blumberg, 2000) evaluated the water exchange between Lake Michigan and Green Bay, which is highly complex, variable, and difficult to measure accurately. There are four main channels through which Green Bay and Lake Michigan are connected. Moving north from the Door Peninsula to Point Detour (on the tip of the Garden Peninsula), these channels are: 1) Porte Des Morts Passage; 2) Rock Island Passage; 3) St. Martin Island Passage; and 4) Poverty Island Passage. These passages are oriented roughly northwest-southeast, range from 2 to 7 km (1.2 to 4.3 miles) wide, and all but Poverty Passage are deeper than 30 m (98 ft) (Miller and Saylor, 1985). These passages also have a cross-sectional area of approximately 52 km^2 (20 mi^2) (Gottlieb, *et al.,* 1990).

Measurements showed that large volumes of water consistently transfer through the Porte des Morts and Rock Island Passages. Warm water was found to be leaving the bay in the upper portion of the water column while cold water enters the bay in the lower part of the water column (Figures 3-2 and 3-3). Currents measured in the passages connecting Green Bay with Lake Michigan typically ranged from 0.12 m/s to 0.30 m/s (0.4 ft/s to 1.0 ft/s) (Gottlieb, *et al.,* 1990). Miller and Saylor (1985) estimated flow into the bay to be approximately 3,300 m^3/s (116,540 cfs) while investigations in 1992 suggested the estimated water volume exchange between Green Bay and Lake Michigan was 3,500 m^3/s (123,600 cfs) (Stratus, 1999a). Modeling results for August 1989 suggest that surface water (epilimnetic) flow from Green Bay to Lake Michigan was about 3,000 m^3/s (105,940 cfs) while bottom water (hypolimnetic) flow to the bay was about 2,870 m^3/s (101,350 cfs) (Blumberg, 2000). This resulted in a net outflow of about 130 m^3/s (4,590 cfs) from the bay to the lake. However, during this period net flow across the Chambers Island transect was about 130 m^3/s (4,590 cfs) towards the upper bay (Blumberg, 2000). Thus in August 1989, the outer bay was in steady state with little change in water surface elevation. The circulation patterns obtained for the August 1989 modeling results show that a large volume of water can enter Green Bay from Lake Michigan (Blumberg, 2000).

The exchange of water between Green Bay and Lake Michigan is much greater than any other source of water into or out of the bay. According to Mortimer (1978), estimated precipitation input to the bay is 105 m^3/s (3,700 cfs), tributary input is 336 m^3/s (11,865 cfs), and evaporation loss is 87 m^3/s (3,070 cfs). These values are all at least an order of magnitude less than the estimated exchange between Green Bay and Lake Michigan.

Water exchange between Green Bay and Lake Michigan at the Sturgeon Bay Ship Canal is limited due to the size of the canal. The east end of the canal, which opens into Lake Michigan is only approximately 49 m (160 ft) wide and about 6.1 m (20 ft) deep. This is a cross-sectional area of about 300 m^2 (3,200 ft^2), compared with a cross-sectional area of 52 km^2 (20 mi^2) between the tips of the Door and Garden Peninsulas.

3.5.3 Green Bay Bathymetry

The bathymetry for each of the Green Bay zones differs from that of the other zones. 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 generally represent a large, relatively deep body of water which only have areas with depths less than 9 m (30 ft) located along the shoreline. The bathymetry for Green Bay zones 2, 3, and 4 are shown on Figures 3-4, 3-5, and 3-6, respectively. These figures were developed using NOAA nautical charts 14902 (1996), 14908 (1991), 14909 (1998a), 14910 (1998b), 14917 (1997a), 14918 (1998c), and 14919 (1997b).

The Green Bay bathymetry is controlled by the bedrock geology. Due to the eastern dip of the bedrock units and the glacial scouring of the basin, the bay gradually deepens to mid-bay moving from west to east. Eastward of this mid-bay point, the bottom is a relatively flat, sediment plain that rises abruptly near the east shore. The bottom contour of the bay also affects the development and distribution of wetland habitat. Numerous wetland areas developed along the west side of the bay due to the gentle and gradual deepening of water while the deeper shores/cliffs of the east side of the bay generally inhibited wetland development (Bosley, 1978).

Bathymetric changes in Green Bay are affected by the currents and water mixing discussed above and physical environment of the bay. In 1968, Moore and Meyer completed an evaluation of the bathymetry of Green Bay (Bertrand, *et al.,* 1976). After completing sounding surveys of the majority of the bay, Moore and Meyer compared their bathymetry results with surveys of the southern and northern portions of the bay which were completed in 1943 and 1950, respectively. Moore and Meyer found significant decreases in depth in the southern portion of the bay. In the central part of the southern bay, depths had decreased by up to 1.2 m (4 ft) while larger areas of the bay had decrease in depth approximately 0.6 m (2 ft); this indicates that significant sedimentation occurred in the southern bay between 1950 and 1968.

In addition to the decreased depths, Moore and Meyer estimated that the Lower Fox River contributed about 226,800 MT (250,000 tons) of sediment annually, or about 36.3 MT (40 tons) of sediment for each square mile of the Fox Wolf drainage basin (Bertrand, *et al.,* 1976). Similarly, the Oconto, Peshtigo, and Menominee Rivers were also estimated to have contributed about 780,200 MT (860,000 tons) of sediment, or about 18.2 MT (20 tons) of sediment for each square mile of the drainage basins for these three watersheds. By comparison, Harris (1994) estimated sediment load from the Lower Fox River into Green Bay in 1993 was approximately 136,100 MT (150,000 tons) annually.

3.5.3.1 Zone 2 Bathymetry

The bathymetry of Zone 2 is generally shallow, with all water depths less than 8 m (26.5 feet) as shown on Figure 3-4. From the mouth of the Fox River to a line connecting Long Tail Point and Point Au Sable (the lower Green Bay AOC), water depths range from 0.3 to 3.4 m (1 to 11 ft), excluding the navigation channel (Figure 3-4).

Water depths west of a line between Long Tail Point and Kidney Island CDF are less than 1.5 m (5 ft). Along the west shore of Green Bay is Peats Lake (also sometimes historically referred to as "Peaks Lake"), a shallow submerged and emergent wetland complex located at the mouth of Duck Creek. Water depths in the Peats Lake area and the Duck Creek delta range from 0.6 to 1.2 m (2 to 4 ft) (Figure 3-4). This area is bounded on the north by the former Cat Island Chain and Grassy Island, which lies at the east end of the chain. The former Cat Island Chain is a series of small islands which, up until 1973, were always above water. Dead Horse Bay is a shallow basin located along the west shore south of Long Tail Point. Water depths in Dead Horse Bay generally range from 0.6 to 2.7 m (2 to 9 ft), with the shallowest waters located immediately adjacent to the west shore of Green Bay, the former Cat Island Chain, or Long Tail Point. In the central part of Dead Horse Bay lies a shallow basin where water depths range from 1.8 to 2.7 m (6 to 9 ft).

East of the line between Long Tail Point and Renard Island, the water depths are greater, generally ranging from 2.1 to 3.7 m (7 to 12 ft). However, Frying Pan Shoal extends from Frying Pan Island to Point Au Sable and water depths on the shoal range from 0.3 to 1.2 m (1 to 4 ft) (Figure 3-4).

North of Long Tail Point and Point Au Sable, only areas located immediately adjacent to the shores of Green Bay have water depths less than 1.8 m (6 ft). Along the east shore of Green Bay in this area, water depths of less than 6 ft (1.8 m) extend from approximately 250 to 760 m (830 to 2,500 ft) from the shore. Additionally, the 3.7-m (12-ft) depth contour is 570 to 1,520 m (1,875 to 5,000 ft) from the shore. On the west side, water depths less than 1.8 m (6 ft) extend much further into the bay, from about 1,120 to 2,130 m (3,670 to 7,000 ft) from shore. Water depth increases more rapidly along the east shore than along the west shore of the bay, and this is consistent throughout the bay.

The navigation channel lies almost entirely within Zone 2. The navigation channel extends approximately 18.8 km (11.7 miles) from the mouth of the Fox River (Figure 3-4). The depth of the navigation channel is maintained between 6.25 and 7.16 m (20.5 and 23.5 ft). The general width of the navigation channel is about 45.7 m (150 ft). From the mouth of the Lower Fox River, the channel extends approximately 5 km (3.1 miles), passing Grassy Island about halfway. The channel turns slightly to the east for a distance of approximately 2.5 km (1.6 miles), then resumes the approximate original course, (north) for a distance of 11.4 km (7.1 miles) until it reaches an area where water depths consistently exceed 7.6 m (25 ft) (Figure 3-4).

There are a number of spits, shoals, and other shallows located in Green Bay that are prominent physical features of the bathymetry. Many of the shoals and shallows are associated with the tributaries, predominantly located along the west side of the bay. In Zone 2 these shallow areas are expressed as the island chains and points extending from the west shore out into the bay. Long Tail and Little Tail Points are two examples of spits/shallows associated with Green Bay tributaries. Long Tail Point is located just south of the Suamico River mouth while Little Tail Point is located just south the Little Suamico River (Figure 3-4). Both these spits/shallow areas are replenished from sediment loads contributed by these two rivers as well as sediments transported from other areas. Long Tail Point and Little Tail Point extend for a distance of approximately 5.1 km (3.2 miles) and 3.5 km (2.2 miles) into the bay, respectively. Similarly, Frying Pan Shoal (extending from Frying Pan Island to Point Au Sable) and the shallow wetlands of Peats Lake are both associated with sediment loads from the Lower Fox River and Duck Creek, respectively (Figure 3-4).

3.5.3.2 Zone 3 Bathymetry

The bathymetry of Zone 3 is less complex than that of Zone 2. The depth of water in this zone is generally greater than 9.1 m (30 ft) deep, and the water depths reveal the general west-to-east cross-section of the bay. Water depths increase gradually along the west shore whereas along the east shore the water depths increase more rapidly (Figure 3-5). Comparison of the 9.1-m (30-ft) depth contour indicates that along the west side of the bay this depth is found approximately 6.5 to 7.0 km (4 to 4.3 miles) from the shore. This is a gradient of approximately 0.0013 to 0.0014. On the east side of the bay, the 9.1-m (30-ft) depth contour is about 1.8 to 3.4 km (1.1 to 2.1 miles) from the shore, which is a gradient of approximately 0.0027 to 0.005.

Water depths in Zone 3 range from about 12.5 m (41 ft) at the zones 2 and 3 boundary to 33.5 m (110 ft), just west of Chambers Island near the zones 3 and 4 boundary. The deepest part of Zone 3 is located just southeast of Green Island where water depths of 34.4 m (113 ft) have been measured.

Within Zone 3, four shallow shoals are located along the west side of the bay, and two shallow water areas extend into the east side of the bay (Figure 3-5). The Menekaunee shoal is associated with the Menominee River on the west side of the bay and extends for a distance of approximately 2.4 km (1.5 mi). The Peshtigo Reef is located near the mouth of the Peshtigo River and extends for a distance of approximately 5 km (3.1 mi). Finally, both the Oconto and Pensaukee shoal are located near the mouth of the Oconto and Pensaukee Rivers, respectively. These two shoals extend for a distance of 6.4 km and 5.6 km (4 and 3.5 mi), respectively. The water depth associated with all these shoals and reef are less than 1.8 m (6 ft) for the distances cited above. On the east side of the bay, Monument Shoal and Sherwood Point Shoal extend for distances of 1.8 and 6.1 km (1.1 and 3.8 mi), respectively. Unlike the shallow areas on the west side of the bay, water depths within these two shoals range as deep as 7.3 to 9.1 m (24 to 30 ft) in the deepest portions (Figure 3-5).

3.5.3.3 Zone 4 Bathymetry

Large portions of Zone 4, from Chambers Island to just south of Big and Little Bay de Noc have water depths exceeding 9.1 m (30 ft). However, in the vicinity of Big and Little Bay de Noc, the water depths decrease and shallow areas with water depths less than 9.1 m (30 ft) are predominant (Figure 3-6). Additionally, a number of shoals are located within this zone.

Bathymetry measurements on the west side of the bay in Zone 4 indicate that the 9.1-m (30-ft) depth contour is generally located between 1.3 to 1.8 km (0.8 to 1.1 mi) from the shore. However, in the vicinity of the Ford River the 9.1-m (30-ft) depth contour is found about 9.1 km (5.7 mi) from shore. The general gradient for the west side of the bay in Zone 4 is 0.005 to 0.0069; however, in the shallow water area near the Ford River, the gradient decreases to 0.001.

The Door Peninsula extends for a distance of about 24.4 km (15.2 mi) along the east side of the bay within Zone 4. Bathymetry measurements on the east side of Zone 4 indicate that the 9.1-m (30-ft) depth contour is located between 0.2 to 2 km (0.12 to 1.2 mi) from the shore. This is a general gradient of 0.0045 to 0.045. Similar to the results for Zone 3, the gradient on the east side of the bay is up to one order of magnitude greater than the gradient on the west side of the bay. The deepest point in the bay is 53 m (176 ft) deep, located about 6.4 km (4 mi) west of Washington Island (Bertrand, *et al.,* 1976).

As noted previously, the four main passages connecting Green Bay with Lake Michigan are: 1) Porte des Morts Passage; 2) Rock Island Passage; 3) St. Martin Island Passage; and 4) Poverty Island Passage. The Porte des Morts Passage is approximately 2.3 km (1.4 mi) wide and water depths in the passage range as deep as 39.3 m (129 ft). The Rock Island Passage is approximately 3.9 km (2.4 mi) wide. The passage is narrow due to the presence of the St. Martin Island Shoal, which extends approximately 3.6 km (2.2 mi) south of St. Martin Island. Water depths in this passage range as deep as 46.6 m (153 ft). The St. Martin Island Passage is located between St. Martin Island and a number of small islands and shallows, including Gull, Little Gull, and Gravelly Islands, as well as the Gravelly Island Shoals (Gull/Gravelly Island complex). This passage is only approximately 2 km (1.2 mil) wide and water depths range as deep as 36.3 m (119 ft). Finally, the Poverty Island Passage is located between the Gull/Gravelly Island complex and Poverty Island. This passage is approximately 3.4 km (2.1 mi) wide and water depths range as deep as 26.5 m (87 ft). No significant waterway passage is located north of Poverty Island. Water depths between Poverty, Summer, and Little Summer Islands and Point Detour at the very tip of the Garden Peninsula, are less than 9.1 m (30 ft). Significant shallow water is present between Summer and Little Summer Islands, with large areas where water depths are less than 1.8 m (6 ft) (Figure 3-6).

Water levels in Big Bay de Noc and Little Bay de Noc are generally much shallower than other water levels in Zone 4. Besides the Escanaba River, six small streams/rivers flow into Little Bay de Noc. The water depth in the north end of Little Bay de Noc is generally less than 9.1 m (30 ft) deep except in the central portion of the channel. The shallowest waters are located along the east shore of Little Bay de Noc, where water depths less than 3.7 m (12 ft) extend for a distance of approximately 3.1 km (1.9 mi) into the bay. Water depths in the north portion of Little Bay de Noc range as deep as 15.5 m (51 ft). South of Escanaba water depths increase significantly in the main channel of the bay, exceeding, 24.4 m (80 ft) just 1 km (0.6 mile) south of the city and ranging as deep as 33.5 m (110 ft) near the beginning of the bay.

Water levels in Big Bay de Noc are also generally much shallower than the other portions of Zone 4. Ten small streams/rivers flow into Big Bay de Noc; Sturgeon River, at the north end of the bay, is the largest. Water depths in the northern portion of Big Bay de Noc are generally less than 9.1 m (30 ft), although two small channels extend through the central part of each arm of the bay, where water levels range as deep as 15.5 m (51 ft). This north end of Big Bay de Noc is generally defined by the presence of Round Island, Big Bay de Noc Shoal, and Ripley Shoal, which extend approximately 12.0 to 14.7 km (7.5 to 9.1 mi) from the northern shore of the bay. Water depths increase gradually in the southern part of Big Bay de Noc, generally ranging from 12.2 to 18.3 m (40 to 60 ft).

Within Zone 4 there are five other significant shoals/reefs besides those already mentioned. These include the Strawberry Islands, Horseshoe Reef, Whaleback Shoal and the Drisco and Corona shoal complexes. The Strawberry Islands are a chain of small islands located between the Door Peninsula and Chambers Island. The shallows associated with these islands extend approximately 3.4 km (2.1 mi) from the shore and water depths of less than 9.1 m (30 ft) extend for a distance of approximately 7.1 km (4.4 mi). Horseshoe Reef is located approximately 9.1 km (5.7 mi) east-northeast (E-NE) of Chambers Island. Water depths of less than 9.1 m (30 ft) extend over a distance of 4.6 km (2.9 mi) and are approximately 1.5 km (0.9 mi) wide. Whaleback Shoal is located approximately 22.3 km (13.9 mi) northeast (NE) of Chambers Island. This shoal has water depths ranging from 1.2 to 9.1 m (4 to 30 ft) over an area 11.2 km^2 (4.3 mi^2). The Drisco Shoal complex is an area actually comprised of the Drisco, North Drisco, and Minneapolis shoals. This shoal complex is located approximately 11.7 km (7.3 mi) south of Peninsula Point at the tip of the Stonington Peninsula. The three shoals that form this complex extend over an area of approximately 8.3 km^2 (3.2 mi^2) with water depths ranging from 2.7 to 9.1 m (9 to 30 ft). Similar to the Drisco Shoal complex, the Corona Shoal complex is comprised of three shoals located near one another. These three shoals are the Peninsula Point, Eleven Foot, and Corona Shoals. These three shoals extend south approximately 6.6 km (4.1 mi) from Peninsula Point. Water depth less than 9.1 m (30 ft) extend about 9.1 km (5.7 mi) going west to east from the edge of Little Bay de Noc to Big Bay de Noc.

3.5.4 Green Bay Ice Cover

The Port of Green Bay is annually closed to shipping from January 1 through March 31 due to ice cover (Haen, 2000). Although the port is officially closed for this three month period, ice cover in the bay is usually present from early to mid-December through mid- to late April (Leshkevich, 1977; Assel, *et al.,* 1979; Assel, *et al.,* 1984; and Gottlieb, *et al.,* 1990).

Ice cover in Green Bay initially occurs over the shallowest water areas of the inner bay as well as both Bays de Noc. Ice typically begins forming loose open pack of ice floes in these areas in early to mid-December, as temperatures usually range from -10°C to -4°C (14°F to 24°F). During December, the ice slowly consolidates from loose pack to a solid ice sheet covering the shallowest areas and slowly expanding. During January, which has the coldest average temperatures, ice cover within the bay usually ranges from 95 percent to 100 percent. Depending upon seasonal conditions, open water areas usually form in the outer bay in late January and February. This occurs first in and around the passages connecting Green Bay with Lake Michigan and along the east side of the outer bay (due to the counter-clockwise currents) because Lake Michigan water is generally about 1°C to 2°C (about 2°F to 4°F) warmer than water within Green Bay. Additionally, water from the Green Bay tributaries is generally the coldest water within the bay, due to the fact that the formation of frazil ice within the river can cool water temperatures below 0°C (32°F).

Frazil ice is comprised of small ice crystals that form in turbulent water. Due to the water movement, the ice crystals flow within the water and act to super-cool the water to temperatures below 0°C (32°F). The ice does not solidify until the water movement slows or until the water comes in contact with solid objects that slow the current velocity. When present, frazil ice can cause difficulties with water intakes and piers/docks located along the rivers or bay. As the water flows from the rivers into the bay, current velocities decrease and ice forms rapidly.

3.6 Sediment Characteristics

Chemical compounds entering the waters of the Lower Fox River and Green Bay move through the water column as either a solid or dissolved phase. Chemicals present as solids (particulates) generally move along with or attached to sediment particles. This is especially true for hydrophobic organic compounds, such as PCBs, dioxin/furan compounds, organochlorine pesticides, and PAHs, which have a strong chemical affinity for organic material. Therefore, the location of accumulated sediment, as well as their chemical and physical properties, is important to understanding the distribution of chemical compounds with these river and bay sediments.

Sediment deposition and resuspension processes are primarily a function of particle size and water velocity. Sediment transport occurs as particles are suspended (or re-suspended) in the water column 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), bathymetry (e.g., shoreline erosion) and other factors.

3.6.1 Sediment Deposition

3.6.1.1 Lower Fox River Sediment Transport and Deposition

Previous investigations have identified distinct deposits of accumulated sediment throughout the Lower Fox River (WDNR, 1989/90; WDNR, 1995; and GAS/SAIC, 1996). Upstream of the De Pere dam, areas which have experienced a net depositional gain of sediment are located in environments where stream flow velocities decrease. These areas are typically located immediately upstream of the locks and dams or areas where the width of the river increases. Downstream of the De Pere dam, sediments have been deposited over much of the river bottom, likely due to such factors as low river gradient and flow reversals (seiches) that occur in this reach.

Detailed modeling efforts have been completed for Deposit A (EWI, 1991) and the De Pere to Green Bay Reach (Gailani, *et al.,* 1991) to evaluate movement of river sediments. Modeling at Deposit A indicated that the critical river flow velocity was 0.09 m/s (0.3 ft/s) (EWI, 1991). Areas where the flow velocity was less than 0.09 m/s (0.3 ft/s) experienced net depositional gain while areas where the flow velocity was greater experienced net erosional loss. Also evaluated were stress ratios on sediment particles, which is the ratio of the bottom shear stress to the "critical" shear stress for resuspension of particles. Sediments accumulated in areas where the stress ratios were below 3 to 5 (EWI, 1991).

Gailani, *et al.* (1991) applied the numerical model SEDZL to evaluate sediment movement (both re-suspension and deposition) in the De Pere to Green Bay reach. The upper layer of soft sediment (described as "less than 3 hours old" rather than a predetermined thickness) is often re-suspended and moves along the river bottom in accordance with the flow rate and shear stress applied to the particle.

TSS data collected by WDNR (1995) and BBL (1998) have been evaluated to estimate movement of sediment through the river and bay system (Table 3-14). A conceptual flow diagram for the TSS load from Lake Winnebago into Green Bay, and thus the movement of PCB contaminated sediment through the system, is shown on Figure 3-7. However, estimates of net deposition or net erosion only reflect an average accumulation or loss of sediment over time for a reach and do not explain finer-scale deposition/erosion events occurring within a reach. Net deposition does not imply a purely depositional environment or vice-versa.

Using the 1989/90 TSS data, WDNR (1995) indicate that over 75,000 MT (82,700 tons) of sediment entered LLBdM from Lake Winnebago (Table 3-14). However, the TSS load at the Appleton gauging station decreased by approximately 8,000 MT (8,800 tons), suggesting this material was deposited within LLBdM, as evidenced by extensive sediment deposits A through F and POG. Stream flow velocities in this reach are below 0.2 m/s (Table 3-12).

The TSS results (WDNR, 1995) also suggest the Appleton to Little Rapids Reach experiences a net loss (erosion) of sediments (Table 3-14 and Figure 3-7). Between Appleton and Kaukauna, the TSS load shows a marginal increase of about 2,500 MT (2,750 tons) (Table 3-14). However, between Kaukauna and Little Rapids, the TSS load doubles from approximately 70,000 MT (77,000 tons) to approximately 142,000 MT (154,000 tons), indicating sediment erosion

(Table 3-14). Sediment deposits V through CC are located between Kaukauna and the Rapide Croche dam. The lack of soft sediment between the Rapide Croche and Little Rapids dams suggest that sediments suspended upstream of the Rapide Croche dam are likely transported to Little Rapids (Deposit DD) or beyond, into the Little Rapids to De Pere Reach. Kankapot, Plum, and Apple Creeks are also located in this stretch of the river. WDNR (1995) estimated that these three creeks contribute about 16,500 MT (18,200 tons) annually, which is only 23 percent of the increased TSS load (Table 3-14). Stream flow velocities in this reach generally exceed 0.2 m/s and range as high as 0.3 m/s (Table 3-12), which likely inhibits overall sediment accumulation.

The TSS data (WDNR, 1995) suggest that the Little Rapids to De Pere Reach experiences overall sediment deposition and accumulation. The TSS load declines by about 61,500 MT (68,000 tons), or by about 43 percent, in this reach (Table 3-14). The De Pere dam slows stream flow velocities to an average of 0.12 m/s (Table 3-12), allowing a significant portion of the TSS load to settle out of the water column. Deposit EE, the largest sediment deposit upstream of the De Pere dam, extends approximately 8.5 km (5.3 mi) upstream of the dam.

TSS data collected in 1998 (BBL, 1998) has been used to evaluate the De Pere to Green Bay Reach. These data, and the resultant calculations, support the finding by Gailani, *et al.* (1991) that more sediment is transported over the De Pere dam than is discharged into the bay and that, overall, sediments continue to accumulate in this reach. The TSS load coming over the De Pere dam is estimated to be about 155,600 MT (171,100 tons) annually but this load declines to about 153,600 MT (167,900 tons) at the mouth (Table 3-14). Using data collected in 1989/90, Gailani, *et al.* (1991) also found that the TSS load declined between the De Pere dam and the river mouth. The average streamflow velocity in this reach was less than 0.08 m/s (Table 3-12), which is the lowest value for any of the river reaches. Thus, the two reaches from Little Rapids to the mouth of the river both experience net sediment deposition.

The effects of high discharge events and sediment resuspension were modeled by Gailani, *et al.* (1991). Stream discharge and TSS measurements were collected at the De Pere dam and the river mouth in 1989/90 as part of the GBMBS. The table below shows how the TSS load increases with increased river discharge. At a typical discharge rate of 105 m^3/s (3,700 cfs), approximately 272 MT (300 tons) of TSS flow over the De Pere dam daily; however, only about 54 MT (60 tons) are discharged at the mouth daily.

TSS Loads in the Lower Fox River, De Pere to Green Bay Reach

Sampling Point	River Discharge		Total Suspended Solids	
	M^3/s	cfs	mg/L	MT/day
1989-80 Results (Gailani, *et al.*, 1991)				
De Pere dam	105	3,700	30	270
	280	9,880	75	1,800
	432	15,250	190	7,100
River Mouth	105	3,700	6	54
	280	9,880	57	1,400
	432	15,250	130	4,900

During increased discharge events (e.g., storms), the TSS load both over the De Pere dam and out into Green Bay increase significantly. Discharge at the Lower Fox River mouth exceeds 272 m^3/s (9,600 cfs) for more than 36 days annually (10 percent of the time) (Table 3-13). The TSS load over the De Pere dam increases by about 1,800 MT (2,000 tons) for storm events with a discharge of 280 m^3/s (9,900 cfs). When discharge is about 430 m^3/s (15,250 cfs), the TSS increases by about 7,100 MT (7,850 tons) daily (Gailani, *et al.,* 1991). Therefore, quadrupling the stream flow rate increases the TSS load by approximately 26 times.

Net deposition in the De Pere to Green Bay Reach is evident by the TSS load discharged to Green Bay at the higher discharge volumes. At typical flows, the TSS load to Green Bay decreases by approximately 80 percent relative to the load over the De Pere dam. At increased flows, the TSS load in this reach still declined by 24 percent to 32 percent between the De Pere dam and the mouth of the river. In addition, Velleux and Endicott (1994) found that even though the TSS load may decrease between the De Pere dam and the mouth of the river, the overall PCB load in the river (and thus entering Green Bay) increases in this reach by up to 50 percent. These results are discussed further in Section 5.5.

3.6.1.2 Green Bay Sediment Transport and Deposition

As noted previously, Moore and Meyer found that water depths in the southern end of Green Bay decreased between 0.6 to 1.2 m (2 to 4 ft) between 1950 and 1968 due to significant sediment accumulation (Bertrand, *et al.,* 1976). The USGS estimated that the average annual sediment load from the Fox River into Green Bay is approximately 136,000 MT (150,000 tons) (Harris, 1994). Chroneer (1996) indicated previous investigators had found annual sediment deposition rates as great as 150 mg/cm^2 in the AOC, for a mass sedimentation rate of 82,500 MT (90,940 tons) annually. The TSS data above suggests that about 154,000 MT (168,800 tons) of sediment were discharged into the bay during

1998 (BBL, 1998). Based on these studies, the annual sediment mass transported into Green Bay likely ranges from about 82,500 MT to a high of about 154,000 MT (90,940 to 169,800 tons).

Along with bay mixing studies, USFWS also evaluated sediment movement through Green Bay and the following summary was adapted from this discussion (Stratus, 1999a). 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. Manchester-Neesvig, *et al.* (1996) determined the primary depositional zone in Green Bay extends along the east shore of Green Bay for a distance of approximately 25 km (15.5 miles) north of the Fox River mouth. The northern end of this zone is a line between Sturgeon Bay and the mouth of the Peshtigo River. A large portion of the sediment (and adsorbed PCBs or other hydrophobic chemical compounds) discharged from the Lower Fox River settle in this depositional zone within the inner bay.

Most Lower Fox River sediments discharged into the bay initially settle within the inner bay (Hawley and Niester, 1993). Also, Lathrop, *et al.* (1990) observed that the Lower Fox River water mass is still distinguishable by temperature, but not by transmissivity, by the time the Lower Fox River plume reaches Chambers Island. Most of the Lower Fox River sediment matter settled out before the water reached Chambers Island (Lathrop, *et al.,* 1990). In addition to the Lower Fox River sediments, Hawley and Niester (1993) estimated a net gain of about 2.4 million kg (5.3 million pounds) of sediment that were transported from the outer bay to the inner bay along the west side of Chambers Island.

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 (Chroneer, 1996). Also, erosion of shore and near-shore sediments was found to be directly related to wind factors (magnitude, direction, and duration) within the bay that affect currents and wave action (Chroneer, 1996). Lick, *et al.* (1995) found that sediment deposits in the bay are located in areas where the stress ratios were less than about 5 to 9, in comparison with the Lower Fox River Deposit A ratios of 3 to 5 (EWI, 1991). Sediments within the bay settle in a far less turbulent environment than those of the Lower Fox River, therefore, the upper most layer of sediment was found to have consolidated in 7 to 14 days, rather than less than 3 hours (Lick, *et al.,* 1995). Moderate to strong winds are the most important factor for bay sediment resuspension and occur, on average, every seven days on the Great Lakes (Lick, *et al.,* 1995).

In addition to the net sediment gain of the inner bay, Hawley and Niester (1993) documented suspended sediment transport from the inner to the outer bay. Sediment transport from the inner to outer bay primarily occurs along the east side of Chambers Island (Hawley and Niester, 1993). They also documented a large volume of sediment transported from the inner bay to the outer bay as a result of a September 1989 storm. Hawley and Niester (1993) estimated that about 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. These studies demonstrate that some inner bay sediments are resuspended and transported to the outer bay. However, circulation patterns around Chambers Island are complex (Figures 3-2 and 3-3, HydroQual, 1999), and there is a net mass of sediment moving from the outer to inner bay. Therefore, sediments resuspended from the inner bay may be transported to the outer bay, where they may either settle out, be transported further into the bay (or Lake Michigan), or be transported back into the inner bay. Currently, no studies have evaluated the extent to which sediments originating in the Lower Fox River are also transported into Lake Michigan.

In addition to these studies, the USFWS summarized a number of Green Bay sediment transport and deposition modeling results developed as part of the GBMBS, which included sediment resuspension throughout the bay (Stratus, 1999a). Eadie, *et al.* (1991) concluded from their measurements of high sediment settling velocities in the bay that the pool of suspended particulate matter in the Green Bay water column must be recharged at a high rate, either from sediment resuspension or horizontal movement (Stratus, 1999a).

3.6.1.3 River and Bay Sediment Dredging

The rapids on the river and the extensive areas of accumulated sediment historically impeded navigation of the Lower Fox River and lower Green Bay. Completion of the lock and dam system facilitated navigation but has resulted in numerous sediment deposits upstream of the De Pere dam. In 1872, the USACE was given authority to maintain a navigation channel. The USACE periodically dredged the channel, which extends from Lake Winnebago out into Green Bay approximately 18.8 km (11.7 miles). The channel was maintained at a depth of approximately 1.8 m (6 ft) between Lake Winnebago and the De Pere dam. Downstream of the dam and into the bay the navigation channel depth ranges from 6 to 7.4 m (20 to 24 ft). The USACE currently only dredges and maintains the navigation channel in Green Bay and as far upstream as the Fort Howard turning basin, located approximately 5.5 km (3.4 miles) upstream of the mouth of the river. The remaining portions of the navigation channel, along with the lock and dam system, have been placed in "caretaker" status. The available

USACE dredging records, from 1957 through 1999, are summarized on Table 3-13.

Dredging records for the Lower Fox River are scarce. The only information available since 1957 indicates that approximately 9,900 m^3 (12,950 yd^3) were dredged from the Menasha Channel and Neenah Harbor in 1965 and 1968, respectively (Table 3-15). Historic information indicates that over $3.3 million were expended on maintaining the Lower Fox River navigation channel between 1872 ands 1914, although no information is available concerning the volume of dredged sediments (Burridge, 1997).

Expansive areas of sediments have accumulated downstream of the De Pere dam and out into the southern end of Green Bay. USACE (1999) records for the De Pere to Green Bay Reach, as well as Green Bay, indicate that over 12.1 million m^3 (15.9 million yd^3) have been dredged from the navigation channel since 1957 (Table 3-15). Prior to 1965, most dredged sediments were disposed of in open water locations without any containment. Approximately 2.8 million m^3 (3.7 million yd^3) of sediment were disposed of at open-water locations since 1957 (Table 3-15). The primary open-water sediment disposal areas were located in the vicinity of the former Cat Island Chain and on the north side of the shoal extending from Point Au Sable to Frying Pan Island (Wisconsin State Commission on Water Pollution, 1939, Figure 3-4). The Bay Port CDF was opened in 1965 and has served as the primary disposal facility for navigation channel sediments (Table 3-15). Almost 7.3 million m^3 (9.4 million yd^3) have been placed in the Bay Port CDF (Table 3-15) and, according to Haen (2000), the facility has capacity for another 1.5 million m^3 (2 million yd^3) of sediment. The Kidney (Renard) Island CDF opened in 1979 and received over 2 million m^3 (2.7 million yd^3) of sediment. According to the dredging records, an average of approximately 282,350 m^3 (369,300 yd^3) of sediment is removed from the channel annually (Table 3-15).

3.6.2 Sediment Grain Size/Lithology

Over 1,300 sediment samples collected from the Lower Fox River during previous site investigations were analyzed for grain size. Only 21 samples were collected in Green Bay during BBL sampling activities in 1998. The results of these analyses, along with the results for other physical parameters, are summarized on tables in Appendix G.

The Lower Fox River sediment grain size distribution reflects the mixture of sand, silt and clay comprising the native silty clay glacial till deposits of the area. Sand and silt are the dominant grain sizes in Lower Fox River sediments, typically accounting for 75 to 90 percent of the particle sizes present. A minority of the sediments contain trace (<1 percent) gravel, while clay normally comprise 10 to 25 percent of the samples.

The grain size data have been listed for each deposit or SMU regardless of sampling depth (Appendix G). In LLBdM, the Appleton to Little Rapids Reach, and the De Pere to Green Bay Reach, silt comprises about 40 percent of the sediments encountered while the sand content ranges between 41 and 46 percent. However, in the Little Rapids to De Pere Reach, where extensive sediment accumulations have been observed at Deposit EE, the silt content increases to 54 percent while sand comprises only about 23 percent of the sediments. These results suggest that the De Pere dam is a significant trap for finer grained sediments migrating down the Lower Fox River.

Sediments within Green Bay have a higher percentage of sand than the river. The 11 samples collected in Zone 2 (2A/2B) indicate that the sand content ranges between about 52 and 93 percent, with an average of 73 percent sand in this zone. In Zone 3A, along the west side of Green Bay, sand content is greater than 97 percent. However, in Zone 3B, on the east side of the bay, the sand content generally ranges between 60 and 80 percent, with one of the four samples having a sand content of 27 percent. The results for Zone 3B reflect the influence of Lower Fox River sediments, with a slightly higher silt/clay content in this area than in the other three areas of Green Bay. In Zone 4, the sand content averages 96 percent, which is similar to Zone 3A. Overall, the average sand content of the bay is 78 percent.

Atterberg Limits data were collected during the 1993 Deposit A investigation by BBL, as well as during both the WDNR and FRG 1998 sampling activities. Those sediments tested are characterized by high liquid and plastic limits (Appendix G). Under the Unified Soil Classification System, the majority of the sediments were classified as high compressibility silts (MH) while a small percentage were classified as highly plastic clays (CH). Classification results were not available for all samples.

3.6.3 Estimated Sediment Thickness and Areal Extent

The sampling points and associated sediment thickness measured during previous sampling activities are plotted on Plates 3-1 through 3-5. The methods used to develop the sediment thickness and areal extent on Plates 3-1 through 3-5 are discussed in Section 5.4.1, where the PCB distribution plots are presented. Plates 3-1 through 3-5 present only the sediments in which PCB was detected. The estimated areal extent of each deposit is listed on the table in Appendix G.

Areas where sediment is absent only indicate that no PCBs were detected/sampled in these locations.

During the early portion of the 1989-90 sampling efforts, sediment thickness was measured to a maximum depth of 1.06 m (3.5 ft). Greater sediment thicknesses were subsequently noted in some deposits and these results are included in the database. However, not all of these results are reflected on Plates 3-1 through 3-4 because accurate coordinates were not available. The maximum depth from which PCB samples were collected in each deposit/SMU group, as well as in each bay zone, is included on the table in Appendix G. The maximum sample depths in each reach or zone are listed below.

Maximum Sediment Sampling Depth

Lower Fox River Reach	Maximum Sampling Depth	Green Bay Zones	Maximum Sampling Depth
LLBdM	1.89 m (6.2 ft)	Zone 2 (2A & 2B)	0.91 m (3 ft)
Appleton to Little Rapids	1.83 m (6 ft)	Zone 3A	0.30 m (1 ft)
Little Rapids to De Pere	2.13 m (7 ft)	Zone 3B	0.62 m (2 ft)
De Pere to Green Bay	3.96 m (13 ft)	Zone 4	0.30 m (1 ft)

During the supplemental data collection activities conducted as part of the RI/FS effort, gravity core and push-core samples were collected. In general, these samples ranged up to approximately 0.6 m (2 ft) in length.

In general, there are three layers observed in sediment cores, and these consist of the following:

Layer 1 The surface layer is primarily fine-grained, unconsolidated sediment with a high organic content. As suggested by previous investigators and modeling results, sediments in this layer are fairly recent in age and are susceptible to re-suspension based on flow velocities and shear stress effects.

Layer 2 Consists of fine grained sediments with slightly more sand and gravel along with shell and wood debris. Based on field observations, these sediments are usually more compact, with less water content than the surface layer and would likely require high flow velocities/shear stresses to achieve resuspension.

Layer 3 This layer is the native glacial material which underlies the river. This material typically consists of red-orange, stiff, damp to dry, silty clay, similar to the glacial till in the region.

Sediment thickness is generally greatest in the central portion of the deposit and thins towards the edges. A discussion of each river reach and deposits of significant areal extent are discussed below.

3.6.3.1 LLBdM Reach

Areas of deposits A, C, D, E, F, and POG exhibit sediment thickness approaching or exceeding 1 m (3.28 ft) (Plate 3-1). Overall, LLBdM has conditions that promote deposition and sediments cover about 313.5 hectares (775 acres) in the lake. The areal extent of these deposits ranges from 12.4 hectares (30.6 acres) for Deposit C to 202.5 hectares (500 acres) for Deposit E. Plate 3-1 indicates that sediments thicker than 1 m (3.28 ft) cover much of the width of the river in Deposit E, which is also the largest deposit in this reach. Downstream of the outlet of LLBdM, deposits G and H have surface areas of 4.1 hectares (10 acres) or less.

3.6.3.2 Appleton to Little Rapids Reach

Sediments cover approximately 153 hectares (378 acres) in this reach. Deposits W and X are the largest deposits in this reach, covering a combined area exceeding 82 hectares (202 acres). The sediment thickness in these deposits ranges as high as 1.52 m (5 ft) and 1.83 m (6 ft), respectively (Plate 3-2). The other two deposits in this reach which exceed 10 hectares (24.7 acres) are deposits S and DD. The sediment thickness in these two deposits, as well as the other remaining deposits is less than 1 m (3.28 ft). These thickness and areal extent results suggest that deposits S, W, X, and DD are located in areas which have conditions favorable for sediment deposition. The areal extent of all the remaining deposits in this reach is less than 10 hectares (24.7 acres).

3.6.3.3 Little Rapids to De Pere Reach

Deposits FF, GG, and HH are contiguous with Deposit EE and these four deposits encompass one continuous depositional area (Plate 3-3), covering approximately 266 hectares (658 acres). Deposit EE, the largest of all deposits upstream of the De Pere dam, extends for a distance of approximately 8.6 km (5.4 miles) and has a surface area of 258 hectares (640 acres) (Appendix G). Sediments with PCB range up to 2.3 m (7.5 ft) thick in this reach. In addition, sediments thicker than 1 m (3.287 ft) are located throughout much of this reach (Plate 3-3). Sediment thicknesses exceed 2.3 m (7.5 ft) in these deposits.

3.6.3.4 De Pere to Green Bay Reach

A large, almost continuous deposit of sediment extends from the De Pere dam to the Fort James-West turning basin (Plate 3-4). Downstream of the turning basin, most of the sediment is routinely removed by dredging operations conducted to maintain the navigation channel, and only isolated areas of sediment are present. Sediment thickness is typically up to 1 m (3.28 ft) between the dam and SMU group 38-43. Downstream of SMU group 38-43 (3.28 ft), large areas of the river bottom are covered by sediment thicker than 1 meter. In the vicinity of the turning basin, sediment thickness is 3.65 m (12 ft). Montgomery Watson (1998) reported sediment thickness up to 5.8 meters (19 ft) near the turning basin itself. The areal extent of sediment is approximately 524 hectares (1,290 acres) (Appendix G). The two largest SMU groups based on areal extent are SUMs 20-25 and 44-49, which cover 113.4 hectares (280 acres) and 107.2 hectares (265 acres), respectively.

3.6.3.5 Green Bay (Zones 2 through 4)

Sediment thickness in Green Bay is shown on Plate 3-5. PCB samples were collected from depths as great as 0.9 m (3 ft) in Zone 2 (2A and 2B), near the mouth of the Fox River. A sediment thickness of 0.62 m (2 ft) was also noted along the east shore of Green Bay in Zone 3B (Appendix G). Due to the number of samples collected in Green Bay, the interpolated sediment thickness results only range as high as 0.30 m (1 ft) on plate 3-5. Sediments containing PCBs cover almost 421,300 hectares (1,041,050 acres). Green Bay zones 2A and 2 B cover a combined 11,080 hectares (27,380 acres) while zones 3A and 3 B cover 155,230 hectares (383,580 acres). Zone 4 sediments cover almost 255,000 hectares (630,116 acres).

In Green Bay, sediment cores were only collected where a Ponar Grab sample indicated that sediments with a high organic carbon content were likely present. Therefore, no core was collected in areas where no sediment was retrieved by the grab sampler or where native clay till was present.

3.6.4 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 collected from the Lower Fox River, Green Bay, and select tributaries to assist in the interpretation of the sediment organics data. These results allow for TOC-normalization of the data for comparisons with sediment reference material or with WDNR calculated SQGs. The average TOC result for each deposit, SMU group, or bay zone is listed in Appendix G and the average TOC results (by percent) for each reach and zone are listed below.

Average Reach/Zone TOC Content

Lower Fox River Reach	Average TOC Content	Green Bay Zones	Average TOC Content
LLBdM	6.47%	Zone 2 (2A & 2b)	1.48%
Appleton to Little Rapids	3.68%	Zone 3A	0.19%
Little Rapids to De Pere	4.98%	Zone 3B	2.33%
De Pere to Green Bay	4.54%	Zone 4	0.14%

The average TOC content in Lake Winnebago is 7.8 percent (78,000 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 Lake Michigan TOC average is 0.35 percent and the USGS reference site samples, which have been collected at various sediment sites throughout the country, is 5.68 percent (Appendix G).

It is likely that high concentrations of organic contaminants within the sediments account for some of the TOC detected, as seen in data for Deposit A. Deposit A had an average TOC concentration of 9.04 percent while the LLBdM Reach as a whole had an average TOC concentration of 6.47 percent. Similarly, the average TOC concentrations in SMU 56/57 ranged from 5.42 to 7.56 percent while the average for the De Pere to Green Bay Reach was 4.54 percent.

3.6.5 Other Physical Parameters

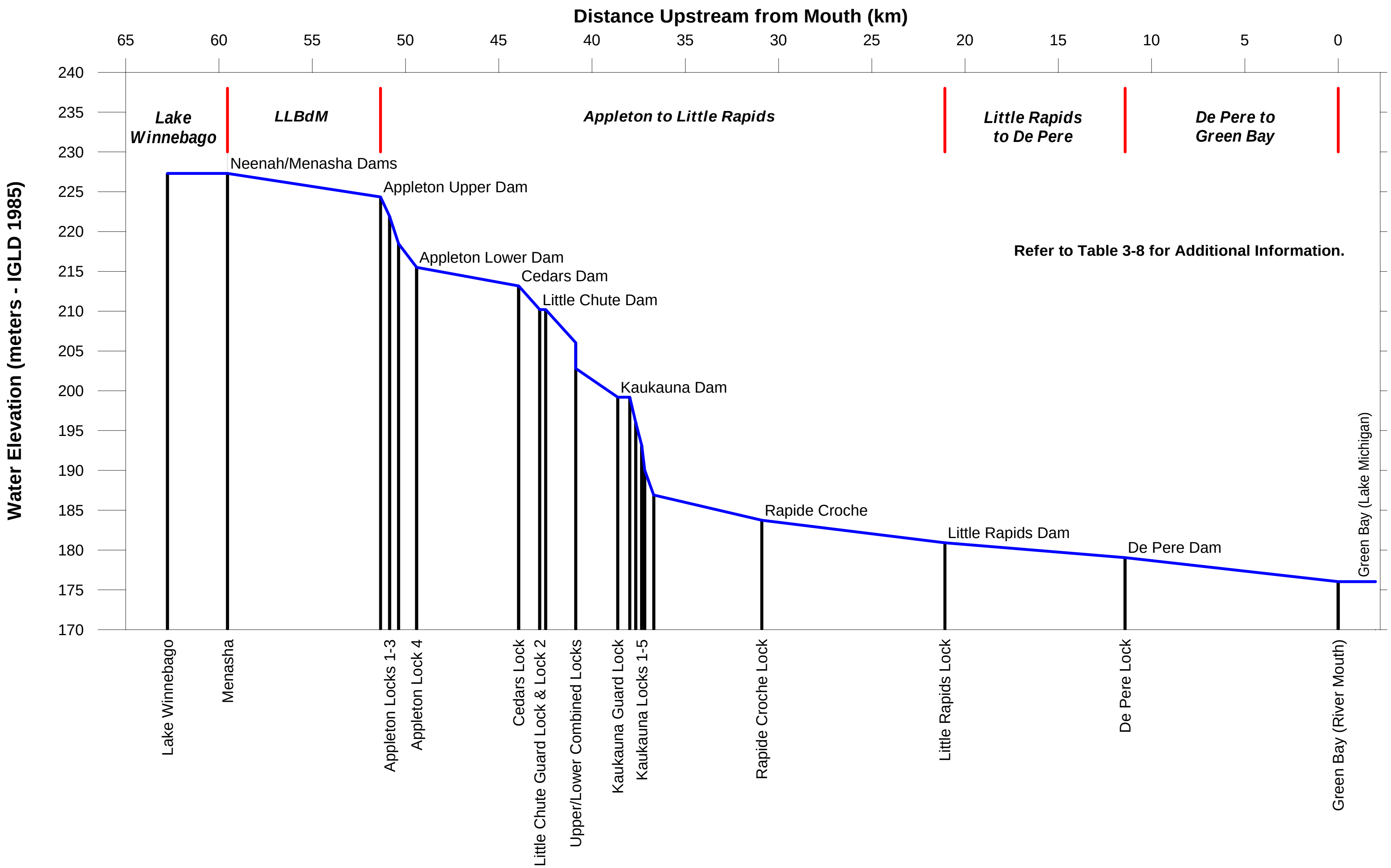
Samples were also collected and submitted for percent solids and bulk density and these data are summarized on tables in Appendix G. Solids generally comprise approximately 40 percent of the sediment samples analyzed (Appendix G). The average values for all three of the reaches upstream of the De Pere dam range from 37 to 42 percent. However, individual values have a much greater range, between 18.1 and 88.2 percent, and may reflect varying sample depths as well as the degree of sediment consolidation. The average result in Green Bay is 44 percent, similar to the river. However, in Green Bay Zone 4, the average percent solids result is approximately 70 percent, indicating that sediments in this portion of the bay are more likely to consist of coarse grained sands rather than fine-grained silt/clay.

The average bulk density results (wet and dry bulk density) for each deposit/SMU group is listed in Appendix G. The average dry bulk density results range from 0.31 to 1.18 grams per cubic centimeter (g/cm^3). The average results for each reach range between 0.51 g/cm^3 and 0.66 g/cm^3, while the river-wide average is 0.55 g/cm^3.

Wet bulk density and specific gravity results are available for only a few deposits/SMUs. Wet bulk density results give an indication of how much the mass of the material will change once sediments are removed from the river (e.g., during remedial efforts). The wet bulk density results ranged from 1.15 g/cm^3 to 1.23 g/cm^3 with an average of 1.17 g/cm^3. The moisture content was also calculated as part of the bulk density determinations and the water content (mass) generally comprises approximately 50 to 75 percent of the sediment sample mass. Specific gravity results ranged from 2.32 to 2.59 with an average value of 2.46.

3.7 Section 3 Figures, Tables, and Plates

Figures, tables, and plates for Section 3 follow this page, and include:



ThermoRetec
Smart Solutions Positive Outcomes

Natural Resource Technology

Remedial Investigation Report

Lower Fox River Elevation Profile

FIGURE: 3-1

REF NO:
CREATED BY:
PRINT DATE:
APPROVED:

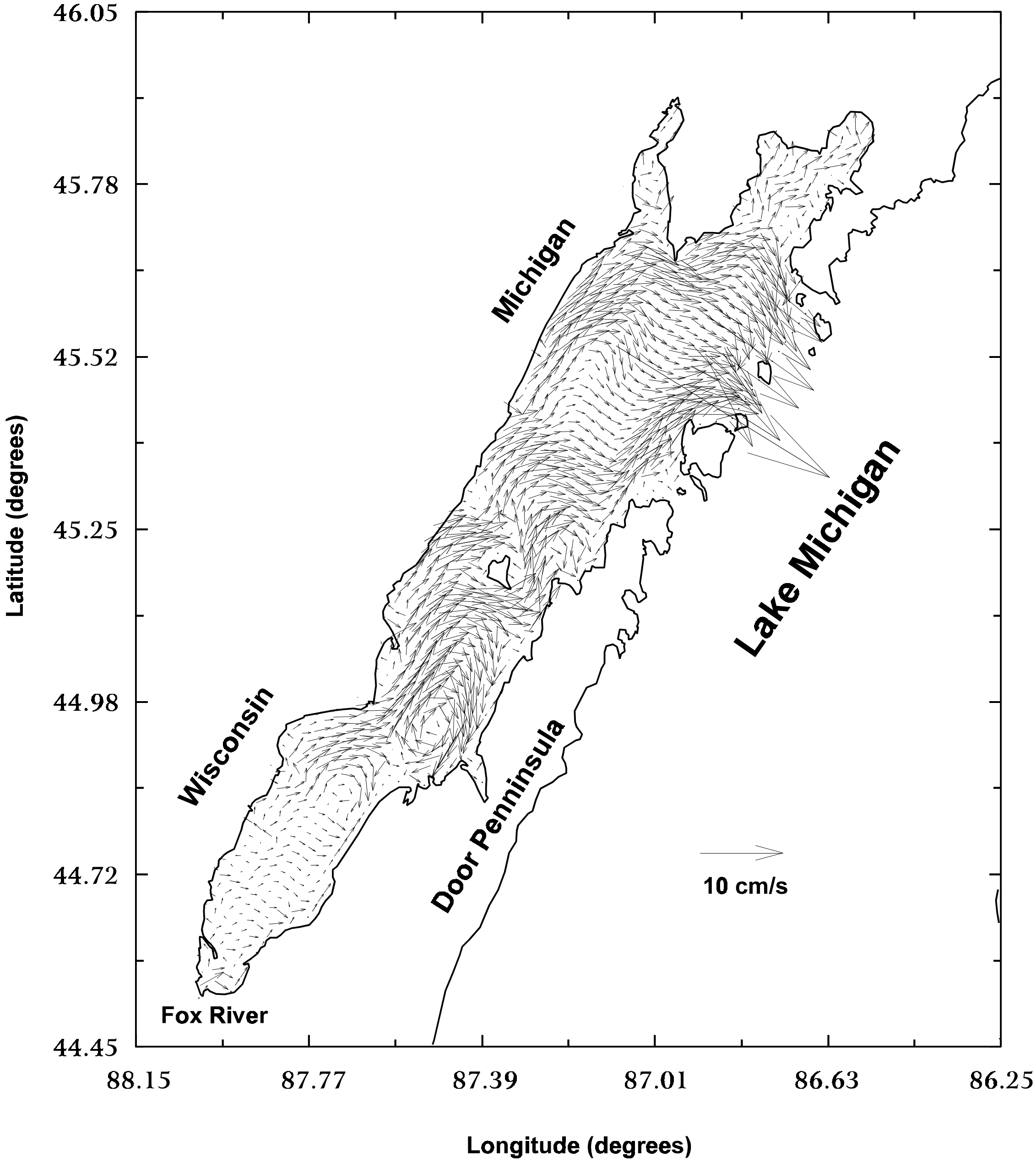


Figure 3-2 Green Bay Monthly Mean Surface Circulation - August 1989

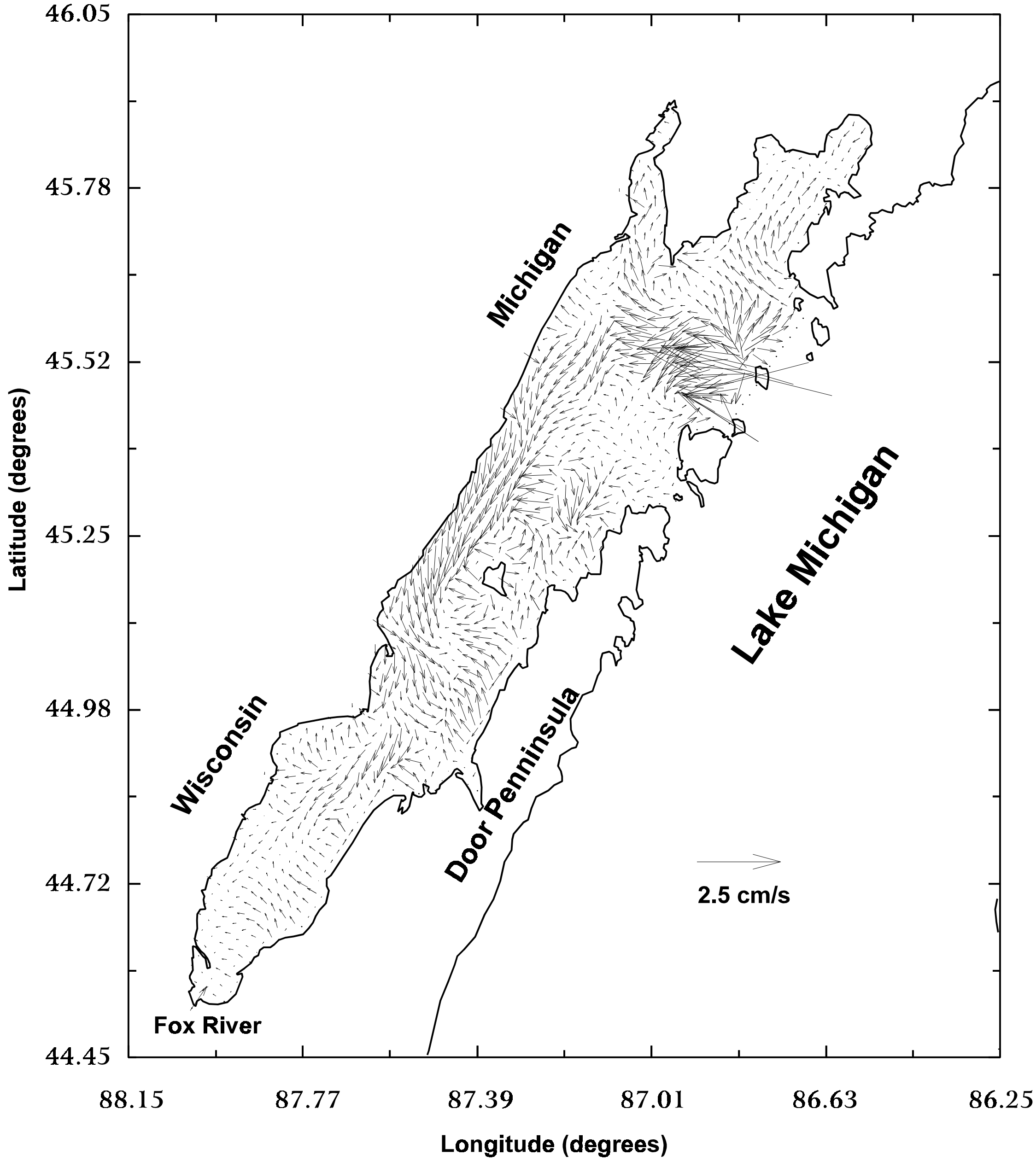
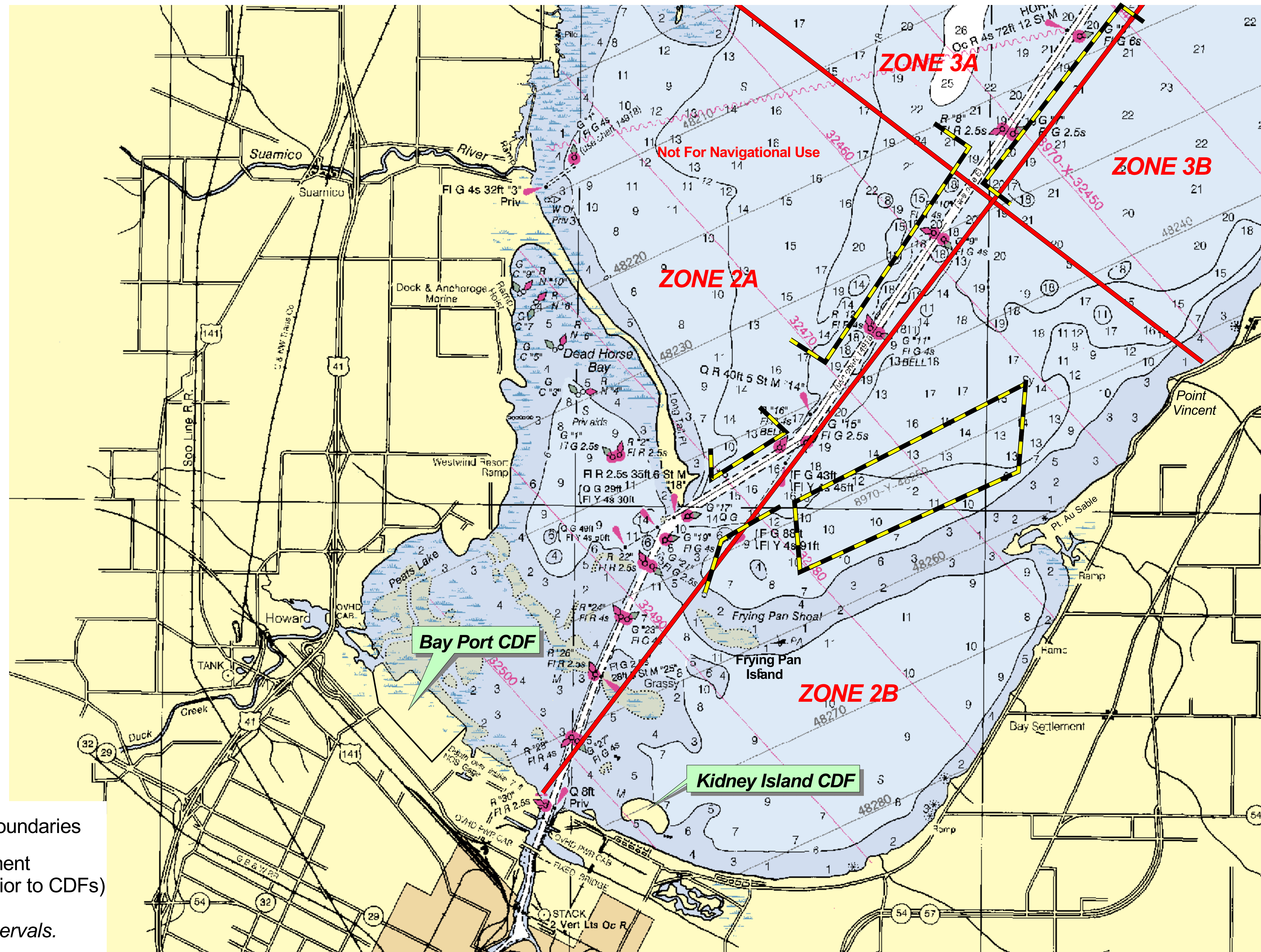


Figure 3-3 Green Bay Monthly Mean Bottom Circulation - August 1989



Green Bay Zone Boundaries

Open Water Sediment Disposal Areas (Prior to CDFs)

Bathymetry contours in 6-foot intervals.

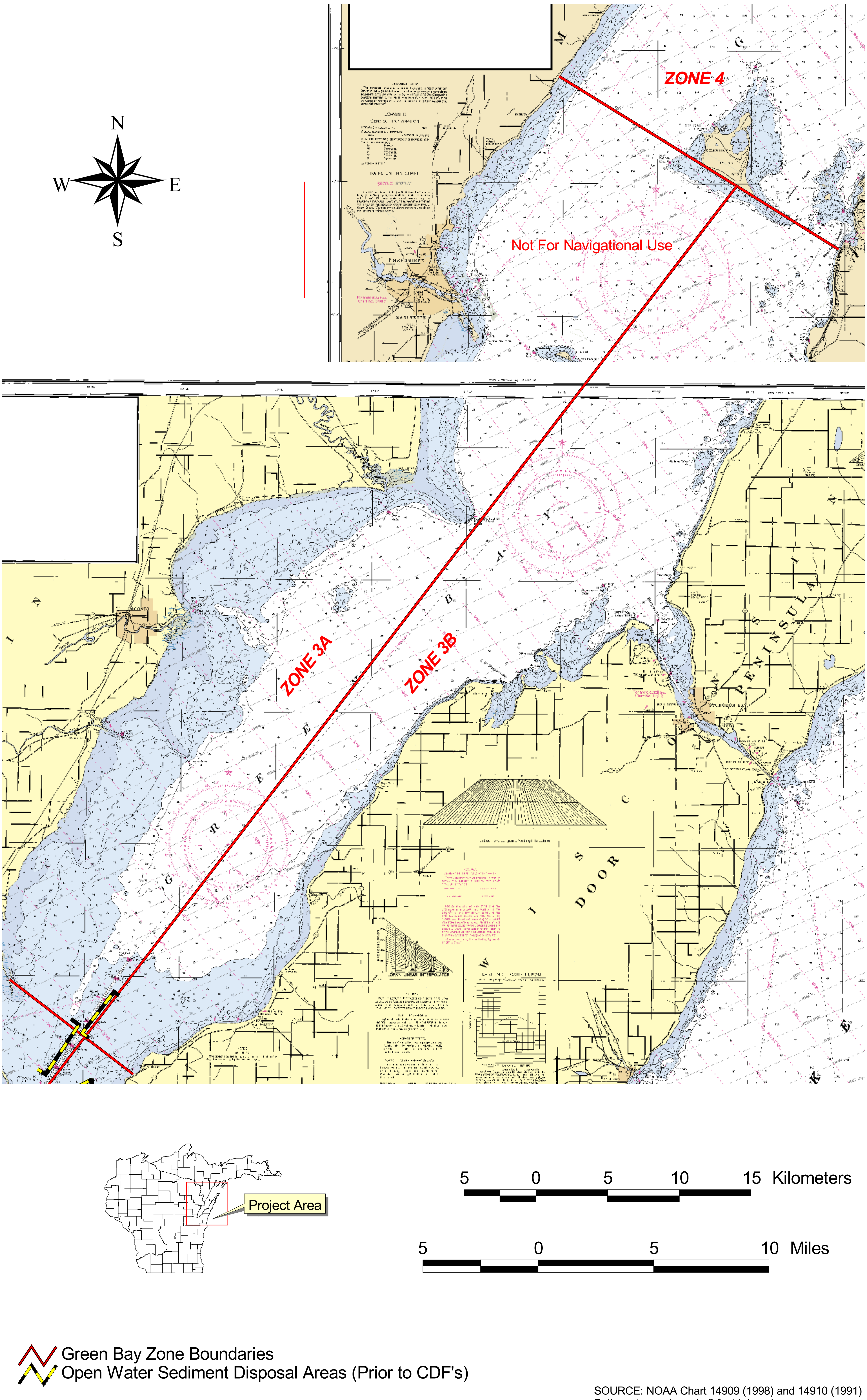
Confined Disposal Facilites (Existing)

1 0 1 2 3 Kilometers

1 0 1 2 Miles

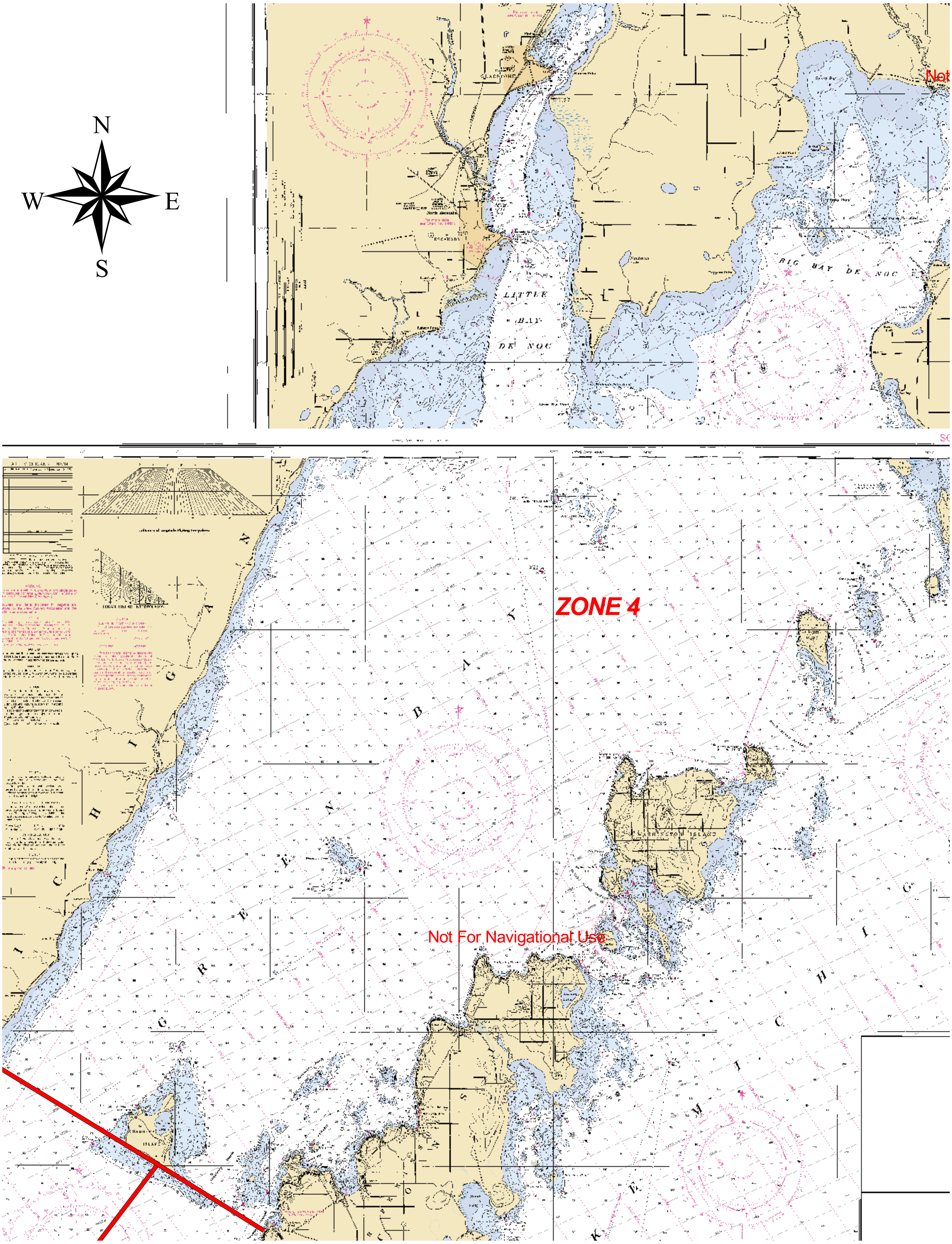
Source: NOAA Chart 14918 (1998)

ThermoRetec	Natural Resource Technology	Remedial Investigation Report	Green Bay Zone 2 Bathymetry	FIGURE NO: RI-14414-340-3-4
			FIGURE: 3-4	CREATED BY: SCJ
				PRINT DATE: 3/7/01
				APPROVED: AGF

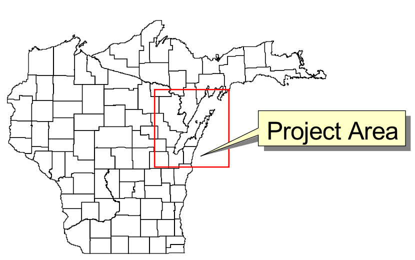


SOURCE: NOAA Chart 14909 (1998) and 14910 (1991)
Bathymetry contours in 6-foot intervals.

ThermoRetec	Natural Resource Technology	Remedial Investigation Report	Green Bay Zone 3 Bathymetry	DRAWING NO: RI-4414-340-3-5
				PRINT DATE: 3/7/01
				CREATED BY: SCJ
			FIGURE 3-5	APPROVED: AGF



Green Bay Zone Boundaries



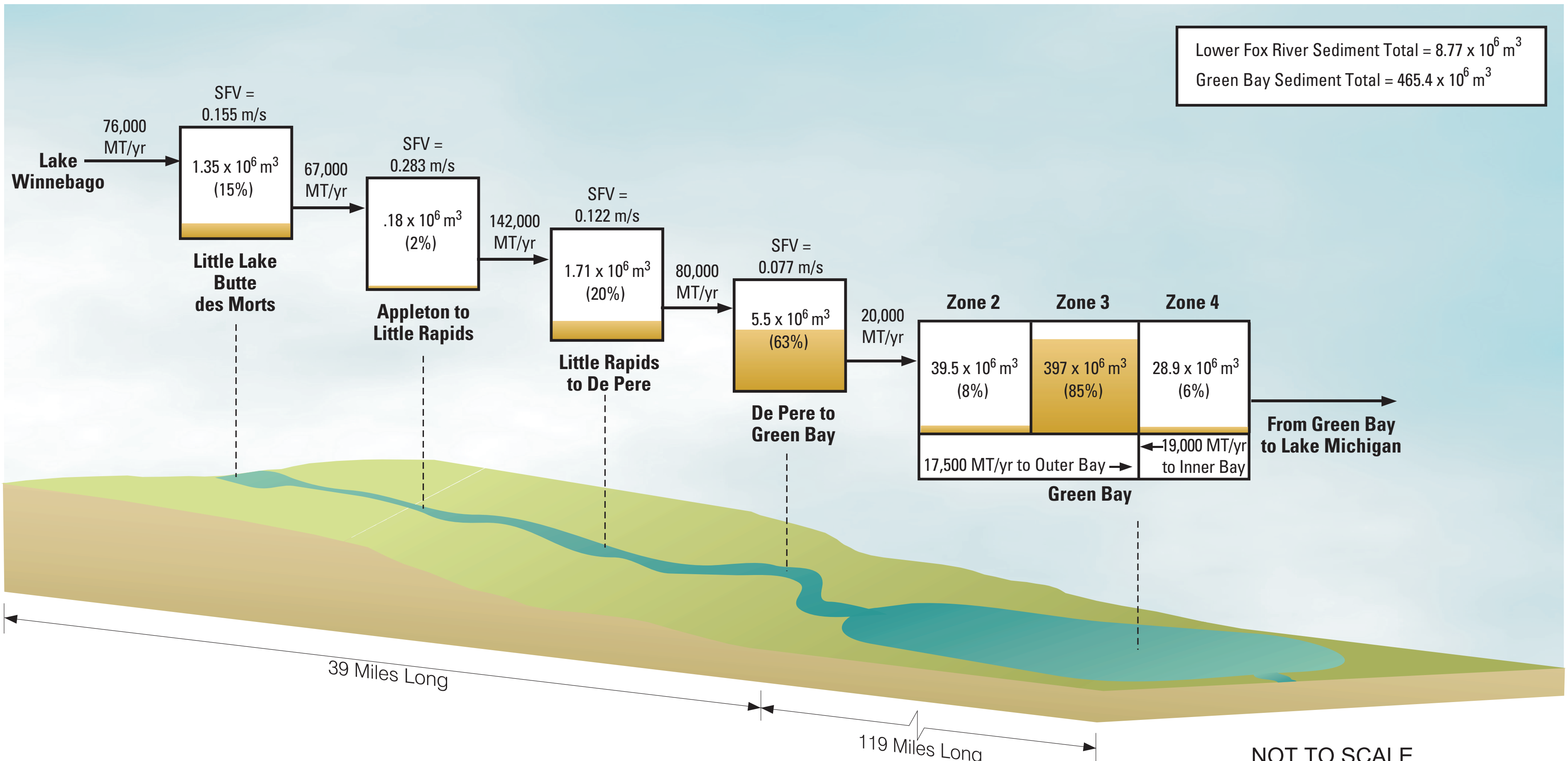
3 0 3 6 9 Kilometers

3 0 3 6 Miles

SOURCE: NOAA Chart 14909 (1998) and 14908 (1991)
Bathymetry contours in 6-foot intervals.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Zone 4 Bathymetry	DRAWING NO: RI-4414-340-3-6
				PRINT DATE: 3/7/01
				CREATED BY: SCJ
			FIGURE 3-6	APPROVED: AGF

Figure 3-7. Estimated Annual Sediment Transport Rates and Stream Flow Velocities



NOT TO SCALE

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

Table 3-1. Land Use Classification for Counties Bordering Green Bay

Land Use Class	Wisconsin Counties										Michigan Counties				Total Land Usage [F]	
	Brown [A]		Door [B]		Kewaunee [C]		Oconto [D]		Marinette [E]		Menominee		Delta			
	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares	Percent	Hectares
Residential	7.8%	10,687	4.0%	5,092	1.9%	172	3.1%	1,904	0.4%	1,483	1.0%	2,726	1.2%	3,661	1.9%	24,984
Ind./Com.	9.3%	12,742	0.9%	1,146	3.3%	297	0.7%	426			0.7%	1,908	0.9%	2,746	1.5%	19,882
Agriculture	58.6%	80,275	49.3%	62,758	69.1%	6,187	37.3%	23,307	12.2%	45,227	14.4%	39,251	8.7%	26,543	22.1%	283,547
Forested			34.1%	43,409	21.7%	1,947	51.6%	32,210	53.1%	196,849	71.9%	195,954	76.2%	232,419	55.0%	705,816
Open	6.7%	9,180	3.3%	4,201	0.4%	38	5.5%	3,454	8.6%	31,881	4.4%	11,993	3.9%	11,899	5.2%	66,477
Vacant			0.1%	127			0.0%	22	0.6%	2,187	0.01%	27	0.01%	31	0.4%	5,443
Public	7.8%	10,687	6.5%	8,274	0.1%	7	0.6%	358	0.01%	37	0.1%	273	0.01%	31	1.5%	19,666
Wetlands	9.8%	13,427	0.6%	764	3.3%	295	0.1%	40	23.0%	85,264	6.8%	18,535	8.3%	25,323	11.2%	143,648
Water	0.01%	14	1.2%	1,528	0.1%	7	1.1%	686	2.1%	7,785	0.7%	1,908	0.8%	2,441	1.1%	14,368
TOTAL	100.0%	137,011	100.0%	127,298	100.0%	8,951	100.0%	62,408	100.00%	370,714	100.0%	272,574	100.00%	305,091	100.0%	1,283,831

Notes: Ind./Com. is Industrial/Commercial - this category also includes lands designated for transportation/utility use.

Open land is non-forested land not currently under cultivation.

A) There was no distinction between forested, open, and vacant land use.

B) Wetlands, beaches, marshes, grasslands, and meadows are combined and equal about 0.6% of land designated as wetlands.

C) Land use information only available for Town of Red River (which borders Green Bay and includes Dyckesville). Total county area is 85,420 hectares and open/vacant land are not distinguished.

D) Land use information only available for the eastern 1/4 of county. Total county area is 263,442 hectares.

E) There was no distinction of urban land use between residential and industrial/commercial.

F) Combined classifications were divided equally when calculating total land usage values.

Table 3-2. Temperature and Precipitation Data for the City of Green Bay, Wisconsin

Temperature Data (Averages: 1961-1990 and Extremes: 1896-1996)

Time Period	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
	Max	Min	Mean	High	Date	Low	Date	High	Year	Low	Year	=>90	<=32	<=32	<=0
January	22.8	5.8	14.3	56	1/26/44	-31	1/30/51	27.6	33	-1.1	12	0	22	30	9.6
February	27.1	9.5	18.3	60	2/21/30	-33	2/10/1899	29	31	4.6	36	0	19	27	6.9
March	38.5	21.4	30	82	3/29/10	-29	3/1/62	41.4	10	19.5	60	0	9.1	26	1.2
April	54	33.9	44	89	4/22/80	7	4/3/54	52.3	15	35.1	7	0	0.6	13	0
May	67.2	43.7	55.5	99	5/31/34	21	5/9/66	63.4	77	47.5	7	0.1	0	1.9	0
June	75.5	53.5	64.5	101	6/1/34	32	6/6/58	72.9	33	57.2	69	1.6	0	0	0
July	80.5	58.9	69.7	104	7/13/36	40	7/6/65	77.4	21	64.9	92	3.2	0	0	0
August	77.5	56.8	67.1	100	8/24/48	38	8/30/15	75.1	47	61.7	50	2	0	0	0
September	69.1	48.8	59	97	9/10/31	24	9/29/49	67.3	31	54.2	74	0.7	0	0.5	0
October	57.4	38.5	48	88	10/6/63	12	10/30/25	58.9	47	39	25	0	0.1	6.7	0
November	42	26.8	34.4	74	11/1/33	-9	11/28/76	43.2	31	25.4	51	0	5.5	21	0.3
December	27.7	12.5	20.2	62	12/1/70	-27	12/19/83	32.1	31	9.1	76	0	19	29	5
Annual	53.3	34.2	43.8	104	7/13/36	-33	02/10/99'	49.5	31	40.4	17	7.7	75	156	23
Winter	25.9	9.3	17.6	62	12/1/70	-33	02/10/99'	27.1	32	10.1	4	0	60	86	21
Spring	53.2	33	43.2	99	5/31/34	-29	3/1/62	49.6	77	37.6	50	0.1	9.7	41	1.2
Summer	77.8	56.4	67.1	104	7/13/36	32	6/6/58	72.6	95	63.1	15	6.8	0	0	0
Fall	56.2	38	47.1	97	9/10/31	-9	11/28/76	54.7	31	42.4	76	0.7	5.6	28	0.3

Precipitation Data (Averages: 1961-1990 and Extremes: 1896-1996)

	Total Precipitation							Snow			# Days Precipitation		
	Mean	High	Year	Low	Year	1 - Day Max		Mean	High	Year	0.01	0.5	1
January	1.15	2.64	50	0.12	81	1.2	13904	11.7	31.5	96	10	0.4	0
February	1.03	4.54	22	0.04	69	2.03	2/22/22	8	20.6	62	8.4	0.4	0.1
March	2.05	4.68	77	0.19	10	1.87	3/19/03	9.2	24.2	89	10.3	1.1	0.1
April	2.4	6.47	29	0.49	89	1.86	4/25/94	2.1	11.8	77	10.8	1.7	0.3
May	2.82	9.7	18	0.06	88	2.6	5/29/42	0.1	4.3	90	11.3	1.8	0.5
June	3.39	10.29	90	0.31	76	4.9	6/22/90	0	0	49	10.8	2.2	0.9
July	3.1	7.46	12	0.7	46	4.39	7/23/12	0	0	48	10	2.1	0.7
August	3.5	9.04	75	0.36	'99	3.83	8/28/75	0	0	48	9.8	2.1	0.6
September	3.47	7.8	65	0.28	76	2.99	9/3/64	0	0	48	10.1	2.2	0.8
October	2.23	5	54	0	52	3.44	10/2/54	0.2	1.7	59	9.1	1.2	0.4
November	2.16	6.19	34	0.16	76	2.23	11/1/85	4.6	17.1	95	9.5	1.1	0.3
December	1.53	3.65	21	0.03	43	1.57	12/27/04	12.5	27	77	10	0.5	0.1
Annual	28.83	38.36	85	16.31	30	4.9	33046	48.5	92	85	120.7	16.9	4.7
Winter	3.71	9.07	22	1.34	61	2.03	2/22/22	31.4	53.2	62	28.3	1.3	0.2
Spring	7.27	14.12	18	3.42	31	2.6	5/29/42	11.5	25.5	77	32.5	4.6	1
Summer	9.99	18.89	14	4.42	76	4.9	6/22/90	0	0	48	30.8	6.4	2.1
Fall	7.86	13.21	31	1.26	76	3.44	10/2/54	4.8	17.1	95	28.9	4.6	1.5

Notes: 1) Information from the Green Bay Airport Station 473269 (GREEN_BAY_WSO_AIRPORT)

2) Temperatures are in degrees Fahrenheit and precipitation is in inches.

Table 3-3. Temperature and Precipitation Data for the City of Appleton, Wisconsin

Temperature Data (Averages 1961-1990 and Extremes 1901-1996)

Time Period	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
	Max	Min	Mean	High	Date	Low	Date	High	Year	Low	Year	=>90	<=32	<=32	<=0
January	23.8	7.2	15.5	55	1/27/44	-30	1/30/51	26.9	90	0.1	12	0	19	27	8.6
February	28.5	11.2	19.9	59	2/23/30	-32	2/20/29	29.6	54	3.9	36	0	16	25	5.9
March	39.6	22.6	31.1	80	3/29/10	-21	3/1/62	42.1	10	22.3	60	0	7.4	24	0.9
April	54.6	35	44.8	89	4/22/80	7	4/6/79	53.1	15	36.6	7	0	0.4	12	0
May	68	46.3	57.2	94	5/31/88	23	5/4/05	69.2	11	49.3	7	0.1	0	1.5	0
June	77.1	56.2	66.6	101	6/20/88	34	6/8/13	72.7	11	59.5	69	1.7	0	0	0
July	81.9	62	71.9	107	7/14/36	41	7/31/03	78.3	16	66.8	92	3.5	0	0	0
August	79	59.7	69.4	103	8/16/88	35	8/27/15	77.5	47	63.7	27	2.2	0	0	0
September	70.3	51.5	60.9	101	9/2/13	25	9/30/93	67.4	8	54.4	93	0.7	0	0.4	0
October	58.1	40.7	49.4	89	10/6/63	15	10/19/92	60	47	38.7	17	0	0	5.2	0
November	42.7	28.2	35.5	73	11/1/35	-7	11/29/29	43	31	26.1	95	0	4.6	19	0.2
December	28.6	13.8	21.2	59	12/8/46	-23	12/21/89	31.4	39	9.9	85	0	17	27	4
Annual	54.4	36.2	45.3	107	7/14/36	-32	2/20/29	50.3	38	40.6	17	8.2	65	142	20
Winter	27	10.7	18.9	59	2/23/30	-32	2/20/29	26.2	32	11.5	18	0	52	79	18
Spring	54.1	34.6	44.4	94	5/31/88	-21	3/1/62	50.7	77	38.5	96	0.1	7.8	38	0.9
Summer	79.3	59.3	69.3	107	7/14/36	34	6/8/13	74.3	88	64.1	15	7.4	0	0	0
Fall	57	40.1	48.6	101	9/2/13	-7	11/29/29	54.8	31	44	76	0.7	4.6	24	0.2

Precipitation Data (Averages 1961-1990 and Extremes 1901-1996)

	Total Precipitation							Snow			# Days Precipitation		
	Mean	High	Year	Low	Year	1 - Day Max		Mean	High	Year	0.01	0.5	1
January	1.12	4.35	29	0.04	81	1.23	1/16/80	10.9	29.9	94	8.8	0.5	0
February	1.08	3.66	81	0.04	69	1.87	2/8/66	7.9	26.1	62	7.2	0.5	0.1
March	2.17	5.36	13	0.16	78	3.12	3/14/13	8.2	28.2	56	9	1.2	0.2
April	2.78	6.64	29	0.2	1	2.3	4/3/81	2	11	85	10.2	1.9	0.4
May	3.19	8.79	42	0.22	88	2.96	5/31/54	0.2	5.3	90	10.8	2.2	0.6
June	3.64	9.07	90	0.17	12	4.18	6/23/90	0	0	48	10	2.4	0.9
July	3.21	8.76	12	0.4	16	3.29	7/2/52	0	0	48	9.3	2.3	0.9
August	3.74	10.3	95	0.5	76	3.7	8/28/75	0	0	48	9.2	2.2	0.7
September	3.66	9.15	86	0.32	67	2.67	9/11/86	0	0	48	9.7	2.5	0.8
October	2.45	6.41	67	0.09	52	2.85	10/24/67	0.2	2	76	8.7	1.3	0.3
November	2.17	5.93	34	0.02	4	2.15	11/22/34	3.8	16.8	59	8.5	1.3	0.3
December	1.54	3.33	68	0.15	94	1.55	12/27/59	11.7	28.1	68	8.5	0.6	0.1
Annual	30.75	40.98	61	19.21	1	4.18	6/23/90	44.5	98.2	59	109.7	18.9	5.4
Winter	3.74	7.27	29	1.26	95	1.87	2/8/66	29.7	57.1	62	24.6	1.6	0.2
Spring	8.14	15.47	13	3.5	39	3.12	3/14/13	10.5	34.5	56	30.6	5.4	1.2
Summer	10.59	19.19	61	4.92	37	4.18	6/23/90	0	0	48	29.3	7.2	2.6
Fall	8.28	15.23	11	1.38	76	2.85	10/24/67	4	17.6	59	27.2	5.1	1.5

Notes:

1) Information from the Appleton Weather Station 470265.

2) Temperatures are in degrees Fahrenheit and precipitation is in inches.

Table 3-4. Temperature and Precipitation Data for the City of Marinette, Wisconsin

Temperature Data (Averages: 1961-1990 and Extremes: 1948-1996)

Time Period	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
	Max	Min	Mean	High	Date	Low	Date	High	Year	Low	Year	=>90	<=32	<=32	<=0
January	24.8	6.1	15.5	50	1/26/73	-30	1/17/82	25.3	64	8.5	77	0	20	30	8.1
February	28.1	8	18.1	57	2/29/64	-30	2/3/96	30.7	54	12.5	63	0	15	27	5.2
March	39.3	19.7	29.5	75	3/30/63	-20	3/1/62	39.3	73	24.3	96	0	5.2	26	1
April	53.3	32.2	42.8	90	4/27/52	5	4/9/89	49.9	87	35.2	50	0	0.2	14	0
May	66.4	43.4	54.9	97	5/30/88	22	3/10/66	64.2	77	47.8	83	0.5	0	2.8	0
June	76.8	53.2	65	100	6/14/87	34	6/8/49	71.4	88	58.2	82	2.7	0	0	0
July	82.8	59	70.9	102	7/6/88	40	7/6/65	76.3	55	64	92	4.9	0	0	0
August	78.9	56.6	67.8	101	8/21/55	34	8/28/86	75.3	55	64.2	50	2.7	0	0	0
September	70	49.2	59.6	96	9/1/53	23	9/23/74	64.9	61	53.7	74	0.6	0	0.8	0
October	57.7	38.4	48.1	89	10/6/63	16	10/18/48	59.2	63	41.7	88	0	0	6.7	0
November	42.9	26.3	34.6	75	11/18/53	-8	11/24/50	41.8	53	28.5	95	0	3.2	21	0.2
December	29.4	13.2	21.4	60	12/1/62	-22	12/23/83	31.3	65	10.9	89	0	16	29	3.9
Annual	54.2	33.8	44	102	7/6/88	-30	1/17/82	48.7	87	41.7	90	12	60	158	18
Winter	27.4	9.1	18.3	60	12/1/62	-30	1/17/82	26.6	87	14.6	79	0	51	86	17
Spring	53	31.8	42.4	97	5/30/88	-20	3/1/62	48.9	77	37.6	50	0.6	5.4	43	1
Summer	79.5	56.3	67.9	102	7/6/88	34	6/8/49	72.9	55	63.9	92	10	0	0	0
Fall	56.9	38	47.4	96	9/1/53	-8	11/24/50	54.1	63	44.6	93	0.6	3.2	28	0.2

Precipitation Data (Averages: 1961-1990 and Extremes: 1919-1996)

Time Period	Total Precipitation							Snow			# Days Precipitation		
	Mean	High	Year	Low	Year	1 - Day Max		Mean	High	Year	=>.01	=>.50	=>1
January	1.62	8.49	96	0	90	2.35	1/27/96	14.5	36	71	8.4	0.8	0.2
February	1.34	4.2	22	0	90	2.16	2/21/37	10.8	29	85	6.6	0.6	0.1
March	2.28	7.03	77	0.16	37	1.65	3/20/21	9.6	26.5	56	7.7	1.2	0.2
April	2.82	6.68	68	0.36	46	1.97	4/17/68	2.5	13	77	8.8	2	0.6
May	3.49	8.81	65	0.77	88	5.17	5/16/65	0.1	3.5	90	10.2	2.1	0.6
June	3.64	11.07	96	0.56	21	3.31	6/22/90	0	0	48	10.3	2.2	1
July	3.27	7.52	91	0.87	81	3.96	7/28/91	0	0	48	10	2.3	0.6
August	3.24	9.97	60	0.53	70	5.05	8/3/60	0	0	48	9.2	2.2	0.8
September	3.62	8.38	65	0.31	67	2.78	9/1/79	0	0	48	10.3	2.4	0.8
October	2.36	6.04	67	0.06	52	2.13	10/7/95	0.1	2.3	76	8.7	1.5	0.5
November	2.58	8.2	85	0.1	76	3.36	11/1/85	2.7	17	51	8.8	1.5	0.5
December	1.9	5.74	59	0	89	3.1	12/28/59	14.7	37.2	68	8.6	0.7	0.2
Annual	32.16	45.27	96	16.65	89	5.17	5/16/65	53.7	115.3	85	106.8	19.4	5.8
Winter	4.86	11.21	96	0	90	3.1	12/28/59	39.6	70.5	79	23.5	2.1	0.5
Spring	8.59	15.64	65	3.83	88	5.17	5/16/65	12.3	32.5	56	27.4	5.4	1.3
Summer	10.15	17.68	96	4.58	37	5.05	8/3/60	0	0	48	29.7	6.7	2.4
Fall	8.56	14.87	34	1.92	76	3.36	11/1/85	2.9	17	51	27.8	5.5	1.7

Notes: 1) Information from the Marinette Weather Station 475091.
2) Temperatures are in degrees Fahrenheit and precipitation is in inches.

Table 3-5. Temperature and Precipitation Data for the City of Sturgeon Bay, Wisconsin

Temperature Data (Averages: 1961-1990 and Extremes: 1905-1996)

Time Period	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
	Max	Min	Mean	High	Date	Low	Date	High	Year	Low	Year	=>90	<=32	<=32	<=0
January	24.8	8.7	16.8	55	1/26/44	-29	1/17/82	27	90	0	12	0	21	30	8.2
February	28.4	11.3	19.8	58	2/23/06	-29	2/10/12	28.8	54	4	36	0	18	27	6.7
March	38.2	21.8	30	76	3/28/46	-23	3/2/62	39.7	46	20.5	23	0	8.3	27	1.5
April	51.6	32.8	42.2	85	4/26/62	2	4/4/23	48.1	55	33.4	7	0	0.6	16	0
May	64.5	41.9	53.2	91	5/31/25	20	4/4/07	59.9	77	43.7	7	0	0	3.6	0
June	74.2	51.4	62.8	100	6/30/10	29	6/9/13	69	21	54.9	15	1	0	0.2	0
July	79.6	57.9	68.8	105	7/13/36	36	7/18/12	77.8	21	62.7	15	1.8	0	0	0
August	77.4	56.8	67.2	102	8/21/55	32	8/30/34	73.6	55	61.5	12	1.2	0	0	0
September	69.1	50	59.6	96	9/9/31	26	9/25/47	66.2	21	54.4	24	0.2	0	0.6	0
October	57.1	40.4	48.8	86	10/6/63	12	10/30/25	57.6	63	40.2	25	0	0	5.9	0
November	42.8	29.9	36.4	71	11/2/90	-6	11/24/50	42.1	31	28.7	95	0	3.9	20	0.1
December	30	16.7	23.4	58	12/9/46	-22	12/27/33	33.9	23	12.8	89	0	17	29	3
Annual	53.1	35	44.1	105	7/13/36	-29	2/10/12	50	5	39.6	17	4.4	69	159	19
Winter	27.7	12.2	20	58	2/23/06	-29	2/10/12	27.6	83	12.7	17	0	56	86	18
Spring	51.4	32.2	41.8	91	5/31/25	-23	3/2/62	46.9	77	36.3	23	0	8.9	46	1.5
Summer	77.1	55.4	66.3	105	7/13/36	29	6/9/13	71.7	21	59.8	15	4.1	0	0.2	0
Fall	56.3	40.1	48.3	96	9/9/31	-6	11/24/50	52.9	31	43.9	32	0.2	4	27	0.1

Precipitation Data (Averages: 1961-1990 and Extremes: 1905-1996)

Time Period	Total Precipitation							Snow			# Days Precipitation		
	Mean	High	Year	Low	Year	1 - Day Max		Mean	High	Year	=>.01	=>.50	=>1
January	1.53	3.78	6	0.2	57	1.32	1/16/80	12.5	41	29	8.8	0.5	0.1
February	1.13	4.1	22	0.02	69	1.57	2/21/37	7.8	39	8	7.3	0.6	0.1
March	2.09	7.18	6	0.19	10	2.17	3/2/06	7.5	29	9	8.1	1.2	0.3
April	2.65	6.18	9	0.5	46	1.97	4/29/09	2	13.5	9	9.6	1.7	0.5
May	3.12	10.54	18	0.15	88	3.85	5/28/73	0.1	9	11	10.4	1.9	0.6
June	3.31	8.26	90	0.61	88	3.07	6/19/13	0	0	5	10.1	2.2	0.8
July	3.36	8.9	5	0.72	36	3.96	7/6/93	0	0	5	10	2.2	0.8
August	3.42	8.68	85	0.29	25	4.57	8/25/10	0	0	5	9.3	2.1	0.7
September	3.88	10.38	65	0.68	76	3.71	9/1/79	0	0	5	10.7	2.2	0.8
October	2.66	6.1	95	0.11	52	2.61	10/19/84	0	6	17	9.4	1.6	0.4
November	2.45	6.72	6	0.22	76	1.98	11/22/34	2.4	19	16	9.2	1.4	0.4
December	1.89	5	59	0.08	43	3.6	12/28/59	11.7	32	9	8.6	0.8	0.1
Annual	31.49	47.36	85	16.99	25	4.57	8/25/10	44.1	129.8	9	111.4	18.4	5.7
Winter	4.55	9.01	22	1.48	57	3.6	12/28/59	31.5	77	8	24.6	1.9	0.3
Spring	7.86	14.5	73	3.79	35	3.85	5/28/73	9.6	45.5	9	28.1	4.8	1.4
Summer	10.09	16.34	85	4.39	30	4.57	8/25/10	0	0	5	29.5	6.4	2.3
Fall	8.99	16.69	12	2.03	76	3.71	9/1/79	2.5	19	16	29.3	5.3	1.7

Notes:
1) Information from the Sturgeon Bay Weather Station 478267.
2) Temperatures are in degrees Fahrenheit and precipitation is in inches.

Table 3-6. Temperature and Precipitation Data for the City of Fayette, Michigan

Temperature Data (Averages: 1961-1990 and Extremes: 1931-1996)

Time Period	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
	Max	Min	Mean	High	Date	Low	Date	High	Year	Low	Year	=>90	<=32	<=32	<=0
January	24.5	10.3	17.4	52	1/22/32	-24	1/23/63	29.1	32	7.8	94	0	23	31	6
February	26.9	11.2	19.1	49	2/19/81	-25	2/1/38	28.5	54	6.8	36	0	19	27	5.3
March	36.1	20.4	28.2	63	3/15/90	-18	3/11/48	36	46	20.9	60	0	9.6	28	1.3
April	48.1	31.3	39.7	78	4/21/73	5	4/7/72	44.6	55	32.7	50	0	0.8	17	0
May	60.5	41.2	50.9	89	5/23/72	20	5/6/54	55.9	82	44	47	0	0	3.2	0
June	69.1	50	59.6	90	6/26/64	29	6/8/49	66.1	95	54	58	0	0	0	0
July	75.6	57.4	66.5	96	7/12/36	39	7/1/60	71.7	83	61.2	92	0.1	0	0	0
August	73.8	57.1	65.4	93	8/19/83	36	8/22/50	71.2	55	59.1	50	0	0	0	0
September	65.8	50.8	58.3	85	9/1/37	26	9/25/47	62.9	31	53.9	74	0	0	0.4	0
October	55	41.2	48.1	77	10/6/63	18	10/27/36	56	47	43.7	36	0	0	4.3	0
November	41.9	30.4	36.2	67	11/16/53	0	11/28/76	42.3	31	29.1	59	0	4	18	0
December	29.6	17.5	23.6	57	12/2/82	-19	12/29/76	31.8	31	13.4	89	0	18	29	1.6
Annual	50.6	34.9	42.8	96	7/12/36	-25	2/1/38	46.5	87	40.2	50	0.2	74	158	14
Winter	27	13	20	57	12/2/82	-25	2/1/38	28	32	14.3	77	0	59	86	13
Spring	48.2	31	39.6	89	5/23/72	-18	3/11/48	43.6	87	34.8	50	0	10	49	1.3
Summer	72.8	54.8	63.8	96	7/12/36	29	6/8/49	68	55	59.3	50	0.2	0	0	0
Fall	54.2	40.8	47.5	85	9/1/37	0	11/28/76	52.6	31	43.5	76	0	4	23	0

Precipitation Data (Averages: 1961-1990 and Extremes: 1931-1996)

Time Period	Total Precipitation							Snow			# Days Precipitation		
	Mean	High	Year	Low	Year	1 - Day Max		Mean	High	Year	=>.01	=>.50	=>1
January	1.49	4.27	50	0.12	86	1.71	1/18/96	14.1	39	50	9.5	0.7	0.1
February	1.1	4.18	53	0.03	93	1.54	2/21/37	10.3	42	45	7.7	0.6	0.1
March	1.9	5.96	82	0.11	93	4.5	3/30/82	9.9	34	72	7.9	1.2	0.2
April	2.33	6.03	54	0.57	71	2.15	4/27/54	2.2	18	50	8.2	1.6	0.4
May	2.86	7.41	60	0.88	88	3.23	5/28/41	0	8.5	54	9.1	2	0.5
June	2.88	7.33	53	0.36	95	2.9	6/30/53	0	0	31	9.7	2	0.5
July	2.61	8.9	52	0.51	39	2.99	7/6/93	0	0	31	9.3	1.9	0.6
August	3.53	6.61	62	0.18	91	2.75	8/16/74	0	0	31	9.2	2.2	0.8
September	3.43	8.1	31	0.8	52	3.45	9/2/37	0	0.5	42	9.8	2.4	0.7
October	2.53	5.27	82	0.18	56	2.8	10/20/82	0.2	3.5	33	8.5	1.5	0.4
November	2.19	6.82	48	0.47	76	2.24	11/2/85	3.5	24.5	51	9.2	1.7	0.4
December	1.96	4.3	68	0.11	94	1.2	12/14/75	13.8	38	68	9.2	0.9	0.1
Annual	28.81	39.96	38	20.42	76	4.5	3/30/82	53	125.8	50	107.7	18.8	4.9
Winter	4.55	9.45	71	1.58	61	1.71	1/18/96	37.9	89	45	26.5	2.3	0.3
Spring	7.09	12.07	54	3.91	80	4.5	3/30/82	12	40.5	43	25.2	4.7	1.2
Summer	9.02	15.76	52	3.33	55	2.99	7/6/93	0	0	31	28.2	6.2	1.9
Fall	8.15	14.44	31	3.3	76	3.45	9/2/37	3.8	26.5	51	27.8	5.6	1.5

Notes:
1) Information from the Fayette Weather Station 202737.
2) Temperatures are in degrees Fahrenheit and precipitation is in inches.

Table 3-7. Water Use in the Lower Fox River/Green Bay Watersheds (1995)

Watershed Name	USGS Hydrologic Unit Code	State	Population			Withdrawals [A]				Domestic Water Use [A]		
			Total [B]	Served by GW Public Supply	Served by SW Public Supply	GW	SW	Total	Per Capita Use	Self-supplied Population	Total Withdrawals	Per Capita Use
Lower Fox	4030204	WI	306,360	75,640	206,430	17.77	28.7	46.47	164.75	24,290	1.45	59.7
Duck-Pensaukee	4030103	WI	66,890	16,770	0	1.44	0	1.44	85.87	50,120	3.01	60.06
Oconto	4030104	WI	25,650	7,280	0	1.35	0	1.35	185.44	18,370	1.1	59.88
Peshtigo	4030105	WI	30,770	7,690	0	0.98	0	0.98	127.44	23,080	1.38	59.79
Menominee	4030108	WI/MI	57,320	21,490	13,740	4.01	2.73	6.74	393.17	22,090	1.48	130.28
Door-Kewaunee	4030102	WI	47,410	17,820	0	3.13	0	3.13	175.65	29,590	1.78	60.16
Cedar-Ford	4030109	MI	18,250	1,410	9,160	0.44	1.13	1.57	148.53	7,680	0.53	69.01
Escanaba	4030110	MI	7,570	3,960	0	1.04	0	1.04	262.63	3,610	0.26	72.02
Fishdam-Sturgeon	4030112	MI	2,170	670	0	0.08	0	0.08	119.4	1,500	0.11	73.33
Totals			**562,390**	**152,730**	**229,330**	**30.24**	**32.56**	**62.80**	**184.76**	**180,330**	**11.10**	**71.58**

Notes:

A) All water units expressed as a million gallons per day (MGD).

B) The population figures cited herein are 1995 estimates for select watersheds only. The overall population of the Lower Fox River and Green Bay system is 595,300.

C) 723.23 MGD of water used for Thermoelectric Power Generation in the Door-Kewaunee watershed is not included because this facility draws water from Lake Michigan.

Total per capita use values are the average value for the column.

GW - Indicates groundwater is source.

SW - Indicates surface water is source.

Table 3-7. Water Use in the Lower Fox River/Green Bay Watersheds (1995) (Continued)

Watershed Name	USGS Hydrologic Unit Code	State	Commercial Water Use [A]				Industrial Water Use [A]			Thermoelectric Power Generation [A]			
			GW	SW	Total	Consumptive Use	GW	SW	Total	GW	SW	Total	Gigawatt Hours
Lower Fox	4030204	WI	0.43	0	0.43	1.78	2.4	101.32	103.72	2	396.6	398.6	1680.14
Duck-Pensaukee	4030103	WI	0	0	0	0.08	0	0	0	0	0	0	0
Oconto	4030104	WI	0	0	0	0.04	0.21	1.18	1.39	0	0	0	0
Peshtigo	4030105	WI	0	0	0	0.04	2.37	7.24	9.61	0	0	0	0
Menominee	4030108	WI/MI	0.14	0.14	0.28	0.17	2.62	9.36	11.98	0	0	0	0
Door-Kewaunee	4030102	WI	1.49	0	1.49	0.39	0.17	0	0.17	C	C	C	C
Cedar-Ford	4030109	MI	0.09	0.09	0.18	0.03	0.1	7.77	7.87	0	0	0	0
Escanaba	4030110	MI	0.06	0.06	0.12	0.07	0.07	5.99	6.06	0	0	0	0
Fishdam-Sturgeon	4030112	MI	0.17	0.17	0.34	0.04	0.03	3.3	3.33	0	0	0	0
Totals			**2.38**	**0.46**	**2.84**	**2.64**	**7.97**	**136.16**	**144.13**	**2**	**396.6**	**398.6**	**1,680.14**

Notes:

A) All water units expressed as a million gallons per day (MGD).

B) The population figures cited herein are 1995 estimates for select watersheds only.
The overall population of the Lower Fox River and Green Bay system is 595,300.

C) 723.23 MGD of water used for Thermoelectric Power Generation in the Door-Kewaunee watershed is not included because this facility draws water from Lake Michigan.

Total per capita use values are the average value for the column.

GW - Indicates groundwater is source.

SW - Indicates surface water is source.

Table 3-7. Water Use in the Lower Fox River/Green Bay Watersheds (1995) (Continued)

Watershed Name	USGS Hydrologic Unit Code	State	Mining Water Use [A]			Livestock Water Use [A]				Irrigation Water Use [A]			
			GW	SW	Total	GW	SW	Total	Consumptive Use	GW	SW	Total	Consumptive Use
Lower Fox	4030204	WI	0	0	0	1.01	0.11	1.12	0.9	0.04	0	0.04	0.24
Duck-Pensaukee	4030103	WI	0	0	0	0	0	0	0	0	0	0	0
Oconto	4030104	WI	0	0	0	0.58	0.07	0.65	0.52	1.31	0	1.31	0.82
Peshtigo	4030105	WI	0	0	0	0.72	2.19	2.91	0.51	1.03	0	1.03	0.91
Menominee	4030108	WI/MI	0.01	0.11	0.12	0.33	0.03	0.36	0.29	0.91	0.04	0.95	1.32
Door-Kewaunee	4030102	WI	0	0	0	1.06	0.12	1.18	0.94	0.22	0	0.22	1.32
Cedar-Ford	4030109	MI	0.12	0.54	0.66	0.12	0.01	0.13	0.12	0.02	0.02	0.04	0.23
Escanaba	4030110	MI	1.27	5.01	6.28	0.02	0	0.02	0.02	0.01	0.01	0.02	0.12
Fishdam-Sturgeon	4030112	MI	0	0.08	0.08	0.03	0	0.03	0.03	0.02	0.02	0.04	0.19
Totals			**1.40**	**5.74**	**7.14**	**3.87**	**2.53**	**6.40**	**3.33**	**3.56**	**0.09**	**3.65**	**5.15**

Notes:

A) All water units expressed as a million gallons per day (MGD).

B) The population figures cited herein are 1995 estimates for select watersheds only. The overall population of the Lower Fox River and Green Bay system is 595,300.

C) 723.23 MGD of water used for Thermoelectric Power Generation in the Door-Kewaunee watershed is not included because this facility draws water from Lake Michigan.

Total per capita use values are the average value for the column.

GW - Indicates groundwater is source.

SW - Indicates surface water is source.

Table 3-7. Water Use in the Lower Fox River/Green Bay Watersheds (1995) (Continued)

Watershed Name	USGS Hydrologic Unit Code	State	Hydroelectric Power Generation [A]			Total Water Use [A]			
			SW	Gigawatt Hours	# Of Facilities	GW	SW	Total	Consumptive Use
Lower Fox	4030204	WI	571.48	63.4	4	23.65	526.73	550.38	28.39
Duck-Pensaukee	4030103	WI	0	0	0	1.44	0	1.44	0.86
Oconto	4030104	WI	321.57	7.2	1	3.45	1.25	4.7	2.42
Peshtigo	4030105	WI	2261.92	67.7	7	5.1	9.43	14.53	2.34
Menominee	4030108	WI/MI	8120.08	403.94	14	8.02	12.41	20.43	4.66
Door-Kewaunee	4030102	WI	0	0	0	6.07	0.12	6.19	9.49
Cedar-Ford	4030109	MI	0	0	0	0.89	9.56	10.45	0.86
Escanaba	4030110	MI	192.22	3.07	1	2.47	11.07	13.54	1.07
Fishdam-Sturgeon	4030112	MI	0	0	0	0.33	3.57	3.9	0.41
Totals			**11,467.27**	**545.31**	**27.00**	**51.42**	**574.14**	**625.56**	**50.50**

Notes:
A) All water units expressed as a million gallons per day (MGD).
B) The population figures cited herein are 1995 estimates for select watersheds only.
The overall population of the Lower Fox River and Green Bay system is 595,300.
C) 723.23 MGD of water used for Thermoelectric Power Generation in the Door-Kewaunee watershed is not included because this facility draws water from Lake Michigan.
Total per capita use values are the average value for the column.
GW - Indicates groundwater is source.
SW - Indicates surface water is source.

Table 3-8. Lower Fox River Gradient and Lock/Dam Information

Lock	Lock Water Elevation		Dam	Dam Water Elevation		Distance Upstream		Gradient**
	(meters*)	(feet*)		(meters*)	(feet*)	Km	Miles	
Lake Winnebago	227.32	745.80		227.32	745.80	62.8	39.0	---
Menasha	227.32	745.80	Menasha Dam	227.32	745.80	59.5	37.0	0.0E+00
Appleton Lock 1	224.36	736.10	Appleton Upper Dam	224.36	736.10	51.3	31.9	3.6E-04
Appleton Lock 2	221.92	728.10				50.9	31.6	
Appleton Lock 3	218.48	716.80				50.4	31.3	
Appleton Lock 4	215.49	707.00	Appleton Lower Dam	215.49	707.00	49.4	30.7	4.6E-03
Cedars Lock	213.18	699.40	Cedars Dam	213.18	699.40	43.9	27.3	4.2E-04
Little Chute Guard Lock	210.19	689.60	Little Chute Dam	210.19	689.60	42.8	26.6	2.7E-03
Little Chute Lock 2	210.19	689.60				42.5	26.4	
Upper Combined Lock	206.04	676.00				40.9	25.4	
Lower Combined Lock	202.81	665.40				40.9	25.4	
Kaukauna Guard Lock	199.19	653.50	Kaukauna Dam	199.19	653.50	38.6	24.0	2.6E-03
Kaukauna Lock 1	199.19	653.50				38.0	23.6	
Kaukauna Lock 2	196.05	643.20				37.7	23.4	
Kaukauna Lock 3	193.12	633.60				37.3	23.2	
Kaukauna Lock 4	190.01	623.40				37.2	23.1	
Kaukauna Lock 5	186.90	613.20				36.7	22.8	
Rapide Croche Lock	183.73	602.80	Rapide Croche	183.73	602.80	30.9	19.2	2.0E-03
Little Rapids Lock	180.90	593.50	Little Rapids Dam	180.90	593.50	21.1	13.1	2.9E-04
De Pere Lock	179.04	587.40	De Pere Dam	179.04	587.40	11.4	7.1	1.9E-04
Green Bay (River Mouth)	176.02	577.50	Green Bay (River Mouth)	176.02	577.50	0.0	0.0	2.6E-04
Entire River	---	---	---	---	---	---	---	**8.2E-04**

Notes: Information obtained from the USACE and from the NOAA Recreational Atlas 14916 (1992).

* IGLD - International Great Lakes Datum, 1985

** Gradient values from upstream dam to this dam

Table 3-9. Lower Fox River Discharge Results
Rapide Croche Gauging Station

Summary of Flow Conditions for Water Years 1918 to 1997	Discharge (m^3/s)	Discharge (cfs)	Date	
Daily Average	122	4,314	--	
Highest Daily Mean	680	24,000	04/18/52	
Lowest Daily Mean	4	138	08/02/36	
Monthly Mean Max.	206	7,286	April	
Monthly Mean Min.	74	2,609	August	
Monthly Discharge Results				
Month	**Average** (m^3/s)	**Average** (cfs)	**Minimum** (m^3/s)	**Maximum** (m^3/s)
January	116	4,082	31	269
February	117	4,126	30	340
March	146	5,156	25	603
April	206	7,286	22	680
May	171	6,048	23	669
June	137	4,821	17	603
July	96	3,372	18	530
August	74	2,609	4	419
September	81	2,872	8	510
October	94	3,315	6	516
November	116	4,084	15	445
December	115	4,043	32	363

Note: A Water Year runs from October 1 through September 30.

Table 3-10. Lower Fox River Stream Velocity Estimates

Model Segments	Deposits Within Lower # Segment	Cross Sectional Area (m^2)	Flow Velocities (m/s)				
			Average Flow ($122m^3/s$)	10 Year Peak ($544m^3/s$)	10 Year Low ($27m^3/s$)	100 Year Peak ($680m^3/s$)	100 Year Low ($4m^3/s$)
Little Lake Butte des Morts Reach							
2/3	A	634.8	0.19	0.86	0.04	1.07	0.006
3/4	B	802.7	0.15	0.68	0.03	0.85	0.005
4/6	C,POG	1,371.5	0.09	0.40	0.02	0.50	0.003
6/7	D,E	1,549.4	0.08	0.35	0.02	0.44	0.003
7/8	D,E	1,495.5	0.08	0.36	0.02	0.45	0.003
8/9	E,F	1,225.6	0.10	0.44	0.02	0.55	0.003
9/10	E	616.8	0.20	0.88	0.04	1.10	0.006
10/11	G,H	348.9	0.35	1.56	0.08	1.95	0.011
Reach Average			**0.15**	**0.69**	**0.03**	**0.86**	**0.005**
Appleton to Little Rapids Reach							
11/12	I,J,K	405.9	0.30	1.34	0.07	1.67	0.010
12/14	L Through R	578.8	0.21	0.94	0.05	1.17	0.007
14/15	S	537.8	0.23	1.01	0.05	1.26	0.007
15/16	T,U	577.8	0.21	0.94	0.05	1.18	0.007
16/17	V,W,X	831.7	0.15	0.65	0.03	0.82	0.005
17/18	W,X,Y,Z	730.7	0.17	0.74	0.04	0.93	0.005
18/19	AA,BB,CC	456.8	0.27	1.19	0.06	1.49	0.009
19/20	--	324.9	0.37	1.67	0.08	2.09	0.012
20/21	--	424.8	0.29	1.28	0.06	1.60	0.009
21/22	DD	652.8	0.19	0.83	0.04	1.04	0.006
Reach Average			**0.24**	**1.06**	**0.05**	**1.33**	**0.008**
Little Rapids to De Pere Reach							
22/23	EE	947.7	0.13	0.57	0.03	0.72	0.004
23/24	EE	1,081.6	0.11	0.50	0.02	0.63	0.004
24/25	EE	1,016.6	0.12	0.53	0.03	0.67	0.004
25/26	EE	985.6	0.12	0.55	0.03	0.69	0.004
26/27	EE through HH	988.6	0.12	0.55	0.03	0.69	0.004
Reach Average			**0.12**	**0.54**	**0.03**	**0.68**	**0.004**
De Pere to Green Bay Reach							
28/29	SMU 20-25	1,727.4	0.07	0.31	0.02	0.39	0.002
29/30	SMU 25-31	1,122.6	0.11	0.48	0.02	0.61	0.004
30/31	SMU 32-37	1,277.5	0.10	0.43	0.02	0.53	0.003
31/32	SMU 38-43	1,574.4	0.08	0.35	0.02	0.43	0.003
32/33	SMU 44-49	1,858.3	0.07	0.29	0.01	0.37	0.002
33/34	SMU 50-55	1,458.5	0.08	0.37	0.02	0.47	0.003
34/35	SMU 56-61	1,906.3	0.06	0.29	0.01	0.36	0.002
35/36	SMU 62-67	1,863.3	0.07	0.29	0.01	0.36	0.002
36/37	SMU 68-73	1,909.3	0.06	0.28	0.01	0.36	0.002
37/38	SMU 73-79	1,801.3	0.07	0.30	0.01	0.38	0.002
38/39	SMU 80-85	1,383.5	0.09	0.39	0.02	0.49	0.003
39/40	SMU 86-91	1,522.4	0.08	0.36	0.02	0.45	0.003
Reach Average			**0.08**	**0.35**	**0.02**	**0.43**	**0.003**
Entire River Averages			**0.14**	**0.61**	**0.03**	**0.77**	**0.004**

Note:
1) The average, peak, and low flow velocities listed are from USGS records for the Rapide Croche gauging station, #04084500.
2) Cross Sectional areas obtained from Velleux & Endicott, 1994 and WDNR, 1995.

Table 3-11. Fox River Mouth Gauging Station Results (1989-1999)

Summary of Flow Conditions	Discharge		Date
	m^3/s	cfs	
Water Year 1999			
Daily Average	106	3,753	---
Maximum Daily	326	11,500	July 23/24, 1999
Minimum Daily	-35	-1230	Aug. 25, 1999
Maximum Monthly Mean	175	6,176	July (1999)
Minimum Monthly Mean	36.6	1,294	October (1998)
Annual Runoff	20.45 cm	8.05 in.	---
Water Years 1989 through 1999			
Daily Average	141	4,999	---
Maximum Daily	957	33,800	Jun. 23, 1990
Minimum Daily	-92	-3,260	Nov. 4,1990
Maximum Monthly Mean	215	7,580	April
Minimum Monthly Mean	92.2	3,256	September
Annual Runoff	27.25 cm	10.73 in.	---
10% of Flow Exceeds	272	9610	---
50% of Flow Exceeds	114	4040	---
90% of Flow Exceeds	54	1920	---

Note: Data from USGS, 2000. Fox River at Oil Tank Depot, Green Bay, Wisconsin.
http://h20.usgs.gov/swr/WI/?statnum=040851385.

Table 3-12. Lower Fox River Total Suspended Solid (TSS) Loads

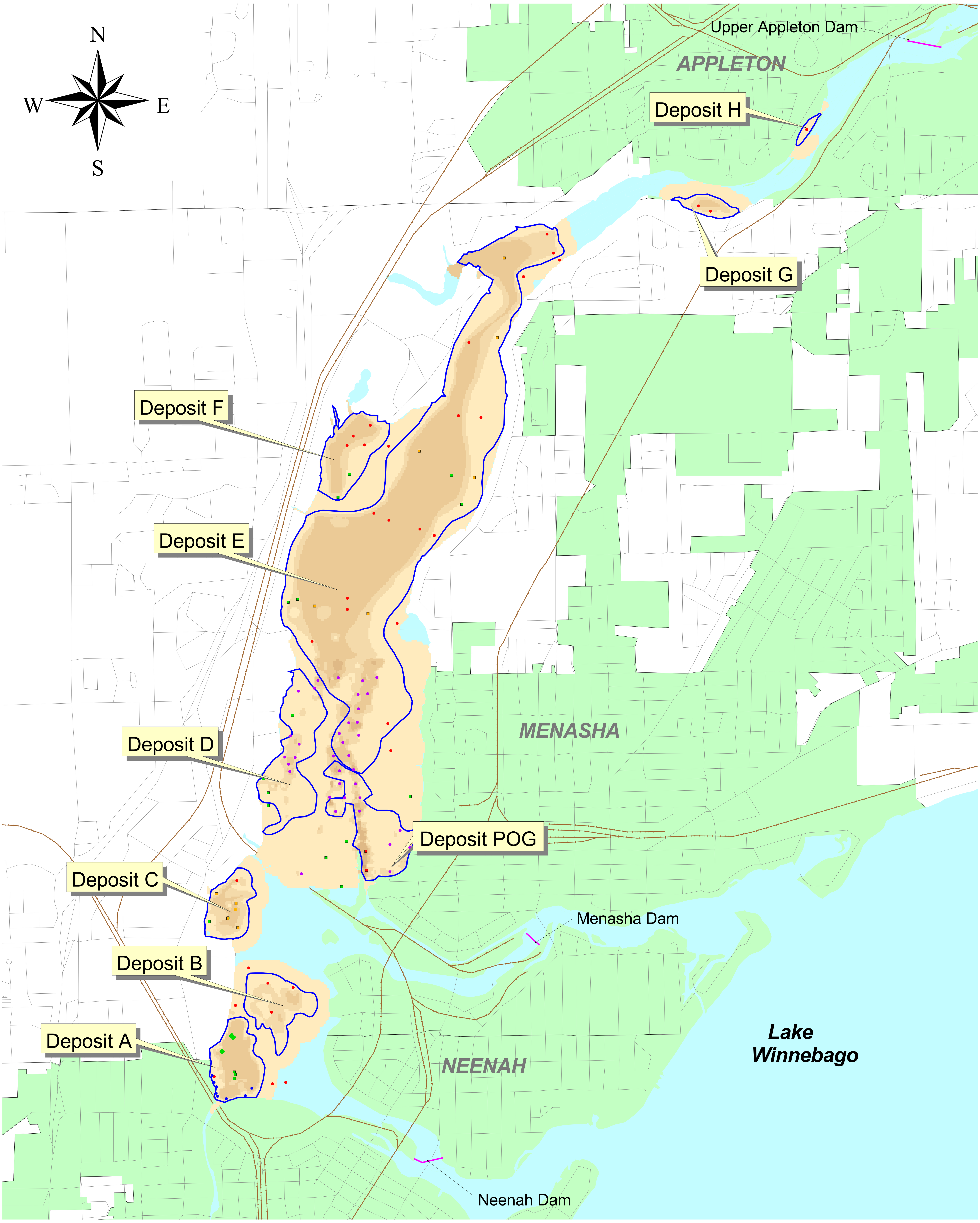
Sampling Point	River Discharge		Total Suspended Solids (TSS)		
	(m^3/s)	(cfs)	(mg/L)	(MT/year)	(Ton/year)
1995 - Mean Values from WDNR, 1995					
Menasha Gauge*	140	4,938	7.7	33,968	37,365
Neenah Gauge*	80	2,809	17	42,661	46,927
Appleton Gauge	93	3,279	23	67,375	74,113
Kaukauna Gauge*	85	3,009	26	69,892	76,881
Little Rapids Gauge**	87	3,058	52	142,060	156,266
De Pere Gauge	85	3,003	30	80,484	88,532
1998 - TSS Values from BBL, 1998 and Discharge Data from USGS, 2000					
De Pere Dam***	106	3,753	46.4	155,571	171,128
River Mouth	106	3,753	45.8	153,559	168,915

Notes: * the stream flow result for this station is actually the flow at the Appleton station.
** the stream flow result for this station is actually the flow at the De Pere station.
*** the stream flow result for this station is actually the average 1998 flow at the mouth.
MT = metric tons.

Table 3-13. USACE Navigation Channel Dredging Records (1957-1999)

Green Bay Dredging Totals and Disposal Locations								
Year	Open Water		Bay Port CDF		Kidney Island CDF		Total	
	m^3	(yd^3)	m^3	(yd^3)	m^3	(yd^3)	m^3	(yd^3)
1957	38,075	49,800	-	-	-	-	38,075	49,800
1958	120,987	158,245	-	-	-	-	120,987	158,245
1959	45,408	59,391	-	-	-	-	45,408	59,391
1960	27,401	35,839	-	-	-	-	27,401	35,839
1961	127,759	167,103	-	-	-	-	127,759	167,103
1962	13,903	18,185	-	-	-	-	13,903	18,185
1963	90,289	118,093	-	-	-	-	90,289	118,093
1964	137,767	180,192	-	-	-	-	137,767	180,192
1965	503,052	657,967	-	-	-	-	503,052	657,967
1966	-	-	115,456	151,011	-	-	115,456	151,011
1967	-	-	335,159	438,371	-	-	335,159	438,371
1968	-	-	57,800	75,600	-	-	57,800	75,600
1969	507,836	664,225	-	-	-	-	507,836	664,225
1970	1,083,137	1,416,690	-	-	-	-	1,083,137	1,416,690
1971	-	-	718,682	940,000	-	-	718,682	940,000
1972	-	-	917,466	1,200,000	-	-	917,466	1,200,000
1973	76,455	100,000	1,131,541	1,480,000	-	-	1,207,997	1,580,000
1974	43,580	57,000	1,021,417	1,335,963	-	-	1,064,997	1,392,963
1975	-	-	691,794	904,832	-	-	691,794	904,832
1976	-	-	-	-	-	-	-	-
1977	-	-	229,366	300,000	-	-	229,366	300,000
1978	-	-	260,288	340,444	-	-	260,288	340,444
1979	-	-	620,213	811,208	19,687	25,750	639,900	836,958
1980	-	-	-	-	-	-	-	-
1981	-	-	-	-	453,964	593,762	453,964	593,762
1982	-	-	-	-	296,214	387,433	296,214	387,433
1983	-	-	-	-	209,187	273,606	209,187	273,606
1984	-	-	-	-	141,150	184,617	141,150	184,617
1985	-	-	91,856	120,143	78,094	102,143	169,950	222,286
1986	-	-	-	-	51,026	66,740	51,026	66,740
1987	-	-	87,256	114,127	120,020	156,980	207,276	271,107
1988	-	-	127,672	166,989	-	-	127,672	166,989
1989	-	-	37,785	49,421	-	-	37,785	49,421
1990	-	-	35,485	46,413	123,208	161,150	158,693	207,563
1991	-	-	-	-	128,600	168,202	128,600	168,202
1992	-	-	111,615	145,987	125,448	164,080	237,063	310,067
1993	-	-	97,712	127,802	145,313	190,062	243,024	317,864
1994	-	-	111,292	145,564	-	-	111,292	145,564
1995	-	-	-	-	141,211	184,697	141,211	184,697
1996	-	-	53,914	70,517	53,914	70,517	107,828	141,034
1997	-	-	128,149	167,612	-	-	128,149	167,612
1998	-	-	178,647	233,661	-	-	178,647	233,661
1999	-	-	78,202	102,284	-	-	78,202	102,284
Totals	**2,815,649**	**3,682,730**	**7,238,767**	**9,467,949**	**2,087,035**	**2,729,739**	**12,141,451**	**15,880,418**

Lower Fox River Records	1965	8,463 m3	(11,069 yd^3)	Menasha Channel
	1968	1,437 m3	(1,880 yd^3)	Neenah Harbor
	Totals	**9,900 m3**	**(12,949 yd^3)**	



Sample Points

- 1989/90 Mass Balance Sediment Data
- 1992/93 LLBdM RI/FS Deposit A Sediment Data
- 1994 Woodward Clyde Deposit A Sediment Data
- 1994 SAIC and GAS Sediment Data
- 1995 WDNR Sediment Data
- 1996 BBL Sediment Data
- 1997 Segment 56/57 Demonstration
- 1998 BBL Sediment/Tissue Data
- 1998 Deposit N Post-Dredge Sediment Data
- 1998 RI/FS Supplemental Data

Soft Sediment Thickness (m)

- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5

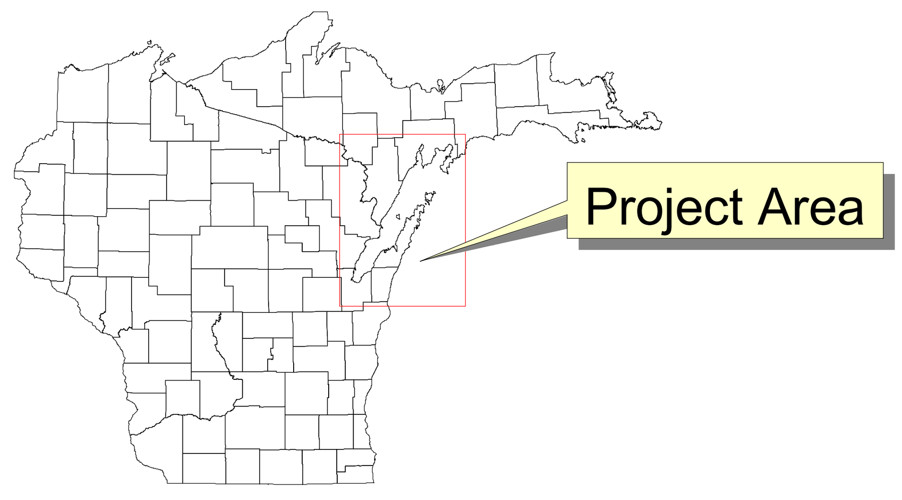
Deposits
Dam Locations
Railroads
Roads
Water

Civil Divisions

- City
- Township
- Village

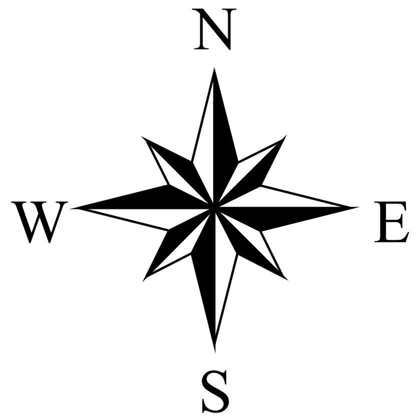
0.5 0 0.5 1 Kilometers

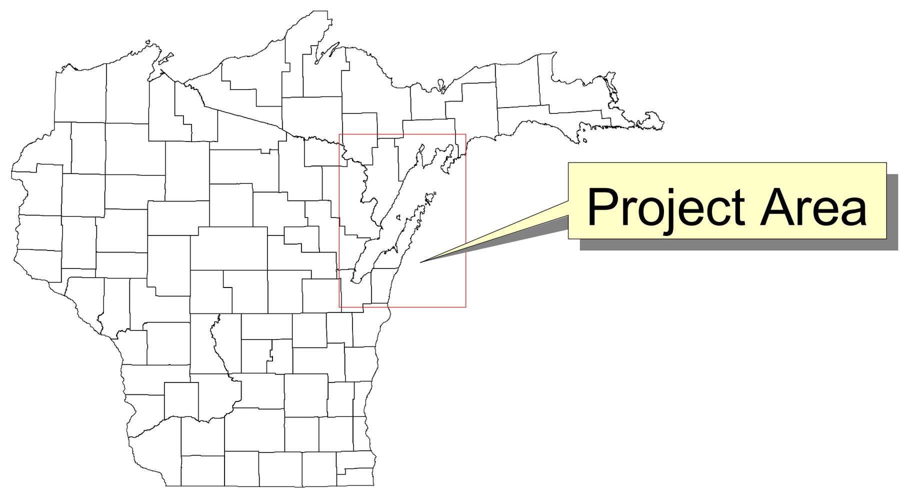
0.5 0 0.5 1 Miles

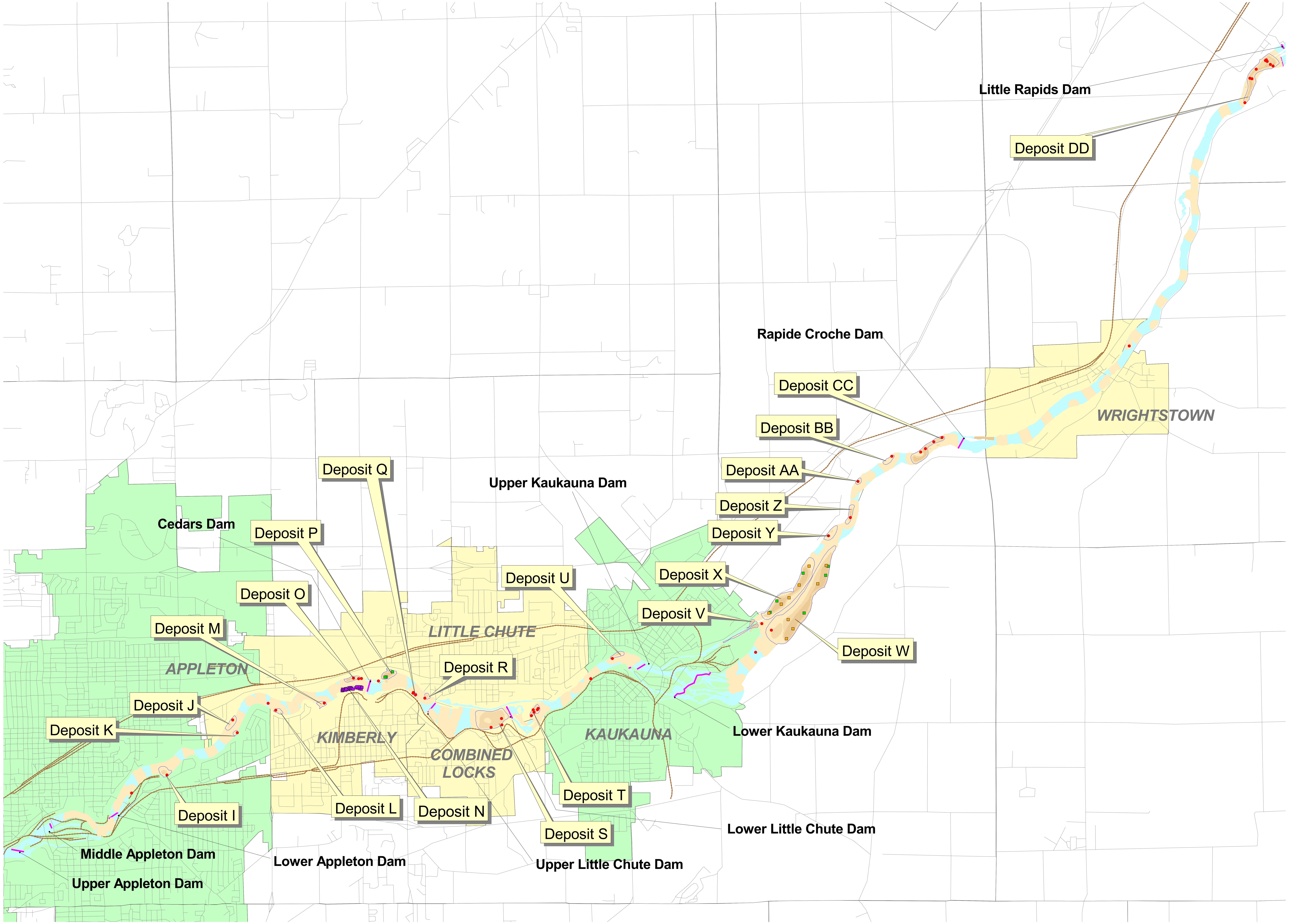


Notes:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, Version 3.2, WTM projection.
2. Blue areas within the river or bay implies areas with no soft sediment.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Lake Butte des Morts Reach	DRAWING NO: RI-14414-340-3-1
				PRINT DATE: 6/18/01
				CREATED BY: SCJ
			PLATE 3-1	APPROVED: AGF







Sample Points
- 1989/90 Mass Balance Sediment Data
- 1992/93 LLBdM RI/FS Deposit A Sediment Data
- 1994 Woodward Clyde Deposit A Sediment Data
- 1994 SAIC and GAS Sediment Data
- 1995 WDNR Sediment Data
- 1996 BBL Sediment Data
- 1997 Segment 56/57 Demonstration
- 1998 BBL Sediment/Tissue Data
- 1998 Deposit N Post-Dredge Sediment Data
- 1998 RI/FS Supplemental Data

Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5
- Deposits
- Dam Locations
- Railroads
- Roads
- Water

Civil Divisions
- City
- Township
- Village

2 0 2 Kilometers

1 0 1 2 Miles

Notes:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, Version 3.2, WTM projection.
2. Blue areas within the river or bay implies areas with no soft sediment.

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Remedial Investigation Report

Sample Locations and Interpolated Thickness of Sediment with PCBs: Appleton to Little Rapids Reach

PLATE 3-2

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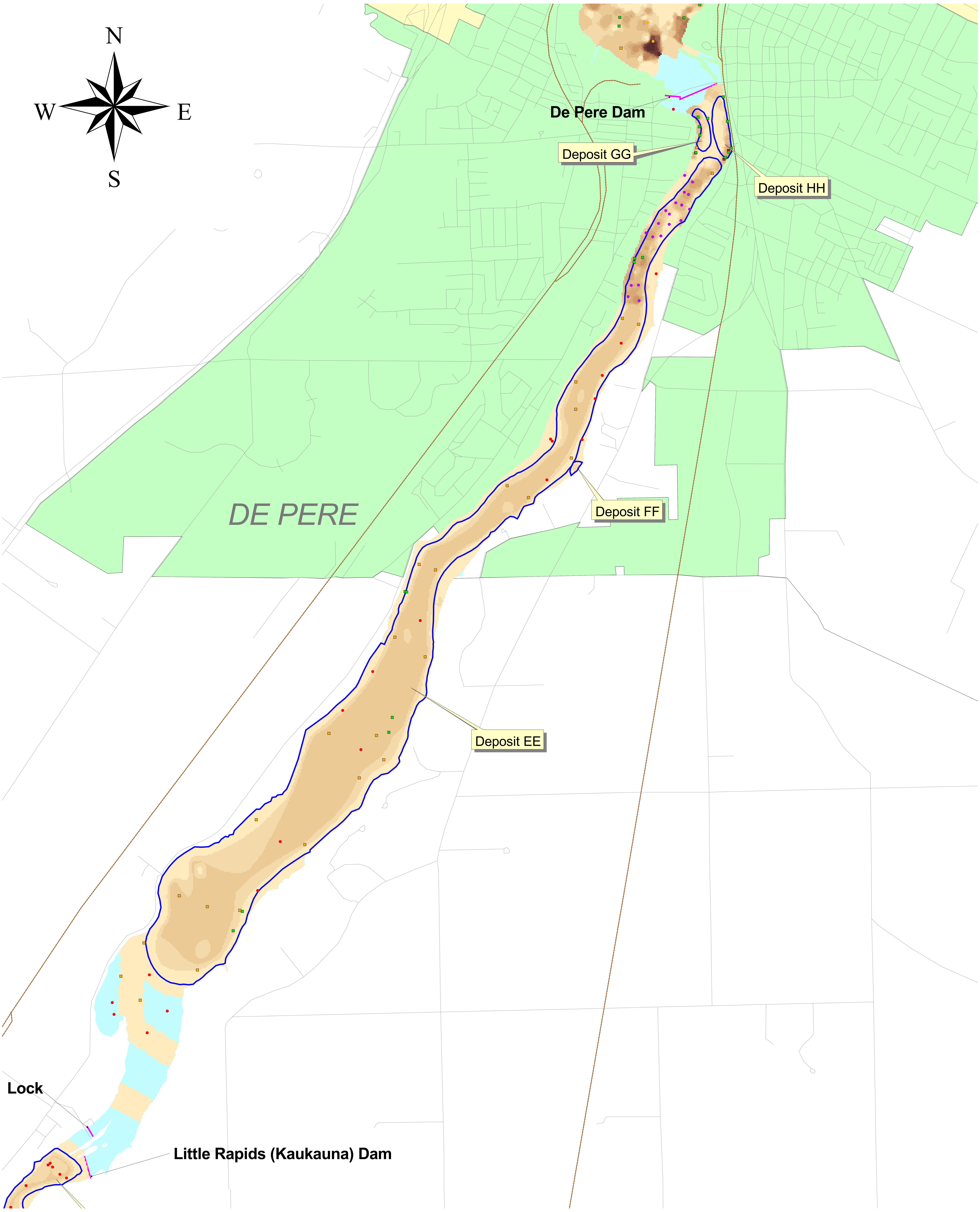
PRINT DATE: 6/18/01
CREATED BY: SCJ
APPROVED: AGF

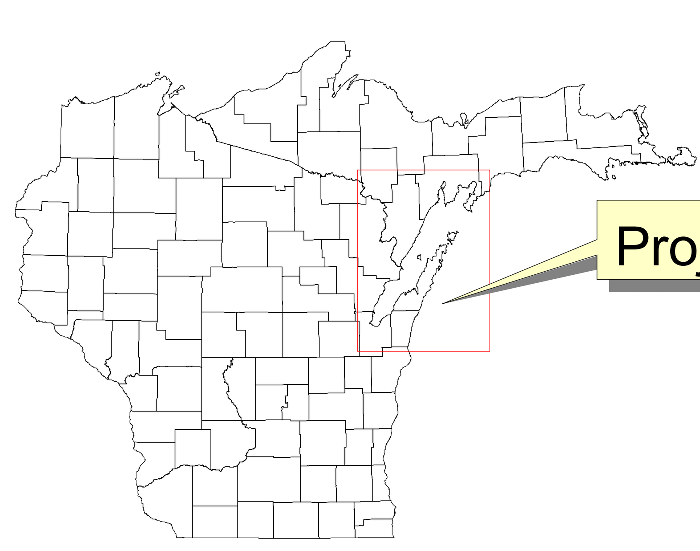


Sample Points
- 1989/90 Mass Balance Sediment Data
- 1992/93 LLBdM RI/FS Deposit A Sediment Data
- 1994 Woodward Clyde Deposit A Sediment Data
- 1994 SAIC and GAS Sediment Data
- 1995 WDNR Sediment Data
- 1996 BBL Sediment Data
- 1997 Segment 56/57 Demonstration
- 1998 BBL Sediment/Tissue Data
- 1998 Deposit N Post-Dredge Sediment Data
- 1998 RI/FS Supplemental Data

Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5
- 2.5-3
- 3-3.5
- 3.5-4
- 4-4.5
- 4.5-5
- 5-5.5
- 5.5-6

Deposits
Dam Locations
Railroads
Roads
Water

Civil Divisions
- City
- Township
- Village



0.5 0 0.5 1 Kilometers

0.5 0 0.5 1 Miles

Notes:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, Version 3.2, WTM projection.
2. Blue areas within the river or bay implies areas with no soft sediment.

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Lower Fox River & Green Bay Remedial Investigation Report

Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Rapids to De Pere Reach

PLATE 3-3

DRAWING NO:	RI-14414-340-3-3
PRINT DATE:	6/18/01
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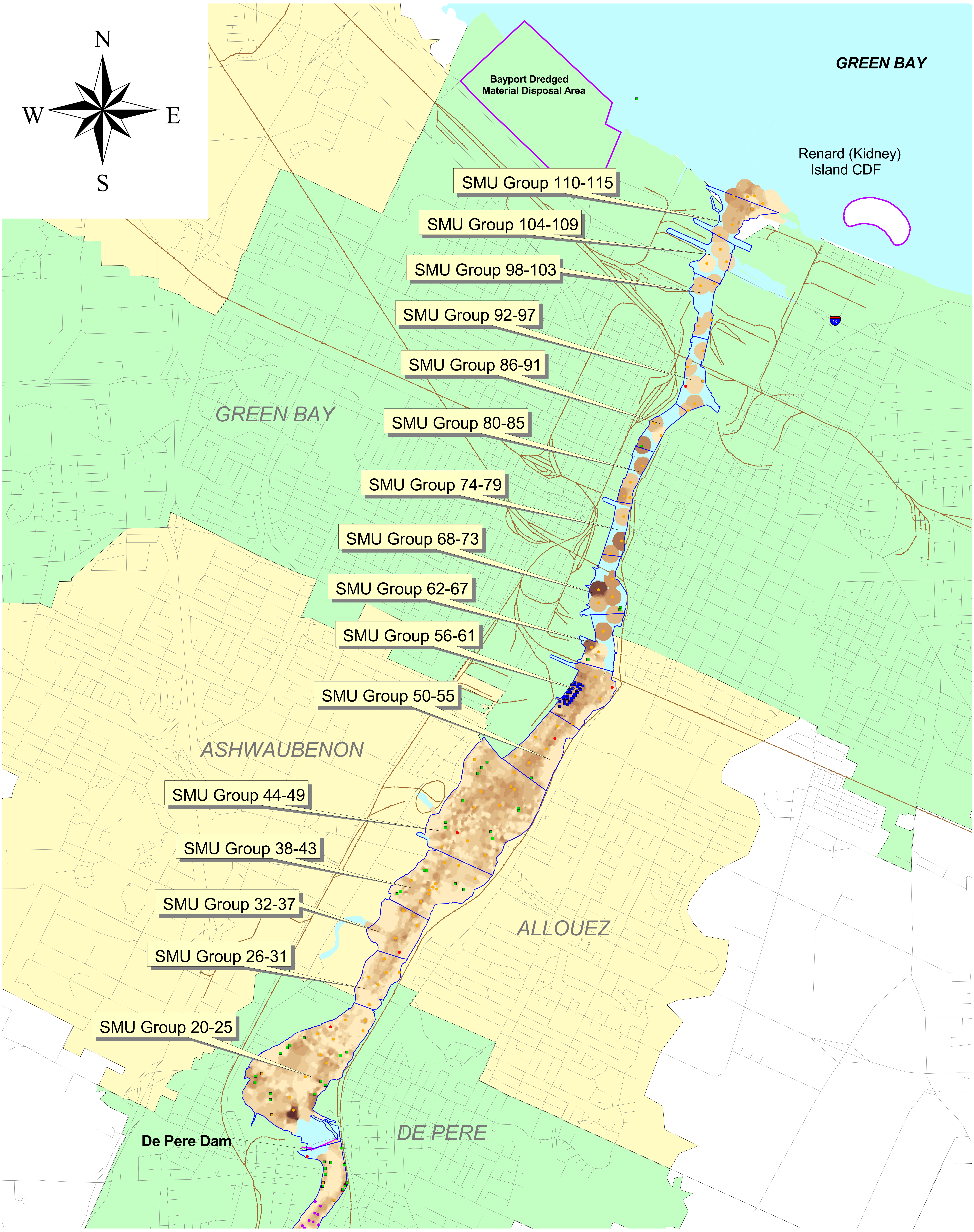
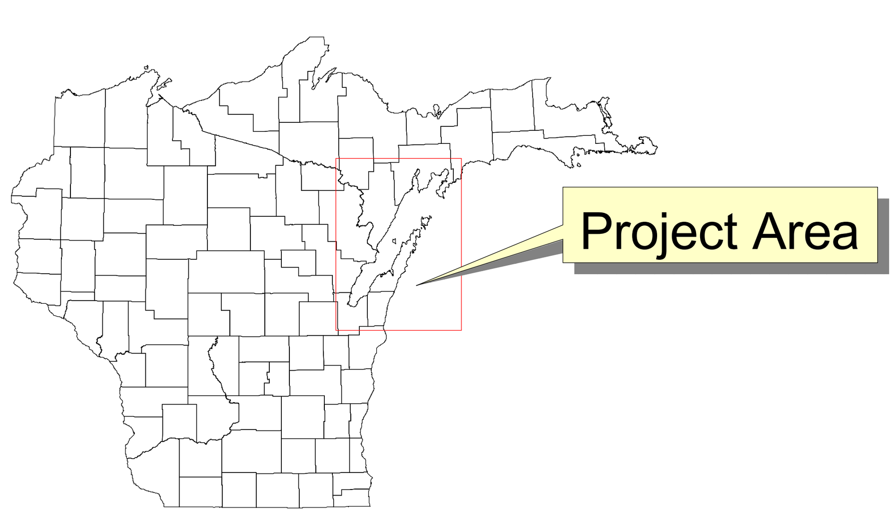


Sample Points
- 1989/90 Mass Balance Sediment Data
- 1992/93 LLBdM RI/FS Deposit A Sediment Data
- 1994 Woodward Clyde Deposit A Sediment Data
- 1994 SAIC and GAS Sediment Data
- 1995 WDNR Sediment Data
- 1996 BBL Sediment Data
- 1997 Segment 56/57 Demonstration
- 1998 BBL Sediment/Tissue Data
- 1998 Deposit N Post-Dredge Sediment Data
- 1998 RI/FS Supplemental Data

Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5
- 2.5-3
- 3-3.5
- 3.5-4
- 4-4.5
- 4.5-5
- 5-5.5
- 5.5-6

Sediment Management Units
Dam Locations
Railroads
Roads
Water

Civil Divisions
- City
- Township
- Village



1 0 1 Kilometers

0.5 0 0.5 1 Miles

Notes:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, Version 3.2, WTM projection.
2. Blue areas within the river or bay implies areas with no soft sediment.

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Lower Fox River & Green Bay Remedial Investigation Report

Sample Locations and Interpolated Thickness of Sediment with PCBs: De Pere to Green Bay Reach

PLATE 3-4

DRAWING NO:	RI-14414-340-3-4
PRINT DATE:	6/18/01
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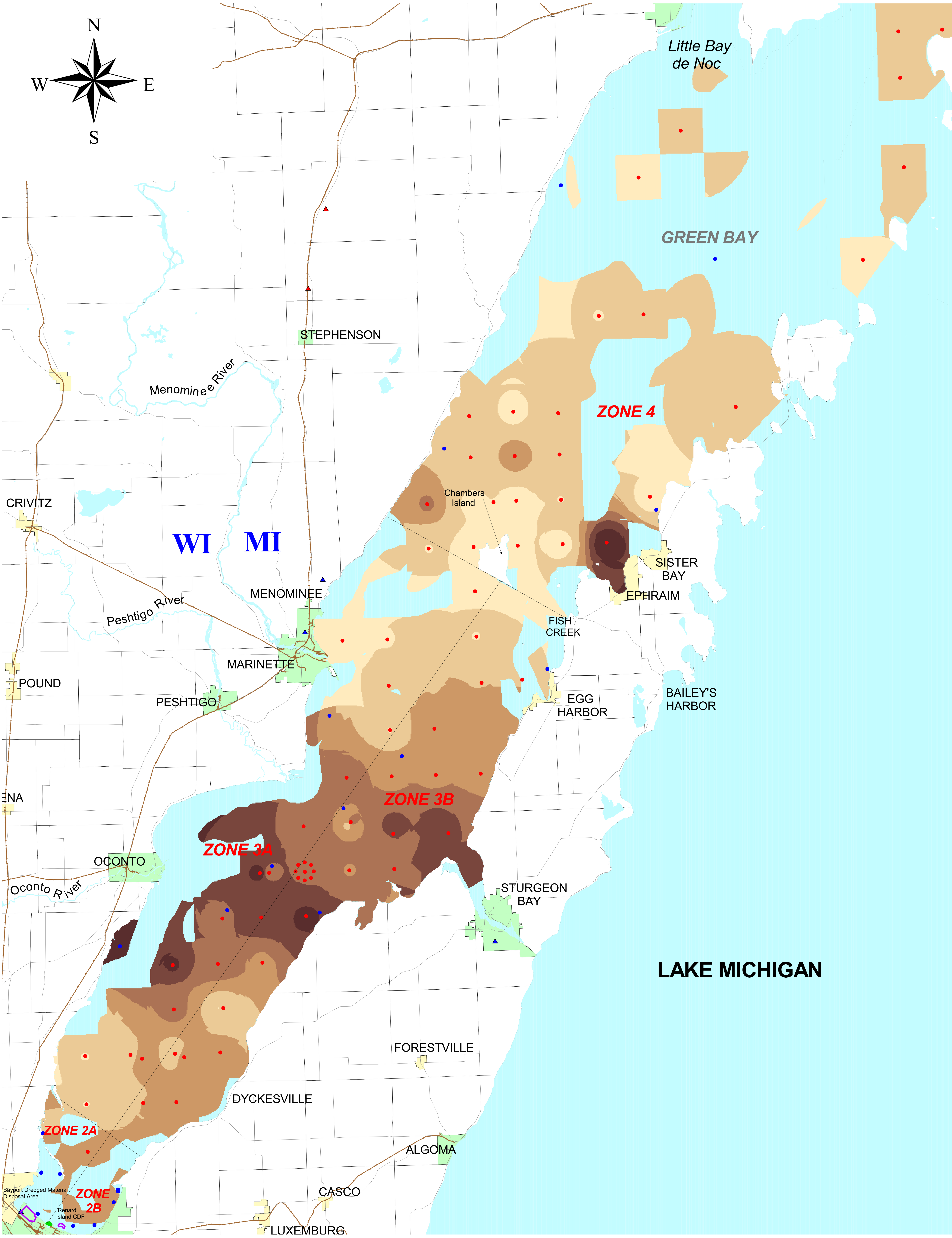
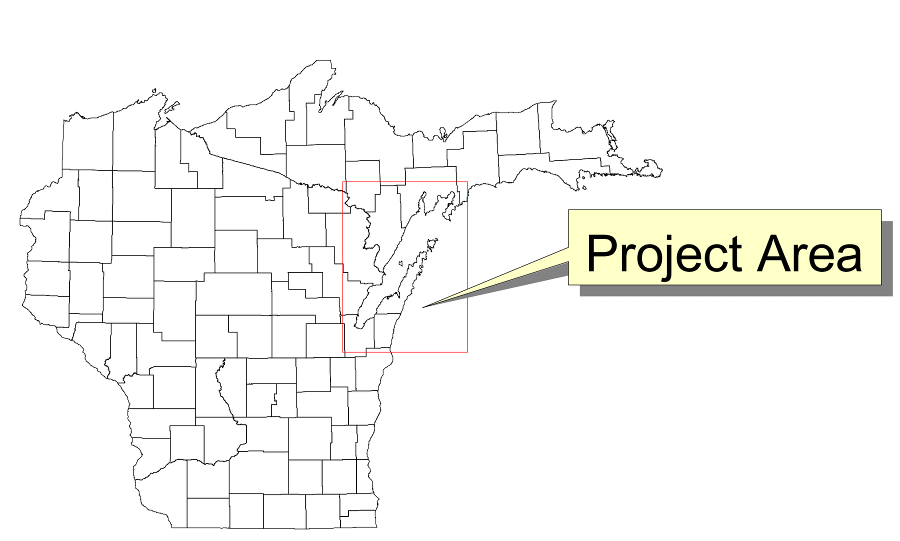


Sample Points
- 1989/90 Green Bay Mass Balance Study (GLNPO)
- 1995 WDNR Sediment Data
- 1998 BBL Sediment/Tissue Data

Environmental Data
- Closed Dump
- Landfill

Soft Sediment Thickness (cm)
- 0-5
- 5-10
- 10-15
- 15-20
- 20-25
- 25-30
- Railroads
- Roads
- Water

Civil Divisions
- City
- Township
- Village



5 0 5 10 15 Kilometers

5 0 5 10 Miles

Notes:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, Version 3.2, WTM projection.
2. Blue areas within the river or bay implies areas with no soft sediment.

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