Remedial Investigation Report

Lower Fox River and Green Bay, Wisconsin

Prepared for:

Wisconsin Dept. of Natural Resources

Prepared by: The RETEC Group, Inc.
Natural Resource Technology, Inc.

December 2002

RETEC

N R T

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Lower Fox River and Green Bay, Wisconsin

Prepared by:

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RETEC Project No.: WISCN-14414-345

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Prepared for:

Wisconsin Department of Natural Resources
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Table of Contents

Executive Summary xix

1 Introduction 1-1
- 1.1 Project Overview and Objectives 1-1
- 1.2 Study Area Overview 1-2
  - 1.2.1 Lower Fox River 1-2
  - 1.2.2 Green Bay 1-3
- 1.3 Study Area River Reaches and Bay Zones 1-6
  - 1.3.1 Lower Fox River Reaches 1-6
  - 1.3.2 Green Bay 1-7
    - 1.3.2.1 Green Bay Zones 1-7
    - 1.3.2.2 Inner and Outer Bays 1-8
    - 1.3.2.3 Lower Green Bay 1-8
- 1.4 Background 1-8
  - 1.4.1 Site History 1-8
  - 1.4.2 Historical PCB Use and Discharges 1-12
  - 1.4.3 Regulatory Response 1-14
    - 1.4.3.1 Clean Water Act 1-14
    - 1.4.3.2 Wisconsin Pollution Discharge Elimination System 1-14
    - 1.4.3.3 Great Lakes Areas of Concern 1-14
- 1.5 Application of NRC Findings and Recommendations 1-15
- 1.6 Section 1 Figures 1-17

2 Database and Investigation Summaries 2-1
- 2.1 Data Quality Evaluation 2-2
- 2.2 Sediment Investigations Included in the FRDB 2-3
  - 2.2.1 1989-1990 Fox River Mass Balance Study Data and 1989-1990 Green Bay Mass Balance Study Data 2-3
  - 2.2.2 1994 Woodward-Clyde Deposit A Sediment Data 2-6
  - 2.2.3 1992/93 BBL Deposit A Sediment Data 2-6
  - 2.2.4 1993 Triad Assessment 2-7
  - 2.2.5 1994 GAS/SAIC Sediment Data 2-8
  - 2.2.6 1995 WDNR Sediment Data 2-8
  - 2.2.7 1996 FRG/BBL Sediment/Tissue Data 2-9
  - 2.2.8 Sediment Remediation Demonstration Projects Data . 2-9
    - 2.2.8.1 Deposit N Demonstration Project 2-11
    - 2.2.8.2 SMU 56/57 Demonstration Project 2-12
  - 2.2.9 1998 FRG/Exponent Data and 1998 FRG/BBL Sediment/Tissue Data 2-15

Table of Contents

2.2.10 1998 RETEC RI/FS Supplemental Data 2-15
2.2.11 Lake Michigan Mass Balance Data 2-17
2.2.12 Fox River Fish Consumption Advisory Data 2-17
2.2.13 USGS National Water Quality Assessment Program (NAWQA) Data 2-17
2.2.14 1997 WDNR Caged Fish Bioaccumulation Study Data 2-17
2.2.15 Minergy Mineralogical Data 2-17
2.3 Ecological Sampling Studies 2-18
2.4 Section 2 Tables 2-19

3 Physical Characteristics 3-1
3.1 Land Use 3-1
3.1.1 Historical Land Use 3-1
3.1.2 Current Land Uses 3-3
3.2 Meteorology 3-5
3.3 Geologic Characteristics 3-6
3.3.1 Regional Geologic Setting 3-7
3.3.1.1 Bedrock Geology 3-7
3.3.1.2 Glacial Geology 3-8
3.3.2 Regional Soils 3-9
3.3.3 Hydrogeology 3-11
3.3.3.1 Regional Hydrogeology 3-11
3.3.3.2 Water Use (1995) 3-15
3.4 Lower Fox River Surface Water Hydrology 3-17
3.4.1 Surface Water Flow Controls 3-17
3.4.1.1 Dams in Wisconsin and on the Lower Fox River 3-17
3.4.1.2 Lower Fox River Dams and Navigational Controls 3-23
3.4.1.3 Neenah-Menasha (Lake Winnebago) 3-24
3.4.2 Lower Fox River Surface Elevation 3-25
3.4.3 Low-Flow and Flood Frequencies 3-26
3.4.4 Measured and Estimated Stream Flow Velocities 3-27
3.4.5 Lower Fox River Bathymetry 3-29
3.4.5.1 LLBdM Reach 3-29
3.4.5.2 Appleton to Little Rapids Reach 3-29
3.4.5.3 Little Rapids to De Pere Reach 3-29
3.4.5.4 De Pere to Green Bay Reach 3-30

Table of Contents

3.5 Green Bay Surface Water Hydrology 3-30
3.5.1 Green Bay Water Level Elevations 3-30
3.5.2 Green Bay Water Circulation, Currents, and Mixing Patterns 3-31
3.5.2.1 Lower Fox River Discharge into Green Bay . . . 3-33
3.5.2.2 Fox River Plume Studies 3-34
3.5.2.3 Inner Bay/Outer Bay Mixing Studies 3-36
3.5.2.4 Green Bay/Lake Michigan Mixing Studies 3-38
3.5.3 Green Bay Bathymetry 3-39
3.5.3.1 Zone 2 Bathymetry 3-41
3.5.3.2 Zone 3 Bathymetry 3-42
3.5.3.3 Zone 4 Bathymetry 3-43
3.5.4 Green Bay Ice Cover 3-45
3.6 Sediment Characteristics 3-46
3.6.1 Sediment Deposition 3-46
3.6.1.1 Lower Fox River Sediment Transport and Deposition 3-46
3.6.1.2 Green Bay Sediment Transport and Deposition 3-49
3.6.1.3 River and Bay Sediment Dredging 3-51
3.6.2 Sediment Grain Size/Lithology 3-52
3.6.3 Estimated Sediment Thickness and Areal Extent 3-53
3.6.3.1 LLBdM Reach 3-55
3.6.3.2 Appleton to Little Rapids Reach 3-55
3.6.3.3 Little Rapids to De Pere Reach 3-55
3.6.3.4 De Pere to Green Bay Reach 3-56
3.6.3.5 Green Bay (Zones 2 through 4) 3-56
3.6.4 Total Organic Carbon 3-56
3.6.5 Other Physical Parameters 3-57
3.7 Section 3 Figures, Tables, and Plates 3-58

4 Ecological Characteristics 4-1
4.1 Overview 4-1
4.1.1 Habitats 4-2
4.1.2 Wildlife Groups 4-3
4.2 Wildlife Habitat 4-5
4.2.1 Open Lands 4-5
4.2.2 Woodlands 4-6
4.2.3 Wetlands 4-8

Table of Contents

4.2.3.1 Wetland Areas and Types 4-8
4.2.3.2 Wetland Losses 4-14
4.2.3.3 Proposed Wetland Restoration Projects 4-18
4.2.4 Riverine Habitat of the Lower Fox River 4-20
4.2.5 Lacustrine Habitat of Green Bay 4-22
4.2.5.1 Overview 4-22
4.2.5.2 Inner Bay Water Quality 4-23
4.2.5.3 Outer Bay Water Quality 4-24
4.3 Benthic Communities 4-25
4.4 Fish 4-27
4.4.1 LLBdM to De Pere Dam Fish Surveys 4-27
4.4.2 De Pere to Green Bay/Duck Creek Fish Surveys 4-28
4.4.3 Green Bay Fishery Observations and Habitat 4-30
4.4.4 Life Histories of Fish Species in the Lower Fox River and Green Bay 4-35
4.4.4.1 Shiners (Minnows) 4-35
4.4.4.2 Gizzard Shad 4-36
4.4.4.3 Rainbow Smelt 4-37
4.4.4.4 Alewife 4-39
4.4.4.5 Yellow Perch 4-41
4.4.4.6 Carp 4-43
4.4.4.7 Walleye 4-45
4.4.4.8 Brown Trout 4-46
4.4.4.9 Sturgeon 4-48
4.5 Birds 4-49
4.5.1 Passerine Birds 4-50
4.5.2 Gulls/Terns 4-51
4.5.3 Diving Birds 4-53
4.5.4 Shorebirds 4-54
4.5.5 Wading Birds 4-55
4.5.6 Waterfowl 4-56
4.5.7 Raptors 4-57
4.6 Mammals 4-59
4.6.1 Mink 4-60
4.6.1.1 Mink Habitat 4-60
4.6.1.2 Domestic Mink Production in Wisconsin 4-61
4.6.1.3 Wild Mink in the Study Area 4-62
4.6.2 Otter 4-62

Table of Contents

4.7 Endangered and Threatened Species 4-63
4.8 Section 4 Figures and Tables 4-64

5 Nature and Extent of Detected Chemicals 5-1
5.1 Detected Compound Sources 5-1
5.1.1 Point Sources 5-1
5.1.1.1 Industrial/Municipal Discharges 5-1
5.1.1.2 Landfills 5-5
5.1.1.3 Spills 5-6
5.1.2 Non-Point Sources 5-7
5.1.2.1 River and Bay Sediments 5-8
5.1.2.2 Stormwater Runoff 5-9
5.1.2.3 Atmospheric Deposition and Volatilization . . . 5-11
5.2 Summary of Detected Chemicals 5-12
5.2.1 Overview 5-12
5.2.2 PCBs 5-14
5.2.3 Dioxin/Furan 5-18
5.2.4 Pesticides 5-19
5.2.5 Inorganic Compounds 5-19
5.2.6 TCLP Results 5-22
5.2.7 Semi-Volatile Organic Compounds (SVOCs) 5-22
5.3 Lake Winnebago (Background) Results 5-23
5.4 Chemical Distribution in Sediments 5-24
5.4.1 Overview 5-24
5.4.2 PCB Distribution 5-25
5.4.2.1 Bed Maps and Sediment Data Interpolation Methods 5-25
5.4.2.2 Lower Fox River and Green Bay PCB Results . . 5-31
5.4.2.3 LLBdM Reach PCB Results 5-32
5.4.2.4 Appleton to Little Rapids Reach PCB Results . 5-36
5.4.2.5 Little Rapids to De Pere Reach PCB Results . . 5-40
5.4.2.6 De Pere to Green Bay Reach PCB Results 5-42
5.4.2.7 Green Bay Zone 2 PCB Results 5-46
5.4.2.8 Green Bay Zone 3 PCB Results 5-48
5.4.2.9 Green Bay Zone 4 PCB Results 5-50
5.4.2.10 General PCB Homolog Distribution 5-52
5.4.3 Dioxin/Furans 5-55
5.4.4 Pesticides 5-56

Table of Contents

5.4.4.1 LLBdM Reach Results 5-56
5.4.4.2 Appleton to Little Rapids Reach Results 5-57
5.4.4.3 Little Rapids to De Pere Reach Results 5-57
5.4.4.4 De Pere to Green Bay Reach Results 5-57
5.4.5 Inorganic Compounds 5-58
5.4.5.1 Mercury 5-58
5.4.5.2 Lead 5-59
5.4.5.3 Arsenic 5-61
5.4.6 Other Organic Compounds 5-62
5.4.6.1 LLBdM Reach SVOC Results 5-62
5.4.6.2 Appleton to Little Rapids Reach SVOC Results 5-63
5.4.6.3 Little Rapids to De Pere Reach SVOC Results . 5-63
5.4.6.4 De Pere to Green Bay Reach SVOC Results . . . 5-64
5.4.6.5 Green Bay SVOC Results 5-64
5.4.7 Other Inorganic Compounds 5-64
5.4.7.1 Cadmium/Chromium 5-64
5.4.7.2 Ammonia 5-65
5.5 Surface Water Sampling Results 5-65
5.5.1 Overview 5-65
5.5.2 PCB Distribution 5-66
5.5.2.1 Distribution in the Lower Fox River 5-67
5.5.2.2 PCB Distribution in Green Bay 5-69
5.5.2.3 PCB Distribution in Lake Michigan 5-69
5.5.3 Mercury Distribution 5-70
5.5.4 Pesticide Distribution 5-70
5.6 Chemical Loading to Green Bay 5-71
5.6.1 PCB Loading to Green Bay 5-71
5.6.2 Mercury and DDT Loading to Green Bay 5-71
5.7 Summary of PCBs in Biota 5-72
5.8 Time Trends of Contaminants in Sediment and Fish 5-72
5.8.1 Sediment Methods 5-72
5.8.2 Fish Methods 5-74
5.8.3 Results 5-75
5.8.3.1 Little Lake Butte des Morts 5-76
5.8.3.2 Appleton to Little Rapids 5-78
5.8.3.3 Little Rapids to De Pere 5-78
5.8.3.4 De Pere to Green Bay (Zone 1) 5-79
5.8.3.5 Green Bay Zone 2 5-80

Table of Contents

5.8.4 Conclusion . . . 5-80
5.9 Section 5 Figures, Tables, and Plates . . . 5-82

6 Chemical Transport and Fate . . . 6-1
6.1 Introduction . . . 6-1
6.2 Transport and Fate Processes . . . 6-1
6.2.1 Chemical Transport Interactions . . . 6-1
6.2.2 Physical Transport . . . 6-3
6.2.3 Biological Interactions . . . 6-4
6.3 Compounds of Potential Concern . . . 6-5
6.3.1 Organic Constituents . . . 6-5
6.3.1.1 PCBs . . . 6-5
6.3.1.2 Dioxins and Furans . . . 6-6
6.3.1.3 DDT . . . 6-7
6.3.1.4 Dieldrin . . . 6-8
6.3.2 Inorganic Constituents . . . 6-9
6.3.2.1 Mercury . . . 6-9
6.3.2.2 Lead . . . 6-10
6.3.2.3 Arsenic . . . 6-11
6.4 Lower Fox River/Green Bay Modeling . . . 6-12
6.4.1 GBTOXe Model . . . 6-12
6.4.2 GBFood Model . . . 6-12
6.4.3 Fox River Food (FRFood) Model . . . 6-13
6.4.4 Whole Lower Fox River Model . . . 6-14
6.5 Section 6 Tables . . . 6-15

7 Summary of Findings . . . 7-1
7.1 Introduction . . . 7-1
7.2 Physical and Ecological Characteristics . . . 7-2
7.3 Nature and Extent of Sediment Impacts . . . 7-4
7.3.1 Overview . . . 7-4
7.3.2 Lower Fox River PCB Impacts . . . 7-6
7.3.2.1 Overview . . . 7-6
7.3.2.2 Little Lake Butte des Morts Reach . . . 7-6
7.3.2.3 Appleton to Little Rapids Reach . . . 7-7
7.3.2.4 Little Rapids to De Pere Reach . . . 7-8
7.3.2.5 De Pere to Green Bay Reach . . . 7-8
7.3.3 Green Bay PCB Impacts . . . 7-9

Table of Contents

7.3.3.1 Overview 7-9
7.3.3.2 Green Bay Zone 2 7-10
7.3.3.3 Green Bay Zone 3 7-11
7.3.3.4 Green Bay Zone 4 7-12
7.3.4 Other Chemical Compounds 7-12
7.4 Chemical Transport and Fate 7-15
7.5 Investigative Assumptions/Uncertainties 7-16

8 References 8-1

Table of Contents

Appendix A	Data Management Summary Report (EcoChem, 2000) Addendum 1 to the Data Management Summary Report (EcoChem, 2002)
Appendix B	Time Trends Analysis (Mountain-Whisper-Light, 2001)
Appendix C	A Windrose diagram, developed from the National Oceanic and Atmospheric Administration
Appendix D	Stratigraphic cross-sections and other pertinent information concerning the regional geology of the area (Krohelski and Brown, 1986).
Appendix E	Bathymetry information available from the NOAA recreational charts for Lake Winnebago and the Lower Fox River (NOAA, 1992)
Appendix F	The USGS hydrographs for two storm events in November 1998
Appendix G	Physical parameters tables
Appendix H	PCB Congeners and Homolog Group List (ATSDR, 1997a)
Appendix I	PCB congener results for each reach and zone

List of Figures

Figure 1-1 Lower Fox River Study Area
Figure 1-2 Green Bay Study Area
Figure 1-3 Little Lake Butte des Morts Reach
Figure 1-4 Appleton to Little Rapids Reach
Figure 1-5 Little Rapids to De Pere Reach
Figure 1-6 De Pere to Green Bay Reach
Figure 3-1 Lower Fox River Elevation Profile
Figure 3-2 Green Bay Monthly Mean Surface Circulation - August 1989
Figure 3-3 Green Bay Monthly Bottom Surface Circulation - August 1989
Figure 3-4 Green Bay Zone 2 Bathymetry
Figure 3-5 Green Bay Zone 3 Bathymetry
Figure 3-6 Green Bay Zone 4 Bathymetry
Figure 3-7 Estimated Annual Sediment Transport Rates and Stream Flow Velocities
Figure 4-1 Lower Fox River Wetland, Habitat, and Animal Distribution: Little Lake Butte des Morts Reach
Figure 4-2 Lower Fox River Wetland, Habitat, and Animal Distribution: Appleton to Little Rapids Reach
Figure 4-3 Lower Fox River Wetland, Habitat, and Animal Distribution: Little Rapids to De Pere Reach
Figure 4-4 Lower Fox River Wetland, Habitat, and Animal Distribution: De Pere to Green Bay Reach
Figure 4-5 Wetland Distribution: Green Bay Zones 2 and 3
Figure 4-6 Wetland Distribution: Green Bay Zone 4
Figure 4-7 Wetland Losses in Green Bay: Duck Creek, Cat Island Chain, and Long Tail Point
Figure 4-8 Green Bay Spawning Areas by Fish Types: Salmon/Trout and Benthic Fish
Figure 4-9 Green Bay Spawning Areas by Fish Types: Pelagic and Game Fish
Figure 4-10 Green Bay Spawning Areas by Fish Species: Walleye, Yellow Perch, and Sturgeon
Figure 4-11 Green Bay Spawning Areas by Fish Species: Carp and Alewife
Figure 4-12 Green Bay Spawning Areas by Fish Species: Emerald Shiners and Gizzard Shad
Figure 4-13 Distribution of Birds in Green Bay: Select Species and Groups
Figure 4-14 Lower Fox River Mink Habitat Suitability: Little Lake Butte des Morts Reach
Figure 4-15 Lower Fox River Mink Habitat Suitability: Appleton to Little Rapids Reach
Figure 4-16 Lower Fox River Mink Habitat Suitability: Little Rapids to De Pere Reach
Figure 4-17 Lower Fox River Mink Habitat Suitability: De Pere to Green Bay Reach
Figure 4-18 Green Bay Mink Habitat Suitability: Zone 2
Figure 4-19 Green Bay Mink Habitat Suitability: Zone 3

List of Figures

Figure 5-1 PCB Sampling Frequency Distribution in Lower Fox River and Green Bay Sediments
Figure 5-2 Summary of Total PCB Concentrations in Lower Fox River and Green Bay Sediments
Figure 5-3 PCB Mass Distribution in Sediments for Each River Reach and Bay Zone
Figure 5-4 PCB Mass by Concentration Ranges in Lower Fox River Sediments
Figure 5-5 Contaminated Sediment Volume by Concentration Ranges in the Lower Fox River
Figure 5-6 PCB Mass by Concentration Ranges in Green Bay Sediments
Figure 5-7 Contaminated Sediment Volume by Concentration Ranges in Green Bay
Figure 5-8 PCB Mass Distribution in Lower Fox River and Green Bay Sediments
Figure 5-9 Ratios of PCB Mass/Sediment Volume in the Lower Fox River and Green Bay Sediment
Figure 5-10 Distribution of PCB Mass/Sediment Volume Ratios in Sediments with More Than 50 μg/kg PCBs
Figure 5-11 Aroclors 1242/1254/1260 PCB Homolog Plots
Figure 5-12 PCB Homolog Distribution in Lower Fox River and Green Bay Sediments
Figure 5-13 1994/95 Total PCB & Mercury Concentrations in Lower Fox River Water
Figure 5-14 1998 Total PCB Concentrations in Lower Fox River Water
Figure 5-15 PCB Homolog Distribution in Water: De Pere Dam Through Green Bay
Figure 5-16 Lower Fox River and Green Bay System - Estimated PCB Mass and Major PCB Flux Pathways
Figure 5-17 Time Trends of PCBs in Sediments for Depths from 0 to 10 cm and from 10 to 30 cm
Figure 5-18 Time Trends of PCBs in Sediments for Depths from 30 to 50 cm and from 50 to 100 cm
Figure 5-19 Time Trends of PCBs in Sediments for Depths over 100 cm

List of Tables

Table 2-1	Fox River Database Studies and Data Classification
Table 2-2	Lower Fox River - Supplemental Data Collection Sampling List
Table 3-1	Land Use Classification for Counties Bordering Green Bay
Table 3-2	Temperature and Precipitation Data for the City of Green Bay, Wisconsin
Table 3-3	Temperature and Precipitation Data for the City of Appleton, Wisconsin
Table 3-4	Temperature and Precipitation Data for the City of Marinette, Wisconsin
Table 3-5	Temperature and Precipitation Data for the City of Sturgeon Bay, Wisconsin
Table 3-6	Temperature and Precipitation Data for the City of Fayette, Michigan
Table 3-7	Water Use in the Lower Fox River/Green Bay Watersheds (1995)
Table 3-8	Lower Fox River Dams
Table 3-9	Lower Fox River - U.S. Army Corps of Engineers - Dam Stability and Inspection Information
Table 3-10	Lower Fox River Gradient and Lock/Dam Information
Table 3-11	Lower Fox River Discharge Results - Rapide Croche Gauging Station
Table 3-12	Lower Fox River Stream Velocity Estimates
Table 3-13	Fox River Mouth Gauging Station Results (1989-1999)
Table 3-14	Lower Fox River Total Suspended Solid (TSS) Loads
Table 3-15	USACE Navigation Channel Dredging Records (1957-1999)
Table 4-1	Major Green Bay Wetland Areas/Complexes
Table 4-2	Lower Fox River Habitats
Table 4-3	Lower Fox River Shoreline and Substrate Types
Table 4-4	Lower Fox River Fish Species Composition
Table 4-5	Lower Fox River Fish Populations in the De Pere to Green Bay Reach
Table 4-6	Green Bay Fish Species
Table 4-7	Lower Fox River and Green Bay Bird Species
Table 5-1	Lower Fox River and Green Bay - Sediment Sampling Results: Summary of Detected Compounds
Table 5-2	Lower Fox River and Green Bay - Distribution of Total PCBs in Sediment
Table 5-3	Lower Fox River - Dioxin/Furan (2,3,7,8-TCDD/F) Results
Table 5-4	Lower Fox River and Green Bay - Pesticide Results
Table 5-5	Lower Fox River and Green Bay - Mercury, Lead, and Arsenic Results
Table 5-6	Lower Fox River and Green Bay - Other RCRA Metals, Copper, Nickel, and Zinc
Table 5-7	Lower Fox River and Green Bay - Miscellaneous Inorganic Compounds
Table 5-8	Lower Fox River and Green Bay - Ammonia Results
Table 5-9	Lower Fox River - Toxicity Characteristic Leaching Procedure (TCLP) Results
Table 5-10	Lower Fox River and Green Bay - Semi-Volatile Organic Compound Results (PAHs)
Table 5-11	Lower Fox River and Green Bay - Miscellaneous SVOC Results

List of Tables

Table 5-12 Lake Winnebago Background Sediment Results
Table 5-13 Lower Fox River - PCB Mass and Sediment Volume by Concentration Range
Table 5-14 Lower Fox River - PCB Mass and Sediment Volume by Deposit/SMU Layer
Table 5-15 Green Bay - PCB Mass and Sediment Volume by Concentration Range and Layer
Table 5-16 Lower Fox River and Green Bay - Water Sampling Results: Summary of Detected Compounds
Table 5-17 Lower Fox River - Total PCB Results in Water
Table 5-18 Green Bay - Total PCB Results in Water
Table 5-19 Lower Fox River and Green Bay - Mercury and DDT (DDD/DDE) Water Sampling Results
Table 5-20 PCB Transport within the Lower Fox River and Green Bay System
Table 5-21 Distribution of Resident Tissue Samples over Time in the Lower Fox River - Total PCBs Only
Table 5-22 Distribution of Resident Tissue Samples over Time in Green Bay - Total PCBs Only
Table 5-23 Results of Sediment Time Trends Analysis for the Lower Fox River
Table 5-24 Mass-Weighted Combined Time Trend for 0 to 10 cm Depth by Reach
Table 5-25 Results of Fish Time Trend Analysis on the Lower Fox River
Table 6-1 Lower Fox River - Fate and Transport Chemical Factors

List of Plates

Plate 3-1	Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Lake Butte des Morts Reach
Plate 3-2	Sample Locations and Interpolated Thickness of Sediment with PCBs: Appleton to Little Rapids Reach
Plate 3-3	Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Rapids to De Pere Reach
Plate 3-4	Sample Locations and Interpolated Thickness of Sediment with PCBs: De Pere to Green Bay Reach
Plate 3-5	Sample Locations and Interpolated Thickness of Sediment with PCBs: Green Bay
Plate 5-1	Interpolated PCB Distribution in Sediments: Little Lake Butte des Morts Reach
Plate 5-2	Interpolated PCB Distribution in Sediments: Appleton to Little Rapids Reach
Plate 5-3	Interpolated PCB Distribution in Sediments: Little Rapids to De Pere Reach
Plate 5-4	Interpolated PCB Distribution in Sediments: De Pere to Green Bay Reach
Plate 5-5	Interpolated PCB Distribution in Sediments: Green Bay

List of Acronyms

AOC	Areas of Concern
ATSDR	Agency for Toxic Substances and Disease Registry
AVM	acoustical velocity meter
BCF	bioconcentration factor
BBL	Blasland, Bouck, & Lee
BEHP	bis2-ethylhexylphthalate
°C	degrees Celsius
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
cm	centimeter(s)
COPC	chemical of potential concern
CWA	Clean Water Act
DDD	p,p'-Dichlorodiphenyldichloroethane
DDE	p.p'-Dichlorodiphenyldichloroethylene
DDT	p.p-Dichlorodiphenyltrichloroethane
DO	dissolved oxygen
ECWRPC	East Central Wisconsin Regional Planning Commission
EIS	Final Environmental Impact Statement
EPA	United States Environmental Protection Agency, Region 5
Exponent	Exponent Environmental Group
°F	degrees Fahrenheit
F&VD	Foth & Van Dyke
FRRAT	Fox River Remediation Advisory Team
FRDB	Fox River Database
FRG	Fox River Group, which is comprised of the following seven companies listed alphabetically: Appleton Papers, Inc., Fort James Corporation; P.H. Glatfelter Company; NCR Corporation; Riverside Paper Corporation; U.S. Paper Mills Corporation; and Wisconsin Tissue Mills, Inc.
FS	Feasibility Study
ft	foot (feet)
ft^2	square feet
ft/s	foot per second
g	gram(s)
g/year	grams per year
GAS	Graef, Anhalt, Schloemer, and Associates, Inc.
GBMBS	Green Bay Mass Balance Study
GBMSD	Green Bay Metropolitan Sewerage District
GBTOXe	Green Bay Toxics Model

List of Acronyms

GIS	Geographic Information System
GLC	Great Lakes Commission
GLNPO	USEPA Great Lakes National Program Office
GLWQA	Great Lakes Water Quality Agreement
gpm	gallons per minute
HDPE	high-density polyethylene
IGLD 1985	International Great Lakes Datum, zero elevation at Rimouski, Quebec, Canada
IJC	International Joint Commission
in	inch(es)
IPS	Integrated Papers Services
kg	kilogram
km	kilometer(s)
km^2	square kilometers
km^3	cubic kilometers
Koc	log water/organic carbon partition coefficient
Kow	log octanol/water partition coefficient
LLBdM	Little Lake Butte des Morts
LTA	long-term average
LUST	leaking underground storage tank
m	meter(s)
m^2	square meters
m/s	meters per second
m^3	cubic meters
m^3/s	cubic meters per second
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MGD	million gallons per day
mi	mile(s)
mi^2	square miles
mi^3	cubic miles
MNFI	Michigan Natural Features Inventory
MSA	Metropolitan Statistical Area
MT	metric tonnes
NWR	national wildlife refuge
NAWQA	USGS National Water Quality Assessment Program
NCP	National Contingency Plan
NCR	National Cash Register
ng/kg	nanograms per kilogram

List of Acronyms

ng/L	nanograms per liter
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NPL (Superfund)	National Priority List
NRC	National Research Council
NURE	National Uranium Resources Evaluation project
NWR	National Wildlife Refuge
OZ	ounce
PAH	polynuclear aromatic hydrocarbon
PCB	Polychlorinated Biphenyl
PCP	Pentachlorophenol
pg/m^3	picograms per cubic meter
ppb	parts per billion (μg/kg or μg/L)
ppm	parts per million (mg/kg or mg/L)
ppt	part per trillion (ng/kg or ng/L)
Project Team	The Fox River Project Team
PRP	Principal Responsibility Parties
PSC	Public Service Commission
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RA	Risk Assessment
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
SAIC	Science Application International Corporation
SAV	submerged aquatic vegetation
SCS	Soil Conservation Service
SEF	Sediment enrichment factor
SLRA	Screening Level Risk Assessment
SMU	Sediment Management Unit
SQG	sediment quality guideline
SRD	Sediment Remediation Demonstration
SVOC	semi-volatile organic compound
SWA	State Wildlife Area
SWE	Snow-Water Equivalent
TCLP	Toxicity Characteristic Leaching Procedure
TOC	total organic carbon
TRI	EPA Toxic Release Inventory database
TSCA	Toxic Substance Control Act

List of Acronyms

TSS	total suspended solids
μg/kg	microgram per kilogram
UP	Michigan's Upper Peninsula
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
UST	underground storage tank
UWSGI	University of Wisconsin Sea Grant Institute
VOC	volatile organic compound
W.A.	Wildlife Area
W.A.C.	Wisconsin Administrative Code
WCC	Woodward-Clyde Consultants (formerly EWI Engineering Associates)
WDNR	Wisconsin Department of Natural Resources
WGNHS	Wisconsin Geological and Natural History Survey
WPDES	Wisconsin Pollution Discharge Elimination System
WPSC	Wisconsin Public Service Corporation
WSCO	Wisconsin State Climatology Office
WTM 27	Wisconsin Trans-Mercator Projection, 1927
WWTP	Wastewater Treatment Plant
WY	Water Year
yd^3	cubic yard
YOY	Young-of-year fish

EXECUTIVE SUMMARY

The Remedial Investigation (RI) report summarizes the physical, chemical, and biological characteristics of the Lower Fox River and Green Bay. The purpose of the RI report is to compile and evaluate these data to support development of the Baseline Human Health and Ecological Risk Assessment (RA) and Feasibility Study (FS). The RA identifies the risks posed to human health and the environment by compounds of concern. The FS develops and evaluates a range of remedial alternatives to support the selection of a remedy that will eliminate, reduce and/or control these risks. This RI/FS report is consistent with the findings of the National Academy of Science's National Research Council Report entitled *A Risk Management Strategy for PCB Contaminated Sediments. (NRC, 2001).*

The RI study area includes the Lower Fox River extending 63 km (39 mi) from Lake Winnebago to Green Bay as well as the entire 4,150 km^2 (1,600 mi^2) of the bay. Green Bay is 190 km (119 mi) in length and averages 37 km (23 mi) in width. The Lower Fox River was subdivided into four river reaches. Green Bay is subdivided into zones 2, 3, and 4 (Figure 1). The Green Bay Area of Concern, as designated by the International Joint Commission, is defined as the De Pere to Green Bay Reach and much of Green Bay Zone 2.

The RI evaluated data from numerous investigations conducted within the study area since 1971, which comprise the Fox River Database (FRDB). Sediment, water, and biological samples in the FRDB include analyses for over 200 chemical parameters. Based on these analyses, a Screening Level Risk Assessment identified polychlorinated biphenyls (PCBs), dieldrin, DDT, dioxins/furans, mercury, lead, and arsenic as the compounds present in the study area that represent potential risks to human health and the environment. However, PCBs are the primary compounds of concern.

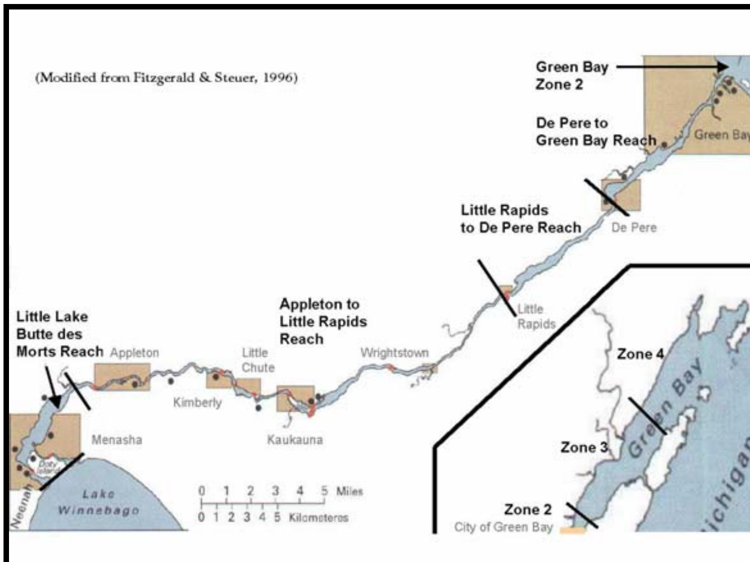

Figure 1. Remedial Investigation Study Areas

Site History and PCB Discharges

In the early 1950s, carbonless copy paper was developed through a process that applied an emulsion containing PCB on paper in a manner that would create document copies. Lower Fox River valley paper mills manufactured and recycled this carbonless paper between 1954 and 1971. About 45 million pounds of PCB were used in the Fox Valley during this time period.

PCBs were released to the environment through manufacturing waste waters and from the de-inking/recycling of waste carbonless copy paper. The Wisconsin Department of Natural Resources (WDNR) estimates the amount of PCB that was discharged to the Lower Fox River from these activities is 313,600 kg (691,370 pounds), with a range from 126,450 kg to 399,450 kg (278,775 to 880,640 pounds). WDNR believes that five facilities contributed over 99 percent of the total PCBs discharged to the Lower Fox River by the end of 1971.

In the late 1970s, commercial production of PCBs in the United States was prohibited due to concerns for human health and the environment. At the present time, some minor unavoidable point source discharges along with atmospheric deposition of PCB continue, but are small compared to the PCB mass present in the river and bay sediments.

Prior to implementation of the federal Clean Water Act in 1972, rough fish were the main species that could live in the Lower Fox River. With implementation of the Clean Water Act and more stringent control over wastewater discharges, water quality in the river improved and game fish began to return to the river. PCBs were detected in trout from Green Bay as early as 1971. Due to continued elevated PCB levels, WDNR issued advisories for public consumption of fish (1976) and waterfowl (1983) derived from Green Bay and the Lower Fox River. The state of Michigan also issued consumption advisories for Green Bay fish in 1977.

PCB Distribution and Sediment Volumes

Considering sediments containing more than 50 μg/kg PCB, about 28,600 kg (63,050 pounds) of PCBs are contained within about 9 million m^3 (11.8 million yd^3) of sediment in the Lower Fox River. In Green Bay, approximately 68,200 kg (150,300 pounds) of PCBs are dispersed in about 465 million m^3 (610 million yd^3) of sediment. The distribution of PCB mass, sediment volume and sediment areal extent are shown on Figure 2. Also shown on Figure 2 is the ratio of PCB mass to sediment volume. The reaches upstream of the De Pere dam are combined on Figure 2 because of their relatively small PCB mass, sediment volume and areal extent.

Much of the PCB discharged into the Lower Fox River has already been transported downstream and is now concentrated in sediments within specific areas:

- The De Pere to Green Bay Reach contains almost 26,000 kg of PCB, which represents about 91 percent of the mass remaining in the river. This reach contains just under 27 percent of the total PCB mass in the system and is concentrated within a relatively small area comprising just over one percent of the total sediment volume. This reach also exhibits the highest mass of PCB per volume of sediment.

- Approximately 70 percent of the total PCB mass in the system has migrated from the river into Green Bay.

- The PCB mass in Green Bay is dispersed over an extraordinarily large area and in an extremely large sediment volume. Almost half of the total PCB mass in Green Bay is found in Zone 2.

Sediment and PCB Transport

Particle size and cohesion along with river/bay conditions, especially current speeds, control the deposition, resuspension, and transportation of sediments (and the PCBs absorbed to them). In the Lower Fox River, sediments have accumulated in 35 separate deposits above

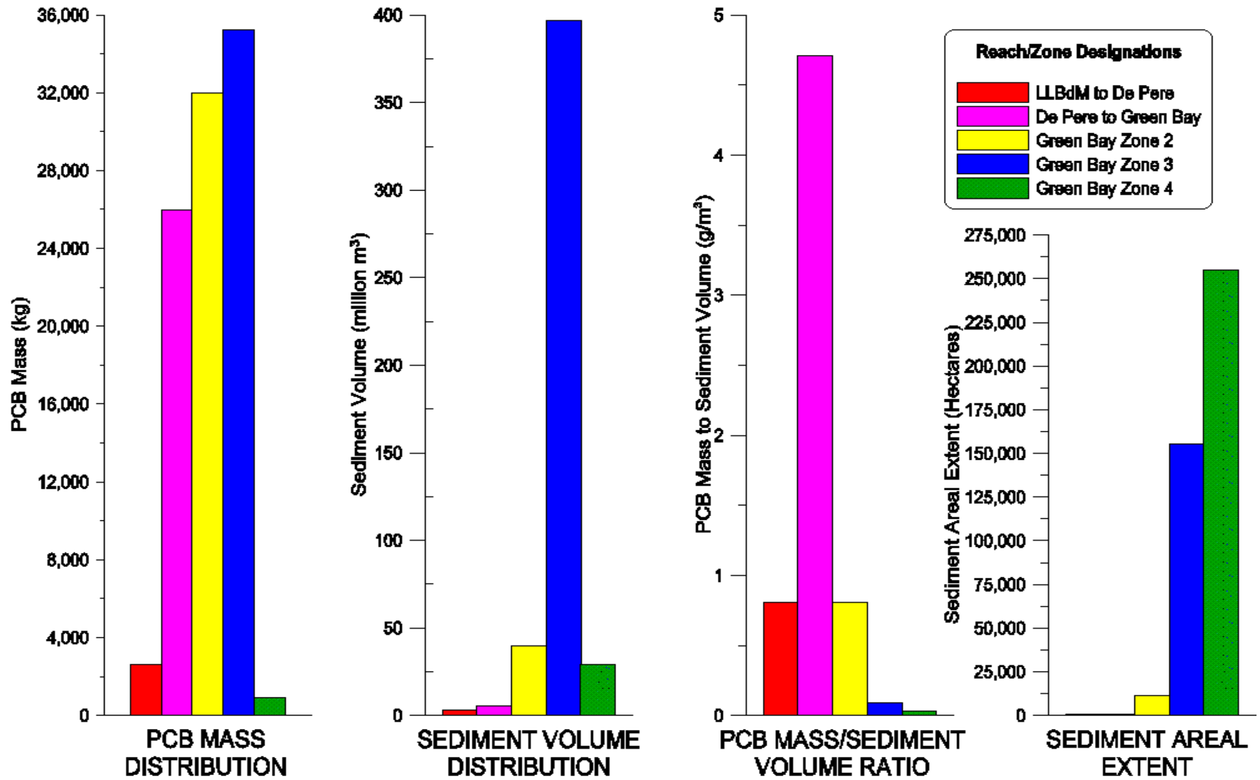

Figure 2. PCB Mass & Sediment Volume/Area Distribution by river reach and bay zone

the De Pere dam. Below the De Pere dam and in Green Bay, where current speeds tend to be lower, sediments cover large areas of the river and bay bottom, except in areas where the sediments are dredged to maintain ship navigation. The highest PCB concentrations have also been observed in the LLBdM and De Pere to Green Bay reaches, in the vicinity of historic discharge points.

The average river discharge was about 122 m^3/s (4,300 cfs) between 1989 and 1998. Due to storm events and spring snowmelt, the river discharge exceeds 272 m^3/s (9,600 cfs) more than 10 percent of the time. These faster currents have the capability to resuspend and transport larger particle sizes and greater volumes of sediment and, therefore, a greater mass of PCB. Field measurements and computer modeling results suggest that these less-frequent, high-discharge events transport much of the PCB mass in the river over the De Pere dam and into Green Bay. In addition to sediment transport, PCB migrates due to dissolution in water and adsorption onto algae and other organic matter. The PCB mass transported from reach to reach increases along the river. Based on sampling data collected as part of the Green Bay Mass Balance study in 1989-90, about 280 kg (610 pounds) of PCB were transported to Green Bay during the study period. Based on work done in 1994-95 as part of the Lake Michigan Mass Balance, it was estimated that 220 kg (485 pounds) of PCB moved from the river into the bay. PCB loads to the bay vary as the river flow varies. This mass represents up to 1 percent of the PCB mass in the river.

Sediment discharged from the Lower Fox River is directed toward the east shore of Green Bay by counterclockwise currents. This sediment-rich water can extend between 20 km to 40 km (12 mi to 24 mi) along the east shore. Fluctuating water levels, wave action and reverses in stream flow in this area facilitate sediment transport and mixing. Consequently, large volumes of sediment containing PCB are present along the southern and eastern portions of Green Bay. At least 68,200 kg (150,300 pounds) of PCBs already reside in the bay. Over 95 percent of the PCB that occurs in Green Bay is derived from the Lower Fox River.

This transport of PCB also extends into Lake Michigan. During 1989/90, it was estimated as part of the Green Bay Mass Balance Study that about 122 kg (270 pounds) of PCBs were transported from Green Bay to Lake Michigan. Other mass transport pathways (such as volatilization) also exist.

Ecological Samples and Characteristics

Exposure of biota to sediments and water containing PCB fosters uptake of PCBs into the food chain. Wetlands, submerged aquatic vegetation, and islands along the Lower Fox River and Green Bay offer nesting/spawning, feeding, and refuge opportunities for fish, birds, and animals. Other lacustrine, riverine, and estuary features also provide habitat for regional wildlife. In addition to birds and fish, the FRDB contains information on PCBs in deer, otter, mink, and various insects and invertebrates. The RA evaluates PCB uptake and accumulation in selected species and the associated human health and environmental risks. Areas with higher PCB concentrations tend to pose a greater risk of exposure.

Effects of Time

The FRDB includes sediment and water results from over a 10 year period while tissue samples were collected between 1971 and 1999. During the 1970s, after PCB discharges into the river ceased, PCB concentrations in fish tissue showed significantly declining concentrations. However, since the mid-1980s, changes in the rate of PCB decline in fish tissue have been observed. Changes in PCB levels in fish tissue have either slowed, remained constant, or is some cases actually increased.

PCB concentration trends in the upper 10 cm (4 in) of sediment are inconsistent, but generally appear to be decreasing over time as more PCB is transported downstream. Soil eroded from the watershed mixes with and may further dilute PCB concentrations in the sediments.

Further Information

The selection of remedies for the Lower Fox River and Green Bay will consider the information within the RI, RA and FS, as well as input by the public and interested parties. For further information, please contact:

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1 Introduction

1.1 Project Overview and Objectives

The RETEC Group, Inc. (RETEC) and was contracted by the Wisconsin Department of Natural Resources (WDNR) in March 1998 to complete a Remedial Investigation (RI), Feasibility Study (FS), and Risk Assessment (RA) for chemically impacted sediments in the Lower Fox River and Green Bay. This project is being conducted under the direction of WDNR, with funding and technical assistance from the United States Environmental Protection Agency, Region 5 (EPA). On July 9, 1998, the EPA proposed adding the Lower Fox River and Lower Green Bay to the National Priority List (NPL) (Superfund). This project has been conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP).

The overall objective of this RI/FS/RA is to develop the necessary supporting information for the selection of a sediment remediation approach for the Lower Fox River and Green Bay that will be protective of human health and the environment. The Lower Fox River study area is defined as the 63 kilometer (km) (39 mile [mi]) portion of the river beginning at the outlet of Lake Winnebago and terminating at the mouth of the river into Green Bay (Figure 1-1). The study area also includes all of Green Bay, which is shown on Figure 1-2.

The RI report, prepared by RETEC and Natural Resource Technology, Inc. (NRT), describes the physical, chemical and biological characteristics of the Lower Fox River and Green Bay. The RA report has been prepared concurrently with this RI report and assesses the potential risks posed to human health and the environment from the compounds found in the Lower Fox River and Green Bay ecosystems. The FS report evaluates applicable remedial alternatives to support the selection of a remedy to eliminate, reduce, and/or control risks identified in the RA. This RI/FS report is consistent with the findings of the National Academy of Science's National Research Council Report entitled *A Risk Management for PCB Contaminated Sediments* (NRC, 2001).

The RI included the following activities:

- Compilation, review, and organization of existing data available for the Lower Fox River and Green Bay.
- Assessment of the quality and usability of the existing data.

- Collection of additional sample data in selected areas of the Lower Fox River during the summer of 1998.

- Description of the physical and ecological characteristics of the Lower Fox River and Green Bay along areas of sediment deposits.

- Evaluation of the occurrence, volume, and mass of chemical parameters of concern in sediment and water.

This RI report describes the magnitude and extent of chemicals of concern in sediments and water only. A substantial amount of chemical data have been collected from a variety of biological organisms. Biological impacts and their implications within the river system are addressed in the RA report.

1.2 Study Area Overview

General descriptions of the Lower Fox River and Green Bay are presented below to provide information about the physical setting of the RI study area and region.

1.2.1 Lower Fox River

The Lower Fox River flows northeast approximately 63 km (39 mi) from Lake Winnebago, the largest inland lake in Wisconsin, to Green Bay (Figure 1-1). The Fox River is the largest tributary to Green Bay, draining approximately 16,395 square kilometers (km^2) (6,330 square mi [mi^2]). The river has a mean discharge into Green Bay of approximately 122 cubic meters per second (m^3/s) (5,000 cubic feet per second [cfs]) (USGS, 1998c; Fitzgerald and Steuer, 1996). The change in river elevation between Lake Winnebago and Green Bay is approximately 51 meters (m) (168 ft) (National Oceanic and Atmospheric Administration [NOAA], 1992).

Historically, the Lower Fox River is impounded by 13 dams and 17 locks, which once made it navigable between Lake Winnebago and Green Bay. Currently, the Rapide Croche Lock is permanently closed to restrict sea lamprey migration and only the last two locks (at Little Rapids and De Pere) are open to recreational boats. The Lower Fox River is bounded upstream by two dams in the cities of Neenah and Menasha that control the pool elevation of Lake Winnebago and discharge to the river. The Neenah and Menasha channels connect Lake Winnebago with Little Lake Butte des Morts (LLBdM). LLBdM is a relatively shallow section of the Lower Fox River, approximately 1,070 m (3,500 ft) wide and extending approximately 4.8 km (3 mi) (Figure 1-3).

Between the outlet of LLBdM and the Little Rapids dam, the Lower Fox River is generally less than 300 m (1,000 ft) wide and the channel meanders more in this stretch of the river than in other downstream reaches (Figure 1-4). Sediment is typically deposited on the inside portion of a meander bend, while the outer part of the meander bend (the cut bank) usually is erosional due to increased stream flow velocities. Between the Little Rapids and De Pere dams the river is again relatively straight, although not as wide or as shallow as LLBdM (Figure 1-5).

From the De Pere dam to the mouth, the Lower Fox River is a large, channelized stream that is stabilized along much of this stretch with either riprap or concrete reinforcement (Figure 1-6). Navigation for ocean bound vessels extends upriver approximately 4.8 km (3 mi) from Green Bay to the Fort James Paper Company (formerly Fort Howard) turning basin via a navigation channel with a maintained water depth of about 7.3 m (24 ft). Flow in this section of the river is sometimes reversed by wind-driven increases in Green Bay water levels, commonly known as seiche events.

1.2.2 Green Bay

The Green Bay of Lake Michigan is a narrow, elongated bay, oriented in a north-northeast -south-southwest (NNE-SSW) direction (Figure 1-2). At the south end, the bay is a freshwater estuary, due to the shallow water depths, while the northern end is a deep-water lake. The bay lies on the northeast shore of Wisconsin and the southeast shores of Michigan's Upper Peninsula (UP). The bay is bounded by the city of Green Bay at the south end and by both Big Bay de Noc and Little Bay de Noc on the north end. Big Bay de Noc and Little Bay de Noc are separated by the UP's Stonington Peninsula (Sinclair, 1960). In Wisconsin, the bay is separated from Lake Michigan by the Door Peninsula while the UP's Garden Peninsula separates Big Bay de Noc from Lake Michigan (Figure 1-2). Green Bay is connected with the remainder of Lake Michigan on its northeast side along a line between Washington, Rock, St. Martin's, Poverty, and Summer Islands (Figure 1-2). Rock Island, which lies about 2.4 km (1.5 mi) north of Washington Island, marks the northern tip of Door County. The islands north of Rock Island lie within the state of Michigan.

Green Bay is approximately 190 km (119 mi) long and has an average width of 37 km (23 mi). The bay covers an area of approximately 4,150 km^2 (1,600 mi^2) and has a volume of about 83 cubic kilometers (km^3) (20 cubic miles [mi^3]). The mean depth of the bay is approximately 20 m (65 ft). The maximum depth reaches 54 m (176 ft) at a location about 6.4 km (4 mi) west of Washington Island (Bertrand, *et al.,* 1976).

The Green Bay watershed drains approximately 40,000 km^2 (15,625 mi^2) or about one-third of the Lake Michigan drainage basin. Two-thirds of the Green Bay drainage is in Wisconsin and one-third in Michigan's UP (Bertrand, *et al.,* 1976). Although there are a number of Green Bay tributaries, the United States Geological Survey (USGS) has measured discharge for 10 tributaries. The measured discharge for these tributaries, along with the drainage area for each, is summarized below. Except for the Lower Fox River, the discharge results listed below are for Water Years 1989 and 1990, which run from October 1, 1998 through September 30, 1990. Data from the Lower Fox River extends from 1898 through 1998.

The Fox River is by far the largest Green Bay tributary based on both discharge and drainage area. The Fox River contributes approximately 42 percent of the total drainage into Green Bay (Bertrand, *et al.,* 1976). Due to its volume, as well as the relatively higher concentration of industrial activity and pollutant load, the Fox River is the tributary of greatest interest with respect to sediment and water quality in Green Bay. Over 95 percent of the polychlorinated biphenyl (PCB) load and 70 percent of the suspended sediments flowing into the bay are derived from the Lower Fox River (WDNR, 1999a; Smith, *et al.,* 1988).

The Menominee River is the only other Green Bay tributary with a mean discharge over 56.6 m^3/sec (2,000 cfs) and a drainage area over 10,000 km^2 (3,861 mi^2). In addition to the ten tributaries that USGS measured, five other Green Bay tributaries have been utilized by LTI Environmental Engineering (LTI, 1999) to model PCB and solids loads into Green Bay. However, stream discharge data were not available for these five tributaries.

Summary of Green Bay Tributaries

Tributary	State	Drainage Area Km^2(mi^2)	Mean Discharge m^3/sec (cfs)
Fox	WI	16,394 (6,330)	149 (5,262)
Duck	WI	394 (152)	1.2 (42.6)
Suamico	WI	157 (60.7)	0.95 (33.4)
Pensaukee	WI	386 (149)	1.7 (59)
Oconto	WI	2,416 (933)	15.9 (560)
Peshtigo	WI	2,991 (1,155)	20 (704)
Menominee	WI/MI	10,748 (4,150)	78 (2,750)
Cedar	MI	917 (354)	N/A
Ford	MI	1,282 (495)	9.3 (327)
Escanaba	MI	2,383 (920)	23 (828)
Tacoosh	MI	75 (29)	N/A
Rapid	MI	352 (136)	N/A
Whitefish	MI	811 (313)	N/A
Sturgeon	MI	523 (202)	5.3 (188)
Fishdam	MI	243 (94)	N/A

Circulation within Green Bay is largely controlled by the prevailing southwesterly winds, which causes a large-scale generally counterclockwise circulation of the bay waters (Miller and Saylor, 1985; Smith, *et al.,* 1988). Localized currents are present throughout the bay and rotate both clockwise and counter-clockwise (HydroQual, 1999). The bay is also subject to seiches, defined as cyclical short-term oscillation of water levels caused by the earth's rotation, wind, and/or abrupt changes in barometric pressure. The seiches typically change water levels by several centimeters in the southern end of Green Bay, resulting in reversed flow in the Lower Fox River. Combined with storm conditions, seiche events have raised water levels at the mouth of the river by over one meter and the seiche effects can extend up to the De Pere dam, 11.3 km (7 mi) upstream from the mouth of the river. Seiche events result in the relatively rapid mixing of sediment-rich tributary waters, and therefore contaminant loads, with the water of Green Bay.

Discharge from the Lower Fox River into Green Bay is directed towards the east by the counterclockwise circulation pattern. Plumes of sediment-rich water can extend up to 20 km along the east shore of the bay (Smith, *et al.,* 1988). Sediment initially deposited in the southern end of the bay can become resuspended due to seiche events and be redeposited further up the east shore. Consequently, the majority of river-related sediment in Green Bay is present along the southern and eastern shores of the bay.

Larger urban areas located along the west shore of Green Bay include the cities of Green Bay, Marinette, Peshtigo, and Oconto, Wisconsin and Escanaba and Menominee, Michigan. The city of Sturgeon Bay, Wisconsin, is the largest urban area located on the east shore of Green Bay (Figure 1-2).

1.3 Study Area River Reaches and Bay Zones

In order to facilitate data presentation and discussion in the RI, the Lower Fox River and Green Bay have been divided into reaches and zones, respectively. These river reach and bay zone designations are used throughout the RI/FS/RA and are described below.

1.3.1 Lower Fox River Reaches

Based on previous investigations, the river has been divided into four reaches and, further, into specific sediment deposits or units within these reaches. Three of these reaches are located upstream of the De Pere dam and the fourth reach extends from the De Pere dam to the mouth of the river. Above the De Pere dam, there are 35 individual sediment deposits (WDNR, 1995). From the De Pere dam to the mouth of the river at Green Bay soft sediment is present over almost the entire river bottom and individual deposits were not established. Rather, the river bottom in this reach was separated into discrete sediment management units (SMUs). The reaches and associated sediment deposits/SMUs discussed in this RI report (as well as in the RA and FS reports) include the following:

- **Little Lake Butte des Morts (LLBdM) Reach** (Figure 1-3) - Extending from the outlet of Lake Winnebago to Appleton for a distance of approximately 10 km (6 mi), this reach includes sediment deposits A through H and POG.

- **Appleton to Little Rapids Reach** (Figure 1-4)- Extending from Appleton to the Little Rapids dam for a distance of approximately 32 km (20 mi), this reach includes deposits I through DD. Sediments in deposits N and O were dredged from the river as part of the sediment remediation demonstration project in the fall of 1998 and the summer through fall of 1999.

- **Little Rapids to De Pere Reach** (Figure 1-5) - Extending from the Little Rapids dam to the De Pere dam for a distance of approximately 9.7 km (6 mi), this reach includes sediment deposits EE through HH. These deposits form a nearly continuous layer of soft sediment that extends for approximately 8.5 km (5 mi) upstream of the De Pere dam.

- **De Pere to Green Bay Reach** (Figure 1-6) - This reach extends about 11.3 km (7 mi) from the De Pere dam to the mouth of the Fox River. Due to the presence of a large and continuous layer of soft sediment between the dam and the river mouth, this area has been divided into 96 SMUs (numbered 20 through 115) and 16 water column segments (6 SMUs to a segment). The SMUs and water column segments were initially established for computer modeling studies. This reach is also referred to as Green Bay Zone 1 for certain modeling activities.

1.3.2 Green Bay

1.3.2.1 Green Bay Zones

Green Bay has been subdivided into four zones by previous investigators (EPA, 1989). Green Bay zones 2, 3, and 4 are shown on Figure 1-2.

- **Zone 1** is identical to, and will be referred to hereinafter as, the De Pere to Green Bay Reach of the Lower Fox River, as discussed above.

- **Zone 2** (Figure 1-2) extends from the river mouth to a line perpendicular with the long axis of the bay (trending northwest-southeast (NW-SE)) about 12.2 km (7.6 mi) from the river mouth. This line crosses the bay near Little Tail Point on the west side of the bay (659,977.31E & 447,330.59N, Wisconsin Trans-Mercator Projection, 1927 [WTM 27]) and near Red Banks/Point Vincent on the east side of the bay (668,804.12E & 441,069.64N, WTM 27) (Velleux, 2000). This is approximately 10 km (6.2 mi) south of Dyckesville, Wisconsin.

- **Zone 3** (Figure 1-2) extends from the east-west line marking the northern boundary of Zone 2 to a line just below Chambers Island. The northern boundary of Zone 3 is located about 87 km (54 mi) north of the mouth of the Fox River. Therefore, Zone 3 extends for a distance of approximately 75 km (47 mi). The boundary line of Zone 3 connects Beattie Point, in the Michigan UP (695,979.10E & 511,652.33N WTM 27) to Fish Creek, Wisconsin (715,892.56E & 500,356.72N WTM 27) on the Door Peninsula (Velleux, 2000).

- **Zone 4** (Figure 1-2) includes the remainder of Green Bay north of Chambers Island, including both Big Bay de Noc and Little Bay de Noc. From the south side of Chambers Island to the northern shores of Big Bay de Noc, the distance is approximately 102 km (63 mi).

Green Bay zones 2 and 3 are further divided into "east" and "west" segments by a line trending northeast-southwest (NE-SW) from the Fox River to Chambers Island. Zones 2A and 3A are located on the west side of this line while zones 2B and 3B are located on the east side of this line (Figure 1-2).

1.3.2.2 Inner and Outer Bays

Green Bay is also divided into the "inner"and "outer" bay and Chambers Island generally serves as the line of demarcation between these two areas. For the purposes of this RI/FS the "inner bay" includes Green Bay zones 2 and 3 and the "outer bay" is Zone 4, although there may be other uses of these terms in other literature and studies. The inner and outer bay designations are based on the physical environment of Green Bay, since water depths of the inner bay are much shallower than depths of the outer bay. Also, due to these depths, the water temperatures and the commercial and sport fisheries of the inner and outer bay are different.

1.3.2.3 Lower Green Bay

Previous researchers, as well as the efforts described herein, indicate that the majority of the PCB impacted sediments occur within the inner bay and the highest concentrations of PCBs are located in Zone 2, south of Long Tail Point and Point Au Sable. Use of the term "lower Green Bay" refers to this portion of Zone 2, located between the mouth of the Lower Fox River and these two points.

1.4 Background

The following information describes the development of the river and bay region as well as historical conditions and resources. This section also describes how historical development and practices have impacted the river and bay regions.

1.4.1 Site History

Green Bay and the Lower Fox River have long been important transportation corridors within the state of Wisconsin. Abundant and reliable food supplies, as well as other natural resources in the area, fostered development prior to arrival of Europeans to the region. French explorers arrived in the region in 1634 when Jean Nicolet landed on the eastern shore of Green Bay at Red Banks (Burridge, 1997). Following this, the French began colonizing the area, focusing on its vast wealth of furs and game, and exploring for routes further west. In addition to naming Green Bay, the French also referred to the bay as "La Baye de Puans" or the "Stinking Bay" (Burridge, 1997). This name reflected the observations of the

French explorers, likely indicating that lower Green Bay was a characteristically eutrophic water body.

French dominance in the area declined after 1731, as British and Canadian influence in the area increased. British and Canadian interests were dominant in the area until the end of the War of 1812, when the area became a territory of the United States (Burridge, 1997). During the 1820s and 1830s, Green Bay was a key entrance into the American west and large scale migration to the area and development occurred (Burridge, 1997).

An important factor in development of the area was the presence of the Fox and Wisconsin Rivers. Early residents proposed connecting Green Bay and the Mississippi River via the Fox and Wisconsin Rivers. In 1839-40, representatives of the U.S. federal government (the Topographical Engineers office) recommended the construction of a series of dams, locks, canals, and other modifications in order to make the Lower Fox River navigable between Green Bay and Lake Winnebago (Burridge, 1997). Channelization of the Lower Fox River began as part of this effort, as did construction of the locks and dams at each of the river's rapids. Following many unsuccessful attempts to complete a viable water-way connecting Green Bay with the Mississippi River, the federal government, through the United States Army Corps of Engineers (USACE), assumed authority for maintaining the Lower Fox River and Green Bay navigation channel and system. With this, came the responsibility for maintaining the Lower Fox River dams, locks, and canals. The structures the USACE took control of in 1872 are listed below. The USACE is still listed as owner of eight dams on the Lower Fox River (Table 3-8).

Lower Fox River Dam, Lock, and Canal Summary - 1872 (Burridge, 1997)

Dam	Canal length	Elevation Drop	Power Generation (horsepower)
Menasha Dam	1,317 m (4,320 ft)	2.5 m (8.2 ft)	2,487
Appleton Upper Dam	1.9 km (1.2 mi)	4.3 m (14 ft)	4,238
Appleton Middle Dam		4.3 m (14 ft)	2,225
Appleton Lower Dam		2.6 m (8.5 ft)	2,558
Cedars Dam (at Kimberly)	no listing	no listing	no listing
Little Chute Dam	1,980 m (6,500 ft)	11 m (36.2 ft)	no listing
Combined Locks Dam	no listing	6.6 m (21.8 ft)	no listing
Grand Kaukauna Dam	2,255 m (7,400 ft)	15.3 m (50.3 ft)	no listing
Rapide Croche Dam	536 m (1,760 ft)	2.6 m (8.6 ft)	no listing
Little Rapids Dam	290 m (950 ft)	2.1 m (7 ft)	no listing
De Pere Dam & Lock	no listing	2.7 m (9 ft)	no listing

Development of the Lower Fox River and Green Bay area increased with development of the river and bay navigation channel and system. Along with development came utilization, exploitation, and degradation of the local resources, including the water quality of the river and bay.

Water quality degradation in the Lower Fox River and Green Bay occurred over an extended period of time, largely beginning in the mid-1800s and continuing through the mid-1900s. As the population of the Green Bay area increased during the early to mid-1800s, the fish and water of Green Bay, along with the timber and land of the region faced increased pressure from exploitation of the local resources (Smith, *et al.,* 1988). During the latter half of the 1800s, the regional forests were cut to supply the sawmills of the Lower Fox River and the lumber markets in the lower Midwest. The previously forested land was converted to agriculture and runoff from the surrounding farmlands and deforested areas added significantly to the nutrient and sediment loads of the Lower Fox River and Green Bay (Smith, *et al.,* 1988).

In addition to these nutrient and sediment loads, the introduction of untreated municipal sewage and industrial wastes also significantly contributed to decline of the Lower Fox River and Green Bay water quality. Both the sawmills and paper mills discharged sawdust and other fibrous material as well as waste sulfite liquors (chemical residues of the pulping operations) into the Lower Fox River. The sawdust and fibrous material formed large mats that floated on the water surface. In Green Bay, these mats reportedly covered several square kilometers of the water surface (Smith, *et al.,* 1988). The waste sulfite liquors and other industrial and municipal waste discharges spurred bacterial growth and algal blooms, severely lowering the dissolved oxygen (DO) levels in the river and bay. This resulted in widespread fish die-offs in the 1920s and 1930s. Low oxygen conditions extended into Green Bay as far as 30 km (19 mi) north of the mouth of the Fox River.

During the late 1800s, the commercial fishing industry had been established in the Green Bay area. However, due to pollution, over fishing, and the introduction of exotic species in Green Bay, several of the bay's most prized fishes disappeared. These included lake sturgeon, herring, and lake trout.

In 1938-39, a Pollution Survey of Green Bay and the Lower Fox River (De Pere to Green Bay Reach) was completed by the Wisconsin State Board of Health -Committee on Water Pollution and the Green Bay Metropolitan Sewerage District (GBMSD). The pollution survey was conducted to investigate the fish die-offs reported by local fishermen in Green Bay and other nuisance concerns.

A similar survey of the Lower Fox River in 1925-26 had found that "intolerable conditions existed for aquatic life during the critical summer months from below Wrightstown to Green Bay" (Wisconsin State Board of Health, 1939). Conclusions of the 1938-39 Pollution Survey (Wisconsin State Board of Health, 1939) included the following:

- Waste sulfite liquors were determined to be the major source of pollution in Green Bay during the winter months, and oxygen depletion occurs along the east side of Green Bay, reflecting the counterclockwise currents of the bay.

- Typical ice coverage in the bay would likely result in oxygen-depleted conditions, especially along the east side of the bay, and near the reported fish die-offs.

- The DO levels at De Pere, the Mason Street bridge in the city of Green Bay, and the mouth of the river were so low that the water could not support fish life during periods of warm temperature and low stream flows (during August and September).

- Although sewage treatment plants had removed large quantities of solids and scum from the river and lowered the bacterial load, the oxygen demand did not decrease significantly because it was calculated that 88 percent of the oxygen demanding materials were associated with the waste sulfite liquors.

The degraded conditions of the Lower Fox River and Green Bay continued into the 1940s and 1950s. Due to high levels of fecal coliform bacteria, resulting from the discharge of untreated municipal sewage, Green Bay's public beach was permanently closed to swimming in 1943. Due to a declining water table and groundwater supplies, as well as the pollution of the Lower Fox River and Green Bay, the city of Green Bay built a water supply pipeline in 1955 to bring Lake Michigan water to the city. The water supply line extends approximately 48 km (30 mi) from Green Bay to Kewaunee and it draws Lake Michigan water through an intake located about 6.4 km (4 mi) offshore.

Yellow perch populations, which had been the mainstay of the local commercial fishing industry, declined significantly during this time period. In 1943, approximately 1.08 million kilograms (kg) (2.4 million pounds) of yellow perch were caught; by 1966 the catch had declined to 73,480 kg (162,000 pounds), a decrease of more than 90 percent (Smith, *et al.*,1988). Further, in 1976, WDNR instituted fish consumption advisories and restricted commercial harvesting due to the presence of PCBs in the fish of the Lower Fox River and Green Bay. Due to the continued presence of PCBs in fish, the WDNR has restricted the commercial yellow perch catch in Green Bay to 90,720 kg (200,000 pounds) annually. The fish consumption advisories, as well as the introduction and migration of exotic species into Green Bay, continue to disrupt and severely limit commercial fishing.

Besides the decline in the commercial fishing catch, the populations of many piscivorous (fish-eating) birds also declined in the 1960s. Bird populations suffered from the eggshell-thinning effects of chlorinated pesticides, such as p.p'-dichlorodiphenyltrichloroethane (DDT) and dieldrin and EPA moved to ban these two pesticides in the early 1970s. The effects associated with chlorinated pesticides lead to concerns about other chlorinated compounds, including PCB, pentachlorophenol (PCP) and dioxins/furans. PCB, DDT and dieldrin were all detected in piscivorous birds in 1987 and 1988, years after the use and discharge of these compounds had been discontinued (Dale and Stromberg, 1993).

1.4.2 Historical PCB Use and Discharges

Based on the historical discharges to the river and bay, numerous compounds can be detected in the sediments and water as well as the aquatic and wildlife species within or frequenting the river and bay. During the early 1980s, more than 100 potentially toxic substances were found in Lower Fox River sediments, water, and fish tissue (Sullivan and Delfino, 1982). Recently, the list of parameters in the river and lower Green Bay have been estimated to include over 360 potentially toxic substances (IJC, 1992), including PCB, mercury, polynuclear aromatic hydrocarbons (PAHs) and ammonia. Other contaminants found in some, but not all deposits/SMU groups include the pesticides DDT, p.p'-dichlorodiphenyldichloroethylene (DDE), and p.p'-dichlorodiphenyl-dichloroethane (DDD), and PCP. Of the potentially toxic substances found, the Baseline Human Health and Ecological Risk Assessment report (RETEC, 2002) concluded that PCBs are the primary chemicals of concern.

During the 1950s, 60s, and 70s, many industries throughout the United States used and/or produced products that contained PCB. PCBs include a class of 209 related chlorinated organic compounds that share similar chemical properties and structure. PCB use was widespread because these compounds are chemically very stable, have a high heat capacity, and do not easily degrade in water. PCBs were historically used in electrical equipment, hydraulic fluids, fire retardants, cutting oil, and a number of other commercial and industrial processes (Merck, 1989).

In the early 1950s, National Cash Register (NCR) developed carbonless copy paper for office and business use. When struck by a typewriter or pressed with a pen, a coating of PCB emulsion on the paper released oils to produce the document copy. In 1954, local paper mills in the Lower Fox River valley began manufacturing carbonless copy paper and PCBs were released to the environment through process waste waters and through the de-inking and recycling of waste carbonless copy paper. Due to rising health concerns about PCBs released to the environment, use of PCBs in the production of carbonless copy paper ceased in 1971. However, recycling of the carbonless copy paper may have continued for a short time thereafter. Monsanto, the primary manufacturer of PCBs in the United States, ceased distribution of PCBs for applications which were uncontained and open to the environment in 1977.

The companies/entities involved in the manufacturing and recycling of carbonless copy papers have been identified as the potentially responsible parties (PRPs) pursuant to CERCLA. These companies formed the Fox River Group (FRG), which collectively have undertaken studies evaluating PCB impacts to the river and bay system. The FRG includes the following seven companies (listed alphabetically): Appleton Papers, Inc.; Fort James Corporation; NCR Corporation; P.H. Glatfelter Company; Riverside Paper Corporation; U.S. Paper Mills Corporation; and Wisconsin Tissue Mills, Inc.

WDNR completed an evaluation of PCB discharges to the Lower Fox River beginning in the 1950s and coinciding with the production and recycling of carbonless copy paper. WDNR (1999a) estimated that approximately 313,600 kg (691,370 pounds) of PCBs were released to the environment during this time, although the discharge estimates range from 126,450 kg to 399,450 kg (278,775 pounds to 880,640 pounds), based on the percentages of PCBs lost during production or recycling of carbonless copy paper. WDNR (1999a) estimated that 98 percent of the total PCB released into the Lower Fox River had occurred by the end of 1971. Further, WDNR (1999a) indicated that five facilities, including the Appleton Papers-Coating Mill, P.H. Glatfelter Company and associated Arrowhead Landfill, Fort James-Green Bay West Mill (formerly Fort Howard), Wisconsin Tissue, and Appleton Papers-Locks Mill, contributed over 99 percent of the total PCBs discharged to the river.

Currently, PCBs are discharged into Green Bay at the mouth of the Lower Fox River through sediment transport and PCB dissolution in the water column. Sediments are the most significant source of PCBs entering the water column (Fitzgerald and Steuer, 1996), and over 95 percent of the PCB load into Green Bay is derived from the Lower Fox River (WDNR, 1999a). Based on the data analyzed as part of this effort, approximately 70,000 kg (154,300 pounds) of PCBs have already escaped from the Lower Fox River into Green Bay.

1.4.3 Regulatory Response

1.4.3.1 Clean Water Act

In response to growing public concern about widespread and serious water pollution, Congress passed the Clean Water Act (CWA) in 1972. The CWA was the first comprehensive national clean water legislation and is the primary federal law protecting our nation's lakes and rivers. The CWA objectives were two-fold: 1) eliminate discharge of pollutants in the water; and 2) achieve water quality levels that support recreational activities, namely fishing and swimming. The objectives were met by allowing the states to set specific water quality criteria, require surface water discharge performance standards and to develop pollution control programs to meet these criteria.

1.4.3.2 Wisconsin Pollution Discharge Elimination System

The implementation of the Wisconsin Pollution Discharge Elimination System (WPDES) program in the mid-1970s greatly reduced the pollutant load to the Lower Fox River. However, low levels of PCBs were still detected in industrial and municipal wastewater discharges associated with the paper mills into 1990, due to the persistence and ubiquitous occurrence of these compounds in the environment (WDNR, 1999a). One of the largest pollutant loads identified within the area of concern (AOC), besides municipal and industrial discharge outfalls, was in-place sediments, especially with respect to PCBs.

1.4.3.3 Great Lakes Areas of Concern

Coinciding with passage of the CWA, the Great Lakes Water Quality Agreement (GLWQA) was signed by the United States and Canada in 1972 and amended in 1978 and 1987. The GLWQA established specific goals and remedial objectives for improving water quality within the Great Lakes Basin. Forty-three AOCs were identified for further assessment and management of Great Lakes water quality. The lower Green Bay and Lower Fox River were designated as an AOC. This AOC includes the Lower Fox River from the De Pere dam to the river mouth (11.3 km [7 mi]) as well as the southern portion of Green Bay.

The lower Green Bay Remedial Action Plan (RAP) (WDNR, 1988) established goals, objectives, and a community frame-work for implementing remedial actions for the lower Green Bay and Fox River AOC. The RAP effort was led by the WDNR with a Citizens Advisory Committee and Technical Advisory Committee, both comprised of representatives of the public and private sectors. Sixteen key actions and 120 associated recommendations were identified to restore the beneficial uses of system. High priority actions included the following:

- Reducing phosphorous and sediment loads to the bay
- Eliminating the toxicity of industrial and municipal discharges and the impacts of contaminated sediment
- Continuing efforts to restore the river's oxygen levels to improve fish habitat

WDNR, the EPA, and U.S. Fish and Wildlife Service (USFWS) have conducted evaluations of PCB contamination in sediment, fish, and wildlife in the Lower Fox River and Green Bay. Due to bio-accumulation of PCBs in fish and fish-eating predators, the WDNR issued the first fish consumption advisory for the area in 1976, while the state of Michigan issued the first Green Bay fish advisory in 1977. Eliminating sediments as a source of PCBs was one of the high priority items established by the RAP. Other significant sources of lake and river water quality degradation include deposition of airborne pollutants, such as PCBs, metals, and PAHs, and polluted runoff, which contributed total suspended solids (TSS) which increase eutrophic conditions within the inner bay (WDNR, 1988).

In addition to the lower Green Bay and Fox River AOC, the Menominee River AOC is located in Green Bay along the shores of the cities of Marinette, Wisconsin and Menominee, Michigan. The Menominee AOC includes the lower 4.8 km (3 mi) of the river from the Upper Scott Paper Company dam (Wisconsin) to the river's mouth and approximately 5 km (3 mi) north and south of the mouth along the adjacent shore of Green Bay. The primary cause of the identified use impairments is arsenic contamination in the turning basin and in sediments along the right bank of the river below the location of the chemical company in Marinette, Wisconsin. Other pollutants, such as mercury, PCBs, and oil and grease have also contributed to use impairments. Although PCBs are present in this AOC, the contribution of PCBs to Green Bay from the Menominee River is far less than from the Lower Fox River. Therefore, the Menominee River AOC is not addressed further in this RI report.

1.5 Application of NRC Findings and Recommendations

Based on national and growing concern regarding the long-term management of PCB-contaminated sediments, the National Academy of Sciences (NAS) was mandated by the United States Congress, via the National Research Council (NRC), to address the complexities and risks associated with managing

PCB-contaminated sediments. The NRC was tasked with reviewing the availability, effectiveness, cost, and effects of technologies used for the remediation of sediments containing PCBs. The results of their findings were published in a document titled *A Risk Management Strategy for PCB-contaminated Sediments* (NRC, 2001). Based on their review of PCB effects at several sites nationally, the NRC also concluded that PCBs in sediment pose a chronic risk to human health and the environment, and that these risks must be managed. The NRC developed a list of recommendations that captured a need for remedies that should be site-specific and risk-based, and that no one remedy (dredging, capping, or monitored natural recovery) is applicable or preferred for all sites.

The recommendations of the NRC were adapted by the EPA in a document titled, *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA, 2002). EPA used the guiding principals defined by the NRC to develop a set of 11 risk management principles for application at CERCLA or RCRA sediment sites. The EPA guidance principles specify use of scientific, risk-based, site-specific remedy decisions using an iterative decision process, as appropriate, which evaluates the short-term and long-term risks of all potential cleanup alternatives. These principles are also consistent with the nine remedy selection criteria defined in the National Contingency Plan (NCP) (40 CFR Part 300.430) and application of these principles does not affect existing statutory and regulatory requirements. A comparison of the NRC-developed and the EPA sediment management principals is given in the white paper titled, *Applicability of the NRC Recommendations and EPA's 11 Management Principles*, which is included in the Responsiveness Summary.

The Lower Fox River and Green Bay RI/FS followed the guidance set forth by both the EPA and the NRC. These included:

- Structuring the documents so that a range of site-specific risks to human health and the environment were delineated, and articulating Remedial Action Objectives (RAOs) around which to structure potential remedial alternatives.

- Using an extensive body of site-specific scientific information and data to bound the problem, and by calibrating and defining the uncertainty of models that were used in the risk assessment and feasibility study.

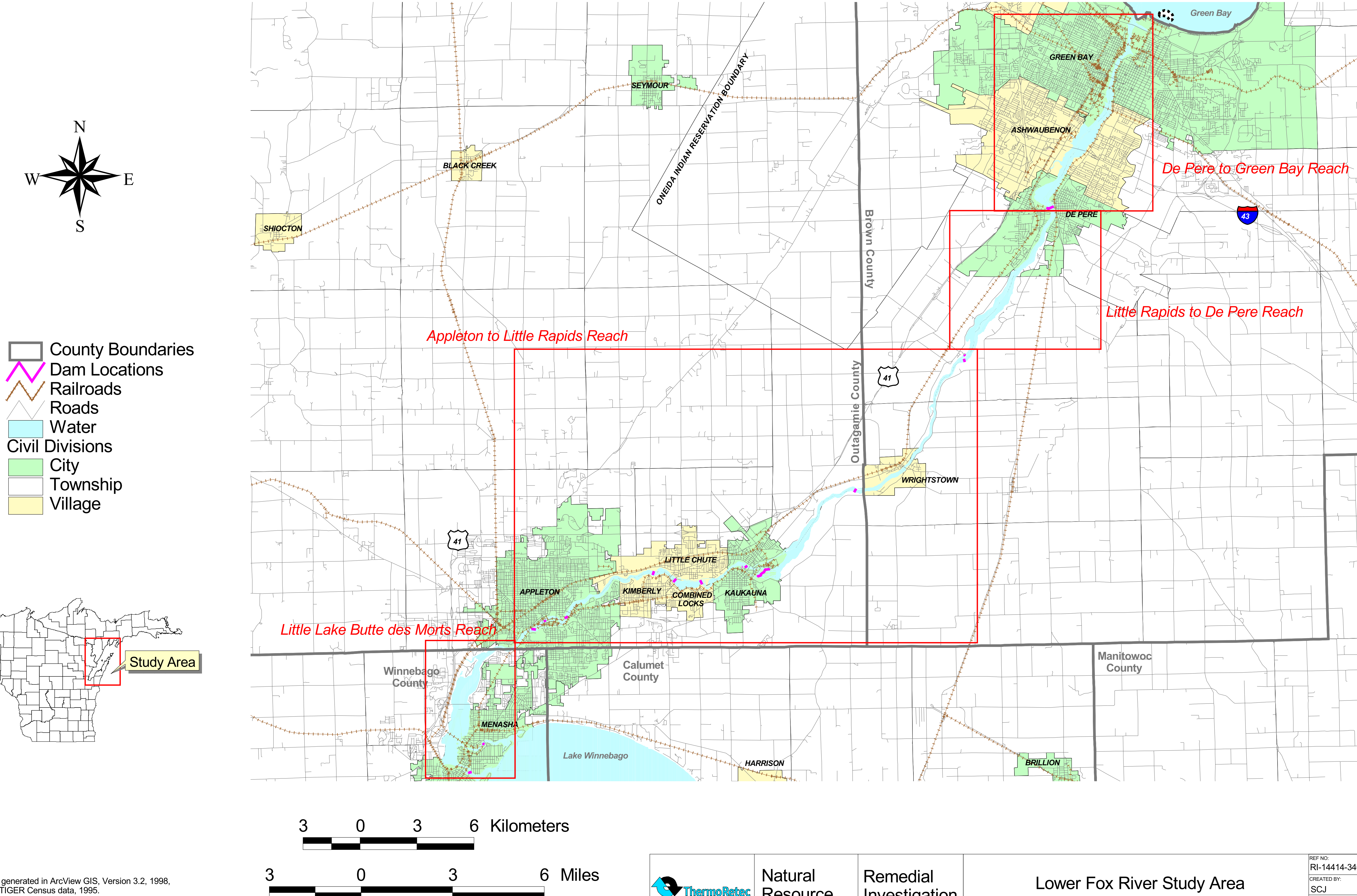
- There are no presumptive remedies. All potential remedial alternatives (including natural attenuation) are evaluated using a range of risk-based sediment clean up values. Local site conditions, feasibility, and estimated long-term risk reduction were defined and estimated for several remedial alternatives (dredging, capping, natural recovery) and carried forward in the FS. Selection of a final remedy will be a management decision defined in the Remedial Action Plan and Record of Decision (ROD),

EPA's 11 risk management principles also are covered by the above bullet, as well as through public involvement, development of sophisticated fate, transport, and bioaccumulation models, early involvement of trustee groups, and implementation of three demonstration projects to test potential remedial technologies.

1.6 Section 1 Figures

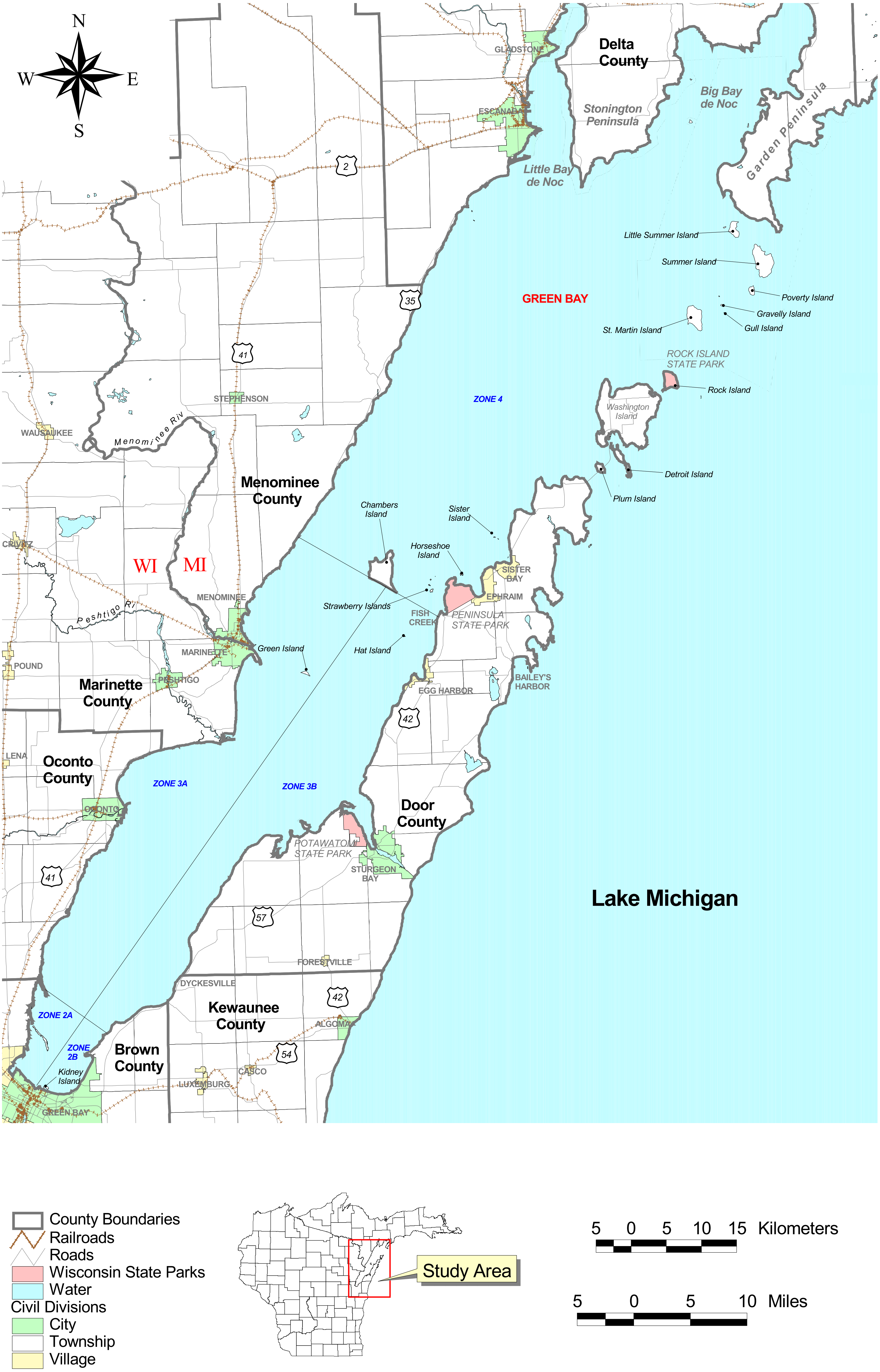
Figures for Section 1 follow this page, and include:

Figure 1-1 Lower Fox River Study Area
Figure 1-2 Green Bay Study Area
Figure 1-3 Little Lake Butte des Morts Reach
Figure 1-4 Appleton to Little Rapids Reach
Figure 1-5 Little Rapids to De Pere Reach
Figure 1-6 De Pere to Green Bay Reach



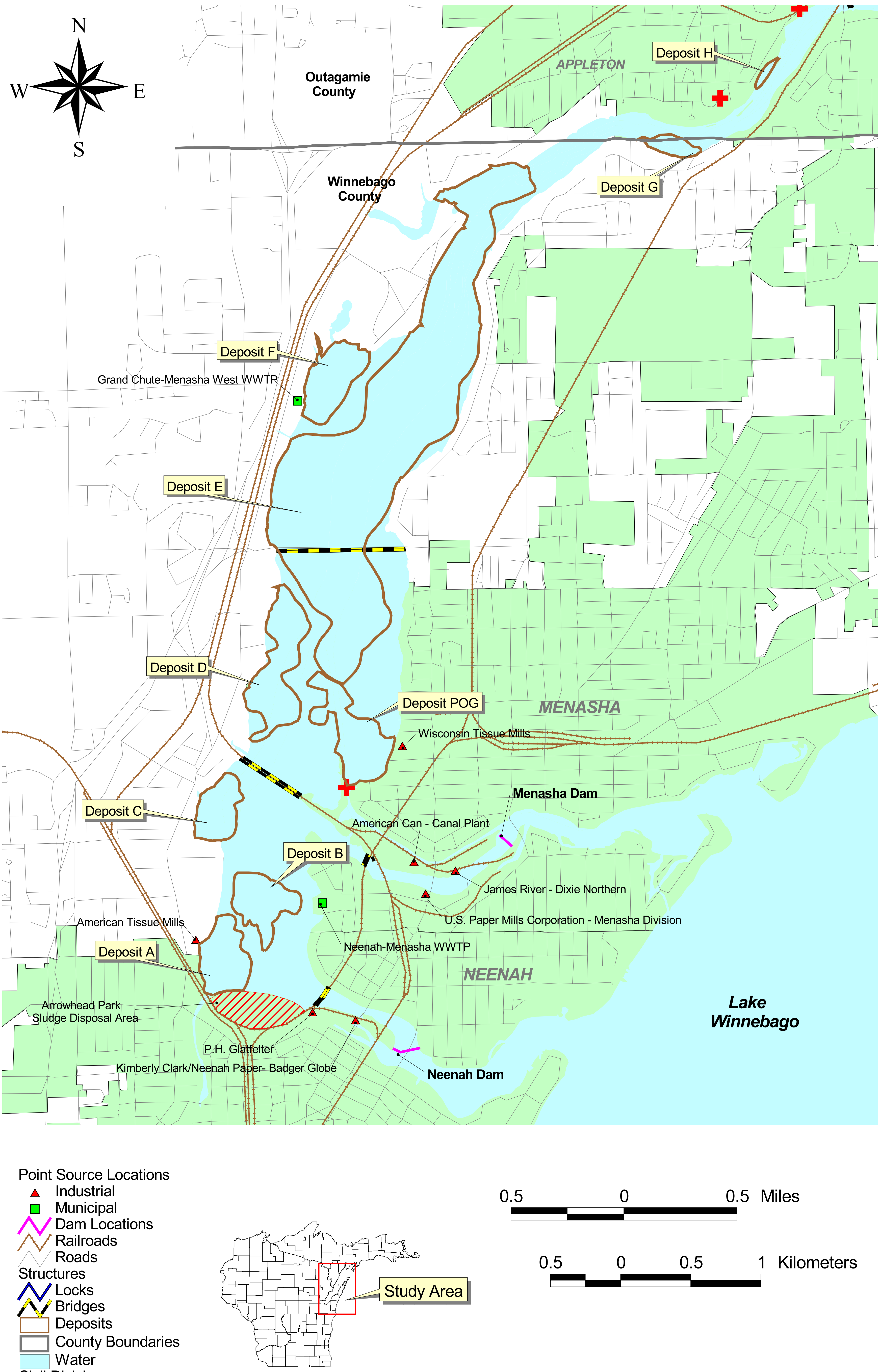
NOTE:
Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.

ThermoRetec *Smart Solutions. Positive Outcomes.*	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Study Area FIGURE 1-1	REF NO: RI-14414-340-1-1 CREATED BY: SCJ PRINT DATE: 3/14/01 APPROVED: AGF



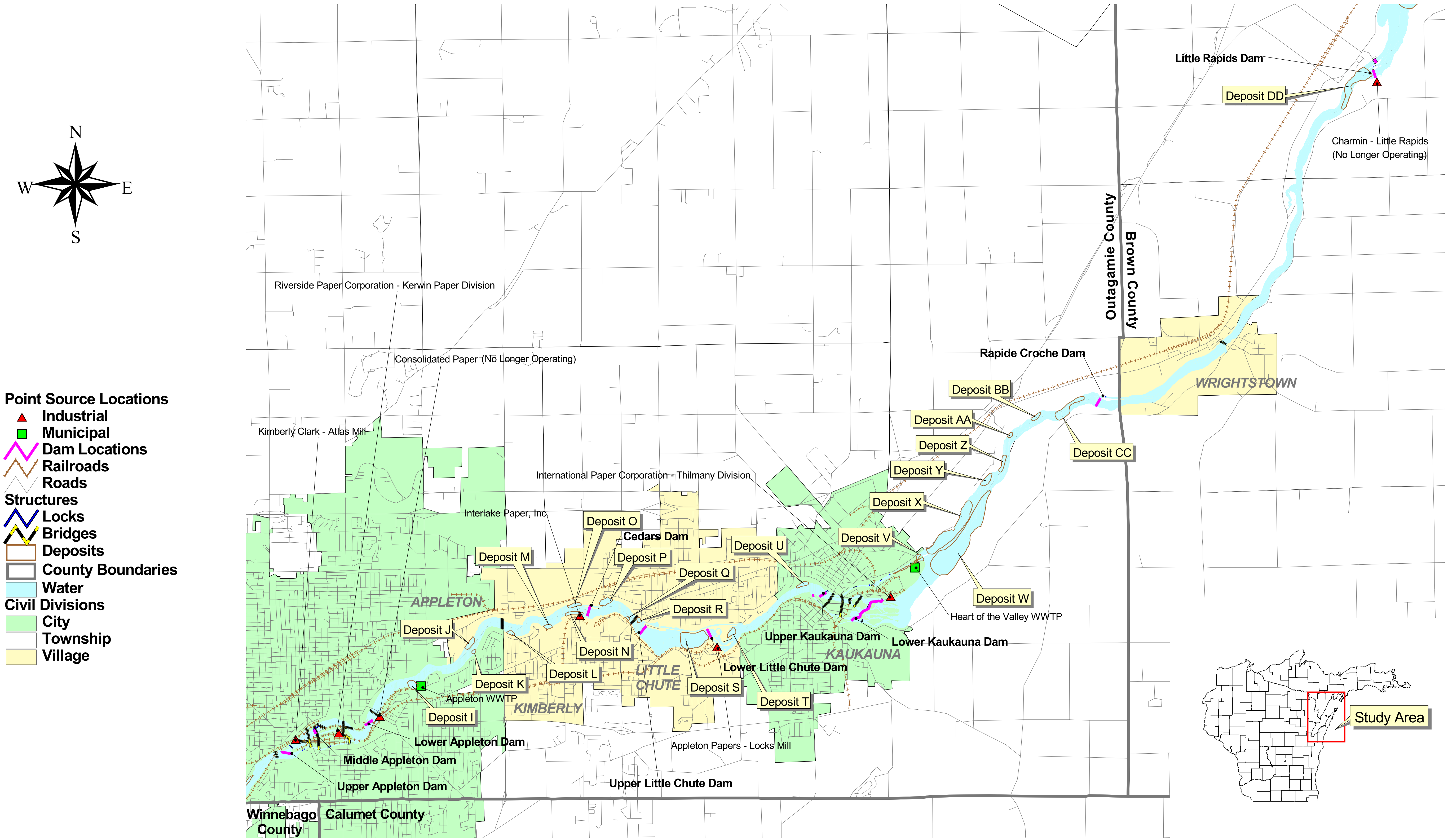
NOTE:
Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Study Area	REF NO: RI-14414-340-1-2
				CREATED BY: SCJ
				PRINT DATE: 3/14/01
			FIGURE 1-2	APPROVED: AGF



NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Little Lake Butte des Morts Reach	REF NO: RI-14414-340-1-3
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 1-3	APPROVED: AGF

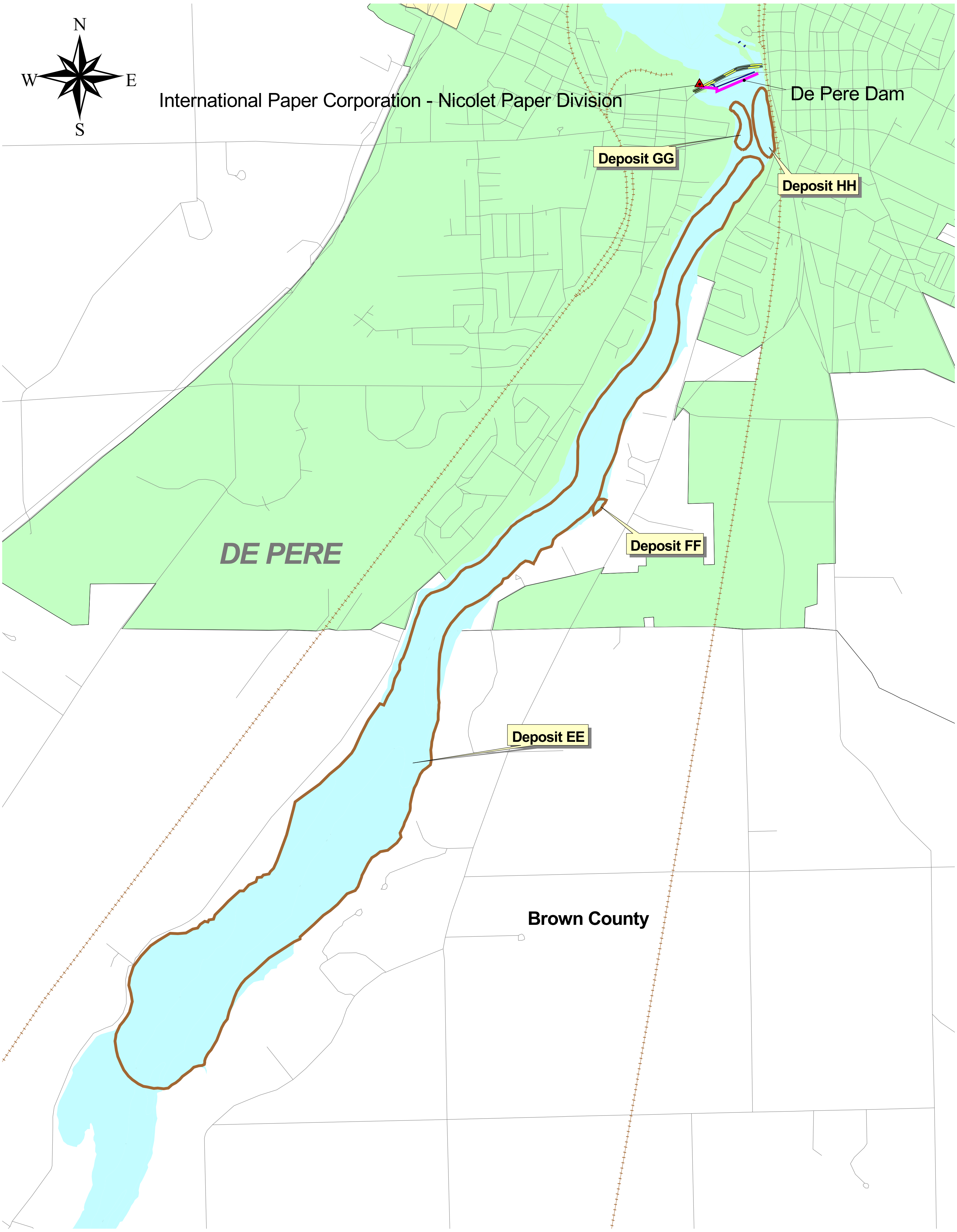


1 0 1 2 3 Kilometers

1 0 1 2 Miles

NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

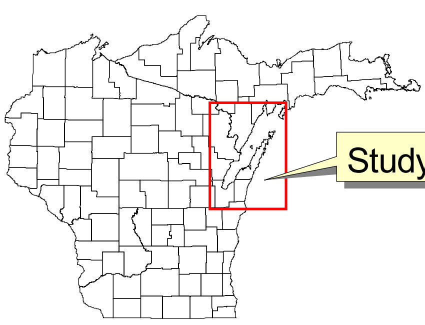
ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Appleton to Little Rapids Reach	REF NO: RI-14414-340-1-4
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 1-4	APPROVED: AGF



Point Source Locations
- Industrial
- Municipal
- Dam Locations
- Railroads
- Roads

Structures
- Locks
- Bridges
- Deposits
- County Boundaries
- Water

Civil Divisions
- City
- Township
- Village

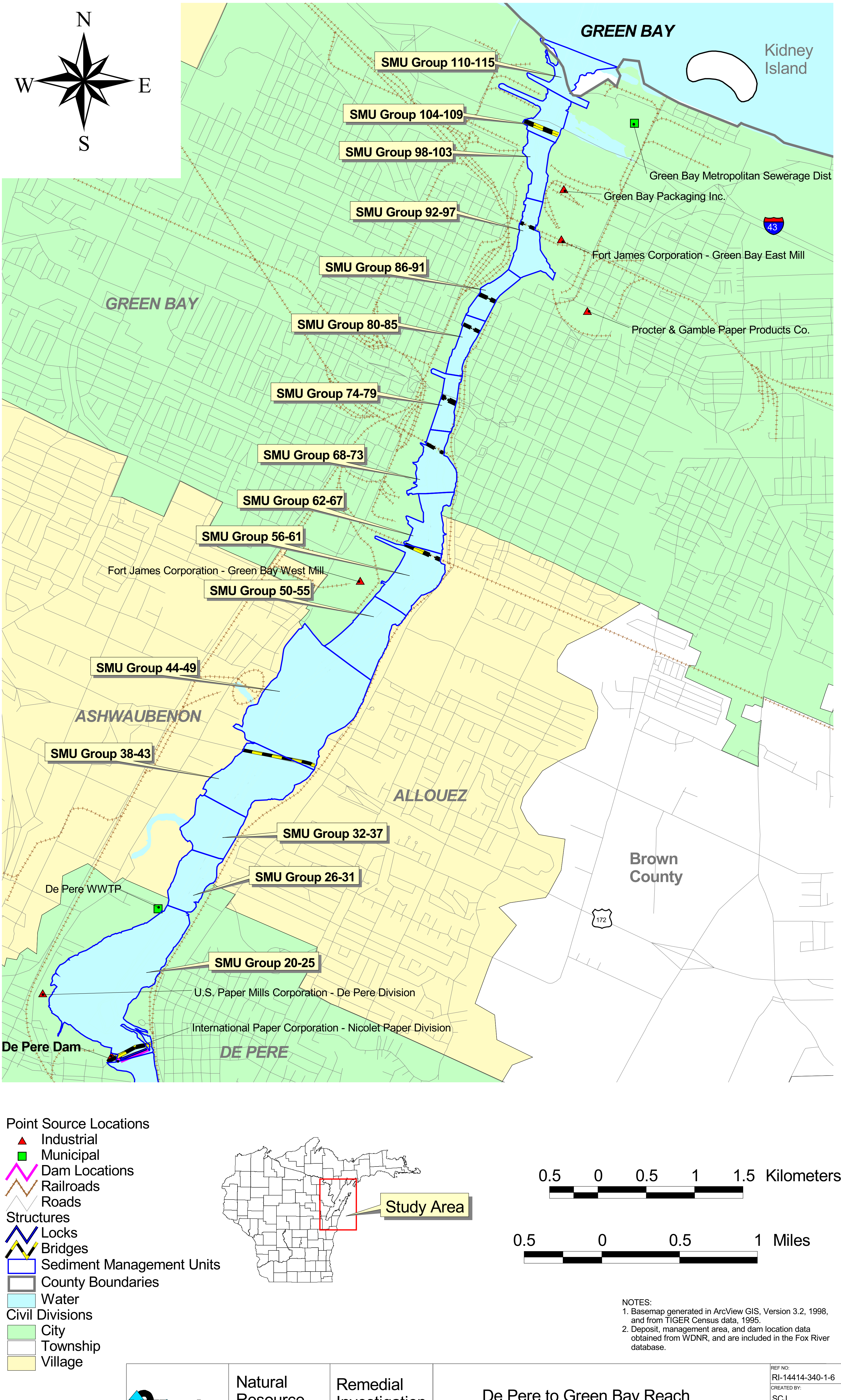


0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Little Rapids to De Pere Reach	REF NO: RI-14414-340-1-5 CREATED BY: SCJ PRINT DATE: 3/7/01 APPROVED: AGF
			FIGURE 1-5	



NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	De Pere to Green Bay Reach	REF NO: RI-14414-340-1-6
			FIGURE 1-6	CREATED BY: SCJ
				PRINT DATE: 3/7/01
				APPROVED: AGF

2 Database and Investigation Summaries

Data have been collected from the Lower Fox River and Green Bay during numerous sampling events over a ten-year period. The *Data Management Summary Report* (DM Report) (EcoChem, 2000) presents the 35 studies which comprised the original Fox River Database (FRDB). EcoChem also completed an evaluation of five additional data sets from 2000 and 2001 which were added to the final FRDB. The evaluation is presented in the *Addendum to the Data Management Summary Report* (DMR Addendum) prepared by EcoChem (EcoChem, 2002). The DM Report and DMR Addendum are included as Appendix A. This section briefly summarizes the data contained within the FRDB and presents some of the larger studies that contributed to the database. The general conclusion of the DM Report is that almost all of the data gathered during previous investigations and included in the FRDB is of good quality.

After the draft RI and DM Reports were released in February 1999, the EPA authorized a peer review of these documents by Roy F. Weston, Inc. (Weston). The general conclusions of the peer review included the following:

1) The quantity and quality of data are good enough to support the need for cleanup action;

2) The data are adequate to determine the distribution of contaminants within the system and direct where cleanup actions should focus; and

3) The data are adequate to support identification and selection of possible remedy technologies (Weston, 1999).

Data included in the FRDB were collected during localized and regional studies pertaining to water and sediment quality, biological count and diversity studies, biological tissue sampling efforts, stream flow, and anthropogenic impacts on river quality and bio-diversity in the watershed. The WDNR, USFWS, EPA, academic researchers, and other public and private groups completed these studies. This RI utilizes the sediment and water quality data which meet data quality objectives established for the project in the *June 1998 Work Plan* (RETEC, 1998a) and the *Quality Assurance Project Plan* (QAPP) (RETEC, 1998b). The main sediment studies from which the FRDB has been derived are summarized below.

This RI focuses mainly on sediment and water sampling results within the Lower Fox River and Green Bay. Although there is a significant amount of fish/bird tissue and other biological sampling data in the FRDB, these data are only summarized herein. The detailed analysis of ecological (biological) sampling and trends are presented in the RA and the *Time Trends Analysis*, included as Appendix B. The RI only introduces the studies that collected these data and provides a brief summary of the PCB concentrations in the ecological samples.

2.1 Data Quality Evaluation

The studies composing the FRDB are listed on Table 2-1, along with information pertaining to the type and quantity of data collected. All the data included in the FRDB have been subject to a validation process to evaluate the RI/FS/RA database quality. Additional details regarding the data quality review are described in the DM Report (EcoChem, 2000). The DM Report classifies data sets used for the FRDB as follows:

- **Useable Data** - data have been thoroughly assessed through review of the analytical data itself and associated quality assurance/quality control (QA/QC) documents. The data are of known and verifiable quality.

- **Supporting Data** - supporting data have not been subjected to as rigorous an assessment as the useable data. As such, the precise data quality is not known. This is due to insufficient or incomplete QA/QC information available at the present time. In these cases, QA/QC information may or may not exist. The collection and assessment of this information might render the data fully useable. Until a full data validation is conducted, these data should be used for supporting purposes only.

- **Indeterminate Data** - status of a data set is described as indeterminate if: it is unknown whether the data set has been validated, and/or, QC data to support validation is not available.

Both the "Useable" and "Supporting" data sets are used in this RI. EcoChem has provided these data for use in the RI and the resulting analysis of the data presented in this document (particularly Section 5) uses the data as received, unless otherwise noted.

Although all but one of the data sets listed in Table 2-1 were classified as either usable or supporting, individual data points were rejected due to QA/QC failure. These rejected data points have not been used in the RI/FS/RA. The Ankley and Call data is the only indeterminate set in the FRDB.

2.2 Sediment Investigations Included in the FRDB

2.2.1 1989-1990 Fox River Mass Balance Study Data and 1989-1990 Green Bay Mass Balance Study Data

In 1989-90, EPA and WDNR conducted sediment and water sampling activities in the Lower Fox River and Green Bay as part of the Green Bay Mass Balance Study (GBMBS). The GBMBS was designed to identify the sources, transport paths, and fate of PCBs in the Lower Fox River and Green Bay. Important components of this effort were two PCB transport models that evaluated and modeled the transport pathways and fate of PCBs in the Lower Fox River and Green Bay. The Upper Fox River (UFR) Mass Balance model evaluated the transport and fate of PCBs between LLBdM and the De Pere dam. Similarly, the Lower Fox River (LFR) Mass Balance model evaluated the transport and fate of PCBs from the De Pere dam into Green Bay. A discussion of these modeling efforts is included in Section 6.

The GBMBS evaluated PCBs, lead, cadmium and dieldrin in the De Pere to Green Bay Reach and Green Bay while efforts upstream of the De Pere dam were limited to evaluating and modeling PCBs (including specific PCB congeners). The GBMBS objectives included:

- Mapping soft sediment deposits and quantifying the current PCB mass in the bottom sediments.

- Collecting data over a one-year period for use in calculating PCB fluxes into and out of the river system, including inputs from permitted wastewater dischargers, landfills, groundwater, urban runoff, Lake Winnebago, atmospheric input and resuspension of in-place polluted sediments. Outputs included transport over De Pere dam and volatilization.

- Increasing the understanding of the physical, chemical, and biological processes that affect the above fluxes.

- Developing a model describing the above processes, and calibrating and validating the model using a comprehensive set of physical and chemical data.

- Conducting predictive simulations to assist in the assessment of specific management scenarios and in selection of specific remediation strategies.

In the Lower Fox River, monitoring and quality assurance programs were developed during 1986 and 1987, and sampling began in 1988. Field work occurred from April 1989 to April 1990 along with data set management and model development. From 1990 to 1992, samples were analyzed, data interpreted, and modeling conducted. As part of this effort, areas with accumulated sediments were identified through poling efforts. This effort identified the sediment deposits outlined on Figures 1-3 through 1-5 and the almost continuous presence of sediment below the De Pere dam (Figure 1-6). Based on the presence of soft sediments within a given area/location, a sample was collected for laboratory analysis of PCBs and other parameters.

A similar time-frame was followed for Green Bay, except that sediment sampling in Green Bay occurred between 1987 and 1990 (Manchester-Neesvig, *et al.*, 1996). Also, due to the areal expanse of Green Bay, 169 sediment sampling stations were established using a 5 km x 5 km (3.1 mi x 3.1 mi) grid. The presence or absence of soft river/bay sediments was established using a Ponar Grab sampler. Based on the presence of soft sediments, a core sample was collected for analysis of PCBs. Although 169 sampling stations were established (based in the 5 km grid), a grab or core sample was collected from only 123 stations and of these, cores from only 64 locations were analyzed for PCBs (Manchester-Neesvig, *et al.*, 1996).

Sediment cores collected from both the Lower Fox River and Green Bay were sliced into as many as 28 individual samples. These samples were submitted for laboratory analysis and provided data on the PCB concentrations throughout the sediment profile. In many instances, these sediment slices represented 1 or 2 cm intervals in the profile and the thickness was based on the total length of the recovered sediment core.

The initial 1989-90 Lower Fox River sediment sampling results indicated that approximately 3,900 kg (8,600 pounds) of PCBs are distributed in about 2,100,000 cubic meters (m^3) or 2,745,000 cubic yards (yd^3) of sediment between Lake Winnebago and the De Pere dam. Of this amount, approximately 50 percent of the PCB mass (1,950 kg [4,300 pounds]) was located in LLBdM (WDNR, 1995). Based on the presence of a continuous layer of sediment extending from the De Pere dam to the mouth of the river, the WDNR collected additional samples downstream of the De Pere dam in 1995. Information pertaining to this sampling event is presented in Section 2.2.6.

In Green Bay, the PCB data were evaluated to provide an estimate of the PCB mass and volume of contaminated sediments. Based on the PCB results, Manchester-Neesvig, *et al.*, (1996) estimated that approximately 8,500 kg (18,740 pounds) of PCB are present in the bay. The majority of the PCB within the bay was estimated to be located along the east shore, from the mouth of the river to approximately Little Sturgeon Bay. Manchester-Neesvig, *et al.,* (1996) also estimated that in order to even remove 20 percent (about 1,700 kg) of the PCB in the bay would require dredging approximately 14 million m^3 (18.3 million yd^3). These results reflect the large diffuse nature of PCB contamination within Green Bay.

Other results indicate that significant factors affecting PCB transport appear to be the concentration and composition of suspended particulate matter, the initial PCB concentration in sediments, and river flow. These factors interact in complex ways and the deposition and resuspension of particulate matter largely controls PCB transport. Under typical flow conditions, the average PCB concentrations in water samples ranges from 4 nanograms per liter (ng/L or parts per trillion) flowing out of Lake Winnebago to an average of 47 ng/L in the De Pere to Green Bay Reach. PCBs are suspended and/or dissolved in the water column as flow moves downstream towards Green Bay. During summer, water sample PCB concentrations range between 50 and 90 ng/L at the De Pere dam. However, in winter, the PCB concentrations are approximately 10 percent of the summer values, indicating a strong seasonal variation (Fitzgerald and Steuer, 1996). In addition, when river flow is at its highest due to storm events or spring runoff, the PCB concentrations in water may exceed 100 ng/L. Based on the seasonal variations in PCB concentrations, it is estimated that more than 60 percent of the PCBs transported over the De Pere dam occurs during 20 percent of the year, when discharge is at its greatest (Fitzgerald and Steuer, 1996).

Based on the seasonal variation in water column PCB concentrations, water samples were collected and analyzed for concurrent concentrations of chlorophyll a, the most common algal pigment. Results of these samples indicate that there may be a link between algal productivity and water column PCB concentrations (Fitzgerald and Steuer, 1996). This potential link may suggest that algal production, predation, sinking, and other dynamics may be an important process facilitating the transport and ultimate fate of PCBs in the river. Additionally, bioaccumulation of PCBs by algae may provide a pathway for PCBs into the food chain and other organisms.

The GBMBS modeling efforts identified the location and magnitude of PCB contaminated sediment, evaluated areas contributing to transport and fish consumption advisories, and was used to predict future PCB concentration changes, with and without human intervention, over 25 years (Velleux and

Endicott, 1994; WDNR, 1995). This effort indicated that river sediment is the most significant continued source of PCBs in the river.

2.2.2 1994 Woodward-Clyde Deposit A Sediment Data

WDNR contracted with Woodward-Clyde Consultants (WCC-formerly EWI Engineering Associates) to perform an RI/FS for Deposit A. Based on the results of this effort, WDNR selected dry sediment removal as the remedial alternative for addressing PCB contaminated sediments from Deposit A (Figure 1-3). Dry sediment remediation includes enclosing Deposit A with a temporary cofferdam followed by the dewatering, treatment, and landfilling of the PCB contaminated sediments.

WCC collected additional sediment samples from 14 locations previously containing PCB levels above 50 ppm. Fifteen geotechnical soil borings were completed to further classify sediment and soil in the areas to be remediated, to measure index and engineering properties, to characterize the sediment and underlying soil interface, and to evaluate the presence or absence of more permeable zones within the underlying soil. Results of the geotechnical evaluation indicated that the soil underlying the sediments were softer than indicated by previous data; however, WCC concluded that the cofferdam could be constructed using sheetpile, earth berm, or portable dam alternatives (WCC, 1994 and 1996).

Several bench scale tests were conducted to evaluate the effort involved with preparing the impacted sediments for disposal. The objectives of the sediment handling operations included reducing the sediment weight and volume through drainage and evaporation and to dry and/or solidify the sediments sufficiently for off-site transportation, handling, and landfill disposal. The test results indicated the sediments could be dried relatively quickly, especially when mixed and heated; also, the sediments could be effectively solidified with a bentonite and cement mix at the existing water content.

2.2.3 1992/93 BBL Deposit A Sediment Data

On behalf of the P.H. Glatfelter Company, Blasland, Bouck, & Lee (BBL) performed an RI/FS for LLBdM Sediment Deposit A in 1992/93 (Figure 1-3). BBL conducted additional sediment sampling in Deposit A as well as a baseline human health and ecological risk assessment which evaluated the risks associated with exposures to surface water, sediment, and fish ingestion. BBL used WDNR fish samples collected through 1992 as the basis for this evaluation.

The main findings of the BBL RI/FS included the following: 1) All locations exhibited decreasing PCB concentration with depth with Aroclor 1242 being the primary PCB detected in sediment; and 2) Ingestion of fish posed the greatest risk for exposure.

2.2.4 1993 Triad Assessment

This sediment study sought to characterize soft sediments in the Lower Fox River using the sediment quality triad approach. Using triad and weight of evidence approaches, WDNR applied sediment quality guidelines (SQGs), human health criteria, and wildlife criteria for the protection of benthic life within the Lower Fox River (WDNR, 1992). These three criteria were used to evaluate the degree of sediment contamination. This approach assessed sediments by determining the presence and degree of anthropogenic contamination (bulk chemistry), by assaying the effects of sediments on normal function (growth, reproduction, survival) of standard test organisms, and by assessing in-situ alterations of the benthic community structure (WDNR, 1996).

In 1992 and 1993, sediments were collected from 10 deposits between Lake Winnebago and Green Bay and the following chemical parameters were analyzed: PCBs; chlorinated pesticides; volatile organic compounds (VOCs); semi-volatile organic compounds (SVOCs), including PAHs and PCP; metals; and ammonia. Additionally, physical characteristics of the sediment were recorded, sediment toxicity was analyzed using acute and chronic bioassays, and macroinvertebrate community structure was examined.

Sediment enrichment factors (SEFs) were calculated by dividing the sediment concentrations in a deposit by a reference sediment concentration to compare chemical composition between deposits. All deposits were found to be chemically enriched by certain constituents and PCBs were the primary constituent that resulted in elevated SEF values. Mercury, total PAHs and ammonia were also found to be enriched in all deposits analyzed. Other enriching contaminants were found in some but not all deposits.

Acute and chronic toxicity testing was also completed. The acute toxicity testing results revealed very low mortality to Ceriodaphnia dubia and Daphnia magna as survival exceeded 90 percent and 70 percent, respectively; Hylella azteca was the most sensitive indicator of acute toxicity with significant mortality rates at five of the ten test sites. The chronic toxicity testing results indicated that both Daphnia magna and Chironomous tentans were adversely affected and exhibited reductions in survival, reproduction, and growth rates (WDNR, 1996).

Macroinvertebrate investigations were inconclusive because of deposit abundance variability, unidentified worm taxa dominant in most deposits, and physical substrate differences. Bioassay tests indicated both acute and chronic toxicity for several deposits throughout the length of the river. The deposits with maximum contaminant concentrations were not always the same as deposits with the maximum toxicity or benthic impact. It was reasoned that this could be due to other factors that can influence toxicity that were not measured, including: dissolved oxygen in the pore water and overlying water; pH levels; substrate variation and/or other confounding factors such as sampling season; specific concentrations of contaminants based on vertical profiles; availability of microfauna for food; nutrient fluxes; and algal growth.

2.2.5 1994 GAS/SAIC Sediment Data

In 1994, WDNR and the Fox River Coalition (individuals representing both public and private sector interests), jointly undertook completion of an investigation of the upper three reaches of the Lower Fox River. Graef, Anhalt, Schloemer & Associates Inc. (GAS) and Science Applications International Corporation (SAIC) were contracted to identify the lateral and vertical extent of PCBs and mercury within bottom sediments at selected deposits upstream of the De Pere dam (GAS and SAIC, 1996). The deposits were selected by WDNR based on a ranking system that included transport, bio-availability and PCB mass as well as other considerations. The deposits studied included: 1) Deposit POG, located on the east side of LLBdM; 2) Deposits D and E, located on the west and north ends of LLBdM; 3) Deposit N, located near the city of Kimberly; and 4) Deposits EE, GG, and HH, located just upstream of the De Pere dam. In addition to identifying the extent and magnitude of PCBs and mercury in sediments, a baseline ecological and human health risk assessment and a preliminary assessment of feasible remedial alternatives were completed.

2.2.6 1995 WDNR Sediment Data

This study was funded and carried out by the WDNR, EPA Great Lakes National Program Office (GLNPO), and the Fox River Coalition. During the 1989-90 sediment sampling activities, a large, continuous sediment layer, which extended from the dam to the mouth of the river, was found in the De Pere to Green Bay Reach. Based on the 1989-90 sediment sampling data, it was estimated that this reach contained between 80 percent and 90 percent of the total PCB mass in the Lower Fox River. Due to the significance of sediments as a continuing source of PCBs, WDNR concluded that sediments downstream of the De Pere dam required further characterization in order to adequately model and predict PCB fate and transport from the river into Green Bay. The primary objectives of the 1995 sampling effort (WDNR, 1998) include the following:

- To further define and quantify the PCB sediment distribution downstream of the De Pere dam to Green Bay

- Estimate the mass and volume of PCB containing sediments and develop maps of PCB distribution in the Lower Fox River

- Provide data to enable further refinement of the PCB transport models for the Lower Fox River

- Provide further basis for making sound management decisions throughout the Lower Fox River and into Green Bay

- Support the Fox River Coalition's effort to prioritize contaminated sediment areas and remediate sites in the Lower Fox River

- Implement a Green Bay Remedial Action Plan recommendation for developing a cleanup strategy for the Lower Fox River sediments

WDNR analyzed hundreds of samples for PCBs, total organic carbon (TOC), moisture content, and particle size (plus QA/QC samples). Sediments containing more than 1,000 microgram per kilogram (μg/kg) (1 ppm) of PCB were detected as deep as 200 cm (78.7 inches) below the river bottom and the PCB concentrations above these locations were not significantly lower. WDNR (1998a) estimated that approximately 26,000 kg (57,320 pounds) of PCB was present in this reach.

2.2.7 1996 FRG/BBL Sediment/Tissue Data

In 1996, BBL performed limited sediment sampling in the same deposits investigated by GAS/SAIC on behalf of the FRG. BBL collected eight sediment samples from deposits POG, N, GG and a reference site. These samples were analyzed for PCBs and TOC.

2.2.8 Sediment Remediation Demonstration Projects Data

Two Sediment Remediation Demonstration (SRD) Projects were conducted between 1998 and 1999 at Deposit N and SMU 56/57 to assess the effectiveness of sediment remediation using dredging techniques in the Lower Fox River.

The Deposit N SRD project, located near the town of Kimberly, was funded and completed through an agreement between the WDNR, EPA GLNPO, and the Fox River Coalition. The Deposit N SRD project was successfully completed to design specifications and achieved the target goals for the project. Deposit N sediment data is included in five different sets in the FRDB (Table 2-1). These data sets include the 1997 Demonstration Project Data, 1998 Deposit N Pre- and Post-Dredge Data, the Operational Monitoring Data, and the 1998/1999 Remediation Data.

The SMU 56/57 SRD project located downstream of the De Pere dam, was conducted on behalf of the WDNR and the FRG, with funding provided by the FRG. However, because the targeted design depths were not achieved only part of the designated PCB mass was removed. The SMU 56/57 sediment data is included in the 1997 Demonstration Project Data Set in the FRDB (Table 2-1). Dredging equipment will be remobilized to SMU 56/57 during the summer of 2000 to remove the remaining PCB-contaminated material under administrative order between EPA and the Fort James Corporation (EPA, 2000a). Each of these demonstration projects is discussed briefly below and is detailed in the *Sediment Technology Memorandum* located in Appendix B of the FS.

The SRD projects assessed various phases of sediment remediation including dredging, dewatering, and disposal. The objectives of the SRD projects included the following:

- Assess the implementability, feasibility and cost of a full-scale sediment remediation project for other areas of the Lower Fox River

- Remove the bulk of PCB mass from impacted sediment located within two large hot spots of the Lower Fox River for source control

- Conduct a mass balance study of PCB mass transport during dredging activities to help assess dredging effectiveness

- Assess the extent of sediment resuspension during dredging and the downstream transport of PCB material along with the performance of containment systems and monitoring devices

- Collect technical information which will be useful during the final evaluation and selection of remedial alternatives such as: flow velocity, sediment characteristics, bulk density, extent of debris and obstructions, dewatering and treatment characteristics, and dredging costs.

2.2.8.1 Deposit N Demonstration Project

The former Deposit N is located within the city limits of Kimberly and adjacent to the Interlake Papers facility, on the south side of the river (Figure 1-4). Deposit N sediments were evaluated during both the WDNR 1989-90 and GAS/SAIC 1994 sampling efforts. Deposit N was estimated to be about 1.21 hectares (3 acres) in size and have an average PCB sediment concentration of 45 ppm. Water depths at the location were generally 244 cm (8 ft) deep and the average sediment thickness was about 61 cm (2 ft). Deposit N Sediment samples collected by Foth & Van Dyke (F&VD) indicated that total PCB results ranged from 550 to 130,000 μg/kg prior to remediation. F&VD estimated that approximately 142 kg (312 pounds) of PCBs were present in Deposit N (F&VD, 2000).

Remedial Action. Sediment removal was conducted using an 8-inch Moray/Utra hydraulic cutterhead dredge with a swinging ladder configuration, a rotating variable-speed cutter, and an intake/suction line. A special containment system was installed around the deposit to ensure that sediments resuspended during construction would remain within the dredged area and be removed in the cleanup process. The containment system consisted of a 80-mil high density polyethylene (HDPE) curtain anchored to the river bed and buoyed by flotation devices. The curtain acted as a flexible wall effectively preventing suspended sediments from flowing downstream with the current. The chronological summary of site activities at Deposit N is listed below.

Hydraulically dredged material was pumped through double-walled piping to the on-shore treatment system. Sediment slurry was screened to remove gravel and sand (>#200 sieve), conditioned with a polymer to increase the percent solids, then pumped into 200 pounds per square inch (psi) filter presses for compression. The compressed solid material was stockpiled and tested for PCBs, mercury, and percent solids. Water separated during pressing was treated through solid filtration and carbon adsorption prior to discharge back to the Lower Fox River.

Based on PCB concentrations relative to Toxic Substances Control Act (TSCA) standards, dried sediment was transported to either the Winnebago County Landfill (PCB concentration less than 50 ppm) or the Wayne Disposal landfill in Belleview, Michigan (PCB greater than 50 ppm) in 1998. During 1999, all dredged sediments were transported to the Winnebago County Landfill (Fitzpatrick, 2000).

Monitoring. The environmental monitoring program focused primarily on bathymetry surveys, sediment sampling, water quality monitoring during dredging, and post-verification surface sediment sampling. WDNR collected water samples during remediation activities to evaluate whether significant concentrations of PCBs were released from the sediment into the water column.

The Fox River Remediation Advisory Team (FRRAT) determined that the best method for assessing the effectiveness of dredging was a mass balance approach. The mass balance approach included three essential components: deposit mass balance, river transport, and process mass balance. Twenty surface sediment samples were used to assess residual concentrations and daily surface water samples collected from upstream and downstream transects at two depths were used to determine river transport (along with estimated flow measurements provided by USGS). Chemical analyses of the byproducts of the treatment products were used to determine PCB fate during the dredging process.

Results. Due to the presence of a hard bedrock substrate located beneath the soft sediments, the target goal of the demonstration project was to remove contaminated sediment down to a design depth of 7.5 to 15 cm (3 to 6 in [inches]) above bedrock. Approximately 5,475 m^3 (7,160 yd^3) of sediment and 50.3 kg (112 pounds) of PCBs were removed from Deposit N during 1998/1999 (F&VD, 2000). Overall, 82 percent of the PCB mass was removed from Deposit N and approximately 31 kg (68 pounds) of PCB remained in the sediments that were not accessible to dredging activities (F&VD, 2000).

The PCB mass balance study conducted during dredging activities (FRRAT, 2000), estimated that the resulting press cake material contained 96 percent of the PCBs removed from the deposit and that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river. The mass balance model did not measure an overall increase in mass of particles transported downstream during dredging (TSS), however, the PCBs transported on the particles did increase (increased net load of 2.2 kg PCB during the active dredging period).

Currently, there are no further plans for additional work at Deposit N. Data collected from Deposit N prior to completion of the SRD has been flagged in the FRDB and only post-remediation data was evaluated as part of the RI/FS and RA. According to WDNR, the remedial activities completed at Deposit N have essentially removed this deposit from the river (Fitzpatrick, 2000).

2.2.8.2 SMU 56/57 Demonstration Project

SMU 56/57 is located within the Green Bay city limits and adjacent to the Fort James Corporation facility, on the west bank of the Lower Fox River (Figure 1-6).

Based on the WDNR 1995 sediment sampling results, SMU 56/57 contained the highest PCB concentrations detected anywhere in the Lower Fox River and Green Bay. An estimated 3,000 kg (6,600 pounds) of PCBs were present within a total sediment volume of approximately 69,800 m^3 (91,300 yd^3) encompassing an area of approximately 3.7 hectares (9.3 acres) (Montgomery Watson, 1998). These sediments were estimated to contain approximately 10 percent of the total PCBs downstream of the De Pere dam, although the volume only represented about 1 percent of the estimated sediment volume downstream of the De Pere dam.

Results of the baseline sediment sampling collected by Montgomery Watson in 1998 indicated that most sediment cores contained PCBs throughout their entire length extending to almost 5 m (16 ft) in some areas. The laboratory results indicated that the highest PCB concentrations were generally located between a depth of 61 to 153 cm (2 to 5 ft) below the sediment surface. Total PCB concentrations ranged as high as 710,000 μg/kg. Approximately one third of the cores reached undetectable PCB concentrations at the deepest interval tested. Similarly, mercury concentrations increased with depth across the site. Concentrations averaged approximately 1 mg/kg in the 0 to 10 cm (0 to 4 in) interval and increased to approximately 7 mg/kg in the 274 to 305 cm (9 to 10 ft) interval.

Remedial Action. The SMU 56/57 dredging demonstration project began on September 1, 1999, with the objective of removing about 61,160 m^3 (80,000 yd^3) of impacted sediment. The target area was isolated from the rest of the river through the installation of an anchored silt curtain. Material was extracted from the riverbed using a hydraulic cutterhead and horizontal auger dredges and dewatered on-shore. Sediment was dewatered through equalization basins and filter presses then transported to an engineered landfill cell owned by the Fort James Corporation for disposal. Process water was treated with polymer, run through sand/carbon filters and discharged back to the river. The chronological summary of site activities at SMU 56/57 is provided below.

Equipment difficulties and the presence of large debris significantly slowed the pilot test progress. During early stages of the project, coal ships docking at the Fort James facility disturbed the silt curtain, ripping it from its moorings on at least one occasion. Also, the liner of one of the two settling ponds was damaged during October 1999 requiring use of that pond to be discontinued until the liner could be repaired. The initial goal of removing 61,160 m^3 (80,000 yd^3) was reduced by nearly half, due to increased costs caused by these and other delays. Dredging was suspended on December 15, 1999, due to ice on river and icing of the wastewater treatment system.

Monitoring. The environmental monitoring program focused primarily on bathymetry surveys, sediment chemistry sampling, and surface water quality monitoring. Post-dredging sampling activities were initiated on December 20, 1999 and continued through early January 2000. An acoustical bathymetry survey completed after suspension of the dredging activities indicated that approximately 22,940 to 23,700 m^3 (30,000 to 31,000 yd^3) of sediment were removed from the target area. A PCB mass balance study was conducted during dredging to compute the mass of PCBs discharged to the river during dredging. Samples were collected from the dredge slurry, dewatered solids, supernatant, and process water effluent.

Results. The target goal of the project was to dredge to a design elevation of 565 feet, mean sea level. Dredging to this design elevation was expected to remove sediments with PCB concentrations greater than 1 ppm. However, the target elevation was not achieved in any of the subunits within the dredge prism. Due to the difficulties encountered during dredging and the on-set of winter, the expected elevation was raised 2 to 3 feet in most areas. A final "cleanup pass" initially intended for all areas was only completed in four of the 59 subareas (WDNR, 2000a). In these areas, the final PCB concentrations in the newly exposed surface sediments showed a general decline compared with pre-dredging concentrations, and in some locations the final PCB concentrations were as low as 0.25 ppm. However, in other areas where no “final pass” was completed down to the targeted sediment elevations, the final PCB concentrations were higher (32 to 280 ppm) than baseline surface concentrations (2 to 5 ppm) (Montgomery Watson, 2000). In these areas, the final sediment elevations achieved were 30 to 230 cm (1 ft to 7.5 ft) above the targeted elevations.

Under an EPA Administrative Order by Consent (AOC No. V-W-00-C-596), the Fort James Corporation continued sediment remediation activities at SMU 56/57 during the summer, 2000. The dredging activities conducted in two phases:

- Phase 1 - removal of contaminated sediment from subunits that were previously disturbed (dredged) during the SRD project to SRD target elevations (estimated 15,290 m^3 [20,000 yd^3]).

- Phase 2 - removal of additional sediment from different subunits that were not disturbed during the SRD project.

The total in-situ dredge volume of the two phases will not exceed 38,225 m^3 (50,000 yd^3), given the need to preserve stable side slopes, not exceed the capacity of the landfill, and avoid leaving residual elevated PCB concentrations. Surficial sediments will be tested to determine if cleanup objectives (1 ppm PCBs) have been met. However, dredging activities will cease after the removal of 38,225 m^3 (50,000 yd^3) regardless of residual PCB concentrations.

Conclusions. Conclusions drawn from both SRD dredging projects indicate the following:

- Pre-dredging data provided sufficient resolution to define the lateral and vertical extent of contamination;
- Contaminated sediment can be removed within the river without increasing surface concentrations; and
- Partial cleanup left significantly higher PCB concentration in some surface sediments where the target elevation was not achieved.

The estimated PCB mass and sediment volume removed during the SMU 56/57 SRD project have been subtracted from the mass and volume estimates for the De Pere to Green Bay Reach in this RI (Section 5.4.2.6).

2.2.9 1998 FRG/Exponent Data and 1998 FRG/BBL Sediment/Tissue Data

During 1998, the FRG hired both BBL and Exponent Environmental Group (Exponent) to evaluate various aspects of the Lower Fox River and Green Bay. BBL collected at least 363 sediment samples for PCBs, with 116 of these samples being collected within Green Bay to supplement the 1989-90 GBMBS data. At least 520 water samples were collected and analyzed for PCBs present in unfiltered or filtered water or present on particulate in the water column. In addition, both BBL and Exponent collected just over 300 tissue samples. This tissue data is included in the FRDB and is discussed further in the RA.

Exponent also completed a Habitat Characterization Assessment of the Lower Fox River and southern half of Green Bay. The habitat characterization data and results are discussed further in Section 4.

2.2.10 1998 RETEC RI/FS Supplemental Data

Based on review of data from the above investigations, the Project Team and WDNR collected supplemental sediment samples in selected areas of the Lower Fox River and Lake Winnebago in June 1998. These data were collected for the following:

- Evaluate upstream background concentrations in sediments for selected chemical parameters
- Collect additional information for use in the RA
- Evaluate the physical properties of the sediments for use in the FS
- Provide additional chemical information from sediment deposits containing PCBs for comparison with other data sets used in the RI

The focus of this evaluation included 12 deposits upstream of the De Pere dam that were estimated to contain over 97 percent of the PCB mass within this stretch of the river (WDNR, 1995).

The supplemental sediment sampling activities were conducted between June 1 and 8, 1998. The sample collection procedures and laboratory analytical methods are listed in the *Quality Assurance Project Plan for Supplemental Data Collection, Lower Fox River RI/FS* (RETEC, 1998b). The sediment samples were collected and analyzed for the parameters listed on Table 2-2.

The 1989-90 WDNR sediment sampling results were used as the basis for further study of a number of the deposits. Five supplemental sediment samples were collected from deposits C, E, W, X, and EE. Deposits E and EE cover such long portions of the river bottom that additional sampling in each deposit was performed to supplement existing data. Samples were collected from the sediment surface to a depth of approximately 45 cm.

Five samples were also collected from the SMUs in the De Pere to Green Bay Reach that exhibited the highest PCB concentrations in 1995. Surface sediment samples were collected and analyzed for use in the RA and to compare the Aroclor concentrations with levels of other chemicals of potential concern (COPC).

Samples were also collected from Lake Winnebago as background data. The background samples from Lake Winnebago were collected in areas where significant deposits of soft sediment were found.

These data have also been utilized in the *Time Trends Analysis* (Mountain-Whisper-Light, 2001). The time trends analysis evaluates whether PCB concentrations in sediment, fish tissue, and bird tissue samples have changed over time compared to previously collected data.

2.2.11 Lake Michigan Mass Balance Data

The Lake Michigan Mass Balance samples were collected in 1994 and 1995. Sediment, water, tissue, and air samples were collected and were analyzed for PCB congeners, volatiles, pesticides/herbicides, metals and other inorganic parameters. Although this data set contains 6,987 samples, much of the data was collected outside of the Lower Fox River and Green Bay region.

2.2.12 Fox River Fish Consumption Advisory Data

This data set is primarily tissue data with a small number of sediment samples. The tissue samples were collected by WDNR in the Fox River and Green Bay between 1971 and 1996. The 1,766 samples in this set were analyzed for PCB congeners and Aroclors, metals, chlorinated pesticides, and dioxins.

2.2.13 USGS National Water Quality Assessment Program (NAWQA) Data

The NAWQA data represent 441 sediment, water, and tissue samples collected by the USGS between 1992 and 1997. These samples were analyzed for an extensive list of chlorinated pesticides and herbicides, organophosphorus pesticides, SVOCs, and metals. Approximately 90 percent of the samples in this set were collected from waterways other than the Fox River and these samples are noted as “reference.”

2.2.14 1997 WDNR Caged Fish Bioaccumulation Study Data

WDNR placed caged fish near Deposit N and SMU 56/57 prior to the start of the SRD projects. The fish and co-located sediment samples were collected and analyzed for PCB congeners. This data set consists of 25 fish tissue and sediment samples.

2.2.15 Minergy Mineralogical Data

The Minergy data are comprised of results from the analysis of 15 sediment samples for 11 different mineral oxides, sulfur, chloride, and other physical tests. None of these samples were analyzed for PCBs, dioxin, pesticide or SVOCs. Therefore, these data are of limited value in analysis of sediment impacts in the river or bay.

2.3 Ecological Sampling Studies

As indicated in Table 2-1, a number of studies that involved analysis of ecological (biological) samples for PCBs and other chemical compounds have been completed. The studies that included ecological sampling are listed below and have been divided into those studies in which only biological samples were collected and those studies that included biological sampling in addition to sediment and water sampling. The studies are listed by the total number of samples included in the FRDB (Table 2-1) and include the following:

Biological Sampling Studies

- State of Michigan Fish Consumption Advisory Data
- 1996 WDNR Fish Tissue Data
- 1998 WDNR Fish Consumption Data
- 1996-1999 USFWS NRDA Fish Tissue Data
- 1998 FRG/Exponent Data
- 1993 USFWS Tree Swallow Data
- 1994-1995 Cormorant Data
- WDNR Wildlife Tissue Data
- 1997 USFWS NRDA Waterfowl Tissue Data
- Stromberg Eagle Data Collection

Studies That Included Biological Sampling

- Lake Michigan Mass Balance Data
- 1989-90 Green Bay Mass Balance Study (GLNPO)
- Fox River Fish Consumption Advisory Data
- 1998 FRG/BBL Sediment/Tissue Data
- USGS NAWQA Data
- 1998 RETEC RI/FS Supplemental Data
- 1998/1999 Deposit N Sediment Remediation Data
- Ankley and Call (Indeterminate)
- 1996 FRG/BBL Sediment/Tissue Data
- 1997 WDNR Caged Fish Bioaccumulation Study Data

Biological sampling often included fish and bird tissue analysis. However, some studies also included analysis of bird eggshells and other biological specimens. Detailed analysis of ecological sampling and trends is presented in the *Time Trends Analysis* (Mountain-Whisper-Light, 2001) and the RA. Again, it should be noted that the Ankley and Call data are classified as indeterminate by the DM Report (EcoChem, 2000). Use of these data are discussed further in the RA.

2.4 Section 2 Tables

Tables for Section 2 follow this page, and include:

Table 2-1 Fox River Database Studies and Data Classification
Table 2-2 Lower Fox River - Supplemental Data Collection Sampling List

Table 2-1. Fox River Database Studies and Data Classification

Data Source	Number of Samples	Matrices[1]	Analyses Conducted[2]	Number of Records	Data Quality Classification
Lake Michigan Mass Balance Data	6,987	A,S,T,W	M, P/H,PCB-C, V, W	91,621	Supporting
1989/90 Green Bay Mass Balance Study (GLNPO)	2,069	S,T,W	B, PCB-C, W	201,701	Supporting
1989/90 Fox River Mass Balance Study	1,967	S,W	PCB-A, PCB-C, W	25,457	Supporting
Fox River Fish Consumption Advisory Data	1,766	S,T	B, DXN, M, P/H, PCB-A, PCB-C, SVOA, V, W	11,620	Supporting
1998 FRG/BBL Sediment/Tissue Data	1,315	S,T,W	B, M, P/H, PCB-A, PCB-C, RAD, SVOA, W	18,824	Useable
1995 WDNR Sediment Data	488	S	M, PCB-A, W	6,433	Useable
USGS NAWQA Data	441	S,T,W	B, M, P/H, PCB, SVOA, V, W	11,879	Supporting
State of Michigan Fish Consumption Advisory Data	434	T	B, DXN, M, P/H, PCB-A, W	6,979	Useable
WDNR Wildlife Tissue Data	417	T	B, M, P/H, PCB-A	2,532	Supporting
1996-1999 USFWS NRDA Fish Tissue Data	376	T	DXN, P/H, PCB-A, PCB-C, W	16,017	Useable
1997-1998 Demonstration Project Data - SMU 56/57	295	S,W	DXN, M, P/H, PCB-A, SVOA, V, W	3,114	Useable
1994 GAS/SAIC Sediment Data	253	S	DXN, M, P/H, PCB-A, SVOA, V, W	5,654	Useable
1998 RETEC RI/FS Supplemental Data	252	S,T	B, DXN, M, P/H, PCB-A, PCB-C, SVOA, V, W	10,781	Useable
1998 FRG/Exponent Data	225	T	B, M, P/H, PCB-A, PCB-C, W	17,708	Useable
1993 USFWS Tree Swallow Data	200	T	B, DXN, P/H, V, W	5,429	Supporting
1996 WDNR Fish Tissue Data	200	T	B, PCB-A, W	1,673	Useable
1998/1999 Deposit N Sediment Remediation Data	197	T,W	PCB-C, W	10,264	Useable
1994-1995 Cormorant Data	193	T	B, DXN, P/H, PCB-C, W	6,178	Supporting
1998 WDNR Fish Consumption Data	130	T	B,M, PCB-A, W	777	Useable
1992/93 BBL Deposit A Data	117	S,W	M, P/H, PCB-A, SVOA, V, W	1,094	Useable
Lake Michigan Tributary Monitoring Data	88	W	M, P/H, PCB-C, V	5,722	Useable
1997 USFWS NRDA Waterfowl Tissue Data	70	T	B, P/H, PCB, V, W	1,680	Supporting
1994 Woodward-Clyde Deposit A Sediment Data	66	S	PCB-A, W	585	Useable
Ankley and Call	62	PW,S,T,W	DXN, M, P/H, PCB, SVOA, W	1,607	Indetereminate
1998 Deposit N Pre-Dredge	53	S	PCB-A, PCB-C, W	1,437	Useable
1998 Deposit N Post-Dredge	43	S	PCB-A, PCB-C, W	690	Useable
Stromberg Eagle Data	31	T	B, DXN, P/H, PCB-A, PCB-C, SVOA, V, W	954	Supporting
1993 Triad Assessment	27	S	B, M, P/H, PCB-A, SVOA, W	631	Supporting
1996 FRG/BBL Sediment/Tissue Data	25	S,T	B, PCB-C, W	2,771	Useable
1997 WDNR Caged Fish Bioaccumulation Study Data	25	S,T	B, PCB-C, W	1,672	Supporting
Minergy Mineralogical Data	15	S	W	219	Supporting
Lower Fox River Background Metals Assessment	14	W	M	78	Supporting
Deposit N Operational Monitoring Data	12	S	M, PCB-A, W	123	Useable
1997 Demonstration Project Data - Deposit N	10	S	M, PCB, W	83	Useable
WPDES Permit Influent Data	8	W	B, DXN, M, P/H, PCB-A, RAD, SVOA, V, W	847	Supporting

Reference - EcoChem, 2000.

1) Matrices
S = Sediment
T = Tissue
W = Water
PW = Sediment Pore Water
A = Ambiant Air

2) Analyses
PCB-A = PCB Aroclor
PCB-C = PCB Congener
PCB = Total PCB only
B = Biological
DXN = Dioxins
M = Metals
P/H = Pesticides/Herbicides
SVOA = Semi-volatiles
V = Volatiles
W = Wet Chemistry (including all Physical and Conventional data)

Table 2-2. Lower Fox River - Supplemental Data Collection Sampling List

Specific Deposit/General Area of Sampling (# of Core/Ponar Grab Sample Locations)	Sampling Parameters (both Chemical & Physical)												
	Core Samples							Surface Samples (Ponar™ Grab Samples)					
	Aroclors[1]	Atterberg limits[2]	Shear strength[2]	Specific gravity[2]	Grain size[2]	Dry density[2]	Consolidation[2]	PCB Congeners	SVOCs	Chlorinated Pesticides	Metals	TOC	Moisture content
C (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
E (6)	18	2	1	2	2	2	1	2	2	2	2	6	6
W (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
X (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
EE/22 (4)	12	2	1	2	2	2	1	2	2	2	2	4	4
EE/23 (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
EE/24 (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
EE/25 (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
EE/26 (5)	15	2	1	2	2	2	1	2	2	2	2	5	5
EE/27 (2)	0	0	0	0	0	0	0	2	0	0	0	2	2
Lake Winnebago	3	0	0	0	3	0	0	3	3	3	3	3	3
Below De Pere Dam	5	2	1	2	5	2	1	5	5	5	5	5	5
Total Number of Field Samples[3]	176	20	10	20	26	20	10	41	34	34	39	65	65

Notes:

1) Samples were collected from select intervals of each core for submittal to the laboratory for analysis.
2) Indicates that an intact core (approximately 30 cm long) was submitted for analysis of the physical parameters.
3) Total includes QA/QC samples collected as equipment rinsate or field duplicate samples.

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:

Figure 3-1 Lower Fox River Elevation Profile
Figure 3-2 Green Bay Monthly Mean Surface Circulation - August 1989
Figure 3-3 Green Bay Monthly Bottom Surface Circulation - August 1989
Figure 3-4 Green Bay Zone 2 Bathymetry
Figure 3-5 Green Bay Zone 3 Bathymetry
Figure 3-6 Green Bay Zone 4 Bathymetry
Figure 3-7 Estimated Annual Sediment Transport Rates and Stream Flow Velocities

Table 3-1 Land Use Classification for Counties Bordering Green Bay
Table 3-2 Temperature and Precipitation Data for the City of Green Bay, Wisconsin
Table 3-3 Temperature and Precipitation Data for the City of Appleton, Wisconsin
Table 3-4 Temperature and Precipitation Data for the City of Marinette, Wisconsin
Table 3-5 Temperature and Precipitation Data for the City of Sturgeon Bay, Wisconsin

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

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

Table 3-8 Lower Fox River Dams

Table 3-9 Lower Fox River - U.S. Army Corps of Engineers - Dam Stability and Inspection Information

Table 3-10 Lower Fox River Gradient and Lock/Dam Information

Table 3-11 Lower Fox River Discharge Results - Rapide Croche Gauging Station

Table 3-12 Lower Fox River Stream Velocity Estimates

Table 3-13 Fox River Mouth Gauging Station Results (1989-1999)

Table 3-14 Lower Fox River Total Suspended Solid (TSS) Loads

Table 3-15 USACE Navigation Channel Dredging Records (1957-1999)

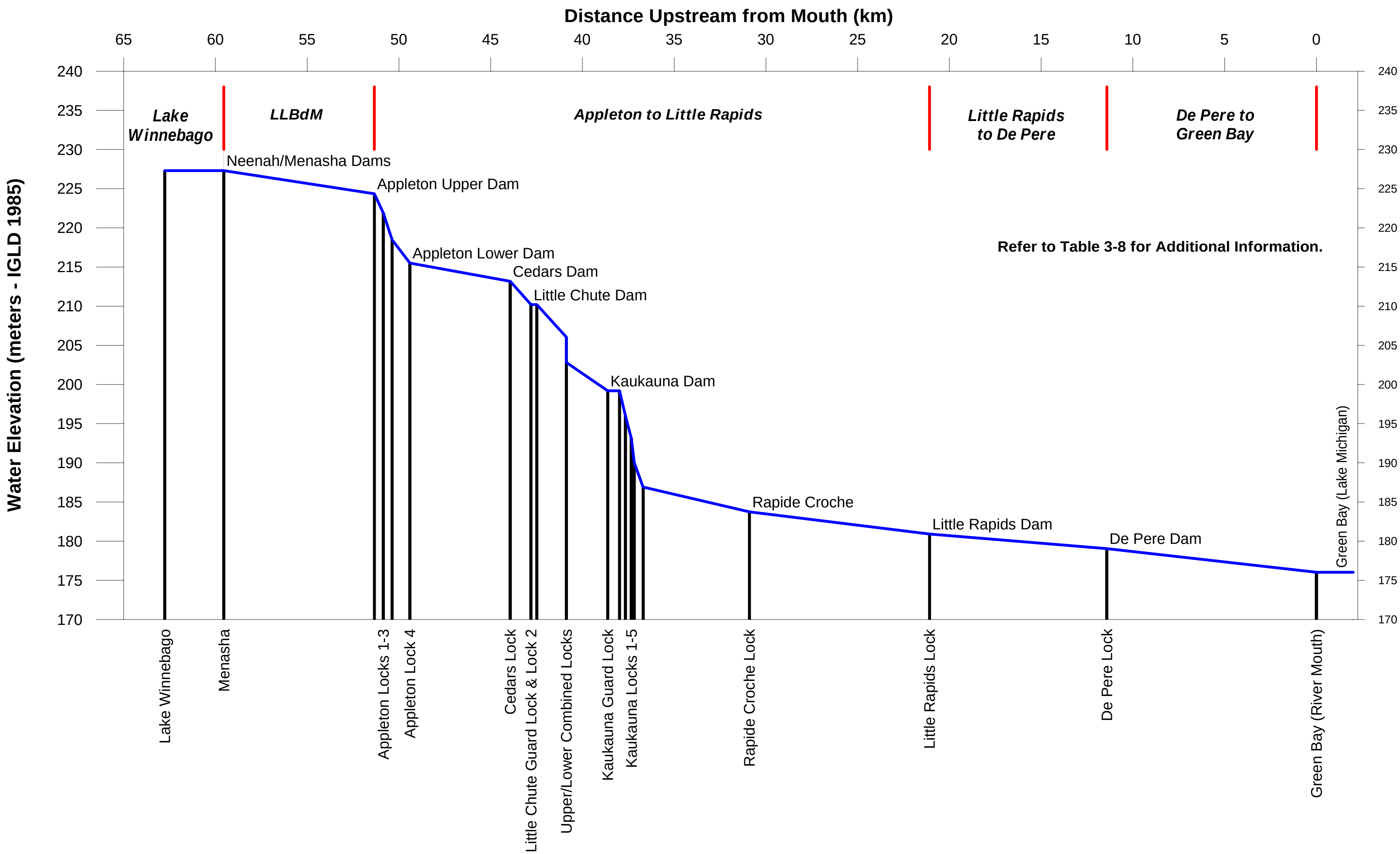
Plate 3-1 Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Lake Butte des Morts Reach

Plate 3-2 Sample Locations and Interpolated Thickness of Sediment with PCBs: Appleton to Little Rapids Reach

Plate 3-3 Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Rapids to De Pere Reach

Plate 3-4 Sample Locations and Interpolated Thickness of Sediment with PCBs: De Pere to Green Bay Reach

Plate 3-5 Sample Locations and Interpolated Thickness of Sediment with PCBs: Green Bay



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:

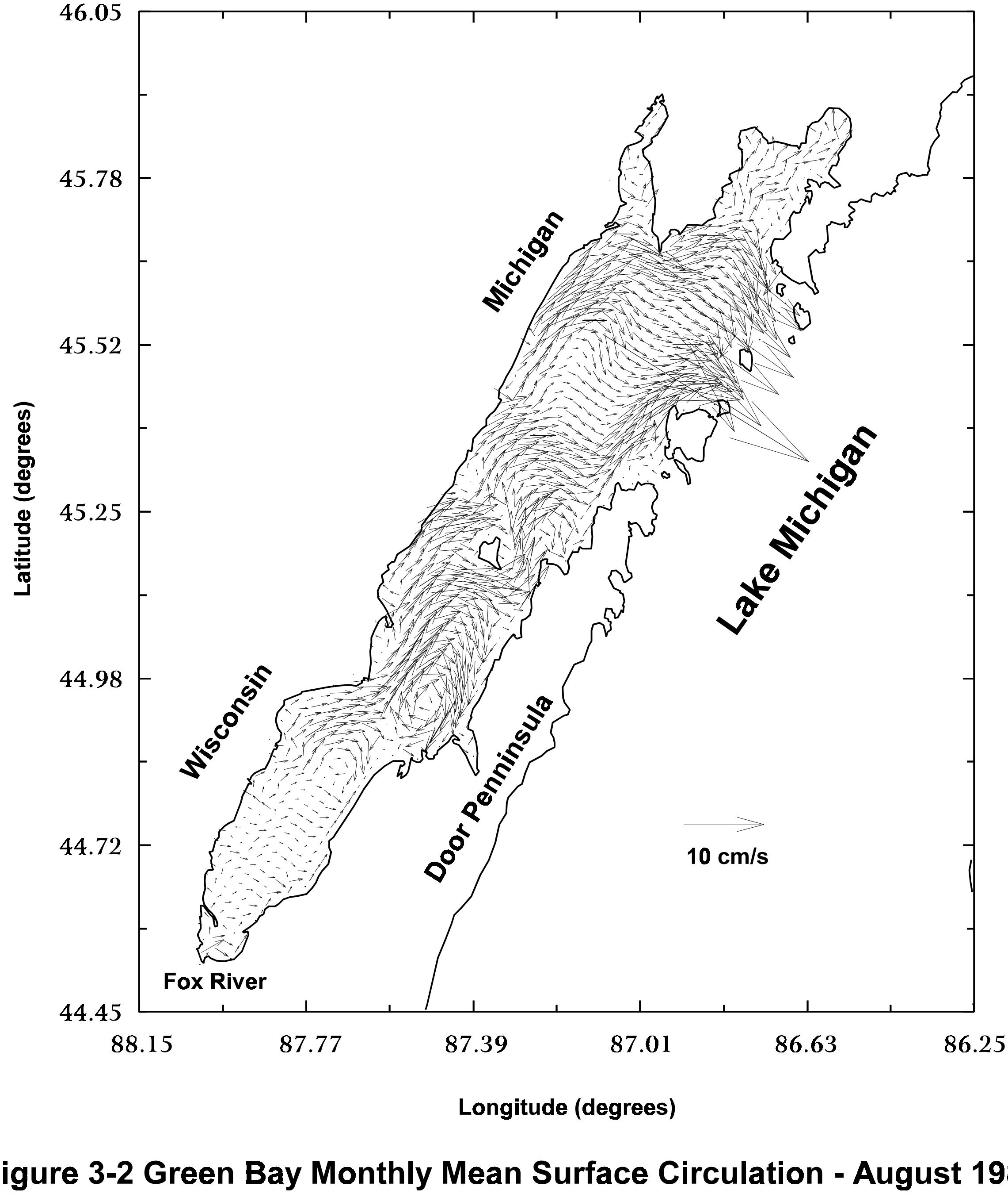


Figure 3-2 Green Bay Monthly Mean Surface Circulation - August 1989

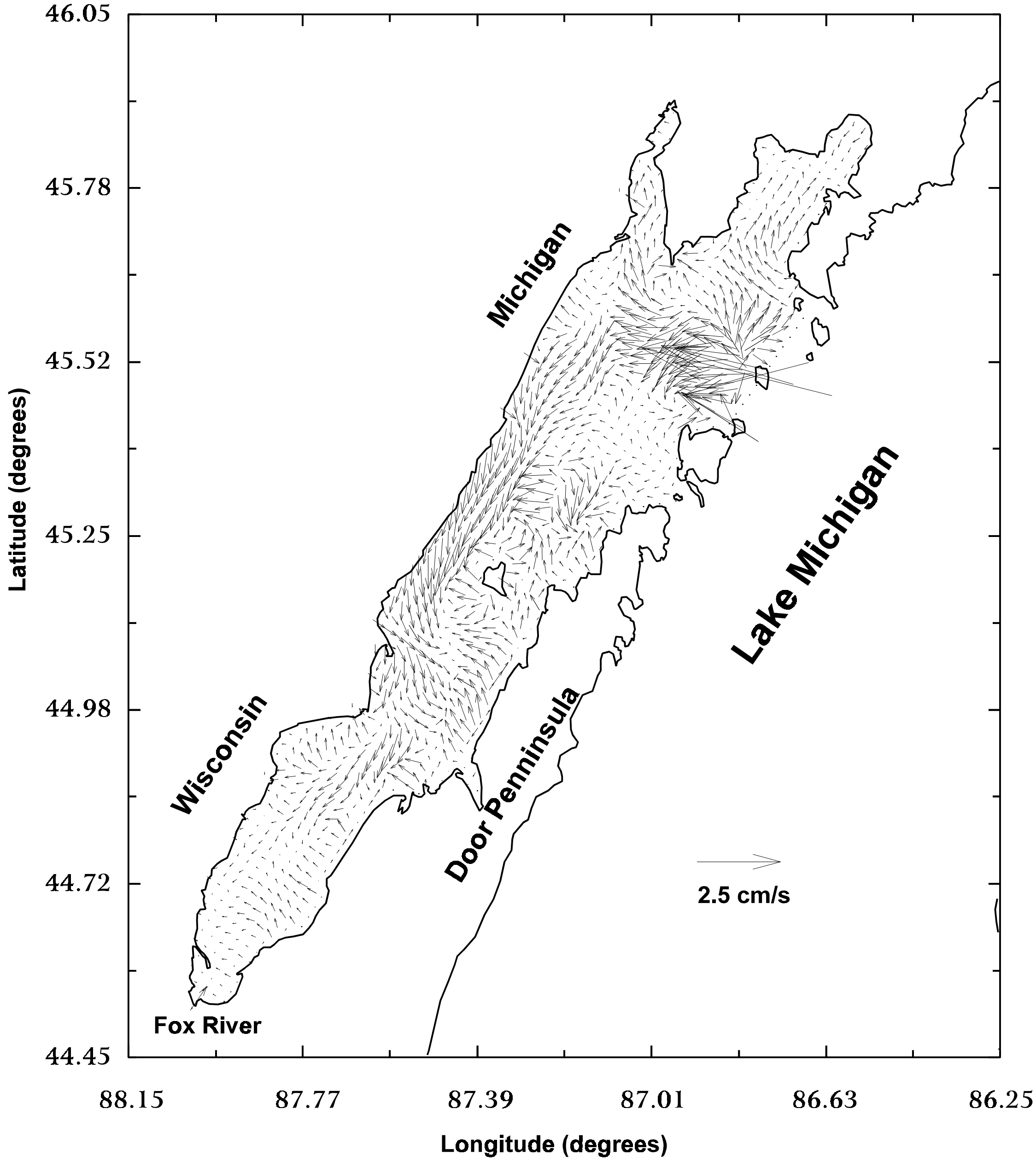
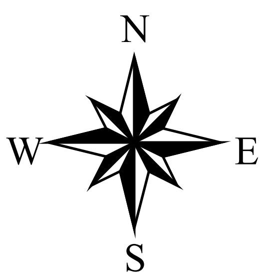
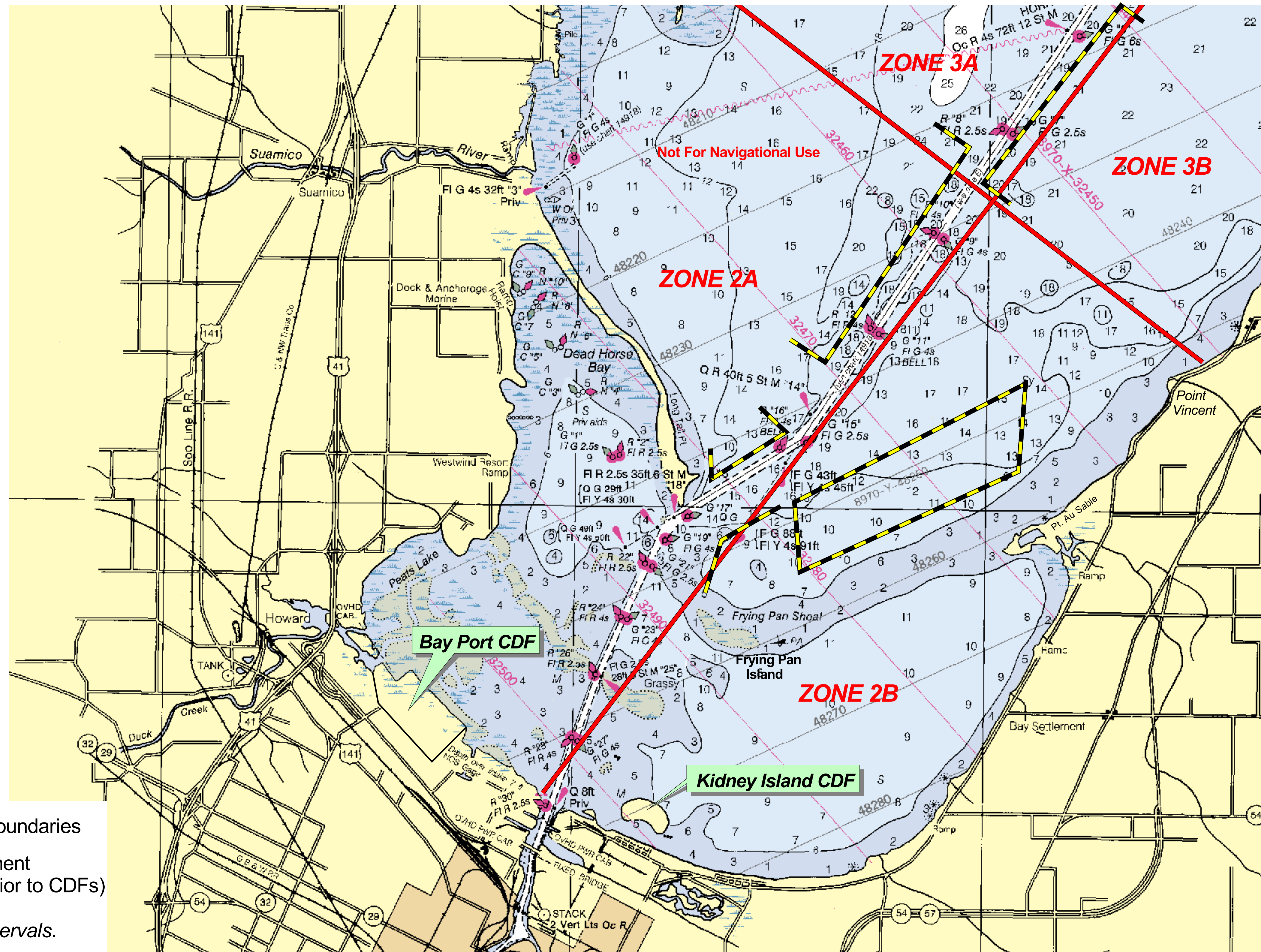


Figure 3-3 Green Bay Monthly Mean Bottom Circulation - August 1989





Green Bay Zone Boundaries

Open Water Sediment Disposal Areas (Prior to CDFs)

Bathymetry contours in 6-foot intervals.

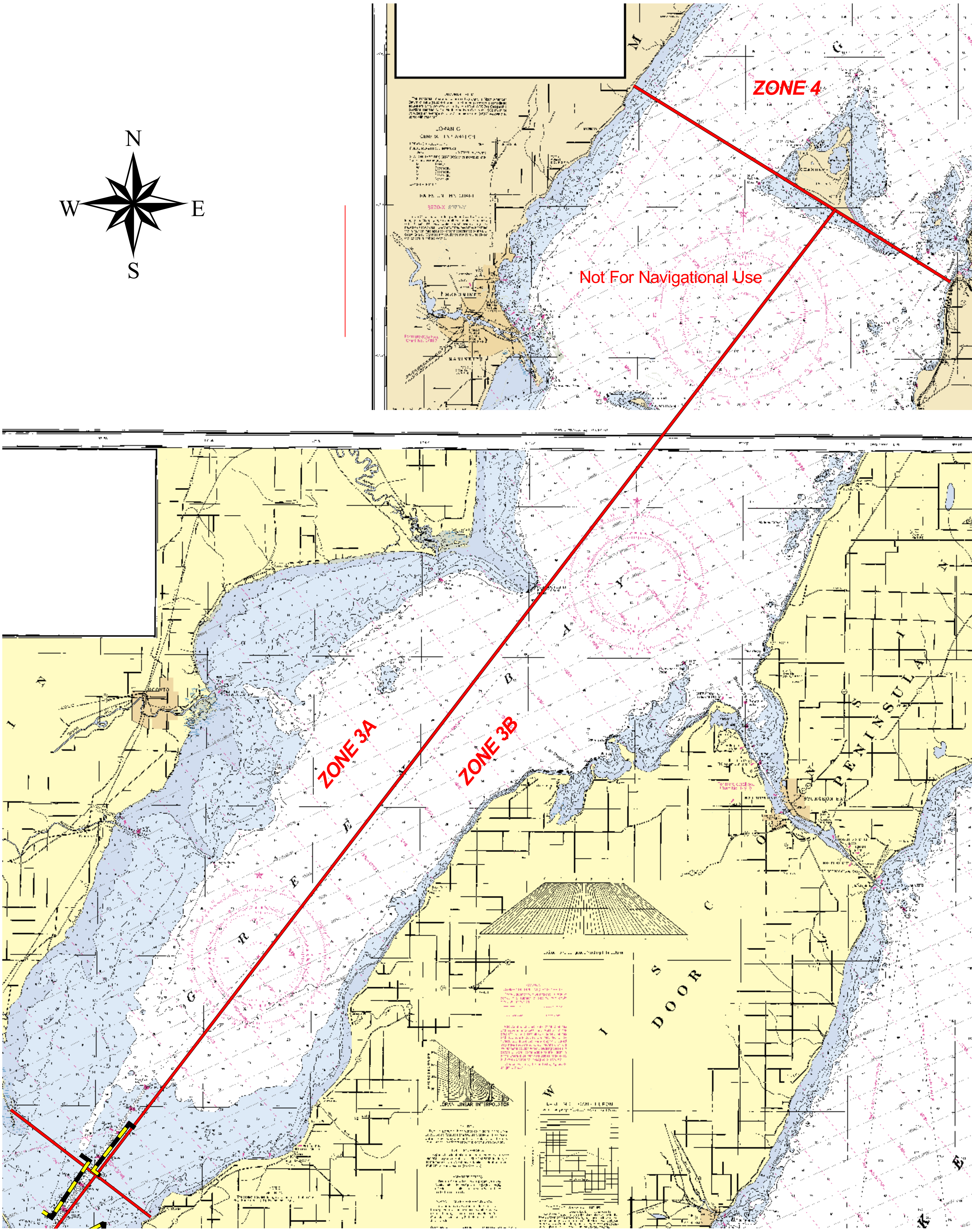
Confined Disposal Facilites (Existing)

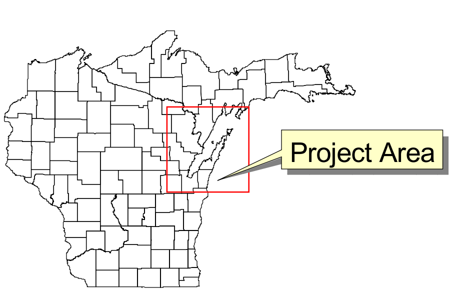
1 0 1 2 3 Kilometers

1 0 1 2 Miles

Source: NOAA Chart 14918 (1998)

ThermoRetec Smart Solutions. Positive Outcomes.	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





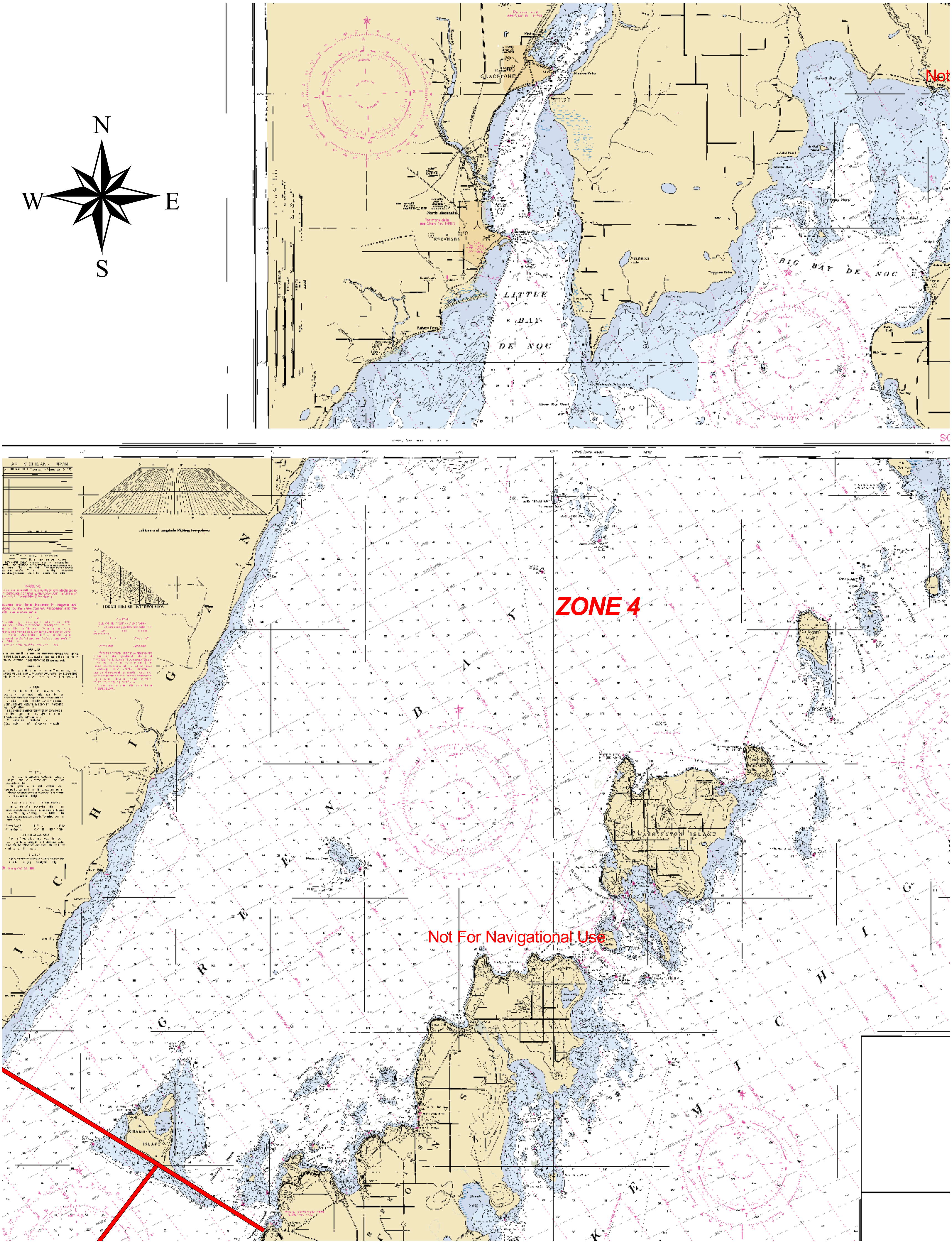
5 0 5 10 15 Kilometers

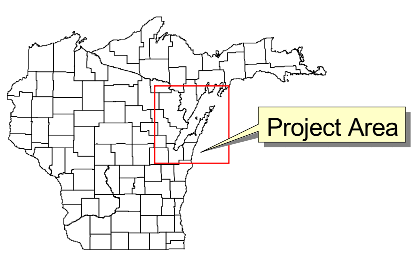
5 0 5 10 Miles

Green Bay Zone Boundaries
Open Water Sediment Disposal Areas (Prior to CDF's)

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

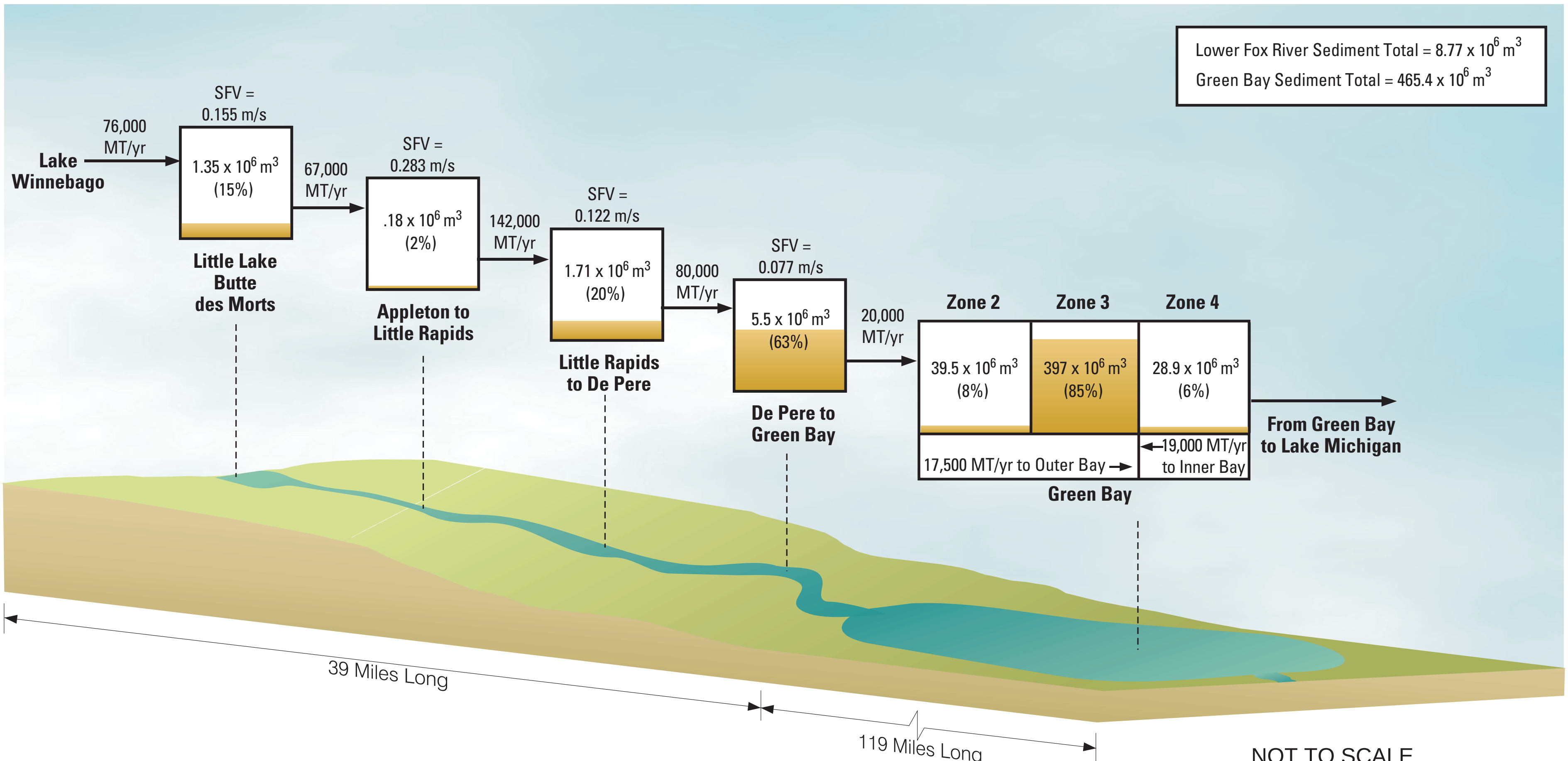
3 0 3 6 9 Kilometers

3 0 3 6 Miles

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

ThermoRetec	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



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

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

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	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
Period	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	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
Period	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	Averages			Daily Extremes				Mean Extremes				Day	Max	Day	Min
Period	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	Total Precipitation							Snow			# Days Precipitation		
Period	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**		**Minimum**	**Maximum**
	(m^3/s)	**(cfs)**	**(m^3/s)**	**(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 ($122 m^3/s$)	10 Year Peak ($544 m^3/s$)	10 Year Low ($27 m^3/s$)	100 Year Peak ($680 m^3/s$)	100 Year Low ($4 m^3/s$)
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

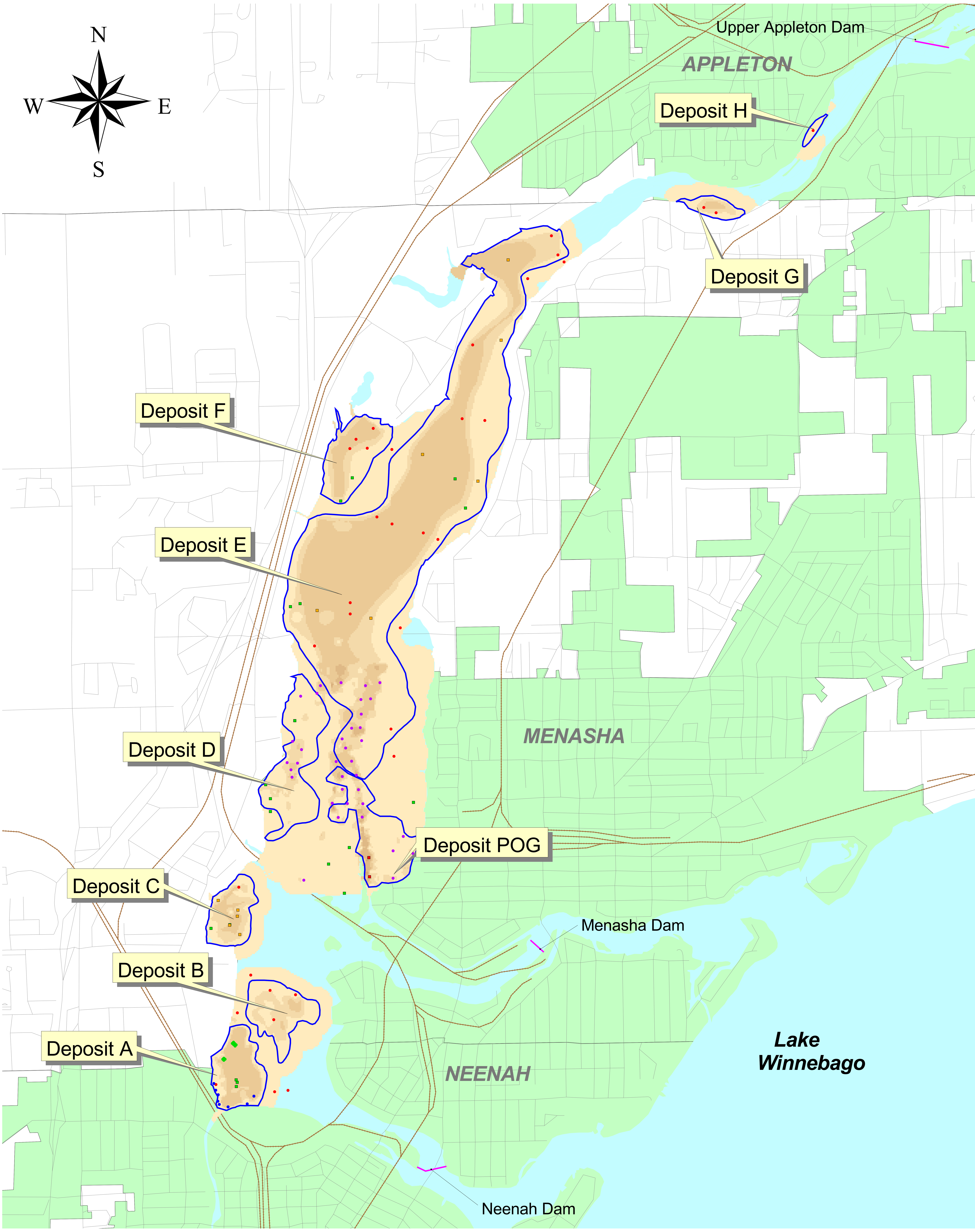
Sampling Point	River Discharge		Total Suspended Solids (TSS)		
	(m^3/s)	(cfs)	(mg/L)	(MT/year)	(Ton/year)
1995 - Mean Values from WDNR, 1995					
Menasha Gauge*	140	4,938	7.7	33,968	37,365
Neenah Gauge*	80	2,809	17	42,661	46,927
Appleton Gauge	93	3,279	23	67,375	74,113
Kaukauna Gauge*	85	3,009	26	69,892	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**	$\mathbf{(12,949\ yd^3)}$	



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

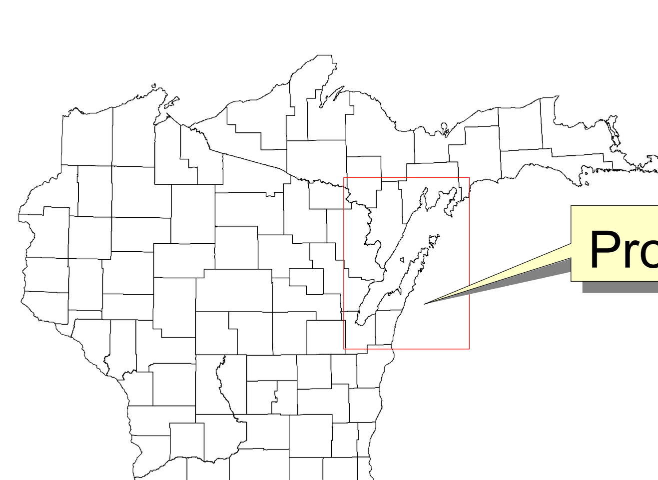
Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5

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.

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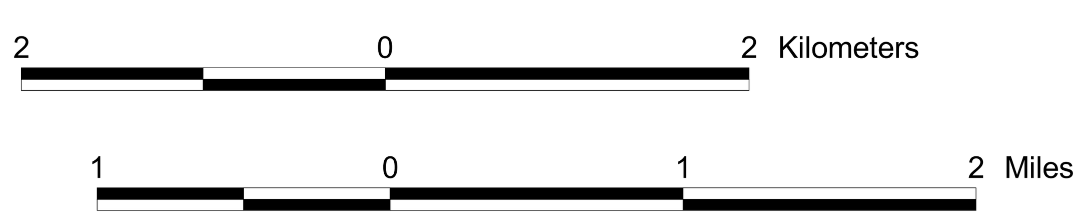
Remedial Investigation Report

Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Lake Butte des Morts Reach

PLATE 3-1

DRAWING NO: RI-14414-340-3-1
PRINT DATE: 6/18/01
CREATED BY: SCJ
APPROVED: AGF



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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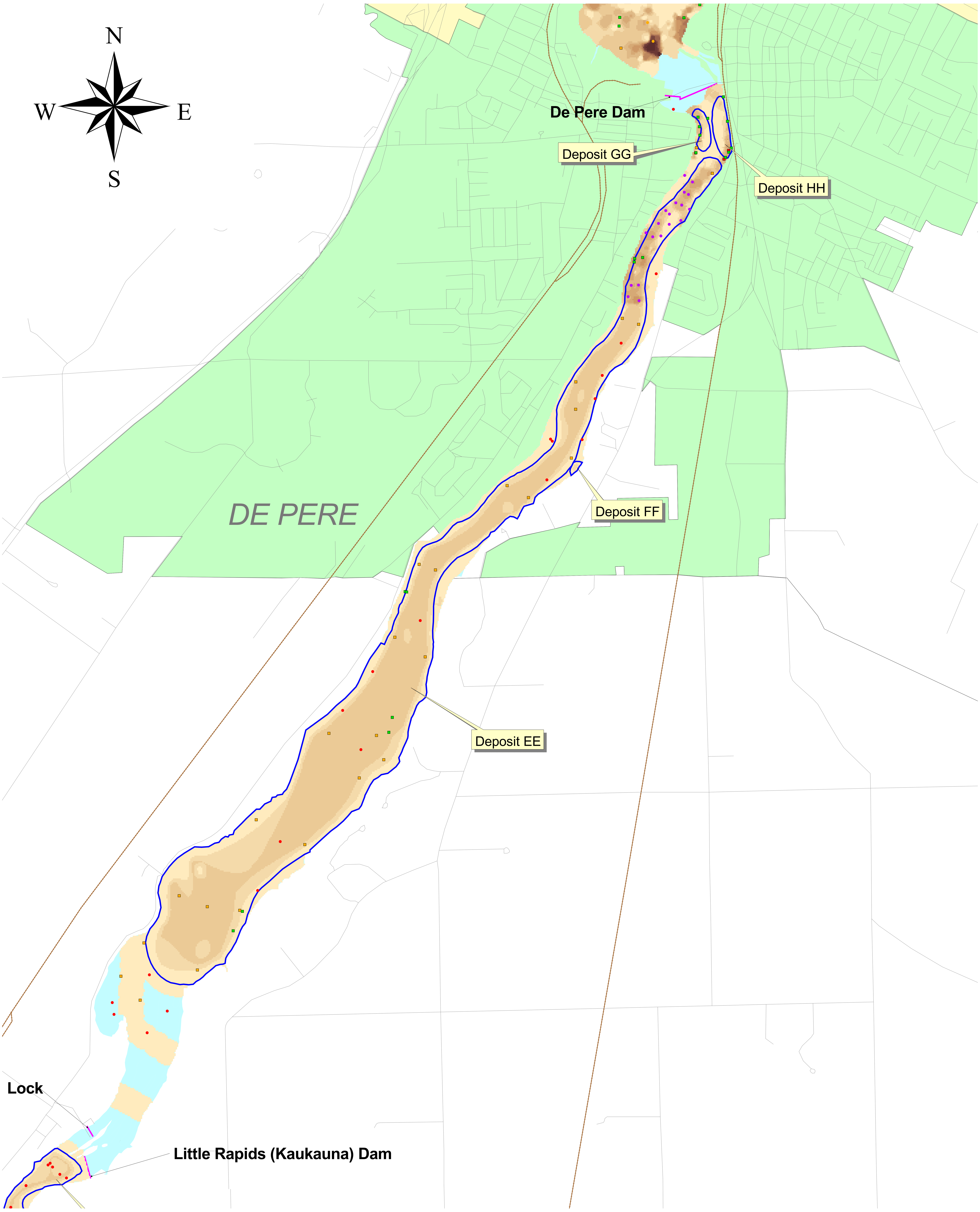
Remedial Investigation Report

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

PLATE 3-2

DRAWING NO: RI-14414-340-3-2
PRINT DATE: 6/18/01
CREATED BY: SCJ
APPROVED: AGF

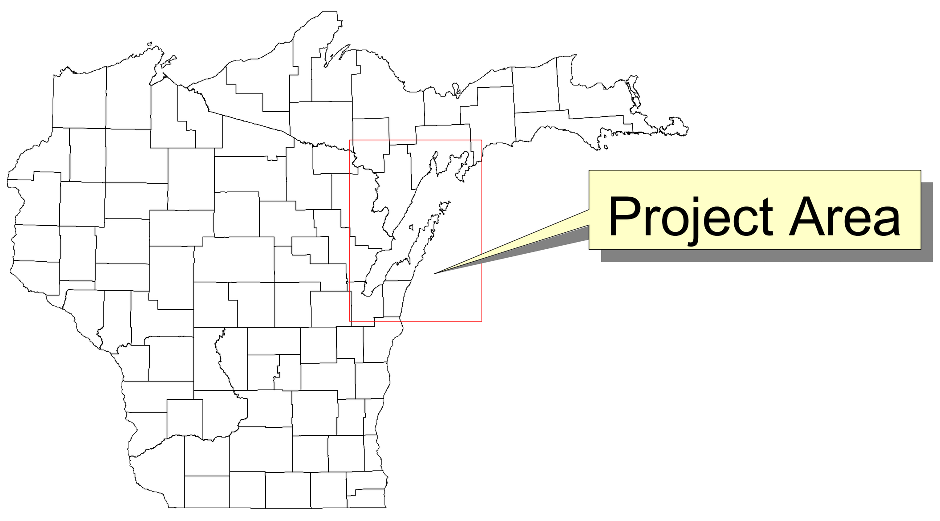


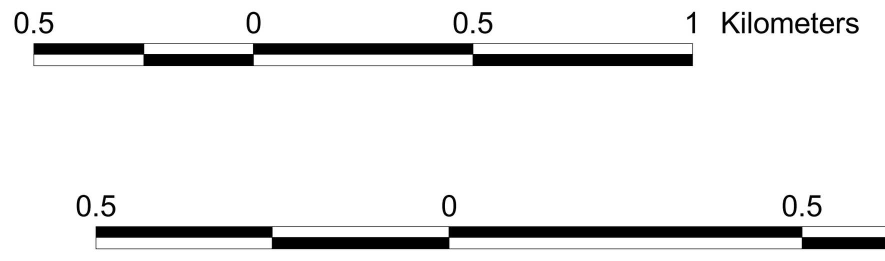
Sample Points
- 1989/90 Mass Balance Sediment Data
- 1992/93 LLBdM RI/FS Deposit A Sediment Data
- 1994 Woodward Clyde Deposit A Sediment Data
- 1994 SAIC and GAS Sediment Data
- 1995 WDNR Sediment Data
- 1996 BBL Sediment Data
- 1997 Segment 56/57 Demonstration
- 1998 BBL Sediment/Tissue Data
- 1998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

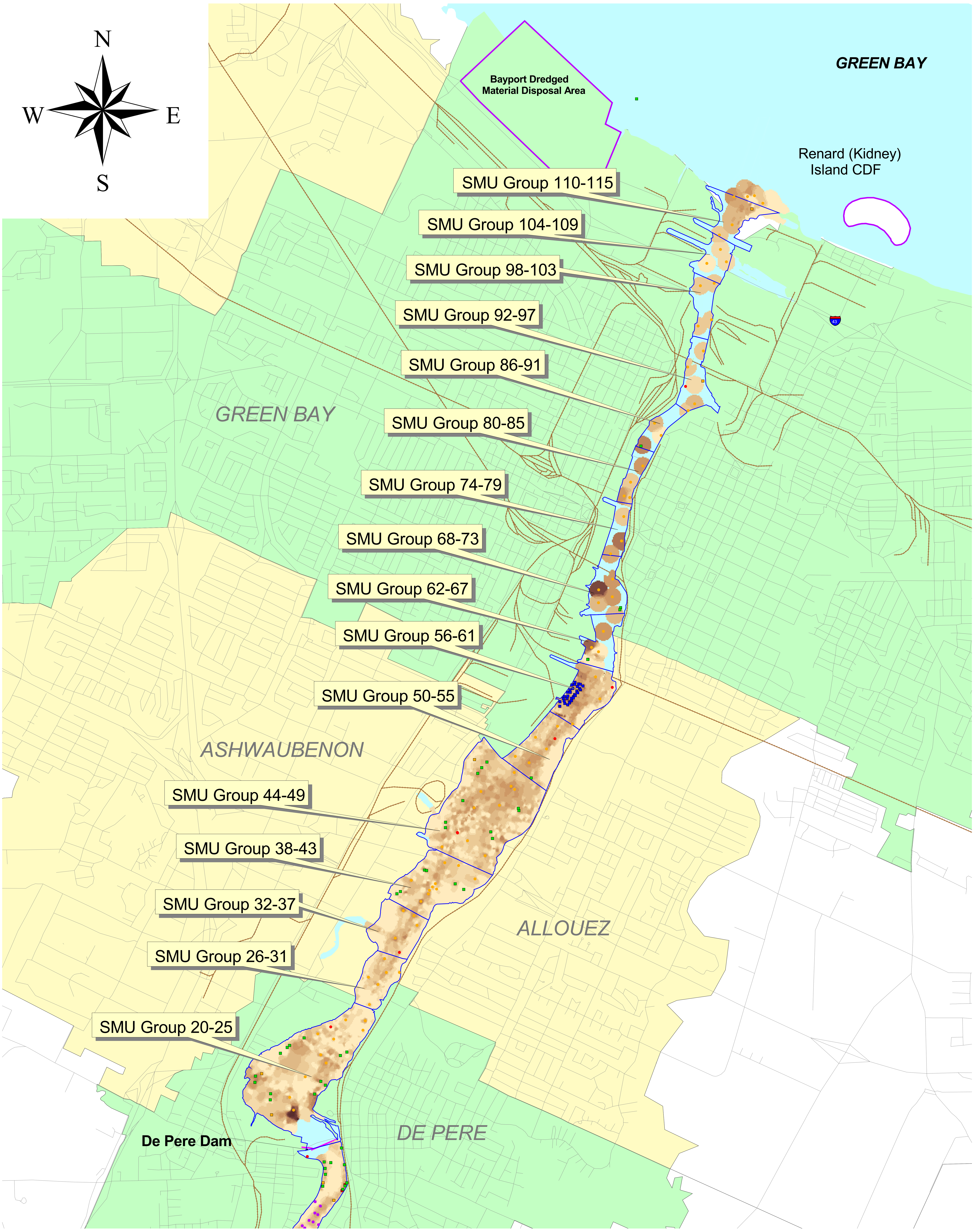
Civil Divisions
- City
- Township
- Village





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	Lower Fox River & Green Bay Remedial Investigation Report	Sample Locations and Interpolated Thickness of Sediment with PCBs: Little Rapids to De Pere Reach	DRAWING NO: RI-14414-340-3-3
			PLATE 3-3	PRINT DATE: 6/18/01
				CREATED BY: SCJ
				APPROVED: AGF

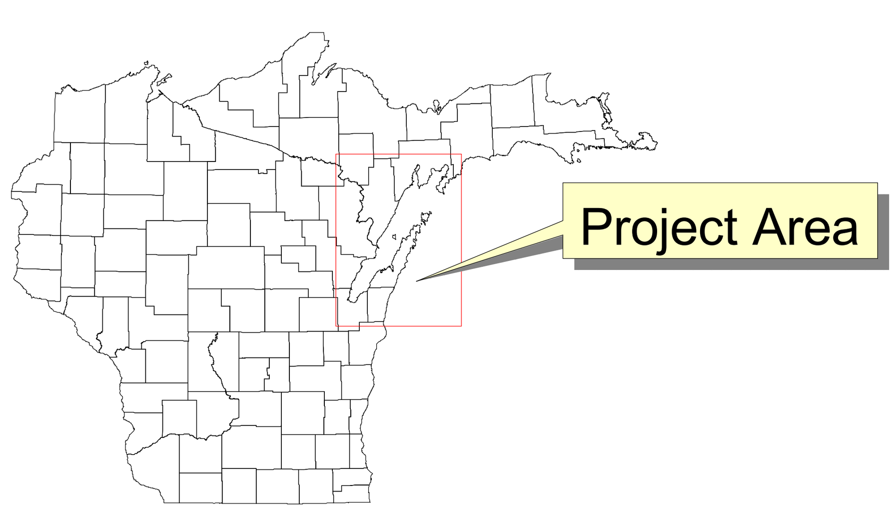


Sample Points
- 1989/90 Mass Balance Sediment Data
- 1992/93 LLBdM RI/FS Deposit A Sediment Data
- 1994 Woodward Clyde Deposit A Sediment Data
- 1994 SAIC and GAS Sediment Data
- 1995 WDNR Sediment Data
- 1996 BBL Sediment Data
- 1997 Segment 56/57 Demonstration
- 1998 BBL Sediment/Tissue Data
- 1998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

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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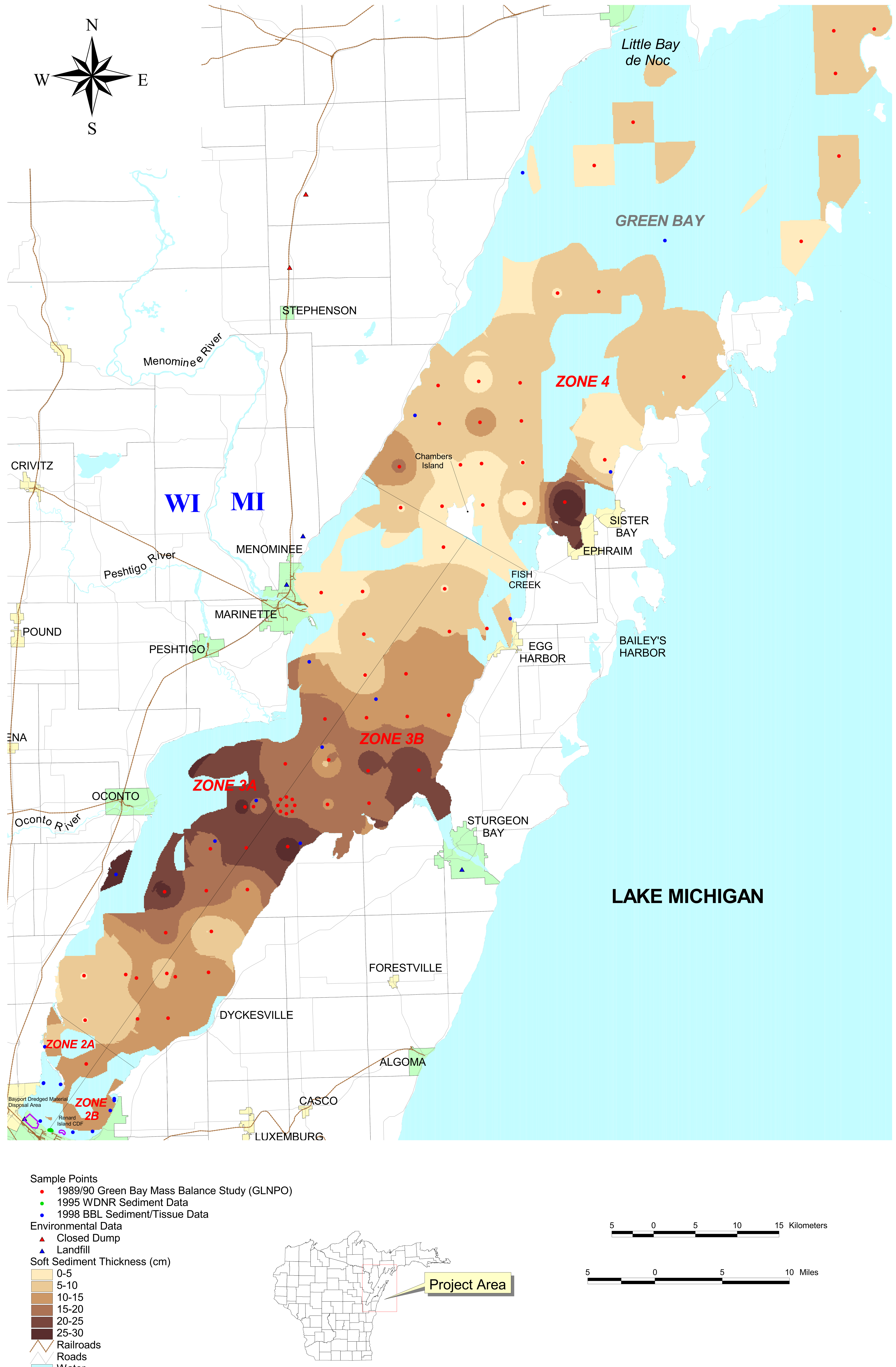
Lower Fox River & Green Bay Remedial Investigation Report

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
CREATED BY:	SCJ
APPROVED:	AGF



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: Green Bay	DRAWING NO: RI-14414-340-3-5
			PLATE 3-5	PRINT DATE: 6/18/01
				CREATED BY: SCJ
				APPROVED: AGF

4 Ecological Characteristics

4.1 Overview

This chapter provides a description of the historical and current ecological characteristics of the Lower Fox River valley and Green Bay, with an emphasis on habitat and specific animals that are present in the area, as well as how they have been affected by both area development and environmental degradation. This information is used in the RA and the assessment of risks posed by historical discharge of PCBs and other pollutants into this system.

In September 1998, Exponent completed the *Habitat Characterization for the Lower Fox River and Green Bay Assessment Area* (Exponent, 1998) on behalf of the FRG. The assessment area began at the outlet of Lake Winnebago and extended to just north of the Oconto Marsh, on the west side of the bay, and Little Sturgeon Bay, on the east side (Exponent, 1998). Much of the information referenced in this section for the Lower Fox River was obtained from this document.

In addition to the Exponent (1998) report, a number of other data sources were utilized for this section. These sources largely consisted of electronic data files compiled by the ESRI ArcView™ (version 3.2) geographic information system (GIS), which was used to develop the maps for this section. Other sources included the USFWS fish and bird injury reports (Stratus, 1999b and 1999c), discussions with USFWS personnel, USGS reports, and specific texts concerning select species.

These data, and the resulting maps, have been used to develop an understanding of the Lower Fox River and Green Bay system. The data sources are listed below and included on the appropriate figures, which will also be used in the RA.

Lower Fox River GIS Data Sources

Habitat Data	Description	Source
Physical and habitat features (bridge, riffles)	in-water polygon shapes	OSI/Exponent, 1999
Shoreline (bulkhead, riprap)	linear colors only along the shoreline	OSI/Exponent, 1999
Wetlands	Green areas along shore and upland	WDNR, 1999d. USFWS, 1993
Bald eagle nesting sites	yellow triangles, discrete points	Stratus, 1999c. Stubenvoll, 1998.
Threatened or endangered resources	TRS1/4S polygons	Natural Heritage Inventory (NHI), 2000
Basemap generated from TIGER census data and ESRI data and maps in ARCVIEW GIS version 3.2, WTM projection.		

Green Bay GIS Data Sources

Habitat Data	Description	Source
Physical and habitat features (bridge, riffles)	in-water polygon shapes	OSI/Exponent, 1999
Wetlands	Green areas along shore and upland	WDNR, 1999d. Minc and Albert, 1998. USFWS, 1981 and 1993.
Bald eagle nesting sites	yellow triangles, discrete points	Stratus, 1999c. Stubenvoll, 1998.
Threatened or endangered resources	Colored Squares by nearest Township, Range, and Section	NHI, 2000 Natural heritage Inventory (NHI), 2000
Fish Distribution	in-water polygons	NOAA, 1997c.
Bird Distribution	in-water polygons	NOAA, 1997c.
Fish Locations	discrete points in Michigan	Great Lakes Commission, 2000.
Bird Locations	discrete points in Michigan	Great Lakes Commission, 2000.
Fish Spawning grounds	in-water polygons	UWSGI, 1980
Basemap generated from TIGER census data and ESRI data and maps in ARCVIEW GIS version 3.2, WTM projection.		

4.1.1Habitats

The abundance and type of wildlife populating an area depends on the presence of suitable habitat, including the availability and distribution of food and water, protective cover, and appropriate breeding and nesting grounds. The Lower Fox River and Green Bay system varies considerably in its potential to provide and support different kinds of habitat and this variability affects the wildlife diversity and populations.

The two major types of habitat present are terrestrial (on-land) and aquatic (within or near the water). The two main terrestrial habitats within the Lower Fox River and Green Bay area are open land and woodland. Aquatic habitats within the area include wetland, riverine, and lacustrine. Cities and villages represent an urban environment that most wildlife typically avoid, except certain passerines that nest almost anywhere (i.e., select species of wrens, swallows, and sparrows, robins, blackbirds, etc.,) and scavengers (i.e., raccoons, squirrels, vermin, etc.).

Within the Lower Fox River valley, the terrestrial habitats are generally located adjacent to the river from a point downstream of Kaukauna to just upstream of De Pere. In the vicinity of the Fox Cities MSA and Green Bay MSA, much of the river shoreline and associated former wildlife habitat has been developed (Figures 1-3 through 1-6). Natural habitats have retreated from the river and exist only in less developed areas such as lands cultivated for agriculture, open meadows, or small, localized woodlands. The aquatic habitat is wetland and riverine, and it is comprised of and confined to the Lower Fox River and its tributaries.

Green Bay represents a lacustrine habitat and the other habitats, listed above, are found in the area surrounding the bay. The land surrounding Green Bay is much less developed than the Lower Fox River valley, as detailed in Section 3.1.2. Open, agricultural land and forests/woodlands comprise between 65 percent and 94 percent of the land use outside of Brown County, while residential and commercial/industrial land use is less than 5 percent. Wetlands also account for up to 20 percent of county land use in these areas (Table 3-1). The communities located along the shores of Green Bay are much smaller and less populated than the cities of the Lower Fox River valley. Excluding the city of Green Bay (as well as the Lower Fox River watershed), approximately 289,000 people inhabit the Green Bay area (Table 3-7). While individual residences or structures may be located along the shores of Green Bay, shoreline development is much less concentrated than in the Lower Fox River valley and extensive open land or forested tracts may be present along or in close proximity to the shore.

4.1.2Wildlife Groups

The significant groups of wildlife found within the Lower Fox River and Green Bay habitats are summarized below.

- Both pelagic and benthic aquatic invertebrates species form the primary prey in the food webs of the river and bay. Species of oligochaetes and chironomids (worms and midges) are typically most abundant and are found throughout the Lower Fox River and Green Bay. Amphipods, crayfish, snails, and mussels are also present in the river and bay. Zebra mussels, an exotic species, are present throughout the river and bay (Szymanski, 2000). Due to their aggressive nature, the presence of zebra mussels in the system will present problems for the native macroinvertebrates that cannot adequately compete with these mussels for food or habitat.

- Fish of the region include salmon, trout, game fish such as walleye, yellow perch, and northern pike, and pelagic and benthic non-game fish. Fish species included within uptake modeling and analysis are discussed in detail in this section.

- Birds of the region include raptors, gulls, terns, diving birds, migratory waterfowl, passerines, shorebirds, and wading birds. These animals are found nesting, feeding, and living in both terrestrial and aquatic habitat environments.

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

- Reptiles and amphibians, including snakes, turtles, frogs, and toads are present in the region (Exponent, 1998). Frogs and toads that dwell in wetlands or nearshore areas are fed upon by wading birds of the region. These include the leopard frog, wood frog, green frog, chorus frog, and Eastern grey-tree frog as well as the American toad (Nikolai, 2000a). Typically, the frogs and turtles confine themselves to the wetland and near shore areas while snakes of many different species and toads are found in association with both terrestrial and aquatic habitats. Salamanders confine themselves to forested wetlands and the Blandings turtle is listed as a threatened species in Wisconsin (Nikolai, 2000a). Many egg laying sites have been eliminated due to development along the Lower Fox River (Nikolai, 2000a).

4.2 Wildlife Habitat

4.2.1 Open Lands

Open land habitat in the Lower Fox River and Green Bay area is largely agricultural and characterized as cropland, orchards, pastures, and meadows with grasses, herbaceous shrubs, and vines. The Fox Cities and Brown County land use maps (East Central Wisconsin Regional Planning Commission, 1996 and Brown County Planning Commission, 1990, respectively) and the habitat characterization report (Exponent, 1998) indicate that this is the largest habitat present within 0.8 km (0.5 mi) of the Lower Fox River.

Along the east side of Green Bay, from the Fox River mouth to Little Sturgeon Bay, open land is the predominant habitat (Exponent, 1998). Use of the land for agricultural purposes is responsible for the presence of this habitat along the east shore of Green Bay. Although the Exponent habitat characterization ended at Little Sturgeon Bay, review of Door County SCS (1978) soil survey maps and land use information (Section 3.1.2) indicates that open land habitat is prevalent throughout the Door Peninsula. Approximately 50 percent and 70 percent of the land use in Door and Kewaunee Counties, respectively, is classified as agricultural.

Extensive tracts of agricultural and open land are also present in Brown and Oconto counties. More than 60 percent and 42 percent of the land in Brown and Oconto counties, respectively, is classified as agricultural or open (Section 3.1.2). However, the percentage of agricultural and open land decreases moving north. Agricultural and open land in Marinette, Menominee, and Delta counties ranges between approximately 13 percent and 21 percent, with forested land comprising the majority of the remaining land use (Table 3-1).

Typical open land vegetative cover includes grasses and legumes such as fescue, bromegrass, vetch, and birdsfoot trefoil. Native vegetation consisting of wild herbaceous plants such as goldenrod, asters, beggar-ticks, violets, and various other spring herbs occur on open landscapes. Grasses and prairie grasses such as wheatgrass, big and little bluestem, indiangrass, switchgrass, and sideoats grama exist in limited areas along the bluffs and open areas with prairie forbs consisting of round-headed bush-cover, New England aster, rigid goldenrod, and prairie blazingstar. Cultivated vegetation in the area includes clover, oats, sorghum, soybeans, alfalfa, and hay. This vegetation, both wild and cultivated, provides food and protective cover for wildlife that populates this habitat.

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

Although open lands are prevalent along the Lower Fox River and east side of Green Bay, pressure from individuals and developers to convert farmland and other open areas into residential housing or urban uses may reduce the acreage of this habitat. The Brown County Year 2020 Land Use and Transportation Plan (HNTB, 1996) expects the county population to increase by about 32 percent, from 194,500 in 1990 to around 257,700 in 2020. The recommended land use plan map indicates that residential housing is intended for large areas along the east shore of Green Bay. Due to the presence of the wetlands and the large tracts of state-owned land along the west side of the bay, residential housing developments in this area will be more limited. However, development of these areas is still expected to impact the nearby habitats.

Increases in housing and population are also expected in Door County. The Door County Development Plan expects that the year-around population will increase by about 5.4 percent (1,380 people) between 1990 and 2015 (Olejniczak and Florence, 1995). Again, much of this growth is expected to decrease open land areas as well as other habitats.

4.2.2Woodlands

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

Agricultural activities have dominated the historical development of northeastern Wisconsin and significant losses of woodlands have occurred in this area. However, large tracts of woodlands and forests remain in the UP. Moving north along the shores of the bay, the acreage of wooded land increases. This is especially true where the growth of agricultural areas has slowed and replanted forests have matured since the trees were logged during the 1800s and early 1900s. Review of the aerial photos used for the SCS soil maps for the counties surrounding Green Bay (1972, 1978, 1988, 1989, 1991, and 1994) indicates that the size of the tracts of woodlands increases moving north. Less than 6.7 percent of the land within Brown County was described as forested compared to 51 percent to 76 percent in Oconto, Marinette, Menominee, and Delta counties (Table 3-1). Over 625,000 hectares (1.54 million acres) of forests are present in Marinette, Menominee, and Delta counties (Table 3-1). Forested land comprises between 22 percent and 34 percent of land use in Door and Kewaunee counties (Table 3-1).

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

Historical development in northeast Wisconsin and Michigan's Upper Peninsula (UP) have reduced the forests, which were originally the dominant habitat in the region. Logging activities, for lumber and to supply raw material to the paper mills in the Fox Valley greatly reduced the woodland acreage. Following logging, these areas were typically cultivated, especially within the Lower Fox River valley and along the southern half of Green Bay. With this lost forested land, the animal populations utilizing this habitat also decreased and changed.

Within the state of Michigan, significant tracts of woodlands and forests are designated as state or federal lands. Parcels of the Escanaba River State Forest stretch from just north of the city of Menominee to just outside the city of Escanaba, a distance of approximately 45 km (28 mi). Some of this land is located on the shores of the bay but most of it is inland about 1.2 to 2.4 km (0.75 to 1.5 mi). Smaller tracts of the Escanaba River State Forest are located along the shores of Little Bay de Noc north of Gladstone and throughout Delta County. All together, the Escanaba River State Forest comprises 168,350 hectares (416,000 acres) of land. The Hiawatha National Forest is located in the central portion of the UP, running from the north end of Big Bay de Noc to the shores of Lake Superior and comprises 348,000 hectares (860,000 acres). Large tracts of land within the Stonington Peninsula are designated as part of the Hiawatha National Forest. Finally, the Lake Superior State Forest comprises over 404,700 hectares (1 million acres) of forested land in the central and eastern UP. The northern portion and eastern side of the Garden Peninsula, as well as much of Summer Island are designated as Lake Superior State Forest land. In addition to these state and federal forests, the J. W. Wells State Park and Beach is located along the west shore of Green Bay between Menominee and Escanaba. Fayette State Park is located on the west side of the Garden Peninsula, just off of Sand Bay on the east shore of Big Bay de Noc.

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

4.2.3Wetlands

4.2.3.1 Wetland Areas and Types

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

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

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

1) Submergent marsh: contains submerged aquatic vegetation (SAV) and/or floating vegetation.

2) Emergent marsh: characterized by shallow water or saturated soils with rushes, cattails, and other emergent species

3) Shoreline (or strand) zone: located at or just above the water line and are typically thin zones, usually dominated by herbs

4) Wet meadow (herbaceous): characterized by saturated or periodically flooded soils dominated by sedges, grasses, and other herbs

5) Shrub swamp & 6) Swamp forest: characterized by periods of standing water and are dominated by woody species adapted to a variety of flooding regimes, including dogwood, cottonwood, tamarack, and spruce

These are general wetland types and not all types are found within each wetland or wetland complex (Minc and Albert, 1998). These can also be lacustrine, riverine, palustrine, and lacustrine/freshwater estuaries. The wetlands located within Green Bay are primarily lacustrine followed by palustrine, and then riverine. The wetland descriptions used by Exponent (1998) are presented below, as well as information pertaining to the typical flora of each wetland type.

Wetlands are characterized by seasonally flooded basins and swales, as well as open, marshy, swampy, or shallow water areas with water-tolerant vegetation. Lower Fox River and Green Bay wetland types observed by Exponent (1998) included the following:

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

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

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

Areas identified and mapped as wetlands by the WDNR along the Lower Fox River are shown on Figures 4-1 through 4-4. Wetland areas along Green Bay, which were identified and mapped by USFWS (1981 and 1993) are shown on Figures 4-5 and 4-6.

Emergent/wet meadow wetland complexes account for 43 percent of all wetlands observed in the Lower Fox River and southern Green Bay assessment area. Shrub/scrub wetlands comprise approximately 27 percent of the wetlands and are located mainly along the west shore of Green Bay. Forested wetlands account for 25 percent of the area and are predominantly located in the northern portion of this assessment area. Open water within designated wetland areas account for 2 percent of the total area and aquatic beds, excavated ponds, and wetlands smaller than 0.8 hectares (2 acres) in size comprise the remaining 3 percent of the assessed area (Exponent, 1998).

Only 135 hectares (334 acres) of wetlands within 0.4 km (0.25 mi) of the shore were identified within the Lower Fox River valley (Exponent, 1998). Of these identified wetlands, 119 hectares (294 acres) or 88 percent were located between LLBdM and the De Pere dam (Figures 4-1 through 4-3). The wetlands in this part of the river were predominately forested wetland (68.9 hectares or 170 acres) and emergent/wet meadow wetlands (32 hectares or 81 acres) (Exponent, 1998). The largest wetland areas are associated with the Stroebe Island Marsh and backwater areas in LLBdM, the Thousand Islands wetlands (adjacent to

Kaukauna/mouth of Kankapot Creek), and the Little Rapids dam, and account for approximately 87 percent of the wetlands upstream of the De Pere dam (Exponent, 1998). Only 16 hectares (40 acres) of wetlands were identified in the De Pere to Green Bay Reach (Green Bay Zone 1), and these were predominantly emergent/wet meadow and forested wetlands (Figure 4-4). Approximately 60 percent of these wetlands (9.5 hectares or 23.4 acres) are associated with marsh at the mouth of the Lower Fox River (Exponent, 1998).

In addition to the wetland analysis, Exponent (1998) documented the presence and areal extent of SAV within each portion of the Lower Fox River. However, it appears that Exponent (1998) did not classify these areas as wetlands. Approximately 350 hectares (865 acres) of SAV are present in the Lower Fox, with only about 8 hectares (20 acres) located downstream of the De Pere dam. Approximately 260 hectares (642 acres) of SAV are present within LLBdM and are likely associated with the Stroebe Island Marsh and the other backwater wetlands of LLBdM; however, SAV is also associated with smaller wetlands, both within LLBdM and other areas of the river. Another 62 hectares (153 acres) of SAV are present in the same part of the river as the Thousand Islands wetlands; therefore, it is assumed that the SAV is again associated with these wetlands. Only 26 hectares (64 acres) of SAV are present in the river downstream of the Rapide Croche dam (Exponent, 1998). This is likely due to the fact that the river is narrower with faster stream flow velocities; conditions that are not favorable (1978) or the establishment of SAV. In addition, water clarity and depth are also other limiting factors which effect the presence or absence of SAV in a given location (Szymanski, 2000).

The USFWS completed a study of the fish and wildlife resources of the Great Lakes coastal wetlands in 1981. This study found that there are at least 17,098 hectares (42,250 acres) of wetlands located along the shores of Green Bay (Table 4-1). The wetland/wetland complexes identified on Table 4-1 include those over 40.5 hectares (100 acres) in size, which is the MNFI study size criterion (Albert, 2000). Although there are a number of fully functioning wetlands under 20.2 hectares (50 acres) along the shores of Green Bay, physical constraints generally inhibit these wetland areas from expanding (Albert, 2000). Therefore, controlling losses in larger wetland complexes is important for maintaining the overall wetland habitat of the region (Albert, 2000). However, the functional value or benefit of smaller wetland areas cannot be discounted. The 40.5 hectare (100 acre) size criteria is only used to focus the discussion below.

Approximately 42 percent of wetland areas larger than 40.5 hectares are located in Wisconsin while about 58 percent are located in Michigan. Both the bathymetry and the physical environment of the bay have a significant influence on the size and location of coastal wetlands. Based on these factors, the distribution of wetlands along the east shore of Green Bay is very limited compared to the west shore of the bay and in both Big Bay de Noc and Little Bay de Noc (Table 4-1; Figures 4-5 and 4-6).

Almost 570 hectares (1,400 acres) of wetlands are located along the east shore of Green Bay. This represents just over 3 percent of all the wetlands larger than 40.5 hectares (100 acres) in the bay (Table 4-1). Wetlands along the east side of Green Bay are generally classified as palustrine (marsh or swamp) (USFWS, 1981). Palustrine wetlands generally lack flowing water and have water depths less than 1.8 m (6 feet) deep. Based on the Exponent (1998) and USFWS (1981) descriptions, many of the wetlands along the east shore of Green Bay are emergent/wet meadow wetlands.

About 8,000 hectares (19,770 acres) of wetlands are present along the west shore of Green Bay, from the Fox River mouth to the city of Escanaba, Michigan, (Table 4-1). This is approximately 47 percent of the Green Bay wetlands greater than 40.5 hectares. Between the Fox River mouth and the city of Oconto, Exponent (1998) classified slightly more than 50 percent of the wetlands as emergent/wet meadow, while approximately 31 percent were shrub/scrub wetlands. The information provided by USFWS (1981) and Minc and Albert (1998) suggest that wetlands further north of the city of Oconto are similar (Table 4-1). The USFWS (1981) primarily classified all the west shore wetlands as lacustrine systems (Table 4-1), although smaller palustrine systems were typically associated with these wetlands. The west shore wetlands are affected by littoral currents, storm driven wave action, wind action, and ice scour, which the primary causes of shoreline sediment deposition and erosion (Minc and Albert, 1998). These lacustrine systems have developed in the shallows of the bay and many of them are associated with the Green Bay tributary spits or deltas. Only wetlands associated with river deltas are classified as riverine systems (Table 4-1). These include select portions of the Atkinson Marsh (Duck Creek), Oconto Marsh (Oconto River), Peshtigo River Wetland, Cedar River Wetland Complex, and Ford River Wetland Complex (Table 4-1). Other riverine wetlands are associated with the other tributaries; however, these wetlands are usually very small and are not included on Table 4-1.

Wetlands found in both Little Bay de Noc and Big Bay de Noc are predominantly lacustrine systems and are generally similar to the west shore wetlands. Approximately 8,527 hectares (21,070 acres) of wetlands are located in these two bays. This is just under 50 percent of the Green Bay wetlands larger than 40.5 hectares (Table 4-1). These wetlands have extensive emergent vegetation development (Minc and Albert, 1998). Also, the wet meadow complexes, shrub swamp, swamp forest wetlands in the UP are typically larger and more a readily extensive than further south in Green Bay. This is primarily due to less development in this region of the bay compared with areas further south.

Due to the fact that the west and north shore wetlands developed on gently sloping lake or outwash plains, these wetlands are considered to be "pulse stable" systems (USFWS, 1981; MDNR, 1998). Periodic, short-term and long-term water level fluctuations are very important to the maintenance and productivity of pulse stable wetlands. High water levels in the mid-1970s and mid-1990s reduced the areal extent of these wetlands, flooded areas of emergent vegetation, and may adversely effect wet meadow or shrub/scrub plant species that may not be able to tolerate flooded conditions for extended periods of time. Conversely, periods of low water levels allow expansion of wetland areas, decomposition of accumulated organic material, and new wetland plants to germinate (MDNR, 1998). Emergent plant species will colonize shallow water areas as the area of wet meadow and shrub/scrub plant species increases lakeward.

The state of Wisconsin has a number of designated wetlands/wildlife areas located in the Green Bay area. The largest of these is the Green Bay West Shores State Wildlife Area (SWA), which comprises 11 separate wetland units. The 11 units are listed below, starting near the Fox River mouth and moving north along the west shore. The status of an area as either a designated SWA or national wildlife refuge (NWR) is also indicated.

Green Bay West Shore Wildlife Area Units

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

Currently, just over 3,015 hectares (7,450 acres) are designated as part of the Green Bay West Shores SWA. However, the WDNR desires to expand this area to a total of 5,639 hectares (13,933 acres) in the future (WDNR, 2000b).

Along the east side of the bay, the Gardener Swamp SWA covers 478 hectares (1,181 acres) in Door County (WDNR, 2000b). Gardener Swamp SWA is located just south of Little Sturgeon Bay, approximately 2.4 km (1.5 mi) from the bay. The WDNR is also currently planning to establish the Red Banks Glades

SWA in Brown County. This planned SWA would cover approximately 204 hectares (503 acres) and be located just inland from the bay, similar to the Gardener Swamp SWA (WDNR, 2000b).

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

4.2.3.2 Wetland Losses

Wetlands, similar to woodlands, were historically more prevalent than they are today. While wetland losses can be attributed to both human and natural processes, those associated with human activities are generally more permanent. Filling of lowland and marshy areas was historically considered advantageous, as these areas were of little recognized use or importance and the resulting land could be developed for numerous purposes. This was probably more predominant along the banks of the Lower Fox River than along the shores of Green Bay, but it has occurred throughout the region (Burridge, 1997; Exponent, 1998). Due to the cities and large areas of developed land located along the banks of Lower Fox River, it is likely that wetland losses along the river resulting from human activities have been more significant than along the shores of the bay. Additionally, water level fluctuations within the bay play an important role in the amount of wetland present immediately adjacent to the shore and extending into the bay during any given time period.

In the Lower Fox River, the only wetland exceeding 8.1 hectares (20 acres) is associated with the Thousand Islands Nature Preserve (Exponent, 1998). Wetland losses in the Lower Fox River were generally associated with filling and development activities, including construction of the locks and dams. Although not directly documented, it is likely that construction of the locks and dams of the Lower Fox River, along with the dredging activities which occurred up through the 1960s (as listed on Table 3-13) likely had long-term detrimental impacts on the riverine wetlands. Exponent (1998) documented development of the Lower Fox River shoreline and these results are discussed below in riverine habitat section.

Green Bay shoreline development has also resulted in wetland habitat loss, some of which has been documented. The Bay Port Industrial Park and CDF is a 243 hectare (600 acre) facility located along the west shore of Green Bay about 3.2 km (2 mi) from the Fox River mouth. This facility was constructed between Interstate 43 and the bay, largely over Atkinson Marsh. In the early 1960s, the

Bay Port Industrial Park was envisioned as a facility to enlarge, enhance, and modernize the Port of Green Bay. In order to fill the incorporated wetlands of Atkinson Marsh and the other low areas, the city of Green Bay offered the site to the USACE as a CDF for placement of sediments dredged from the navigation channel and other harbor work. The USACE began disposing of dredge spoils at Bay Port in 1966 and approximately 7.24 million m^3 (9.47 million yd^3) have been placed in the CDF through the end of 1999 (Table 3-13).

Wetland losses along the west shore of Green Bay from the Fox River mouth to the city of Marinette, Wisconsin were studied in the mid-1970s (Bosley, 1976 and 1978). Using land survey information from 1834 through 1844, it was estimated that at least 223 km^2 (86 mi^2) of coastal wetlands were present along the west shore of Green Bay (Bosley, 1976). In the mid-1970s, Bosley (1978) estimated that the west shore wetland areas had decreased to approximately 63 km^2 (24.3 mi^2) at low water levels and about 45.3 km^2 (17.5 mi^2) at high water levels. This represents a loss of 72 percent to 80 percent of the west shore wetlands. In 1981, the USFWS estimated that there were approximately 63.5 km^2 (25.5 mi^2) between the mouths of the Fox and Menominee Rivers, similar to Bosley's (1978) estimate.

Schideler (1994a) documented the loss of wetland areas between 1951 and 1986 resulting from natural processes, specifically water level fluctuations and storm effects. Schideler (1994a) analyzed the size and extent of Long and Little Tail Points and their associated wetlands. The Long Tail Point area included the point and all wetlands from just east of the Fox River mouth to the location where Long Tail Point joins the shore. This area included the Duck Creek delta, Peats Lake, Atkinson Marsh, Peters Marsh, Dead Horse Bay, and the other bayhead islands between Long Tail Point and the mouth of the river, including the Cat Island Chain and Grassy Island. Much of this area is shown on Figure 4-7. The Little Tail Point area included the point and all wetlands from just south of the Suamico River to just north of the Little Suamico River.

Estimated net wetland losses in the Long and Little Tail Point areas between 1951 and 1986 were approximately 420 hectares (1,040 acres) and 200 hectares (500 acres), respectively (Schideler, 1994a). The net loss (or gain) of wetland is the total difference between total wetland losses and total wetland gains. Typically, there is some amount of loss in one area with wetland gains occurring in other areas. The most significant periods of high water levels found during this time frame were in 1952-53, 1973-74, and 1985-86. As mentioned above, although the wetlands of Green Bay are pulse-stable systems, extended periods of high water reduce overall wetland areas. Additionally, if significant wind action, wave action or storms occur during these periods of high water, significant sediment volumes may be displaced, thereby disturbing, reducing, or destroying the wetland. Schideler (1994a) observed such results in the Long Tail Point area and the specific areas of wetland losses are listed below and shown as blackened areas on Figure 4-7.

Wetland Losses in Select Areas of Lower Green Bay, 1951-1986.

Location	1951-1982 Hectares (Acres)	1982-1986 Hectares (Acres)	Total losses Hectares (Acres)
Long Tail Point	57.6 (142.3)	50 (123.6)	107.6 (265.9)
Duck Creek Delta	136 (336.2)	82.8 (204.5)	218.8 (540.7)
Duck Creek (Upstream)	12.2 (30.1)	18.9 (46.6)	31.1 (76.7)
Peters Marsh/Peats Lake	40.9 (101.1)	11.1 (27.4)	52 (128.5)
Dead Horse Bay	2.4 (6)	10.5 (26)	12.9 (32)
Cat Island Chain	16.7 (41.3)	2.1 (5.3)	18.8 (46.6)
Other Bayhead Islands	5.0 (12.3)	0 (0)	5.0 (12.3)
Bay Port	12.4 (30.7)	13.1 (32.3)	25.5 (63.0)
TOTALS	**283.3 (700)**	**188.5 (465.7)**	**471.8 (1,165.7)**

Most of the wetlands within this area are exposed to bay waters; therefore, the day-to-day wind/wave actions, storms, and water level fluctuations all impact these wetlands. The greatest wetland losses were associated with Long Tail Point and the Duck Creek delta, where over 324 hectares (800 acres) of wetlands were lost (Figure 4-7). Conversely, the wetland losses for Dead Horse Bay, which is largely protected from bay wave/wind action and storms by Long Tail Point, were only about 2.4 hectares (6 acres) during this time period. The most significant event affecting wetland losses between 1951 and 1982 was the April 1973 storm described in Section 3.5.2.1.

Water levels were high during 1973-74 and in April 1973 a strong storm blowing out of the northeast struck Green Bay. Significant wetland losses resulted from this storm. It is estimated that most of the wetland loss listed for the Duck Creek delta occurred during this storm, as flood waters washed into Duck Creek and destroyed wetlands upstream of the mouth (Erdman, 1999a). Long Tail Point was also severely eroded during this storm; so much so, that a large lighthouse that had been located just off the tip of the point since the 1800s was completely destroyed (Erdman, 1999a).

The Cat Island Chain was also virtually destroyed following the April 1973 storm, as all portions of the chain that had previously been above water were eroded below the water surface. The Cat Island Chain was a group of three large islands and approximately eight to ten smaller islands (Schideler, 1994a) (Figure 4-7) that had been a stable and constant feature in Green Bay since the first navigational charts were drawn in 1845 (Neville Public Museum). This chain acted as barrier islands, protecting the other shoreline wetlands in this area (Smith, 1999a). Review of the 1905 Green Bay Lake Survey Chart 725 (USACE, 1905) indicates that emergent vegetation was present over much of the area south and west of the Cat Island Chain, except in the immediate area of Peats (Peaks) Lake. It is speculated that loss of the Cat Island Chain resulted from the armoring of the shoreline in the vicinity of the Bay Port CDF (Smith, 1999a). Wetlands located on the bay side of the reinforced shoreline were completely eroded during the storm (Schideler, 1994a). The armored shore provided no dampening effect to absorb wave energy in the south end of the bay; therefore, the wave energy was simply reflected back into the bay (Smith, 1999a). Consequently, the bayhead islands, including those of the Cat Island Chain, were affected by severe wave action from both the bay and shore side, thereby facilitating erosion. Based on the high water level, the sediments composing these islands were removed and dispersed throughout the lower bay. Due to the recent low water level conditions, only about 37.2 m^2 (400 ft^2) remains of the chain today (USACE, 1998c).

Although there was an overall net loss of wetlands in the Long Tail Point area during this time frame, there were some wetland gains (Schideler, 1994a). The most important of these gains, in Schideler's opinion, was the construction of the Kidney (Renard) Island CDF. This facility and its construction are discussed in more detail in Section 4.2.3.3. Other small increases in wetland areas were noted in Dead Horse Bay, Peats Lake, Peters Marsh, and along the shoreline of the Bay Port facility.

Wetland losses were also documented for the Little Tail Point area (Schideler, 1994a). Between 1951 and 1974, this area experienced a net loss of just 2 hectares (5 acres). However, between 1974 and 1986, the net wetland loss was approximately 200 hectares (495 acres) (Schideler, 1994a). The majority of these losses were associated with Little Tail Point and the nearby mainland (85 hectares or 210 acres), the Sensiba SWA (44 hectares or 109 acres), and the mouths of the Suamico and Little Suamico Rivers (29.5 hectares or 73 acres and 43 hectares or 106 acres, respectively).

Schideler (1994b) completed a similar review of the Oconto, Pensaukee, and Peshtigo wetland areas over the same period of time. Between the early 1950s and 1974, the Oconto and Peshtigo areas actually had a net gain of about 15.8 hectares (39 acres) and 1.8 hectares (4.5 acres), respectively, while the Pensaukee area had a net loss of about 3.4 hectares (8.4 acres) (Schideler, 1994b). However, from 1974 through about 1987, all these wetlands decreased in size. The Pensaukee wetlands lost approximately 74 hectares (183.1 acres) while the Oconto and Peshtigo wetlands decreased by about 170 hectares (419 acres) and 145 hectares (358 acres), respectively. The wetland losses observed for all of the west shore wetlands likely resulted from increased water levels. The west shore wetland areas are likely re-establishing themselves based on the low water levels Green Bay is currently experiencing (USACE, 2000b).

4.2.3.3 Proposed Wetland Restoration Projects

Wetland redevelopment has been identified as a priority for restoration of the Green Bay area and ecosystem (RAP Biota & Habitat Work Group, 1994 & 1996). Three of the top four priorities identified by the Green Bay RAP Committee in 1994 included the following: 1) restoration of the Cat Island Chain; 2) protection, enhancement, and restoration of the river and bay wetlands; and 3) enhancement or creation of near-shore and in-lake habitat. In addition, establishment of the Kidney (Renard) Island CDF has facilitated wetland restoration east of the Fox River mouth. However, because sediments placed within this CDF are contaminated with PCBs, the overall impacts, both positive and negative, are still debated.

The USACE, along with the USFWS and other governmental and private agencies, are currently reviewing plans to re-establish the Cat Island Chain. The Cat Island Chain restoration proposal plans to use sediments from the northern most end of the navigation channel or further north in the bay, which are less likely to contain significant concentrations of PCBs or other chemical compounds (Smith, 1999b). The restored Cat Island Chain would provide additional bird and fish habitat in this area. The islands would also protect and facilitate recovery of the other west shore wetlands in lower Green Bay (Smith, 1999b). These wetland areas include Peats Lake, Peters Marsh, the Duck Creek delta, and the remaining portions of Atkinsons Marsh. The current plans include constructing three man-made islands of dredged material along the previous landforms. The USACE believes the work could commence in 2002 and would begin with the western most island, located closest to the western shore of Green Bay (Campbell, 1999). The three islands would be approximately 62.7 hectares (155 acres), 21.5 hectares (53 acres), and 15.6 hectares (38.6 acres), respectively (USACE, 1998c). Based on the fact that Kidney Island, which is about 21 hectares (52 acres), has already received more than 2.1 million m^3 (2.7 million yd^3) of sediment, it is possible that these three islands could receive well over 9.2 million m^3 (12 million yd^3) of sediment. Revegetation activities must also be undertaken in conjunction with island restoration to prevent exotic species from overtaking these areas (Nikolai, 2000a).

In addition to the Cat Island Chain restoration project, other activities would be undertaken to facilitate wetland and habitat recovery. Reintroduction of SAV in the area of the Duck Creek delta and Peats Lake would provide habitat for fish fry, as well as facilitate wetland recovery. Additionally, the riprapped areas of shoreline in the southern bay would be softened by promoting the growth of emergent vegetation and through creation of nearby sandbars. Softening this shoreline would reduce wave energy in the south end of the bay, thereby allowing further establishment of more SAV and emergent vegetation along the shore.

Kidney Island CDF has received over 2.1 million m^3 (2.7 million yd^3) of sediment since 1979 and has been a controversial project in the Green Bay area. Some consider the CDF an unsuitable habitat restoration alternative, due to the fact that PCBs and other chemical compounds contaminate the sediments contained therein. Also, the location of the CDF immediately offshore of Green Bay's historic Bay Beach has been a concern to some local residents. Concerns for the Kidney Island CDF were included in the Final Environmental Impact Statement (EIS), completed when expansion of the CDF was proposed (USACE, 1985). However, the presence of the CDF has fostered re-establishment of emergent vegetation around the perimeter of the island, especially in the quiet water between the CDF and the shoreline to the south. Some colonial nesting birds (e.g., terns) use the island as nesting grounds (Erdman, 1999b).

Neither the Bay Port nor Kidney Island CDFs have achieved their original project objectives. The Bay Port Industrial Park has not yet become the port facility originally intended and Kidney Island has not evolved into the wetland habitat and possible marina that was envisioned. Consequently, future island restoration projects like that proposed for the Cat Island Chain, and further use of CDF sediments contaminated by significant levels of PCBs or other chemical compounds may be of concern to some Green Bay area stakeholders (Erdman, 1999b).

The MDNR (1998) released a restoration and management plan for Portage Marsh. This marsh is located along the west shore of Green Bay south of the city of Escanaba (Figure 4-6). A dike system was established to facilitate access to the marsh in 1984; however, the dikes have impeded water exchange between the bay and marsh and limited water level fluctuations. Therefore, areas that were once wetlands are becoming uplands. Also, continued use of the area by off-road vehicles has contributed to further degradation. Therefore, the restoration and management plan called for prohibition of off-road vehicle use within the marsh and removal or opening of some dikes in order to allow water exchange between the bay and marsh as well as facilitate water level fluctuations (MDNR, 1998). Also, because wet meadow areas of the marsh were beginning to see the establishment of various trees (marking transition to a shrub swamp or swamp forest type wetland), the MDNR proposed controlled burning of select areas. This burning would facilitate growth of wet meadow plant species and, in select areas, provide more open water spaces for increased use by wildlife (especially migratory waterfowl).

4.2.4 Riverine Habitat of the Lower Fox River

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

The *Habitat Characterization Assessment* (Exponent, 1998) divided the Lower Fox River into two parts, upstream and downstream of the De Pere dam. The upstream portion is comprised of the LLBdM, Appleton to Kaukauna, and Kaukauna to De Pere reaches, while the downstream portion is comprised of the De Pere to Green Bay Reach. Eight different aquatic habitats were identified within the Lower Fox River (Exponent, 1998). These habitat types and the percentage of each type within the river are listed on Table 4-2 and shown for each reach on Figures 4-1 through 4-4.

The largest category described by Exponent (1998) was the Island/Peninsula habitat (Table 4-2). Most areas where island/peninsula habitat was observed are small, unnamed outcroppings and areas within the Lower Fox River which were formed during lock and dam construction and channelization of the river in the 1800s. A few notable areas for this habitat type are Stroebe and James Islands in LLBdM (Figure 4-1), the Thousand Islands Nature Conservancy near Kaukauna (Figure 4-2), and the unnamed islands associated with the Cedar, Combined, Rapide Croche, and Little Rapids Locks (Exponent, 1998).

Backwater, cuts, and coves are the second largest habitat category observed within the river (Table 4-2) (Exponent, 1998). These areas are relatively undisturbed by human activities and, thus, they are very desirable for wildlife and fish (Exponent, 1998). These habitat areas are also generally small and scattered throughout the river, making them an important habitat for maintenance of current fish and wildlife populations that use them. These areas are shown on Figures 4-1 through 4-4.

Two other important habitat types are the dam riffles and submerged rock, piling, or ruin environments. Although these two habitats constitute just over 12 percent of the Lower Fox River, game fish are often associated with these areas. Fish such as walleye prefer rocky substrates with fast running water for spawning purposes. Walleye are an important game fish of the Lower Fox River. Although, sandbars and silt deposits are rare along the Lower Fox River, they are important for turtle nesting and shorebird feeding activities (Nikolai, 2000b).

In addition to reviewing the aquatic habitat, Exponent (1998) evaluated the riverbanks and substrate characteristics. The shoreline classifications are shown on Figures 4-1 through 4-4 (Exponent, 1998). The river shoreline was divided into both developed and natural riverbank, with subcategories of each (Table 4-3). About 44.6 percent of the river shoreline is developed and protected with either riprap or bulkheads while the remaining 55.4 percent is natural bank (Table 4-3).

Slightly more than 22.4 km (13.9 mi) of the 28 km (17.4 mi) of developed shoreline is protected with riprap (Table 4-3) and, according to Exponent (1998), riprap is preferable to bulkheads. Riprap tends to offer some habitat possibilities as some fish will find protection and feeding opportunities and some birds will nest in the crevices and gaps of the riprap. Bulkheads offer little in the way of habitat due to the smooth surfaces and vertical walls.

The Lower Fox River has about 34.8 km (21.6 mi) of natural shoreline (Table 4-3). Almost 44 percent of the entire river shoreline is classified as riparian canopy, which includes tree-lined and forested banks of the river (Exponent, 1998). About 15.9 km (9.9 mi) of riparian canopy shoreline is situated between the Cedars and Little Rapids locks (Figure 4-2). This is one of the least developed portions of the Lower Fox River, with steep banks that inhibit significant agricultural or urban development. Shorelines with either groundcover or wetland comprise almost 6.8 km (4.2 mi) while sand and gravel beaches comprise less than 1 percent of the shore (Table 4-3).

The river substrate summary is included on Table 4-3 (Exponent, 1998). The areal extent of the river is about 21.8 km^2 (8.4 mi^2). Soft silty sediment (Type 1) comprises about 11.7 km^2 (4.5 mi^2) or about 53 percent of the river bottom. Compact sand and gravel (Type 3) accounts for about 6.3 km^2 (2.4 mi^2), or about 29 percent of the river bottom (Table 4-3). The river bottom downstream of LLBdM is essentially made up of either Type 1 or Type 3 sediments. Half of the bottom material in LLBdM is Type 2, semi-compact sand/clay, sediments. The most prevalent areas of Type 3 sediment (compact sand/gravel) are located between the Appleton and Little Rapids dams (Table 4-3), suggesting the increased current velocities associated with the generally narrow river width, transport silt and other fine-grained sediments further downstream of these areas. Between Appleton and Little Rapids, the only significant accumulation of soft silty Type 1 sediment is in the part of the river where the Thousand Island Nature Conservancy and wetlands are located.

Downstream of the Little Rapids dam, the majority of the river bottom is Type 1 soft, silty sediments. The areal extent of the river from Little Rapids to the mouth of the Lower Fox River is almost 9.1 km^2 (3.5 mi^2), but only 0.3 km^2 (0.12 mi^2) of Type 3 river bottoms were noted in this stretch (Table 4-3). These results confirm the sediment sampling results of previous investigations, which found long, continuous deposits of soft sediment between Little Rapids and the river mouth (WDNR, 1995 and 1998; GAS/SAIC, 1996; Exponent, 1998).

4.2.5 Lacustrine Habitat of Green Bay

4.2.5.1 Overview

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

Other unique aspects of lacustrine environments are related to water currents, sediment deposition and erosion, and the wetland complexes that develop therein. Unlike rivers, which normally have a unidirectional current (gravitational), lacustrine currents are more complex, variable, and weaker (Maitland and Morgan, 1997). Sediments transported from the Lower Fox River and other tributaries into Green Bay are deposited down current from the mouth as the river and bay waters mix and the water velocities decrease. Together with littoral transport, which moves sediments along a lake shore, these factors result in sediment accumulations (like the Duck Creek delta) and the spits, shoals, and shallows located near the tributary mouths on the west side of the bay (refer to Figures 3-4 through 3-6). Because wind, wave action, and currents are the primary causes for erosion and redeposition within the Great Lakes (USACE, 1998d), sediment erosion within Green Bay is largely confined to shore and near-shore areas where water depths are shallower. These actions may resuspend deposited sediment and move it through the bay. Lacustrine environments typically develop larger wetlands than riverine systems, especially in areas of extensive shallow water and low current velocities.

Lacustrine environments are generally categorized based on the biological conditions of the system and the three classifications are eutrophic, oligotrophic, and dystrophic. Lower Green Bay is eutrophic and hypereutrophic (extreme eutrophic conditions) while the northern portion of the bay is generally oligotrophic. The general characteristics of eutrophic and oligotrophic conditions are listed below (Maitland and Morgan, 1997). In addition, Green Bay is also mesotrophic in areas; the mesotrophic condition is an intermediate classification between the eutrophic and oligotrophic conditions.

General Trophic Classifications Which Apply to Green Bay

Character	Eutrophic	Oligotrophic
Basin shape	Broad and shallow	Narrow and deep
Substrate	Organic silt	Stones or inorganic silt
Shoreline	Weedy	Stony
Water transparency	Low	High
Water color	Green or Yellow	Blue or Green
Dissolved solids	High (much N/Ca)	Low (poor in N)
Suspended solids	High	Low
Oxygen	Low (especially under ice or thermocline)	High
Phytoplankton	Few species/high numbers	Many species/low numbers
Zooplankton	Few species/high numbers	Many species/low numbers
Macrophytes	Many species/some abundant	Few species/rarely abundant
Zoobenthos	Many species/high numbers	Many species/low numbers
Fish	Many species	Few species

Eutrophic lakes are nutrient rich, usually shallow, turbid waters that may experience oxygen deficiencies under the ice or in deeper areas at certain times of the year (Maitland and Morgan, 1997). Oligotrophic lakes are typically deep, clear waters that are nutrient poor and rarely, if ever, have oxygen deficiencies (Maitland and Morgan, 1997).

4.2.5.2 Inner Bay Water Quality

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

The silty substrates, shallow water depths, extensive wetlands, and green color were all observed by the earliest explorers of the region. The process of eutrophication is natural and generally occurs over an extended period of time, as fresh waters tend to become silty. Potential nutrients within bottom sediments are typically only released when the water becomes shallow enough that macrophytes utilize them (Maitland and Morgan, 1997). This was the general state of the inner bay (particularly the southern end) when European settlers arrived in the region.

The hypereutrophic conditions of the lower bay were likely brought on by development, which greatly accelerated eutrophication. The Lower Fox River served as the primary disposal system for domestic and industrial wastes, which contributed significant quantities of nutrients (particularly phosphorous and nitrogen), to the bay through much of 20th century. Intense farming with heavy application of fertilizers, especially in the lowland areas of the rivers and lakes leads to enrichment of runoff waters with nutrients (Maitland and Morgan, 1997), and this has occurred in the Lower Fox River and Green Bay area (Harris, 1994).

Fish dies-offs on the east side of the bay in 1938-39 (Wisconsin State Board of Health, 1939) indicated the impacts of poor water quality and the lack of DO within the inner bay. Water quality and benthic community studies throughout the mid-1900s showed low DO. and degraded water quality. Recent waste treatment practices have greatly reduced the loads of organic material in the river and bay since the 1960s and 1970s and resulting in DO concentrations generally remaining above the standard of 5 mg/L (Harris, 1994). Since at least 1975 there have not been any large fish die-offs related to low DO levels (Lychwick, 2000c). However, DO concentrations have dropped below 5 mg/L during summer months when algal blooms occur (Harris, 1994). Recurring algal blooms are one sign that the eutrophic conditions of the southern bay continue today.

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

4.2.5.3 Outer Bay Water Quality

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

4.3 Benthic Communities

The benthic macroinvertebrates of the Lower Fox River and Green Bay environment include adult and larval insects, mollusks, crustaceans, and worms that predominantly burrow directly into the fine-grained substrate for most of their life cycle. The benthic macroinvertebrate community plays a vital role in ecosystem functions such as nutrient cycling and organic matter processing. These creatures are also an important food resource for the benthic and pelagic fish communities, and semi-aquatic organisms such as birds and mammals feed on them occasionally as well.

Many of the benthic community surveys have focused on oligochaetes, chironomids, and the burrowing mayfly (*Hexagenia*). The oligochaetes and chironomids are thought to be tolerant of organic enrichment and/or degraded habitats, like that of the Lower Fox River and lower Green Bay, whereas other species are less tolerant of enriched/degraded habitats. *Hexagenia* are considered to be pollution sensitive or intolerant taxa.

Historical macroinvertebrates surveys completed between 1938 and 1978 examined populations and taxa richness near the mouth of the Lower Fox River and in lower Green Bay (Markert, 1978). The 1938-39 pollution survey found that oligochaetes and chironomids dominated the benthic communities. *Hexagenia* were also detected at 16 of 51 stations sampled in 1938-39 (Markert, 1978), suggesting that water quality conditions had not reached their worst in the bay. In addition, very low numbers of leeches, sowbugs, scuds, clams, and snails were all observed at various locations in 1938-39 (Markert, 1978).

Water quality deteriorated significantly between 1938-39 and 1952 as measured by the benthic community populations. Comparison of the 1938-39 and 1952 sampling data indicated that both the oligochaete and chironomid populations had increased. During 1938-39 oligochaetes and chironomids were completely absent in a few locations in the southern bay (Surber and Cooley, 1952). However, in 1952 established populations of both groups were observed at locations as far north as Oconto and Little Surgeon Bay, indicating that the water quality in the southern bay was progressively worsening (Surber and Cooley, 1952).

Similar deteriorating water quality results were noted in 1978 (Markert, 1978). In 1978, the density of oligochaetes and midges was greater than in 1938-39, while *Hexagenia* were not observed at all in 1978, indicating further degradation of water quality was continuing. However, comparison of the 1952 and 1978 sample results indicated that there was some improvement in water quality since the 1950s (Markert, 1978).

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

The 1992-93 results reflect recovery from the severely impaired conditions found in the 1960s and 1970s (IPS, 1994). These results were bolstered in 1994 by the presence of snails, clams, and mussels at the LLBdM sites in deposits D and POG (IPS, 1995). The results of these early 1990s studies indicated that the density of the benthic community populations had increased significantly compared with studies completed during the 1980s in LLBdM (IPS, 1995). Downstream of LLBdM, in deposits N and EE/FF, the 1992-1994 benthic community results indicated that benthic community populations increased; however, oligochaetes and chironomids were still dominant and there was no corresponding increase in community diversity to accompany the population increase. Similarly, conditions in the middle and outer portions of Green Bay seemingly reflected an improvement in general water quality due to an increase in scuds and sow bugs, which were typically observed in more northern reaches of the bay (IPS, 1995). However, the presence of zebra mussels probably signals future difficulty for the benthic communities of Green Bay due to the ability of this exotic species to out-compete the local benthic species for food and habitat (IPS, 1995).

4.4 Fish

The WDNR has completed a number of fish surveys in the Lower Fox River and inner Green Bay. However, due to the numerous factors that may effect fish populations, simple review and comparison of the survey results from various years is not valid. Year to year fish populations do not necessarily indicate whether conditions within the river and bay are degraded or improving because other environmental, physical, or biological factors may be impacting select species at any given time. Surveys reviewed for the Lower Fox River and Green Bay zones 1 and 2 provide data on the fish present within the system. In addition, the personal observations from WDNR and MDNR personnel familiar with both the commercial and sport fisheries of Green Bay are included. The RA addresses the possible population impacts that result from anthropogenic and natural stresses.

Fish samples collected for PCB analysis are included in the FRDB and the fish surveys summarized herein are population counts only and include those species evaluated in the RA or RA food web model. Therefore, this discussion is not intended to be a comprehensive evaluation of all species in the system. Rather, this summary provides insight into the role that fish have in PCB uptake into the food chain. Further analysis of PCB uptake are included in the RA.

Environmental degradation of the Lower Fox River and Green Bay either directly or indirectly impacts the resources of the Oneida and Menominee Nation Trust Lands. Issues of concern to both tribes are addressed herein. The fisheries of the Lower Fox River and Green Bay are important to the Oneida and Menominee Indian Nations for cultural reasons. Fish have historically been a staple part of the diet of the Oneida and Menominee people as a major source of protein because fish can be dried, canned, salted, or smoked for use throughout the year (Stratus, 1999b).

4.4.1LLBdM to De Pere Dam Fish Surveys

The WDNR has conducted a number of fish population surveys of the Lower Fox River in association with water quality studies. The surveys listed below consist of tabulated data only and are unpublished. They were completed during several time periods with a variety of survey equipment and for different purposes. Therefore, is not appropriate to analyze whether particular data indicates an increasing or decreasing population because the factors affecting fish populations are much more complex than the survey numbers may suggest.

WDNR Lower Fox River Fish Surveys

Survey Area	Year(s)	WDNR Investigators	Purpose
LLBdM to De Pere	1976	Marinac & Coble	Determine species present and relative abundance
Rapide Croche to Wrightstown	1976	Langhurst	Evaluate stocks as water quality improves in the future
LLBdM to Wrightstown	1977	Meyers	Community and populations
LLBdM	1983	Meyers	Evaluate northern pike populations and spawning areas
LLBdM to Wrightstown	1993/1994	Bruch & Lychwick	Fisheries and habitat status
Little Rapids to De Pere	1994/1995	Lychwick	Population surveys

The fish population results from these studies are summarized on Table 4-4. At least 43 different fish species were identified in the river upstream of the De Pere dam (Table 4-4). Twenty-four species were game fish and nineteen species were non-game fish (as defined by state statute). The 1983 LLBdM fish survey indicates that approximately 60 percent of the species captured were game fish, and that black bullhead and black crappie were the predominant type (Table 4-4).

Population results for the LLBdM to the De Pere dam indicate that game fish typically comprise about 30 percent to 40 percent of the fish captured (Table 4-4). Yellow perch, walleye, white bass, and bullheads have all been the dominant game fish species at one point or another. The 1994-95 walleye results for the Little Rapids to De Pere Reach suggests that improved water quality due to decreases in the suspended solid load have facilitated an increase in the walleye populations. (Lychwick, 2000b). Carp was the most prevalent fish observed upstream of the De Pere dam. Carp typically accounted for 50 percent to 90 percent of non-game fish and approximately 50 percent to 60 percent of the all fish captured in the surveys.

4.4.2De Pere to Green Bay/Duck Creek Fish Surveys

WDNR has conducted surveys in Green Bay zones 1 (the De Pere to Green Bay Reach) and 2 and in Duck Creek. These surveys are discussed together because these areas are interconnected and fish found within any of these waters may also inhabit other areas.

The Oneida Indians came to Wisconsin from New York in the 1800s. Duck Creek lies within the Oneida Reservation and became an important resource for the tribe because of the abundant waterfowl and fish associated with it. Because PCBs have been found within fish caught in Duck Creek, the results of the 1998 Duck Creek fish assessment are summarized here. The assessment was completed cooperatively by the USFWS, WDNR, and Oneida Nation. Although the Duck Creek assessment is published (Cogswell and Bougie, 1998), the 1987 through 1998 survey data for the De Pere to Green Bay Reach are only tabulated and unpublished. The two surveys summarized in this section are listed below.

WDNR Green Bay Zones 1 and 2 Fish Surveys

Survey Area	Year(s)	WDNR Investigators	Purpose
De Pere to Green Bay	1987/1998	Lychwick	Evaluate early spring spawning populations
Duck Creek Assessment	1995/1996	Cogswell/Bougie	Populations survey spring through fall

The fish population results from these studies are summarized on Table 4-5. Annual fyke net surveys were completed by WDNR for the De Pere to Green Bay Reach between 1987 and 1998 (Table 4-5). Only the data from April of each year is listed on Table 4-5 due to the different length of time each survey was conducted.

Game fish account for 70 percent to 90 percent of the total captured fish population. The dominant game fish typically include yellow perch, which is also one of the primary commercial species in the bay, as well as walleye, white bass, and white perch. Furthermore, walleye is the only other game fish that generally comprises more than 10 percent of the total fish population (Table 4-5). This may reflect the success of the historic WDNR walleye stocking programs, as there is now a sustainable natural reproducing population (Lychwick, 2000b). Non-game fish below the De Pere dam are predominantly carp, white sucker, drum, and quillback.

In Duck Creek, 21 species (7 non-game and 14 game fish) were observed that were also present in the De Pere to Green Bay Reach (Cogswell and Bougie, 1998). In addition to the species listed on Table 4-5, 34 other fish species were also observed in Duck Creek. However, many of these were small non-game fish like shiners, chubs, and darters. Cogswell and Bougie (1998) found that the fish-supporting capacity of Duck Creek is limited by several factors, including low water flow, low DO, high water temperatures, and degraded water quality. Duck Creek is an intermittent stream and has been significantly impacted by the agricultural activities of the watershed. Sediment erosion from tilled fields has been found to account for over 75 percent of the total phosphorous load in the creek (WDNR, 1997).

Walleye and northern pike of Green Bay frequented several tributaries during their life. Walleye and northern pike originally tagged within the Lower Fox River were found in Duck Creek, and 46 percent of the northern tagged in Duck Creek were recaptured at several locations in Green Bay (Cogswell and Bougie, 1998). Also, the age and size range of the walleye captured in Duck Creek was similar to those in the Lower Fox River during spring (Cogswell and Bougie, 1998), indicating fish migration between Green Bay and its tributaries. Similarly, Lychwick (2000a) indicated that tagging studies in the De Pere to Green Bay Reach (Green Bay Zone 1) and Green Bay Zone 2 revealed that fish migrate between the bay and river. These results suggest that the fish move to locations where food and habitat characteristics are favorable.

4.4.3 Green Bay Fishery Observations and Habitat

To facilitate analysis of PCB uptake in the RA, the Project Team has categorized fish of Green Bay into four groups (Table 4-6). These groups include salmon/trout, benthic, pelagic, and game fish. Many of the salmon and trout of the region are found in cold-water fisheries of the northern part of Green Bay. The benthic fish are those that generally feed or live near the bottom of the bay while the pelagic fish are those which typically feed or live near the water surface. The game fish listed on Table 4-6 are those typically sought by sport or commercial fisherman.

The general spawning areas in Green Bay for each of these fish groups is shown on Figures 4-8 and 4-9 (NOAA, 1997c). The NOAA (1997c) spawning data only extended to a line just north of Door County, Wisconsin. Therefore, additional spawning observation data for the remaining portion of Zone 4 were obtained from the Great Lakes Commission (GLC) (2000). Whereas the NOAA (1997c) data identified the spawning locations by select fish group and species, the GLC (2000) data did not include such distinctions. Rather, GLC (2000) data is simply shown as points on Figures 4-8 through 4-12 indicating locations where fish spawn.

Spawning areas for the salmon/trout are in the vicinity of the tributaries and the central portion of the bay, where water temperatures are generally colder (Figure 4-8). The spawning areas for the pelagic and benthic fish are similar (Figures 4-8 and 4-9) and concentrated mainly in the areas of significant wetlands (Figures 4-5 and 4-6). Game fish spawning areas are also similar but include additional areas on the east side of the bay, likely due to the fact that some species, like walleye, prefer gravel beds to the SAV associated with the wetlands.

Most of the species discussed herein are pelagic fish (shiners, gizzard shad, smelt, and alewife) as indicated on Table 4-6. Yellow perch and walleye are game fish, carp and sturgeon are benthic species, and brown trout represent the salmon/trout group. Identified spawning areas for most of these fish in the southern half of Green Bay are shown on Figures 4-10 through 4-12. In the northern portion of the bay, walleye spawn in the river tributaries, and along the reefs, shorelines, and islands of both Big Bay de Noc and Little Bay de Noc while yellow perch spawn in the shallow waters of these bays (Schneeberger, 1999). Alewife, gizzard shad and shiners all spawn in the nearshore waters of both bays while carp are concentrated in the northern end of Little Bay de Noc and along the shoreline of Big Bay de Noc (Schneeberger, 1999). Smelt historically ran in most of the rivers and streams in the area but have recently been spawning in more offshore waters as well (Schneeberger, 1999).

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

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

Green Bay south of the Peshtigo Reef (west side) and Sturgeon Bay (east side) is generally a warm water fishery, with eutrophic water conditions, significant plankton populations, and numerous fish species (Toneys, 1999; Belonger, 2000). This fishery is separated from the cold-water fishery to the north by localized currents between the Peshtigo Reef and Sturgeon Bay (Figures 3-2 and 3-3) and differing trophic conditions in this area (Lychwick, 2000b). North of Peshtigo Reef and Sturgeon Bay the fishery is a cold water, meso-oligotrophic system with reduced plankton populations and fewer fish species (Schneeberger, 2000).

Heavily pursued sport fish south of the Sturgeon Bay-Peshtigo line include walleye, yellow perch, northern pike, and spotted muskellunge (muskie). Small mouth bass, brown trout and salmonids are also pursued north of Sturgeon

Bay-Peshtigo (Toneys, 1999; Belonger, 2000). The yellow perch and alewife are the predominant commercial species in the southern area, especially during the summer. During the winter, the lake whitefish become an important commercial species. The whitefish prefer cold waters and are fished in the northern bay year-round. However, whitefish migrate south in pursuit of food when water temperatures decrease in the southern end of the bay (Toneys, 1999; Belonger, 2000). Tagging studies of yellow perch and small mouth bass indicate that these fish tend to stay within the area where they were caught. For example, yellow perch caught in the warm waters of the southern bay do not typically migrate to the cold water fishery in the northern bay (Toneys, 1999). Similarly, the Sturgeon Bay Canal is prone to seiche effects and water temperature changes of 5.5°C to 11°C (10°F to 20°F) in a single day, which tend to limit the movement of fish through this channel (Toneys, 1999). Therefore, fish within Green Bay may move into Lake Michigan and vice-versa, but this canal is not a significant migration route (Toneys, 1999).

A thermocline has been observed in the Sturgeon Bay-Peshtigo area, and this also influences fish movement in the bay. The thermocline tends to form and stay near a depth of 3 to 12 m (10 to 40 feet), based on weather conditions. If a consistent northeast wind is experienced, this may push the thermocline down to depths of approximately 18 m (60 feet) (Belonger, 2000).

In northern Green Bay, walleye, yellow perch, northern pike, splake, chinook salmon, small mouth bass, white bass, and carp are all sought by sport fishermen. In Michigan, the annual sport catch of walleye may range between 30,000 and 90,000 kg (66,100 and 198,400 pounds) while the yellow perch catch is on the order of 10,000 to 80,000 kg (22,050 to 176,400 pounds) (Schneeberger, 2000). Lake whitefish and rainbow smelt are the main commercial species. The annual whitefish catch ranges from 1 million to 1.5 million kg (2.2 million to 3.3 million pounds) while the smelt catch is on the order of 50,000 to 200,000 kg (110,230 to 440,900 pounds) (Schneeberger, 2000).

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

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

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

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

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

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

Habitat differences adequately defined fish assemblages for Green Bay zones 3 and 4, but they were not a good predictor for Zone 2 (Brazner and Beals, 1997).

Macrophyte level was the habitat characteristic that best predicted fish assemblages. When macrophyte cover and richness is high, the same is generally true of fish richness and abundance (Brazner and Beals, 1997). An exception to this is where macrophyte cover is so dense that it has limited utility for fish.

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

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

For 21 of the 54 fish species caught, either more than 80 percent of the individuals or at least a significant number of them were caught in one zone. These results demonstrate that regional differences were stronger determining factors of fish assemblage than habitat or development. Of these 21 zone-biased fish species, freshwater drum, white bass, and gizzard shad were caught almost exclusively in Zone 2, and golden shiners, pumpkinseeds and logperch were most often caught in Zone 4 (Brazner, 1997). Although rainbow smelt, trout, perch, and banded killfish were predominantly caught only in Zone 3, none of these were the most abundant fish taken in this zone.

The bay zone and habitat of the specific fish species that have been selected for risk evaluation of the Lower Fox River and Green Bay are summarized below (Brazner, 1997).

Fish Species	Dominant Zone Occurrence	Dominant Habitat
Yellow Perch	Green Bay Zone 2 (74 percent)	wetland habitat (74 percent)
Spottail Shiner	Green Bay Zone 2	beach habitat
Alewife	Throughout bay	beach habitat
Gizzard Shad	Green Bay Zone 2	various habitat
Emerald Shiner	Green Bay Zone 2	various habitat
Common Shiner	Throughout bay	wetland habitat
Golden Shiner	Green Bay Zone 4	undeveloped wetland habitat
Common Carp	Green Bay Zone 2	undeveloped wetland habitat
Rainbow Smelt	Green Bay Zone 3	beach habitat
Trends for brown trout and walleye were not evaluated because an insufficient number of individuals were collected. Only two brown trout and nine walleye were caught as part of these efforts		

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

The section describes the important receptor species identified in the RA. The discussion also illustrates the interactions of fish within the Lower Fox River and Green Bay system and the uptake of PCB into the food chain. The fish discussed herein represent only a small segment of the fish community in the system.

4.4.4.1 Shiners (Minnows)

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

All shiner species are relatively small forage fish that average 5 to 10 cm (2 to 4 in) in length. Golden shiners are silver with a dusky stripe along their side and a small, almost vertical mouth. Common shiners are olive on top with a dark stripe running down the middle of their back, and one or two stripes along their upper sides. Emerald shiners are light olive on top, with a dusky stripe along their back, a silver stripe with emerald reflections along their side, and a large mouth.

Shiners generally inhabit shallow areas with limited current and are rarely found in riffles, but common shiners can tolerate some turbidity (Becker, 1983). Frequently these fish are found over similar substrates (sand, mud, gravel), but common and golden shiners are more dependent on vegetation than emerald shiners (Becker, 1983). Water temperatures can strongly influence the distribution of these fish; preferred temperature is 25˚C (77˚F), but common and golden shiners have been shown to tolerate temperatures up to 34˚C (93˚F) (Becker, 1983). These open water fish rarely go below the thermocline (11 to 15 meters). Interestingly, golden shiners have a remarkable ability to survive under low dissolved oxygen conditions. In Michigan lakes when oxygen levels were between 0 and 0.2 mg/kg, golden shiners have survived where other fish have not (Becker, 1983).

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

Most species of shiners are omnivorous, feeding equally on plant and animal matter (USFWS, 1983b). They are known to feed at the bottom of streams or lakes, in the wet column and near the surface. Males typically grow faster and larger than females, and they range in lengths from about 9 to 20 cm (3.5 to 8 inches), depending on the age, sex, and species of shiner observed (USFWS, 1983b; Becker, 1983).

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

4.4.4.2 Gizzard Shad

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

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

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

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

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

4.4.4.3 Rainbow Smelt

Rainbow smelt (*Osmerus mordax*) are widespread and abundant non-indigenous pelagic planktivores in the Great Lakes (Jones, *et al.,* 1995). Smelt are common and are an important prey in Green Bay but are not found above the De Pere dam in the upper Fox River. These fish average 15 to 20 cm (6 to 8 in) in length, but despite their small size, they have comparatively large mouths. Rainbow smelt are olive colored on top, and sliver with blue or pink iridescence on their sides. They also have a silver stripe on their sides.

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

While YOY fish are pelagic, they move towards a bottom existence as they age. The fish often school offshore, prefer cool clear water, and are most abundant in water depths of 18 to 26 m (59 to 85 ft), although they can be found in water depths of 14 to 64 m (46 to 210 ft) (Becker, 1983). Optimum temperatures range from 6.1˚C to 13.3˚C (43˚F to 56˚F), and feeding temperatures peak at 10˚C (50˚F). Rainbow smelt reach sexual maturity in approximately 2 years (at that time they are about 170 mm [6.7 in] in length) and can live up to 8 years (Becker, 1983). Males live approximately 5 years, reaching a length of about 21.8 cm (8.6 in), while females typically live about 7 years and reach a length around 31 cm (12.2 in) (Becker, 1983).

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

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

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

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

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

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

4.4.4.4 Alewife

Alewife (*Alosa pseudoharengus*) are non-indigenous small anadromous pelagic planktivores that prefer open water and sandy habitats. Alewife, along with shad sardines, and menhaden, are members of the herring family Clupeidae, which are predominantly marine species. Individuals of these landlocked populations are generally half the size (averaging approximately 16 cm [6.3 in] in length) of the marine alewife (approximately 36 cm [14.2 in] in length) (Scott and Crossman, 1973). Alewife are blue-green colored on top and sliver on the sides, with thin dark stripes on their top and upper sides.

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

8.16 million kg (18 million pounds) have been caught and processed primarily as poultry feed since 1966 (Becker, 1983).

Alewife populations in Lake Michigan have varied widely. In the 1920s in Lake Michigan, sea lampreys were introduced and greatly reduced the number of large predatory fish. Therefore, when the alewife were introduced in the 1940s, they had few predators and populations had an opportunity to increase. In the 1960s and early 1970s, alewife were the dominant forage fish accounting for 70 to 90 percent of fish by weight in Lake Michigan. Lamprey populations peaked in the 1950s, but in the late 1950s lamprey populations control methods were found. Since then, lamprey populations have been markedly reduced. In the early 1980s, alewife populations in Lake Michigan began to decline dramatically (Mason and Brandt, 1996). This decline, and the continued lower levels of alewife, are believed to be related to predation by trout and salmon which are its primary predators (Flath and Diana, 1985); walleye and perch also prey on alewife. Additionally, alewife die-offs are believed to occur because of rapid temperature changes and wide fluctuations in temperature (Hewett and Stewart, 1989). Severely cold winters, and the spring and summer return of alewife to shallow warmer waters, can initiate die-offs (Scott and Crossman, 1973). This species is likely more temperature sensitive than other species because it is naturally adapted to marine conditions where temperature variations are not as dramatic.

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

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

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

4.4.4.5 Yellow Perch

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

Preferred habitat for yellow perch is shoreline areas with sand, gravel or muddy sediments, modest to moderate amount of aquatic vegetation, and water depths of less than 10 m (30 ft) in clear lakes with temperatures of 18˚C to 21˚C (64˚F to 70˚F) (Becker, 1983; Scott and Crossman, 1973; USFWS 1983a). A study examining the frequency of littoral fishes in a Wisconsin lake determined that yellow perch (YOY and adults) were highly associated with complex macrophyte beds (Weaver, *et al.,* 1997). Of the sites examined, the only locations where yellow perch were not caught were two sites having the lowest abundance of vegetation. Turbidity adversely affects growth of juveniles and temperatures of 32˚C (90˚F) can be lethal, but yellow perch are tolerant of low oxygen levels. In Lake Michigan, oxygen levels of 0.1 to 0.3 parts ppm killed numerous yellow perch, but many also survived (Becker, 1983). Bluegill, largemouth bass, and walleye are fish species that cannot survive low oxygen concentrations.

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

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

Similar to walleye, yellow perch provide no protection for the eggs or fry (Becker, 1983), which hatch anywhere from 8 to 27 days following spawning. The speed with which hatching occurs depends on water temperature (Becker, 1983). Shorter hatching periods are typically associated with warm water while 27-day hatching periods have been observed in 8.5˚C to 12˚C (47˚F to 53˚F) water (Becker, 1983). Larvae are approximately 0.5 cm (0.2 in) upon hatching and they swim to the surface, where they remain in the upper 0.9 to 1.2 m (3 to 4 ft) of water for the first 3 to 4 weeks. Microscopic zooplankton are important to the survival of perch fry. If the zooplankton are too large, the young fry perish (Becker, 1983). YOY perch continue to consume zooplankton and other aquatic insects until they are quite large. Perch do not typically begin to feed on other fish until they have reached a length of about 18 cm (7 in) or more, sometime between the age of 3 and 4 years (Becker, 1983).

Mature yellow perch generally range in length from 15 to 25 cm (6 to 10 in) and from 170 to 454 g (6 to 16 oz) (UWSGI, 2000c). Males reach maturity in about 1 year while females mature in 2 years in Green Bay (Belonger, 2000). In Wisconsin waters, yellow perch generally live about 7 to 10 years (USFWS, 1983a). Brandt, *et al.,* (1980) found that the distribution of juvenile and adult perch differs with temperature. Juvenile perch catches are highest in waters 15˚C to 20˚C (59˚F to 68˚F) while catches of adult perch are greatest in waters that are 7˚C to 8˚C (44.5˚F to 46.5˚F).

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

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

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

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

4.4.4.6 Carp

Carp (*Cyprinus carpio*) is an abundant bottom-dwelling species found in southern Green Bay. Along with shiners, the carp are within the minnow and carp family Cyprinidae. Adult carp have been found to range in length from 41 to 58 cm (16 to 23 in) and weigh from 1 to 10 kg (2.2 to 22 pounds) (Weber and Otis, 1984). Carp have two distinct barbles on each side of the upper jaw. These fish are grey/grey-green colored on top, have a dark edge on the upper side, white to yellow on the underside.

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

Carp have the ability to range widely; some tagged fish have traveled 1,090 km (680 mi), and a carp tagged in Lake Winnebago was recaptured 148 km (92 mi) away (Becker, 1983). Most tagging studies of carp have found that they are generally recaptured within a few kilometers (Becker, 1983). Generally carp are wary and bolt for vegetation and cover or deeper water with little provocation. The exception to this behavior is during spring when spawning occurs (Becker, 1983).

Spawning occurs from April to August in Wisconsin and peaks in late May to early June when temperatures range from 18˚C to 28˚C (64˚F to 82˚F) (Becker, 1983; Scott and Crossman, 1973). An investigation of spawning carp in Lake Winnebago and nearby lakes, determined that carp preferred to spawn in areas of shallow vegetated waters (0.15 to 1.2 m [.49 to 3.9 ft] deep) (Weber and Otis, 1984). These preferences have also been supported by other authors (Becker, 1983; Scott and Crossman, 1973). A single female carp may release 50,000 to 620,000 eggs during the primary spawning period (Becker, 1983). Carp eggs float through the water and, due to an adhesive coating surrounding the egg, attach themselves to underwater vegetation, debris, or any other object to which the egg will adhere (USFWS, 1982). Spawning over areas with dense vegetation will increase the success of reproduction, but some studies have indicated that carp will not spawn in water cooler than 16˚C (60˚F).

Incubation lasts for 3 to 16 days depending on the temperature (Becker, 1983). Young move off vegetation 4 to 5 days after hatching, and go to the bottom (Becker, 1983). Through their first summer, carp fry are strongly associated with vegetation as protective cover in 15 to 30 cm (6 to 12 in) of water (Weber and Otis, 1984). Young carp leave this shallow weedy habitat when they are 76 to 102 mm (3 to 4 in) and generally too large for predators to consume (Becker, 1983). After the first season of growth, carp are generally 13 to 19 cm (5 to 8 in) long (Scott and Crossman, 1973). Although young carp are food for both birds and other fish, when they reach 1.4 to 1.8 kg (3 to 4 pounds), they are too large to be a prey item. Carp are generally mature at age 2 (males) or 3 (females) and usually live for 9 to 15 years (Becker, 1983).

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

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

4.4.4.7 Walleye

Walleye (*Stizostedion vitreum*) is a popular, year-round game and commercial fish found in Lake Michigan, generally in areas less than 7 m (23 ft) deep (Magnuson and Smith, 1987). The walleye is the largest member of the perch family (Percidae - a group that includes sauger, darters, and yellow perch) in North America. It is not a member of the pike family as commonly believed. Walleye have strong canine teeth and very large mouths that extend past the eye (Becker, 1983). Walleye are yellow-olive/brown colored on top and brassy yellow-blue along sides. They have five to twelve dusky saddles that become less visible as they age (Becker, 1983).

Walleye are found throughout the Fox and Wolf River basins and their connecting lakes, as well as Green Bay (Becker, 1983). Walleye are tolerant of a range of environmental conditions, particularly turbidity and low light, but they are not tolerant of low oxygen levels. Winter kills due to low DO conditions have occurred in Wisconsin (Becker, 1983). Walleye prefer quiet waters over sand, gravel, and mud substrates (Becker, 1983). They generally rest in deep dark waters during the day and migrate to rocky shoals and weed beds to feed at night, but they may be active during the day if it is cloudy or the waters are turbid (Becker, 1983). YOY fish can be found near the sediments in 6 to 10 m (19.7 to 32.8 ft) of water (Scott and Crossman, 1973), but can be caught in surface waters up to lengths of approximately 35 mm (1.5 in) (WDNR, 1970). Larger fish are generally in depths of 14 m (45.9 ft) or less and form loose schools (Scott and Crossman, 1973). Schooling is common during feeding and spawning.

Walleye generally spawn between mid-April and early May, and they have specific spawning habitat requirements (Becker, 1983; USFWS, 1984). Preferred spawning habitat are shallow shoreline areas, shoals, riffles, and dam faces with rocky substrate and good water circulation from wave action and currents (USFWS, 1984). The fish may travel long distances to spawn. Lake Winnebago walleye, for instance, may swim 100 miles up the Wolf River before they reach suitable spawning habitat (Becker, 1983). The female walleye will lay an average of 50,000 eggs and generally spawns out completely in one night. Summer territories and spawning grounds are distinct areas. The range of summer area is generally limited to 3 to 8 km (1.9 to 5 mi), but the recorded range has varied from 0.8 to 110 km (0.5 to 68.4 mi). A study of walleye in Lake Poygan found that walleye traveled an average distance 47 km (29.2 mi) (Becker, 1983).

Walleye spawn soon after the ice melts and temperatures reach 3°C to 7°C (37°F to 45°F), and spawning peaks when temperatures are 6°C to 10°C (43°F to 50°F) (Becker, 1983). In Lake Winnebago, the timing of spawning has been recorded as a 2- to 3-week period between the first week in April and the first week in May (WDNR, 1970). Walleye from Green Bay move upstream into the Fox River to spawn; however, their movement is restricted by the De Pere dam (Magnuson and Smith, 1987). Walleye do not build nests and spawning occurs at night generally on gravel bottoms, but they can spawn on vegetation. In Lake Winnebago, flooded marsh areas are preferred spawning grounds (Becker, 1983). Continuous flowing water over the eggs is important for hatching success.

Fry move off wetlands a day or two after hatching and obtain an open water existence. They stay in open water until they are about 30 mm (1.25 in) and then return to shore around June (Becker, 1983). By the end of July, walleye in Lake Winnebago are about 75 mm (3 in) or larger. At this size, walleye shift from a zooplankton-only diet to also include fish and invertebrates. By fall they are generally 130 mm (5 in) (Becker, 1983).

Female walleye grow faster and become larger than males; however, growth of the walleye is dependent upon the food supply, temperature, and population density (USFWS, 1984). Female walleye reach maturity in 3 to 6 years and males reach maturity in 2 to 4 years (Scott and Crossman, 1973). In Wisconsin waters walleye generally live about 7 to 10 years (UWSGI, 2000e), but walleye can live more than 20 years (Lychwick, 2000a) in Green Bay.

4.4.4.8 Brown Trout

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

As compared to other species of trout, brown trout grow faster, live longer, and better tolerate degraded habitats, warm temperatures (up to 29˚C [84°F]), and turbidity (Becker, 1983). They are fairly common in cold waters of Wisconsin, and self-sustaining populations in Lake Michigan are enhanced with stocking. In Green Bay, this species is generally limited to the northern two-thirds of the Bay, which contain deeper and colder waters. Preferred temperatures are 10˚C to 18˚C (50˚F to 64˚F) (Becker, 1983). In addition, brown trout tagging studies indicate that these fish move between the waters of northern Green Bay and Lake Michigan (Toneys, 1999).

Brown trout are most often found along the shore in waters no deeper than 15 m (50 ft) (Becker, 1983) and they have been known to inhabit waters along the west shore of Green Bay from the towns of Oconto and Marinette (Magnuson and Smith, 1987). Wild brown trout fingerlings that were tagged have been found to travel an average of 16 km (10 mi) in 1 year. Hatchery-reared trout released in Wisconsin waters generally remained within 24 km (15 mi) of the release point, but some tagged fish after 1 year were found to range up to 323 km (200 mi) (Becker, 1983).

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

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

4.4.4.9 Sturgeon

The Menominee Indians have lived in Wisconsin longer than any other tribe. The lake sturgeon is included in this section because it was the most important fish to the Menominee Indians for both cultural and religious reasons. The Menominee Nation historically celebrated the return of the lake sturgeon (*Namä'o* in Menominee) at Keshena Falls on the Wolf River, a tributary of the Lower Fox River (Beck, 1995). Return of the sturgeon in spring was a cause for religious celebration because of its importance as a food source after the winter, when the supply was typically lowest (Beck, 1995).

Prior to the 1800s, lake sturgeon (*Acipenser fulvescens*) were common and abundant in the Lake Michigan, Lake Superior, and Mississippi River drainage basins (Becker, 1983). Lake sturgeon were also abundant in Green Bay and the larger tributaries, including the Fox-Wolf, Menominee, Peshtigo, and Oconto rivers (USFWS, 1998). Native American populations, especially the Menominee Nation, utilized the sturgeon for various cultural and spiritual purposes and annually celebrated the return of the sturgeon to its ancestral spawning grounds within the Lake Winnebago-Wolf-Upper Fox River system (USFWS, 1995). Areas where sturgeon either spawn or have been observed within the Lower Fox River or Green Bay are shown on Figures 4-1 through 4-4 and 4-10. Because the sturgeon are a threatened species, spawning locations are approximate and are shown as a block representing the nearest township, range and section (Natural Heritage Inventory, 2000).

Following the establishment of the commercial fishing industry, sturgeon were viewed as a nuisance fish because they became entangled in and ripped fishing nets. During this period, they were simply thrown onto the shore and left to rot (Becker, 1983; Beck, 1985). After 1870, a large commercial fishing industry subsequently evolved for sturgeon. The roe was prized for caviar, the flesh was delicious either smoked or fresh, and the high-quality gelatin material isinglass was obtained from the swim bladder.

Due to the aggressive fishing and length of time required for sturgeon to mature and reproduce, the abundance of lake sturgeon had declined so much that by the 1880s and 1890s it was no longer worth pursuing (USFWS, 1998). Along with the loss of suitable spawning habitat and the construction of dams along many of the significant tributaries, especially on the Lower Fox River, sturgeon populations declined to levels from which they have never fully recovered. Becker (1983) recounts that the Lake Michigan sturgeon catch in 1880 was 1,741,600 kg (38,839,600 pounds); in 1966 only 907 kg (2,000 pounds) of sturgeon were taken from the lake. The state of Michigan has listed the lake sturgeon as a threatened species (Table 4-6).

Sturgeon were also valued by Native American populations due to its large size and longevity. Lake sturgeon typically live 50 and 80 years, growing to lengths up to 2.4 meters (8 feet) long and maturing slowly (Becker, 1983; USFWS, 1998). Historical records from the 1800s indicate that lake sturgeon weighing over 45.4 kg (100 pounds) and measuring over 2 meters (6.5 feet) were captured near Milwaukee (USFWS, 1998). Previous researchers found that over 97 percent of sturgeon captured which were more than 30 years old were female (Becker, 1983).

The slow growth and maturity rate of sturgeon may be one reason that significant decreases in sturgeon populations over a very short period have had such a crucial impact on the current and future populations. Males typically mature in about 15 years and are usually about 114 cm (45 inches) at this age. Additionally, most males spawn every 1 to 2 years. However, female sturgeons mature more slowly and spawn less frequently. Females typically mature when they are about 24 to 26 years old and about 140 cm (55 inches) long. Unlike the males, female sturgeon only spawn once every 4 to 6 years and typically produce and release anywhere between 50,000 and 700,000 eggs (Becker, 1983).

Without teeth, sturgeons rely on suction to feed, much like suckers and other bottom-feeding fish. Sturgeon feed on small organisms including insect larvae, snail, leeches, small clams, and other invertebrates. Although not typically preyed upon by other fish, Becker (1983) notes that otter have been noted to drag sturgeon from the water onto the ice of Lake Winnebago in the winter and that suckers, carp, crayfish, and other sturgeon may prey upon the sturgeon eggs.

4.5 Birds

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

- Passerines
- Gulls and Terns
- Diving Birds

- Shorebirds
- Wading birds
- Waterfowl
- Raptors

Some of the most common birds in the region are shown on Table 4-7. The species list (Table 4-7) was developed by the Project Team for use in the RA, based on the species' importance with respect to uptake of PCBs into the food chain within each group and its status as a threatened or endangered species. A brief description of each bird group is presented below.

Information about the probability of sighting a specific bird was taken from Temple, *et al.* (1997), which is a summary of data collected by WDNR, the University of Wisconsin, and the Wisconsin Society for Ornithology. Sightings have been collected by professional and amateur bird watchers using a standardized format since 1982. Figure 4-13 shows the general distribution of the birds within these groups throughout Green Bay (NOAA, 1997c). As with the fish data in Zone 4, bird data obtained from the GLC (2000) did not differentiate specific species. Therefore, locations where birds of concern either nest or have been observed in Green Bay Zone 4 are simply shown as points on Figures 4-13.

4.5.1 Passerine Birds

A large number of passerine birds exist within the Lower Fox River and shorelines of Green Bay. Common passerine species include blackbirds, wrens, sparrows, and swallows (Table 4-7). These birds typically feed on insects, seeds, and small invertebrates found through foraging along the ground. The passerines listed on Table 4-7 for the Green Bay area include six species of blackbirds, wrens, and sparrows. A large number of blackbirds, wrens, sparrows, and swallows feed on the insects or insect larvae which are found in and above the surface water of the Lower Fox River and Green Bay. Additionally, typical habitats for these birds are wetlands, open meadows, and grasslands (Exponent, 1998; Harrison and Greensmith, 1993). The blackbirds tend to nest in loose colonies while sparrows and wrens typically nest individually (Harrison and Greensmith, 1993). These birds are migrant to partially migrant, and dependent on local winter weather conditions and food supply (Harrison and Greensmith, 1993). None of the passerines are listed on state or federal endangered/threatened species list (Table 4-7).

The red-winged blackbird (*Agelaius phoeniceus*) is the most common bird within this group found in Wisconsin. The annual probability of sighting this bird is well over 95 percent and they are typically found in Wisconsin from late February through late November (Temple, *et al.,* 1997). The likelihood of sighting the other birds in this group (Table 4-7) ranges from approximately 35 to 55 percent, and these species are usually sighted between April and October (Temple, *et al.,* 1997).

Tree swallows (*Tachycineta bicolor*) are also common migratory songbirds that breed in and migrate through the Lower Fox River and Green Bay. Tree swallows nest in semi-colonial groups in natural cavities (trees, posts, streambanks) near water. Tree swallows feed exclusively on insects, predominately aquatic insects. Tree swallow population data is not available from the Lower Fox River and Green Bay because studies of these birds in this region have used artificial nest boxes rather than relying on naturally nesting populations (Ankley, *et al.,* 1993; Custer, *et al.,* 1998). The annual probability of sighting this bird is about 80 percent and they are typically found in Wisconsin from April through September (Temple, *et al.,* 1997).

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

4.5.2Gulls/Terns

The gulls/terns group for the Green Bay area includes two species of gulls and four species of terns (Table 4-7). All six of these species feed on fish, insects, and eggs, as well as scavenging for other food over open water or in wetland areas (Exponent, 1998; Harrison and Greensmith, 1993). These birds tend to nest in large colonies (Harrison and Greensmith, 1993). The black (*Chilidonias niger*) and Forster's (*Sterna forsteri*) terns prefer to nest in marsh areas while the other four species prefer to nest on the ground, often on remote islands or in areas protected from predators (Exponent, 1998). The annual probability of sighting the tern species in Wisconsin ranges from approximately 25 percent to 45 percent, while the likelihood of sighting the two gulls is about 65 percent (Temple, *et al.,* 1997). The two gulls remain in the area throughout the year, while the terns migrate to other areas. The terns are typically present in Green Bay from April through October (Temple, *et al.,* 1997).

The Forster's, Common (*Sterna hirundo*), and Caspian (*Sterna caspia*) terns are migratory species of colonial waterbirds that breed in the Great Lakes and generally winter in more southern coastal areas. In Wisconsin, the Caspian, Common, and Forster's terns are endangered species while Caspian and Common terns as threatened species in Michigan (Table 4-7). All three of these terns are protected under the Migratory Bird Treaty Act (Exponent, 1998). Due to the tern's endangered status within Wisconsin, the locations of tern nests in the

Lower Fox River and Green Bay area are presented as blocks on Figures 4-1 through 4-4 and 4-13.

Based on the protected status of these three terns, a number of studies have been conducted to evaluate the remaining Green Bay populations, as well as the effects of PCB uptake through the consumption of bay fish. These birds typically nest on islands where they are generally safe from predators. The primary nesting locations for Forster's terns are the Bay Port and Kidney Island CDFs, Long Tail Point, and the Oconto Marsh. Common terns primarily nest on Kidney Island and the Pensaukee Dredge Spoil Island while the Caspian tern nesting colonies are on Gravelly and Gull Islands, located just south of Summer Island between Green Bay and Lake Michigan (Stratus, 1999c).

Tern populations have generally been increasing over the past 20 years. From 1978 and 1987 the nesting pairs of Forster's terns observed in the state of Wisconsin increased from 136 pairs to 435 pairs, while the population of Common terns increased from 60 pairs to 600 pairs between 1979 and 1986. Similarly, the number of Caspian tern nests located on Gravelly and Gull Islands increased from about 600 to over 1,000 between 1977-78 and 1991. This increase is reflective of the overall Great Lakes Caspian tern population, which has grown by at least 90 percent since the 1970s (Stratus, 1999c). Although the tern populations continue to increase, the impacts of PCB uptake are evident and well documented (Stratus, 1999c).

Both common and Forster's tern were listed in 1979 as endangered in the state of Wisconsin. To enhance population success, Forster's tern platforms were placed at several locations in the state, including Green Bay. The six monitored island platforms in Green Bay indicated feeding, but not nesting activity. For the common tern, fencing and ring-billed gull control have been used to enhance breeding success. However, due to the difficulty in maintaining them, these platforms are no longer placed in these areas (Nikolai, 2000b).

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

Population data reported in June 1997 for the previous year indicates that for both species, population status is uncertain and requires additional study (Matteson, 1998). Six common tern colony sites are present in Wisconsin and two are in Green Bay: Kidney Island CDF and the Pensaukee Dredge Spoil Island, with an estimated number of breeding pairs of 16 and 75, respectively. Similarly, nine Forster's tern colony sites are located in Wisconsin, and Long Tail Point and the South Oconto Marsh have about 70 and 45 breeding pairs, respectively.

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

4.5.3 Diving Birds

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

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

Double-crested Cormorants. Double-crested cormorants (*Phalacrocorax auritus*) are a migratory species of colonial waterbird that breed in the Great Lakes and generally winter in coastal areas, including Alaska. These birds nest in large communities in a variety of habitats including cliffs, grassy slopes, low bushes, or dead trees. Cormorants consume approximately 25 percent of their body weight each day and on average weigh 1.9 kg (4.2 pounds). Their primary food is small fish, such as rainbow smelt, alewife and even perch, when available.

Similar to the terns described above, numerous studies have been conducted to evaluate double-crested cormorant populations and the effects of PCBs. Prior to the 1960s, it is estimated that at least several hundred nesting pairs of cormorants were located throughout the state. Beginning in the 1950s and continuing through the 1970s, the double-crested cormorant population in the Great Lakes region experienced large population declines, largely from the presence of contaminants. More recently, populations of double-crested cormorants in the Great Lakes region have greatly increased (Weseloh, *et al.,* 1994).

In 1972, the double-crested cormorant was listed as a Wisconsin state endangered species due to the lack of nesting pairs of birds in the state. Beginning in 1973, state, academic and federal agencies (WDNR, USFWS, National Parks Service, University of Wisconsin, Wisconsin Society of Ornithology) combined efforts to catalog the colony location, size, and reproductive success of the double-crested cormorant throughout Wisconsin. By 1986, populations in the state increased such that the double-crested cormorant was removed from the Wisconsin state endangered species list.

Prior to 1979, inland breeding populations exceeded the number of nesting birds on the Great Lakes. Since 1990, however, the Great Lakes population of double-crested cormorants has exceeded the inland population levels by approximately five times (Matteson, 1998). The nesting population in the Green Bay and Lake Michigan region, as of 1997, accounted for 81 percent of the total breeding population (Matteson, *et al.,* 1998). The largest colonies for double-crested cormorants in Green Bay are Cat, Jack, Hat, and Snake islands (Stratus, 1999c). Of these islands, Cat Island is located closest to the mouth of the Fox River and contains the second highest density of double-crested cormorants. Cormorant nesting locations along the Lower Fox River and Green Bay are shown on Figures 4-1 through 4-4 and Figure 4-13.

4.5.4 Shorebirds

The shorebirds group for the Green Bay area includes eight species of plovers, sandpipers, and snipe (Table 4-7). As indicated by the name, birds within this group feed and nest along the shore, typically foraging for small crustaceans, insects, worms, and other invertebrates (Harrison and Greensmith, 1993). These birds nest along the ground, sometimes on rocky or sandy shores and others within marsh or wetland areas.

The common snipe and spotted sandpiper are the most sighted birds within this group in Wisconsin. These birds are generally present from April/May through September/October and have an annual sighting probability of about 50 percent (Temple, *et al.,* 1997). The likelihood of sighting the other birds within this group ranges from approximately 15 percent to 25 percent as these species generally migrate further north. Therefore, these birds are generally present around May, and then may be sighted between late June and October (Temple, *et al.,* 1997). The piping plover is very uncommon in the region and it is listed on Michigan, Wisconsin, and federal endangered species lists (Table 4-7).

4.5.5Wading Birds

The wading birds group for the Green Bay area includes 13 species of heron, woodcock, rail, egret, bittern, and crane (Table 4-7). As indicated by the name, birds within this group typically feed in shallow, near-shore waters and emergent wetland areas. They typically forage for small fish and crustaceans, amphibians, insects, worms, and other invertebrates (Harrison and Greensmith, 1993).

Within this group, the bitterns, rails, and woodcock are generally small birds, ranging in height from 18 to 51 cm (7 to 20 inches). These birds, along with the sandhill crane, generally nest on the ground. The herons, egrets and cranes are much larger birds, ranging from 61 to 122 cm (24 to 48 inches). The herons and egrets generally prefer to nest in trees but, if necessary, will nest in marshes and lowlands if suitable habitat is not available (Harrison and Greensmith, 1993). Rookeries for both the great blue and black-crowned night herons are located in the Thousand Islands Nature Conservancy as well as in Green Bay (Nikolai, 1998). The herons, woodcock, and crane, are common in Wisconsin and the UP from mid-spring through mid-fall (Temple, *et al.,* 1997), as these are all migratory birds. However, the likelihood of sighting a bittern is less than 30 percent, and both egrets and rails are very uncommon in the area (Temple, *et al.,* 1997). The king rail, least bittern, snowy egret, and yellow rail are each included on one of the state or federal threatened or endangered species lists (Table 4-7). However, yellow rail habitat is maintained in the Seney National Wildlife Refuge, located north of Lake Michigan in the central portion of the UP where these birds have been consistent summer residents since the 1800s (De Vore, 1999).

4.5.6Waterfowl

The waterfowl of the Green Bay area includes 21 different species (Table 4-7). These birds typically feed in the water on plants, insects, aquatic organisms, shellfish, crustaceans, and occasionally on small fish (Exponent, 1998; Harrison and Greensmith, 1993). Waterfowl tend to nest in or very near water, generally preferring swamps and marshes to open water habitat (Exponent, 1998; Harrison and Greensmith, 1993). Some of these birds may nest in loose colonies while others nest individually.

Waterfowl are typically migratory birds; however, the location of their summer and winter destinations plays a significant role of when particular species are present in the Green Bay area. Mallard and Black ducks as well as Canada geese are present in the area throughout the year and the annual probability of sighting for these species ranges from 50 percent up to about 95 percent (Temple, *et al.,* 1997). Coot, teal, ruddy, and wood ducks are all present in the bay from early spring through late fall and are somewhat common, with sighting probabilities ranging from 50 percent to 75 percent (Temple, *et al.,* 1997). A number of species migrate further north into Canada during the summer; some winter in the Green Bay region, while others migrate further south, spending only a short time in the area. The species which winter in the area include mergansers, goldeneye, the greater scaup, and bufflehead. These species are fairly common in the area, with sighting probabilities of 30 percent to 60 percent (Temple, *et al.,* 1997). Species which pass through the region, typically found anywhere between March and May and again in October and November, include the canvasback, redhead, and ring-necked ducks, as well as the lesser scaup, northern shoveler, and whistling swan. These species are also fairly common, with sighting probabilities ranging from 35 percent to 55 percent (Temple, et *al.,* 1997). Being migratory in nature, waterfowl are generally protected under the Migratory Bird Treaty Act (Exponent, 1998). However, many of the ducks and geese included in this group are game species, with an established hunting period that occurs during October in Wisconsin and Michigan.

Since at least 1975, WDNR has completed a mid-winter waterfowl survey to evaluate the numbers of migratory waterfowl wintering along the Lower Fox River. The results from these surveys indicate that, overall, the number of migratory water fowl in the region have increased from between 1,000 to 2,000 individuals in the 1970s to well over 4,000 individuals recently. These populations are controlled by many factors, including the severity of the winter weather and access to an adequate supply of food. However, increases in bird populations, especially among the primarily piscivorous birds, like the goldeneye and the mergansers, suggests that the populations are increasing from survey lows observed in the 1960s and 1970s (Nikolai, 1998).

4.5.7 Raptors

The raptors included in this group are the bald eagle, osprey, peregrine falcon, and merlin. The bald eagle and the osprey tend to be piscivorous, feeding on suckers, northern pike, muskellunge, bullheads, as well as small mammals, waterfowl, other birds, and carrion (Exponent, 1998; Harrison and Greensmith, 1993). Eagles and ospreys prefer open water areas, but, when necessary, eagles will hunt in open meadow and light woodlands (Harrison and Greensmith, 1993). Bald eagle and osprey nesting locations (both active and inactive nests) in the Lower Fox River are shown on Figure 4-1 through 4-4 while nesting locations within Green Bay are shown on Figure 4-13. The two falcon species typically hunt other birds or small mammals. Preferring open land, they are not generally found in heavily forested areas (MDNR, 2000).

Typically, these birds nest in high places, such as the tops of trees or rock ledges (Exponent, 1998; Harrison and Greensmith, 1993). Of the four species listed on Table 4-7, the eagle and osprey are more common in Wisconsin than the peregrine falcon or merlin. The annual probability of sighting the eagle and osprey is around 55 percent and 45 percent, respectively (Temple, *et al.,* 1997). The likelihood of sighting the two falcons is less than 25 percent, as both are less common in the area. The eagle winters within the Green Bay/Lake Michigan area, simply moving as necessary in order to find open water for hunting (MDNR, 2000). However, the osprey and the falcons are migratory birds and generally return to the region from March through October (Temple, *et al.,* 1997). The peregrine falcon is listed as an endangered species in both states and federally (Table 4-7). The bald eagle, osprey, and merlin are listed threatened species in Michigan and federally, while in Wisconsin only the osprey is listed as a threatened species (Table 4-7). These birds are also protected under the Migratory Bird Treaty Act (Exponent, 1998).

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

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

The return and recovery of bald eagles has been well documented in both Wisconsin and Michigan (Bowerman, 1993; Dykstra and Meyer, 1996; Meyer, *et al.,* 1997), and includes surveys along the Lower Fox River and Green Bay. These studies have been summarized by the USFWS (Stratus, 1999c). The following section summarizes the Stratus (1999c) analysis of the information taken principally from those reports.

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

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

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

Eagle nesting locations within the Lower Fox River and Green Bay are shown on Figure 4-1 through 4-4 and 4-13, respectively. There are two active nests within the Lower Fox River; one within the Little Lake Butte des Morts Reach (Figure 4-1), and one at Kaukauna in the Appleton to Little Rapids Reach (Figure 4-2).

Within the bay (Figure 4-13), there is one nest active in Green Bay Zone 2, two nests in Zone 3A, and nine nests were active in Green Bay Zone 4. There are no reported nests in Zone 3B along the Green Bay side of the Door Peninsula, but there is a single active nest at the northernmost tip on the Lake Michigan side.

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

4.6 Mammals

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

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

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

4.6.1 Mink

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

4.6.1.1 Mink Habitat

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

Channelization of the Lower Fox River has contributed to a general decline of mink habitat in the region. The habitat suitability, as determined by Exponent (1998), was based on shoreline characteristics included in WDNR wetland maps and WISCNLAND GIS maps of the project area and are shown for the Lower Fox River on Figures 4-14 through 4-17. The suitability definitions are as follows:

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

As previously discussed, much of the shoreline has been developed between Neenah and Kaukauna and between De Pere and Green Bay. Most of the shoreline in the LLBdM Reach and between Appleton and Kaukauna is characterized by Exponent as either “poor” or “unsuitable” on Figures 4-14 and 4-15, respectively. This reflects the development of these areas. However, in the less developed areas of the Appleton to Little Rapids and Little Rapids to De Pere reaches, large tracts of the shoreline are characterized as “marginal” to “good” habitat (Figures 4-15 and 4-16, respectively). Mink habitat suitability in the De Pere to Green Bay Reach is largely characterized as “unsuitable” (Figure 4-17), which is similar to the LLBdM Reach.

In Zone 3, mink habitat suitability characterization efforts in Green Bay extended only just beyond Marinette, on the west side, and Sturgeon Bay, on the east side, (Figures 4-18 and 4-19). The shoreline in Green Bay zones 2A and 3A, on the west side, are generally characterized as “marginal to good” (Figures 4-18 and 4-19, respectively). The habitat in Zone 2B is generally characterized as “poor to “unsuitable,” although “moderate” to “good” habitat is present with increasing distance from the mouth of the Lower Fox River (Figure 4-18). The habitat suitability in Zone 3B is generally characterized as “moderate” to “good” except in areas where development has occurred, such as the cities of Dyckesville and Sturgeon Bay (Figure 4-19).

4.6.1.2 Domestic Mink Production in Wisconsin

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

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

4.6.1.3 Wild Mink in the Study Area

Wild mink population estimates for Wisconsin and Michigan are not available. Approximately 22,600 mink were trapped in the state of Wisconsin in 1998-99 (WDNR, 1999b). However, these records do not indicate how many were collected in the counties along the Lower Fox River or Green Bay.

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

4.6.2 Otter

WDNR harvest records for 1998-99 suggest that otter are present in the counties along the Lower Fox River and west side of Green Bay but not in counties along the east side of the bay. This may either be due to habitat requirements or it may reflect the influence of chemical contamination. Because the WDNR records do not indicate where selected fur-bearing species are trapped (other than a specific county) it is difficult to assess which factor (habitat or chemical contamination) is more restrictive. WDNR (1999b) records show that a combined 26 otters were collected in Outagamie and Winnebago counties while 56 otters were collected in Marinette and Oconto counties separately in 1998-99. However, only one otter was taken in Brown County (WDNR, 1999b). According to Gilbertson (1988), no otters were trapped in Door and Kewaunee Counties in 1984 and the 1998-99 harvest records suggest that this trend continues (WDNR, 1999b).

4.7 Endangered and Threatened Species

A number of different animals have been or are currently on the Wisconsin, Michigan, or Federal Endangered and Threatened Species List. According to the 1973 Endangered Species Act, the term endangered species means “any species which is in danger of extinction throughout all or a significant portion of its range” while a threatened species is “any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.”

Listed endangered or threatened animals which have historically been found in the vicinity of the Lower Fox River or Green Bay include: ospreys, Common terns, Forster's terns, Caspian terns, and great egret (Matteson, *et al.,* 1998). The ospreys, Common terns, and Forster's terns have nested along the Lower Fox River as well as at upstream locations in Lake Winnebago, Lake Butte des Morts, and Lake Poygan. The osprey have been sighted near Kaukauna and have attempted to nest in the vicinity of Combined Locks, while the terns have been observed farther upstream. Additionally, Common, Caspian, and Forster's terns as well as great egrets have nested on some of the islands located in Green Bay. Very few nesting pairs have been observed over the past few years and recovery of these populations is slow (Matteson, *et al.,* 1998).

As mentioned above, populations of both eagles and the double-crested cormorants have recovered to the point where both birds have been removed from the Wisconsin endangered species list. Other populations, specifically wild mink and otter, have been found to be declining around the Lower Fox River and Green Bay, but are not currently listed by state or federal agencies. WDNR also reported a bed of clams or mussels which may be threatened. The sediment bed which these clams/mussels inhabit is approximately 20 feet wide and 100 feet long and it is located near the mouth of Mud Creek in the Lower Fox River (Szymanski, 1998).

The endangered and threatened mammals, fish, and birds of the region are listed below.

Endangered/Threatened Species in Wisconsin & Michigan

List	Endangered	Threatened
Mammals		
Wisconsin	Timber wolf and pine marten	None
Michigan	Timber wolf, cougar, lynx, prairie vole, and Indiana bat	Least shrew
Federal	Timber wolf, Gray bat, Indiana Bat, and Ozark Big-eared bat	Lynx
Fish		
Wisconsin	None	None
Michigan	None	Lake Sturgeon, Sauger
Federal	None	None
Birds		
Wisconsin	Peregrine Falcon, Caspian Tern, Common Tern, Foster' Tern, Piping Plover, and Snowy Egret	Osprey and Yellow Rail
Michigan	Peregrine Falcon, Piping Plover, and King Rail	Bald Eagle, Merlin, Osprey, Caspian Tern, Common Tern, Least Brittern, and Yellow Rail
Federal	Peregrine Falcon, Piping Plover, and King Rail	Bald Eagle and Piping Plover

4.8 Section 4 Figures and Tables

Figures and tables for Section 4 follow this page, and include:

Figure 4-1 Lower Fox River Wetland, Habitat, and Animal Distribution: Little Lake Butte des Morts Reach

Figure 4-2 Lower Fox River Wetland, Habitat, and Animal Distribution: Appleton to Little Rapids Reach

Figure 4-3 Lower Fox River Wetland, Habitat, and Animal Distribution: Little Rapids to De Pere Reach

Figure 4-4 Lower Fox River Wetland, Habitat, and Animal Distribution: De Pere to Green Bay Reach

Figure 4-5 Wetland Distribution: Green Bay Zones 2 and 3

Figure 4-6 Wetland Distribution: Green Bay Zone 4

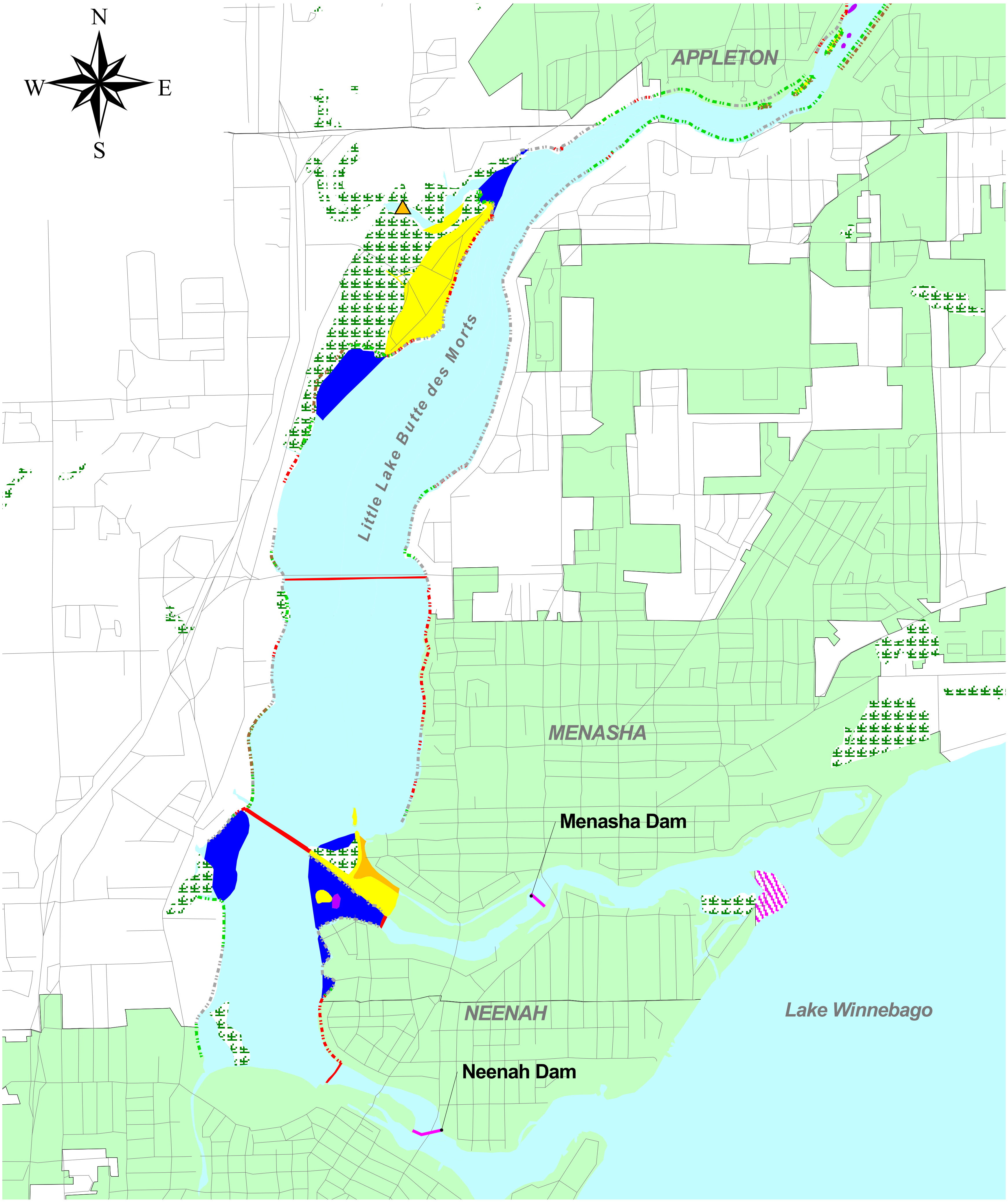
Figure 4-7 Wetland Losses in Green Bay: Duck Creek, Cat Island Chain, and Long Tail Point

Figure 4-8 Green Bay Spawning Areas by Fish Types: Salmon/Trout and Benthic Fish

Figure 4-9 Green Bay Spawning Areas by Fish Types: Pelagic and Game Fish

Figure 4-10	Green Bay Spawning Areas by Fish Species: Walleye, Yellow Perch, and Sturgeon
Figure 4-11	Green Bay Spawning Areas by Fish Species: Carp and Alewife
Figure 4-12	Green Bay Spawning Areas by Fish Species: Emerald Shiners and Gizzard Shad
Figure 4-13	Distribution of Birds in Green Bay: Select Species and Groups
Figure 4-14	Lower Fox River Mink Habitat Suitability: Little Lake Butte des Morts Reach
Figure 4-15	Lower Fox River Mink Habitat Suitability: Appleton to Little Rapids Reach
Figure 4-16	Lower Fox River Mink Habitat Suitability: Little Rapids to De Pere Reach
Figure 4-17	Lower Fox River Mink Habitat Suitability: De Pere to Green Bay Reach
Figure 4-18	Green Bay Mink Habitat Suitability: Zone 2
Figure 4-19	Green Bay Mink Habitat Suitability: Zone 3

Table 4-1	Major Green Bay Wetland Areas/Complexes
Table 4-2	Lower Fox River Habitats
Table 4-3	Lower Fox River Shoreline and Substrate Types
Table 4-4	Lower Fox River Fish Species Composition
Table 4-5	Lower Fox River Fish Populations in the De Pere to Green Bay Reach
Table 4-6	Green Bay Fish Species
Table 4-7	Lower Fox River and Green Bay Bird Species



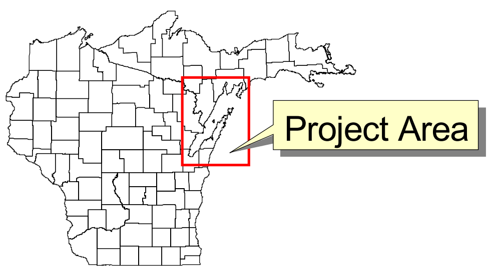
Physical Habitat Features
- Bridge
- Cuts, Coves, Backwaters
- Dam Riffles
- Island
- Lock Channel
- Submerged piling, ruin, rock
- Tributary

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

- Wetlands
- Bald Eagle Nesting Sites

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

Civil Divisions
- City
- Township
- Village

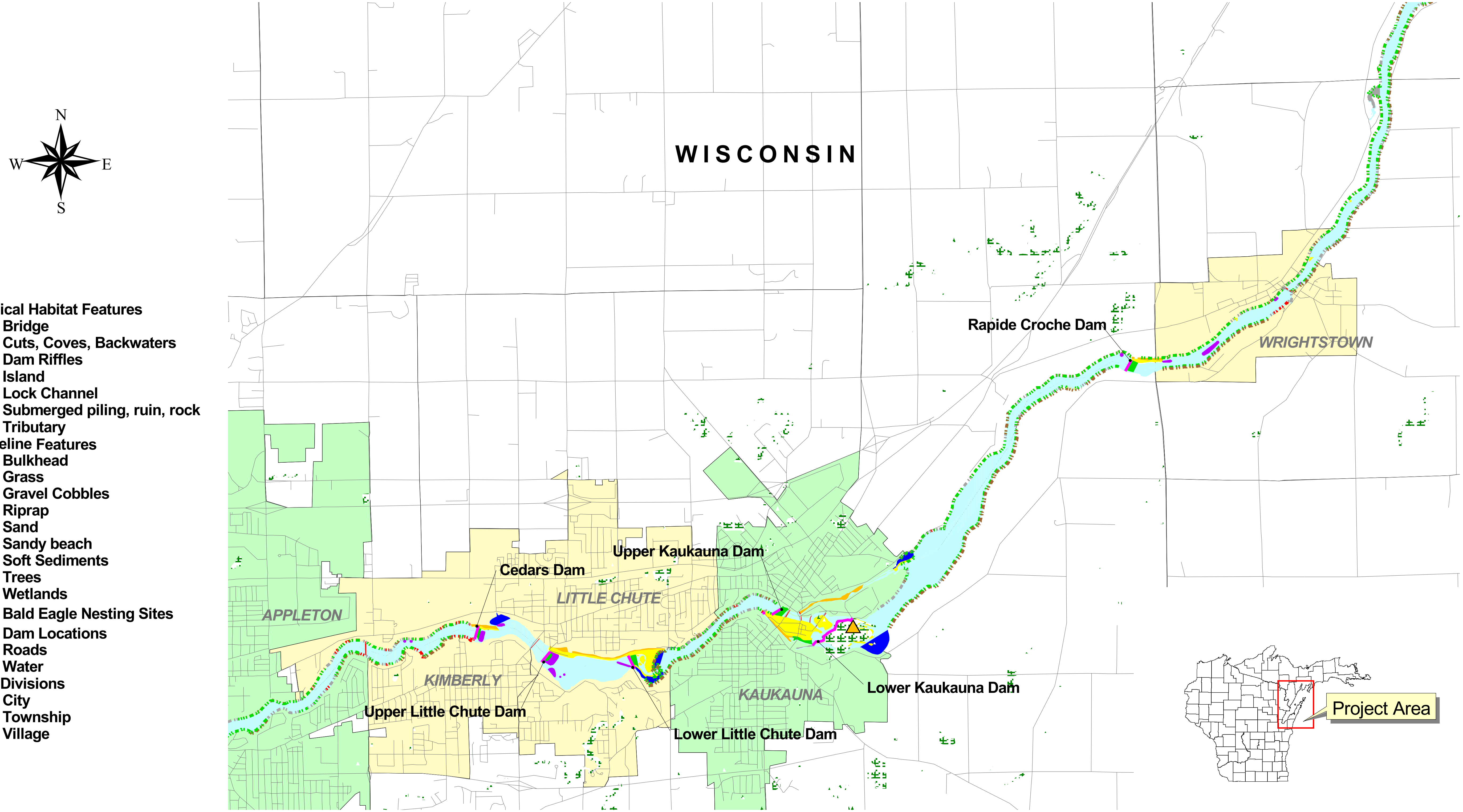


0.5 0 0.5 1 Kilometers

0.5 0 0.5 1 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Wetland, Habitat, and Animal Distribution: Little Lake Butte des Morts Reach	REFERENCE NO: RI-14414-340-4-1
			FIGURE 4-1	CREATED BY: SCJ
				PRINT DATE: 3/7/01
				APPROVED: AGF



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

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

- Bald Eagle Nesting Sites
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village

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

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1 0 1 2 Miles

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Wetland, Habitat, and Animal Distribution: Appleton to Little Rapids Reach	REFERENCE NO: RI-14414-340-4-2
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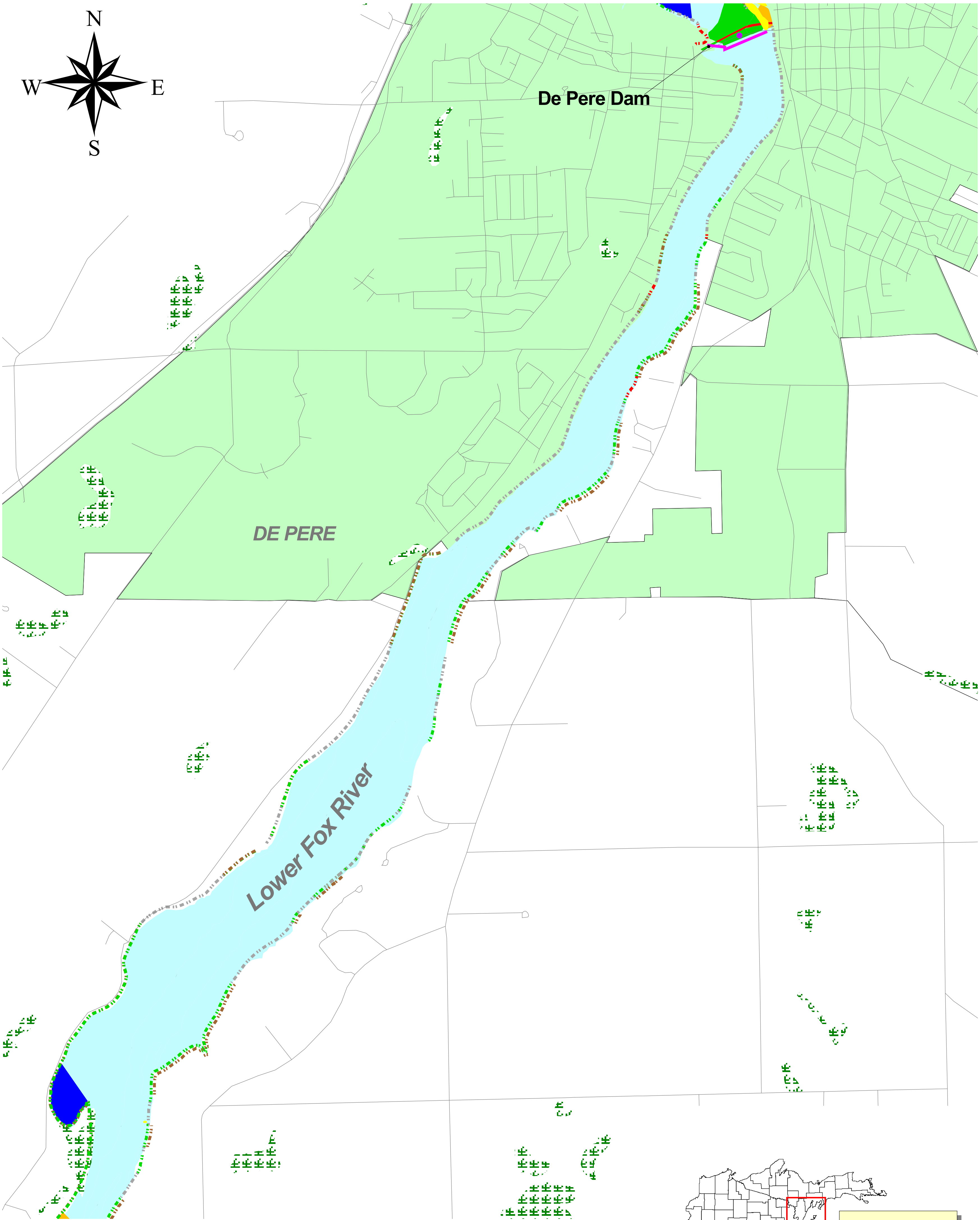
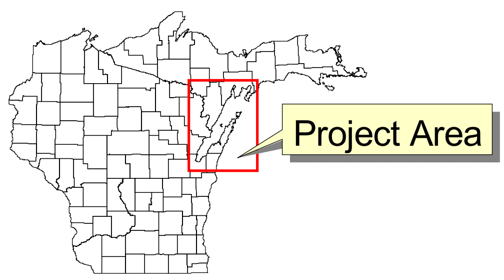
				PRINT DATE: 3/7/01
			FIGURE 4-2	APPROVED: AGF





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

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

- Wetlands
- Dam Locations
- Roads
- Water

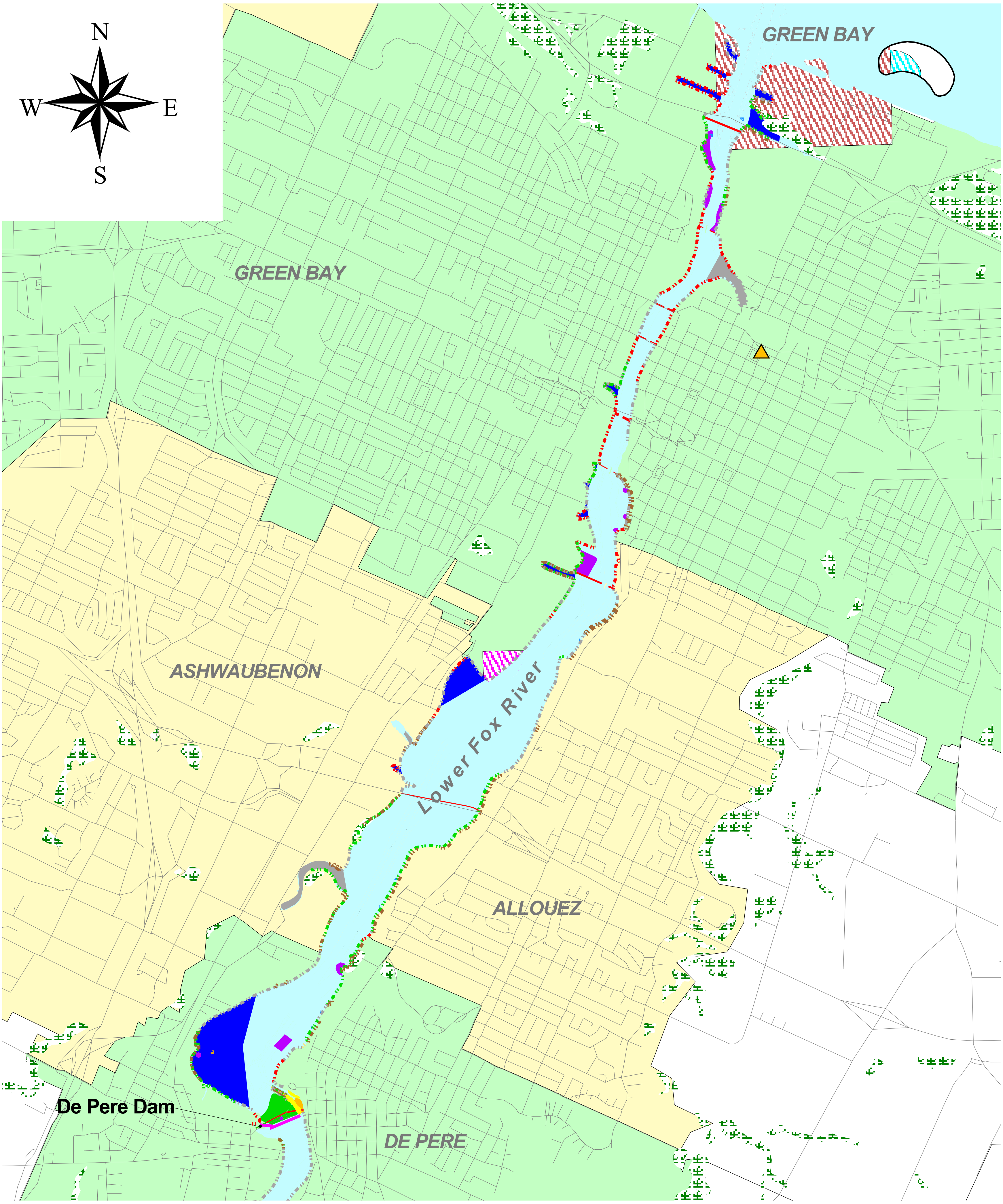
Civil Divisions
- City
- Township
- Village

0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Wetland, Habitat, and Animal Distribution: Little Rapids to De Pere Reach	REFERENCE NO: RI-14414-340-4-3
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 4-3	APPROVED: AGF



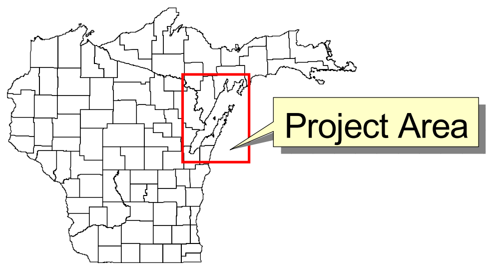
Physical Habitat Features
- Bridge
- Cuts, Coves, Backwaters
- Dam Riffles
- Island
- Lock Channel
- Submerged piling, ruin, rock
- Tributary

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

- Wetlands
- Bald Eagle Nesting Sites

Threatened or Endangered Resources
- Caspian Tern
- Forster's Tern
- Lake Sturgeon
- Dam Locations
- Roads
- Water

Civil Divisions
- City
- Township
- Village



1 0 1 Kilometers

0.5 0 0.5 1 Miles

Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
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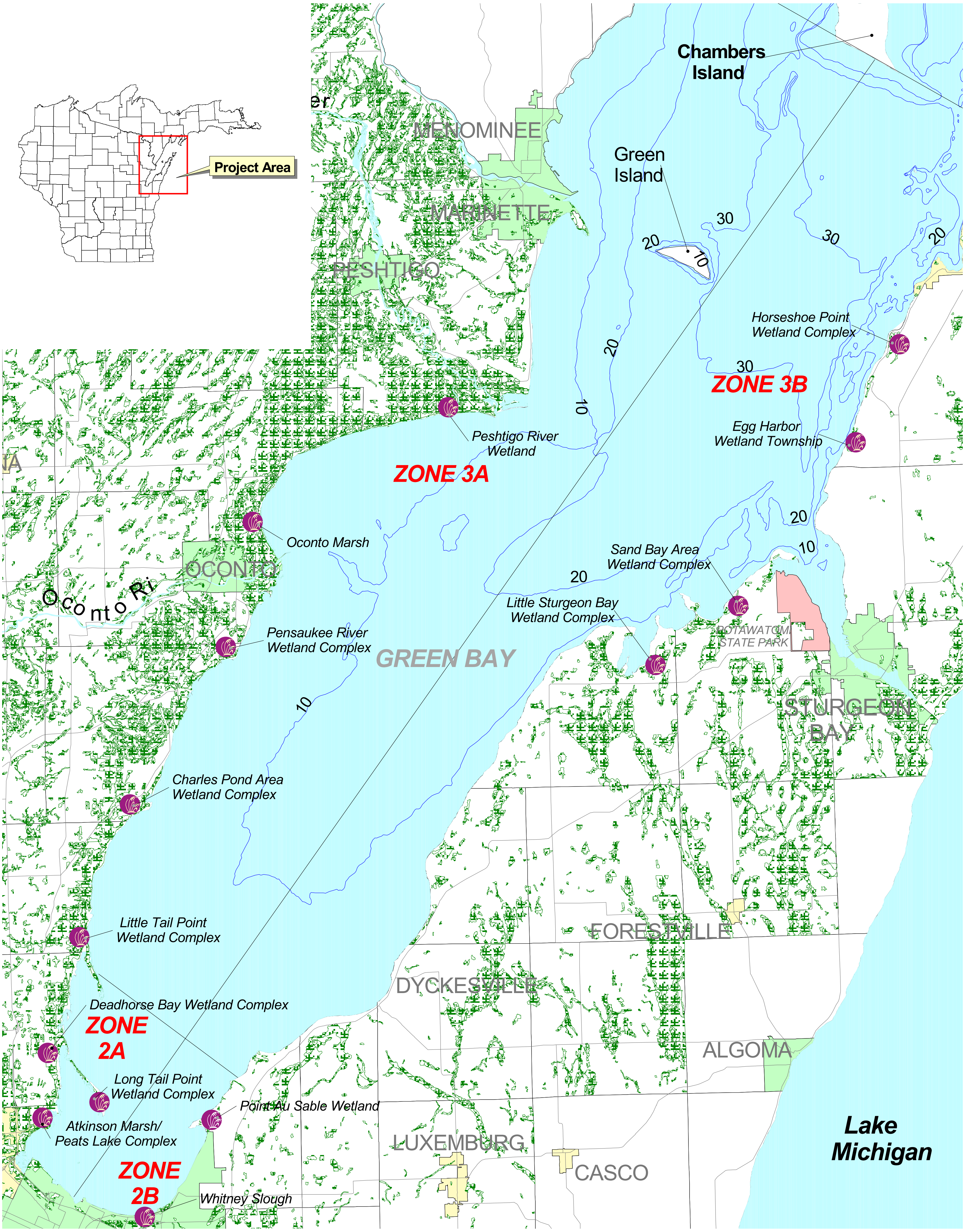
3. Wetlands data obtained from WDNR, 1999.
4. Physical habitat and shoreline features provided by Exponent, 1999.

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Wetland, Habitat, and Animal Distribution: De Pere to Green Bay Reach	REFERENCE NO: RI-14414-340-4-4 CREATED BY: SCJ PRINT DATE: 3/7/01 APPROVED: AGF
			FIGURE 4-4	



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

Civil Divisions
City
Township
Village

5 0 5 10 Kilometers

5 0 5 Miles

N W E S

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

ThermoRetec Smart Solutions. Positive Outcomes.

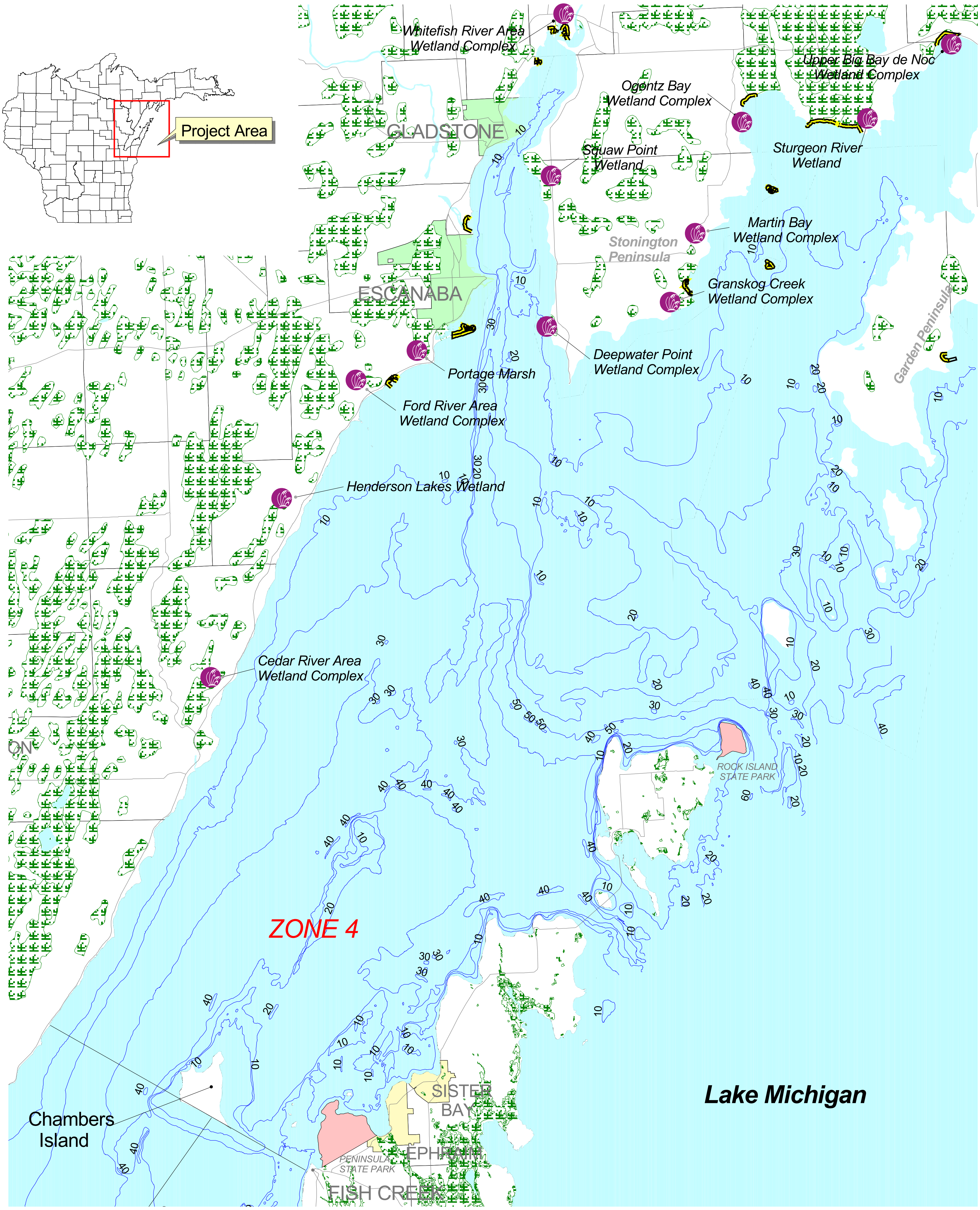
Natural Resource Technology

Remedial Investigation Report

Wetland Distribution: Green Bay Zones 2 & 3

FIGURE 4-5

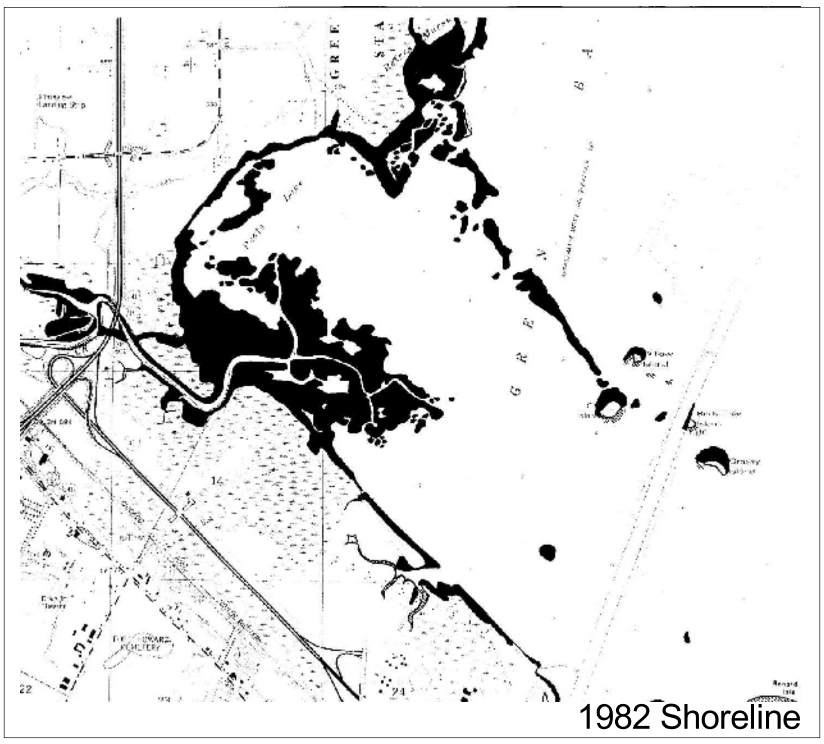
DRAWING NO: RI-14414-340-4-5
PRINT DATE: 1/23/01
CREATED BY: SCJ
APPROVED: AGF



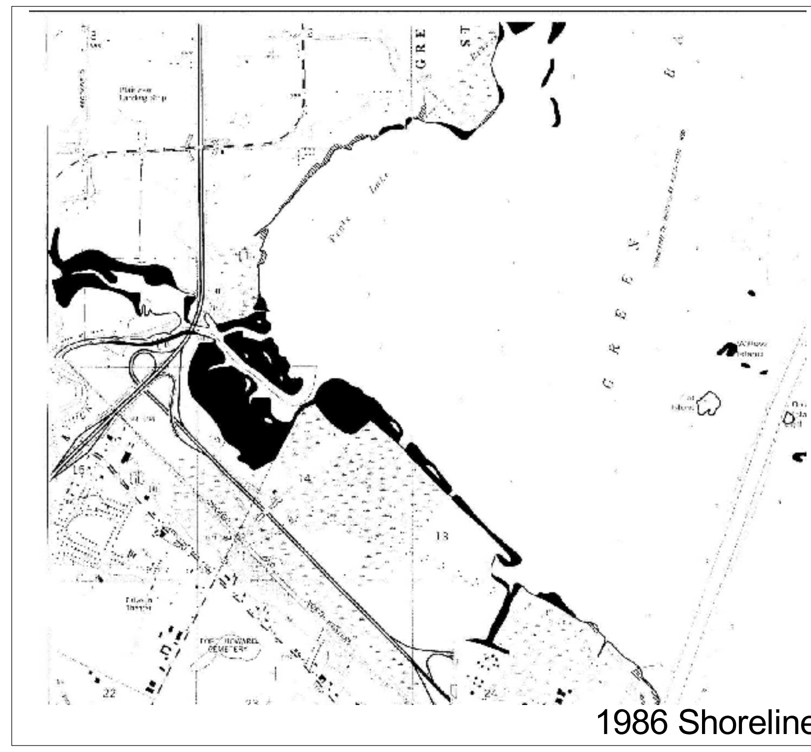
NOTES:
1. Basemap generated in ArcView GIS, version 3.2, from ESRI Data & Maps on CD-ROM and TIGER census data.
2. Aerial ground surveys and survey resource data collected in 1991 and 1992. Data compiled from USFWS, WDNR, Michigan DNR, Bureau of Endangered Resources, USACE, Bay-Lake Regional Planning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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Wetland Distribution: Green Bay Zone 4	DRAWING NO: RI-14414-340-4-6
			FIGURE 4-6	PRINT DATE: 1/23/01
				CREATED BY: SCJ
				APPROVED: AGF

Duck Creek and Cat Island Chain Area

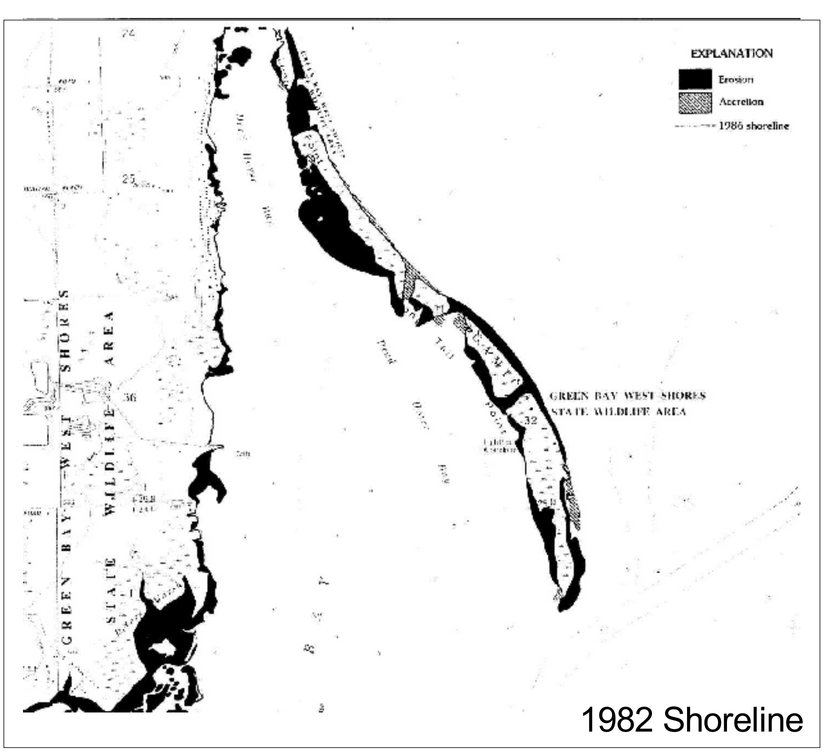


250 0 250 500 750 Feet

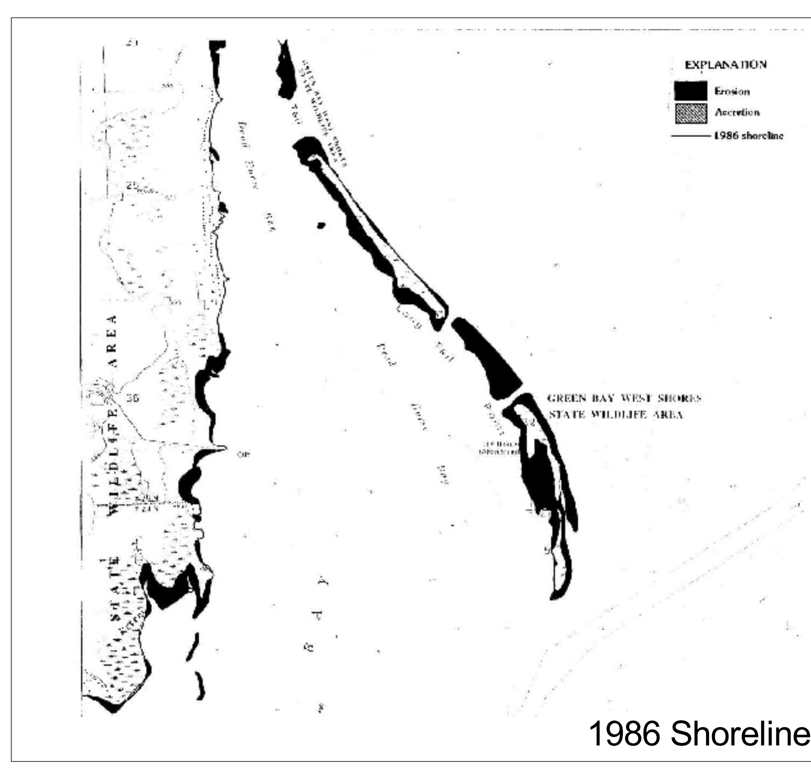


250 0 250 500 750 Feet

Long Tail Point Area



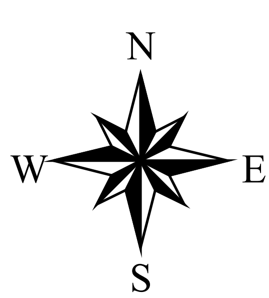
250 0 250 500 750 Feet

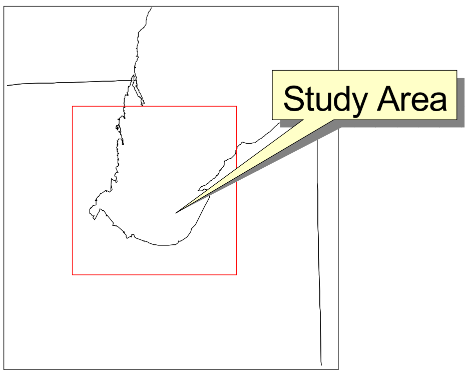


250 0 250 500 750 Feet

Wetland Losses

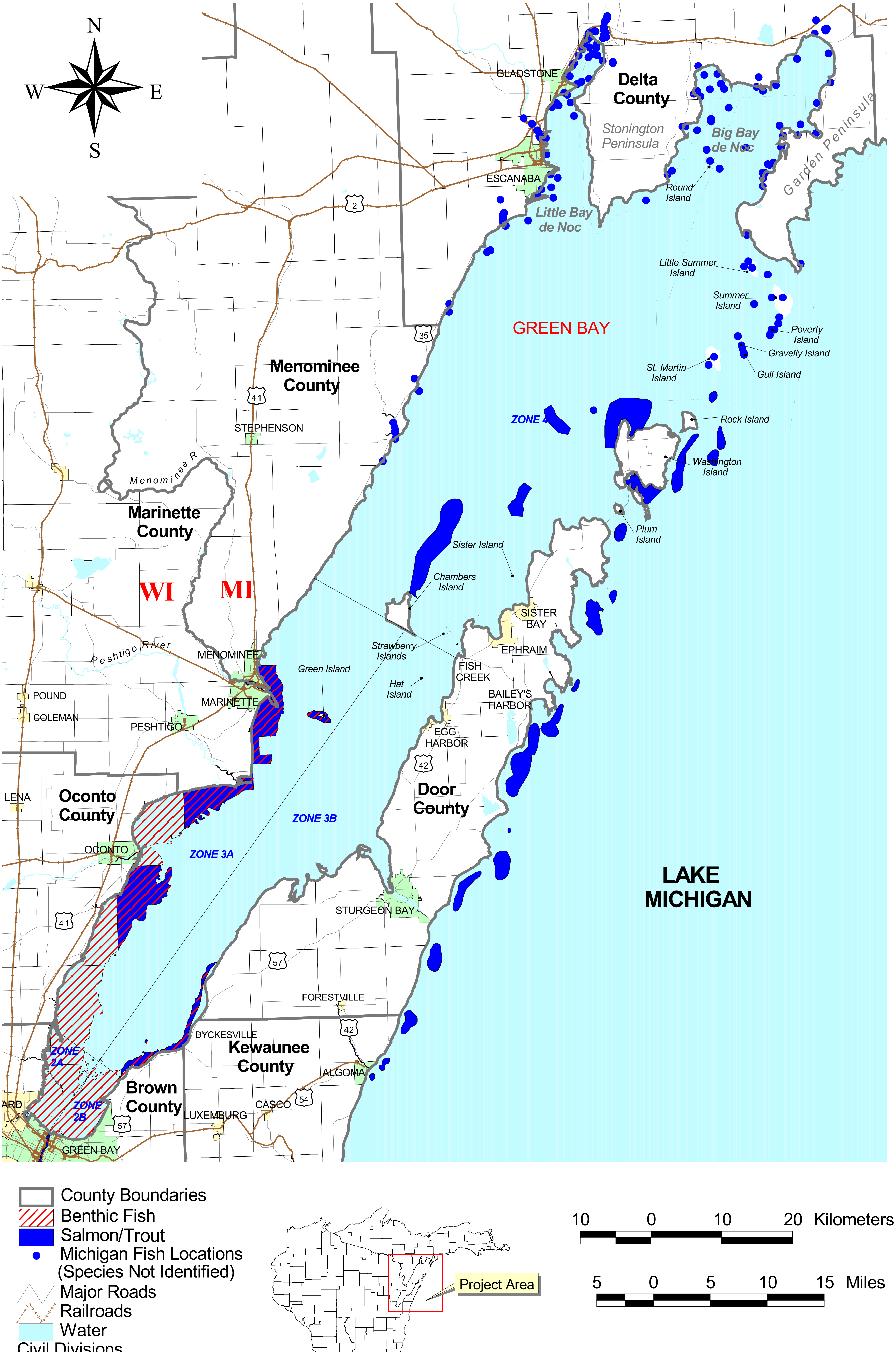
Wetland Gains





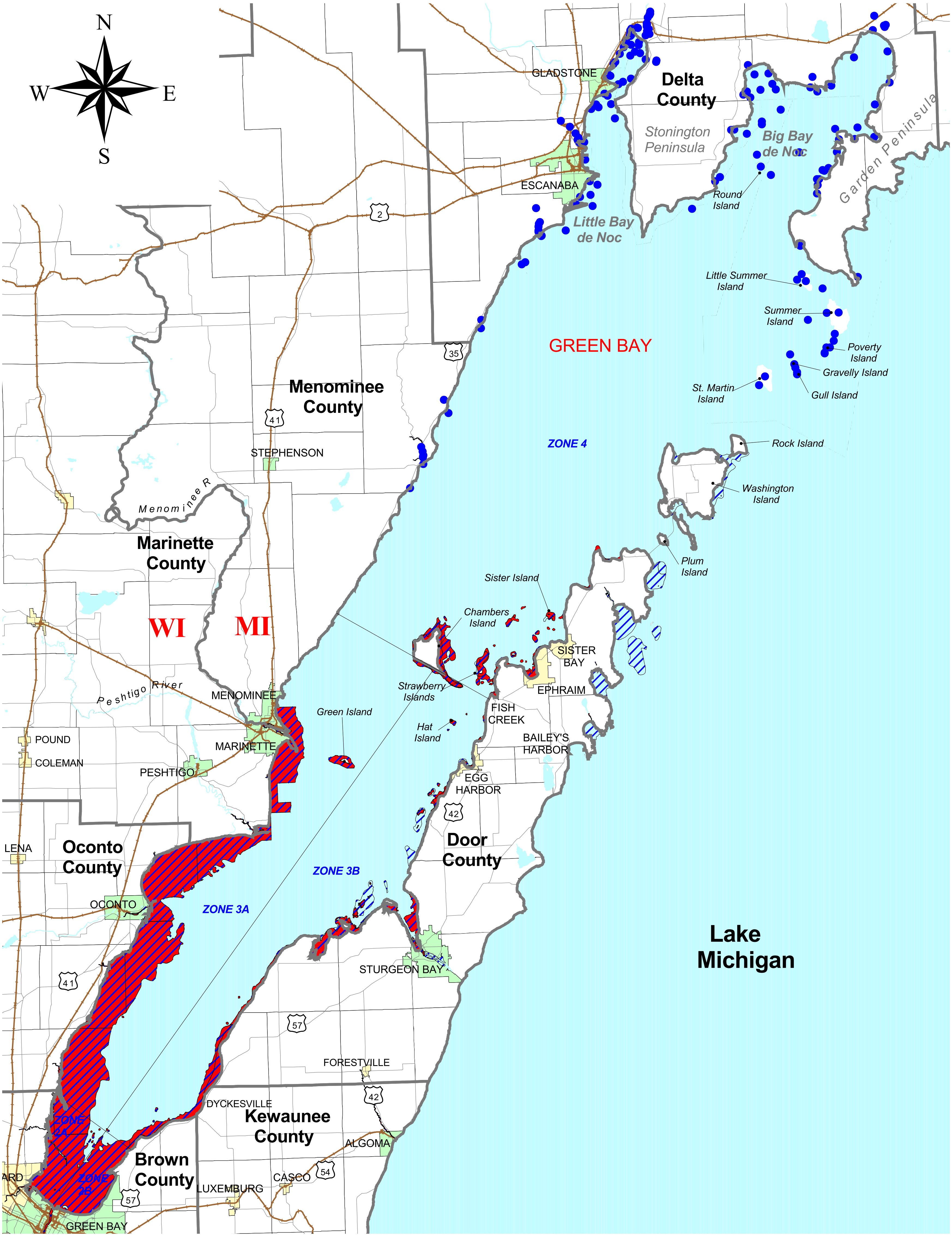
Reference: G.L. Schideler, USGS 1994
Map MF - 2254

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Wetland Losses in Green Bay: Duck Creek, Cat Island Chain, & Long Tail Point FIGURE 4-7	DRAWING NO: RI-4414-340-4-7 PRINT DATE: 3/7/01 CREATED BY: SCJ APPROVED: AGF



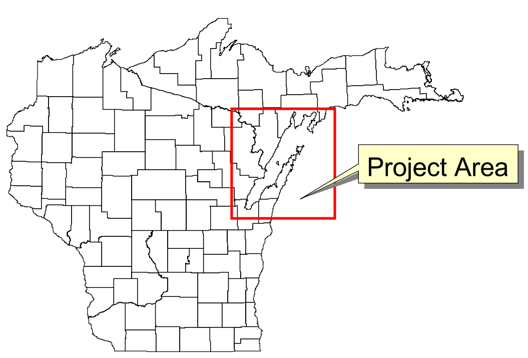
NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin fish habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and lake trout data obtained from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan fish locations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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Spawning Areas by Fish Types: Salmon/Trout and Benthic Fish	DRAWING NO: RI-4414-340-4-8
			FIGURE 4-8	PRINT DATE: 3/7/01
				CREATED BY: SCJ
				APPROVED: AGF



- County Boundaries
- Game Fish
- Pelagic Fish
- Michigan Fish Locations (Species Not Identified)
- Major Roads
- Railroads
- Water

Civil Divisions
- City
- Township
- Village



10 0 10 20 Kilometers

5 0 5 10 15 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.

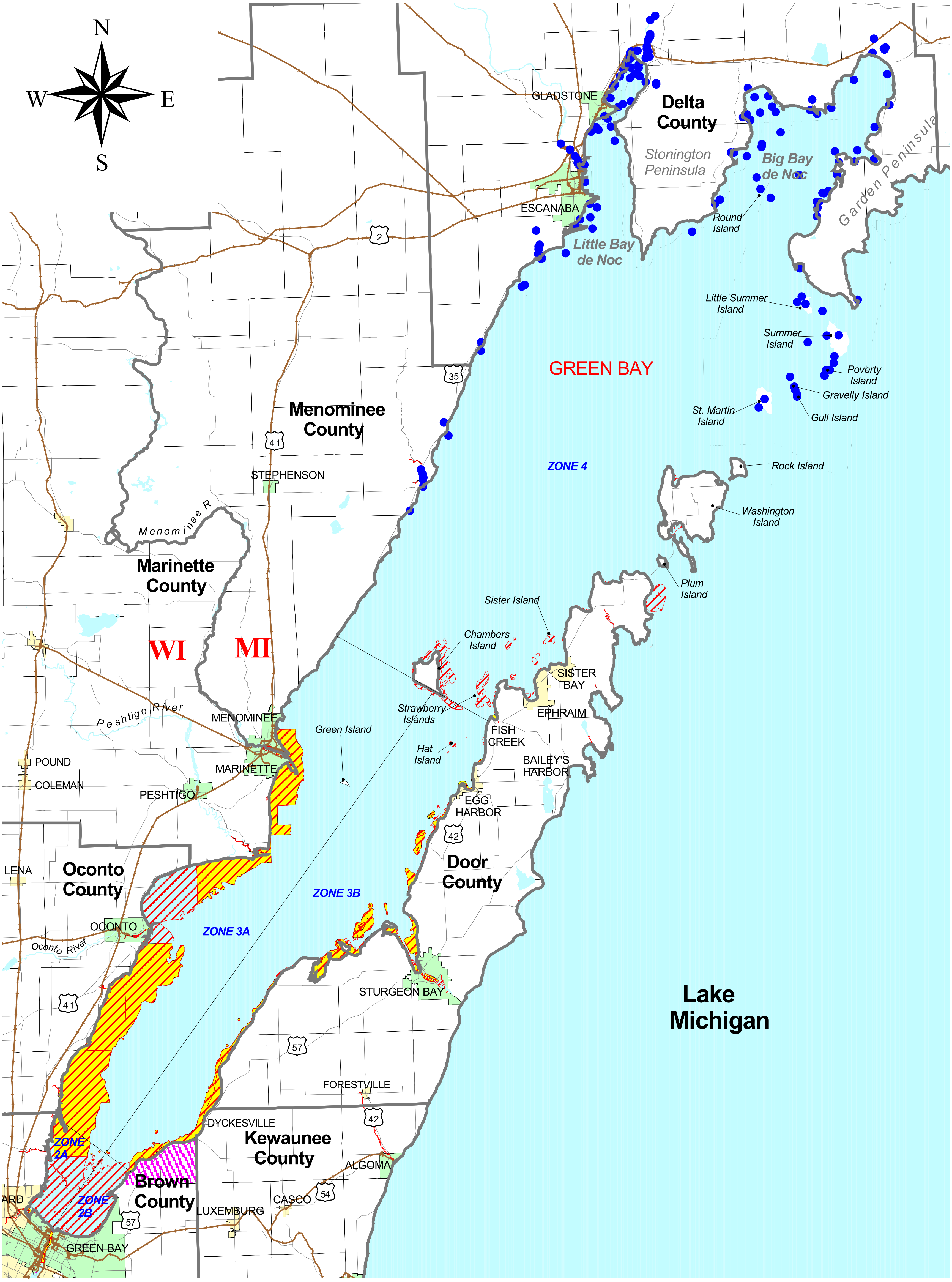
Natural Resource Technology

Remedial Investigation Report

Green Bay Spawning Areas by Fish Types: Pelagic and Game Fish

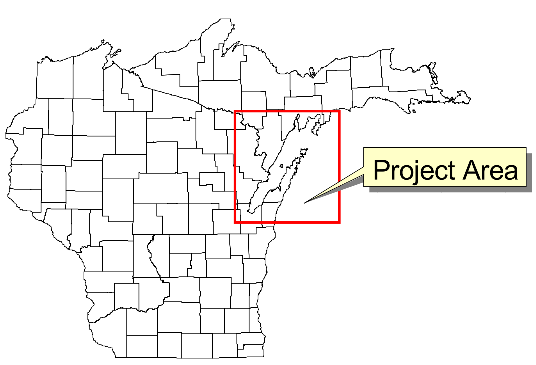
FIGURE 4-9

DRAWING NO: RI-4414-340-4-9
PRINT DATE: 1/23/01
CREATED BY: SCJ
APPROVED: AGF



County Boundaries
Lake Sturgeon
Yellow Perch
Walleye
Michigan Fish Locations (Species Not Identified)
Major Roads
Railroads
Water

Civil Divisions
City
Township
Village



10 0 10 20 Kilometers

5 0 5 10 15 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.

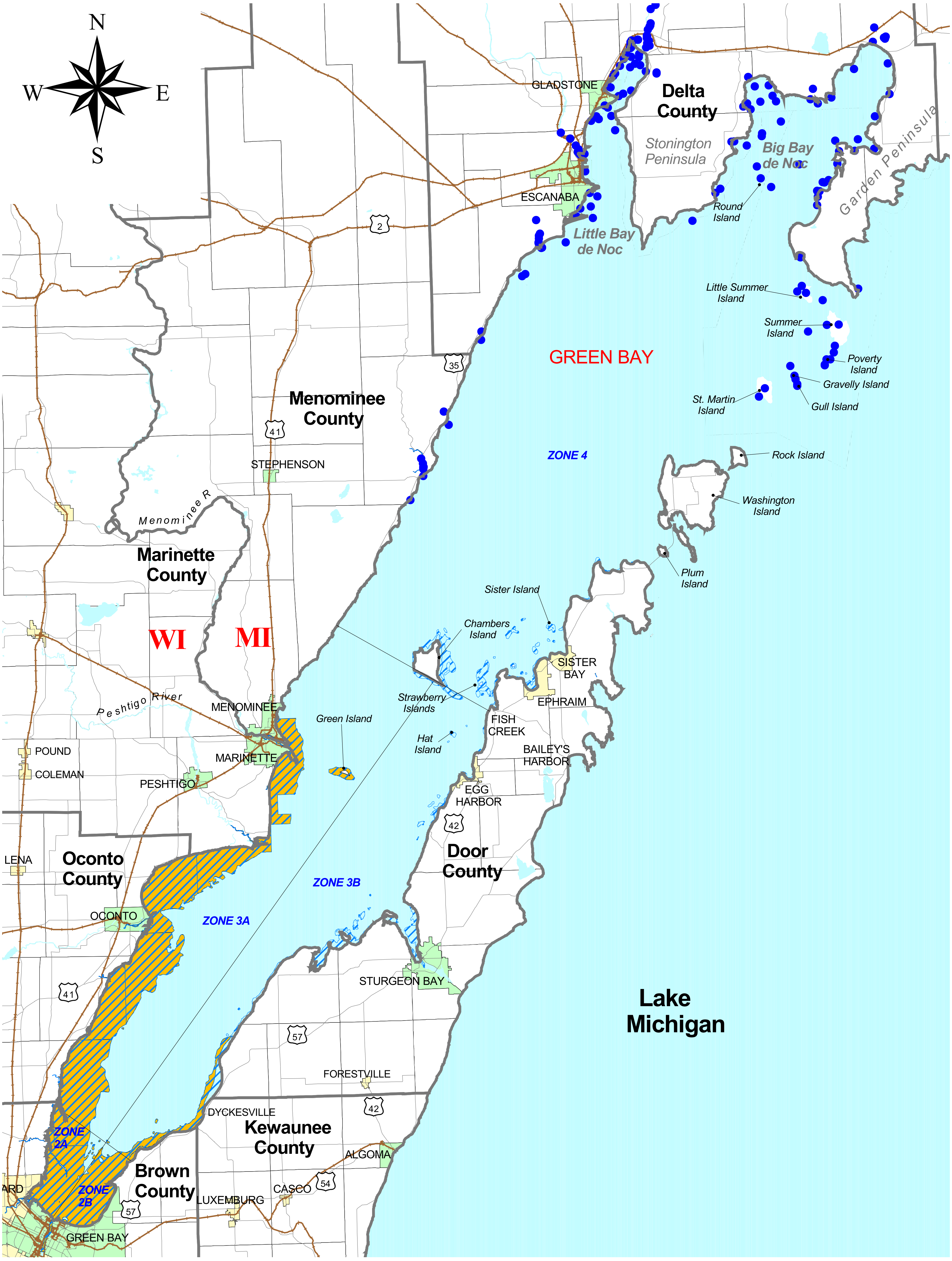
Natural Resource Technology

Remedial Investigation Report

Green Bay Spawning Areas by Fish Species: Walleye, Yellow Perch, and Sturgeon

FIGURE 4-10

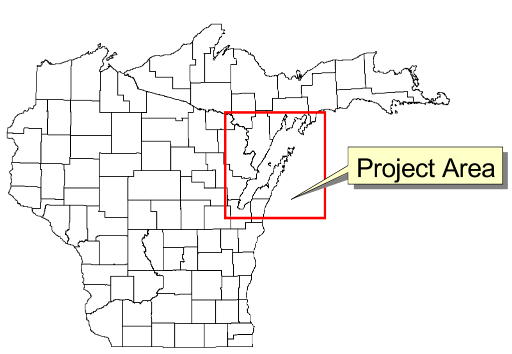
DRAWING NO: RI-4414-340-4-10
PRINT DATE: 3/7/01
CREATED BY: SCJ
APPROVED: AGF



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

Civil Divisions

- City
- Township
- Village

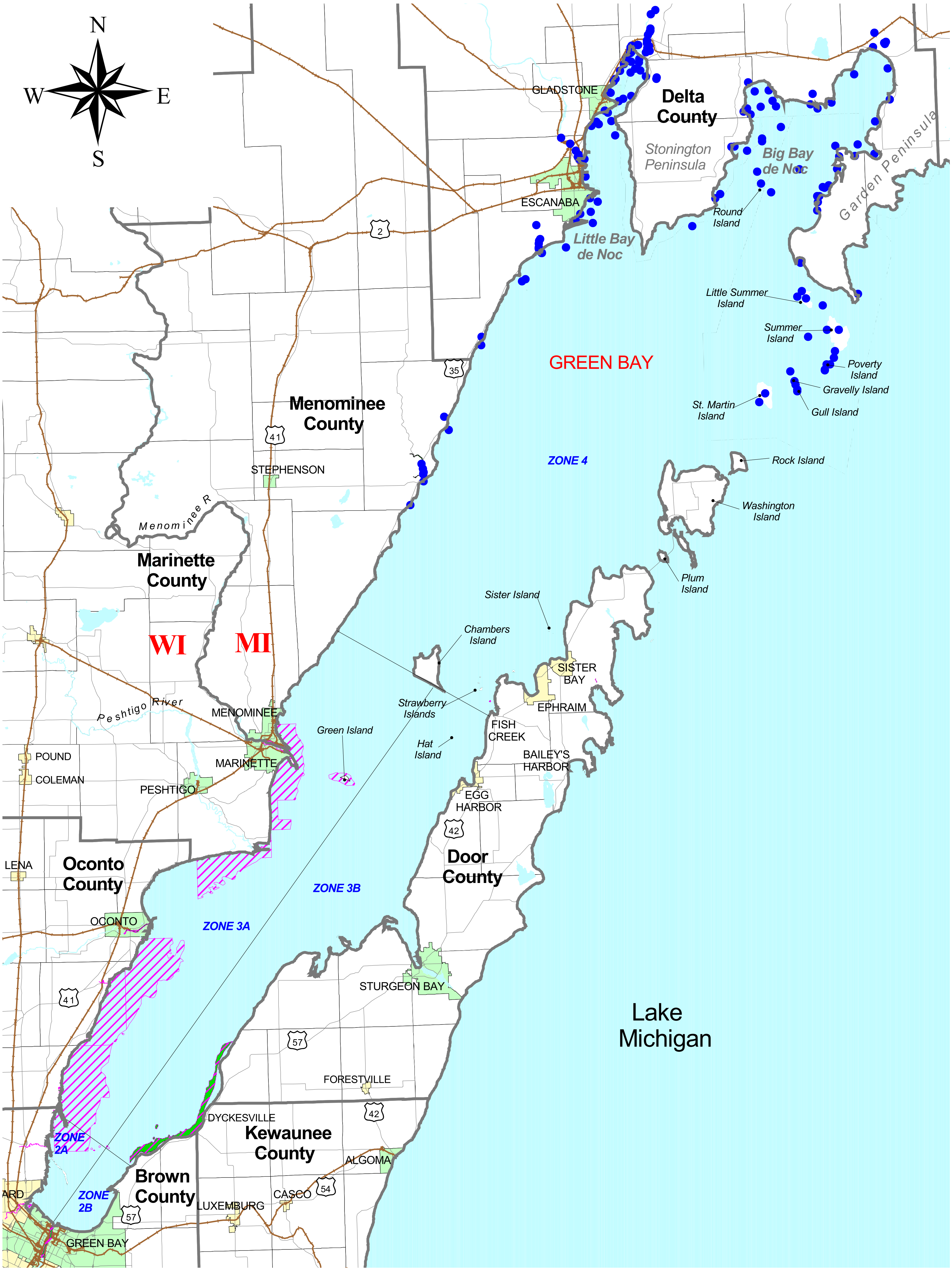


10 0 10 20 Kilometers

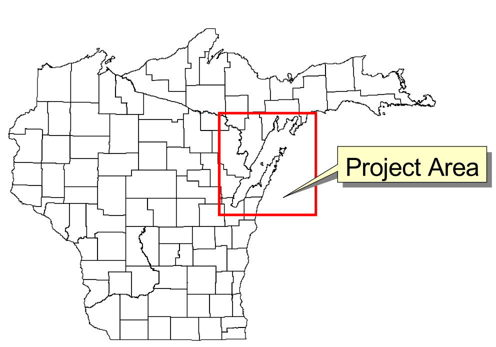
5 0 5 10 15 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Spawning Areas by Fish Species: Carp and Alewife	DRAWING NO: RI-4414-340-4-11
			FIGURE 4-11	PRINT DATE: 3/7/01
				CREATED BY: SCJ
				APPROVED: AGF



County Boundaries
Gizzard Shad
Emerald Shiner
Michigan Fish Locations (Species Not Identified)
Major Roads
Railroads
Water
Civil Divisions
City
Township
Village

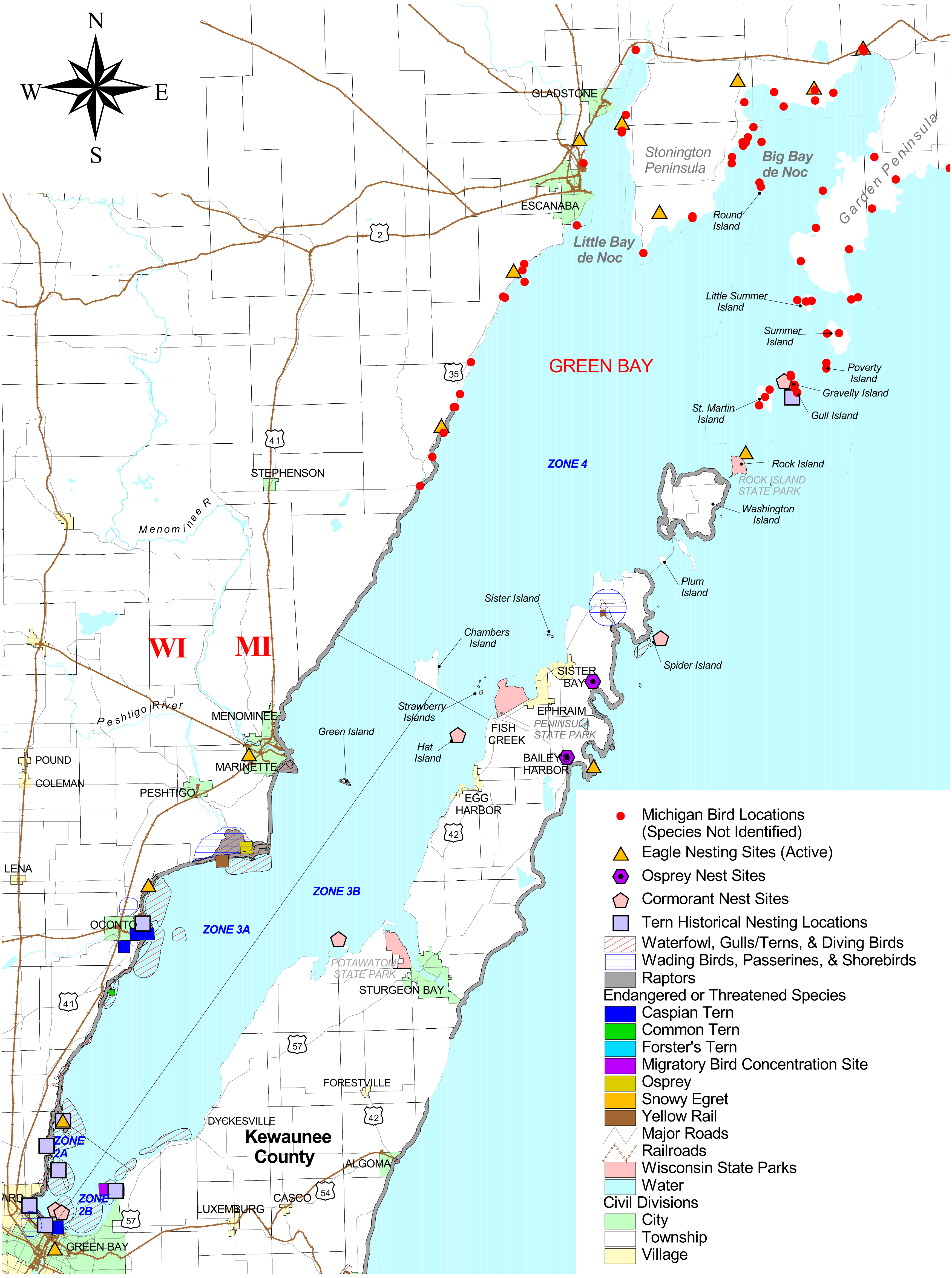


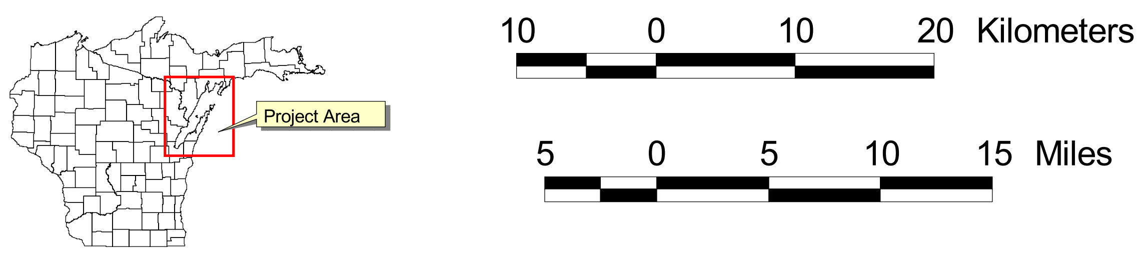
10 0 10 20 Kilometers

5 0 5 10 15 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Spawning Areas by Fish Species: Emerald Shiners and Gizzard Shad	DRAWING NO: RI-4414-340-4-12
				PRINT DATE: 3/7/01
				CREATED BY: SCJ
			FIGURE 4-12	APPROVED: AGF



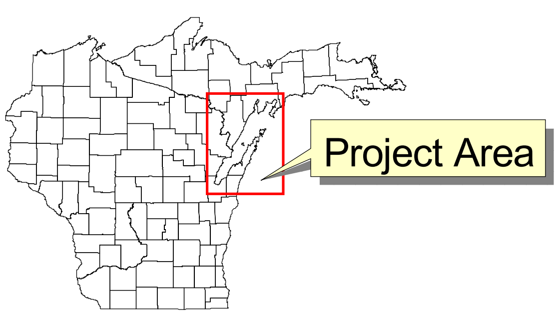


NOTES:
1. Basemap generated from TIGER census data, 1995 in ArcView GIS, version 3.2, WTM projection.
2. Wisconsin bird habitat data obtained from NOAA, 1997 Environmental Sensitivty Index Metadata, and from U. of Wisconsin Sea Grant Institute, 1980.
3. Michigan bird locations obtained from Great Lakes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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Distribution of Birds in Green Bay: Select Species and Groups	DRAWING NO: RI-4414-340-4-13
				PRINT DATE: 3/7/01
				CREATED BY: SCJ
			FIGURE 4-13	APPROVED: AGF

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

Civil Divisions
- City
- Township
- Village

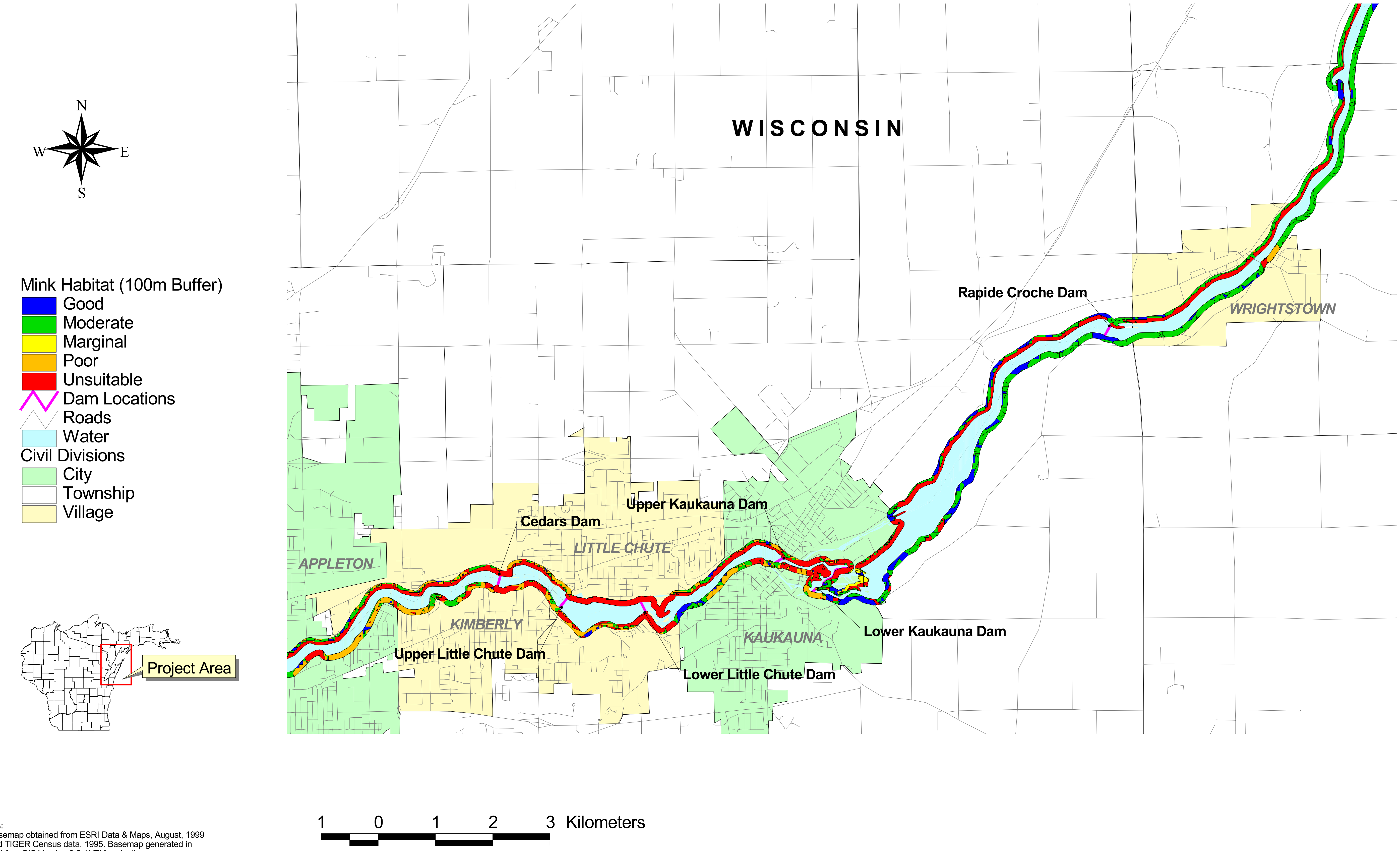


0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

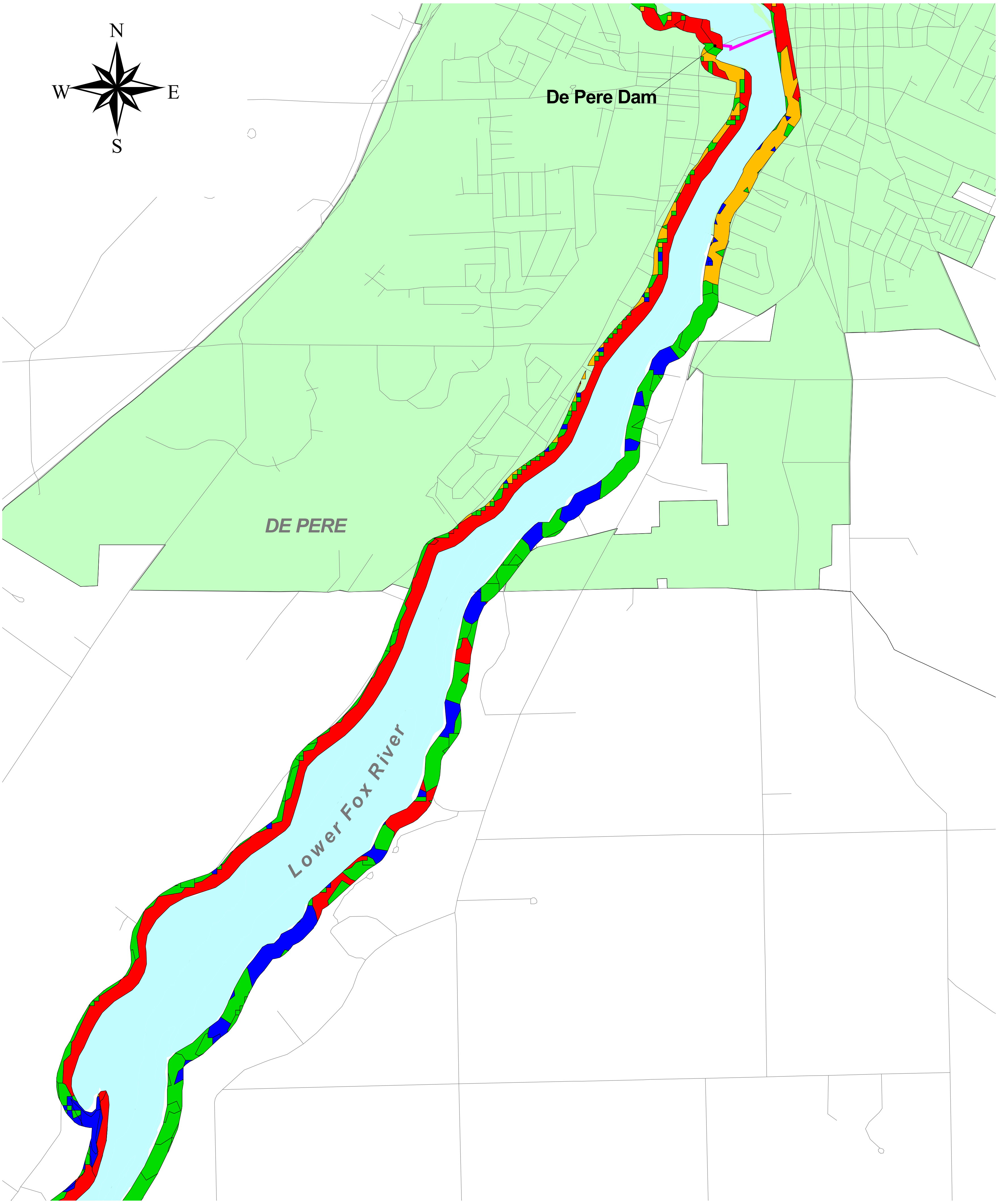
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Mink Habitat Suitability: Little Lake Butte des Morts Reach	REFERENCE NO: RI-14414-340-4-14
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 4-14	APPROVED: AGF



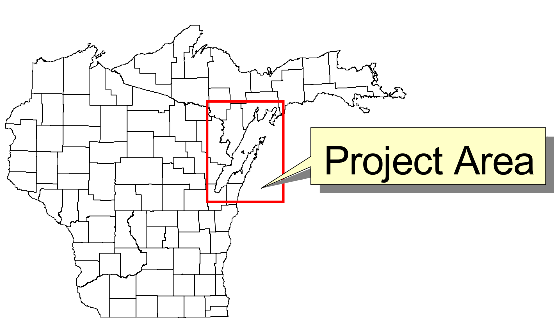
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Mink Habitat Suitability: Appleton to Little Rapids Reach	REFERENCE NO: RI-14414-340-4-15
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 4-15	APPROVED: AGF



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

Civil Divisions
- City
- Township
- Village

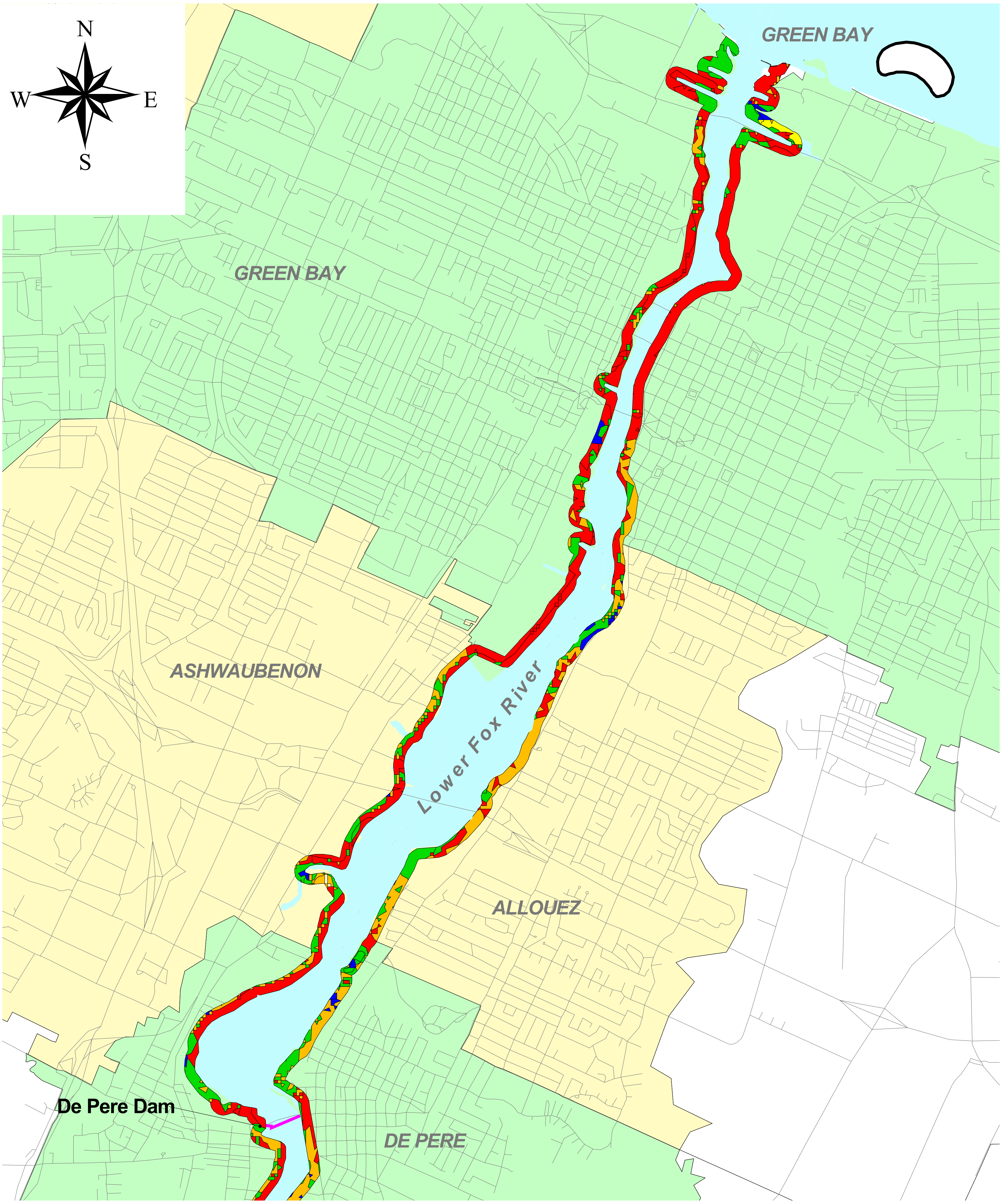


0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

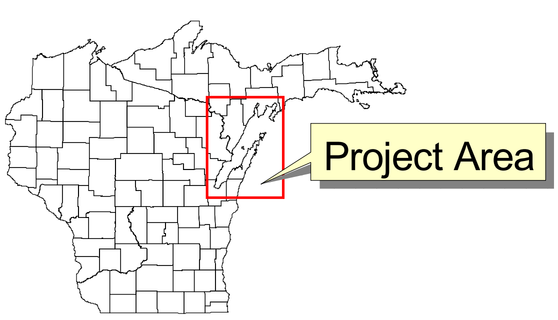
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Mink Habitat Suitability: Little Rapids to De Pere Reach	REFERENCE NO: RI-14414-340-4-16
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 4-16	APPROVED: AGF



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

Civil Divisions
- City
- Township
- Village

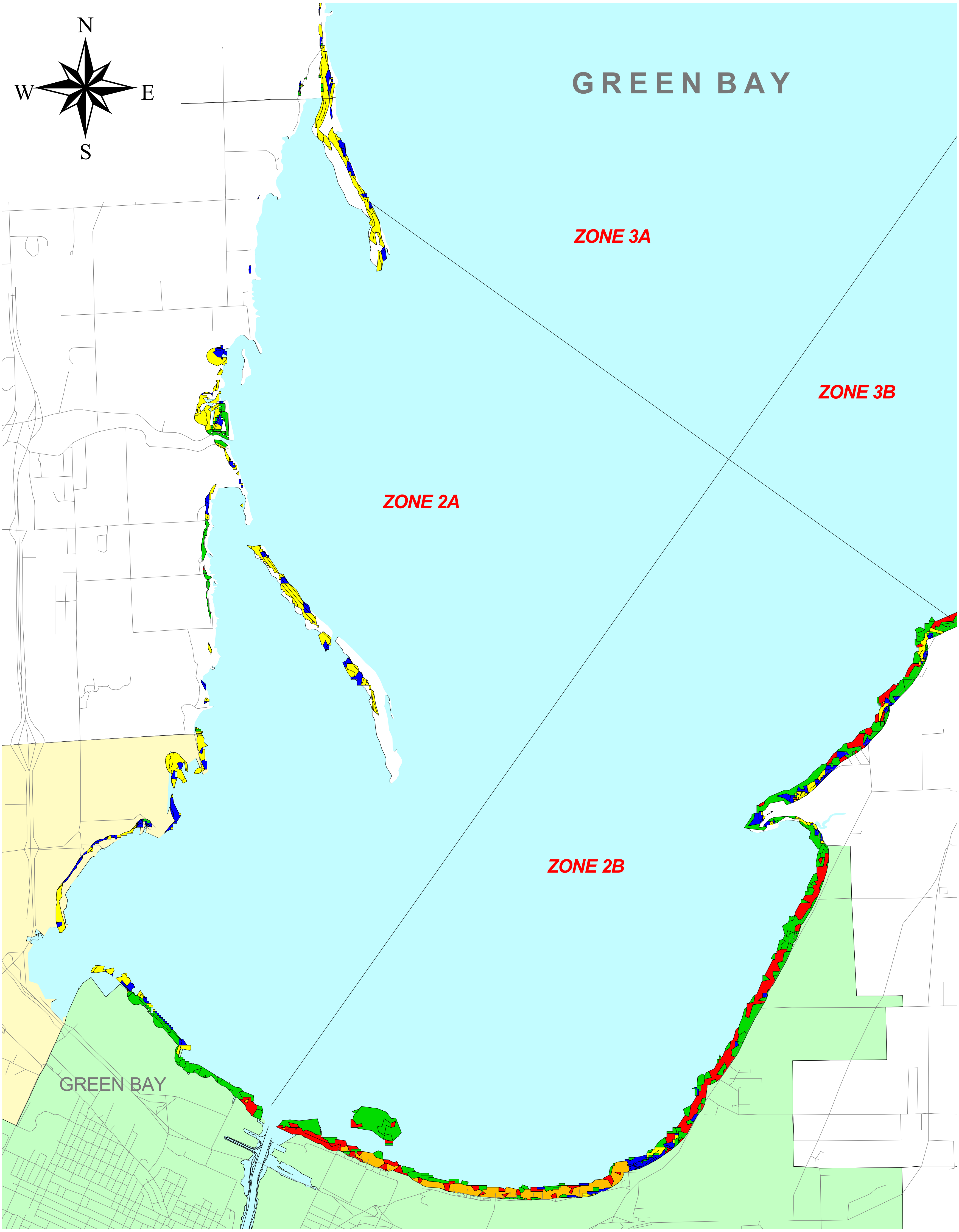


0.5 0 0.5 1 1.5 Kilometers

0.5 0 0.5 1 Miles

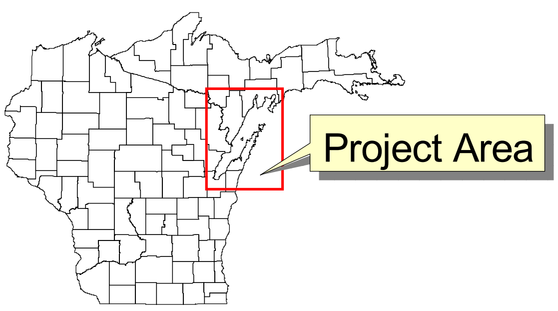
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Lower Fox River Mink Habitat Suitability: De Pere to Green Bay Reach	REFERENCE NO: RI-14414-340-4-17
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 4-17	APPROVED: AGF



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

Civil Divisions
- City
- Township
- Village

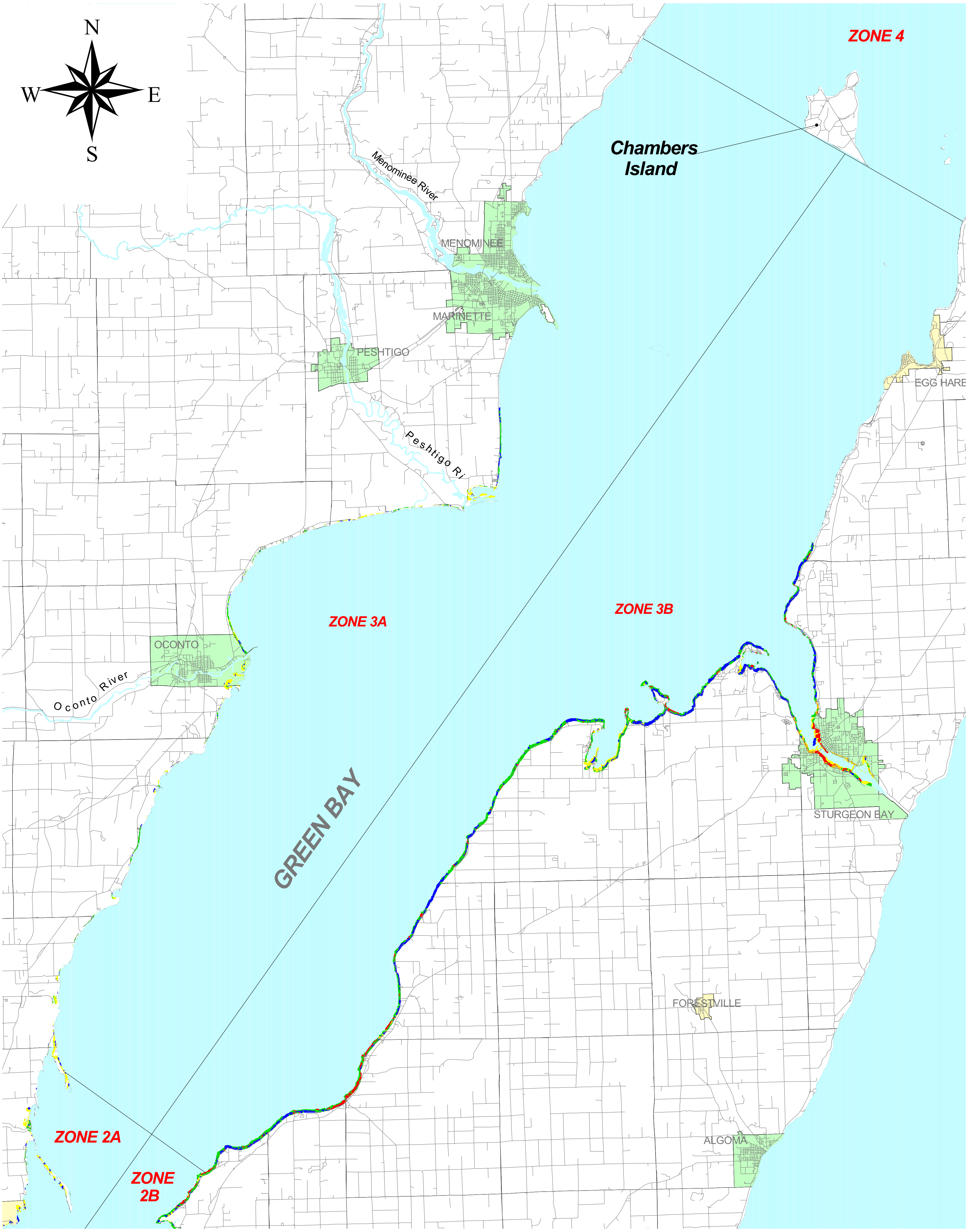


1 0 1 2 Kilometers

1 0 1 Miles

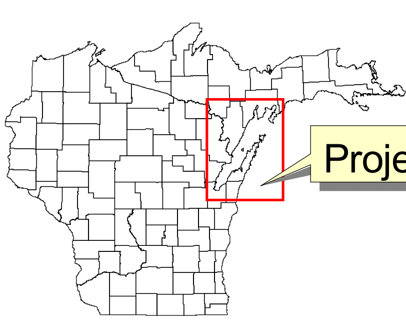
Notes:
1. Basemap obtained from ESRI Data & Maps, August, 1999 and TIGER Census data, 1995. Basemap generated in ArcView GIS Version 3.2, WTM projection.
2. Mink data obtained from Exponent, 2000.
3. Suitability Index based on WISCLAND land use maps and WDNR wetland maps. Good = forest shrub/scrub or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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Mink Habitat Suitability: Zone 2	REFERENCE NO: RI-14414-340-4-18
				CREATED BY: SCJ
				PRINT DATE: 3/7/01
			FIGURE 4-18	APPROVED: AGF



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

Civil Divisions
- City
- Township
- Village



3 0 3 6 9 Kilometers

3 0 3 6 Miles

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

ThermoRetec Smart Solutions. Positive Outcomes.	Natural Resource Technology	Remedial Investigation Report	Green Bay Mink Habitat Suitability: Zone 3	REFERENCE NO: RI-14414-340-4-19 CREATED BY: SCJ PRINT DATE: 3/7/01
			FIGURE 4-19	APPROVED: AGF

Table 4-1. Major Green Bay Wetland Areas/Complexes[1]

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

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

L = Lacustrine wetland

P = Palustrine wetland

R = Riverine wetland

Table 4-2. Lower Fox River Habitats

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

Prepared from information compiled by Exponent (1998).

Table 4-3. Lower Fox River Shoreline and Substrate Types

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

Prepared from information compiled by Exponent (1998).

Descriptions of the Areas (Exponent, 1998).

Area 1: LLBdM to Appleton Lock 1
Area 2: Appleton Lock 1 to Cedars Lock
Area 3: Cedars Lock to Rapide Croche Lock
Area 4: Rapide Croche Lock to Little Kaukauna Lock
Area 5: Little Kaukauna Lock to De Pere Dam

Area 1: De Pere Dam to Highway 172 Bridge
Area 2: Highway 172 Bridge to Ft. Howards (Ft. James) RR trestle
Area 3: Fort Howard RR trestle to E. Mason Street Bridge
Area 4: E. Mason Street Bridge to mouth of the Fox River

Descriptions of Substrate Types (Exponent, 1998).

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

Table 4-4. Lower Fox River Fish Species Composition

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

Notes:

A) As Listed in Wisconsin State Statute Chapter 29.01.

B) No differentiation made between Shortnose/Longnose Gar - value listed for Shortnose Gar represents both species.

C) No differentiation made between Bullheads (black, brown, yellow) - value listed for black bullhead represents all three species.

Table 4-4. Lower Fox River Fish Species Composition (Continued)

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

Notes:

A) As Listed in Wisconsin State Statute Chapter 29.01.

B) No differentiation made between Shortnose/Longnose Gar - value listed for Shortnose Gar represents both species.

C) No differentiation made between Bullheads (black, brown, yellow) - value listed for black bullhead represents all three species.

Table 4-5. Lower Fox River Fish Populations in the De Pere to Green Bay Reach

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

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

Table 4-5. Lower Fox River Fish Populations in the De Pere to Green Bay Reach (Continued)

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

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

Table 4-6. Green Bay Fish Species

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

E = ENDANGERED   D = DELISTED
T = THREATENED   X = Included in Risk Assessment Food Web Models.

Table 4-7. Lower Fox River and Green Bay Bird Species

Common Name	Species Name	Food Web	Wisconsin Listing	Michigan Listing	Federal Listing
Raptors					
Bald eagle	Haliaeetus leucocephalus	X	D	T	T
Merlin	Falco Columbarius			T	
Osprey	Pandion haliaetus		T	T	
Peregrine falcon	Falco peregrinus		E	E	E
Gulls and Terns					
Black tern	Chilidonias niger				
Caspian tern	Sterna caspia		E	T	
Common tern	Sterna hirundo	X	E	T	
Forster's tern	Sterna fosteri	X	E		
Herring gull	Larus argentatus				
Ring-billed gull	Larus delawarensis				
Diving Birds					
Belted kingfisher	Megaceryle alcyon				
Common loon	Gavia immer				
Double-crested cormorant	Phalacrocorax auritus	X			
Horned grebe	Podiceps auritus				
Pied-billed grebe	Podilymbus podiceps				
Passerine Bird					
Brewer's blackbird	Euphagus cyanocephalus				
Red-winged blackbird	Agelaius phoeniceus				
Yellow-headed blackbird	Xanthocephalus xanthocephalus				
Marsh wren	Cistothorus palustris				
Sedge wren	Cistothorus platensis				
Tree swallows	Tachycineta bicolor				
Swamp sparrow	Melospiza georgiana				
Shorebird					
Common snipe	Capella gallinago				
Dunlin	Calidris alpina				
Least sandpiper	Calidris minutilla				
Pectoral sandpiper	Calidris melanotos				
Piping plover	Charadrius melodus		E	E	E/T
Sanderling	Calidris alba				
Semipalmated sandpiper	Calidris pusilla				
Spotted sandpiper	Actitis macularia				

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Table 4-7. Lower Fox River and Green Bay Bird Species (continued)

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

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