# Final Feasibility Study

## Lower Fox River and Green Bay, Wisconsin
## Remedial Investigation and Feasibility Study

**Prepared for:**

***Wisconsin Dept. of Natural Resources***

**Prepared by: The RETEC Group, Inc.**

## December 2002

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**RETEC Project No.: WISCN-14414-561**

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# December 2002

# EXECUTIVE SUMMARY FEASIBILITY STUDY

## Lower Fox River and Green Bay

The Feasibility Study (FS) developed and evaluated a range of remedial alternatives for the Lower Fox River and Green Bay (Figure 1) to manage the risk associated with the presence of industrial contaminants discharged to the river. This RI/FS report is consistent with the findings of the National Academy of Sciences Research Council Report entitled *A Risk Management Strategy for PCB-Contaminated Sediments* (NAS, 2001).

Each alternative was compared to nine evaluation criteria including: 1) risk reduction, 2) overall protectiveness of human health and the environment, 3) implementability, 4) short-term effectiveness associated with the remedy action, 5) permanence, 6) reduction in toxicity, mobility and volume, 7) cost, 8) regulatory acceptance, and 9) community acceptance.

The area of concern includes the Lower Fox River extending 63 km (39 mi) from Lake Winnebago to the mouth of Green Bay, and includes the entire 4,150 km$^2$ (1,600 mi$^2$) of the bay. Remedial alternatives were developed for the four reaches of the Lower Fox River including: Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (same as Green Bay Zone 1); as well as the four zones of Green Bay: Zone 2, Zone 3A, Zone 3B, and Zone 4.

The purpose of the FS is to support the selection of a remedy that will eliminate, reduce and/or control short-term and long-term risks. The evaluation in the FS used data developed in the Remedial Investigation (RI), Risk Assessment (RA), and Model Documentation reports to support the screening of alternatives. This screening of alternatives followed EPA's Superfund Guidance document for conducting RI/FS studies under CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act of 1980).

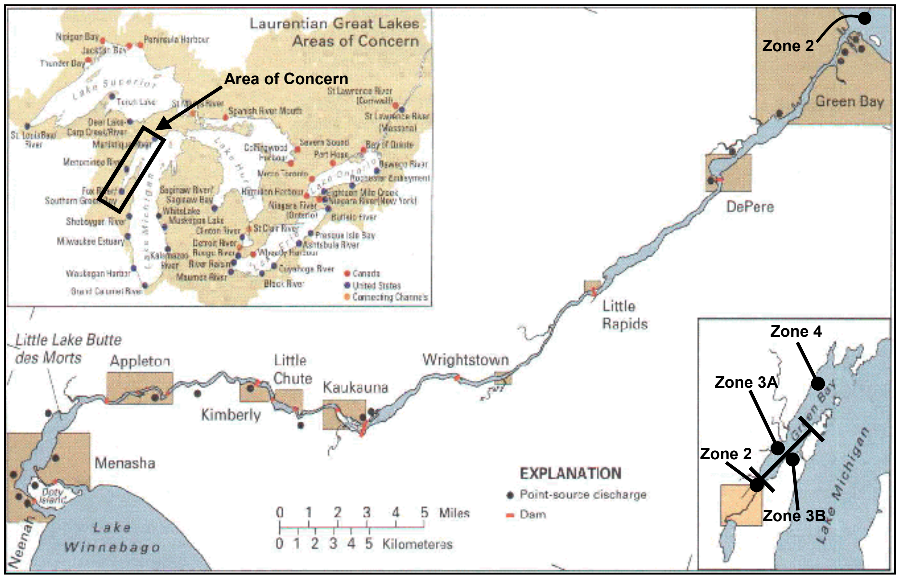

**Figure 1 (Fitzgerald & Steuer, 1996)**

## Site History and PCB Discharges

Between 1954 and 1971, paper mills in the Lower Fox River valley manufactured and recycled carbonless copy paper that contained polychlorinated biphenyls (PCBs), resulting in the release of an estimated 300,000 kg (600,000 pounds) of PCBs to the river. The highest PCB concentrations detected in site sediments were 223 mg/kg in the Little Lake Butte des Morts Reach and 710 mg/kg in the De Pere to Green Bay Reach. WDNR issued PCB consumption advisories in 1976 and 1983 for fish and waterfowl, respectively. The State of Michigan also issued consumption advisories for Green Bay fish in

1977. These advisories are still in effect today.

## PCB Distribution, Volume, and Transport

The Remedial Investigation identified the sources of PCBs, the estimated mass, and volume of PCBs in bedded sediments. The RI also estimated the sediment and PCB mass transport rates. Between 65 and 175 kg of PCBs are transported downstream annually from each reach, and 280 kg of PCBs move into Green Bay annually. A significant portion of the PCB loading that occurs in Green Bay is derived from the Lower Fox River. This transport of PCBs also extends to Lake Michigan.

PCBs discharged into the river, in large part today, remain in the bedded sediments of the river and bay. For sediments containing more than 50 $\mu$g/kg PCBs, approximately 28,600 kg (63,050 pounds) of PCBs remain in the Lower Fox River (Figure 2) compared to approximately 68,200 kg (150,300 pounds) of PCBs in Green Bay (Figure 3). As stated in the RI report, the PCBs are contained within about 11.8 million cy of sediment in the river. In Green Bay, the PCBs are dispersed in a much greater volume of sediment, approximately 610 million cy.

## Risks to Human and Ecological Receptors

The chemicals of concern (COCs) from the Baseline Risk Assessment (RA) included polychlorinated biphenyls (PCBs) (total and selected congeners), mercury, and DDE as the primary compounds of risk to human health and the environment, with PCBs presenting the highest risk. The exposure pathway presenting the greatest level of risk to both human health and ecological receptors is through fish consumption (other than direct risk to benthic invertebrates). Receptors at risk include recreational anglers, high-intake fish consumers, benthic invertebrates, fish, birds, and riverine mammals. PCBs contribute more than 70 percent of the cancer risks found from the consumption of fish and waterfowl.

The risk assessment also derived sediment quality thresholds (SQTs) that were linked to estimated magnitudes of risk to valued receptors. SQTs were developed for over 100 pathways and receptors and arrayed to show the magnitude and protectiveness of potential risks. SQTs themselves are not cleanup criteria, but were used to evaluate levels of PCB risk and help develop FS action levels.

## Remedial Action Objectives

The FS reviewed multiple community, state, federal, and private documents to identify common expectations for the Fox River and Green Bay. From this review, five remedial action objectives were formulated. These objectives lay the foundation for remedial expectations for the FS and provide a metrics to measure long-term success. These objectives include:

1. Achieve surface water quality criteria, to the extent practicable;
2. Protect humans who consume aquatic organisms (i.e., remove consumption advisories);
3. Protect ecological receptors (i.e., healthy invertebrate, bird, fish, mammal populations);
4. Reduce transport of PCBs from the river into Green Bay and Lake Michigan; and

5. Minimize contaminant releases during remediation.

These objectives can be further defined into measurable metrics for evaluating long-term remedial success. These measurable expectations were defined by WDNR and EPA as the ability for recreational anglers to consume fish within 10 years following completion of a remedy and 30 years for high-intake fish consumers for human health (RAO 2).

Ecological expectations were defined by WDNR and EPA as the ability to achieve safe ecological thresholds for piscivorous birds and mammals. Although not a specific metric, the FS used 30 years following remedy completion (RAO 3). These expectations assumed several years of active remediation followed by 30 years of recovery, after which the endpoints are measured and compared to protective fish tissue levels.

Other metrics used to measure remedial success include the time to achieve state surface water criteria (RAO 1) and the time for PCB loading rates from the Lower Fox River into Green Bay to equal the combined loading estimates from other tributaries into Green Bay (10 kg/yr PCBs) (RAO 4). For relative comparison between different remedies and action levels, the FS used 30 years following remedy completion to achieve these goals.

## Array of Remedial Action Levels

The FS evaluated remedial alternatives, risks, duration, and costs relative to a series of potential sediment cleanup values. These values, termed "remedial action levels," were 125, 250, 500, 1,000, and 5,000 ppb PCBs. For all action levels, it was assumed that different levels of residual risk would remain after remediation. Natural processes would be relied upon to further decrease COC sediment concentrations to protective levels.

## Remedial Alternatives

Over 100 technologies were screened during the feasibility study. The remedial alternatives retained for detailed analysis included:

A. No action;

B. Monitored natural recovery (MNR);

C. Dredge and off-site disposal;

D. Dredge and on-site disposal (CDF);

E. Dredge and thermal treatment;

F. *In-situ* containment (capping); and

G. Dredge to confined aquatic disposal (CAD) site.

The alternatives were considered for each of the four river reaches and Green Bay zones (Table 1). All of the active remedies are designed to be completed in 10 years, in combination with natural recovery after remedy completion, with the degree of recovery dependent on the action level selected. Each of these remedial options categories is discussed below. However, final selection of a remedy will be governed by site-specific conditions and expectations.

**Monitored Natural Recovery.** Natural recovery refers to the processes by which COCs decline over time by biodegradation, dilution, or transport mechanisms. Institutional controls will remain in place to restrict site use until the system has recovered to protective thresholds. Natural recovery of sediments primarily occurs through three processes: burial; mixing and transport; or dechlorination/ biodegradation. The FS determined that all three of these processes occur in the Lower Fox River system, but the success of these processes is continually influenced by ongoing physical processes resulting in limited overall effectiveness in many areas. To evaluate a natural recovery option, it was assumed that the current systems of dams on the river would remain in perpetuity. A long-term monitoring program would be implemented to ensure that sediment, water, and fish tissue PCBs would decline over time.

**Table 1 Summary of Evaluated Remedial Alternatives by Reach and Zone**

| Alternative Description | Lower Fox River Reaches | | | | Green Bay Zones | | | |
|---|---|---|---|---|---|---|---|---|
| | Little Lake Butte des Morts | Appleton to Little Rapids | Little Rapids to De Pere | De Pere to Green Bay | Zone 2 | Zone 3A | Zone 3B | Zone 4 |
| A No Action | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| B Monitored Natural Recovery | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| C Dredge and Off-Site Disposal | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | |
| D Dredge to CDF | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | |
| E Dredge and Thermal Treat | ✔ | ✔ | ✔ | ✔ | | | | |
| F Cap | ✔ | | ✔ | ✔ | | | | |
| G Dredge to CAD | | | | | ✔ | ✔ | ✔ | |

**Removal (Dredging).** Removal involves excavation of site sediments using mechanical or hydraulic dredging techniques. Dredging is a common practice for managing impacted sediments but would require careful consideration of: dewatering methods, disposal options, physical obstructions, site access, staging areas, community disturbance, and potential release of contaminants to the environment during implementation. Removal of impacted sediments is a permanent solution and does not require long-term maintenance or access restrictions.

**Treatment.** The FS also evaluated treatment and non-treatment options. Retained treatment options included thermal, technologies such as desorption and vitrification, where the resulting product would have the potential for beneficial reuse.

**Disposal.** Disposal of dredged material can managed in three ways: permanent placement in upland, nearshore, and in-water facilities. It is generally expensive and requires intensive dewatering techniques to adequately prepare sediments for long-term disposal. Several on-site and off-site disposal options were retained in the FS including: nearshore fills, free-standing confined disposal facilities (CDFs), submerged aquatic disposal sites (CADs), and upland landfills where impacted sediments are placed in containment structures designed to isolate and contain contaminants over the long-term.

**Containment (Capping).** Containment involves the physical isolation and immobilization of chemicals in sediments. Capping is a common method for containing impacted sediments in-place. It would require long-term restrictions on site access and land use rights, in addition to long-term monitoring and maintenance to ensure integrity of the capping structure. The capping alternative would require careful consideration of site conditions, navigational channels, river currents, vessel propeller wash, water depths, and ice scour as well as other factors that may limit the installation and subsequent permanence of cap placement.

## Comparative Analysis

Each alternative was compared to the nine evaluation criteria defined above for each river reach and Green Bay zone. Risk reduction and overall protectiveness are discussed below. Implementablity and effectiveness were determined as feasible for each retained alternative based on availability, previous experience, and performance-based results. Reduction of toxicity, mobility, and volume is related to cost. Both are dependent on the action level selected. Thermal treatment is the only alternative that permanently reduces PCB volume and mass. Relative costs are discussed below, and community acceptance of the retained alternatives will be evaluated during public comment periods and outreach programs.

## Risk Reduction

The ability of the seven remedial alternatives to achieve the FS expectations were quantified by relative risk reduction over time using hydrodynamic and bioaccumulation models over a projected 100-year time frame. These models predicted the number of years required to reach protective thresholds for human health and the environment (e.g., number of years required to remove fish consumption advisories). The projected number of years required to consistently meet protective water quality, human health, ecological health, and PCB transport thresholds following remediation (the RAOs) were compared to different action levels and costs for each alternative. Results are presented on Figures 2 and 3. A comparative analysis of action levels that meet protective levels between the different river reaches is presented on Figures 4 and 5.

**Water Quality.** The state surface water quality criteria for protection of human health are not met for any combination of remedial scenario and action level in the river. Only the wildlife criteria (0.12 ng/L) is met in 16 years after remediation for the 125 ppb action level, increasing to 69 years for the 1,000 ppb action level.

**Human Health.** As shown on Figures 4 and 5, in order to remove recreational fish consumption advisories within 10 years following remediation (WDNR's expectation), remedies implemented to the 1,000 ppb PCB action level for surface sediments would be required for most of the river reaches. Action levels ranging from 250 ppb to 1,000 ppb would be required to remove high-intake consumer advisories within 30 years following remediation depending upon the specific reach of the river. For Green Bay, none of the remedies are projected to achieve the protective human health values. These model projections account for dynamic physical properties of the system including water velocity, water depth, currents, flooding, natural deposition, scour events, and storm events.

**Ecological Health.** To meet the protective ecological thresholds in the expected 30-year time frame following remedy completion, an estimated minimum action level of 1,000 ppb would be required in the Little Lake Butte de Morts and Appleton to Little Rapids reaches. A minimum action level of 250 ppb would be required in the Little Rapids to De Pere and De Pere to Green Bay reaches. The No Action alternative (passive remediation) would require greater than 100 years to meet protective ecological thresholds in the Lower Fox River (Figure 4). In Green Bay, none of the remedies will meet protective ecological thresholds in 100 years based on projected fish tissue concentrations, regardless of the action taken in the Lower Fox River (Figure 5).

**PCB Transport.** One of the long-term goals of the project is to reduce the transport and load of PCBs to Green Bay, and subsequent movement to Lake Michigan. The total annual average loading rates of PCBs to Green Bay from all tributaries combined (without the Fox River) is currently 10 kg/year PCBs. The Fox River fate and transport models were used to predict the number of years required to reduce the PCB loads from the Fox River into Green Bay over time after remedy completion. At the expected 30-year time frame following remedy completion, the projected loading rates from the Fox River were compared to the loading rates of all other Green Bay tributaries combined. These levels could be considered "background" levels.

Remedies to at least the 5,000 ppb action level would be required in the De Pere to Green Bay Reach to meet projected expectations. PCB load expectations for these two action levels would require 24 years to meet tributary levels. At the 1,000 ppb action level, the target level is achieved in 4 years following remediation. The model predications for PCB loading rates from the mouth of the Fox River (De Pere to Green Bay Reach) takes into consideration the cumulative PCB loads from the upper reaches; therefore, only the last reach was evaluated in the FS.

It is important to note there is uncertainty associated with these projected estimations of risk reduction and duration to meet protective thresholds. The model projections were calibrated over a finite time interval and projected out to 100 years based on the trends observed during the short calibration period. The projected risk reductions/durations cannot predict the actual number of years to reach protective thresholds with considerable precision. However, the strength of these models is the relative risk reduction estimates for comparing between different action levels and remedial alternatives. More information on the models may be found in the Lower Fox River and Green Bay Model Documentation Report.

## FS Costs

Total remediation costs were estimated for each remediation alternative and each PCB action level (±30 percent), as presented on Figures 2 and 3. In the Lower Fox River, the costs for active remediation (Alternatives C through F) range from approximately $38,300,000 to $769,100,000 per river reach (Table 2). In Green Bay, the costs for active remediation (Alternatives C, D, and G) range from approximately $11,000,000 to $1,155,100,000 (Table 3). Costs include land acquisition, mobilization, permits, facility construction, dredging and dewatering, disposal, materials, labor oversight, public outreach, site restoration efforts, operation and maintenance costs, in addition to long-term monitoring efforts for 30 years following remediation.

The cost for passive remediation, or monitored natural recovery (Alternative B), is approximately $9,900,000 per reach/zone over a 30-year period. MNR costs include maintenance of institutional controls along with sediment, surface water, bird and fish tissue sampling, and invertebrate sampling events conducted every 5 years for 30 years. Costs are calculated as net present worth costs.

The largest variability in costs are observed between different action levels. Remediation costs are directly proportional to sediment volumes; therefore, as the action level decreases (becomes more protective), the sediment volume requiring removal increases and the cost increases. For example, the cost to place an *in-situ* sand cap (Alternative F) in the Little Lake Butte des Morts Reach will cost approximately $145,200,000 at the 125 ppb action level but only $66,200,000 at the 5,000 ppb action level.

When comparing costs between different alternatives in the Lower Fox River, the active remedy costs are 3 to 78 times higher than the passive remedy costs. Among the active remedies, the Dredge and Treat Alternative is the least-cost remedy (ranging from a 3-fold to 40-fold increase over the MNR Alternative). The Capping Alternative and Dredge to CDF Alternative are generally the medium-cost remedies (ranging from a 4-fold to 60-fold increase over the MNR Alternative). The Dredge and Off-site Disposal Alternative is the highest-cost remedy (ranging from a 4-fold to 78-fold increase over the MNR Alternative). In Green Bay, the active remedy costs are similar when compared within a single action level.

## Further Information

Remedy selection for the Lower Fox River and Green Bay will be based on the information contained within the RI, RA and FS, as well as numerous opportunities for input by the public and interested parties. For further information regarding the Lower Fox River RI, FS, RA, or MDR documents, please contact:

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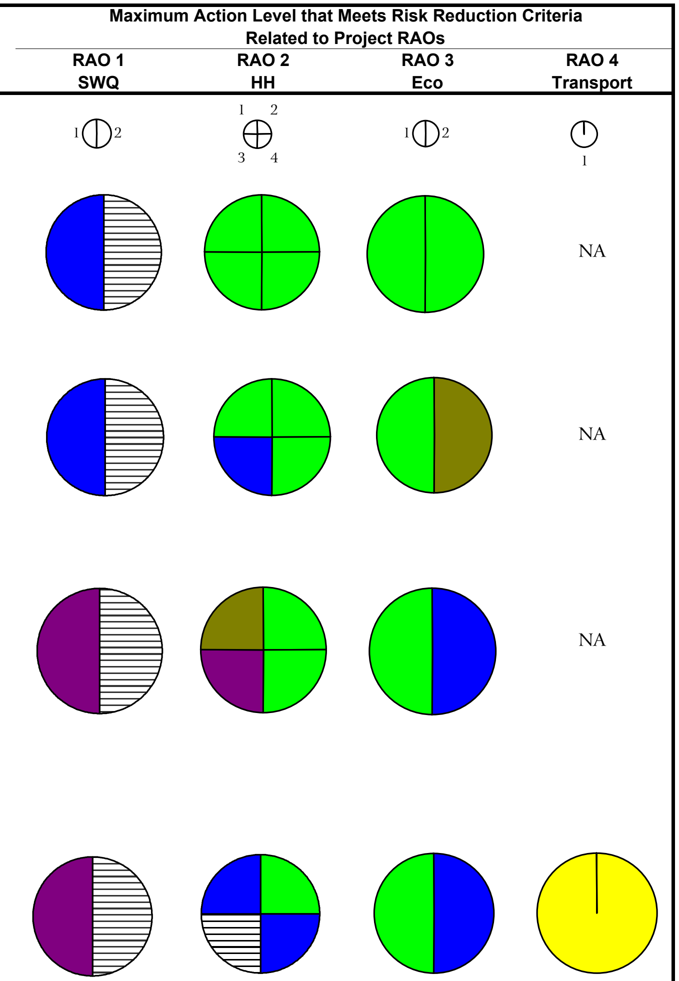
Wisconsin Department of Natural Resources
101 S. Webster Street
Box 7921
Madison, Wisconsin 53703

## Figure 2 Lower Fox River Summary of Remedial Action Levels and Projects Risk Reduction by Reach

| Lower Fox River Reaches | Remediation Alternative | PCB Action Level (ppb) 125 | 250 | 500 | 1,000 | 5,000 |
|---|---|---|---|---|---|---|
| Little Lake Butte des Morts | Impacted Volume (cy) | 1,689,173 | 1,322,818 | 1,023,621 | 784,192 | 281,689 |
| | PCB Mass (kg) | 1,838 | 1,814 | 1,782 | 1,715 | 1,329 |
| | Remedial Cost (in 1,000s $) | | | | | |
| | A/B: No Action | $9,900 | $9,900 | $9,900 | $9,900 | $9,900 |
| | C1: Dredge, Off-site Disp. (Pass. Dewater) | $231,500 | $185,600 | $147,800 | $116,700 | $48,500 |
| | C2: Dredge, Off-site Disp. (Mech. Dewater) | $126,200 | $102,500 | $82,800 | $66,200 | $28,300 |
| | D: Dredge to CDF, Off-site TSCA Disp. | $116,000 | $110,300 | $105,100 | $68,000 | $54,500 |
| | E: Dredge and Thermal Treatment | $117,200 | $96,000 | $78,500 | $63,600 | $29,300 |
| | F: Cap and Dredge to CDF | $145,200 | $138,600 | $99,300 | $90,500 | $66,200 |
| Appleton to Little Rapids | Impacted Volume (cy) | 182,450 | 80,611 | 56,998 | 46,178 | 20,148 |
| | PCB Mass (kg) | 106 | 99 | 95 | 92 | 67 |
| | Remedial Cost (in 1,000s $) | | | | | |
| | A/B: No Action | $9,900 | $9,900 | $9,900 | $9,900 | $9,900 |
| | C: Dredge, Off-site Disp. | $38,300 | $25,000 | $21,700 | $20,100 | $16,500 |
| | E: Dredge and Thermal Treatment | $26,200 | $19,700 | $17,900 | $17,100 | $15,200 |
| Little Rapids to De Pere | Impacted Volume (cy) | 1,483,156 | 1,171,585 | 776,791 | 586,788 | 186,348 |
| | PCB Mass (kg) | 1,210 | 1,192 | 1,157 | 1,111 | 798 |
| | Remedial Cost (in 1,000s $) | | | | | |
| | A/B: No Action | $9,900 | $9,900 | $9,900 | $9,900 | $9,900 |
| | C1: Dredge to NR 500 Facility (Pass. Dewater) | $224,200 | $180,700 | $124,200 | $95,100 | $38,100 |
| | C2A: Dredge to Comb. Dewater/Disp. Facility | $72,300 | $63,200 | $51,400 | $43,900 | $32,400 |
| | C2B: Dredge to Sep. Dewater/Disp. Facilities | $179,800 | $152,800 | $118,300 | $99,900 | $65,300 |
| | C3: Dredge to NR 500 Facility (Mech. Dewater) | $161,700 | $130,800 | $90,300 | $69,100 | $28,400 |
| | D: Dredge to CDF, Off-site TSCA Disp. | $72,300 | $66,800 | $58,400 | $52,500 | $44,400 |
| | E: Dredge and Thermal Treatment | $142,700 | $123,800 | $99,500 | $86,200 | $61,900 |
| | F: Cap and Dredge to CDF | $143,700 | $114,300 | $87,800 | $62,900 | $34,700 |
| De Pere to Green Bay | Impacted Volume (cy) | 6,868,500 | 6,449,065 | 6,169,458 | 5,879,529 | 4,517,391 |
| | TSCA Volume (cy) | 240,778 | 240,778 | 240,778 | 240,778 | 240,778 |
| | PCB Mass (kg) | 26,620 | 26,581 | 26,528 | 26,433 | 24,950 |
| | Remedial Cost (in 1,000s $) | | | | | |
| | A/B: No Action | $9,900 | $9,900 | $9,900 | $9,900 | $9,900 |
| | C1: Dredge to NR 500 Facility (Pass. Dewater) | $769,100 | $723,100 | $692,300 | $660,600 | $511,100 |
| | C2A: Dredge to Comb. Dewater/Disp. Facility | $196,000 | $186,900 | $180,400 | $173,500 | $138,700 |
| | C2B: Dredge to Sep. Dewater/Disp. Facilities | $564,500 | $534,100 | $513,500 | $491,800 | $388,000 |
| | C3: Dredge to NR 500 Facility (Mech. Dewater) | $595,200 | $561,000 | $537,800 | $513,500 | $397,200 |
| | D: Dredge to CDF, Off-site TSCA Disp. | $611,800 | $566,400 | $536,200 | $505,100 | $360,700 |
| | E: Dredge and Thermal Treatment | $404,500 | $384,000 | $370,000 | $355,100 | $283,300 |
| | F: Cap and Dredge to CDF | $432,600 | $403,900 | $381,900 | $357,100 | $234,400 |




**Notes:**

Threshold criteria used to evaluate risk reduction:

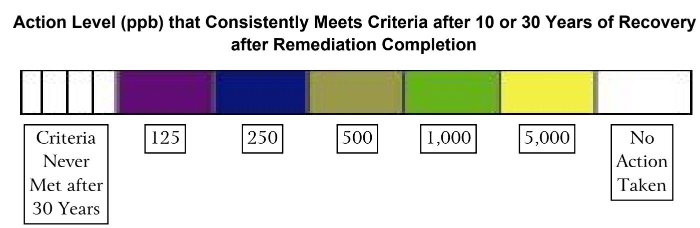
RAO 1: 1 = Wildlife Criteria 30-year, 2 = Human Surface Water Drinking Criteria 30-year.

RAO 2: 1 = High-intake Fish Consumer Cancer 30-year, 2 = High-intake Fish Consumer Noncancer 30-year, 3 = Recreational Angler Cancer 10-year, 4 = Recreational Angler Noncancer 10-year.

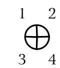
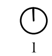
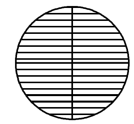
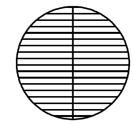
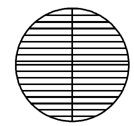
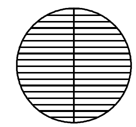
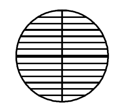
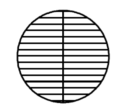
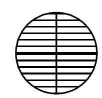
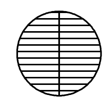
RAO 3: 1 = Carnivorous Bird Deformity NOAEC 30-year, 2 = Piscivorous Mammal NOAEC 30-year.

RAO 4: 1 = Tributary Load to Reach Green Bay Level 30-year.

NA - Not applicable.



## Figure 3 Green Bay Summary of Remedial Action Levels and Projected Risk Reduction by Zone

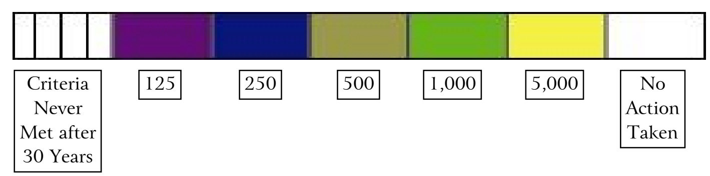
| Green Bay Zone | Remediation Alternative | Action Level (ppb) | | | | | Maximum Action Level that Meets Risk Reduction Criteria Related to Project RAOs | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 125 | 250 | 500 | 1,000 | 5,000 | RAO 1 SWQ | RAO 2 HH | RAO 3 Eco | RAO 4 Transport |
| | | | | | | |  |  |  |  |
| Green Bay | Impacted Volume (cy) | NE | NE | 29,748,004 | 29,322,254 | 4,070,170 | | | | |
| Zone 2 | PCB Mass (kg) | NE | NE | 29,896 | 29,768 | 6,113 | | | | |
| | Remedial Cost (in 1,000s $) | | | | | | | | | |
| | A/B: No Action | NA | NA | $9,900 | $9,900 | $9,900 | NE |  |  | NA |
| | C: Dredge, Off-site Disp. | NA | NA | NA | NA | $507,200 | | | | |
| | D: Dredge to CDF, Off-site TSCA Disp. | NA | NA | $824,700 | $814,100 | $166,500 | | | | |
| | G: Dredge to CAD | NA | NA | $707,400 | $697,800 | $124,000 | | | | |
| Green Bay | Impacted Volume (cy) | NE | NE | 16,328,102 | 14,410 | NE | | | | |
| Zone 3A | PCB Mass (kg) | NE | NE | 2,156 | 2 | NE | | | | |
| | Remedial Cost (in 1,000s $) | | | | | | | | | |
| | A/B: No Action | NA | NA | $9,900 | $9,900 | NA | NE |  |  | NA |
| | C: Dredge, Off-site Disp. | NA | NA | NA | $11,000 | NA | | | | |
| | D: Dredge to CDF, Off-site TSCA Disp. | NA | NA | $474,300 | NA | NA | | | | |
| | G: Dredge to CAD | NA | NA | $389,100 | NA | NA | | | | |
| Green Bay | Impacted Volume (cy) | NE | NE | 43,625,096 | NE | NE | | | | |
| Zone 3B | PCB Mass (kg) | NE | NE | 4,818 | NE | NE | | | | |
| | Remedial Cost (in 1,000s $) | | | | | | NE |  |  | NA |
| | A/B: No Action | NA | NA | $9,900 | NA | NA | | | | |
| | D: Dredge to CDF, Off-site TSCA Disp. | NA | NA | $1,155,100 | NA | NA | | | | |
| | G: Dredge to CAD | NA | NA | $1,010,900 | NA | NA | | | | |
| Green Bay | Impacted Volume (cy) | NE | NE | 0 | NE | NE | | | | |
| Zone 4 | PCB Mass (kg) | NE | NE | 0 | NE | NE | | | | |
| | Remedial Cost (in 1,000s $) | | | | | | NE |  |  | NA |
| | A/B: No Action | NA | NA | $9,900 | NA | NA | | | | |

**Notes:**

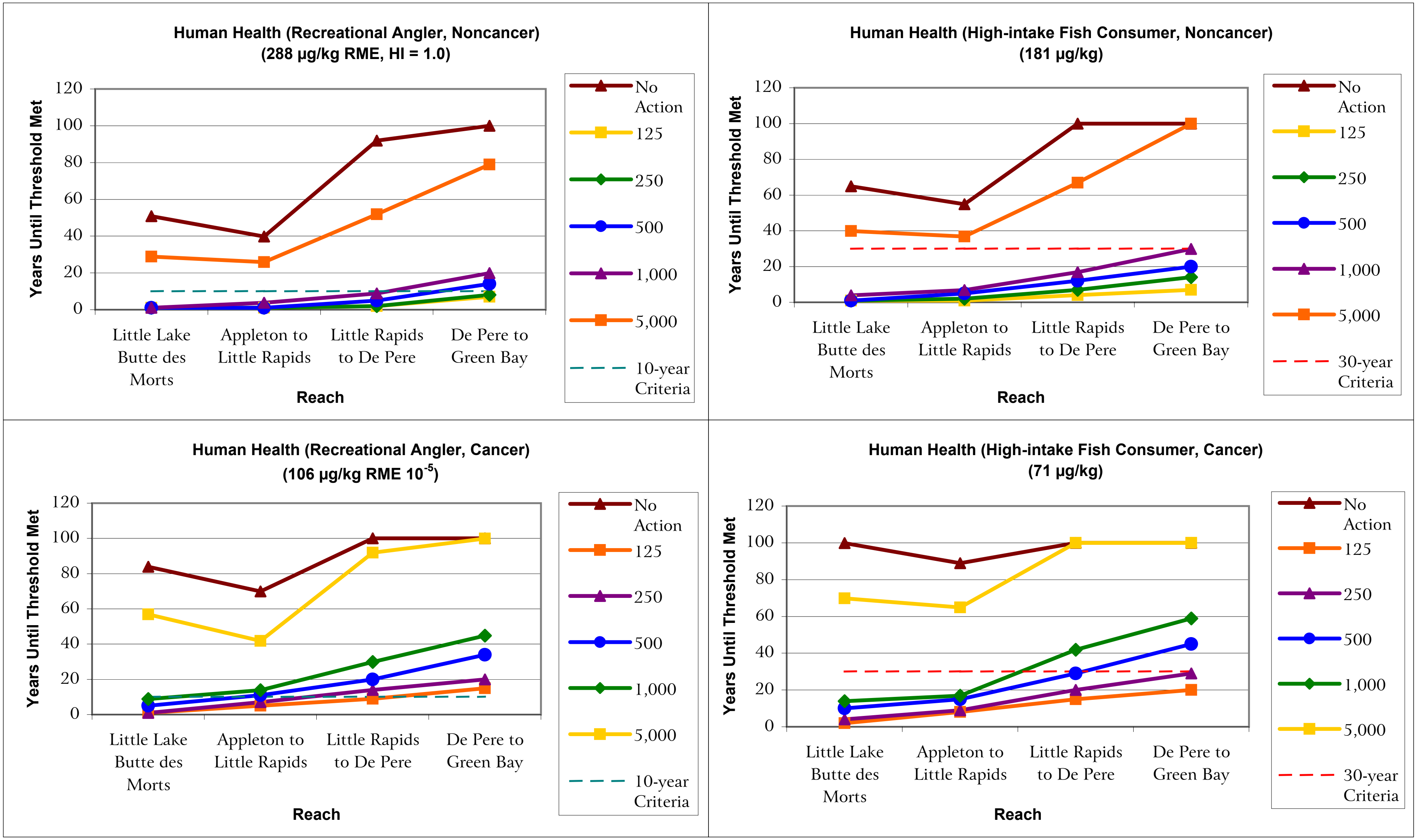
Threshold criteria used to evaluate risk reduction:

RAO 1: 1 = Wildlife Criteria 30-year, 2 = Human Surface Water Drinking Criteria 30-year.
RAO 2: 1 = High-intake Fish Consumer Cancer 30-year, 2 = High-intake Fish Consumer Noncancer 30-year, 3 = Recreational Angler Cancer 10-year, 4 = Recreational Angler Noncancer 10-year.
RAO 3: 1 = Carnivorous Bird Deformity NOAEC 30-year, 2 = Piscivorous Mammal NOAEC 30-year.
RAO 4: 1 = Tributary Load to Reach Green Bay Level 30-year.
NA - Not applicable.
NE - Not evaluated.

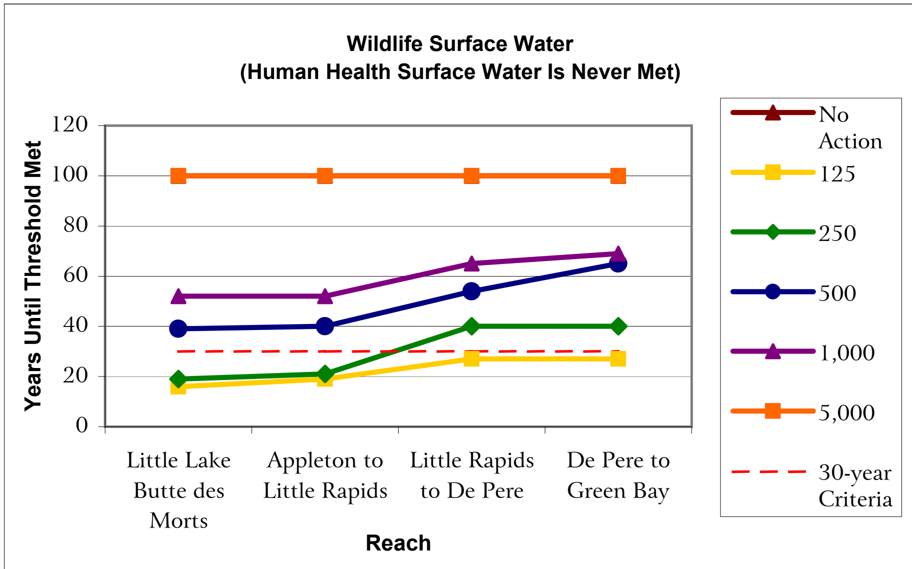
**Action Level (ppb) that Consistently Meets Criteria after 10 or 30 Years of Recovery after Remediation Completion**

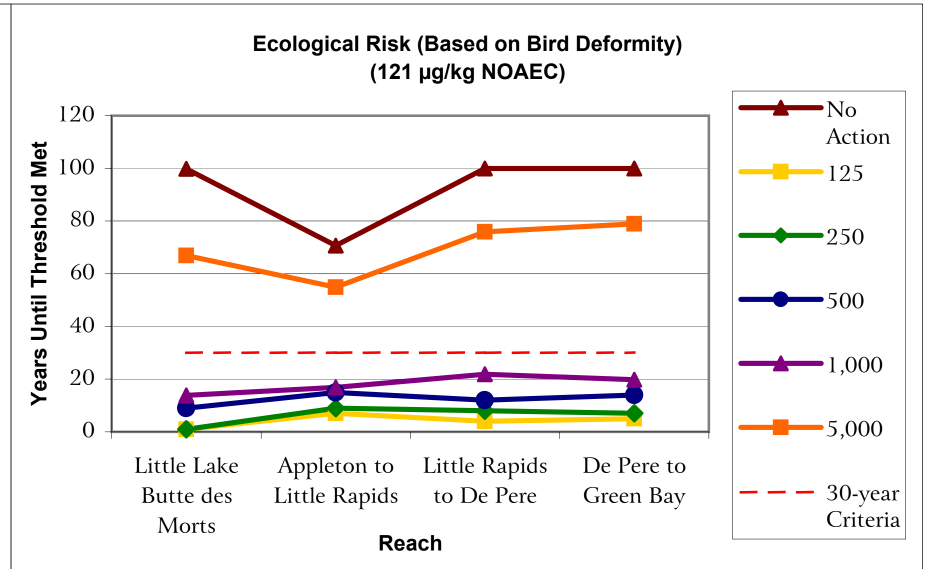


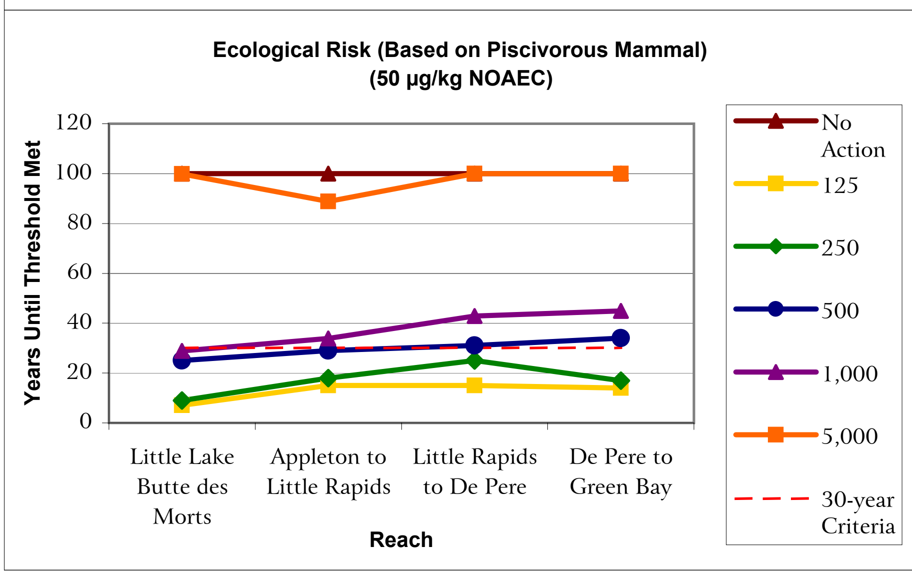
## Figure 4 Comparison of Human Health Protectiveness - All Reaches



## Figure 5 Comparison of Protection - All Reaches




**RAO 4 not evaluated in Fox River reaches.**

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# List of Acronyms

| | |
|---|---|
| 2,3,7,8-TCDD | 2,3,7,8-tetrachlorodibenzo-*p*-dioxin |
| 2,3,7,8-TCDF | 2,3,7,8-tetrachlorodibenzo-*p*-furan |
| ˚C | degrees centigrade |
| ˚F | degrees Fahrenheit |
| $\mu$g/kg | micrograms per kilogram |
| $\mu$g/L | micrograms per liter |
| AOC | Area of Concern |
| APEG | potassium polyethylene glycol |
| ARAR | Applicable or Relevant and Appropriate Requirement |
| ARCS | Assessment and Remediation of Contaminated Sediments |
| ASRA | Alternative-specific Risk Assessment |
| ATP | anaerobic thermal processor |
| AVM | acoustic velocity meter |
| BBL | Blasland, Bouck, and Lee |
| BCD | base catalyzed decomposition |
| Be-7 | beryllium-7 |
| BLRA | Baseline Human Health and Ecological Risk Assessment |
| BOD | SMU 56/57 Basis of Design Report |
| CAD | confined aquatic disposal |
| CAMP | Comprehensive Analysis of Mitigation Pathways |
| CDF | confined disposal facility |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act of 1980 (Superfund Statute) |
| cf | cubic feet |
| CFR | Code of Federal Regulations |
| cfs | cubic feet per second |
| CH | highly plastic clay |
| cm | centimeter |
| cm/s | centimeters per second |
| cm/yr | centimeters per year |
| COC | chemical of concern |
| COPC | chemical of potential concern |
| Cs-137 | cesium 137 |
| CTE | central tendency exposure |
| CTF | confined treatment facility |
| CWA | Clean Water Act |
| cy | cubic yard |
| cy/hr | cubic yards per hour |
| DAMOS | Disposal Area Monitoring System |

# List of Acronyms

| | |
|---|---|
| DDD | 4,4'-dichlorodiphenyl dichloroethane (includes isomers o,p'-DDD and p,p'-DDD) |
| DDE | 4,4'-dichlorodiphenyl dichloroethylene (includes isomers o,p'-DDE and p,p'-DDE) |
| DDT | 4,4'-dichlorodiphenyl trichloroethylene (includes isomers o,p'-DDT and p,p'-DDT) |
| DGPS | differential global positioning system |
| DM | data management |
| DO | dissolved oxygen |
| DOD | United States Department of Defense |
| DOER | Dredging Operations and Environmental Research Program |
| DRE | destruction removal efficiency |
| EPA | United States Environmental Protection Agency |
| ESRI | Environmental Systems Research Institute |
| EWI | EWI Engineering Associated, Inc. |
| FEMA | Federal Emergency Management Agency |
| FRDB | Fox River Database |
| FRFood | Lower Fox River Food Web Model |
| FRG | Fox River Group |
| FRM | Fox River Model |
| FS | Feasibility Study |
| ft | foot or feet |
| $ft^2$ | square feet |
| $ft^3$ | cubic feet |
| ft/ft | feet per foot |
| ft/s | feet per second |
| g | gram |
| g/cc | grams per cubic centimeter |
| GAC | granular activated carbon |
| GAS | Graef, Anhalt, Schloemer and Associates, Inc. |
| GBFood | Green Bay Food Web Model |
| GBHYDRO | Green Bay Hydrodynamics Model |
| GBMBS | Green Bay Mass Balance Study |
| GBSED | Green Bay Sediment Transport Model |
| GBTOX | Green Bay Toxics Model |
| GBTOXe | Enhanced Green Bay Toxics Model |
| $g/cm^3$ | grams per cubic centimeter |
| GLNPO | Great Lakes National Program Office (EPA) |
| GLSFA | Great Lakes Sport Fish Advisory Task Force |

# List of Acronyms

| | |
|---|---|
| GLWQI | Great Lakes Water Quality Initiative |
| GM | General Motors |
| gpm | gallons per minute |
| GRA | general response action |
| HAZMAT | hazardous materials |
| HDPE | high-density polyethylene |
| HI | hazard index |
| HQ | hazard quotient |
| HTTD | high-temperature thermal desorption |
| IDA | inter-deposit area |
| IGLD | International Great Lakes Datum |
| IJC | International Joint Commission |
| $K_d$ | log soil/water partition coefficient |
| kg | kilogram |
| kg/yr | kilograms per year |
| km | kilometer |
| $km^2$ | square kilometer |
| $K_{oc}$ | organic carbon partitioning coefficient |
| $K_{ow}$ | octanol water partitioning coefficient |
| L | liter |
| LCL | Lower Confidence Limit |
| LFR | Lower Fox River |
| LLBdM | Little Lake Butte des Morts |
| LOAEC | Lowest Observed Adverse Effect Concentration |
| LTA | long-term average |
| LTMP | Long-term Monitoring Plan |
| m | meter |
| $m^2$ | square meter |
| $m^3$ | cubic meter |
| m/s | meters per second |
| $m^3/s$ | cubic meters per second |
| $mg/cm^2$ | milligrams per square centimeter |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| MH | high-compressibility silt |
| $mi^2$ | square mile |
| m/km | meters per kilometer |
| MNR | monitored natural recovery |
| Mpa | mega Pascal |

# List of Acronyms

| | |
|---|---|
| MSL | mean sea level |
| MT | metric tons |
| MT/yr | metric tons per year |
| NAAQS | National Primary and Secondary Ambient Air Quality Standards |
| NAS | National Academy of Sciences |
| NCP | National Contingency Plan |
| NESHAPS | National Emissions Standards for Hazardous Air Pollutants |
| ng/kg | nanograms per kilogram |
| ng/L | nanograms per liter |
| NGVD29 | National Geodetic Vertical Datum 1929 |
| NOAA | National Oceanic and Atmospheric Administration |
| NOAEC | No Observed Adverse Effect Concentration |
| NPDES | National Pollutant Discharge Elimination System |
| NR | Natural Recovery |
| NRC | National Research Council |
| NRDA | Natural Resources Damage Estimate |
| O&M | operation and maintenance |
| OBAI | Ogden-Beeman and Associates |
| OSHA | Occupational Safety and Health Administration |
| PAH | polynuclear aromatic hydrocarbon |
| PCB | polychlorinated biphenyl |
| PCDD | dibenzo-*p*-dioxin |
| PCH | planar chlorinated hydrocarbon |
| PCP | pentachlorophenol |
| POTW | publicly-owned treatment works |
| PPE | personal protective equipment |
| ppb | parts per billion |
| ppm | parts per million |
| ppt | parts per trillion |
| PRP | potentially responsible party |
| psi | pounds per square inch |
| PSNS | Puget Sound Naval Shipyard |
| $Q_{7,10}$ | 7-day average low stream flow with a 10-year frequency |
| RA | Risk Assessment |
| RAO | Remedial Action Objective |
| RBFC | risk-based fish concentration |
| RCRA | Resource Conservation and Recovery Act |
| RETEC | Remediation Technologies, Inc. |
| RI | Remedial Investigation |

# List of Acronyms

| | |
|---|---|
| RI/FS | Remedial Investigation and Feasibility Study |
| RME | reasonable maximum exposure |
| ROD | Record of Decision |
| rpm | revolutions per minute |
| SCS | Soil Conservation Service |
| SEDTEC | Sediment Technologies CD-ROM by Environment Canada |
| SFV | stream flow velocity |
| SITE | Superfund Innovative Technology Evaluation |
| SLRA | Screening Level Risk Assessment |
| SMU | Sediment Management Unit |
| SQT | sediment quality threshold |
| SRD | sediment remediation demonstration |
| SVE | soil vapor extraction |
| SVOC | semivolatile organic compound |
| SWAC | surface-weighted average concentration |
| TBC | information "to be considered" |
| TEL | threshold effect concentration |
| TEQ | toxic equivalency factor |
| TMDL | total maximum daily loads |
| TOC | total organic carbon |
| TSCA | Toxic Substances Control Act |
| TSS | total suspended solids |
| TWA | time-weighted average |
| UCL | Upper Confidence Limit |
| UFR | Upper Fox River |
| UFR/LFR | Upper Fox River/Lower Fox River Sediment Transport Model |
| UP | Michigan's Upper Peninsula |
| U.S. | United States of America |
| USACE | United States Army Corps of Engineers |
| U.S.C. | United States Code |
| U.S.C.A. | United States Code, Amended |
| USCS | Unified Soil Classification System |
| USFWS | United States Fish and Wildlife Service |
| USGS | United States Geological Survey |
| UV | ultraviolet |
| VOC | volatile organic compound |
| v/v | volume per volume |
| WAC | Wisconsin Administrative Code |
| WASP4 | Water Quality Analysis Simulation Program Version 4 |

# List of Acronyms

| | |
|---|---|
| WDNR | Wisconsin Department of Natural Resources |
| wLFR | whole Lower Fox River |
| wLFRM | Whole Lower Fox River Fate and Transport Model |
| WPDES | Wisconsin Pollutant Discharge Elimination System |
| WQC | water quality criteria |
| WSEV | Window Subsampling Empirical Variance |
| w/w | weight per weight |
| WY | water year |
| yr | year |

# 1 Introduction

This Feasibility Study Report (FS) develops and evaluates a range of remedial alternatives for contaminated sediments in the Lower Fox River and Green Bay (Wisconsin). The FS Report was prepared by The RETEC Group, Inc. (formerly known as ThermoRetec Consulting Corporation [ThermoRetec]), on behalf of the Wisconsin Department of Natural Resources (WDNR). WDNR directed the project and received both funding and technical assistance from the United States Environmental Protection Agency (EPA) Region 5.

The FS completes the remedial investigation and feasibility study (RI/FS) program for the Lower Fox River and Green Bay Superfund site in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP). Preparation of the FS conformed to procedures outlined in the EPA guidance document: *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA RI/FS Guidance) (EPA, 1988). This RI/FS report is consistent with the findings of the National Academy of Sciences National Research Council report entitled *A Risk Management Strategy for PCB-Contaminated Sediments* (NRC, 2001).

This FS develops remedial alternatives exclusively for the cleanup of contaminated sediments in the Lower Fox River and Green Bay for the long-term protection of human health and the environment. The following major components of the RI/FS program supported preparation of the FS:

- **Data Management (DM).** DM involved the development of a usable database produced through the identification, acquisition, review (validation), catalog, classification and archive of known available data sources (electronic and hard copy) pertinent to the Lower Fox River/Green Bay Risk Assessment (RA) and RI/FS. Usable data includes water, sediment, and fish tissue chemistry data. DM procedures and results are provided in the *Data Management Summary Report* prepared by EcoChem, Inc. under subcontract to ThermoRetec (EcoChem, 2000).

- **Remedial Investigation (RI).** The RI provided a compilation, review, and organization of physical, chemical and biological characteristics of the Lower Fox River and Green Bay. These characteristics provide the framework for a site conceptual model describing the magnitude and extent of chemicals of concern (COCs) in both sediment and water, and in the valued biological resources within the Lower Fox River and Green

Bay. Relevant physical and chemical characteristics of the Lower Fox River and Green Bay such as geology, surface water hydrology, sedimentation, chemical distribution, and fish/bird habitats are presented in the *Remedial Investigation for the Lower Fox River* (RI Report) (RETEC, 2002a). A summary of the RI is presented in Section 2 of this FS Report.

- **Risk Assessment (RA).** The RA involved the identification of COCs and risk-based sediment cleanup goals based upon realistic assessments of potential risks to ecological and human receptors. The RA provides an assessment of risks to human health and the environment that will support selection of a remedy to eliminate, reduce, or control those risks. The RA is presented in two documents: *Screening Level Human Health and Ecological Risk Assessment* (SLRA) (RETEC, 1998) and *Baseline Human Health and Ecological Risk Assessment* (BLRA) (RETEC, 2002b). A summary of the RA is presented in Section 3 of this FS Report.

- **Model Documentation Report (MDR).** The MDR compiled the fate and transport and bioaccumulation models used to estimate and forecast the movement of contaminated PCB sediment in the Lower Fox River and Green Bay. This report provides a "concise" compilation of the models used in the RI/FS including the Whole Lower Fox River Fate and Transport Model (wLFRM) developed by WDNR, the Lower Fox River Food Web Model (FRFood) developed by ThermoRetec, the Enhanced Green Bay Toxics Model (GBTOXe) developed by HydroQual, and the Green Bay Food Web Model (GBFood) developed by QEA. These models were used to predict long-term risk reduction in surface water and fish tissue levels over time after remedy completion.

## 1.1 Site Description

The project study area includes the Lower Fox River and Green Bay aquatic systems. The Lower Fox River is located in northeastern Wisconsin within the eastern ridges and lowlands of the state. The Lower Fox River is defined as the 39-mile portion of the Fox River, beginning at the outlet of Lake Winnebago and terminating at the mouth of the river into Green Bay, Lake Michigan (Figure 1-1). The river flows north and drains approximately 6,330 square miles, making it a primary tributary to Green Bay and a part of the Great Lakes system. Green Bay is a freshwater system approximately 120 miles long which drains into Lake Michigan (Figure 1-2), and is located on the state border between Wisconsin and Michigan along a northeast- to southwest-trending axis.

Historic discharges from municipal, industrial, and agricultural sources in the Lower Fox River region have degraded sediment and water quality and adversely impacted the ecology of the river and bay. The SLRA identified a list of chemicals of potential concern (COPCs) which included: polychlorinated biphenyls (PCBs) (total and Aroclors), dioxins/furans, 4,4'-dichlorodiphenyl trichloroethylene (DDT) and its metabolites, dieldrin, and several metals (arsenic, lead, and mercury). The BLRA concluded that the chemicals of concern (PCBs, mercury, DDE) represented the potential risks to human health and ecological receptors.

PCBs in the Lower Fox River pose the major potential threat to human health and ecological receptors due to their tendency to sorb to sediments, persist in the environment, and bioaccumulate in aquatic organisms. Contaminated sediments acting as “sinks” for PCBs and other contaminants are also subject to physical and chemical processes that affect the overlying water column and adjoining water bodies in natural (uncontrolled) environments. For example, PCBs from sediment in the Lower Fox River are discharged into Green Bay at the mouth of the river through sediment transport and PCB dissolution in the water column. The RA and RI should be referred to for a complete description of human and ecological impacts as well as the fate and transport of PCBs and other COCs, respectively.

## 1.2 Feasibility Study Process

The FS develops and evaluates a range of remedial alternatives for the Lower Fox River and Green Bay. This analysis provides the basis for selection of an appropriate cleanup remedy that meets site-specific remedial action objectives. While this is a state-lead (WDNR) effort, the overall assessment follows the procedures and paradigms developed as part of CERCLA and the NCP. The primary steps of the FS process include:

- Establishment of remedial action objectives (RAOs),
- Identification and screening of general response actions (GRAs) and remedial technologies that address the GRAs, and
- Development and detailed analysis of remedial alternatives.

Figure 1-3 illustrates how each section of this FS Report relates to fundamental steps of the FS process. By following EPA RI/FS guidance, a list of potential remedial alternatives for the Lower Fox River and Green Bay was developed and evaluated. The remedial alternatives provide the basis for the development of a Record of Decision (ROD). The following subsections describe the organization and contents of this FS Report.

### 1.2.1 Summary of the Remedial Investigation - Section 2

Section 2 summarizes the RI Report in terms of the hydrological, physical, chemical, and biological characteristics of the river. The summary describes the following elements of the river system that are pertinent to the FS process:

- **Environmental Setting:** a chronology of major developments and regulatory actions in the Lower Fox River region that have impacted the quality of the river and the river/bay ecosystem;

- **Physical Characteristics:** a detailed description of the four reaches comprising the Lower Fox River and the four zones of Green Bay;

- **Soft Sediment Thickness:** a summary of soft sediment thicknesses and distribution in the Lower Fox River and Green Bay;

- **Nature and Extent of Contaminants of Concern:** a summary of sediment chemical concentrations and vertical distributions across the four reaches and four zones;

- **Fate and Transport:** a generalized description of the processes by which chemical compounds are transported from their source(s) to potential human and environmental receptors; and

- **Time Trends:** a description of statistical changes in PCB concentrations in sediments, birds, and fish in both the river and bay over time.

### 1.2.2 Summary of the Baseline Human Health and Ecological Risk Assessment - Section 3

Section 3 summarizes the assessment of potential risks to ecological and human receptors that live, feed, and recreate in the Lower Fox River and Green Bay. Results of the risk assessment provide the basis for setting risk-based sediment cleanup goals and determining an appropriate remedial alternative that will eliminate, reduce, or control those risks. The summary describes the following elements of the RA that are pertinent to the FS process:

- **Overview of the Risk Assessment:** a description of potential risks associated with the Lower Fox River and the primary components (i.e., COPCs, sediment quality thresholds [SQTs], etc.) that are identified as part of the process;

- **Human Health Risk Assessment:** a brief discussion of the general methodology used for assessing potential risks posed to human health, including a summary of the results;

- **Ecological Risk Assessment:** a description of the general methodology used for assessing potential risks posed to ecological receptors, including a summary of the results; and

- **Sediment Quality Thresholds:** a summary of the assumptions and methods used to develop an array of SQTs with varying degrees of protectiveness to human health and the environment.

Sections 2 and 3 precede Sections 4 through 10 in this FS Report since they were integral to the direction of the FS process described in the following subsections.

### 1.2.3 Development of Remedial Action Objectives and General Response Actions - Section 4

The first step in the FS process involves establishing RAOs by integrating data from three key sources: site characteristics, human health and ecological risk, and applicable or relevant and appropriate requirements (ARARs).

Section 4 presents the RAOs and discusses the basis for establishing the RAOs for the Lower Fox River and Green Bay. This section also lists the ARARs and information that is "to be considered" (TBC) that constitute the regulatory/ guidance body for the project.

The GRAs selected to address the RAOs were developed from eight primary remediation strategy categories:

- No Action,
- Institutional Controls,
- Monitored Natural Recovery,
- Containment,
- Removal,
- *In-situ* Treatment,
- *Ex-situ* Treatment, and
- Disposal.

These GRAs were used to identify and screen appropriate action levels in Section 5 and remedial technologies in Section 6.

### 1.2.4 Development of PCB Action Levels for the Lower Fox River and Green Bay - Section 5

Prior to the development of remedial alternatives, the extent (volumes and areas) of contaminated sediments are identified, to which the GRAs apply. This task was accomplished by identifying areas of contaminated sediment based on analytical data and modeling. Action levels were used to define volumes and potential areas for remediation. These action levels, coupled with monitored natural recovery processes, will be used to determine the relative time frame expected for attainment of the project RAOs and residual SQT concentrations.

Section 5 identifies volumes and areas of impacted sediment and defines the extent of contaminated sediments to be addressed in the remedial alternatives.

### 1.2.5 Identification and Screening of Technologies - Section 6

A master list of remedial technology types and process options applicable to remediation of the Lower Fox River and Green Bay sediments was compiled for each GRA. An initial screening was performed to determine which technology types and process options were technically practicable and implementable. A second and final screening was performed to evaluate the various process options representing technology types that were retained from the initial screening. These were evaluated based on effectiveness, cost, and administrative (i.e., permitting issues, equipment availability, etc.) implementability.

Section 6 presents a description of the screening process and results of the screening. Additional criteria and other considerations that influence the development and analysis of remedial alternatives for the Lower Fox River and Green Bay are also presented in Section 6.

### 1.2.6 Reach-specific Remedial Alternatives - Section 7

Technology types and process options that were retained after completion of the screening were combined to develop remedial alternatives for each of the four river reaches and four Green Bay zones. A range of alternatives was developed as follows:

- No action as a baseline to which other remedial options are compared.

- Monitored natural recovery in which sediments will attenuate over time without active remediation. Provide institutional controls until remedial action objectives are met.

- Contain the COCs in place to reduce and/or eliminate exposure to human and ecological receptors.

- Remove and treat contaminated sediments to reduce the risk of human and ecological exposure to COCs.

- Remove and contain contaminated sediments within an on-site or off-site disposal facility to reduce risk to human and ecological receptors and minimize long-term management.

Section 7 presents potential remedial alternatives for the four river reaches and four zones of Green Bay. Section 7 also provides a discussion of the basis for development of the remedial alternatives, considerations for implementation of the different process options incorporated into each remedial alternative, and costs associated with implementation of each remedial alternative.

### 1.2.7 Alternative-specific Risk Assessment - Section 8

The reach-specific remedial alternatives are further evaluated in terms of risk reduction and residual risks. This evaluation identifies residual ecological or human health risks based on estimates of the effective reduction of the concentrations of COCs in the Lower Fox River and Green Bay attributable to a selected alternative.

Section 8 presents the alternative-specific risk assessment. This evaluation is intended to support a risk-based remedial alternative selection for the Lower Fox River and Green Bay. An alternative-specific risk assessment provides further comparative data on each remedial alternative that can be used as an additional decision-making tool in the ROD.

### 1.2.8 Detailed Analysis of Remedial Alternatives - Section 9

Each of the remedial alternatives was evaluated using criteria specified in the EPA RI/FS guidance. The criteria are divided into three categories as follows:

- Threshold Criteria
  - Overall Protection of Human Health
  - Compliance with ARARs

- Balancing Criteria
  - Long-term Effectiveness and Permanence
  - Reduction of Toxicity, Mobility, and Volume Through Treatment
  - Short-term Effectiveness

  - Implementability
  - Cost

- Regulatory/Community Criteria
  - State Acceptance
  - Community Acceptance

The regulatory/community criteria are typically addressed in the ROD and will be considered in the FS process during review by WDNR. WDNR will hold public meetings during the public comment period and will solicit comments on the contents of the RI and FS reports.

Section 9 presents a detailed analysis of each remedial alternative developed for the four reaches and four zones.

### 1.2.9 Comparative Analysis of Alternatives - Section 10

A comparative analysis focused on synthesizing the detailed analysis of Section 9 into a readily accessible decision-making tool will be performed in Section 10. This comparison is in contrast with the detailed analysis conducted in Section 9 in which each alternative is analyzed independently without a consideration of other alternatives. The purpose of the comparative analysis is to identify the advantages and disadvantages of each alternative relative to one another, so that the key tradeoffs the decision-maker must weigh can be identified. To accomplish this, numerical measures are used to evaluate how each alternative compares relative to all others with respect to addressing each of the following questions:

- What is the residual human health risk after implementation of an alternative?

- What is the residual ecological risk after implementation of an alternative?

- What is the level of disruption to local communities associated with the construction of each alternative?

- What is the administrative effort necessary to implement each alternative?

- What is the volume of contaminated sediment removed from the Lower Fox River and Green Bay?

- What is the cost of implementing each alternative?
- What is the incremental cost of reducing risk for each alternative?

Section 10 presents a synoptic comparison of the predicted performance of each of the reach-specific alternatives in relation to specific decision-making evaluation criteria.

### 1.2.10 References - Section 11

This section is a compilation of references cited in the FS. These references will be included in the administrative record for the project.

## 1.3 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 concluded that PCBs in sediment pose a chronic risk to human health and the environment, and that these risks must be managed. The NRC recommended that remedies 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 United States Environmental Protection Agency (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 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (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 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* 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:

- Using EPA risk assessment frameworks (EPA, 1989b for human health risk; 1997 and 1998b for ecological risk) that were based on the framework developed by NRC in 1983 which recommended a tiered and iterative approach;

- Using an extensive body of site-specific scientific information and data to bound the problem;

- Defining the problem in a site-specific manner through review of all existing scientific information in a preliminary assessment;

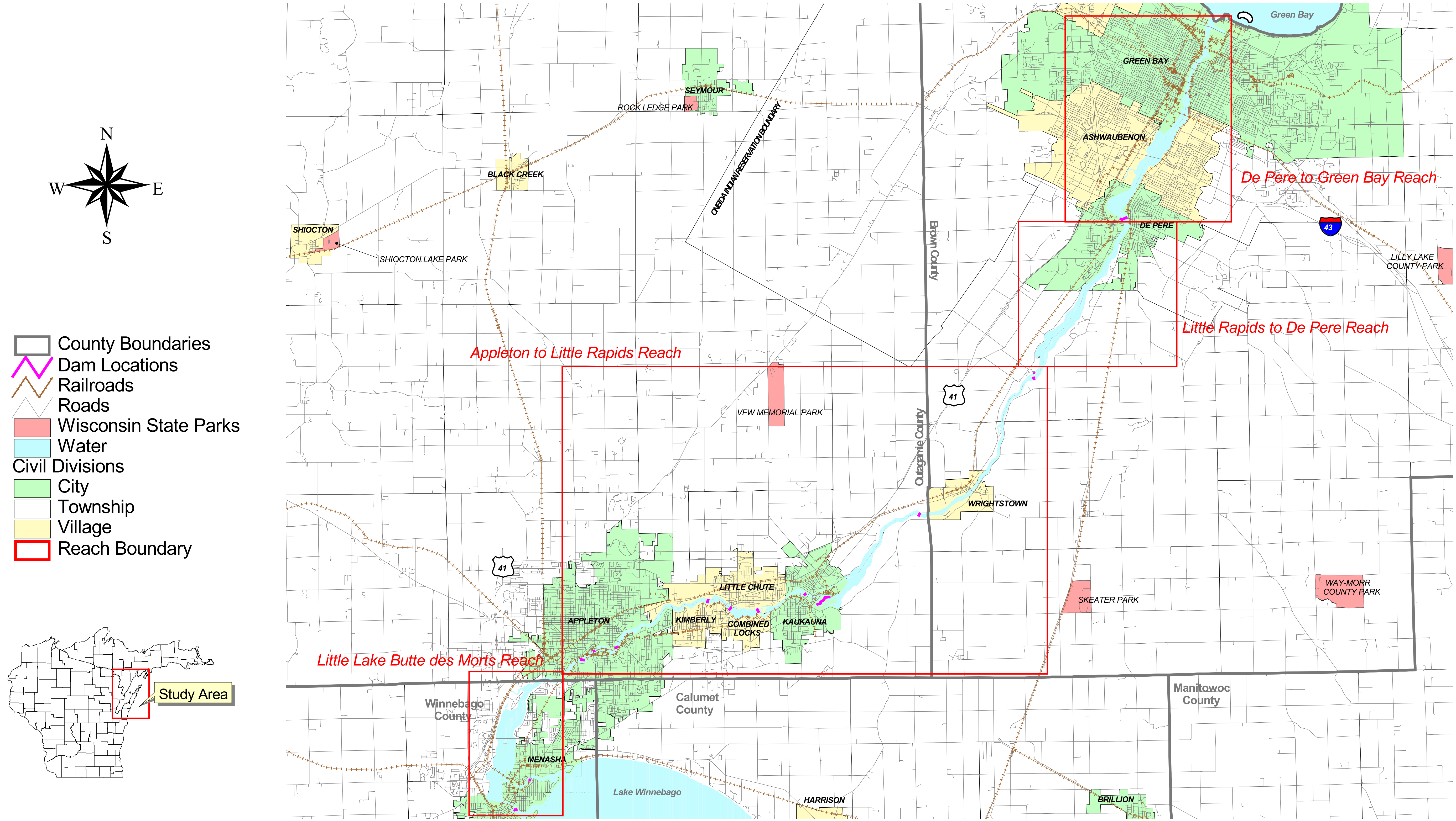
- Calibrating and defining the uncertainty of models that were used in the assessment; and by

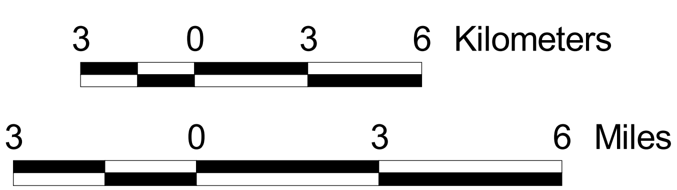
- Structuring the documents so that a range of site-specific risks to human health and the environment were delineated, and articulating RAOs around which to structure potential remedial alternatives.

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. These are discussed throughout the FS.

## 1.4 Section 1 Figures

Figures for Section 1 follow this page and include:




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

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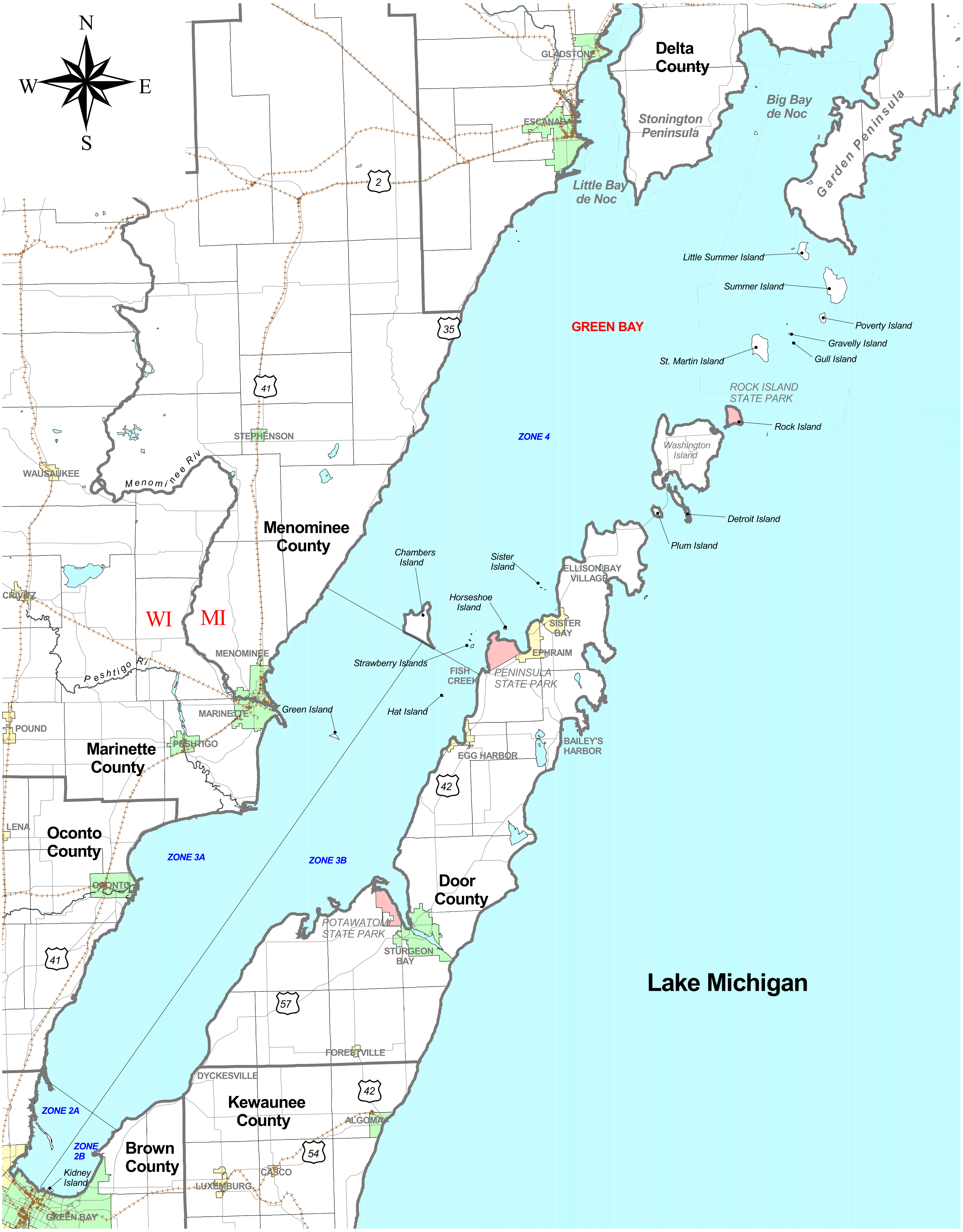
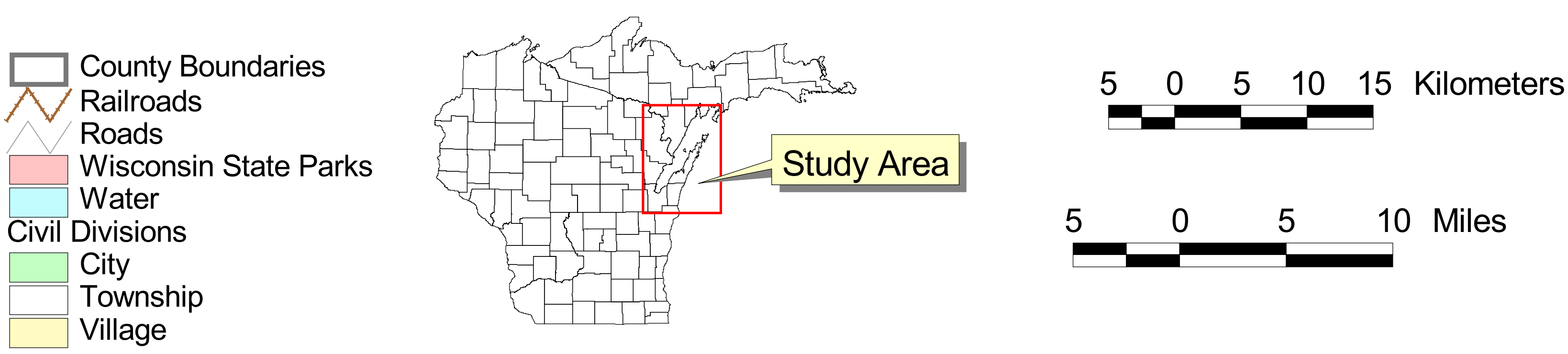
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Lower Fox River Study Area | REF NO: FS-14414-535-1-1 |
| | | | | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/9/01 |
| | | | FIGURE 1-1 | APPROVED: AGF |




NOTE:
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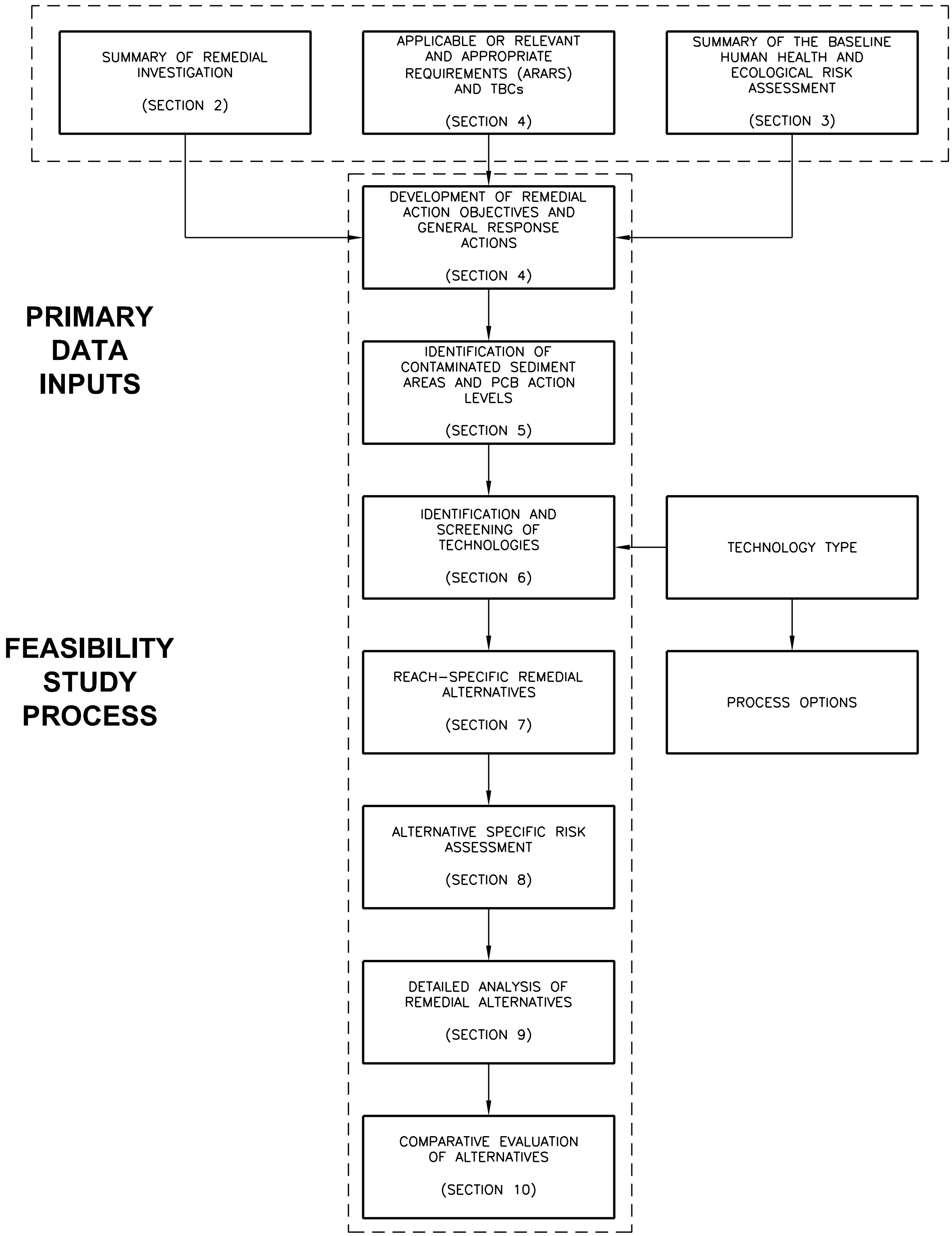
| | | | FIGURE 1-2 | |




ThermoRetec

LOWER FOX RIVER AND GREEN BAY FEASIBILITY STUDY

WISCN-14414-535

**OVERVIEW OF FEASIBILITY STUDY PROCESS**

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**FIGURE 1-3**

# 2 Remedial Investigation Summary

This section summarizes information from the Remedial Investigation (RI) Report for the Lower Fox River and Green Bay that is relevant to the feasibility study. Specifically, this summary of the RI Report will:

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

References and data sources pertaining to information presented in the RI summary can be found in the *Lower Fox River and Green Bay Remedial Investigation Report* (RETEC, 2002a).

## 2.1 Environmental Setting and Background

### 2.1.1 Lower Fox River Setting

The Lower Fox River flows northeast approximately 63 kilometers (km) (39 miles) from Lake Winnebago to Green Bay, Wisconsin (Figure 1-1). The Lower Fox River is the primary tributary to lower Green Bay, draining approximately 16,395 square kilometers ($km^2$) (6,330 square miles [$mi^2$]) with a mean discharge of 122 cubic meters ($m^3$) per second (4,300 cubic feet per second [cfs]). The change in river elevation between Lake Winnebago and Green Bay is approximately 51 meters (168 feet).

#### Reach Designations

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

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

These four reaches were based on similar water depths, current velocities, contaminant concentrations and distribution, and dam/lock structures (Figures 2-1 through 2-4). These reach designations were used during the RI to streamline the evaluation and reporting of sediment, water, and biological tissue data. Specific sediment deposits were identified in the first three reaches (Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere). These deposits were labeled A through HH and POG. Deposits were originally designated based on physical attributes, then later the chemical nature and extent of each deposit was determined. The De Pere to Green Bay Reach was divided into 96 Sediment Management Units (SMUs) to support the modeling efforts of the 1989 Green Bay Mass Balance Study. Table 2-1 summarizes the 35 sediment deposits (labeled A through HH) upstream of the De Pere dam and 96 Sediment Management Units (SMUs 20 through 115) downstream of the De Pere dam.

### 2.1.2 Green Bay

Green Bay is a narrow, elongated bay, approximately 190 km (119 miles) in length and an average of 37 km (23 miles) in width (Figure 1-2). The bay is bounded by the city of Green Bay at the south end and by both Big and Little Bays de Noc, in Michigan's Upper Peninsula (UP), on the north end. Wisconsin's Door Peninsula separates the majority of Green Bay from Lake Michigan. Urban areas located along the west shore of Green Bay include the cities of Marinette, Peshtigo, and Oconto, Wisconsin, and Escanaba and Menominee, Michigan. The city of Sturgeon Bay, Wisconsin, is located on the east shore of Green Bay.

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

#### Zone Designations

The Green Bay Mass Balance Study (GBMBS) (EPA, 1989a) divided the bay into four morphometric zones based on physical/chemical/biological characteristics observed in the bay: identified as zones 1, 2, 3, and 4 (Figure 1-2). Observations included eutrophication, chemical contaminants, foraging areas, habitat gradients, and distribution of fish populations. Green Bay Zone 1 is the same as the De Pere to Green Bay Reach of the Lower Fox River. Zones 2 and 3 are further divided into A and B segments by a center line extending out from the mouth of the Lower Fox River to Chambers Island. Zones 2A and 3A are located on the west side of this line while zones 2B and 3B are located on the east side of this line. Table 2-2 summarizes the physical characteristics of the Green Bay zones.

### 2.1.3 Site History

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

### 2.1.4 Current Land Use

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

Regional land use along the Lower Fox River is identified on maps prepared by planning commissions in both the Fox Cities and Brown County. Land use details on these maps provide a general description of development in the river vicinity.

The approximated general land use percentages for areas within about 0.25 mile of the bank of the Lower Fox River are summarized below.

| Land Use[1] | Fox River Cities[2] (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[3] | 7.2% | 1.3% | 4.3% |
| Wetlands | 5.1% | 1.6% | 3.4% |
| Vacant | 1.9% | 10.2% | 6.0% |

**Notes:**

1 Percentages are approximate and are intended to provide a general indication of land use along the Lower Fox River.

2 The Fox Cities includes all communities between Neenah/Menasha and Kaukauna.

3 Public land includes school properties.

The majority of the Lower Fox River is accessible to the public, including individual landowners along the banks. About 25 percent of the river shoreline area is considered wildlife habitat (agriculture, woodland, wetland). The wildlife habitat is largely located between Kaukauna and De Pere in both the Appleton to Little Rapids and Little Rapids to De Pere reaches.

Land use in the vicinity of Green Bay was collected from available county records for Brown, Door, Kewaunee, Oconto, and Marinette counties in Wisconsin and for Delta and Menominee counties in Michigan. A summary of the land use in the counties bordering Green Bay is presented in Table 2-3. The counties located along Green Bay are largely undeveloped. Brown County, Wisconsin is the only county where more than 5 percent of the total land is used for residential or industrial/commercial purposes. Also, between 65 and 85 percent of all land in these counties is classified as either agricultural or forested, reflecting the overall rural nature of this area. Wetlands comprise 3 to 20 percent of the land in the counties. The largest wetland areas are located in Brown, Oconto, and Marinette counties, all located along the western side of Green Bay. Door County, located on the eastern side of the bay, has less than 3.3 percent wetlands.

## 2.2 Physical Characteristics

Knowledge of the physical characteristics of a site provide the foundation for developing a site conceptual model and understanding the distribution and transport of contaminants throughout the river/bay system. Physical characteristics briefly described in this section for the Lower Fox River and Green Bay include: regional geology, sediment grain size, river and bay bathymetry, surface water hydrology, and sediment bulk density. In addition, a brief history of dredging activities is provided. The RI Report contains considerably more detail for each of these subjects.

### 2.2.1 Geologic Characteristics

Presented here is a brief summary of geology in the Lower Fox River and Green Bay basins. The RI contains considerably more detail pertaining to the bedrock formations, glacial stratigraphy, and native material underlying the recent soft sediment deposits.

#### 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. 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.

The Lower Fox River valley and Green Bay is underlain by a bedrock sequence of Precambrian granite overlain by Paleozoic sandstones, dolomite, and shale. The surface of the bedrock units slope east, approximately 5.7 to 7.6 meters per kilometer (m/km) (30 to 40 feet per mile), toward and beneath Lake Michigan. This regional dip has resulted in the Silurian Niagara Escarpment, east of and parallel to the Lower Fox River lowlands, and erosion of the Ordovician Maquoketa shale in the western part of the study area.

Due to the erosion of the Silurian dolomite and Ordovician shale bedrock units, the uppermost bedrock in the Lower Fox River valley and along the western side of Green Bay (from the city of Green Bay to Little Bay de Noc) are Ordovician age limestone/dolomite units. Additionally, bedrock units of the western shore of Green Bay are comprised of the Galena and Platteville formations. Within Michigan, these units are referred to as the Trenton and Black River Formation and they are contemporaneous with the Galena and Platteville units.

#### Glacial Geology and Regional Soils

Unconsolidated Quaternary glacial deposits cover the bedrock units 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 meters (50 feet) over much of the area to over

61 meters (200 feet) in the area around Wrightstown (Attig *et al.*, 1988). On the Door and Garden peninsulas, these deposits are generally less than 3 meters (10 feet) thick, and are thinner along the shores of the bay.

Soils and river sediments in the region are predominantly silt and clay units with varying amounts of sand and gravel due to the glacial events that occurred in region. The glacial deposits also affect the surficial soils in the vicinity of the Lower Fox River, many of which are described as silty clay loam, silty clay, and clay. In the northern portion of Green Bay, especially along the west side of the bay, outwash and glacial lake plains (typically dominated by sands) developed and ultimately affected soil formation, while on the Door and Garden peninsulas, clay till deposits are predominant. Superimposed on the glacial deposits are modern fluvial and alluvial sediments associated with slopewash, river, and floodplain deposits (Krohelski and Brown, 1986).

### 2.2.2 Sediment Grain Size

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.

In Little Lake Butte des Morts, 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 is 54 percent while sand comprises only about 23 percent of the sediments. These results confirm that the De Pere dam is a significant trap for finer-grained sediments on the Lower Fox River.

Sediments within Green Bay have a higher percentage of sand than those in the river. Sand content in Zone 2 (2A/2B) ranges between about 52 and 93 percent, with an average of 73 percent. In Zone 3A, along the west side of Green Bay, sand content is greater than 97 percent, while the sand content in Zone 3B generally ranges between 60 and 80 percent. The results for Zone 3B reflect the influx of sediments from the Lower Fox River, 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 collected during the 1993 and 1998 sampling activities characterized the sediments by high liquid and plastic limits. Under the Unified

Soil Classification System (USCS), the majority of the sediments were classified as high-compressibility silts (MH) while a small percentage were classified as highly plastic clays (CH).

### 2.2.3 Lower Fox River Bathymetry

The Lower Fox River is relatively narrow, generally less than 305 meters (1,000 feet) wide over much of its length, and ranges up to approximately 6.1 meters (20 feet) deep in some areas. Where the river widens significantly, water depths generally decrease to less than 3 meters (10 feet) and in the case of Little Lake Butte des Morts, water depths range between 0.61 and 1.53 meters (2 and 5 feet) except in the main channel. In general, however, the main channel of the river ranges from approximately 1.8 to 6.1 meters (6 to 20 feet) deep. Bathymetry information from the NOAA recreational charts (NOAA, 1992) is included on Figures 2-5 through 2-8.

The Little Lake Butte des Morts Reach is approximately 10 km (6 miles) in length and the water depth is generally less than 1.8 meters (6 feet). The main flow channel, which starts near the edge of sediment Deposit C, is approximately 2.4 meters (8 feet) deep on the south end and increases to approximately 5.8 meters (19 feet) near the outflow of the lake. Water depths outside the main channel and along the banks of the river are generally less than 1.8 meters (6 feet) deep (NOAA, 1992).

The Appleton to Little Rapids Reach is the longest reach of the river, extending approximately 32 km (20 miles). This reach meanders more than any other reach and is comprised of a series of large contiguous pools. Water depths in the main channel range between 1.8 and 3 meters (6 and 10 feet). Water depths in other areas of the reach vary from as little as 0.3 meter (1 foot) just downstream of Kaukauna to as great as 16 feet near the Rapide Croche dam. Between the Rapide Croche and Little Rapids dams, the river is generally narrow and main channel water depths are usually between 1.4 and 3.7 meters (8 and 12 feet).

The Little Rapids to De Pere Reach is approximately 10 km (6 miles) in length and the channel is relatively straight. The width is greatest at the upstream end and decreases downstream. The main channel depth is usually greater than 2.7 meters (9 feet) and increases to 5.5 meters (18 feet) approaching the De Pere dam. Along the banks of the river the water depths are generally less than 1.8 meters (6 feet).

Water depths in the De Pere to Green Bay Reach range between 1.8 and 7.3 meters (6 and 24 feet) in the main channel. This reach is approximately 11.3 km (7 miles) long and the lower 4.8 km (3 miles) of the reach are dredged by the U.S.

Army Corps of Engineers (USACE) in order to maintain a 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 meters (6 feet). Between De Pere and the Fort James-West turning basin (formerly Fort Howard), the depth of water is generally less than 1.8 meters (6 feet) 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. The authorized navigation channel depth in this reach is 24 feet deep.

### 2.2.4 Lower Fox River Surface Water Hydrology

The slope of the bedrock and the pre-glacial bedrock valleys control drainage in the Lower Fox River valley. The Lower Fox River lies along the axis of a former bedrock valley which was filled with glacial and proglacial lake sediments. The Lower Fox River and its tributaries have flowed over and cut through these relatively flat glacial lake plain sediments.

#### Surface Water Flow Controls - Neenah-Menasha (Lake Winnebago)

Lake Winnebago is a highly controlled waterway with specific water level targets, depending on the season of the year. These controls influence flow in the Lower Fox River. The USACE oversees the Lake Winnebago flow controls and set specific water level targets to provide water usage for hydro power and navigation while preserving or enhancing fish, wildlife, wetland habitat, and water quality in the Lower Fox River and the Lake Winnebago pool. The local water level datum for Lake Winnebago is the Oshkosh datum.

Lake Winnebago seasonal water level targets have a range of less than 107 cm (3.5 feet) between the low (5.5 cm or 0.18 feet Oshkosh) and high (105 cm or 3.45 feet Oshkosh) water levels allowed under the plan. The water level targets are 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 is slowly lowered to the winter drawdown level of 21 cm (0.68 foot) Oshkosh. This drawdown level provides storage needed to contain spring runoff. Typically, drawdown commences at a rate designed to achieve a target level by about March 1.

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 to early April. Following breakup of the ice, the Lake Winnebago pool is refilled. The target navigation stage, 91 cm (3.0 feet)

Oshkosh, is to be achieved by the beginning of May, typically the start of the navigation season.

**Summer Navigation.** During the navigation season (May to mid-October), 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. When the navigation season ends, the water level in Lake Winnebago is decreased to approximately 61 to 76 cm (2.0 to 2.5 feet) Oshkosh by December 1. The only outflow constraint is to observe a maximum safe discharge of about 510 cubic meters per second ($m^3$/s) (18,000 cfs), while allowing only gradual changes in stage to minimize impacts on wildlife.

## Lower Fox River Navigational Controls

There are 17 locks (Fox locks) and 12 dams located on the Lower Fox River between Lake Winnebago and the De Pere dam (Table 2-4). The Fox locks are an important aspect of navigation on the Lower Fox River. The Neenah and Menasha dams control flow out of Lake Winnebago, while the other 10 dams located between Little Lake Butte des Morts and De Pere control flow in the lower portion of the river. These dams control water levels and flow volumes throughout the river to provide a continued source of power for the hydroelectric plants associated with the dams and allow for navigation.

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 can be restored.

The State of Wisconsin and the USACE signed a memorandum of agreement in September 2000 for the transfer of the Fox River locks from federal to state control. This agreement does not actually transfer the control or property yet, but it rather 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; and

- 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.

## Lower Fox River Surface Elevation

The Lower Fox River decreases about 48.2 meters (158 feet) between the Menasha dam and De Pere dam and approximately 51.5 meters (169 feet) between the Menasha dam and the mouth of the river. The overall gradient for the Lower Fox River is 51.5 meters (169 feet) over 63 km (39 miles) or $8.2 \times 10^{-4}$ feet per foot (ft/ft). The river profile is shown on Figure 2-10.

Three areas exist where the water level elevation decline approaches or exceeds 9.1 meters (30 feet) between dams occurs largely within the Appleton to Little Rapids Reach, specifically in river stretches between the Appleton Upper and Appleton Lower dams, and between the Little Chute 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. These three sections of the river contain limited soft sediment deposits because of increased flow velocities.

## Measured and Estimated Stream Flow Velocities

Average stream flow velocity in each reach of the river has been estimated using discharge measurements collected from USGS gauges along the river (Table 2-5). These estimates were completed using the river cross-sections determined for the GBMBS modeling efforts (WDNR, 1995). Stream flow velocity is an important factor in evaluating areas where net sediment deposition is likely to occur. The overall Lower Fox River velocity average is just under 0.14 meters per second (m/s).

The average stream flow velocity in the Little Lake Butte des Morts Reach is just over 0.15 m/s (0.5 feet per second [ft/s]) and ranges from 0.08 to 0.35 m/s (0.26 to 1.15 ft/s). However, in Little Lake Butte des Morts proper, the average stream flow velocity is 0.13 m/s (0.42 ft/s) and ranges from 0.08 to 0.20 m/s (0.26 to 0.65 ft/s).

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 Little Lake Butte des Morts Reach and almost double the velocity found in Little Lake Butte des Morts proper. This reach had the greatest estimated stream flow velocities, ranging from 0.15 to 0.37 m/s (0.48 to 1.23 ft/s).

In the Little Rapids to De Pere Reach, the average stream flow velocity is 0.12 m/s (0.40 ft/s); this is approximately half of the average velocity for the Appleton to Little Rapids Reach. Flow velocities in this reach range from 0.11 to 0.13 m/s (0.37 to 0.42 ft/s), which is the smallest variation in flow velocities noted in any reach.

The De Pere to Green Bay Reach has an average stream flow velocity of 0.08 m/s (0.25 ft/s); this is the lowest found in the entire river. Due to these overall low stream flow velocities, it is not surprising that the largest volume of deposited sediment is located in this reach (Section 2.3).

## Low Flow and Flood Frequencies

The flow of the Lower Fox River has been monitored by as many as six stream gauging stations operated by the United States Geological Survey (USGS). The historical river discharge information from the Rapide Croche dam station (#04084500) is presented on Table 2-6. This gauging station recorded stream flow and discharge between October 1917 and September 1997. The water year (WY) extends from October 1 through September 30 of the following year.

The Rapide Croche results 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). According to the monthly results, following winter snowmelt and the generally heavy spring rains, April has the highest discharge volumes, while the late summer months of August and September generally have the lowest flows. These results are similar to the other Lower Fox River gauges. In addition, the results indicate that only 4 months, March through June, have average daily discharge volumes exceeding the annual average of 122 $m^3$/s (4,300 cfs). Based on the 7-day average low stream flow with a 10-year frequency ($Q_{7,10}$), the low-flow value is 26.9 $m^3$/s (950 cfs).

A similar flood frequency evaluation at the Rapide Croche gauging station was completed by USGS (Krug *et al.*, 1992). The results indicated that 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 five to six times greater than the average discharge of 122 $m^3$/s (4,300 cfs).

The Federal Emergency Management Agency (FEMA) mapped the 100-year flood elevation at the mouth of the Lower Fox River at 178.31 meters (585 feet) IGLD 1985 (FEMA, 1984). This is approximately 1.82 meters (6 feet) higher than the long-term average elevation of 176.485 meters (579.02 feet) IGLD 1985.

However, FEMA (1984) did not indicate what the flow rate was for this 100-year flood event (National Flood Insurance Program, 1984).

### 2.2.5 Green Bay Bathymetry

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

The bathymetry of Zone 2 is generally shallow, with all water depths less than 8 meters (26.5 feet). From the mouth of the Lower Fox River to a line connecting Long Tail Point/Point Sable (the Lower Green Bay AOC), water depths range from 0.3 to 3.4 meters (1 to 11 feet), excluding the navigation channel (Figure 2-9). Water depths at the very southern end of Green Bay are extremely shallow and generally less than 1.5 meters (5 feet). 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 Lower Fox River to a line from Dyckesville (on the east shore). The depth of the navigation channel is maintained between 6.25 and 7.16 meters (20.5 and 23.5 feet), while water depths in Zone 2 are generally less than 3.7 meters (12 feet) over much of this area.

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/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 Point is located just south of the Suamico River mouth while Little Tail Point is located just south the Little Suamico River (Figure 2-9).

The depth of water in Zone 3 is generally greater than 10 meters (30 feet). Water depths in Zone 3 range from about 12.5 meters (41 feet) at the boundary between Zones 2 and 3 to 33.5 meters (110 feet) just west of Chambers Island, near the boundary between zones 3 and 4. The deepest part of Zone 3 is located just southeast of Green Island where water depths of 34.4 meters (113 feet) have been measured.

Large portions of Zone 4, from Chambers Island to just south of Big and Little Bays de Noc, have water depths exceeding 9.1 meters (30 feet). However, in the vicinity of Big and Little Bays de Noc, the water depths decrease and shallow areas with water depths less than 9.1 meters (30 feet) are predominant. Similar to Zone 3, the depth 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 meters (176 feet) deep, located about 6.4 km (4 miles) west of Washington Island.

### Green Bay-Lake Michigan Passages

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 miles) wide and water depths in the passage range as deep as 39.3 meters (129 feet). The Rock Island Passage is approximately 3.9 km (2.4 miles) wide and water depths range as deep as 46.6 meters (153 feet). The passage is narrow due to the presence of the St. Martin Island Shoal, which extends south of St. Martin Island. 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 miles) wide and water depths range as high as 36.3 meters (119 feet). Finally, Poverty Island Passage is located between the Gull/Gravelly Island complex and Poverty Island. This passage is approximately 3.4 km (2.1 miles) wide and water depths range up to 26.5 meters (87 feet). No significant waterway passage is located north of Poverty Island.

## 2.2.6 Green Bay Surface Water Hydrology

### Green Bay Water Level Elevations

Green Bay water level elevations are controlled by and related to the water level in the Lake Michigan-Huron basin. These two lakes are connected through the Straits of Mackinac and are treated as a single lake basin. Water levels within the Great Lakes are measured according to the International Great Lakes Datum (IGLD 1985) which has its zero reference elevation point located at Rimouski, Quebec, Canada.

The overall annual long-term average (LTA) elevation for the Lake Michigan-Huron basin is 176.49 meters (579.02 feet) IGLD 1985 (USACE, 1996). The monthly LTA elevation ranges from a low of 176.34 meters (578.54 feet) IGLD 1985 in February to a high of 176.64 meters (579.53 feet) IGLD 1985 in July (USACE, 1998b). Historically, the lowest and highest monthly water elevation levels were recorded in March 1964 and October 1986, and the basin has an overall range of approximately 1.92 meters (6.3 feet).

Water levels within the Great Lakes are currently dropping. Between March 1999 and February 2000, only 68 percent of the normal annual precipitation fell in the Lake Michigan-Huron basin. In addition, snowmelt runoff is responsible for about 40 percent of the annual water supply into the Great Lakes. In March 2000, the snow-water equivalent was less than 10 cm (4 inches) throughout Michigan and Wisconsin. In addition to less snowfall, the warmer winters of 1998, 1999, and 2000 have reduced ice cover over the lakes and increased evaporation. Combined, these factors have contributed to lake levels which are approaching the record low for the Lake Michigan-Huron basin (USACE, 2000b).

### Green Bay Water Circulation, Currents, and Mixing Patterns

Green Bay has complex water currents and circulation patterns. However, there is an overall general counterclockwise movement of water in the bay. Water from Lake Michigan moves into the bay and south along the west shore. Water from the 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 affected by the presence of spits and shoals on the west side of the bay.

HydroQual, Inc. completed modeling analysis of current patterns in Green Bay using 1989/90 GBMBS data. A 3-dimensional circulation model calculated the monthly mean surface and bottom circulation patterns for August 1989. 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 *et al.*, 2000).

Water circulation in Green Bay is controlled by a number of different factors: 1) surface water elevation changes induced by wind and barometric pressure; 2) wind speed and direction; 3) river discharge; 4) upwelling of the thermocline in Lake Michigan; 5) thermal and density gradients between the bay and Lake Michigan; 6) ice cover and; and 7) the Coriolis effect.

Long-term averaging of Green Bay currents reveals steady, residual circulation patterns responsible for the net mass transport of suspended solids. The monthly averaging of currents shows a relatively consistent circulation pattern, with the magnitude of the currents varying from month to month. Figures 2-12 and 2-13 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 so many 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. Estimated flushing times for the inner portion of Green Bay are much lower than for the entire bay. The areas within 10 and 25 km of the mouth of the Lower Fox River flush in about 25 and 100 days, respectively (Mortimer, 1978).

## Lower Fox River Discharge into Green Bay

The USGS acoustic velocity meter (AVM) located at the mouth of the Lower Fox River records the river discharge into Green Bay. The Lower Fox River is the largest tributary to Green Bay, contributing approximately 42 percent of the total drainage, over 95 percent of the PCB load, and 70 percent of the suspended sediments (WDNR, 1999a; Smith *et al.*, 1988). The average discharge is 122 $m^3/s$ (4,300 cfs). However, water levels in the bay cyclically rise higher than levels in the river and flow is reversed, affecting the De Pere to Green Bay Reach of the river. This reversal in flow is due to wind-induced increases in water levels (seiche effect) and a small lunar tide. A seiche is produced when northeast winds push water to the south end of the bay. Water levels in this end of the bay can increase as much as 0.9 meter (3 feet), although the fluctuation often ranges between 0.15 and 0.3 meter (0.5 and 1 foot). The seiche occurs daily and, as evidenced by the AVM data, results in reversed stream flows in the lower reach of the river. The flow reversal can be significant, with recorded velocities exceeding 92 $m^3/s$ (3,250 cfs) on a daily basis and even greater flow reversal recorded for individual storm events. The seiche also produces a counterclockwise flow in Green Bay, which facilitates mixing of the river and bay water nutrient loads.

## Lower Fox River Plume Studies

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

The Lower Fox River plume was also discernible in the water column by higher chloride and higher conductivity measurements. A plume with higher chloride and conductivity concentrations extended from the river mouth along the east shore of the bay for a distance of approximately 42 km (26 miles), which is consistent with other observations. A plume of lower-conductivity water was also detected along the western shore of the inner bay and was ascertained to be outer bay or Lake Michigan water moving south along the western shore.

The plume studies show that Long Tail Point, which begins about 6 km (3.7 miles) north of the river mouth on the western side of the bay, forms a mixing barrier in the southernmost portion of Green Bay. This barrier allows Lower Fox River water to move farther up the bay before becoming thoroughly mixed with other water. The August 1989 surface and bottom water currents (Figures 2-11 and 2-12) 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 (Lathrop *et al.*, 1990).

## Inner Bay/Outer Bay Mixing Studies

Chambers Island is the boundary between inner and outer Green Bay. Flow around Chambers Island is an important aspect of circulation in Green Bay. Previous studies have found that net flow is from the inner to outer bay and that most of the flow from the inner to outer bay occurs along the eastern side of Chambers Island.

**Currents.** Water flow around Chambers Island is more complex than a simple counterclockwise motion. During the summer months, the colder, deeper water tends to flow south into the inner bay on 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. These results are shown on Figures 2-11 and 2-12. 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 and the combined surface currents are then directed northeast towards Washington Island (Blumberg *et al.*, 2000). Around Chambers Island, surface currents are clockwise northwest of the island and counterclockwise southeast of the island (Figure 2-12). 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 (Miller and Saylor, 1993).

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.

**Water Exchange.** Water exchange between the inner and outer bays has a net outward flow of approximately 130 $m^3/s$ (4,591 cfs). Current velocities were greatest east of Chambers Island, sometimes ranging as high as 0.35 m/s (1.1 ft/s). West of Chambers Island, the velocities typically range from 0.12 to 0.24 m/s (0.4 to 0.8 ft/s). Current velocities in the inner bay typically range up to 0.12 m/s (0.4 ft/s) (Miller and Saylor, 1993).

**Sediment Transport.** Approximately 17,500 metric tons (MT) (19,290 tons) of sediment were transported from the inner bay to the outer bay, generally along the east side of Chambers Island, between May and October 1989. 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 (Hawley and Niester, 1993). 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.

## Green Bay/Lake Michigan Mixing Studies

The exchange of water between Green Bay and Lake Michigan is highly variable and complex. The four main channels connecting Green Bay and Lake Michigan are: Poverty Passage, Porte des Morts Passage, Rock Island Passage, and St. Martin Island Passage, and are described in the Green Bay bathymetry section.

Large volumes of water consistently move between the bay and the lake through the Porte des Morts and Rock Island passages. Currents measured in the passages connecting Green Bay with Lake Michigan typically ranged from 0.12 to 0.30 m/s (0.4 to 1.0 ft/s). The estimated flow into the bay is approximately 3,300 $m^3/s$ (116,540 cfs or 871,000 gallons per second). In 1992, the estimated water volume exchange between the bay and the lake was about 3,500 $m^3/s$ (123,600 cfs).

Warm water leaves 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 2-11 and 2-12). August 1989 modeling results suggest that warm surface water (epilimnetic) flow from Green Bay to Lake Michigan was about 3,000 $m^3/s$ (105,940 cfs), while cold bottom water (hypolimnetic) flow to the bay was about 2,870 $m^3/s$ (101,350 cfs). This resulted in a net outflow of about 130 $m^3/s$ (4,590 cfs) from the bay. These results indicate that 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 (Miller and Saylor, 1985; Blumberg *et al.*, 2000).

The estimated precipitation input to the bay is 105 $m^3$/s, tributary input is 336 $m^3$/s, and evaporation loss is 87 $m^3$/s. These values are all at least an order of magnitude less than the estimated exchange between Green Bay and Lake Michigan.

### 2.2.7 Green Bay and Lower Fox River Ice Cover

The Port of Green Bay is closed to shipping from January 1 through March 31 due to ice cover (Haen, 2000). Although the port is officially closed for this 3-month period, ice cover in the bay is usually present from early to mid-December through mid- to late April (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-ice floes in these areas in early to mid-December, as temperatures usually range from -10 to -4 degrees centigrade (˚C) (14 to 24 degrees Fahrenheit [˚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 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 counterclockwise currents) because Lake Michigan water is generally about 1 to 2 ˚C 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 composed 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. Therefore, frazil ice can cause difficulties with intake structures and pier/dock structures located along the rivers or bay, where it is present. Additionally, as the water flows from the rivers into the bay, current velocities decrease and ice forms rapidly.

Ice thickness in the Lower Fox River averages 12 to 24 inches thick from year to year and may occasionally measure greater than 36 inches thick (Paulson, 2000; Boronow, 2000). Many areas of the lower reaches and near dams/drops remain open with flowing water year-round. The pools above the dams usually freeze over solid (Boronow, 2000). Flowing water and temperature influence ice thickness from year to year in addition to snowfall, rainfall, and snowpack conditions.

In either late January or February, open-water areas usually form in the outer bay, especially in and around the passages connecting Green Bay with Lake Michigan and along the east side of the outer bay. This occurs because Lake Michigan water is generally about 1 to 2 °C warmer than water within Green Bay and it reflects the influences of the generally counterclockwise currents.

### 2.2.8 Total Organic Carbon

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

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

### 2.2.9 Other Physical Parameters

Percent solid results indicate that solids generally comprise approximately 40 percent of the sediment samples analyzed. 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. The results indicate that the nature of the material changes significantly throughout each river reach and individual deposits may require additional characterization prior to implementation of selected remedial alternatives. The average result in Green Bay is 44 percent; similar to the river. However, in Green Bay Zone 4, the average solid result is approximately 70 percent, indicating that sediments in this portion of the bay are much more likely to consist of coarse-grained sands rather than fine-grained silt/clay.

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 and

0.66 g/$cm^3$, while the river-wide average is 0.55 g/$cm^3$. These results are lower than the average dry bulk density for soils of 1.3 to 1.35 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 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.

### 2.2.10 River and Bay Sediment Dredging

Due to the expansive areas of sediments that have accumulated downstream of the De Pere dam and out into the southern end of Green Bay, the USACE periodically dredges the navigation channel. The original navigation channel extends from Lake Winnebago out into Green Bay approximately 18.8 km (11.7 miles). However, the USACE currently only dredges and maintains the navigation channel in Green Bay and as far upstream as the Fort James turning basin, which is 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 a caretaker status.

The only dredging records available for the Lower Fox River (above the De Pere dam) since 1957 indicate that approximately 9,900 $m^3$ (12,950 cubic yards [cy]) were dredged from the Menasha Channel and Neenah Harbor in 1965 and 1968, respectively.

USACE records below the De Pere dam and for Green Bay indicate that over 12.1 million $m^3$ (15.9 million cy) have been dredged from the navigation channel since 1957. According to the dredging records, on average, approximately 282,350 $m^3$ (369,300 cy) of sediment are removed from the channel annually. Between 1957 and 1965, approximately 2.8 million $m^3$ (3.7 million cy) of sediment were disposed of at open-water locations. 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 (Figure 2-9). The Bay Port CDF was opened in 1965 and has served as the primary disposal facility for navigation channel sediments. Almost 7.3 million $m^3$ (9.4 million cy) have been placed in the Bay Port CDF and, according to Dean Haen (Haen, 2000), the facility still has capacity for another 1.5 million $m^3$ (2 million cy) of sediment. The Kidney (Renard) Island CDF opened in 1979 and received over 2 million $m^3$ (2.7 million cy) of sediment. The last year this CDF received sediments was 1996. Since its closure, the CDF has a navigation channel depth of 20.5 to 23.5 feet.

## 2.3 Soft Sediment Thickness

The soft sediment thickness of river sediments is generally from 1 to 2 meters thick (3 to 6.5 feet) while some of the larger deposits can range up to 3.28 meters (10.76 feet) thickness (Table 2-1). The thickest deposits are located in the De Pere to Green Bay Reach, with sediment thickness ranging up to 5.8 meters (19 feet) near the turning basin (Montgomery-Watson, 1998).

### 2.3.1 Calculation of Thickness

During the early portion of the 1989/1990 sampling efforts, sediment thickness was measured to a maximum depth of 1.06 meters (3.5 feet). Greater sediment thicknesses were subsequently noted in some deposits from later studies and these results are included in the database. The maximum depths from which PCB samples were collected in each deposit/SMU group, as well as in each bay zone, are listed in Table 2-7. If these depths were greater than 1.06 meters (3.5 feet), then the maximum sediment thickness of these deposits was changed to match the PCB sampling depth. In some areas, no sediment thickness data was collected because either: 1) PCBs were not detected in these areas, or 2) results of poling data showed no soft sediment was present. Sediment thickness contours were primarily dependent on Option 1.

### 2.3.2 Mapping the Occurrence of Sediment

Interpolated grids were developed for the presence or absence of sediment in the Lower Fox River and Green Bay. Sediment occurrence grids, also called sediment thickness contour maps, for the Lower Fox River were developed from field measurement of sediment thickness (Figures 2-5 through 2-8). The occurrence of sediment was interpolated separately for all nine depth layers on the Lower Fox River. If the thickness at a sampling location was less than half the layer thickness, then the area was designated as not containing sediment. Using this approach, sediment was also absent in deeper layers because the sample depth did not extend to the modeled depth (e.g., if a sample was collected from 0 to 50 cm, then the interpolation results indicate that there is no sediment in the 50- to 100-cm layer).

For Green Bay, the occurrence-of-sediment grid was developed from the GBMBS using a 5,000-meter (16,400-foot) by 5,000-meter (16,400-foot) grid. Based on sampling results, each grid cell was determined to be either soft sediments or glacial till (no soft sediments present). Grid cells that were not sampled were assigned to either the soft sediment or glacial till categories based on professional judgement, which included consideration of adjacent cells where sampling occurred and the depositional environment. For instance, areas near the mouth of the Lower Fox River that were not sampled were considered to contain soft sediment, as this is a depositional zone for sediments from the river. The 5,000-meter (16,400-foot) grid was translated into a 100-meter (328-foot) grid to match the sediment interpolation grids and allow a direct overlaying of the different grids.

## 2.4 Nature and Extent of Chemicals of Concern

The Screening Level Risk Assessment (SLRA) identified chemicals of potential concern (COPCs) in the Lower Fox River and Green Bay which included: PCBs, dioxins/furans, DDT (and its metabolites), dieldrin, arsenic, lead, and mercury (RETEC, 1998). The Baseline Risk Assessment (BLRA) concluded that the chemicals of concern (COCs) were PCBs, mercury, and DDE (RETEC, 2002b). The COCs represent potential risks to human and ecological receptors as described in Section 3. Although PCBs are the primary focus of the FS, all three compounds (PCBs, mercury, DDE) are carried forward in the FS.

### 2.4.1 Historical Sources of Chemicals of Concern in the Lower Fox River

#### Polychlorinated Biphenyls (PCBs)

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

The use of PCBs in carbonless paper manufacturing ceased in 1971. 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 to 399,450 kg (278,775 to 880,640 pounds) based on the percentages of PCBs lost during production or recycling of carbonless copy paper. Further, WDNR (1999a) estimated that 98 percent of the total PCBs released into the Lower Fox River had occurred by the end of 1971. In addition, WDNR (1999a) indicated that five facilities, including the Appleton Papers-Coating Mill, P. H. Glatfelter Company and associated Arrowhead Landfill, Fort James-Green Bay West Mill (formerly Fort Howard), Wisconsin Tissue, and Appleton Papers-Locks Mill, contributed over 99 percent of the total

PCBs discharged to the river. A portion of these PCBs settled into river sediments.

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

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

Sediments are the most significant source of PCBs entering the water column and over 95 percent of the PCB load into Green Bay is derived from the Lower Fox River. PCBs from sediment deposits are discharged into Green Bay at the mouth of the Lower Fox River through sediment transport and PCB dissolution in the water column. Up to 280 kg (620 pounds) of PCBs were transported from the Lower Fox River into Green Bay during a 1-year period in 1989–1990. Approximately 122 kg (270 pounds) of PCBs are transported from Green Bay to Lake Michigan annually. Based on the data included in the Fox River database, the estimated mass of PCBs in sediments of the Lower Fox River and Green Bay is approximately 100,000 kg (220,000 pounds).

### Mercury and DDE

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

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

### 2.4.2 PCB Distribution in Sediments

This section discusses: 1) data interpolation methods for determining PCB spatial distributions, 2) occurrence of sediment, 3) PCB sediment volume and mass distribution, and 4) riverbed maps showing the occurrence of PCBs in the sediments of the Lower Fox River and Green Bay. These bed maps were prepared from surface and subsurface sediment profile data contained within the Fox River database (FRDB) and originating at specific points along the river and in the bay. Specific details of the bed mapping procedure may be found in the Remedial Investigation Report (RETEC, 2002a). The distribution of PCBs in sediments within each river reach and zone of Green Bay are illustrated on Plates 2-1 through 2-5.

#### Data Interpolation for the Lower Fox River

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

The interpolations for the Lower Fox River are based on the results included in the FRDB as of March 1, 2000, consisting of about 900 sample results and locations in the Lower Fox River from nine studies conducted between 1989 and 1999. The 1999 data set included post-dredge sampling data from the Deposit N sediment removal demonstration project.

Data for the Lower Fox River were first screened to remove older data that were geographically too close to locations with newer data. Sediment data for the Lower Fox River has been collected in various studies since 1989. In order to use the most recent data available, the data were assigned to three different time periods: 1989 through 1992, 1993 through 1995, and 1996 through 1998. All of the data from the period 1996 through 1998 were used in the interpolation. A relationship was developed between similar ranges of PCB concentrations and the distances between data points in each range. From this analysis, a distance of less than 133 meters (436 feet) was determined to indicate that an older sample location was too close to a newer sample location. In this case, the older data were not used in the interpolations. This analysis was conducted first on the 1993 through 1996 data set to create a new data set for the 1993 through 1998 period. The analysis was then repeated using the 1989 through 1992 data set. In this way, the entire data set from 1989 through 1998 was used, but older data were superceded by newer data.

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

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

In addition to inverse weighting, a maximum set distance was selected for which data points may influence grid point results. Erroneous interpolations can occur if data are extrapolated over excessive distances. To prevent this condition, grid point values were computed using data within a certain distance or radius of the grid point location. Data points located further from the grid point than the established radius were not used in the interpolation. If there were no data points within the interpolation radius of a grid point, then no value was interpolated for that grid point.

The interpolation radius for computing sediment thickness was set at 100 meters. For all other parameters, the interpolation radius varied among the river reaches. In the Little Lake Butte des Morts Reach, complete coverage of the river required that a radius of 400 meters (1,312 feet). For the Appleton to Little Rapids Reach, the river is more narrow and linear. For this reach, the interpolation radius was computed as one-third of the average river width, or 79 meters (259 feet), to minimize the influence of separate deposits on the interpolation. The Little Rapids to De Pere and De Pere to Green Bay reaches used an interpolation radius of 1,000 meters (3,280 feet), as specified in Technical Memorandum 2e and Technical Memorandum 2e Addendum (WDNR, 1999b, 2001).

Data interpolations for the Fox River were conducted for nine different layers of sediment depth: 0 to 10, 10 to 30, 30 to 50, 50 to 100, 100 to 150, 150 to 200, 200 to 250, 250 to 300, and greater than 350 cm. These sediment depths were selected based on previous and current modeling efforts as well as being defined by WDNR (1999b).

### Data Interpolation for Green Bay

Interpolation of sediment data from Green Bay followed the same methods as used in the Lower Fox River. The data set for the Green Bay interpolations included approximately 240 sample results and locations from 3 studies conducted between 1989 and 1998.

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

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

Green Bay data were integrated for four different layers of sediment depth: 0 to 2, 2 to 10, 10 to 30, and greater than 30 cm. In addition to these four sediment layers, a composite sediment layer was developed for a thickness of 0 to 10 cm. This layer was computed as a thickness-weighted average of the 0- to 2- and 2- to 10-cm layers. The 0- to 10-cm composite layer was developed for use in the RA and food web modeling. The other two layers were selected to coincide with layering developed for the river.

## Occurrence of Sediment

The occurrence-of-sediment grids were used to edit the PCB concentration grids. This was necessary because the PCB interpolation could not identify areas where sediment was absent. Without an overlay of sediment thickness, PCB concentrations could be interpolated into areas that do not contain sediment. By using the occurrence-of-sediment grids, the PCB interpolation was restricted to those areas where sediments are present.

## PCB Sediment Volume and Mass Distribution

The interpolated grids provided a means of computing the volume of contaminated sediment and the mass of PCB in the Lower Fox River and Green Bay (Tables 2-1 and 2-2). Each grid point represents a grid cell with an area 10 meters (33 feet) by 10 meters (33 feet) in the Lower Fox River and an area 100 meters (330 feet) by 100 meters (330 feet) in Green Bay. The sediment volume at each grid cell in a layer was computed as the area of grid cell multiplied by the layer thickness. The volume within a layer above some PCB concentration was estimated by summing the number of grid points above the PCB concentration and multiplying by the area of a grid cell and the thickness of the layer. The grid points were also counted within a river reach, deposit/SMU area, or Green Bay zone to determine the volume of contaminated sediment within an area of the river or bay. The estimated volume of sediments with PCBs will be discussed for each reach or zone below.

Mass calculations were computed in a manner similar to the volume calculation. The mass was computed by multiplying the sediment volume by the bulk density and the PCB concentration at a grid cell. Summing the mass over the grid cells within a reach, deposit/SMU, or zone yielded the mass of PCB within that area of the river or bay. The estimated mass of PCBs will be discussed for each reach or zone below.

## PCB Bed Maps

Maps showing the distribution of PCBs in sediment were constructed directly from the interpolated grids using GIS ArcView and Spatial Analyst. The methods used to produce these maps were the same as those outlined in Technical Memorandum 2e, the Addendum to Technical Memorandum 2e, and Technical Memorandum 2f (WDNR, 1999b, 2001, 2000b, respectively). The interpolated grid was displayed and color contoured into different ranges based on PCB concentration. Areas where sediment is absent were not included in the color contouring. Similarly, areas outside the interpolation radius were not included in the color contouring. The concentration intervals selected for the bed maps were based upon a combination of observed concentration ranges, cleanup level evaluations, the 50 ppb PCB detection limit, variability of data collection, and criteria for bed mapping. The total PCB concentration ranges and mapping intervals used for the Lower Fox River and Green Bay (in micrograms per kilogram [$\mu$g/kg]) are:

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

Sediment bed maps for total PCBs are shown on Plates 2-1 through 2-5, and are discussed below.

## 2.4.3 Extent of PCB Chemical Impacts

Approximately 96,800 kg (213,400 pounds) of PCB in the Lower Fox River and Green Bay system are distributed in about 474 million $m^3$ (620 million cy). Review of the PCB mass and contaminated sediment volume herein considers sediments which contain more than 50 $\mu$g/kg PCB. The results are summarized below and indicate that the De Pere to Green Bay Reach and Green Bay Zone 2, combined, contain almost 60 percent of the total PCB mass in the system in less than 10 percent of the total contaminated sediment volume. The PCB mass and volume of contaminated sediment for each river reach and bay zone are listed in Table 2-7.

As shown in Table 2-7, over 96 percent of the total PCB mass within the Lower Fox River and Green Bay is located between the De Pere dam and the northern boundary of Zone 3, which is bounded by Chambers Island. The magnitude and extent of PCB-impacted sediments for each river reach and zone of Green Bay are summarized below.

### Little Lake Butte des Morts Reach

The nine sediment deposits in this reach (deposits A through H and POG) contain about 1,540 kg (3,395 pounds) of PCBs in about 1.35 million $m^3$ (1.77 million cy) of sediment with concentrations greater than 50 $\mu$g/kg PCB (Plate 2-1). These deposits cover about 314 hectares (775 acres) and thicknesses range up to approximately 1.9 meters (6.2 feet) thick. The highest detected total PCB concentration in sediment was 222,722 $\mu$g/kg (average 15,043 $\mu$g/kg). Upstream deposits A, B, and POG have the highest PCB mass to volume ratios in this reach. These three deposits contain 952 kg (2,100 pounds) of the PCBs in about 252,000 $m^3$ (329,600 cy) of sediment. About 910 kg (2,000 pounds) of the PCBs in these three deposits is present in the upper 100 cm (3.28 feet) of sediment. Deposits A/B, E, and POG contain over 1,400 kg (3,086 pounds) of PCBs, or about 91 percent of the PCBs present in this reach. About 53 percent of the mass in the deposits listed above are present in the upper 30 cm (1 foot) of sediment.

### Appleton to Little Rapids Reach

Sediment accumulation in the Appleton to Little Rapids Reach is more localized compared with the other three reaches. The 22 sediment deposits in this reach (deposits I through DD) contain about 94 kg (207 pounds) of PCBs in about 184,790 $m^3$ (241,700 cy) of sediment, with concentrations greater than 50 $\mu$g/kg PCBs (Plate 2-2). These deposits cover approximately 153 hectares (378 acres) and generally occur in areas of slower stream flow velocities (e.g., where the river widens, in the vicinity of dams/locks, eddy pools along the banks, etc.). Sediment thicknesses range up to approximately 100 cm (3.23 feet) thick. The highest detected total PCB concentration in sediment was 77,444 $\mu$g/kg (average 6,406 $\mu$g/kg). Only deposits W, X, and DD have a volume exceeding 30,000 $m^3$ (39,240 cy) of sediment and these are located where the river widens and/or upstream of a dam. The average sediment volume in each of the remaining 19 deposits in this reach is about 3,780 $m^3$ (4,944 cy). Approximately 32 kg (71 pounds) of PCBs remain in deposits N and O following completion of the 1999 sediment remediation demonstration project, and no future attempt to remove this mass is currently under consideration. The total surface area of this reach is approximately 7,000,000 $m^2$ while deposits with measurable PCBs are only 870,000 $m^2$ (12.6 percent). In general, surface sediment PCB concentrations are less than 1,000 $\mu$g/kg in this section.

### Little Rapids to De Pere Reach

Sediment accumulation in this reach extends over a long distance and large area. The four sediment deposits in this reach (deposits EE through HH) contain 980 kg (2,160 pounds) of PCBs in approximately 1.71 million $m^3$ (2.24 million cy) of sediment with concentrations greater than 50 $\mu$g/kg PCB (Plate 2-3). The four deposits in this reach are essentially a single sediment unit covering about 266 hectares (657 acres). Sediment thicknesses range up to 2.3 meters (7.5 feet) thick in select areas, especially near the De Pere dam. The highest detected total PCB concentration in sediment was 54,000 $\mu$g/kg (average 6,292 $\mu$g/kg). Concentrations exceeding 5,000 $\mu$g/kg exist at the southernmost limit to Deposit EE, and at the northernmost part of the reach behind the De Pere dam. Almost all of the PCBs are contained in the upper 100 cm (3.28 feet) of sediments, with 535 kg (1,180 pounds) contained in the upper 0 to 30 cm (0 to 1 foot).

## De Pere to Green Bay Reach (Green Bay Zone 1)

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

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

The mass of PCBs increases significantly with depth. Approximately 16,150 kg (35,530 pounds) of PCBs, or about 55 percent of the total PCB mass in the Lower Fox River, occurs in the upper 100 cm (3.28 feet) of sediment. Approximately 10,600 kg (23,370 pounds) of PCBs (36 percent of the PCBs in the river) are buried below 100 cm (3.28 feet).

PCBs are fairly evenly distributed in the surface sediments within this reach. Of the 5,210,000 $m^2$ of sediment surface within this reach, 4,500,000 $m^2$ (87 percent) have PCB concentrations greater than 1,000 $\mu$g/kg.

## Green Bay Zone 2

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

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

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

### Green Bay Zone 3

This zone contains approximate 35,240 kg (77,700 pounds) of PCBs in approximately 397 million $m^3$ (519 million cy) of sediment with concentrations greater than 50 $\mu$g/kg (Plate 2-5). PCB distribution results show that sediments with the highest concentrations have accumulated along the east shore of Green Bay, extending from Dyckesville to Egg Harbor, reflecting the influence of Green Bay current patterns. Sediments in Zone 3A cover about 85,890 hectares (212,240 acres) and have an average thickness of just 0.21 meter (0.7 foot). In Zone 3B, the sediments cover about 69,340 hectares (171,340 acres) and have an average thickness of about 0.31 meter (1 foot). The highest detected total PCB concentration in sediment was 1,320 $\mu$g/kg (average 448 $\mu$g/kg) in Zone 3B.

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

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

### Green Bay Zone 4

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

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

## 2.4.4 Extent of Other COPC Impacts

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

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

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

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

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

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

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

- SVOCs, which result from both point and non-point sources in urban and rural areas, were detected throughout the Lower Fox River at concentrations exceeding the background levels observed in Lake Winnebago. The SVOCs detected at higher concentrations included PAHs and also occurred in widespread areas of the river. Total PAH concentrations below 4,000 $\mu$g/kg typically do not warrant further assessment. Total PAH concentrations along the Lower Fox River ranged non-detectable to 60,000 $\mu$g/kg. A number of locations from Little Lake Butte des Morts to the mouth of the river exceeded 4,000

$\mu$g/kg with the highest values frequently observed downstream of more urbanized areas. None of the sediments samples collected within Green Bay Zone 2 exceeded 4,000 $\mu$g/kg, and PAHs were not detected in zones 3 or 4.

## 2.5 Chemical Fate and Transport

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

Other modes of contaminant transport such as volatilization, atmospheric deposition, and point source discharges are negligible when compared to the river transport. Figures 2-13 and 2-14 each present a conceptual model of PCB fate and transport in the Lower Fox River and Green Bay system by TSS load and PCB mass, respectively. Total suspended solids (TSS) loads are from the Fox River into Green Bay and are summarized on Table 2-8.

### 2.5.1 Lower Fox River Sediment Deposition

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

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

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

The Appleton to Little Rapids Reach experiences a net loss of sediment. Between Appleton and Kaukauna, the river shows a marginal increase of approximately 2,500 MT (2,750 tons) in the TSS load. However, between Kaukauna and Little Rapids, the river experiences a net erosion as the TSS load doubles from approximately 70,000 MT (77,000 tons) to approximately 142,000 MT (154,000 tons) (Figure 2-13). The lack of soft sediment between Rapide Croche dam and Little Rapids suggest that resuspended sediments are likely transported to Little Rapids (Deposit DD) or further downstream. Based on the net increase of TSS load, the fast stream velocities (as high as 0.3 m/s), the narrow river sections, and the lack of many sediment deposits, the Appleton to Little Rapids Reach is subject to a net loss of sediment.

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

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

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

### 2.5.2 Green Bay Sediment Deposition

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

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

Approximately 17,500 MT of sediment is transported from the inner bay to the outer bay along the east side of Chambers Island. However, about 19,000 MT of sediment is transported from the outer bay to the inner bay along the west side of the island, following dominant circulation patterns (Figures 2-11 and 2-12). Therefore, there is a net sediment gain in the inner bay of approximately 2,400 MT. Approximately 10 to 33 percent of the inner bay tributary sediment load (the majority of which is from the Lower Fox River) is transported to the outer bay.

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

### 2.5.3 PCB Transport

Review of sediment transport through the river reaches and bay zones was evaluated to assess where PCB transport is occurring with all movement. The conceptual models show the PCB mass/volume contained with each reach/zone (greater than 50 µg/kg PCB) and how much PCBs are transported from one reach/zone into the next annuli (Figures 2-13 and 2-14).

#### Fox River

Approximately 1,540 kg of PCBs are present within the Little Lake Butte des Morts Reach. The sediments of the lake have long acted as a continuing source of PCBs to the river/bay system. WDNR (1995) estimates are that less than 1 kg per year is annually transported from Lake Winnebago into Little Lake Butte des Morts (Figure 2-14). Approximately 40 kg of PCBs are resuspended and transported from Little Lake Butte des Morts to the Appleton to Little Rapids Reach, even though Little Lake Butte des Morts is a net depositional area.

The Appleton to Little Rapids Reach exhibits increased stream flow velocities compared with the rest of the river. Stream flow velocity in this reach averages about 0.283 m/s, which is more than twice the entire river average of 0.137 m/s. Only about 94 kg of PCBs are located within sediments in this reach. These data show that little of the sediment or PCBs are deposited permanently within this reach.

Within the Little Rapids to De Pere Reach, the De Pere dam acts as a sediment trap. Approximately 64 kg per year of PCBs enter the reach and 77 kg per year are transported over the De Pere dam. Although net sediment deposition occurs in this reach (Figure 2-13), dissolution of PCBs from sediment into the water column becomes more important than does actual transport of sediment to which PCB is sorbed. Stream flow velocities downstream of the Little Rapids dam decrease to approximately 0.122 m/s, which is below the river average of 0.137 m/s.

The De Pere to Green Bay Reach has the greatest PCB mass and volume of sediment within the Lower Fox River (over 25,900 kg of PCB). Over 90 percent of the PCB mass and 60 percent of the PCB-impacted sediment present in the Lower Fox River are located within this reach. The average stream flow velocity in this reach is approximately 0.077 m/s, well below the river average of 0.137 m/s. This low river velocity accounts for the high volumes of sediments deposited within this reach. Although approximately 80,000 MT TSS flows over the De Pere dam, only about 20,000 MT TSS (about 25 percent) is transported passed the river mouth and into the bay. On a mass and volume basis, this reach has the most significant sediment load in the river. Sediments in this reach act as the major continuing source of PCBs into Green Bay.

## Green Bay and Lake Michigan

Based on river water sample results, approximately 220 to 280 kg (484 pounds) of PCBs were transported from the Lower Fox River into Green Bay annually in 1989/90 and 1994/95. These results suggested that roughly one percent of the PCB mass within the river is discharged into the bay annually. However, recent 1998 data suggest that the PCB load into Green Bay may be decreasing and only about 125 kg of PCBs were discharged from the river into the bay based on the 1998 data, which is just over 0.4 percent of the river mass. The average estimates of the PCB mass entering Green Bay from the Lower Fox River annually range between 125 and 220 kg per year. Based on peak flow conditions within the river, the highest estimated PCB load into Green Bay is about 550 kg per year. Approximately 120 kg of PCBs are transported from Green Bay into Lake Michigan annually (Figure 2-14). However, the results of these studies suggest that the PCB mass located between the De Pere dam (in the Lower Fox River) and Chambers Island (in Green Bay) is so large that, at these low rates of loss, a large mass of PCBs will remain in these sediments far into the future.

## Other PCB Pathways

In addition to PCB input to the river and bay from contaminated sediments, other PCB sources and sinks exist. Approximately 3 to 5 kg of PCBs are introduced into the river from other discharge locations where PCBs remain in effluent lines or from continued carbonless paper recycling. Due to the ubiquitous and resilient nature of PCBs, low concentrations of PCBs have been detected at discharge locations that continue to contribute PCBs to the system. Estimates of atmospheric deposition of PCBs into Green Bay range from 2 to 35 kg annually. Based on a 1987 and 1988 USGS PCB mass-loading study of major tributaries into Green Bay, more than 90 percent of the PCB load into Green Bay was attributable to the Lower Fox River. The other Green Bay tributaries contributed only about 10 kg annually to the bay (Figure 2-14).

In addition to accumulation of PCBs in river and bay sediments, PCBs do exit the system through volatilization (Figure 2-14). A number of studies have indicated that PCB volatilization from the water exceeds atmospheric deposition. PCB losses through volatilization to the atmosphere ranges between 0 and 5 kg/yr for the Lower Fox River, whereas volatilization losses in Green Bay range between 130 and 500 kg annually. The surface area for Green Bay is a significant volatilization pathway.

# 2.6 Time Trends of Contaminants in Sediment and Fish

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

## 2.6.1 Sediment Methods

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

Exploratory analysis demonstrated that PCB concentrations varied across locations in the river. To adequately conduct the analysis of time trends, it was necessary to undertake a separate evaluation of the spatial layout; a horizontal evaluation within the river bed and a vertical evaluation with each depth stratum. The deposit designations used in the RI/FS (e.g., A, POG, EE, or SMU 26, shown on Figures 2-1 through 2-4) were found to be unsuited to defining spatially-cohesive subsets, many samples had no deposit designation and some deposit designations spanned stretches of a river reach too long to allow adequate assessment and control of spatial structure. Based upon analysis of the spatial layout, 23 distinct geographic "deposit groups" were determined, forming data subsets with spatial structures far more amenable to statistical analysis. These were given designations that reflected the general deposit designations in the RI/FS, with the added benefit that these groups designated non-overlapping spatial sets. The statistical groups analyzed are shown on Figures 2-15 through 2-17.

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

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

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

### 2.6.2 Fish Methods

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

All data used in these analyses were from the Fox River database. A total of 1,677 fish samples were available for analysis, divided into three main sample types: fillet without skin, fillet with skin, and whole body. Inadequate sample size presented the greatest obstacle to analysis. There were several cases where there were substantial data, but there was inadequate spread in the years between collections. It should be noted that within the Little Rapids to De Pere Reach, there were no fish groups with both sufficient sample size and time spread. There were over a hundred combinations of reach, species, and sample type with at least one observation, but only 19 of these had sufficient numbers of samples and a sufficient time spread for analysis of time trends. Carp and walleye provided the largest number of observations of any species. These 19 combinations represent 867 samples—over half of all samples of whole body, fillet with skin, and fillet without skin. In addition to the 19 combinations, there were 4 analyses which could statistically combine samples from the fillet and whole body categories (within a single reach and single species) to come up with a single time trend estimate.

Data on PCBs in fish were analyzed as the logarithm of PCB concentration in micrograms per kilogram. The percent lipid content of samples was significantly associated with PCB concentration in most species and sample types, and was thus used as a normalization term in all analyses.[1]

Regression models for PCB concentrations versus time were fitted using the logarithm of percent lipid content and time as independent variables. A linear spline function was included in some time trends analyses to accommodate different rates of change in PCB concentrations during earlier versus later periods. The maximum likelihood method was used to accommodate observations below detection limit. A test for changing trends was also carried out.

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

### 2.6.3 Time Trend Results

Results of the sediment time trends are presented in Table 2-10, and are represented graphically on Figures 2-15 through 2-17. Seventy percent of all calculated slopes (32 out of 46) were negative. However, only 13 out of the 46 slopes were statistically significant, such that a hypothesis of no change in PCB

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

concentration over time could be rejected. Of those, 10 were negative,[2] and within that subset eight were in the 0- to 10-cm (0- to 4-inch) segment.

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

While those data suggest an overall decline in PCBs in the Lower Fox River, a more careful analysis of the subsurface data suggest that these declines are restricted to the upper 0 to 10 cm (4 inches). While 32 out of the 46 analyses were negative, there is a strong trend toward fewer and weaker negative slopes at increasing depth. Table 2-10 and Figures 2-15 through 2-17 show in general that the subsurface deposits do not significantly decline in sediment PCB concentrations. For Little Lake Butte des Morts, the figures suggest that there is a generally increasing trend in subsurface PCBs, and an indeterminate mixture of trends that is not distinguishable from zero in the Appleton and De Pere reaches. For Little Rapids to De Pere, there are consistently negative trends in the 10- to 30-cm (0.33- to 1-foot) strata, but in the lower strata, the data are consistent with either zero trend (30 to 50 cm [1 to 1.6 feet]), or an increasing trend (50 to 100 cm [1.6 to 3.3 feet]).

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

Like sediment PCB concentrations, fish tissue PCB concentrations showed a significant but slow rate of change throughout the lower Fox River and lower Green Bay (Table 2-11). Initial exploration of the data demonstrated that there were statistically significant declines in tissue PCB concentrations in all species in all reaches. More detailed analyses were then conducted to determine if there had been a constant linear rate of decline, or if significant changes in the rate of decline, or "breakpoints," could be identified. Among fish time trends analyzed,

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

9 out of 19 combinations of reach, species, and sample type showed a statistically significant change in slope during earlier and later periods. In all of the reaches of the river, and in Zone 2, there were steep declines in fish tissue PCB concentrations from the 1970s, but with significant breakpoints in declines beginning around 1980. After the breakpoint, depending upon the fish species, the additional apparent declines were either not significantly different from zero, or were relatively low (5 to 7 percent annually). However, for two species there were increases in PCB concentrations after the breakpoint; walleye in Little lake Butte des Morts and carp in Green Bay Zone 1.

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

## Little Lake Butte des Morts

Time trend results for sediments in Little Lake Butte des Morts are presented in Table 2-10 and on Figures 2-15 through 2-17. With the exception of two strata at 10 to 30 cm (0.33 to 1 foot) in two separate deposit groups, slopes are negative (9 out of 11 analyses). However, statistically significant negative slopes (decreasing PCB concentration over time) was found only in surface sediments (0 to 10 cm [0 to 4 inches]) of four deposit groups (AB, D, F, GH). The estimated rates of decrease ranged from 8 to 24 percent per year, with wide confidence intervals for these rates of change; a rate of decrease of as little as 1 to 5 percent and as much as 15 to 43 percent per year. While the slopes were negative, there were no significant trends at deposits C or POG. In fact, for POG the estimated annual slope was -18.6 percent per year, but the upper and lower confidence bound on the estimate ranged from -43.3 to +16.9 percent per year.

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

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

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

For the fish examined in this reach, an early rapid decline was observed until around 1987, followed by either a slower decline or a flattening without further decline, depending upon the species (Table 2-11). Within this reach, time trends were conducted on carp and walleye (skin-on fillet and whole body), and northern pike and perch (skin-on fillet). For carp, the breakpoints identified for the skin-on fillet and whole body were 1979 and 1987, respectively. Walleye data fillet and whole body data show that the breakpoint occurs between 1987 and 1990. The fillet data suggests no change in concentration after the breakpoint, while the whole body data showed a sharp rate of increase (22 percent per year). However, the latter analysis, when tested, was not significantly different from zero. For northern pike skin-on fillets, the analysis showed no breakpoint, but a constant rate of decline of 12 percent per year. By contrast, yellow perch skin-on fillets declined sharply until 1981, and have since remained at constant levels. A meta-analysis conducted on all fish data combined yields a statistically significant, but slow rate of decline of 4.9 percent (range 2.1 to 7.5 percent decrease) per year.

## Appleton to Little Rapids

For this reach, there were only sufficient data to evaluate Deposit Group IMOR, Deposit N (pre-demonstration dredging), and Deposit Group VCC. For these three groupings, surface sediments at IMOR showed an estimated annual increase of 9.9 percent, while the other two showed decreases in total PCB concentrations (Table 2-10). While Deposit N surface sediments were found to be significant, there were non-significant increases observed in the subsurface sediments. Again, confidence limits around the estimated mean for all deposits was wide. Meta-analysis for the reach showed a non-significant increase of 0.6 percent per year.

For fish in this reach, the only tissue type with sufficient numbers and time spread of data were walleye skin-on fillet. Analysis of those data showed a relatively constant rate of decline of 10 percent (range 5.6 to 17.9 percent decrease) per year (Table 2-11).

## Little Rapids to De Pere

Time trends in sediments for this reach have a majority of negative slopes; but two of only three significant slopes were negative and occur in the 0- to 10-cm (0- to 4-inch) and 10- to 30-cm (0.33- to 1-foot) depth strata. One large, positive, statistically significant slope occurs at the 30- to 50-cm (1- to 1.6-foot) depth (Table 2-10, Figure 2-16).

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

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

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

## De Pere to Green Bay (Zone 1)

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

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

For fish, Green Bay Zone 1 and Zone 2 PCB exposures were found to be significantly different (Table 2-11). This difference was determined using two methods: 1) cross-sectional analyses, which compared fish PCB concentrations within a single year (e.g., 1989 data only) between the zones; and 2) estimating the significant differences between time trend slopes calculated separately for the two zones. Four out of five cross-sectional analyses showed statistically significant differences, either in the relationship of lipid content and PCB concentration or in the mean PCB concentration, while controlling for lipid content. All three time trend analyses comparing the two zones showed significantly different trends in the two reaches. Thus, the time trends in the two zones were handled separately.

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

#### Green Bay Zone 2

Zone 2 shows decreasing trends with no significant breakpoints in most species tested, including carp. Significant decreases of between 4 and 15 percent annually were found in alewife, carp, and yellow perch. The exception to this was gizzard shad, which showed a significant increasing trend of 6 percent PCBs in tissues per year (Table 2-11).

### 2.6.4 Conclusion

The objective of the time trends analysis was to determine if PCB concentrations in the Lower Fox River were decreasing over time. For PCB concentrations in surface sediment, the data suggest an overall decline. PCB concentrations in surface sediments in the Lower Fox River are generally decreasing over time, but apparent detectable loss is limited to the top 10 cm (4 inches) of sediment. The apparent declines observed in surface sediments is consistent with the continued observed transport of PCBs from the river to Green Bay, as discussed in Section 2.5. The rate of change in surface sediments is both reach- and deposit-specific. The change averages an annual decrease of 15 percent, but ranges from an increase of 17 percent to a decrease of 43 percent (Table 2-12). A large fraction of analyses provided little useful information for projecting future trends because of the lack of statistical significance and the wide confidence limits observed. This is especially true for sediments below the top 10 cm (4 inches); changes in the sediment PCB concentrations cannot be distinguished from zero, or no change.

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

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

The time trends analysis dealt strictly with the testing of changes in PCB concentrations over time, and not with the mechanisms that could control changes in sediment and tissue loads. As discussed in Section 2.5, studies have shown that PCBs are being transported out of the Lower Fox River into Green

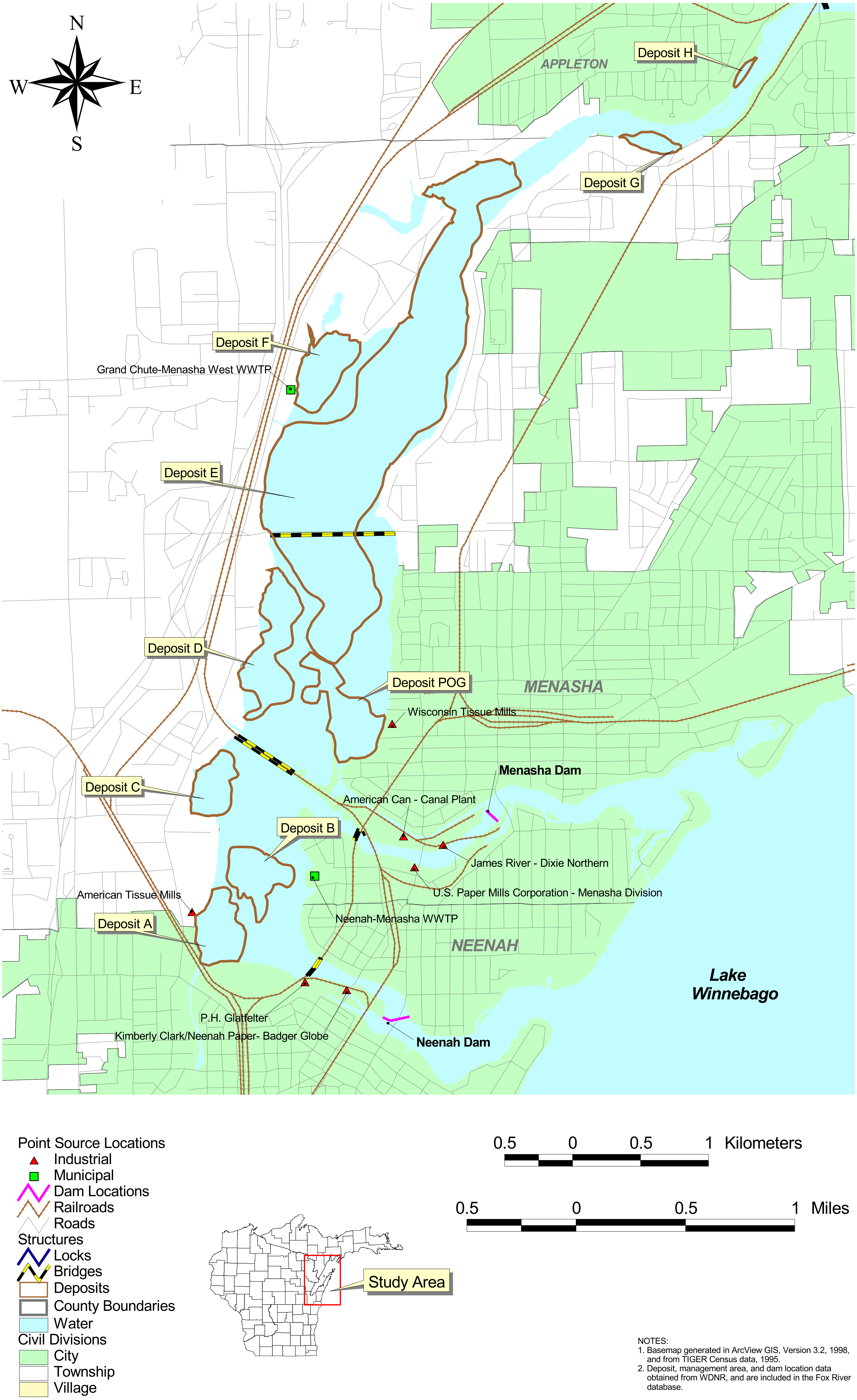
Bay, while PCBs in Green Bay migrate into Lake Michigan. Therefore, PCB dispersal is one factor in the observed PCB declines. In addition, some of the variability observed in the data may be accounted for by changes in river profile, burial, scour by flood or ice, and propeller wash in the lower reaches of the river. As the analysis focused solely on the existing data, these potential mechanisms could not be adequately controlled or accounted for.

The conclusions of a general decrease in PCB burdens in sediments and fish of the Lower Fox River and in Zone 1 of Green Bay are consistent with findings by other researchers in the Great Lakes. Deceases in PCB concentrations have been observed in Lake Michigan (Offenberg and Baker, 2000; DeVault *et al.*, 1996; Lamon *et al.*, 1998), Lake Ontario (DeVault *et al.*, 1996; Gobas *et al.*, 1995) and Lake Superior (Smith, 2000). The yearly rate of decline for PCBs in biota and sediment of Lake Superior has been estimated at 5 to 10 percent per year (Smith, 2000), which is generally consistent with the trends observed in the Lower Fox River (Table 2-12). However, several other researchers have also noted breakpoints, or constant levels of PCBs beginning in the mid- to late 1980s. Lake trout and smelt are reported to have been relatively constant in Lake Ontario since 1985 (Gobas *et al.*, 1995). PCB body burdens in Lake Erie walleye were shown to be declining between the periods of 1977 and 1982, but after that period remained constant through 1990 (DeVault *et al.*, 1996). Time tends analysis for salmonids in Lake Michigan showed generally decreasing tissue concentrations, but upper-bound forecast estimates for lake trout and chinook indicated that there would be a steady, or slightly increasing annual average PCB concentration. These findings are consistent with the time trends analysis for the Lower Fox River, and suggest that there may continue to be slow, gradual declines, or steady-state concentrations for many years to come.

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

## 2.7 Section 2 Figures, Tables, and Plates

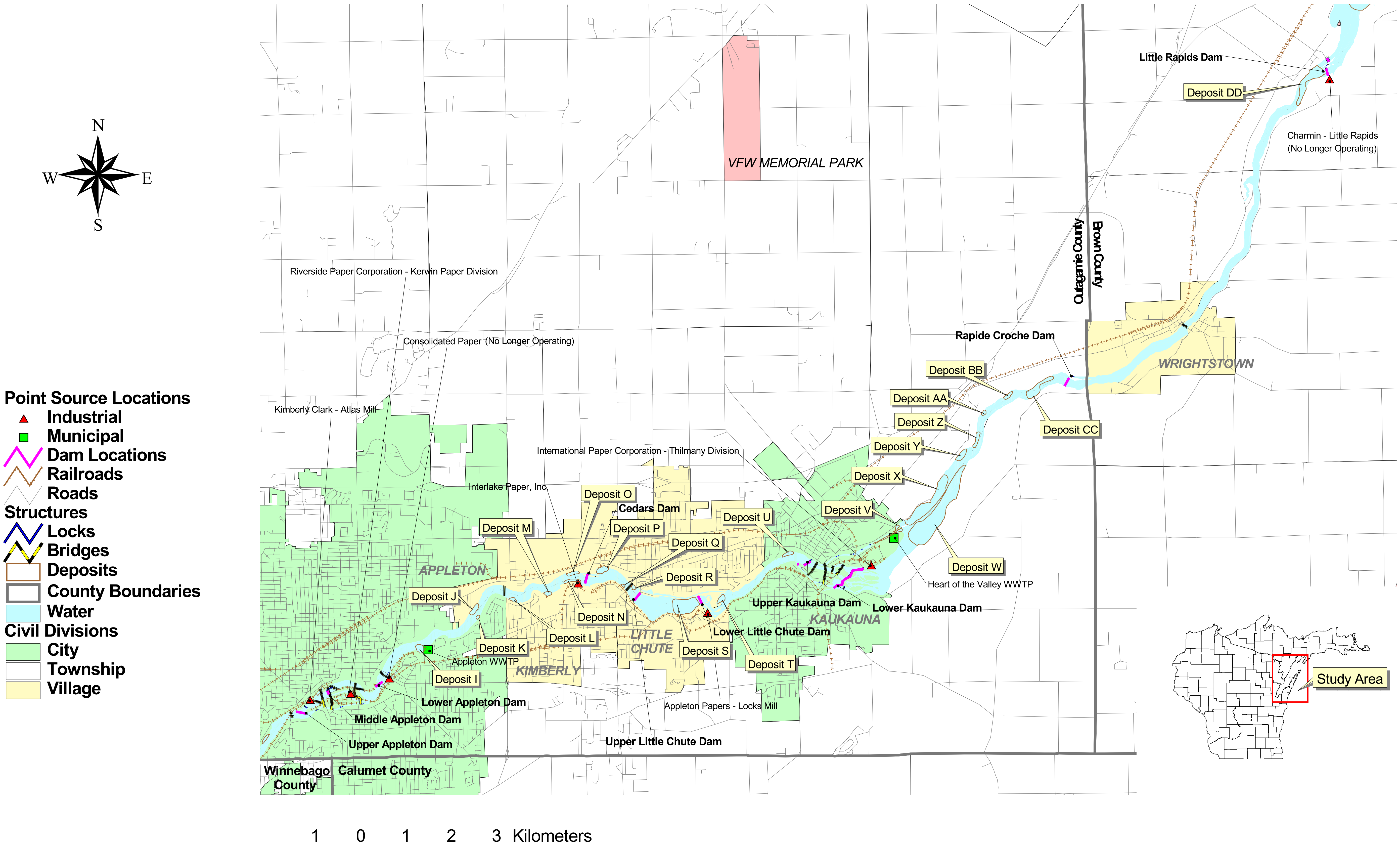
Figures, tables, and plates for Section 2 follow page 2-50 and include:




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.

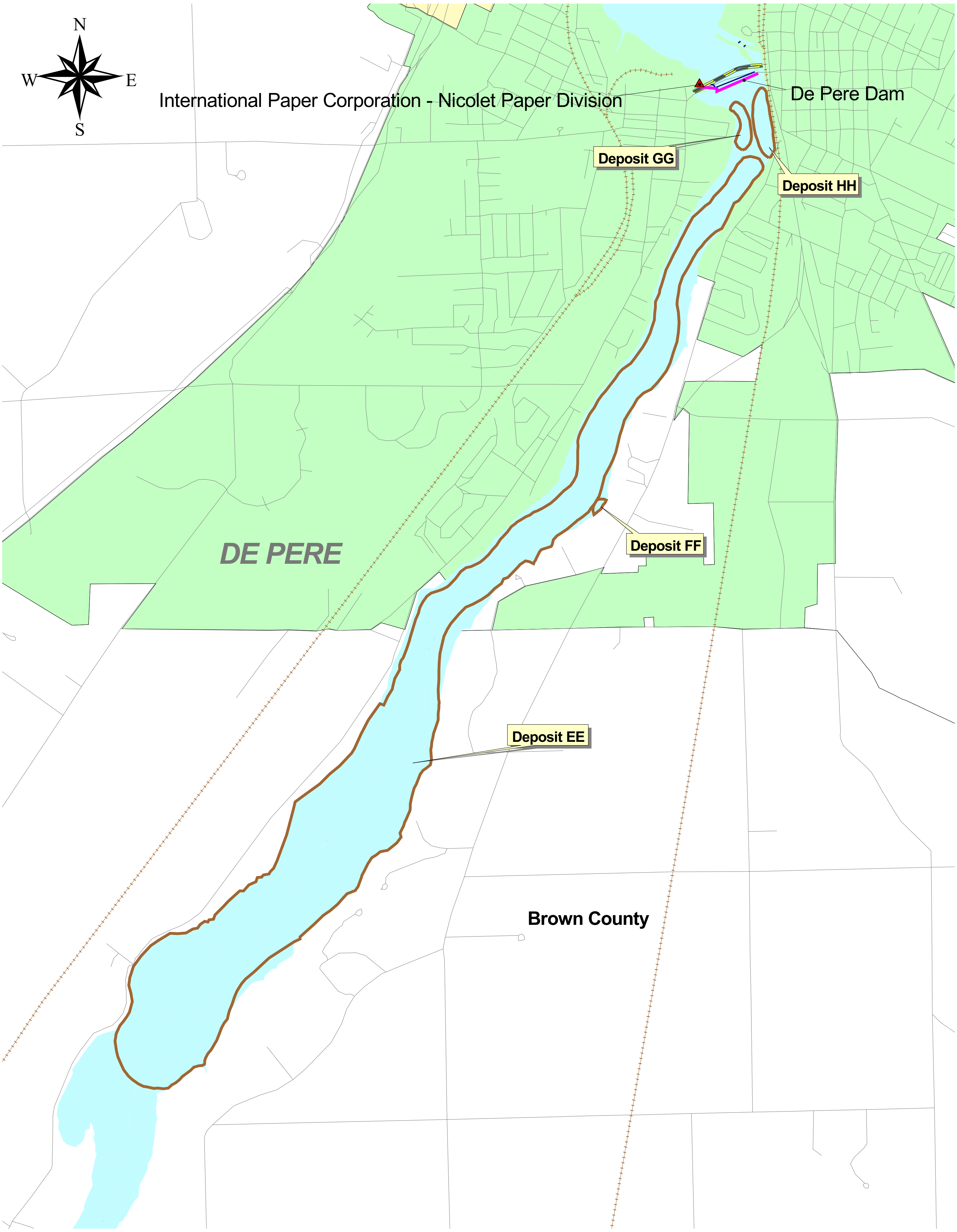
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Little Lake Butte des Morts Reach | REF NO: FS-14414-535-2-1 CREATED BY: SCJ PRINT DATE: 3/7/01 APPROVED: AGF |
|---|---|---|---|---|

FIGURE 2-1




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.

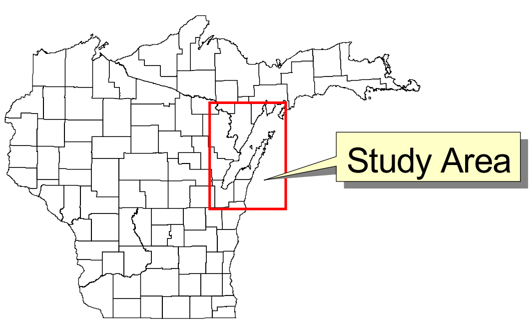
| | | | | |
|---|---|---|---|---|
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Appleton to Little Rapids Reach | REF NO: FS-14414-535-2-2 |
| | | | | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/7/01 |
| | | | FIGURE 2-2 | APPROVED: AGF |




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

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

**Civil Divisions**
- City
- Township
- Village

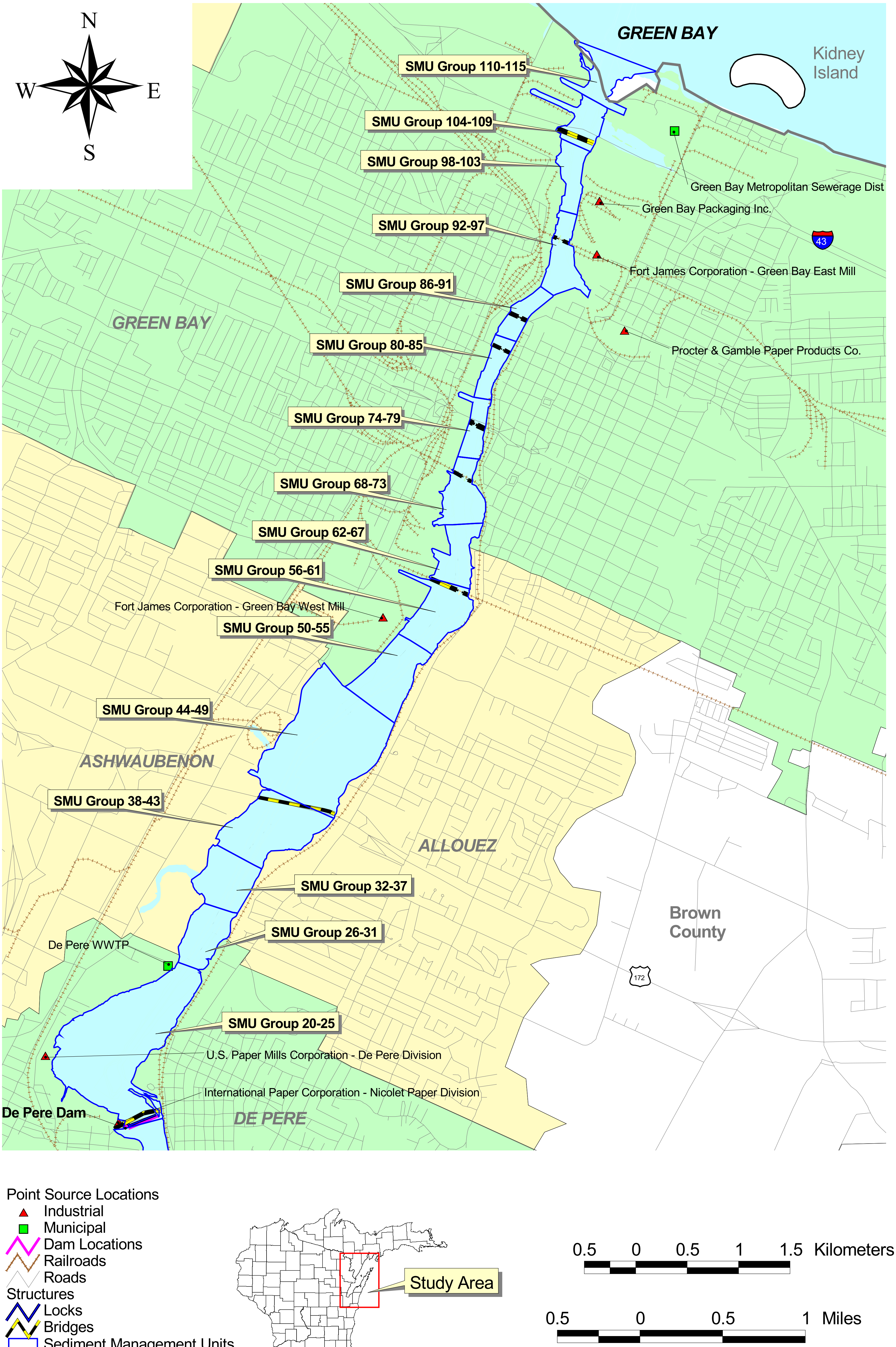



0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles

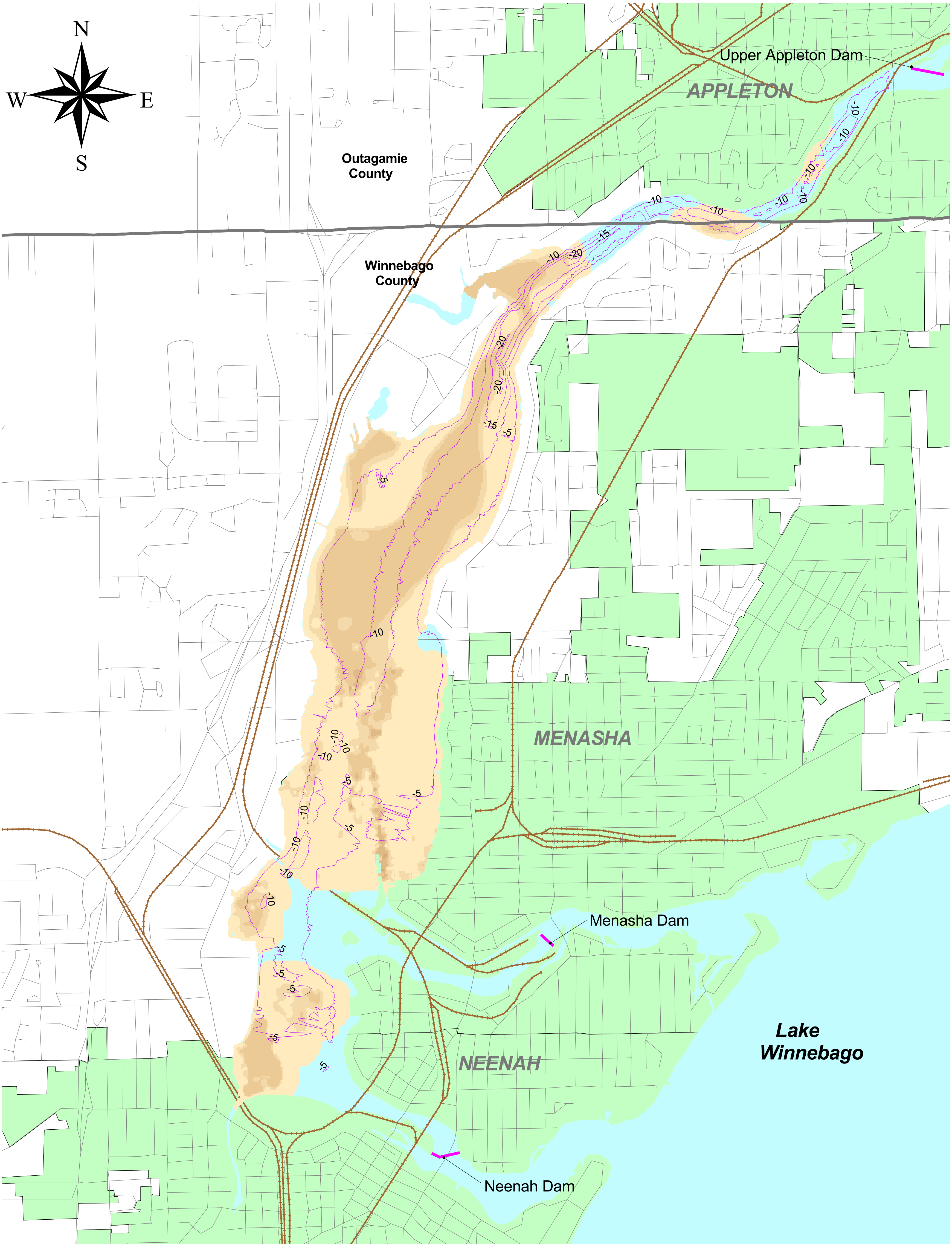
NOTES:
1. Basemap generated in ArcView GIS, Version 3.2, 1998, and from TIGER Census data, 1995.
2. Deposit, management area, and dam location data obtained from WDNR, and are included in the Fox River database.

| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Little Rapids to De Pere Reach | REF NO: FS-14414-535-2-3 |
|---|---|---|---|---|
| | | | | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/7/01 |
| | | | FIGURE 2-3 | 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 | Lower Fox River & Green Bay Feasibility Study | De Pere to Green Bay Reach | REF NO: FS-14414-535-2-4 |
|---|---|---|---|---|
| | | | FIGURE 2-4 | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/7/01 |
| | | | | APPROVED: AGF |



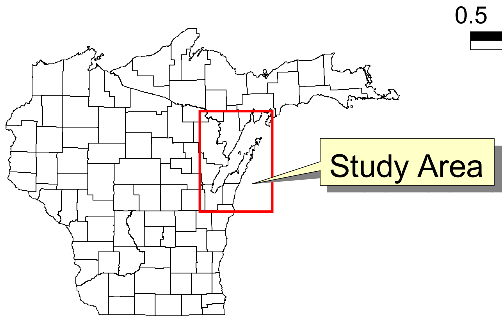

Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5

Bathymetric Countours (5 ft. intervals)
Dam Locations
Railroads
Roads
County Boundaries
Water

Civil Divisions
- City
- Township
- Village

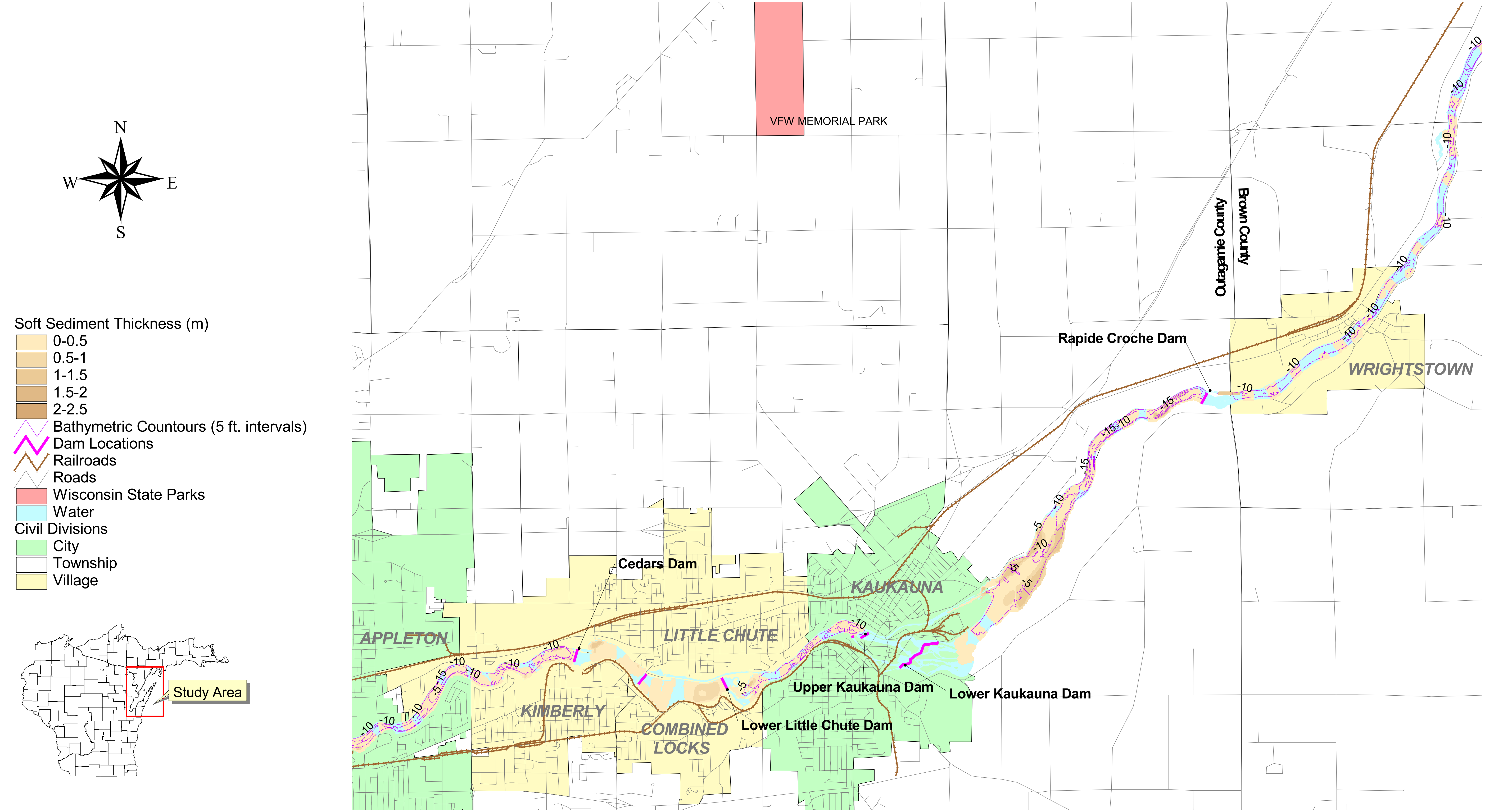
0.5 0 0.5 1 Kilometers

0.5 0 0.5 Miles




NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. 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 Feasibility Study | Soft Sediment Thickness (m) and Bathymetry (ft): Little Lake Butte des Morts | REF NO: FS-14414-535-2-5 |
|---|---|---|---|---|
| | | | FIGURE 2-5 | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/9/01 |
| | | | | APPROVED: AGF |

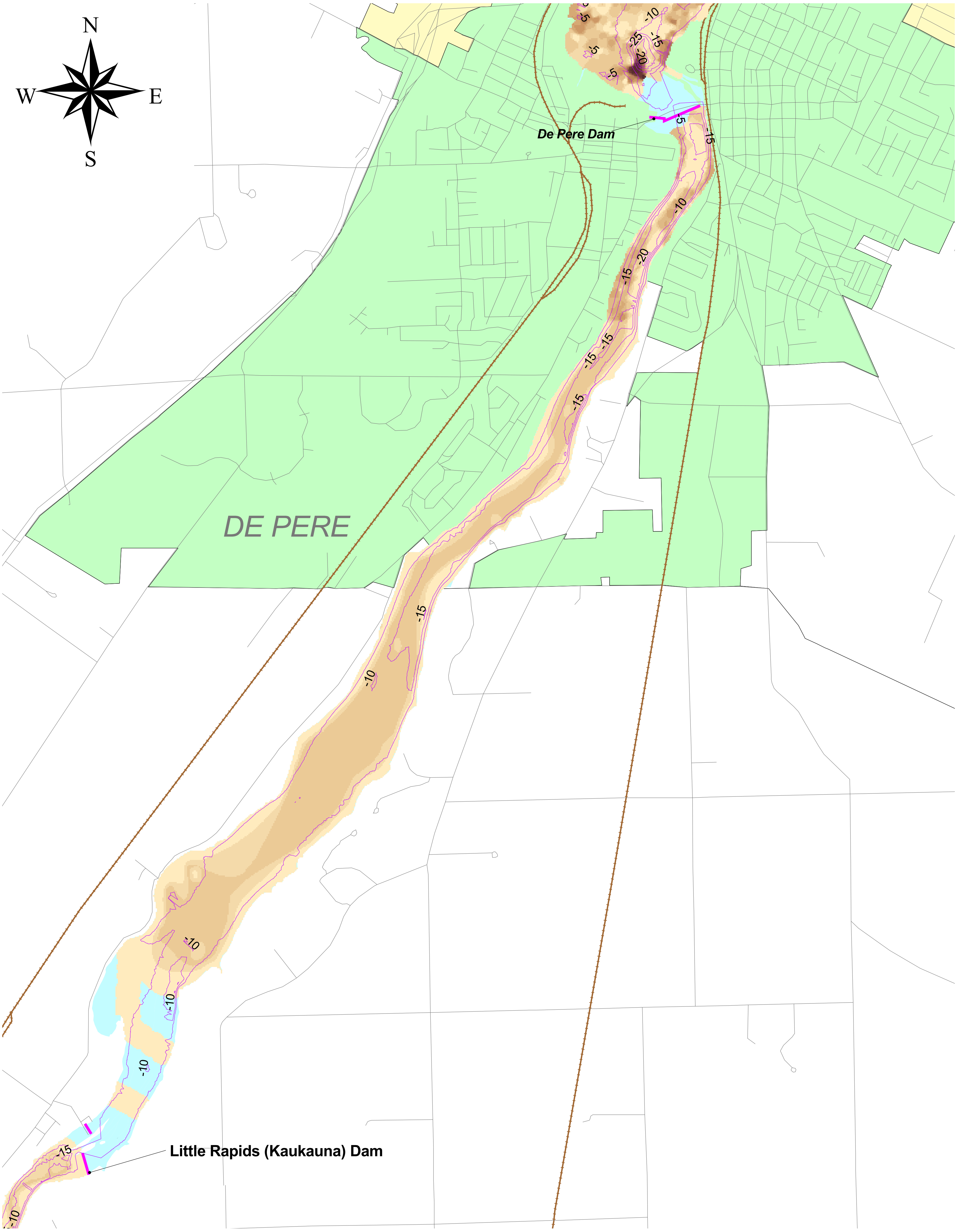



NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

1 0 1 2 Kilometers

1 0 1 2 Miles

| | | | | |
|---|---|---|---|---|
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Soft Sediment Thickness (m) and Bathymetry (ft): Appleton to Little Rapids | REF NO: FS-14414-535-2-6 |
| | | | | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/9/01 |
| | | | FIGURE 2-6 | APPROVED: AGF |

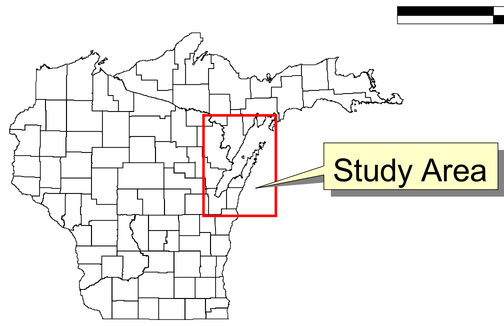



Soft Sediment Thickness (m)
- 0-0.5
- 0.5-1
- 1-1.5
- 1.5-2
- 2-2.5
- Bathymetric Countours (5 ft. intervals)
- Dam Locations
- Railroads
- Roads
- County Boundaries
- Water

Civil Divisions
- City
- Township
- Village

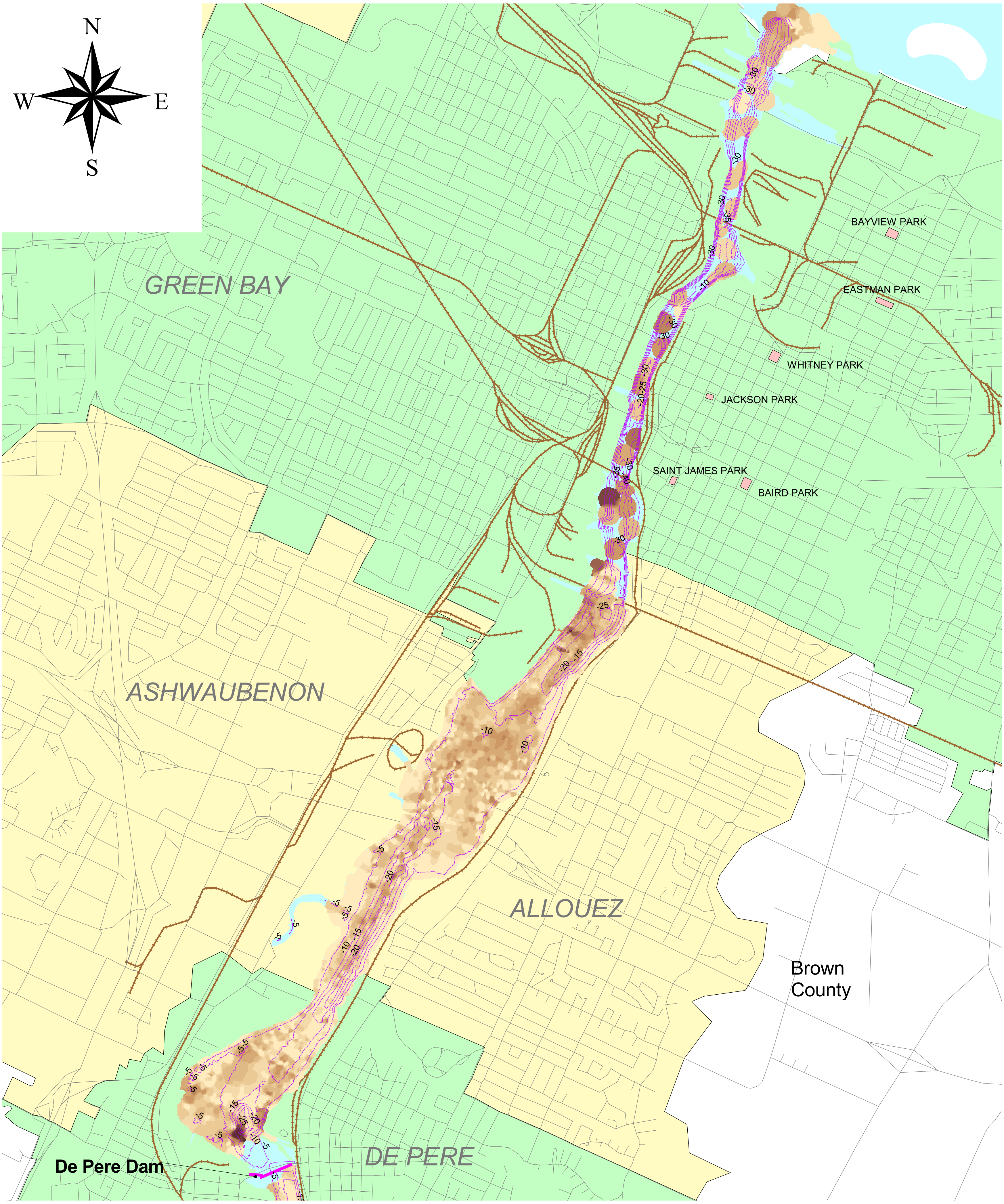
1 0 1 Kilometers

0.5 0 0.5 1 Miles




NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. Blue areas within the river or bay implies areas with no soft sediment.

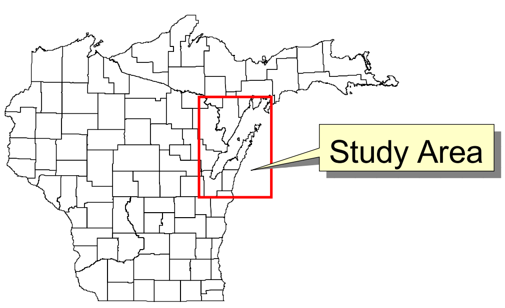
| | | | | |
|---|---|---|---|---|
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Soft Sediment Thickness (m) and Bathymetry (ft): Little Rapids to De Pere | REF NO: FS-14414-535-2-7 |
| | | | | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/9/01 |
| | | | FIGURE 2-7 | APPROVED: AGF |




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

Bathymetric Countours (5 ft. intervals)
Dam Locations
Railroads
Roads
County Boundaries
Wisconsin State Parks
Water

Civil Divisions
- City
- Township
- Village

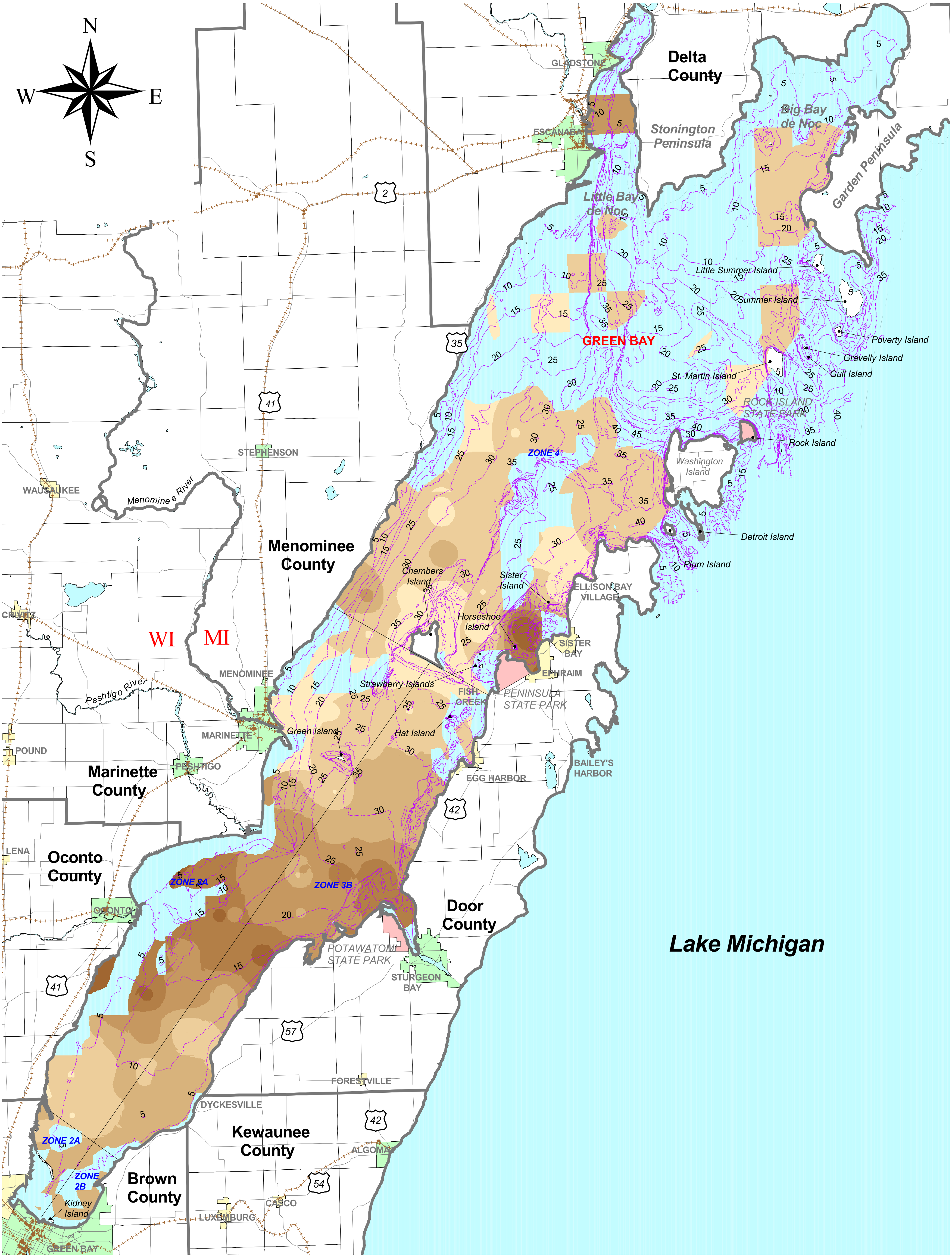



0.5 0 0.5 1 1.5 Miles

0.9 0 0.9 1.8 Kilometers

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. 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 Feasibility Study | Soft Sediment Thickness (m) and Bathymetry (ft): De Pere to Green Bay | REF NO: FS-14414-535-2-8 |
|---|---|---|---|---|
| | | | | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/9/01 |
| | | | FIGURE 2-8 | APPROVED: AGF |

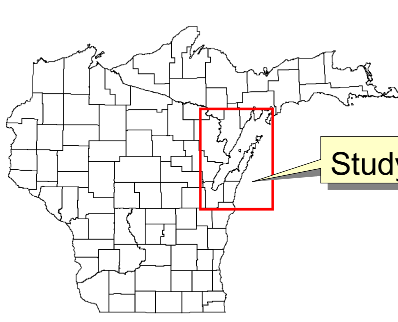



Soft Sediment Thickness (cm)

- 0 - 5
- 5 - 10
- 10 - 15
- 15 - 20
- 20 - 25
- 25 - 30
- Bathymetric Contours (5 m intervals)
- Railroads
- Roads
- County Boundaries
- Wisconsin State Parks
- Water

Civil Divisions

- City
- Township
- Village



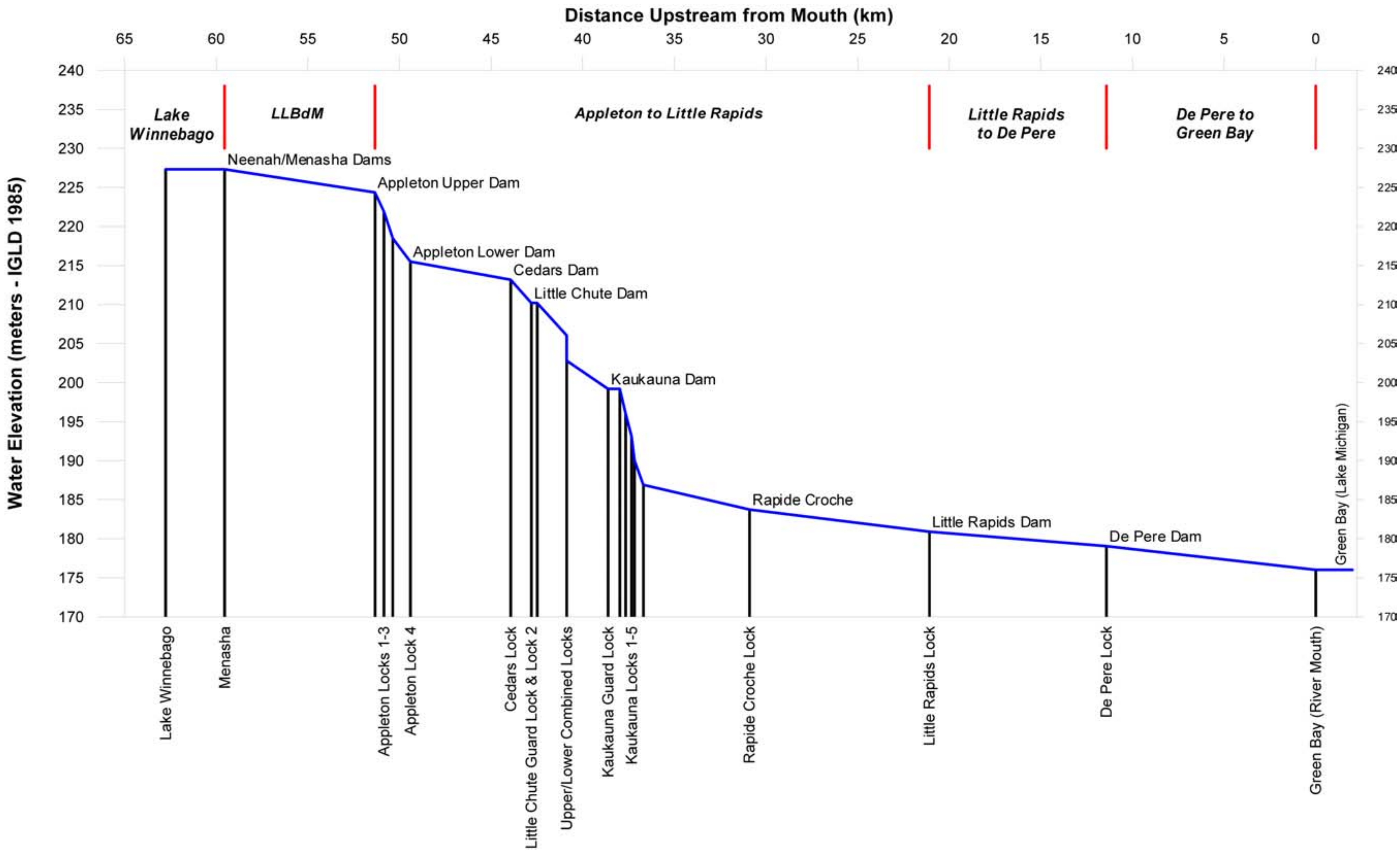

5 0 5 10 15 Kilometers

5 0 5 10 15 Miles

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. Sediment thickness data obtained from WDNR, 1999, and is based on coring data.
3. Bathymetric contours (ft) obtained from IGLD, 1985.
4. 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 Feasibility Study | Soft Sediment Thickness (cm) and Bathymetry (m): Green Bay | REF NO: FS-14414-535-2-9 |
|---|---|---|---|---|
| | | | FIGURE 2-9 | CREATED BY: SCJ |
| | | | | PRINT DATE: 3/12/01 |
| | | | | APPROVED: AGF |

## Figure 2-10 Lower Fox River Elevation Profile



# Figure 2-11 Green Bay Monthly Mean Bottom Circulation—July 1989

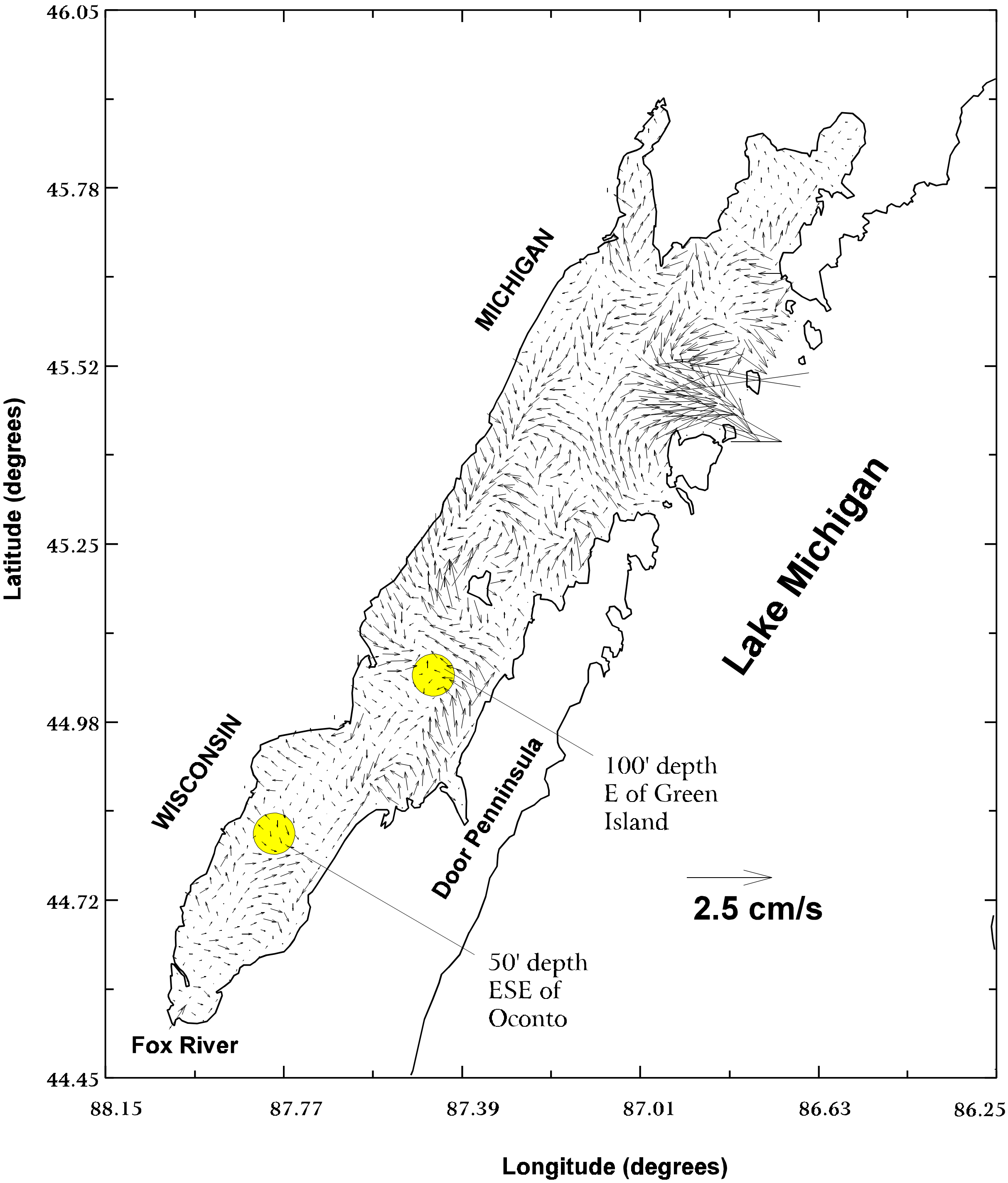
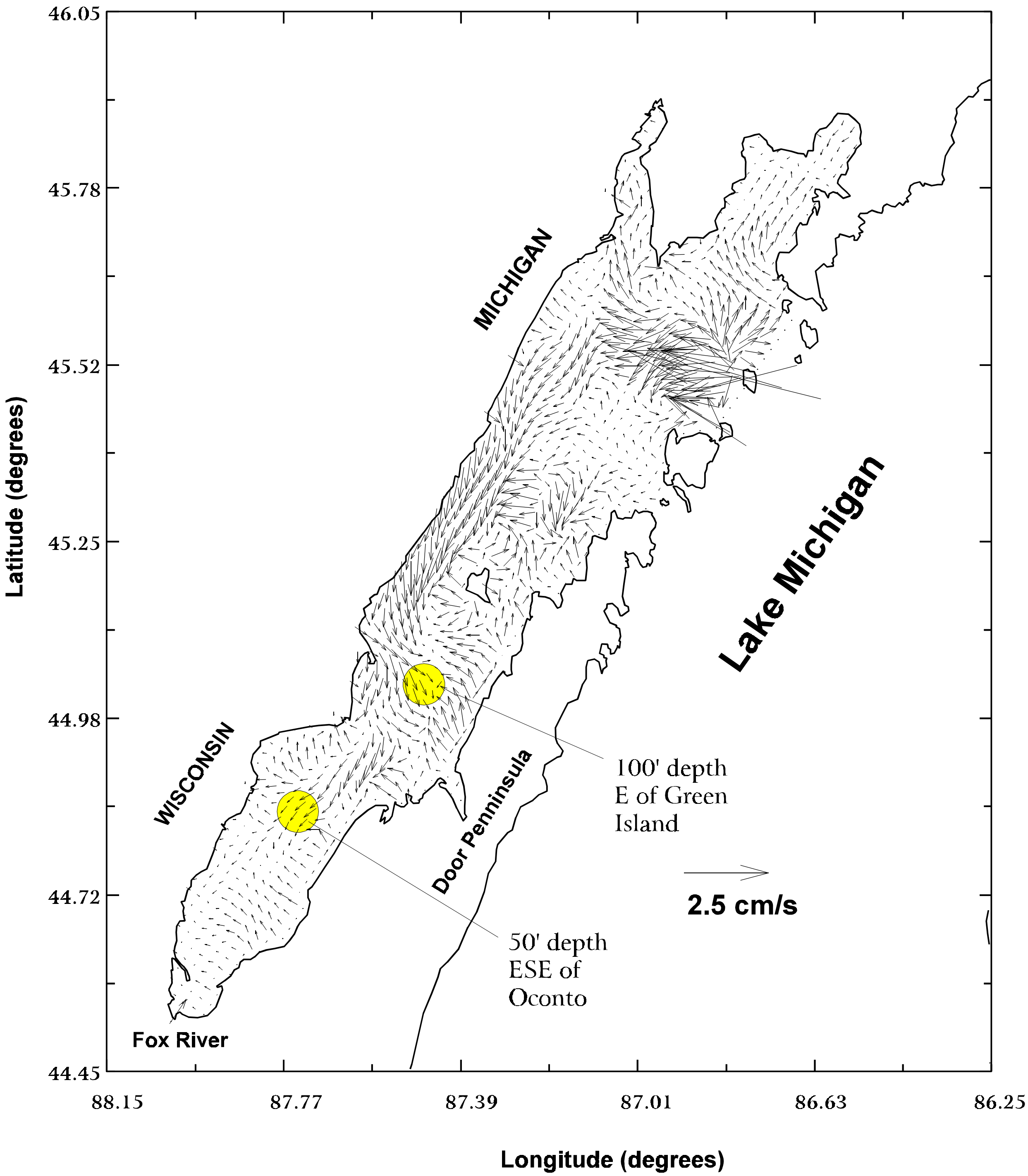
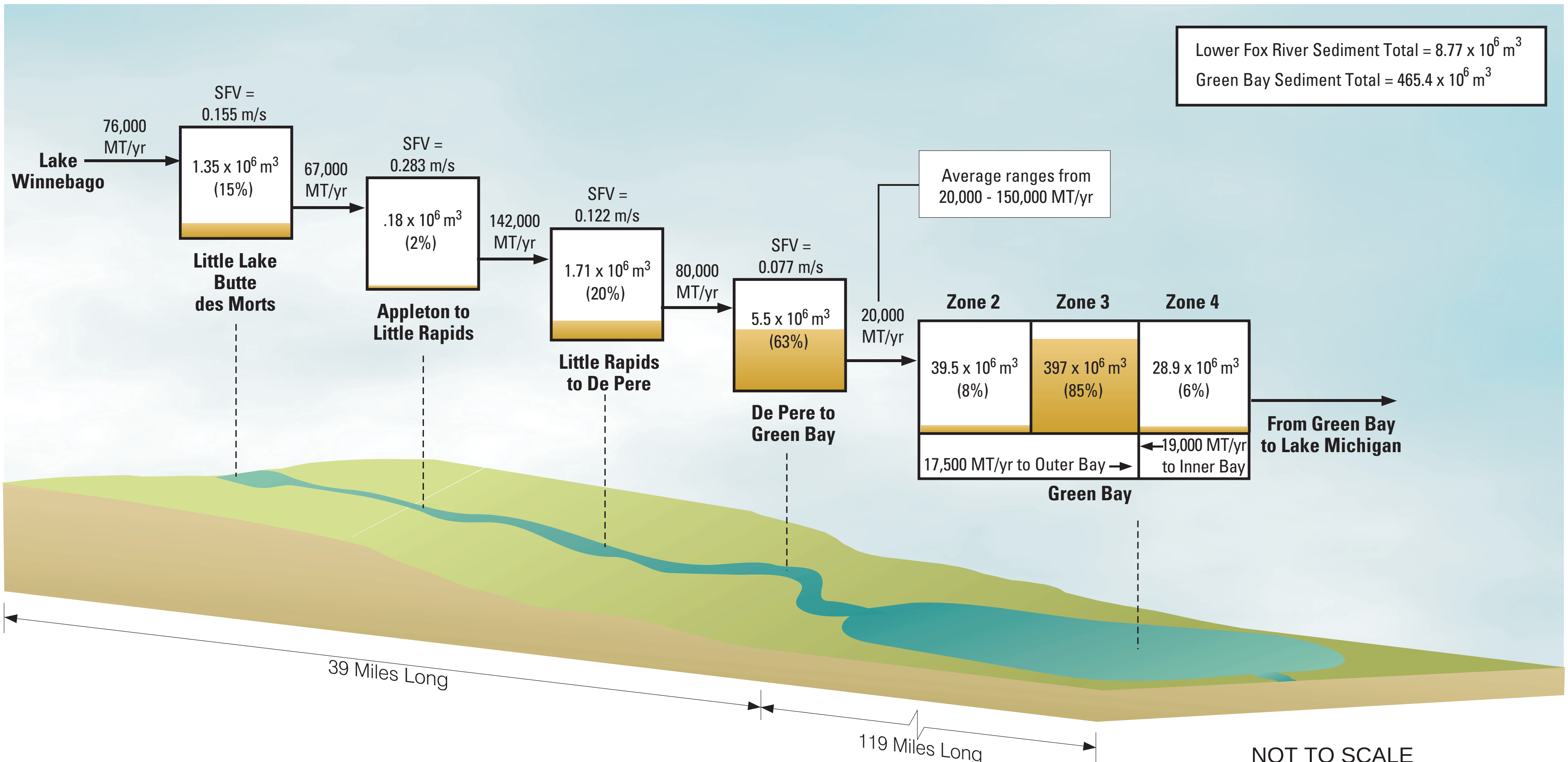


**Figure 2-12 Green Bay Monthly Mean Bottom Circulation—August 1989**



# Figure 2-13 Estimated Annual Sediment Transport Rates and Stream Flow Velocities

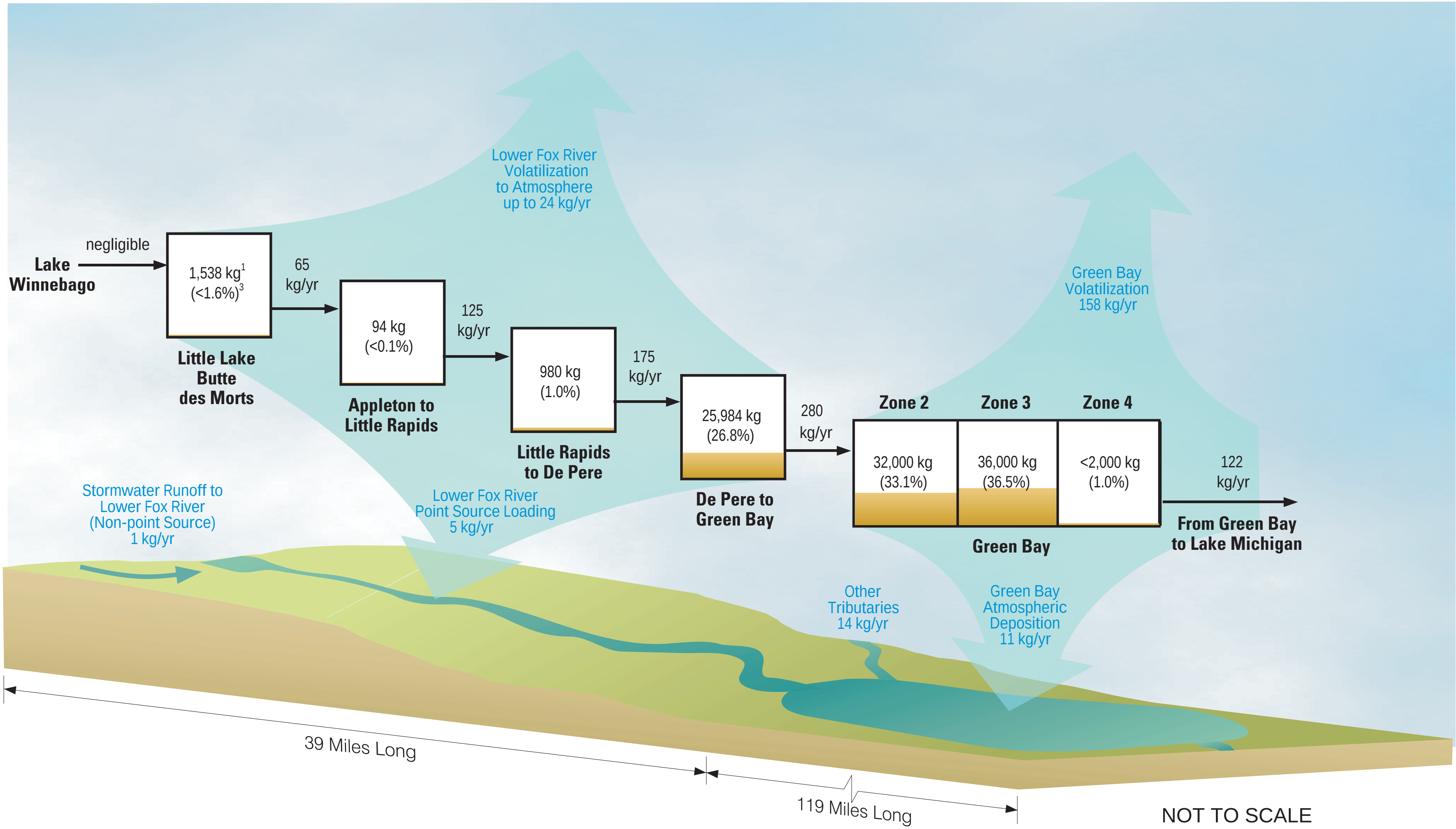



NOT TO SCALE

**Notes:** 1.Sediment volumes contain PCB concentrations > 50 µg/kg PCBs.
2. MT/yr = metric ton per year.
3. Data source for discharge rates is Steuer *et al.*, 1995.
4. Percentages correspond to fraction of total sediment volumes residing in each river reach or bay zone. Volume estimates obtained from RI Tables 5-13, 5-14 and 5-15 (ThermoRetec, 2001a).
5. SFV = Stream Flow Velocity.
6. The average Stream Flow Velocity for the entire Lower Fox River is 0.137 m/s.
7. 1 x $10^6 m^3$ = one million cubic meters of sediment

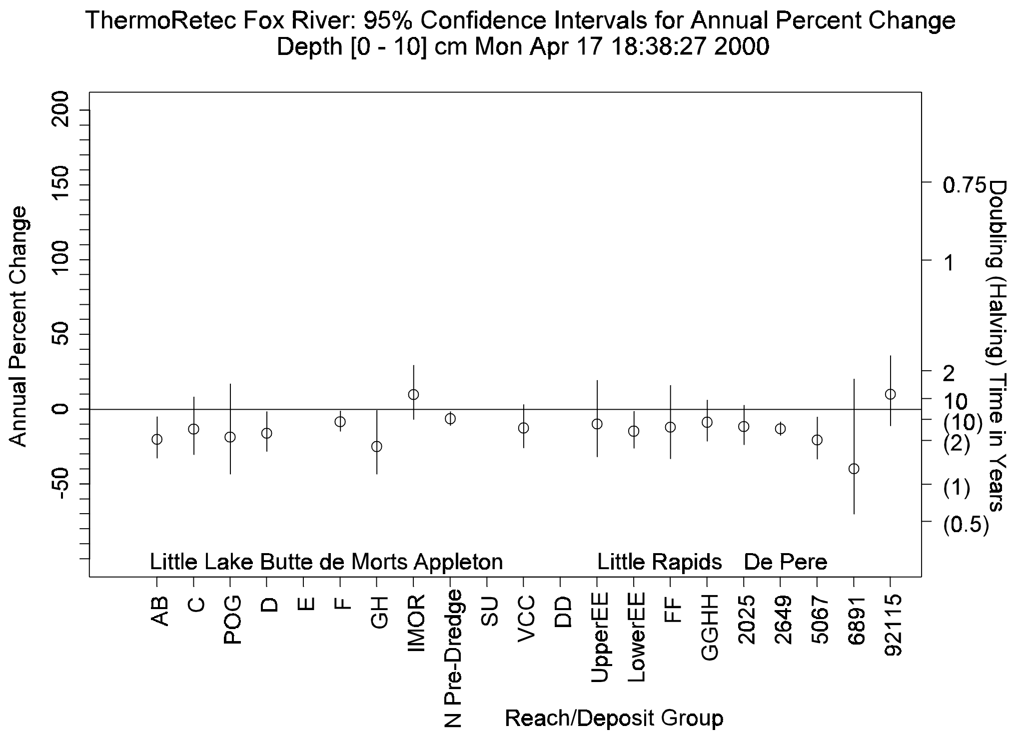
F:\PROJECTS\DOCS\4414\DOC\FS\DRAFT\FIGURES\SEC2\SEC2FIGS.PDF

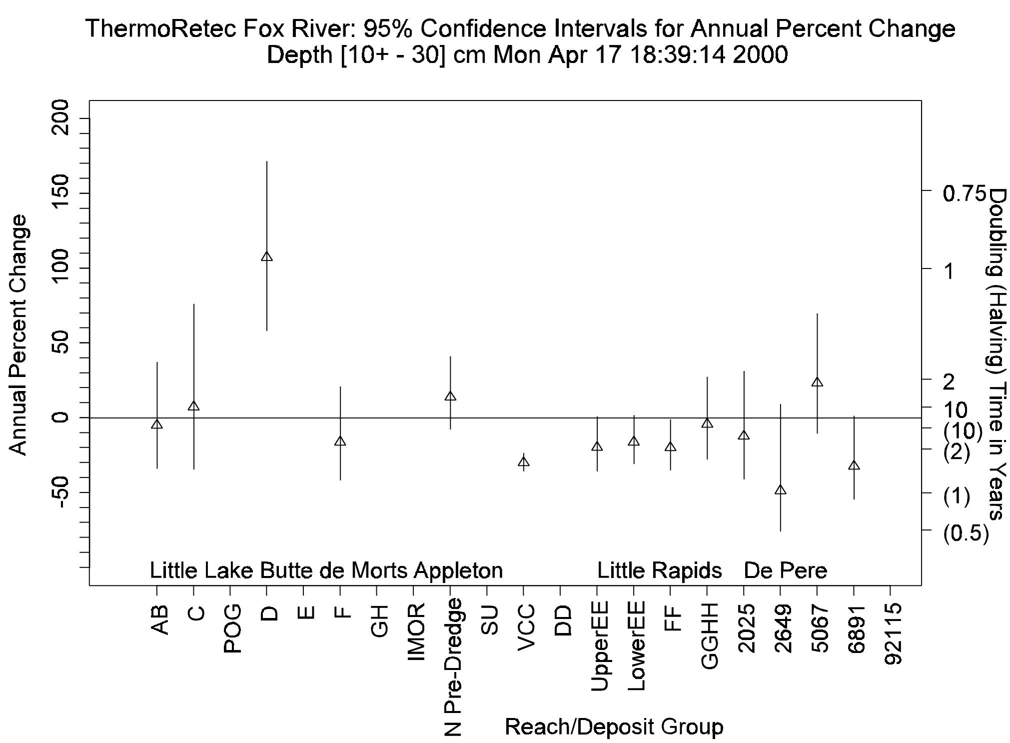
# Figure 2-14 Lower Fox River and Green Bay System Estimated PCB Mass and Major PCB Flux Pathways



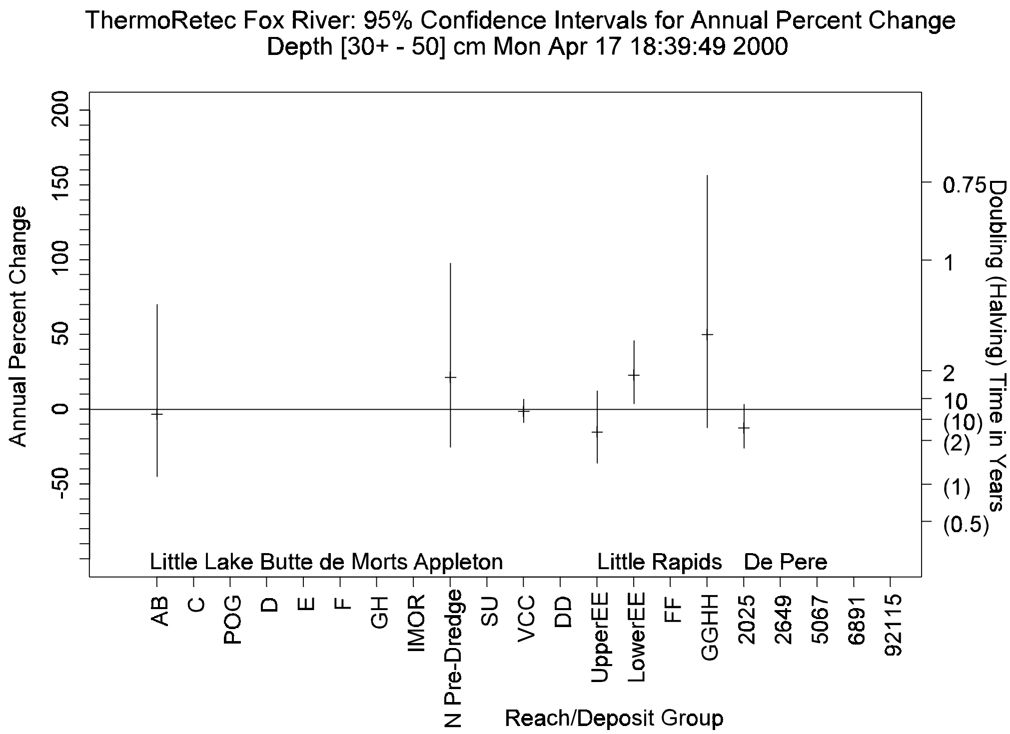

Notes: 1. PCB mass in sediments with PCB concentrations of 50 µg/kg or more.
2. Flux rates are average estimated loading rates per year.
3. Percentages correspond to fraction of total PCB mass in project area residing in each reach or zone. PCB mass estimates obtained from Tables 5-13, 5-14 and 5-15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

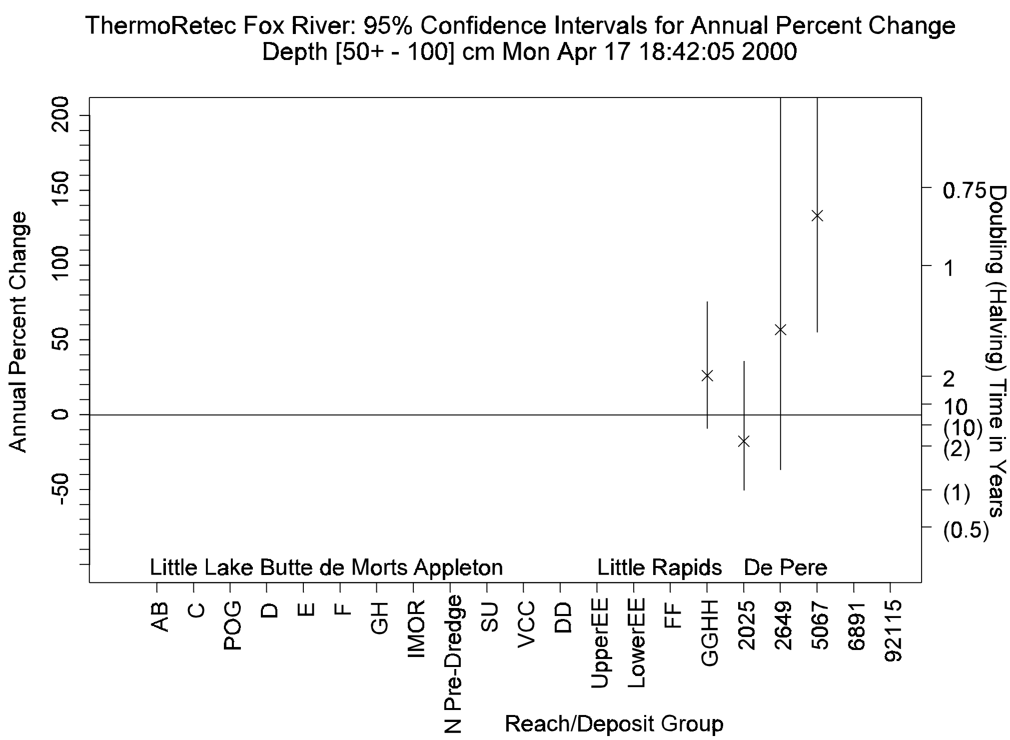
## Figure 2-15 Time Trends of PCBs in Sediments for Depths from 0 to 10 cm and from 10 to 30 cm



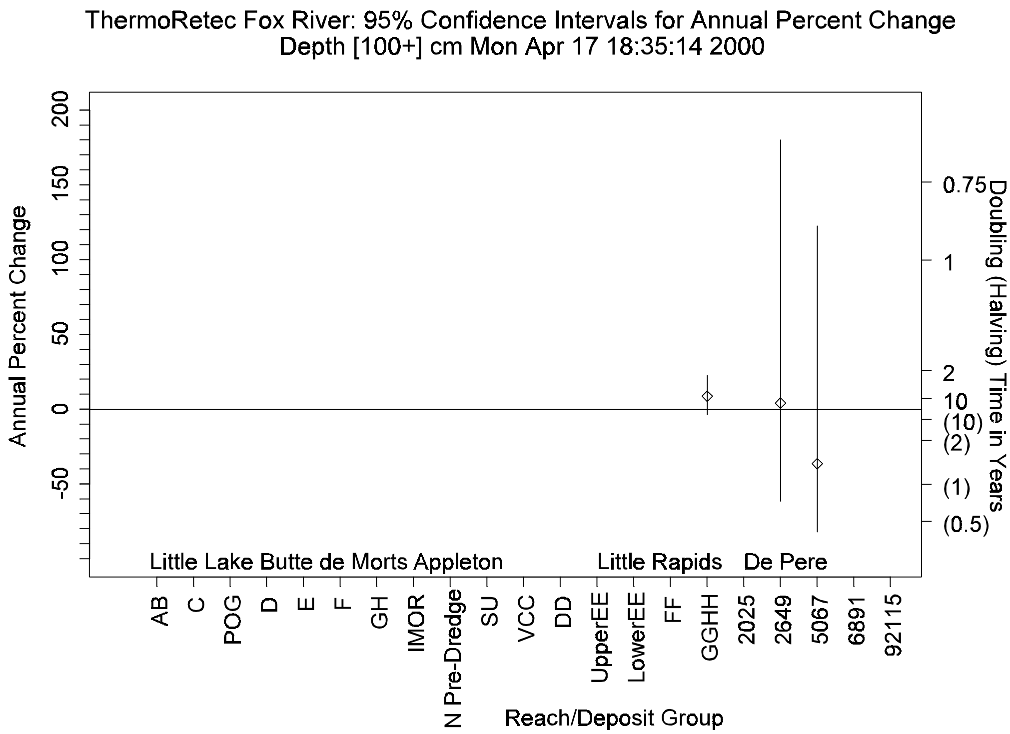



# Figure 2-16 Time Trends of PCBs in Sediments for Depths from 30 to 50 cm and from 50 to 100 cm



# Figure 2-17 Time Trends of PCBs in Sediments for Depths over 100 cm



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# Table 2-1 Physical Characteristics of the Lower Fox River

| | | Areal Extent | | | | Hydraulic Parameters | | Grain Size (all Depths)[5] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deposit or SMU Group | Total PCB Mass[1] (kg) | Surface Area[1] (hectares) | Average Thickness (m)[2] | Maximum PCB Sample Depth (m)[2] | Volume[1] ($m^3$) | Average Flow[3] (m/s) | 100-year Peak[4] (m/s) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | Percent Moisture | Average Dry Bulk Density (g/cc) | Specific Gravity |
| *Little Lake Butte des Morts Reach* | | | | | | | | | | | | | | |
| **Reach Total** | **1,847.4** | **313.5** | **0.39** | **1.89** | **1,533,205** | **0.16** | **0.82** | **0.6** | **45.7** | **39.0** | **14.7** | **64** | **0.61** | **2.51** |
| A | 237.4 | 15.3 | 0.71 | 1.80 | 107,730 | 0.19 | 1.07 | 0.0 | 37.5 | 45.2 | 17.3 | — | 0.59 | NA |
| B | 410.9 | 14.7 | 0.28 | 0.43 | 41,740 | 0.15 | 0.85 | 0.0 | 64.7 | 25.1 | 10.1 | — | 1.00 | NA |
| C | 38.9 | 12.4 | 0.48 | 0.91 | 59,230 | 0.09 | 0.50 | 0.0 | 26.1 | 53.8 | 20.1 | — | 0.42 | 2.59 |
| D | 82.6 | 25.2 | 0.26 | 1.22 | 66,710 | 0.08 | 0.44 | 0.3 | 43.8 | 44.1 | 11.9 | — | 0.62 | NA |
| E | 452.8 | 202.5 | 0.43 | 1.74 | 869,910 | 0.08 | 0.45 | 0.3 | 27.7 | 50.2 | 21.8 | — | 0.53 | 2.43 |
| F | 10.9 | 16.9 | 0.57 | 1.83 | 95,920 | 0.10 | 0.55 | 0.0 | 27.1 | 50.8 | 22.1 | — | 0.31 | NA |
| G | 0.7 | 4.1 | 0.20 | 0.30 | 8,380 | 0.35 | 1.10 | 0.0 | 55.7 | 31.0 | 13.3 | — | 0.68 | NA |
| H | 0.7 | 1.1 | 0.06 | 0.38 | 690 | 0.35 | 1.95 | 0.0 | 67.7 | 20.3 | 12.0 | — | 0.91 | NA |
| POG | 303.5 | 21.3 | 0.48 | 1.89 | 103,030 | 0.09 | 0.50 | 2.2 | 57.4 | 34.4 | 6.0 | — | 0.40 | NA |
| IDAs[6] | 309.0 | NA | NA | 0.15 | 179,865 | NA | NA | 3.2 | 49.3 | 35.6 | 12.0 | — | NA | NA |
| *Appleton to Little Rapids Reach* | | | | | | | | | | | | | | |
| **Reach Total** | **108.5** | **153.1** | **0.13** | **1.83** | **197,015** | **0.22** | **1.22** | **0.0** | **40.5** | **40.3** | **19.2** | **55** | **0.71** | **2.44** |
| I | 0.2 | 3.0 | 0.12 | 0.54 | 3,570 | 0.30 | 1.67 | 0.0 | 35.0 | 45.3 | 19.8 | — | 0.81 | NA |
| J | 0.1 | 2.5 | 0.06 | 0.42 | 1,630 | 0.30 | 1.67 | 0.0 | 15.0 | 65.7 | 19.3 | — | 0.65 | NA |
| K | 0.1 | 0.5 | 0.09 | 0.21 | 480 | 0.30 | 1.67 | 0.0 | 62.7 | 22.3 | 15.0 | — | 0.77 | NA |
| L | 0.1 | 1.1 | 0.05 | 0.30 | 570 | 0.21 | 1.17 | 0.0 | 45.3 | 34.0 | 20.8 | — | 1.02 | NA |
| M | 0.2 | 1.3 | 0.12 | 0.36 | 1,650 | 0.21 | 1.17 | 0.0 | 7.3 | 63.3 | 29.3 | — | 0.46 | NA |
| N | 29.6 | 2.3 | 0.22 | 0.89 | 4,880 | 0.21 | 1.17 | 0.5 | 41.1 | 46.9 | 11.6 | — | — | NA |
| O | 2.0 | 1.9 | 0.13 | 0.35 | 2,430 | 0.21 | 1.17 | 0.0 | 39.4 | 43.6 | 17.0 | — | 0.57 | NA |
| P | 5.3 | 3.1 | 0.41 | 0.94 | 12,800 | 0.21 | 1.17 | 0.0 | 36.0 | 49.6 | 14.4 | — | 0.67 | NA |
| Q | 0.2 | 0.4 | 0.05 | 0.55 | 210 | 0.21 | 1.17 | 0.0 | 49.0 | 39.7 | 11.3 | — | 0.49 | NA |
| R | 0.0 | 0.8 | 0.13 | 0.13 | 990 | 0.21 | 1.17 | 0.0 | 12.0 | 56.0 | 32.0 | — | 0.99 | NA |
| S | 0.1 | 16.6 | 0.08 | 0.34 | 12,550 | 0.23 | 1.26 | 0.0 | 46.5 | 36.0 | 17.5 | — | 0.54 | NA |
| T | 11.3 | 2.1 | 0.40 | 0.52 | 8,360 | 0.21 | 1.18 | 0.0 | 87.7 | 7.3 | 5.0 | — | 0.46 | NA |
| U | 0.2 | 1.7 | 0.03 | 0.26 | 600 | 0.21 | 1.18 | 0.0 | 51.8 | 35.8 | 12.5 | — | 0.76 | NA |
| V | 0.0 | 2.4 | 0.00 | 0.63 | 60 | 0.15 | 0.82 | 0.0 | 32.2 | 52.0 | 15.8 | — | 0.41 | NA |
| W | 6.8 | 56.4 | 0.09 | 1.52 | 53,490 | 0.16 | 0.87 | 0.0 | 50.1 | 32.5 | 17.4 | — | 0.66 | 2.34 |
| X | 2.5 | 25.6 | 0.12 | 1.83 | 30,820 | 0.16 | 0.87 | 0.0 | 33.2 | 52.8 | 14.0 | — | 0.52 | 2.54 |
| Y | 0.3 | 3.2 | 0.04 | 0.34 | 1,330 | 0.17 | 0.93 | 0.0 | 45.0 | 39.7 | 15.3 | — | 0.67 | NA |
| Z | 0.4 | 2.4 | 0.18 | 0.83 | 4,280 | 0.17 | 0.93 | 0.0 | 34.7 | 42.7 | 22.7 | — | 0.76 | NA |
| AA | 0.0 | 0.8 | 0.05 | 0.35 | 390 | 0.27 | 1.49 | 0.0 | 54.7 | 20.7 | 24.7 | — | 1.18 | NA |
| BB | 0.1 | 1.6 | 0.05 | 0.39 | 780 | 0.27 | 1.49 | 0.0 | 47.7 | 33.0 | 19.3 | — | 0.93 | NA |
| CC | 0.7 | 8.5 | 0.17 | 0.43 | 14,300 | 0.27 | 1.49 | 0.0 | 31.3 | 26.0 | 42.7 | — | 0.92 | NA |
| DD | 33.5 | 14.9 | 0.19 | 0.53 | 28,620 | 0.19 | 1.04 | 0.0 | 32.6 | 42.1 | 25.3 | — | 0.65 | NA |
| IDAs[6] | 14.8 | NA | NA | 0.10 | 12,225 | NA | NA | NA | NA | NA | NA | — | NA | NA |

# Table 2-1 Physical Characteristics of the Lower Fox River (Continued)

| Deposit or SMU Group | Total PCB Mass[1] (kg) | Areal Extent | | | | Hydraulic Parameters | | Grain Size (all Depths)[5] | | | | Percent Moisture | Average Dry Bulk Density (g/cc) | Specific Gravity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Surface Area[1] (hectares) | Average Thickness (m)[2] | Maximum PCB Sample Depth (m)[2] | Volume[1] ($m^3$) | Average Flow[3] (m/s) | 100-year Peak[4] (m/s) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | | | |
| *Little Rapids to De Pere Reach* | | | | | | | | | | | | | | |
| **Reach Total** | **1,245.5** | **266.2** | **0.55** | **2.30** | **1,932,690** | **0.12** | **0.68** | **1.6** | **25.1** | **48.1** | **25.2** | **64** | **0.56** | **2.47** |
| EE | 828.4 | 258.8 | 0.64 | 2.30 | 1,660,390 | 0.12 | 0.68 | 0.5 | 26.8 | 49.7 | 23.0 | — | 0.50 | 2.47 |
| FF | 0.1 | 0.5 | 0.14 | 0.46 | 700 | 0.12 | 0.68 | 0.0 | 27.2 | 51.6 | 21.1 | — | 0.72 | NA |
| GG | 81.0 | 2.4 | 0.76 | 2.30 | 18,320 | 0.12 | 0.68 | 1.2 | 18.0 | 57.6 | 23.1 | — | 0.48 | NA |
| HH | 70.2 | 4.5 | 0.66 | 2.30 | 29,550 | 0.12 | 0.68 | 2.8 | 21.7 | 57.1 | 18.4 | — | 0.53 | NA |
| IDAs[6] | 265.8 | NA | NA | 1.83 | 223,730 | NA | NA | 3.7 | 31.9 | 24.3 | 40.1 | — | NA | NA |
| *De Pere to Green Bay Reach* | | | | | | | | | | | | | | |
| **Reach Total** | **25,983.8** | **523.6** | **1.06** | **3.96** | **5,518,180** | **0.08** | **0.44** | **0.0** | **42.5** | **40.6** | **16.9** | **51** | **0.57** | **2.36** |
| 20 to 25 | 5,557.3 | 113.4 | 0.93 | 2.13 | 1,054,580 | 0.07 | 0.39 | 0.0 | 42.3 | 42.5 | 15.2 | — | 0.60 | 2.32 |
| 26 to 31 | 761.2 | 22.0 | 0.75 | 2.13 | 166,230 | 0.11 | 0.61 | 0.0 | 50.8 | 34.5 | 14.7 | — | NA | NA |
| 32 to 37 | 1,172.9 | 26.8 | 0.87 | 2.74 | 233,230 | 0.10 | 0.53 | 0.0 | 31.8 | 49.9 | 18.3 | — | 0.34 | NA |
| 38 to 43 | 1,149.5 | 46.5 | 0.87 | 2.74 | 402,360 | 0.08 | 0.43 | 0.0 | 34.5 | 47.4 | 18.1 | — | 0.50 | NA |
| 44 to 49 | 5,211.2 | 107.2 | 1.29 | 3.35 | 1,379,690 | 0.07 | 0.37 | 0.0 | 37.8 | 44.6 | 17.6 | — | 0.59 | 2.40 |
| 50 to 55 | 1,829.7 | 32.9 | 1.23 | 1.52 | 405,280 | 0.08 | 0.47 | 0.0 | 40.5 | 44.2 | 15.3 | — | 0.55 | NA |
| 56 to 61 | 5,174.7 | 29.7 | 1.54 | 3.96 | 457,490 | 0.06 | 0.36 | 0.0 | 32.1 | 51.9 | 16.0 | — | 0.65 | NA |
| 62 to 67 | 861.3 | 18.2 | 1.05 | 2.13 | 190,570 | 0.07 | 0.37 | 0.0 | 29.8 | 51.7 | 18.6 | — | NA | NA |
| 68 to 73 | 1,858.2 | 21.6 | 1.56 | 2.74 | 337,250 | 0.06 | 0.37 | 0.5 | 34.8 | 41.6 | 23.1 | — | 0.39 | NA |
| 74 to 79 | 430.2 | 11.8 | 1.20 | 1.52 | 141,950 | 0.07 | 0.38 | 0.0 | 34.8 | 42.2 | 23.0 | — | 0.71 | NA |
| 80 to 85 | 385.3 | 10.6 | 1.55 | 2.13 | 164,650 | 0.09 | 0.49 | 0.0 | 45.4 | 36.8 | 17.8 | — | NA | NA |
| 86 to 91 | 253.1 | 11.3 | 0.92 | 2.13 | 103,400 | 0.08 | 0.45 | 0.0 | 45.5 | 37.6 | 17.0 | — | 0.78 | NA |
| 92 to 97 | 254.8 | 19.8 | 0.60 | 0.91 | 118,500 | NA | NA | 0.0 | 60.3 | 27.9 | 11.8 | — | 0.62 | NA |
| 98 to 103 | 94.3 | 14.0 | 0.59 | 0.91 | 82,200 | NA | NA | 0.0 | 73.2 | 17.8 | 9.0 | — | NA | NA |
| 104 to 109 | 151.1 | 17.0 | 0.44 | 0.30 | 74,550 | NA | NA | 0.0 | 41.7 | 40.5 | 17.8 | — | 0.63 | NA |
| 110 to 115 | 839.0 | 20.8 | 1.52 | 1.52 | 206,250 | NA | NA | 0.0 | 44.2 | 38.9 | 16.9 | — | 0.50 | NA |
| **Entire River Values**[7] | **29,185** | **1,256** | **0.53** | **3.96** | **9,181,090** | **0.15** | **0.79** | **0.6** | **38.4** | **42.0** | **19.0** | **59** | **0.61** | **2.45** |

**Notes:**

1 Volume, mass and surface area listed in the table corresponds to the 50 ppb action level.
2 The average thickness is based on surface area and volume of sediment. The maximum thickness is represented by the deepest sampling depth interval.
3 The average flow for the river is 122 $m^3$/s.
4 The 100-year peak stream flow is 680 $m^3$/s.
5 Grain size results are averaged for all samples collected, regardless of depth. Gravel content is difference of 100 and sum of sand/silt/clay content.
6 IDAs are inter-deposit areas in each reach.
7 Physical characteristics generated from data in the Fox River Database (except flow) and may vary from PCB mass and volume estimates generated in later sections for remediation.
8 NA - Parameter value or average value is not available.
9 "—" - Percent moisture value averaged for reach.

# Table 2-2 Physical Characteristics of Green Bay

| Deposit or Zone | Total PCB Mass[1] (kg) | Areal Extent | | | | Hydraulic Parameters | | Grain Size (all Depths) | | | | Percent Moisture | Average Bulk Density (g/cc) | Specific Gravity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Surface Area[1] (hectares) | Average Thickness (m)[2] | Maximum PCB Sample Depth (m)[2] | Volume[1] ($m^3$) | Average Flow[3] (m/s) | 100-year Peak[4] (m/s) | Gravel (%) | Sand (%) | Silt (%) | Clay (%) | | | |
| **Bay Totals** | **67,556** | **421,288** | **0.25** | **0.91** | **465,396,800** | **0.05** | **unknown** | **0.4** | **82.7** | **11.4** | **5.6** | **NA** | **NA** | **NA** |
| 2A | 14,118 | 5,931 | 0.34 | 0.91 | 20,033,600 | 0.05 | unknown | 0.1 | 73.3 | 18.0 | 8.6 | NA | NA | NA |
| 2B | 17,273 | 5,150 | 0.38 | 0.91 | 19,458,000 | 0.05 | unknown | | | | | NA | NA | NA |
| 3A | 18,537 | 85,891 | 0.21 | 0.30 | 181,301,800 | 0.05 | unknown | 0.0 | 98.4 | 0.8 | 0.9 | NA | NA | NA |
| 3B | 16,703 | 69,339 | 0.31 | 0.62 | 215,681,400 | 0.05 | unknown | 0.1 | 62.7 | 24.9 | 12.4 | NA | NA | NA |
| 4 | 925 | 254,977 | 0.01 | 0.30 | 28,922,000 | 0.05 | unknown | 1.4 | 96.3 | 1.9 | 0.5 | NA | NA | NA |

**Note:**

1 Volume, mass and surface area listed in the table corresponds to the 50 ppb action level.

2 The average thickness is based on surface area and volume of sediment. The maximum thickness is represented by the deepest sampling depth interval

3 The average flow for the bay is based on HydroQual Modeling Efforts (Blumberg *et al.*, 2000).

4 The 100-year peak stream flow is unknown within Green Bay.

5 NA - Parameter value or average value is not available.

# Table 2-3 Land Use Classification for Counties Bordering Green Bay

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

**Notes:**

Ind./Com. is Industrial/Commercial. This category also includes lands designated for transportation/utility use.

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

[1] For Brown County, there was no distinction between forested, open, and vacant land use.

[2] For Door County, wetlands, beaches, marshes, grasslands, and meadows are combined and equal about 0.6% of land designated as wetlands.

[3] For Kewaunee County, only land use in the Town of Red River was available. This is the area which borders Green Bay and in which Dyckesville is located. Also, open and vacant land are not distinguished.

[4] Land use information only available for the eastern one-quarter of Oconto County. Total area of Oconto County is 263,442 hectares (650,976 acres).

[5] There was no distinction of urban land use between residential and industrial/commercial or Marinette County.

[6] Combined classifications were divided equally when calculating total land usage values.

## Table 2-4 Lower Fox River Gradient and Lock/Dam Information

| Lock | Lock Water Elevation (meters IGLD*) | Lock Water Elevation (feet IGLD*) | Dam | Dam Water Elevation (meters IGLD*) | Dam Water Elevation (feet IGLD*) | Miles Upstream | Gradient** |
|---|---|---|---|---|---|---|---|
| Lake Winnebago | 227.11 | 745.10 | | 227.11 | 745.10 | 39.0 | — |
| Menasha | 227.11 | 745.10 | Menasha Dam | 227.09 | 745.03 | 37.0 | 6.6E-06 |
| Appleton Lock 1 | 224.15 | 735.40 | Appleton Upper Dam | 224.15 | 735.40 | 31.9 | 3.6E-04 |
| Appleton Lock 2 | 221.19 | 725.70 | | | | 31.6 | |
| Appleton Lock 3 | 218.27 | 716.10 | | | | 31.3 | |
| Appleton Lock 4 | 215.28 | 706.30 | Appleton Lower Dam | 215.27 | 706.25 | 30.7 | 4.6E-03 |
| Cedars Lock | 212.96 | 698.70 | Cedars Dam | 212.95 | 698.66 | 27.3 | 4.2E-04 |
| Little Chute Guard Lock | 209.98 | 688.90 | Little Chute Dam | 209.97 | 688.88 | 26.6 | 2.6E-03 |
| Little Chute Lock 2 | 209.98 | 688.90 | | | | 26.4 | |
| Upper Combined Lock | 205.83 | 675.30 | | | | 25.4 | |
| Lower Combined Lock | 202.60 | 664.70 | | | | 25.4 | |
| Kaukauna Guard Lock | 198.97 | 652.80 | Kaukauna Dam | 198.96 | 652.76 | 24.0 | 2.6E-03 |
| Kaukauna Lock 1 | 198.97 | 652.80 | | | | 23.6 | |
| Kaukauna Lock 2 | 195.83 | 642.50 | | | | 23.4 | |
| Kaukauna Lock 3 | 192.91 | 632.90 | | | | 23.2 | |
| Kaukauna Lock 4 | 189.80 | 622.70 | | | | 23.1 | |
| Kaukauna Lock 5 | 186.69 | 612.50 | | | | 22.8 | |
| Rapide Croche Lock | 183.52 | 602.10 | Rapide Croche | 183.52 | 602.10 | 19.2 | 2.0E-03 |
| Little Kaukauna (Little Rapids) Lock | 180.69 | 592.80 | Little Kaukauna (Little Rapids) Dam | 180.69 | 592.80 | 13.1 | 2.9E-04 |
| De Pere Lock | 178.83 | 586.70 | De Pere Dam | 178.81 | 586.66 | 7.1 | 1.9E-04 |
| Green Bay (River Mouth) | 175.81 | 576.80 | Green Bay (River Mouth) | 175.81 | 576.80 | 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, 1955.

** Gradient values from upstream dam to this dam.

# Table 2-5 Lower Fox River Stream Velocity Estimates

| Model Segments | Deposits Within Lower # Segment | Cross-sectional Area ($ft^2$) | Cross-sectional Area ($m^2$) | Flow Velocity (m/s) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Average Flow (4,300 cfs) | @ Average Flow (122 $m^3$/s) | 10-year Peak (19,200 cfs) | @ 10-year Peak (544 $m^3$/s) | 10-year Low (950 cfs) | @ 10-year Low (27 $m^3$/s) | 100-year Peak (24,000 cfs) | @ 100-year Peak (680 $m^3$/s) | 100-year Low (140 cfs) | @ 100-year Low (4 $m^3$/s) |
| *Little Lake Butte des Morts Reach* | | | | | | | | | | | | | |
| 2/3 | A | 6,832.6 | 634.8 | 0.63 | 0.192 | 2.81 | 0.857 | 0.14 | 0.042 | 3.51 | 1.071 | 0.02 | 0.006 |
| 3/4 | B | 8,640.3 | 802.7 | 0.50 | 0.152 | 2.22 | 0.677 | 0.11 | 0.034 | 2.78 | 0.847 | 0.02 | 0.005 |
| 4/6 | C, POG | 14,762.7 | 1,371.5 | 0.29 | 0.089 | 1.30 | 0.396 | 0.06 | 0.020 | 1.63 | 0.496 | 0.01 | 0.003 |
| 6/7 | D, E | 16,678.0 | 1,549.4 | 0.26 | 0.079 | 1.15 | 0.351 | 0.06 | 0.017 | 1.44 | 0.439 | 0.01 | 0.003 |
| 7/8 | D, E | 16,097.0 | 1,495.5 | 0.27 | 0.081 | 1.19 | 0.364 | 0.06 | 0.018 | 1.49 | 0.454 | 0.01 | 0.003 |
| 8/9 | E, F | 13,191.8 | 1,225.6 | 0.33 | 0.099 | 1.46 | 0.444 | 0.07 | 0.022 | 1.82 | 0.555 | 0.01 | 0.003 |
| 9/10 | E | 6,638.9 | 616.8 | 0.65 | 0.197 | 2.89 | 0.881 | 0.14 | 0.044 | 3.62 | 1.102 | 0.02 | 0.006 |
| 10/11 | G, H | 3,755.2 | 348.9 | 1.15 | 0.349 | 5.11 | 1.558 | 0.25 | 0.077 | 6.39 | 1.948 | 0.04 | 0.011 |
| **Reach Average** | | | | **0.51** | **0.155** | **2.27** | **0.691** | **0.11** | **0.034** | **2.83** | **0.864** | **0.02** | **0.005** |
| *Appleton to Little Rapids Reach* | | | | | | | | | | | | | |
| 11/12 | I, J, K | 4,368.6 | 405.9 | 0.98 | 0.300 | 4.40 | 1.340 | 0.22 | 0.066 | 5.49 | 1.675 | 0.03 | 0.010 |
| 12/14 | L through R | 6,230.0 | 578.8 | 0.69 | 0.210 | 3.08 | 0.939 | 0.15 | 0.046 | 3.85 | 1.174 | 0.02 | 0.007 |
| 14/15 | S | 5,788.9 | 537.8 | 0.74 | 0.226 | 3.32 | 1.011 | 0.16 | 0.050 | 4.15 | 1.264 | 0.02 | 0.007 |
| 15/16 | T, U | 6,219.3 | 577.8 | 0.69 | 0.211 | 3.09 | 0.941 | 0.15 | 0.047 | 3.86 | 1.176 | 0.02 | 0.007 |
| 16/17 | V, W, X | 8,952.3 | 831.7 | 0.48 | 0.146 | 2.14 | 0.654 | 0.11 | 0.032 | 2.68 | 0.817 | 0.02 | 0.005 |
| 17/18 | W, X, Y, Z | 7,865.6 | 730.7 | 0.55 | 0.167 | 2.44 | 0.744 | 0.12 | 0.037 | 3.05 | 0.930 | 0.02 | 0.005 |
| 18/19 | AA, BB, CC | 4,917.3 | 456.8 | 0.87 | 0.267 | 3.90 | 1.190 | 0.19 | 0.059 | 4.88 | 1.488 | 0.03 | 0.009 |
| 19/20 | — | 3,497.0 | 324.9 | 1.23 | 0.375 | 5.49 | 1.673 | 0.27 | 0.083 | 6.86 | 2.092 | 0.04 | 0.012 |
| 20/21 | — | 4,573.0 | 424.8 | 0.94 | 0.287 | 4.20 | 1.280 | 0.21 | 0.063 | 5.25 | 1.600 | 0.03 | 0.009 |
| 21/22 | DD | 7,026.3 | 652.8 | 0.61 | 0.187 | 2.73 | 0.833 | 0.14 | 0.041 | 3.42 | 1.041 | 0.02 | 0.006 |
| **Reach Average** | | | | **0.78** | **0.238** | **3.48** | **1.060** | **0.17** | **0.052** | **4.35** | **1.326** | **0.03** | **0.008** |
| *Little Rapids to De Pere Reach* | | | | | | | | | | | | | |
| 22/23 | EE | 10,200.5 | 947.7 | 0.42 | 0.128 | 1.88 | 0.574 | 0.09 | 0.028 | 2.35 | 0.717 | 0.01 | 0.004 |
| 23/24 | EE | 11,642.3 | 1,081.6 | 0.37 | 0.113 | 1.65 | 0.503 | 0.08 | 0.025 | 2.06 | 0.628 | 0.01 | 0.004 |
| 24/25 | EE | 10,942.9 | 1,016.6 | 0.39 | 0.120 | 1.75 | 0.535 | 0.09 | 0.026 | 2.19 | 0.668 | 0.01 | 0.004 |
| 25/26 | EE | 10,609.4 | 985.6 | 0.41 | 0.124 | 1.81 | 0.552 | 0.09 | 0.027 | 2.26 | 0.690 | 0.01 | 0.004 |
| 26/27 | EE through HH | 10,641.6 | 988.6 | 0.40 | 0.123 | 1.80 | 0.550 | 0.09 | 0.027 | 2.26 | 0.687 | 0.01 | 0.004 |
| **Reach Average** | | | | **0.40** | **0.122** | **1.78** | **0.543** | **0.09** | **0.027** | **2.22** | **0.678** | **0.01** | **0.004** |
| *De Pere to Green Bay Reach* | | | | | | | | | | | | | |
| 28/29 | SMU 20–25 | 18,593.3 | 1,727.4 | 0.23 | 0.070 | 1.03 | 0.315 | 0.05 | 0.016 | 1.29 | 0.393 | 0.01 | 0.002 |
| 29/30 | SMU 25–31 | 12,083.5 | 1,122.6 | 0.36 | 0.108 | 1.59 | 0.484 | 0.08 | 0.024 | 1.99 | 0.605 | 0.01 | 0.004 |
| 30/31 | SMU 32–37 | 13,751.3 | 1,277.5 | 0.31 | 0.095 | 1.40 | 0.426 | 0.07 | 0.021 | 1.75 | 0.532 | 0.01 | 0.003 |
| 31/32 | SMU 38–43 | 16,947.0 | 1,574.4 | 0.25 | 0.077 | 1.13 | 0.345 | 0.06 | 0.017 | 1.42 | 0.432 | 0.01 | 0.003 |
| 32/33 | SMU 44–49 | 20,002.8 | 1,858.3 | 0.21 | 0.066 | 0.96 | 0.293 | 0.05 | 0.014 | 1.20 | 0.366 | 0.01 | 0.002 |
| 33/34 | SMU 50–55 | 15,698.8 | 1,458.5 | 0.27 | 0.083 | 1.22 | 0.373 | 0.06 | 0.018 | 1.53 | 0.466 | 0.01 | 0.003 |
| 34/35 | SMU 56–61 | 20,519.3 | 1,906.3 | 0.21 | 0.064 | 0.94 | 0.285 | 0.05 | 0.014 | 1.17 | 0.357 | 0.01 | 0.002 |
| 35/36 | SMU 62–67 | 20,056.6 | 1,863.3 | 0.21 | 0.065 | 0.96 | 0.292 | 0.05 | 0.014 | 1.20 | 0.365 | 0.01 | 0.002 |
| 36/37 | SMU 68–73 | 20,551.6 | 1,909.3 | 0.21 | 0.064 | 0.93 | 0.285 | 0.05 | 0.014 | 1.17 | 0.356 | 0.01 | 0.002 |
| 37/38 | SMU 73–79 | 19,389.5 | 1,801.3 | 0.22 | 0.068 | 0.99 | 0.302 | 0.05 | 0.015 | 1.24 | 0.377 | 0.01 | 0.002 |
| 38/39 | SMU 80–85 | 14,891.8 | 1,383.5 | 0.29 | 0.088 | 1.29 | 0.393 | 0.06 | 0.019 | 1.61 | 0.491 | 0.01 | 0.003 |
| 39/40 | SMU 86–91 | 16,387 | 1,522 | 0.26 | 0.080 | 1.17 | 0.357 | 0.06 | 0.018 | 1.46 | 0.446 | 0.01 | 0.003 |
| **Reach Average** | | | | **0.25** | **0.077** | **1.13** | **0.346** | **0.06** | **0.017** | **1.42** | **0.432** | **0.01** | **0.003** |
| **Entire River Averages** | | | | **0.45** | **0.137** | **2.01** | **0.612** | **0.10** | **0.030** | **2.51** | **0.766** | **0.01** | **0.004** |

**Notes:**

[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 2-6 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 | April 18, 1952 |
| Lowest Daily Mean | 4 | 138 | August 2, 1936 |
| Monthly Mean Maximum | 206 | 7,286 | April |
| Monthly Mean Minimum | 74 | 2,609 | August |

| Month | Monthly Discharge Results Average ($m^3/s$) | Average (cfs) | Minimum ($m^3/s$) | Maximum ($m^3/s$) |
|---|---|---|---|---|
| January | 116 | 4,082 | 31 | 269 |
| February | 117 | 4,126 | 30 | 340 |
| March | 146 | 5,156 | 25 | 603 |
| April | 206 | 7,286 | 22 | 680 |
| May | 171 | 6,048 | 23 | 669 |
| June | 137 | 4,821 | 17 | 603 |
| July | 96 | 3,372 | 18 | 530 |
| August | 74 | 2,609 | 4 | 419 |
| September | 81 | 2,872 | 8 | 510 |
| October | 94 | 3,315 | 6 | 516 |
| November | 116 | 4,084 | 15 | 445 |
| December | 115 | 4,043 | 32 | 363 |

**Note:**

A water year runs from October 1 through September 30.

## Table 2-7 Lower Fox River and Green Bay Maximum PCB Sampling Depth

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

**Note:**

* Includes sediments containing PCB concentrations greater than 50 $\mu$g/kg.

## Table 2-8 Lower Fox River Mouth Gauging Station Results (1989–1997)

| Summary of Flow Conditions | Discharge $m^3/s$ (cfs) | Date (or month) |
|---|---|---|
| Daily Average: WY 1989–1997 | 149 (5,262) | — |
| Highest Daily Mean: WY 1989–1997 | 957 (33,800) | June 23, 1990 |
| Lowest Daily Mean: WY 1989–1997 | -92 (-3,250) | November 4, 1990 |
| Monthly Mean Maximum: WY 1989–1997 | 210 (7,420) | April |
| Monthly Mean Minimum: WY 1989–1997 | 103 (3,635) | September |
| Monthly Mean Maximum: WY 1997 | 244 (8,620) | April |
| Monthly Mean Minimum: WY 1997 | 56 (1,980) | September |
| Daily Maximum: WY 1997 | 419 (14,800) | March 28, 1997 |
| Daily Minimum: WY 1997 | -15 (-530) | May 28, 1997 |

## Table 2-9 Total Suspended Solid (TSS) Loads from the Lower Fox River into Green Bay

| Sampling Point | River Discharge ($m^3/s$) | (cfs) | Total Suspended Solids (TSS) (mg/L) | (MT/year) | (Ton/year) |
|---|---|---|---|---|---|
| *Mean Values from WDNR, 1995 Lower Fox River Reaches* | | | | | |
| 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 |
| *Mean Values from Gailani et al., 1991 De Pere to Green Bay Reach* | | | | | |
| De Pere dam | 105 | 3,700 | 30 | 99,164 | 109,081 |
| River mouth | 105 | 3,700 | 6 | 19,833 | 21,816 |
| **Sampling Point** | **River Discharge $m^3/s$** | **cfs** | **Total Suspended Solids mg/L** | **MT/year** | |
| De Pere dam | 105 | 3,706.50 | 30 | 99,338 | |
| | 280 | 9,884.00 | 75 | 662,256 | |
| | 432 | 15,249.60 | 190 | 2,588,475 | |
| River mouth | 105 | 3,706.50 | 6 | 19,868 | |
| | 280 | 9,884.00 | 57 | 503,315 | |
| | 432 | 15,249.60 | 130 | 1,771,062 | |

**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

MT - metric tons.

# Table 2-10 Results of Sediment Time Trends Analysis on the Lower Fox River

| Deposit Group | Depth Range (cm) | $Log_{10}$ (PCB) Time Trend Slope Estimate | WSEV Standard Error | WSEV *p*-Value | Estimated Annual Compound Percent Increase (Decrease) in PCB Level | Estimated Annual Compound Percent Increase (Decrease) in PCB Level 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|---|---|
| *Little Lake Butte des Morts Reach* | | | | | | | |
| AB | 0–10 | -0.0970 | 0.0348 | 0.0131 | -20.0252 | -32.5184 | -5.2190 |
| | 10–30 | -0.0213 | 0.0647 | 0.7535 | -4.7785 | -33.8607 | 37.0914 |
| | 30–50 | -0.0144 | 0.1113 | 0.8995 | -3.2580 | -44.9528 | 70.0179 |
| C | 0–10 | -0.0612 | 0.0342 | 0.1481 | -13.1527 | -30.2218 | 8.0920 |
| | 10–30 | 0.0317 | 0.0770 | 0.7018 | 7.5669 | -34.2398 | 75.9520 |
| POG | 0–10 | -0.0893 | 0.0567 | 0.1900 | -18.5943 | -43.3347 | 16.9478 |
| D | 0–10 | -0.0755 | 0.0317 | 0.0307 | -15.9649 | -28.0617 | -1.8339 |
| | 10–30 | 0.3168 | 0.0454 | 0.0009 | 107.3860 | 58.5121 | 171.3292 |
| F | 0–10 | -0.0373 | 0.0136 | 0.0252 | -8.2308 | -14.6158 | -1.3684 |
| | 10–30 | -0.0760 | 0.0749 | 0.3246 | -16.0577 | -41.6741 | 20.8094 |
| GH | 0–10 | -0.1244 | 0.0541 | 0.0443 | -24.9124 | -43.1170 | -0.8818 |
| *Appleton to Little Rapids Reach* | | | | | | | |
| IMOR | 0–10 | 0.0412 | 0.0255 | 0.1810 | 9.9476 | -6.5658 | 29.3796 |
| N Pre-dredge | 0–10 | -0.0281 | 0.0065 | 0.0233 | -6.2555 | -10.6450 | -1.6504 |
| | 10–30 | 0.0572 | 0.0440 | 0.2061 | 14.0840 | -7.4773 | 40.6698 |
| | 30–50 | 0.0846 | 0.0932 | 0.3877 | 21.5002 | -25.2171 | 97.4021 |
| VCC | 0–10 | -0.0582 | 0.0275 | 0.0878 | -12.5329 | -25.6543 | 2.9044 |
| | 10–30 | -0.1537 | 0.0164 | 0.0000 | -29.8115 | -35.4198 | -23.7163 |
| | 30–50 | -0.0060 | 0.0151 | 0.6984 | -1.3741 | -8.7096 | 6.5507 |
| *Little Rapids to De Pere Reach* | | | | | | | |
| Upper EE | 0–10 | -0.0447 | 0.0435 | 0.3618 | -9.7861 | -31.6823 | 19.1279 |
| | 10–30 | -0.0944 | 0.0429 | 0.0554 | -19.5286 | -35.6413 | 0.6181 |
| | 30–50 | -0.0712 | 0.0536 | 0.2173 | -15.1118 | -35.8039 | 12.2499 |
| Lower EE | 0–10 | -0.0682 | 0.0193 | 0.0387 | -14.5308 | -25.8145 | -1.5310 |
| | 10–30 | -0.0759 | 0.0390 | 0.0695 | -16.0283 | -30.5817 | 1.5761 |
| | 30–50 | 0.0900 | 0.0330 | 0.0213 | 23.0209 | 3.8593 | 45.7177 |
| FF | 0–10 | -0.0549 | 0.0557 | 0.3400 | -11.8664 | -32.9367 | 15.8238 |
| | 10–30 | -0.0962 | 0.0390 | 0.0389 | -19.8690 | -34.8569 | -1.4327 |
| GGHH | 0–10 | -0.0394 | 0.0231 | 0.1643 | -8.6641 | -21.2286 | 5.9045 |
| | 10–30 | -0.0182 | 0.0596 | 0.7631 | -4.0982 | -27.7264 | 27.2546 |
| | 30–50 | 0.1762 | 0.1008 | 0.1188 | 50.0238 | -12.1753 | 156.2737 |
| | 50–100 | 0.1012 | 0.0700 | 0.1586 | 26.2311 | -9.1644 | 75.4191 |
| | 100+ | 0.0365 | 0.0249 | 0.1587 | 8.7556 | -3.5026 | 22.5710 |
| *De Pere to Green Bay Reach* | | | | | | | |
| SMU Group 20–25 | 0–10 | -0.0528 | 0.0231 | 0.0838 | -11.4462 | -23.5795 | 2.6135 |
| | 10–30 | -0.0556 | 0.0750 | 0.4796 | -12.0176 | -40.9140 | 31.0108 |
| | 30–50 | -0.0580 | 0.0322 | 0.1016 | -12.4973 | -25.8079 | 3.2014 |
| | 50–100 | -0.0847 | 0.1058 | 0.4306 | -17.7243 | -50.1718 | 35.8538 |
| 26–49 | 0–10 | -0.0608 | 0.0109 | 0.0000 | -13.0594 | -17.4071 | -8.4827 |
| | 10–30 | -0.2882 | 0.1440 | 0.0764 | -48.5003 | -75.6756 | 9.0355 |
| | 50–100 | 0.1957 | 0.1419 | 0.2399 | 56.9258 | -36.6450 | 288.6939 |
| | 100+ | 0.0177 | 0.1548 | 0.9146 | 4.1538 | -61.2934 | 180.2628 |
| 50–67 | 0–10 | -0.0998 | 0.0345 | 0.0136 | -20.5271 | -33.1743 | -5.4864 |
| | 10–30 | 0.0912 | 0.0649 | 0.1800 | 23.3725 | -10.2622 | 69.6138 |
| | 50–100 | 0.3677 | 0.0684 | 0.0030 | 133.1723 | 55.5425 | 249.5468 |
| | 100+ | -0.1963 | 0.2223 | 0.4112 | -36.3596 | -81.8094 | 122.6480 |
| 68–91 | 0–10 | -0.2208 | 0.0944 | 0.1013 | -39.8569 | -69.8854 | 20.1142 |
| | 10–30 | -0.1685 | 0.0765 | 0.0550 | -32.1613 | -54.4475 | 1.0282 |
| 92–115 | 0–10 | 0.0413 | 0.0426 | 0.3493 | 9.9747 | -10.9075 | 35.7515 |

# Table 2-11 Results of Fish Time Trends Analysis on the Lower Fox River

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

## Table 2-12 Mass-weighted Combined Time Trend for 0 to 10 cm Depth by Reach

| Deposit Group | $Log_{10}$(PCB) Time Trend Slope Estimate | WSEV Standard Error | PCB Mass (kg) | *p*-value | Annual Percent Change in PCB Concentration | Percent Change 95% Lower-bound | Percent Change 95% Upper-bound |
|---|---|---|---|---|---|---|---|
| *Little Lake Butte des Morts* | | | | | | | |
| AB | -0.09705 | 0.034798 | 71.7 | | | | |
| C | -0.06124 | 0.03423 | 25.4 | | | | |
| POG | -0.08935 | 0.056669 | 113.5 | | | | |
| D | -0.07554 | 0.031669 | 32.1 | | | | |
| F | -0.0373 | 0.013582 | 142.5 | | | | |
| GH | -0.12443 | 0.054119 | 15.7 | | | | |
| **Reach, Combined** | **-0.07071** | **0.01831** | **400.9** | **0.0001*** ** | **-15.0** | **-21.8** | **-7.7** |
| *Appleton* | | | | | | | |
| IMOR | 0.041186 | 0.025457 | 13.7 | | | | |
| N Pre-dredge | -0.02805 | 0.006544 | 6.9 | | | | |
| VCC | -0.05816 | 0.02746 | 5.2 | | | | |
| **Reach, Combined** | **-0.0025** | **0.01469** | **25.9** | **0.9** | **0.6** | **-5.9** | **7.5** |
| *Little Rapids* | | | | | | | |
| Upper EE | -0.04473 | 0.043487 | 85.0 | | | | |
| Lower EE | -0.06819 | 0.019322 | 25.4 | | | | |
| FF | -0.05486 | 0.055669 | 36.7 | | | | |
| GGHH | -0.03936 | 0.023149 | 131.6 | | | | |
| **Reach, Combined** | **-0.04567** | **0.018764** | **278.7** | **0.01*** | **-10.0** | **-17.3** | **-2.0** |
| *De Pere* | | | | | | | |
| SMU Group 2025 | -0.05279 | 0.02305 | 225.6 | | | | |
| SMU Group 2649 | -0.06078 | 0.010894 | 356.8 | | | | |
| SMU Group 5067 | -0.09978 | 0.034549 | 92.4 | | | | |
| SMU Group 6891 | -0.22081 | 0.094396 | 72.1 | | | | |
| SMU Group 92115 | 0.041293 | 0.042639 | 37.1 | | | | |
| **Reach, Combined** | **-0.07296** | **0.012829** | **784.0** | **<0.0001*** ** | **-15.5** | **-20.2** | **-10.4** |

**Notes:**

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

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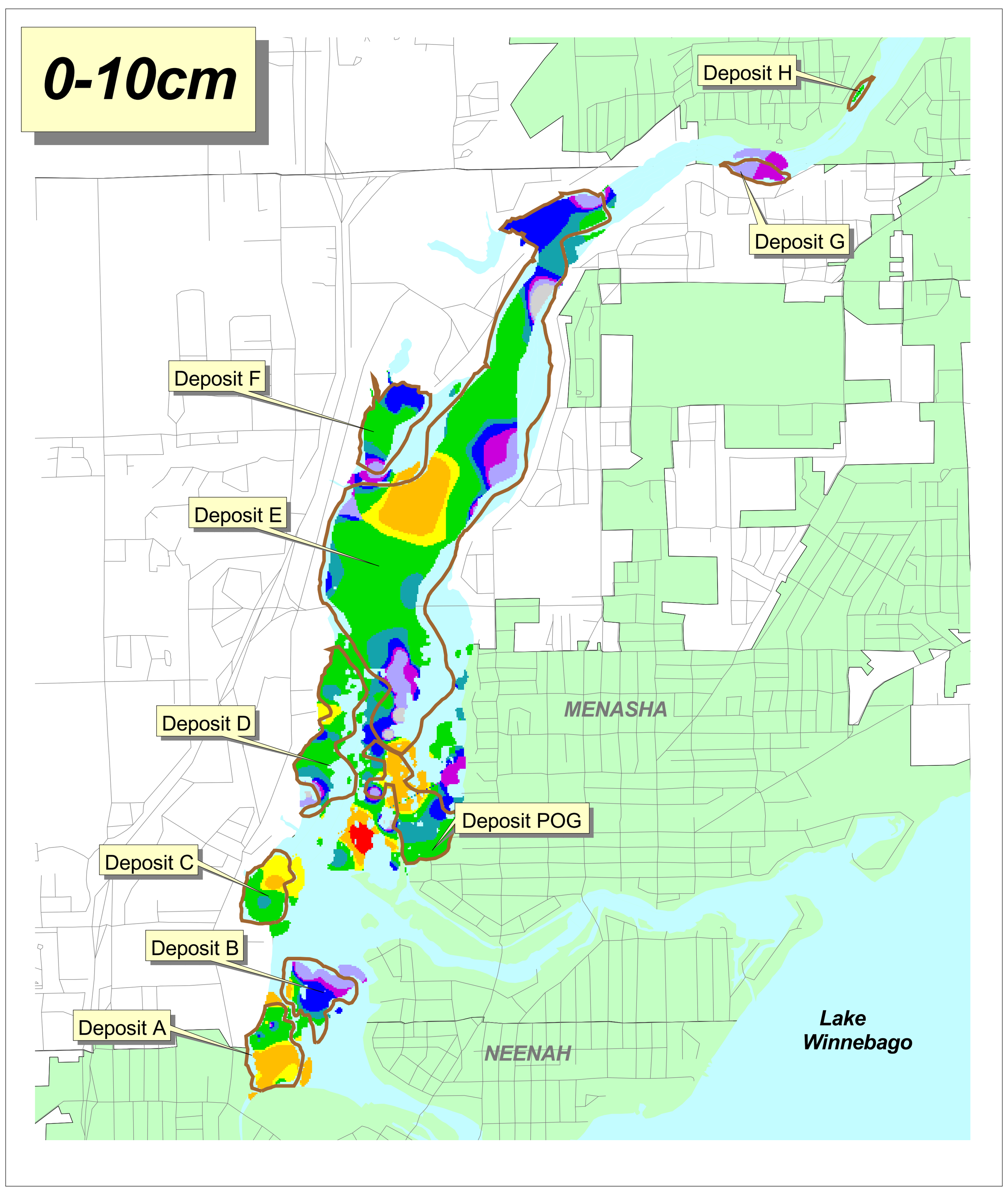
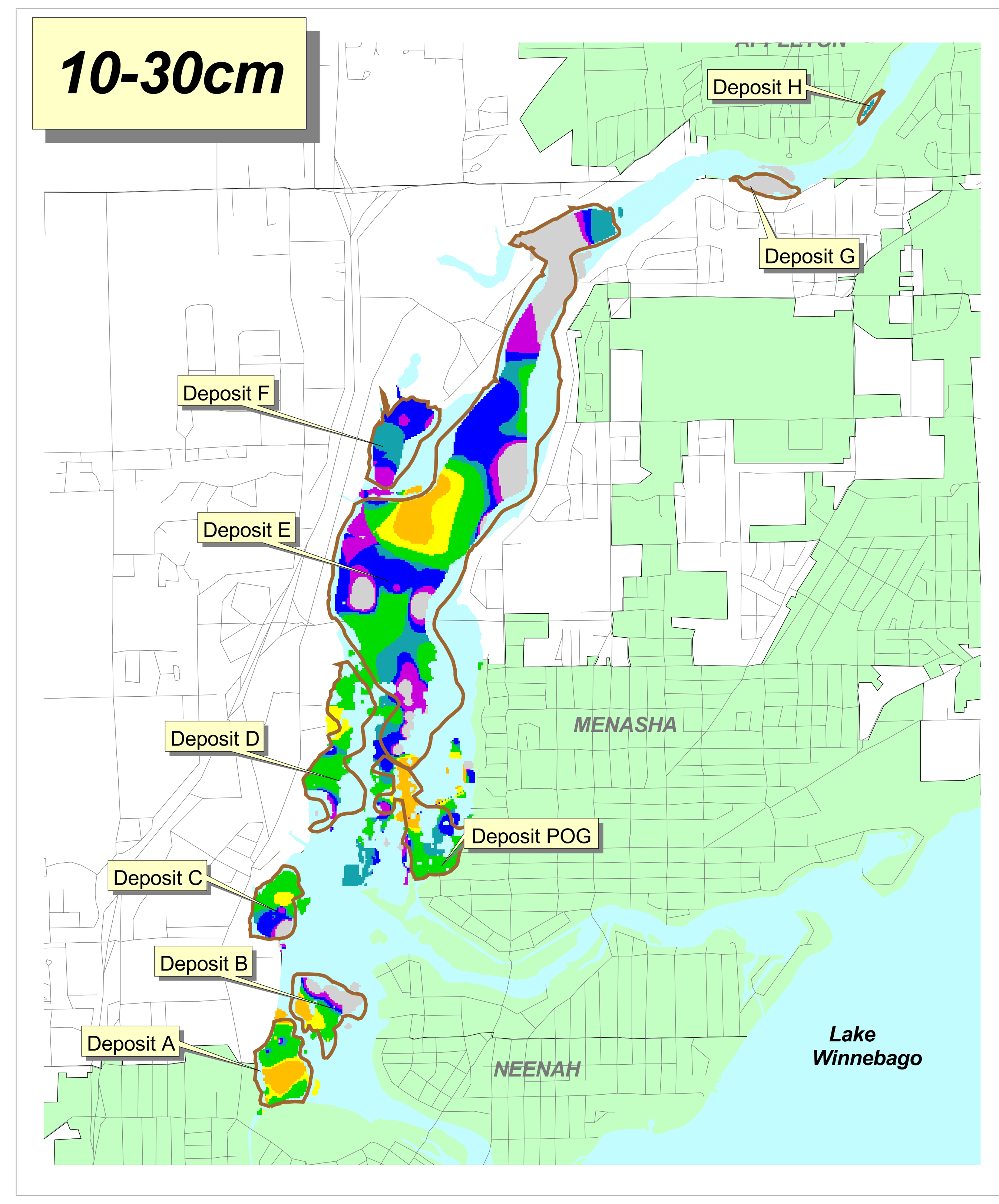
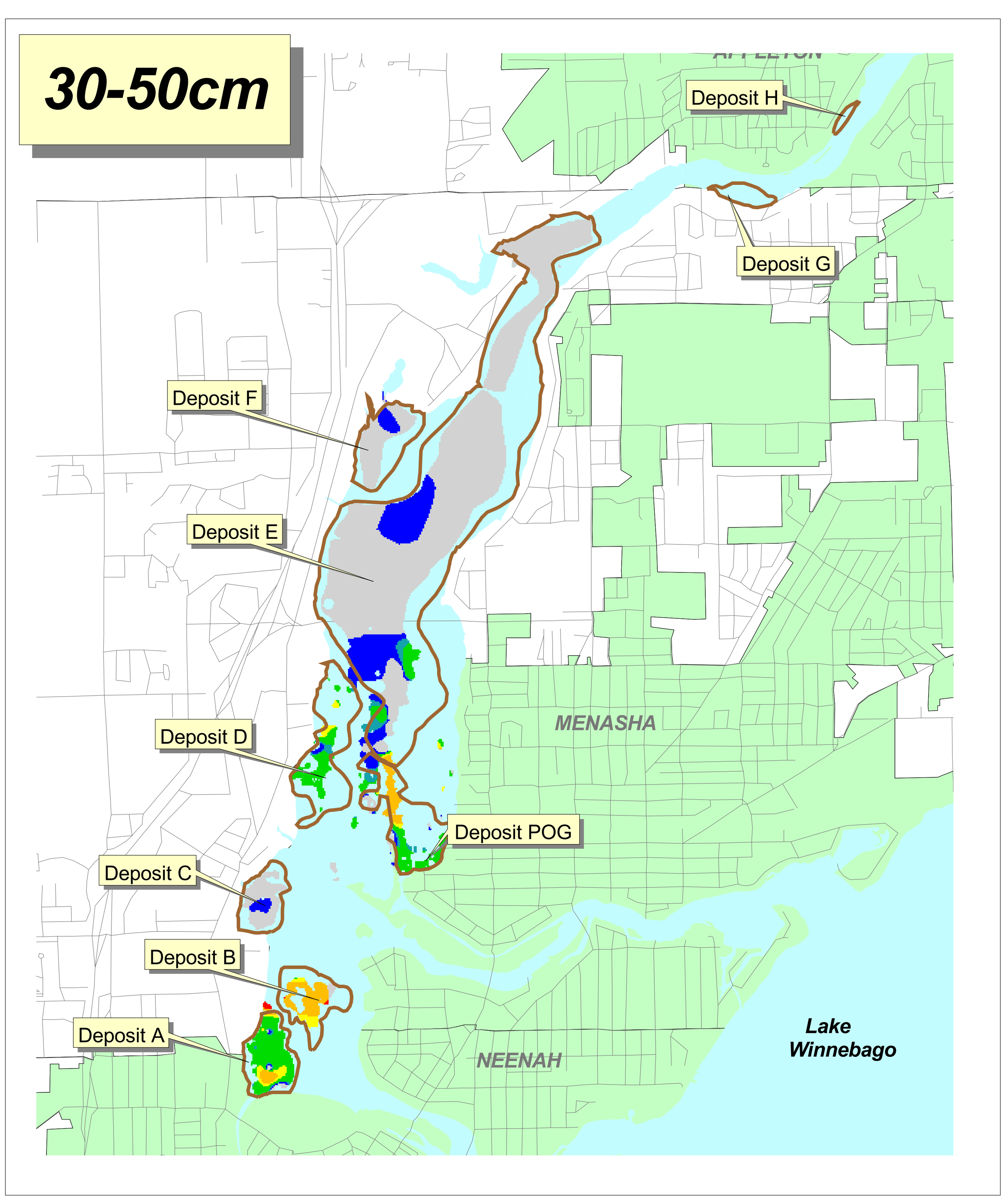
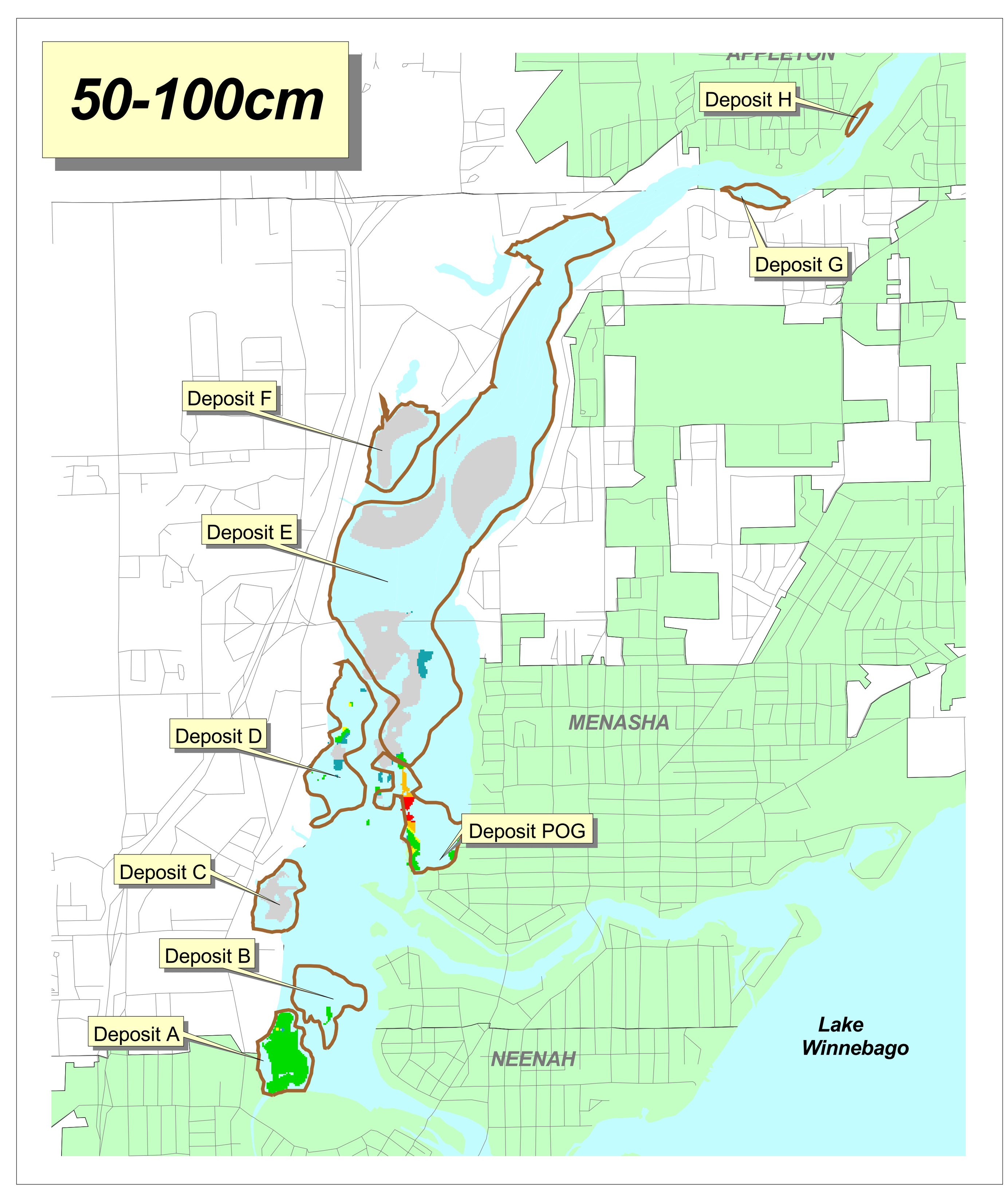
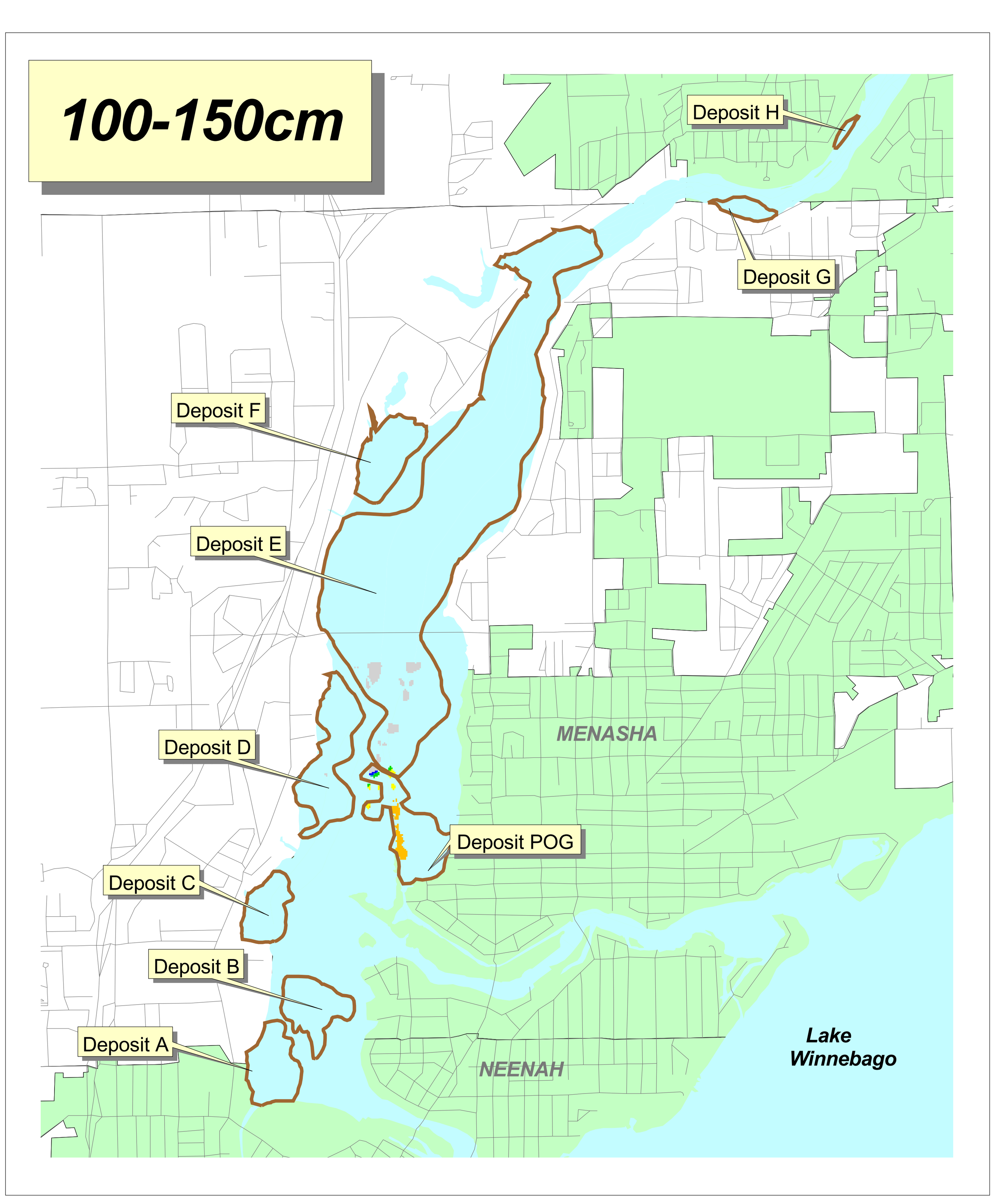


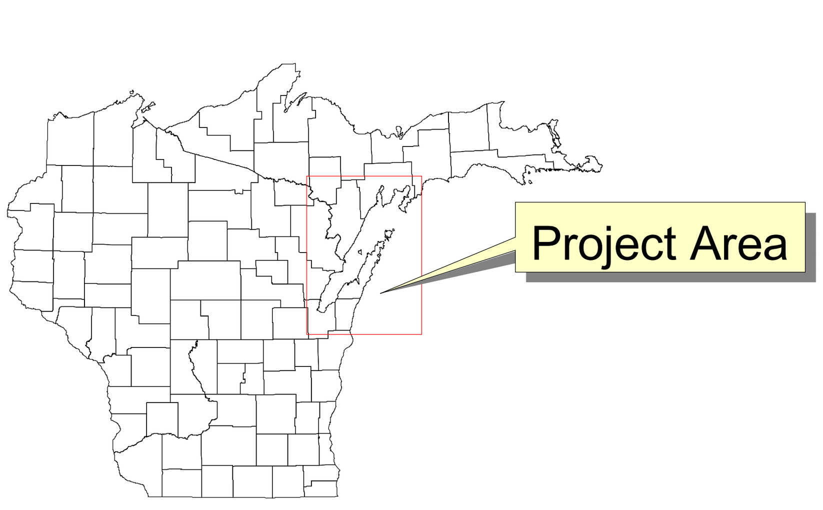




PCB Sediment Concentrations (ug/kg)
- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- 5,000-10,000
- 10,000-50,000
- >50,000
- Deposits
- Roads
- Water

Civil Divisions
- City
- Township
- Village

N
W E
S

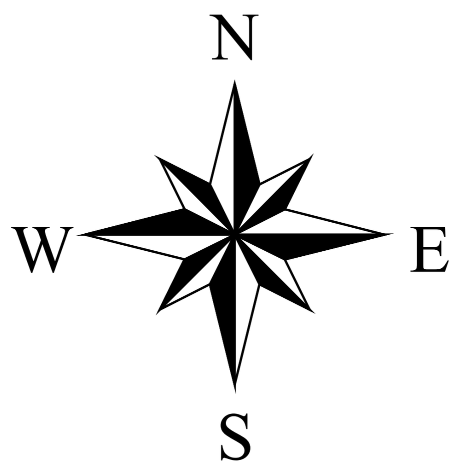


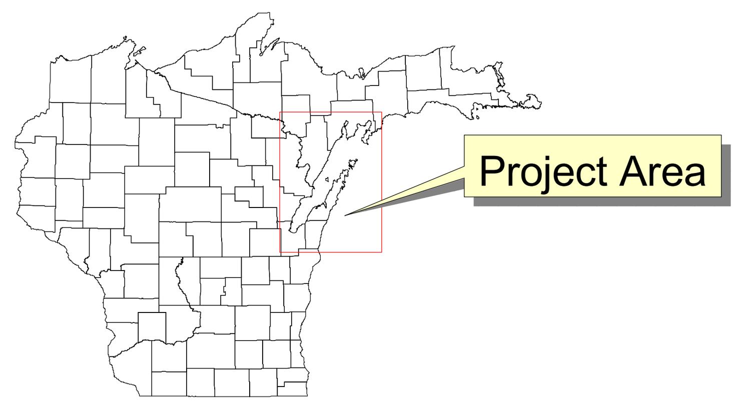

1 0 1 2 3 Kilometers

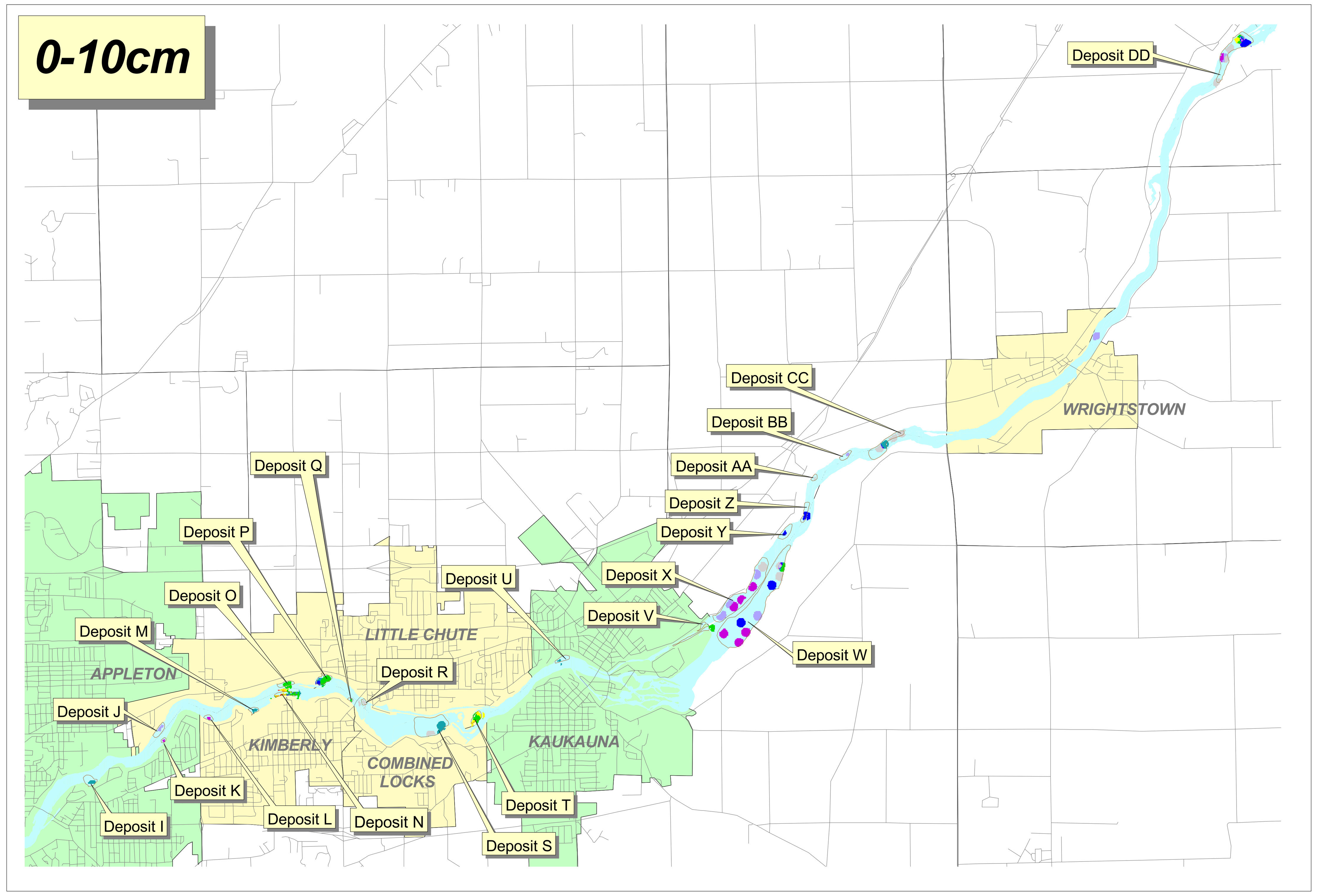
1 0 1 2 Miles

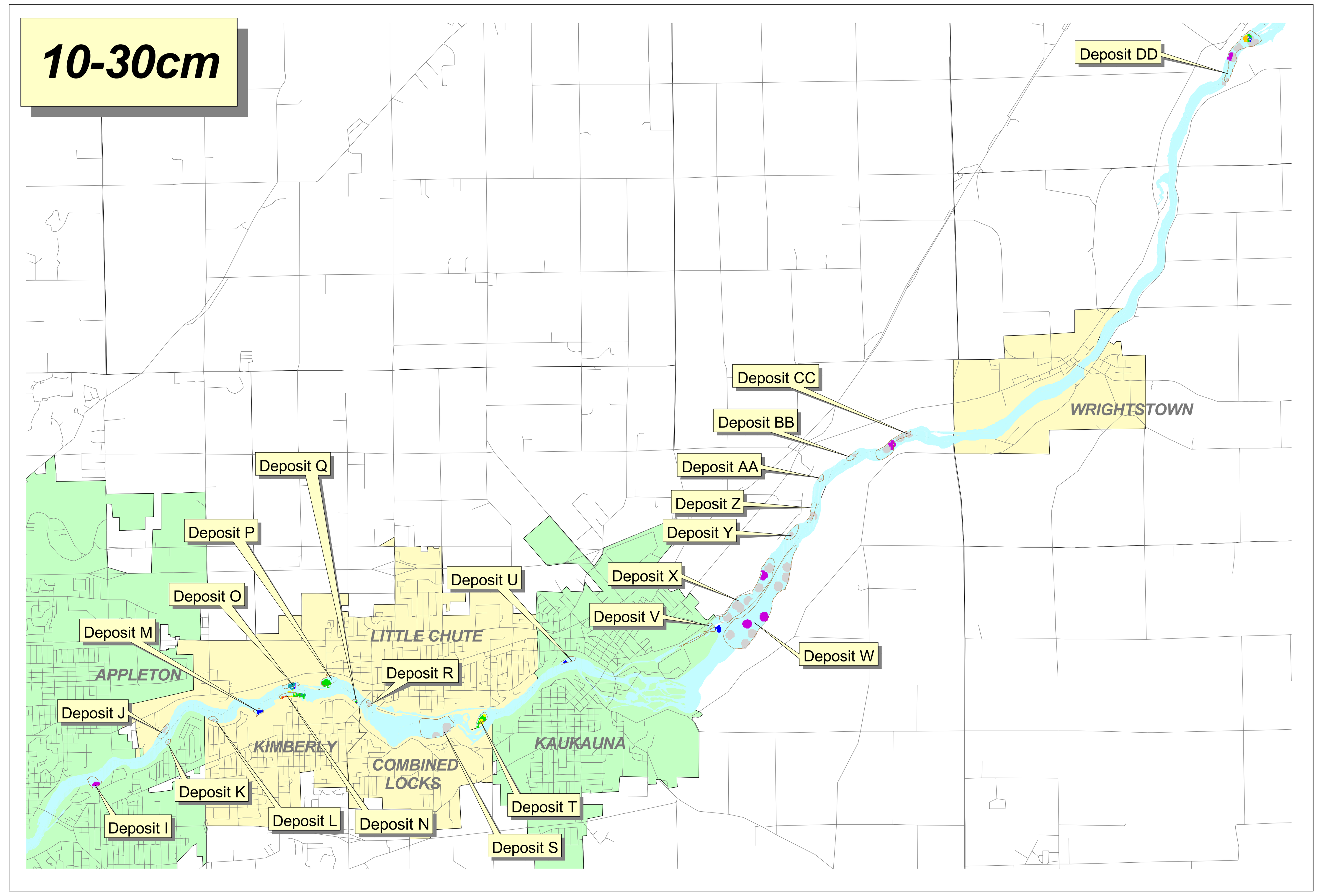
NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

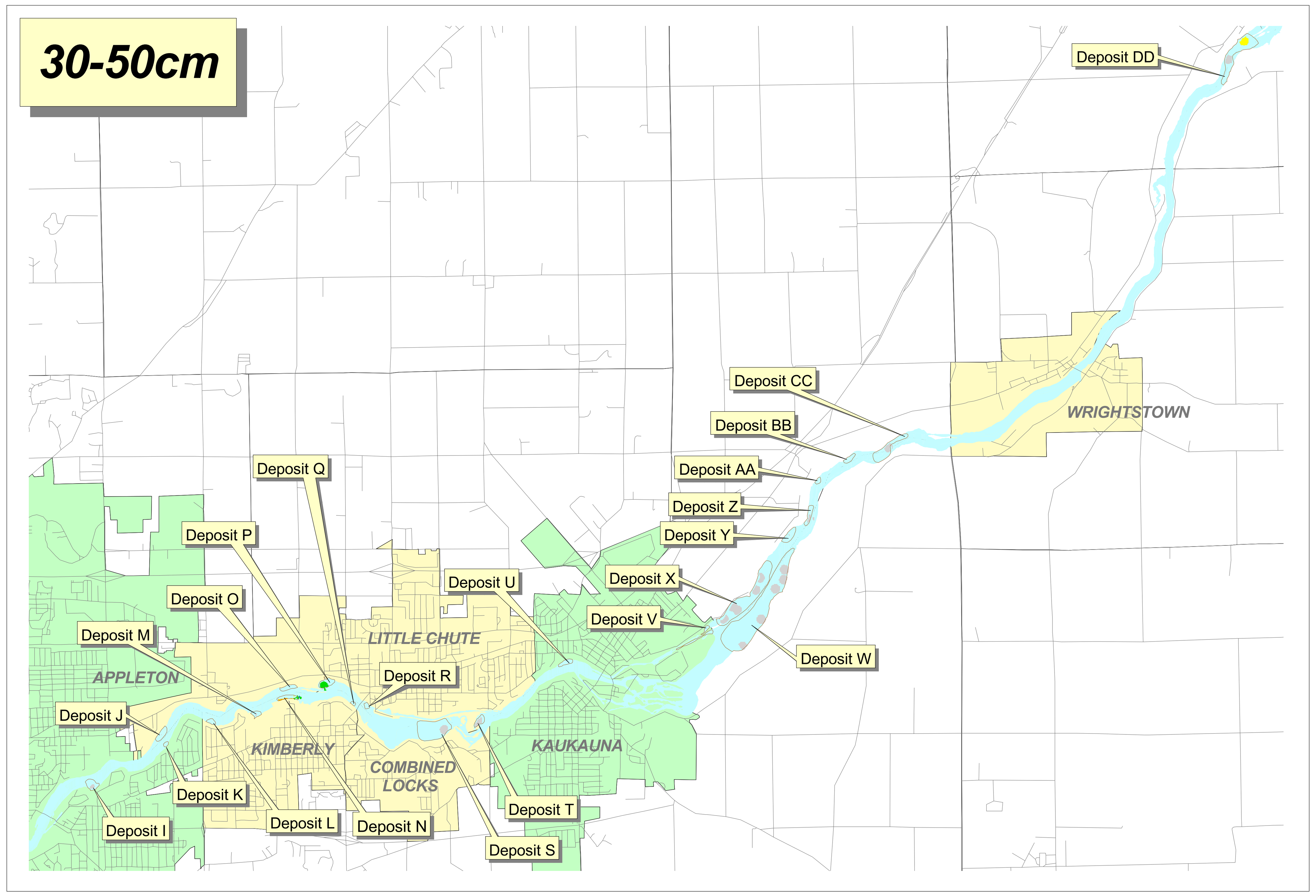
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Interpolated PCB Distribution in Sediments: Little Lake Butte des Morts Reach | DRAWING NO: FS-14414-535-2-1 |
|---|---|---|---|---|
| | | | | PRINT DATE: 3/8/01 |
| | | | | CREATED BY: SCJ |
| | | | PLATE 2-1 | APPROVED: AGF |

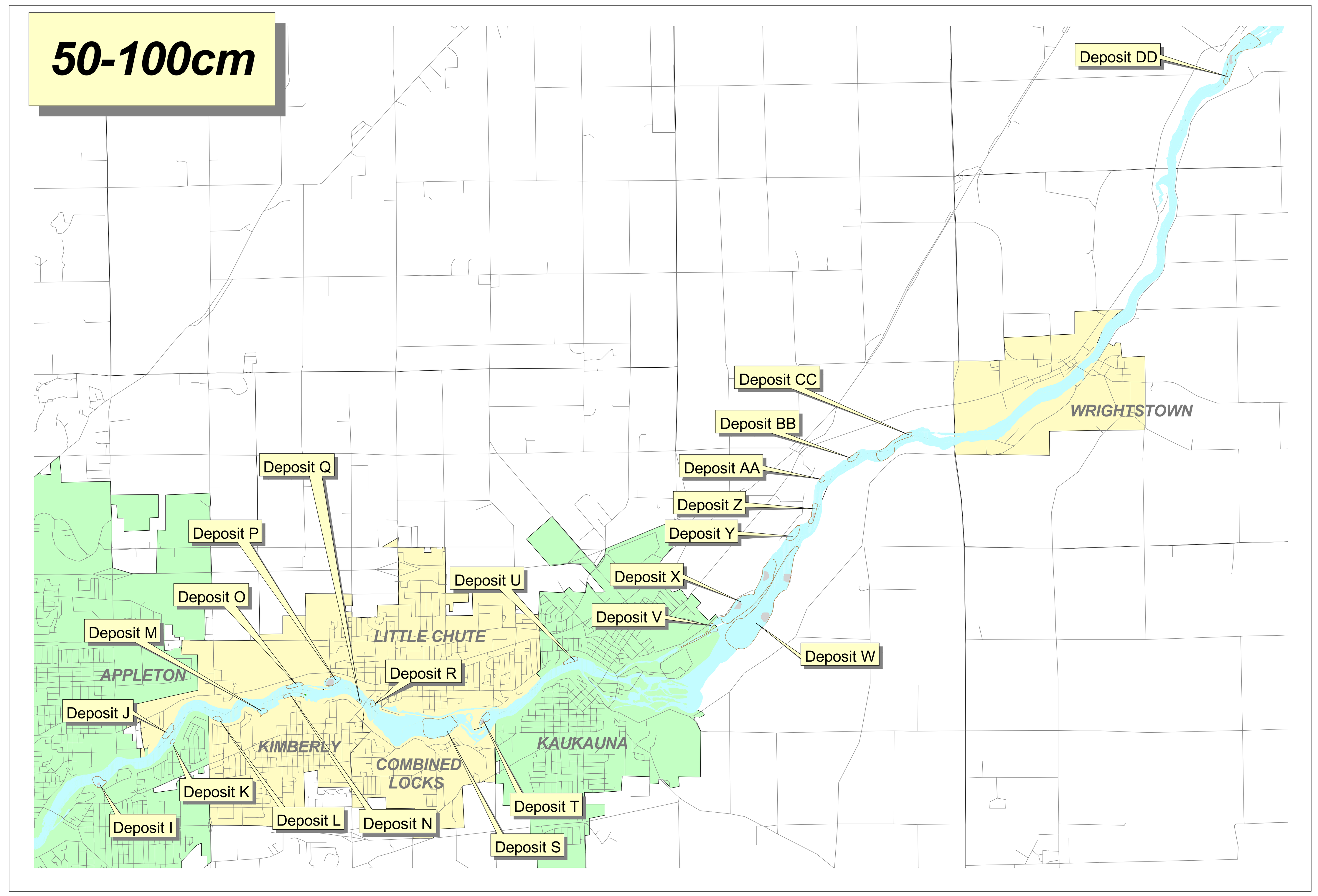



PCB Sediment Concentrations (ug/kg)
- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- 5,000-10,000
- 10,000-50,000
- >50,000
- Deposits
- Roads
- Water

Civil Divisions
- City
- Township
- Village

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998, and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. Deposit N has been removed, but is still shown for reference.
5. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

2 0 2 4 6 Kilometers

2 0 2 4 Miles

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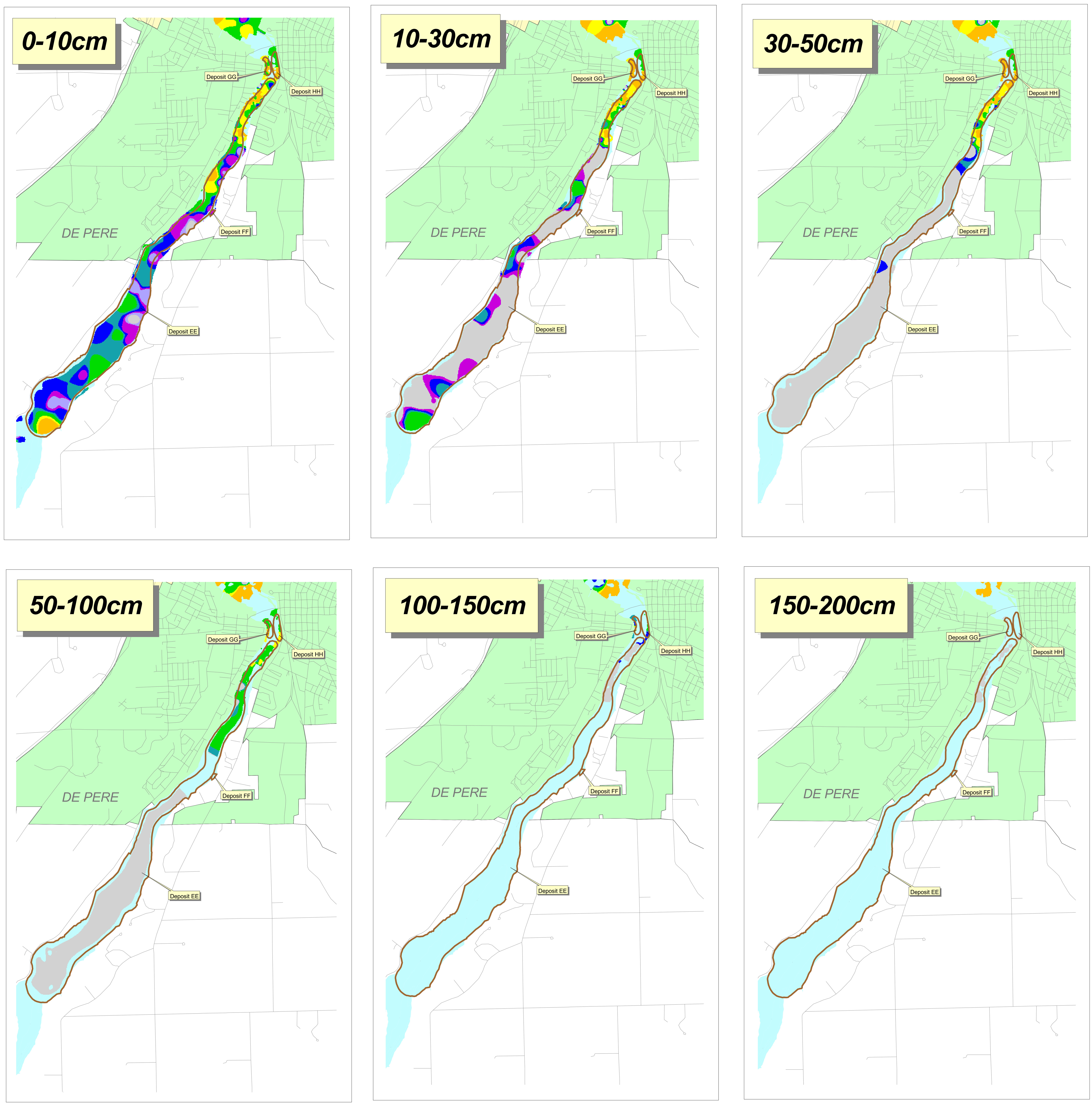
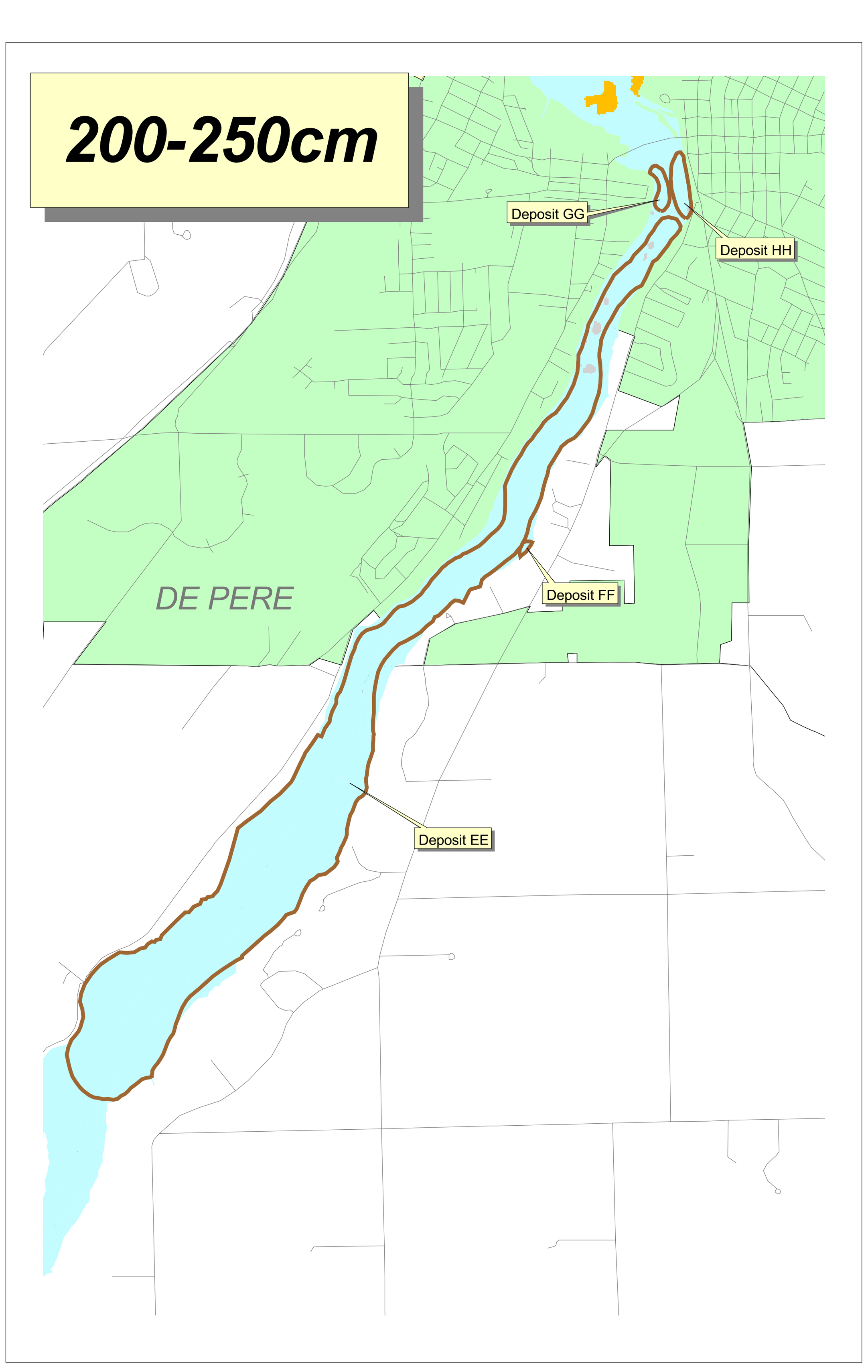
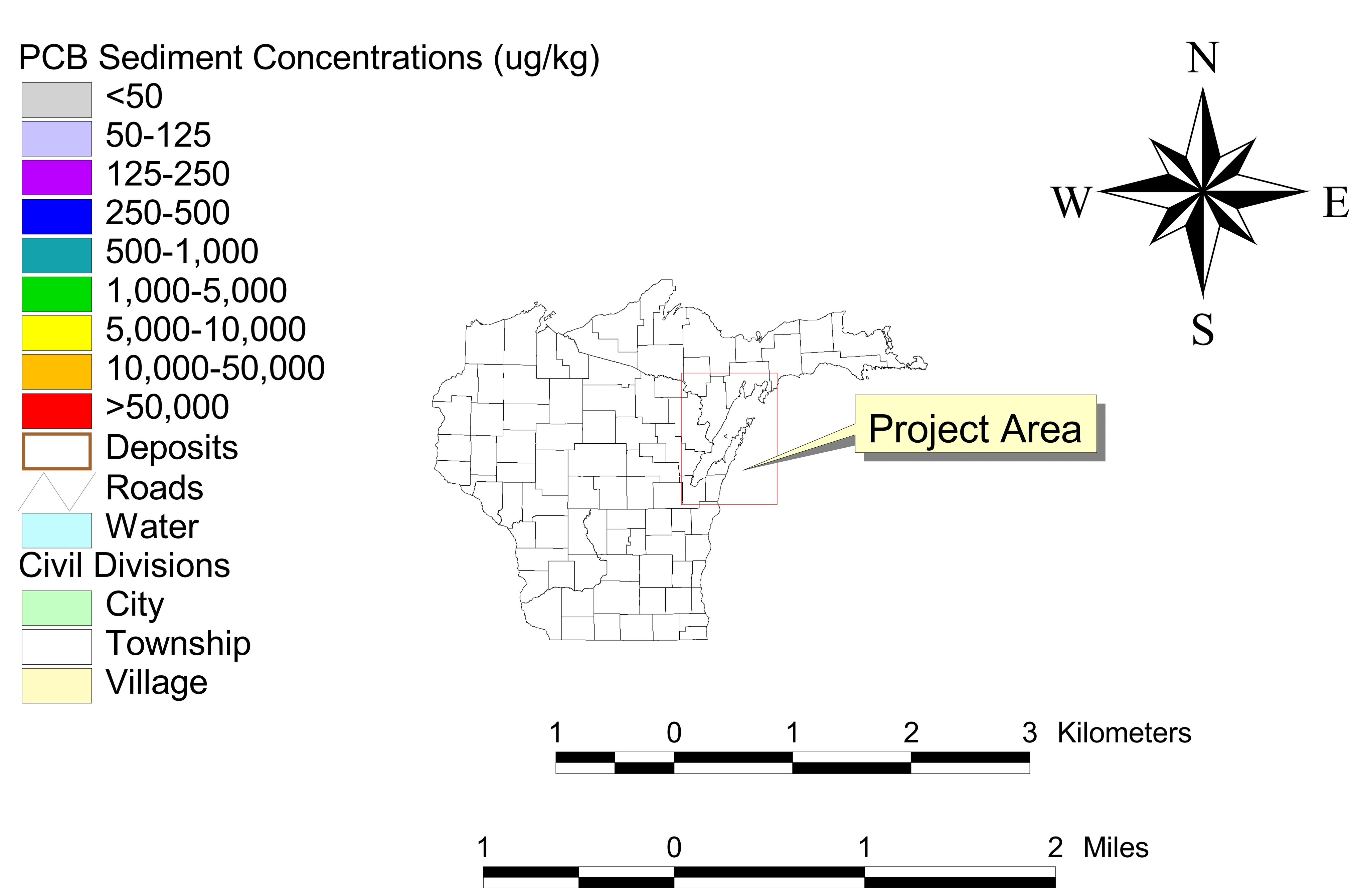
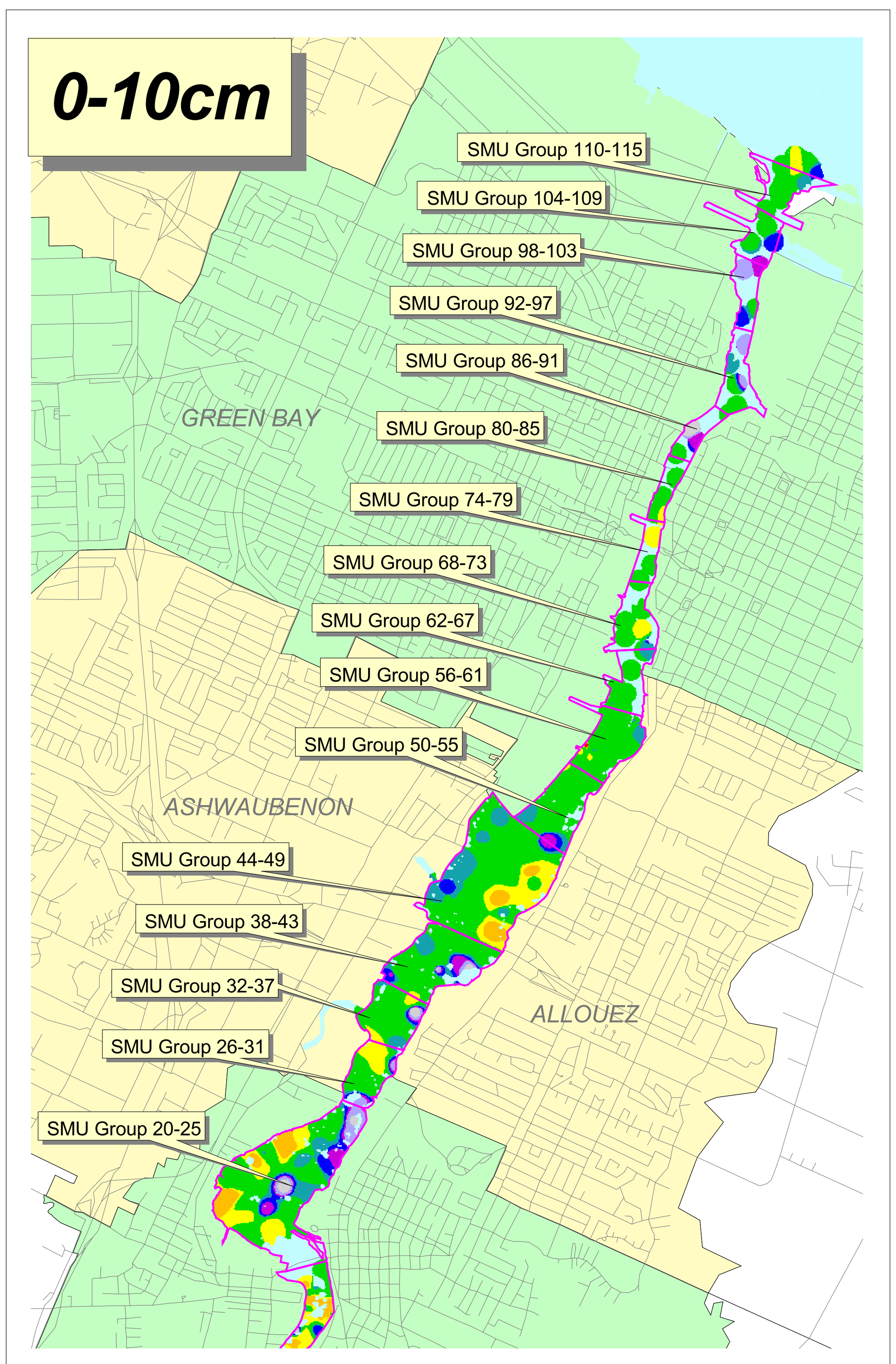


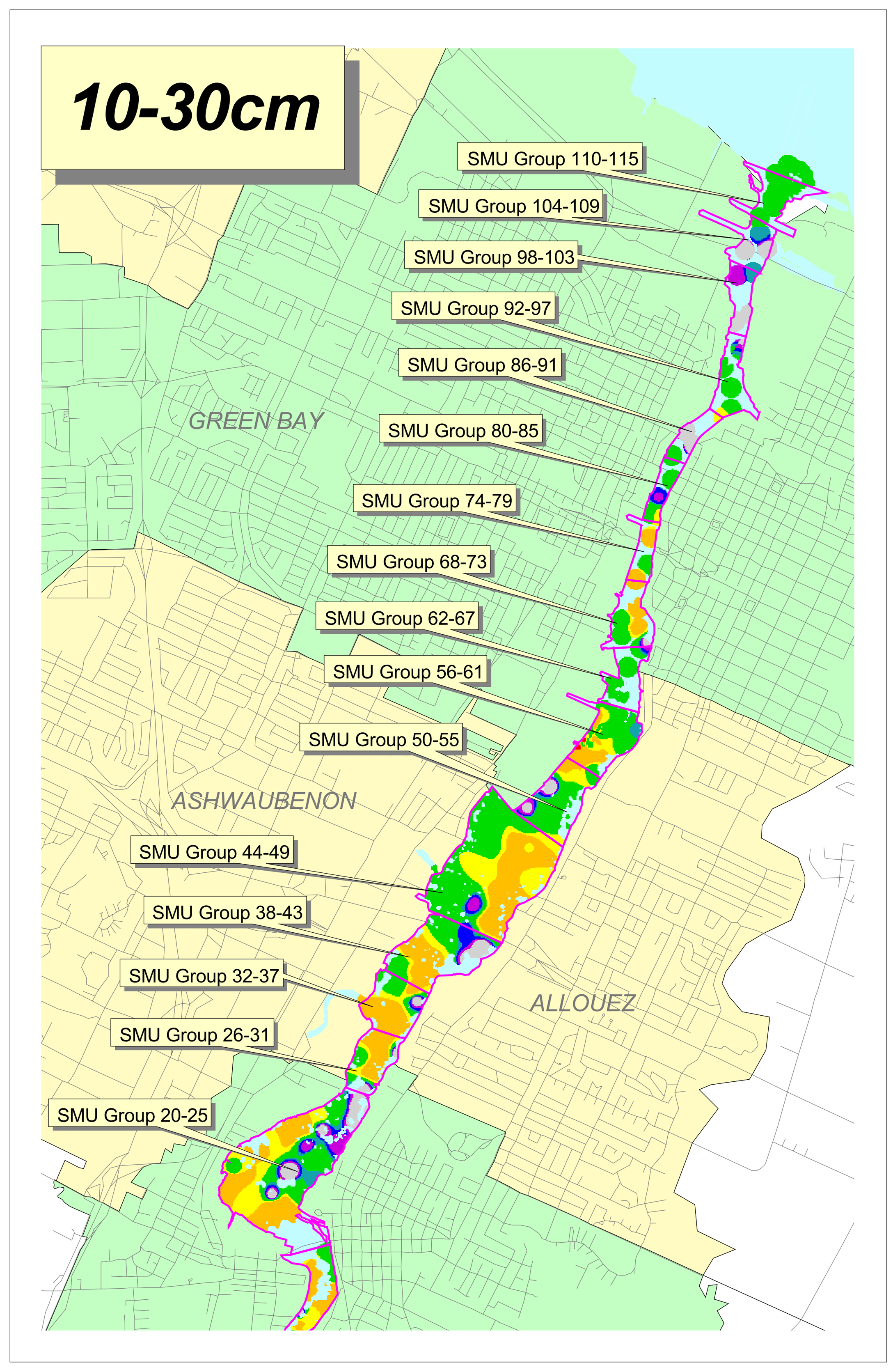



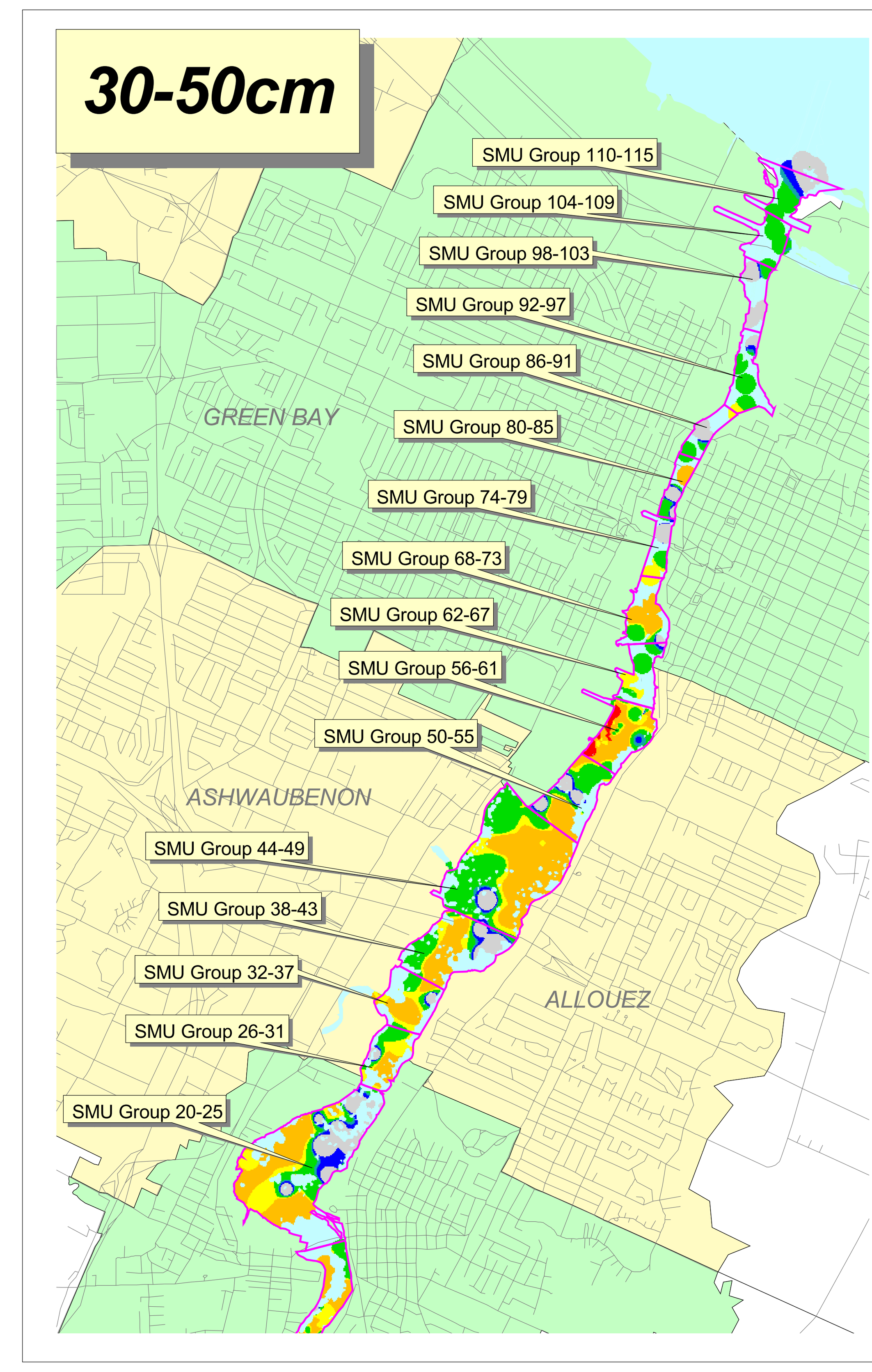



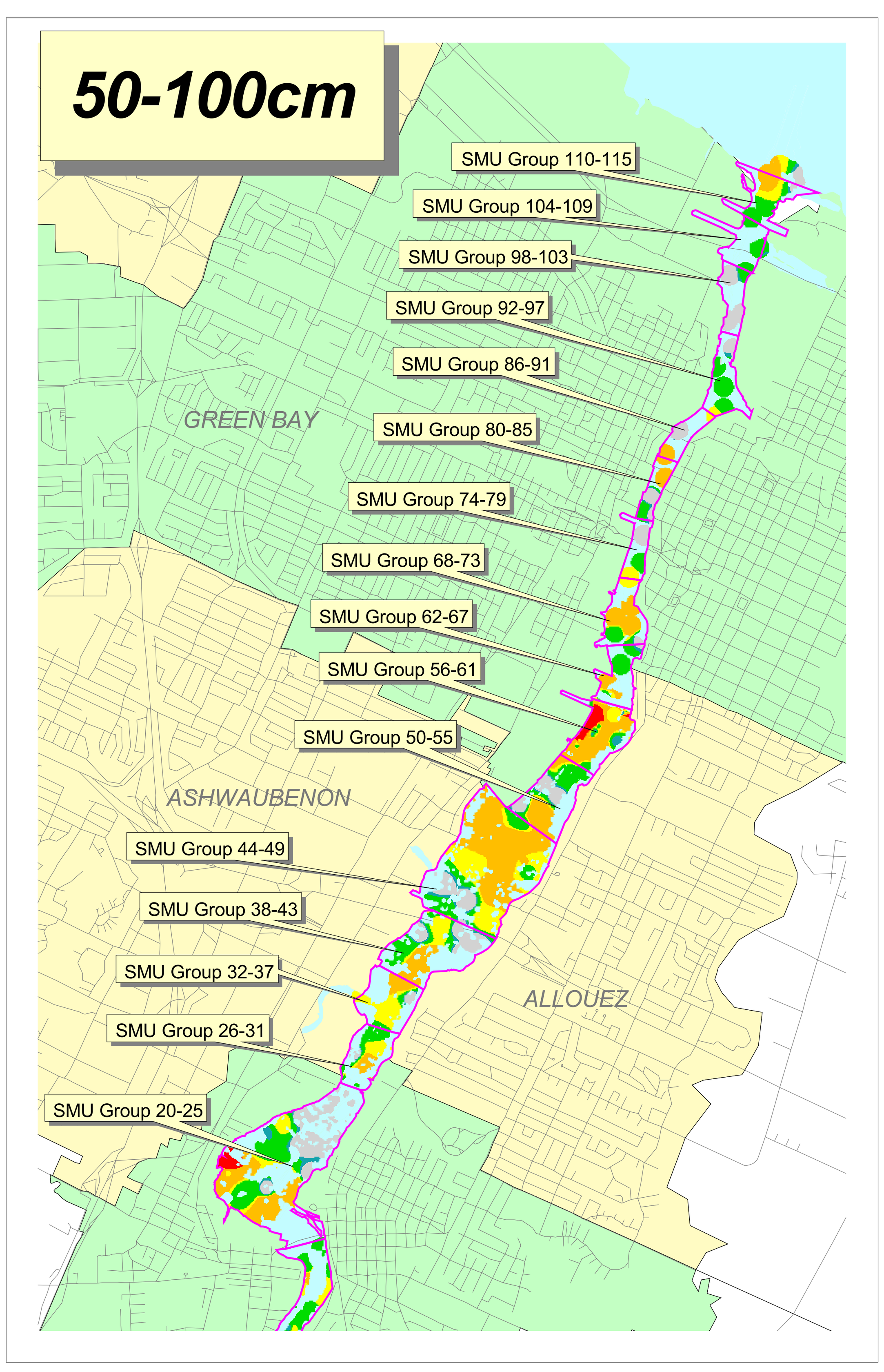

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

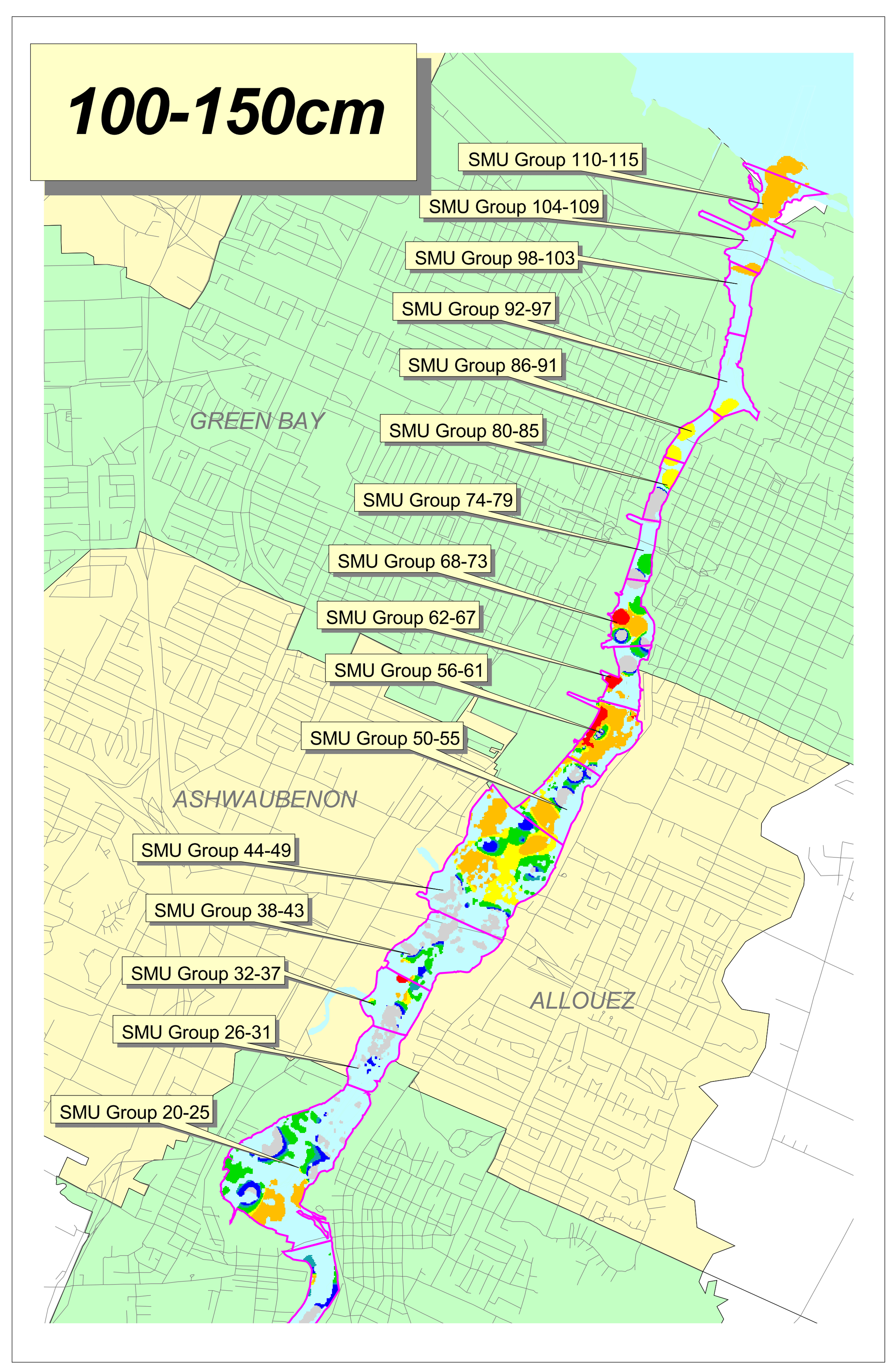
| | | | | |
|---|---|---|---|---|
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Interpolated PCB Distribution in Sediments: Little Rapids to De Pere Reach | DRAWING NO: FS-14414-535-2-3 |
| | | | | PRINT DATE: 3/8/01 |
| | | | | CREATED BY: SCJ |
| | | | PLATE 2-3 | APPROVED: AGF |

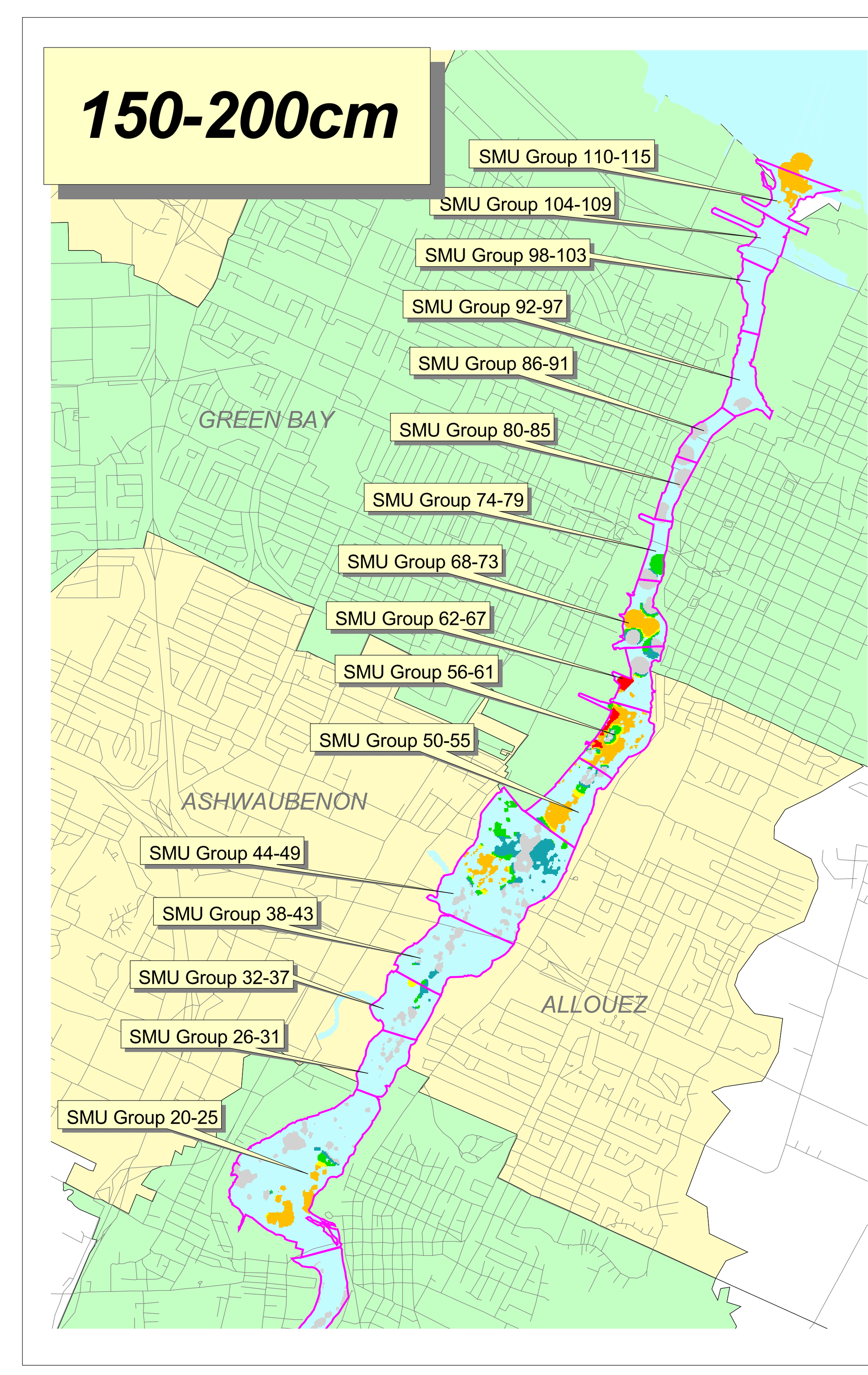


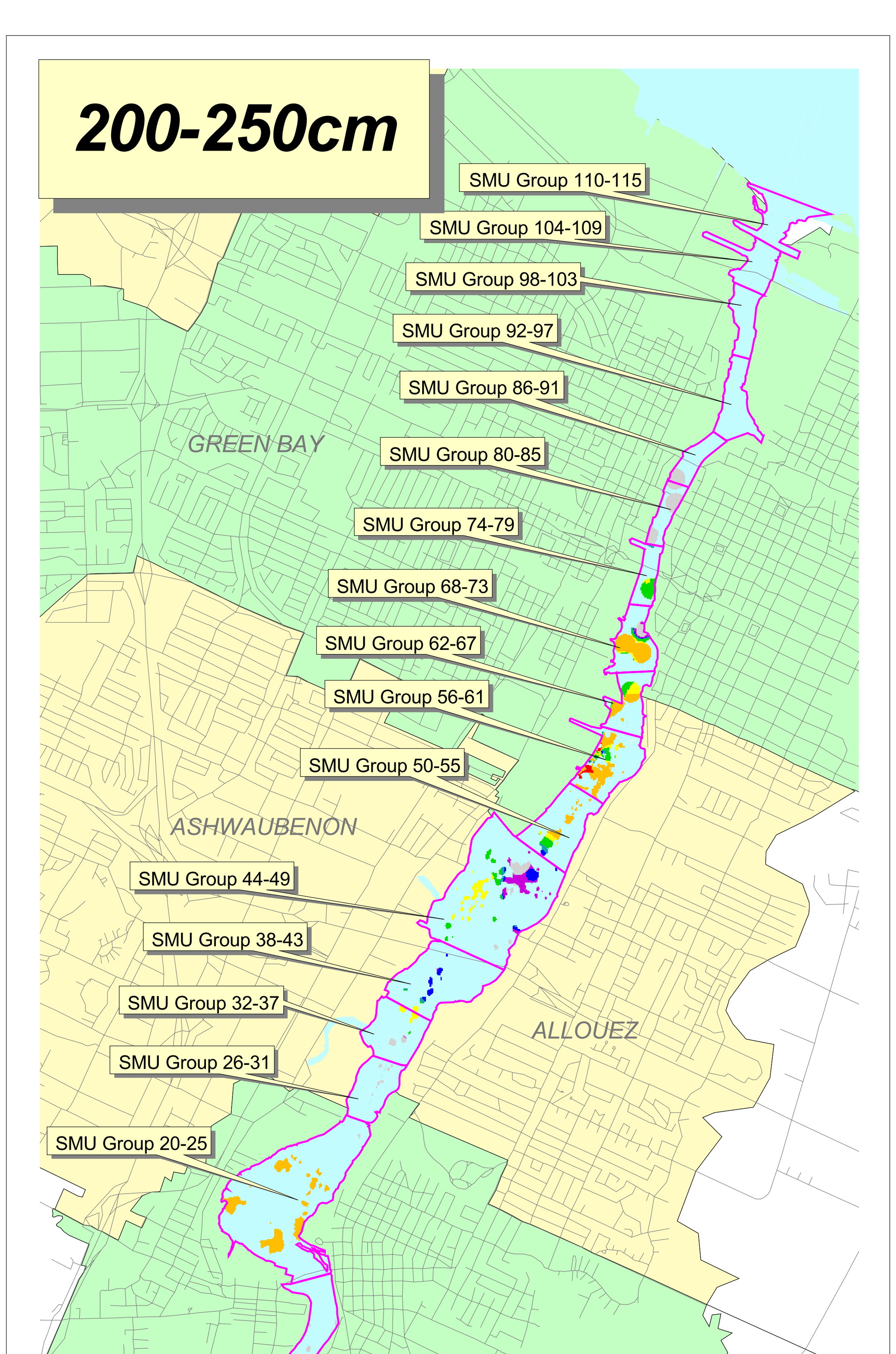



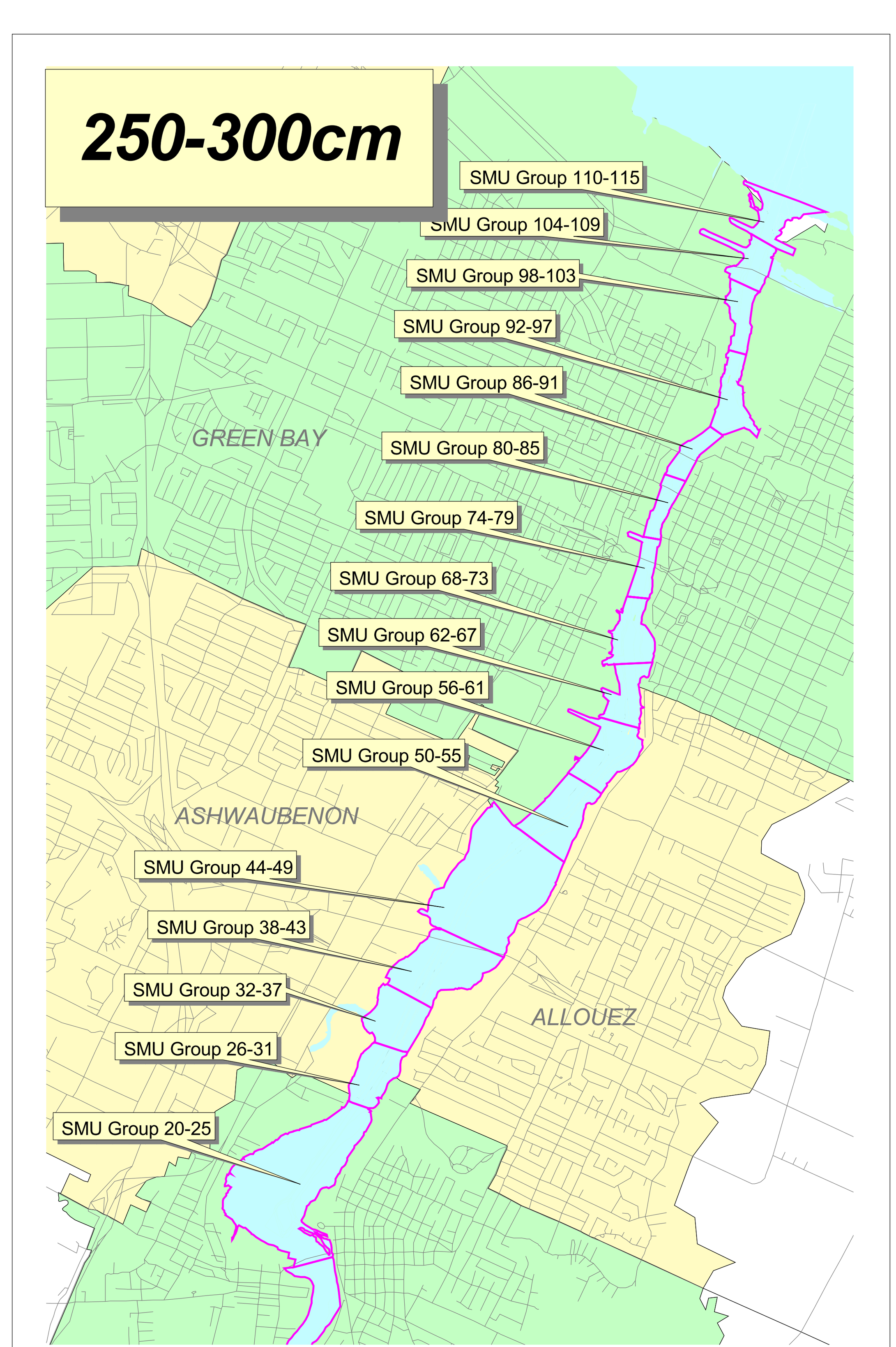



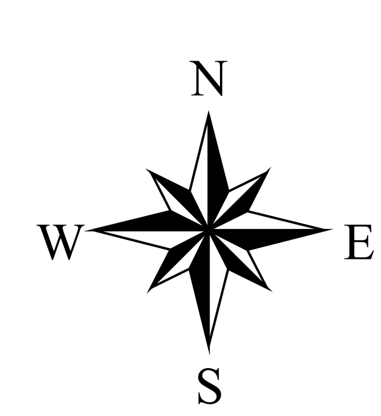



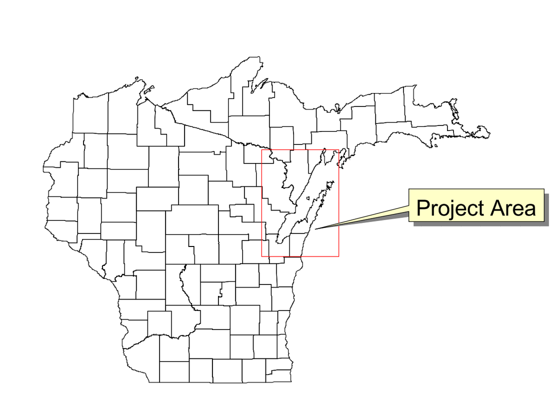

PCB Sediment Concentrations (ug/kg)

- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- 5,000-10,000
- 10,000-50,000
- >50,000
- Sediment Management Units
- Roads
- Water

Civil Divisions

- City
- Township
- Village




2 0 2 4 Kilometers

2 0 2 Miles

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 300 cm depths. Assume no exceedences beyond depths shown.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

| | | | | |
|---|---|---|---|---|
| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Interpolated PCB Distribution in Sediments: De Pere to Green Bay Reach | DRAWING NO: FS-14414-535-2-4 |
| | | | | PRINT DATE: 3/8/01 |
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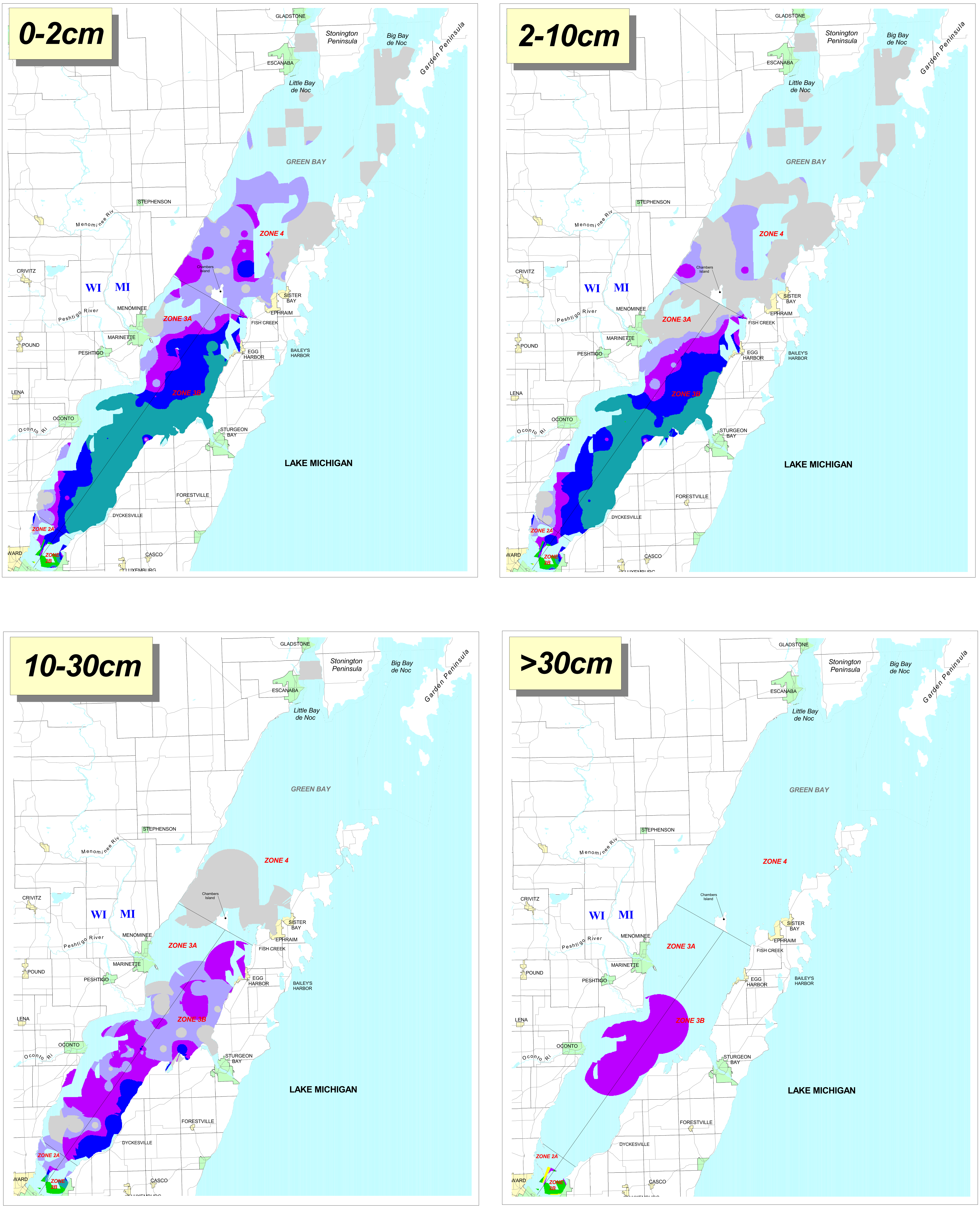
| | | | PLATE 2-4 | APPROVED: AGF |

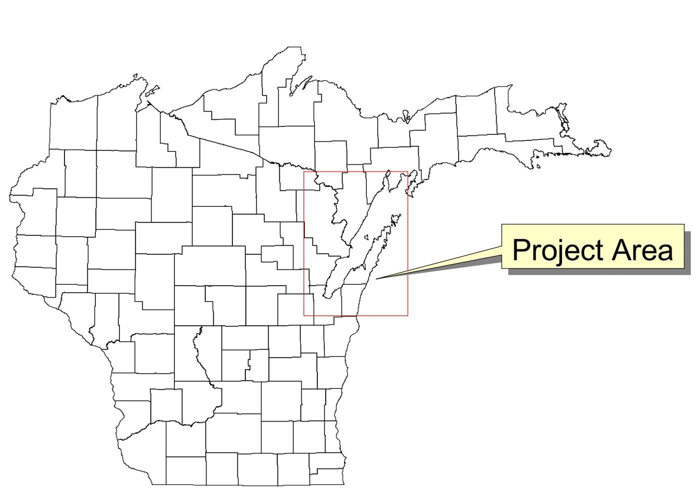



PCB Sediment Concentrations (ug/kg)

- <50
- 50-125
- 125-250
- 250-500
- 500-1,000
- 1,000-5,000
- >5,000
- Roads
- Water

Civil Divisions

- City
- Township
- Village




N
W E
S

20 0 20 40 Kilometers

20 0 20 Miles

NOTES:
1. Basemap generated in ArcView GIS, version 3.2, 1998 and TIGER census data, 1995.
2. PCB sediment concentration data obtained from WDNR, and was generated in ArcView Spatial Analyst, version 1.1.
3. Distribution of PCB-impacted sediment defined by interpolated depth intervals (layers) below surfaces greater than 30 cm depths.
4. The less than 50 ug/kg layer implies the presence of soft sediment with detectable PCB concentrations.

| ThermoRetec Smart Solutions. Positive Outcomes. | Natural Resource Technology | Lower Fox River & Green Bay Feasibility Study | Interpolated PCB Distribution in Sediments: Green Bay | DRAWING NO: FS-14414-535-2-5 |
|---|---|---|---|---|
| | | | | PRINT DATE: 3/8/01 |
| | | | | CREATED BY: SCJ |
| | | | PLATE 2-5 | APPROVED: AGF |

# 3 Summary of the Baseline Human Health and Ecological Risk Assessment

As a follow-up to the Screening Level Risk Assessment (SLRA) which identified chemicals of potential concern (COPCs), a Baseline Human Health and Ecological Risk Assessment (BLRA) for the Lower Fox River and Green Bay (RETEC, 2002b) has been prepared as a companion document to the RI and FS. This BLRA was undertaken to provide an assessment of risks to human health and the environment that will support the selection of a remedy to eliminate, reduce, or control those risks. Specific goals of the BLRA for the Lower Fox River and Green Bay were to:

- Examine how the COPCs carried forward from the SLRA (RETEC, 1998) move from the sediment and water into humans and ecological receptors within the Lower Fox River and Green Bay.

- Quantify the current (or baseline) human health and ecological risk associated with the COPCs.

- Distinguish those COPCs which pose the greatest potential for risk from those that pose negligible risks to human health and the environment.

- Determine which exposure pathways lead to the greatest risks.

- Determine which COPCs are carried forward in the FS as COCs.

- Support the selection of a remedy to eliminate, reduce, or control identified risks by calculating sediment quality thresholds (SQTs).

The COPCs carried forward from the SLRA included polychlorinated biphenyls (PCBs) (total and selected congeners), dioxins/furans (2,3,7,8-TCDD and 2,3,7,8-TCDF), DDT and its metabolites DDE and DDD, dieldrin, and three metals (arsenic, lead, and mercury). For both assessments, risk was characterized for the four reaches of the Lower Fox River, including Little Lake Butte des Morts, Appleton to Little Rapids, Little Rapids to De Pere, and De Pere to Green Bay (Green Bay Zone 1) as well as the zones of the bay: Zone 2, Zone 3A, Zone 3B, and Zone 4. Therefore, risks between each of these reaches and zones could be compared.

Details of the human health risk assessment and the ecological risk assessment are provided in Sections 3.1 and 3.2, respectively. General conclusions of both assessments were that:

- Fish consumption is the exposure pathway that represents the greatest level of risk for receptors (other than direct risk to benthic invertebrates).

- The primary COC is total PCBs. Other COCs carried forward for remedial evaluation and long-term monitoring are mercury and DDE.

- In general, areas with the greatest risk are Green Bay zones 1 and 2, although for human health, estimated risk did not differ greatly between the river reaches and bay zones.

SQTs were estimated for PCBs with the assumption that a remedial action targeting PCBs would also capture the other COCs. The SQTs themselves are not cleanup criteria, but are a good approximation of protective sediment values and can be considered to be “working values” from which to select a remedial action level. The SQTs and risk associated with SQTs are further evaluated and discussed in Section 8 of this FS. Safe concentrations in fish for human and ecological receptors were determined for:

- Human and ecological receptors (e.g., fish-eating humans, fish, piscivorous birds, and piscivorous mammals);

- Appropriate human health risk levels ($10^{-5}$ for cancer risk in humans and a hazard index (HI) of 1.0 for noncancer risk based on fish consumption), and both the no observed adverse effect concentrations (NOAECs) and lowest observed adverse effect concentrations (LOAECs) for ecological receptors; and

- Two different assumptions regarding fish consumption rates for humans: subsistence fishing and sport fishing.

Once the “safe” PCB fish tissue concentrations were determined, corresponding sediment concentrations that would need to exist in the river or bay were calculated. This was accomplished using a bioenergetic food web model—the FRFood Model. PCB SQTs are the output of the model and are further discussed in Section 3.3. The development and validation of the mathematical model used to define SQTs is described in the BLRA (Section 7) and the FRFood Model Documentation Memorandum (RETEC, 2002c).

The SQTs themselves do not provide specific cleanup goals, but rather provide the resources managers (Wisconsin and federal agencies) an array of risk-based thresholds from which to select remedial action levels for evaluation in the FS. The final selection of the remedial action levels carried forward in the FS is a policy decision left to the response agencies. A summary of the results of the BLRA are presented in the two sections below. In addition, the SQTs are presented in Section 3.3.

## 3.1 Human Health Risk Assessment

Using the results of the SLRA as its starting point, the human health risk assessment for the Lower Fox River and Green Bay calculated cancer risks and noncancer hazard indices for the following receptors:

- Recreational anglers,
- High-intake fish consumers,
- Hunters,
- Drinking water users,
- Local residents,
- Recreational water users (swimmers and waders), and
- Marine construction workers.

For the human health risk assessment, two evaluations were performed, a baseline risk assessment and a focused risk assessment. For the baseline risk assessment, all data for a specific medium for each COPC were used to evaluate exposures and risks. The highest cancer risks and noncancer hazard indices were calculated for recreational anglers and high-intake fish consumers due primarily to consumption of fish containing PCBs. For the focused risk assessment, which examined only exposure to PCBs in fish by recreational anglers and high-intake fish consumers, and only fish tissue data from 1989 and after were used.

In a follow-up, focused assessment, potential risks to recreational anglers and high-intake fish consumers were examined in more detail. Using fish concentration data from 1990 on (and walleye data from 1989 in Green Bay), the cancer risks were as high as $9.8 \times 10^{-4}$ for recreational anglers and $1.4 \times 10^{-3}$ for high-intake fish consumers. These risks are 100 times greater than the $10^{-5}$ cancer risk level commonly used in Wisconsin according to administrative rules such as Chapter NR 105 Wisconsin Administrative Code for the protection of human health based on fish consumption (Chapter 105 specifies a $10^{-5}$ risk level for fish consumption). These risks are 1,000 times greater than the $10^{-6}$ cancer risk level, which is the point at which risk management decisions may be made under Superfund. The highest cancer risks for recreational anglers and high-intake fish consumers are more than 20 times greater than background risks calculated for eating fish from Lake Winnebago (which is a background location relative to the Lower Fox River and Green Bay).

The hazard indices were as high as 36.9 for the recreational angler and 52.0 for the high-intake fish consumer; far in exceedance of the value of 1.0 established to protect people from long-term adverse noncancer health effects. The noncancer health effects associated with exposure to PCBs include reproductive effects (e.g., conception failure in highly exposed women), developmental effects (e.g., neurological impairment in highly exposed infants and children), and immune system suppression (e.g., increased incidence of infectious disease in highly exposed infants). The highest noncancer hazard indices for recreational anglers and high-intake fish consumers are more than 20 times greater than background hazard indices calculated for eating fish from Lake Winnebago (which is a background location relative to the Lower Fox River and Green Bay).

To provide perspective on the number of individuals who are potentially exposed in the state of Wisconsin, there are on the order of 136,000 registered recreational anglers, and about 5,000 high-intake fish consumers, based on fish licenses and a variety of surveys, respectively. The high-intake fish consumers can include low-income minority anglers, Native American anglers, Hmong/Laotian anglers, and anyone else who consumes an amount of fish consistent with the assumptions used to define a "high-intake fish consumer."

Cancer risks and hazard indices were calculated by river reach and Green Bay zone. However, there was relatively little difference between the highest risk in any reach or zone, which occurred in the Green Bay Zone 3A, and the lowest risk in any reach or zone, which occurred in the Little Rapids to De Pere Reach. The risk in Green Bay Zone 3A is 2.3 times greater than the risk in the Little Rapids to De Pere Reach.

The cancer risks and hazard indices were examined in detail in four species: carp, perch, walleye, and white bass. Carp generally had the highest concentrations of PCBs in each reach or zone where data were available and so exhibited the highest cancer risks and hazard indices. The lowest concentrations of PCBs occurred for perch, walleye, or white bass, depending on the river reach or Green Bay zone. The cancer risks and hazard indices for these three species are comparable.

The only other receptors with cancer risks exceeding $10^{-6}$ were the hunters and drinking water users. Cancer risks for the marine construction worker slightly exceed the $1 \times 10^{-6}$ level in the Little Lake Butte des Morts Reach. The risks to the hunter were as high as $8.3 \times 10^{-5}$, but were at least 10 times lower than the risks to the anglers. The risk to the hunter was due to ingestion of PCBs in waterfowl. The risk to drinking water users exceeded $10^{-6}$ only in the De Pere to Green Bay Reach. This exceedance was due to arsenic in surface water, and the arsenic value was from one detected value in a total of four samples. A more systematic sampling of this water for arsenic might show this single detected value to be anomalous. Additionally, the water in this reach is not currently used as a source of drinking water, and there are no plans to use it as such in the foreseeable future (this reach of the Lower Fox River is not classified for use as a source of drinking water). The cancer risks to drinking water users in all other reaches of the Lower Fox River and zones of Green Bay were below the $10^{-6}$ level, as were the cancer risks for the local residents and recreational water users (swimmers and waders).

The only other receptors with hazard indices exceeding 1.0 were the hunter, drinking water user, and local resident. The highest HI for these receptors was 3.8, only slightly above 1.0. These hazard indices are more than 10 times lower than the highest hazard indices for the high-intake fish consumers and about 10 times lower than the highest hazard indices for the recreational angler. The hazard indices were below 1.0 for the recreational water users and marine construction workers in all reaches of the Lower Fox River and zones of Green Bay.

In conclusion, recreational anglers and high-intake fish consumers are at greatest risk for contracting cancer or experiencing noncancer health effects. A summary of these risks is presented on Figures 3-1 and 3-2. The highest cancer risks are more than 20 times greater than background risks calculated for eating fish from Lake Winnebago (which is a background location relative to the Lower Fox River and Green Bay). The primary reason for these elevated risks and hazard indices is ingestion of fish containing PCBs.

## 3.2 Ecological Risk Assessment

As part of the ecological BLRA exposure assessment, assessment endpoints selected for risk evaluation were:

- **Aquatic Invertebrates:** Insects and other invertebrates that live in the water and are important prey items for fish and other insects.

- **Benthic Invertebrates:** Insects and other invertebrates that live in or on the sediment that are important in recycling nutrients and a principal part of fish diets.

- **Benthic Fish:** Fish, such as carp and catfish, that live on and forage in the sediments and are in turn eaten by other fish, birds, mammals, and people.
- **Pelagic Fish:** Fish, such as walleye and yellow perch, that live in the water column, and eat other fish or insects that live in the water or on the sediments. These fish may be in turn eaten by other fish, birds, mammals, and people.
- **Insectivorous Birds:** Birds, such as swallows, that eat insects that hatch from the sediment.
- **Piscivorous Birds:** Birds, such as cormorants or terns, that principally eat fish from the Lower Fox River or Green Bay.
- **Carnivorous Birds:** Birds, such as eagles, that will eat a variety of prey, including fish or small mammals.
- **Piscivorous Mammals:** Mammals, such as mink, that eat fish as an important part of their diet.

Risk was characterized for these assessment endpoints principally based on the calculation of hazard quotients (HQs). HQs are the ratios of measured COPC concentrations in media (water, sediment, tissue) as compared to safe COPC concentrations in these media. HQs that are greater than 1.0 imply that risk may be present. Where available, both NOAEC and LOAEC HQs were calculated. Effects evaluated were reproductive dysfunction, death at birth, or deformities in the surviving offspring. When NOAEC HQs exceeded 1.0, but LOAEC HQs were less than 1.0, then it was concluded that there was potential risk. When both the NOAEC and LOAEC HQs exceeded 1.0, it was assumed that risk was present.

Besides HQs, other factors that were considered in determining risk to assessment endpoints were: field studies, habitat, and population levels. Together, each of the components of the evaluation provided a weight of evidence for the presence or absence of risk.

Risks were evaluated by river reach and bay zone, and are summarized below and on Figures 3-1 through 3-3.

### 3.2.1 Little Lake Butte des Morts Reach

In summary, the results taken in total suggest that only measured or estimated concentrations of total PCBs are at sufficient levels to cause, risk to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks from total PCBs are indicated for water column invertebrates, benthic and pelagic fish, insectivorous and piscivorous birds. Measured or estimated concentrations of mercury are found to be at sufficient concentrations to cause or potentially cause risk to water column and benthic invertebrates, and piscivorous birds. Concentrations of 2,3,7,8-TCDD, DDD, and DDT are only sufficient to be of risk to benthic invertebrates. Sediment concentrations of elevated PCBs are widespread and persistent throughout the reach. Concentrations of arsenic, dieldrin, and all o,p'- isomers of DDT and its metabolites are not found to pose risk to any assessment endpoint. While all assessment endpoints are potentially at risk or are at risk based upon HQs from total PCBs, it was concluded on the weight of evidence that only benthic invertebrates, carnivorous birds, and piscivorous mammals are at risk to elevated levels of PCBs.

### 3.2.2 Appleton to Little Rapids Reach

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause risk to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks are indicated for all other receptors except insectivorous birds, for which there are no data. Measured or estimated concentrations of mercury were found to be at sufficient concentrations to cause or potentially cause risk to benthic invertebrates, piscivorous birds, and carnivorous birds. Concentrations of lead are only of risk to benthic invertebrates. Concentrations of all chlorinated pesticides (dieldrin, o,p'-DDD, o,p'-DDE, o,p'-DDT, p,p'-DDD, p,p'-DDE, p,p'-DDT) are not found to pose risk to any assessment endpoint. Surface sediment concentrations of elevated PCBs indicate reach-wide effects, but are likely limited to specific deposits. Carnivorous birds may have potential risks from PCB exposure, but there do not appear to be any apparent impairments to successful reproduction. Piscivorous mammals are estimated to be at risk to PCBs in this reach.

### 3.2.3 Little Rapids to De Pere Reach

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks are indicated for benthic and pelagic fish, and piscivorous birds. There are no data to evaluate insectivorous birds. Measured or estimated concentrations of mercury are found to be at sufficient concentrations to cause, or potentially cause, risk to aquatic invertebrates, benthic invertebrates, pelagic fish, piscivorous birds, and carnivorous birds. Concentrations of arsenic, dieldrin, all o,p'- isomers of DDT and its metabolites, and p,p'-DDD are not sufficient to pose risk to any assessment endpoint. While all fish and birds are potentially at risk from mercury and total PCBs, only water column and benthic invertebrates and piscivorous mammals are assumed to be at risk, based on elevated HQs.

There are persistent risks to benthic infaunal communities in sediments from exposure to lead, mercury, 2,3,7,8-TCDD, total PCBs, p,p'-DDE, and p,p'-DDT. Surface sediment concentrations of elevated PCBs are fairly uniformly distributed throughout the reach, and thus it is inferred that invertebrate communities are at risk throughout the entire reach. Apparent population level impacts of COCs on reproduction and survival for benthic and pelagic fish are not indicated, although sublethal effects may occur. Carnivorous birds may have sublethal risks from PCB exposure, and because of their status are considered to be at risk. Piscivorous mammals are estimated to be at risk to PCBs in this reach.

### 3.2.4 De Pere to Green Bay Reach (Green Bay Zone 1)

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause risk to benthic invertebrates and piscivorous mammals. Total PCBs are at sufficient levels to potentially cause risk to aquatic invertebrates and insectivorous birds. Concentrations of dieldrin, all o,p'- isomers of DDT and its metabolites, and p,p'-DDT are not sufficient to pose risk to any of the evaluated assessment endpoints. Measured concentrations of mercury were found to be at sufficient concentrations to cause or potentially cause risk to benthic invertebrates. Risks to fish and birds are discussed in the risk summary for Green Bay Zone 2.

### 3.2.5 Green Bay Zone 2

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause risks to benthic invertebrates, carnivorous birds, and piscivorous mammals. Potential risks are indicated for benthic and pelagial fish, and piscivorous birds. Measured or estimated concentrations of mercury are at sufficient concentrations to cause or potentially cause risk to aquatic invertebrates, benthic invertebrates, pelagial fish, piscivorous birds, and carnivorous birds. Measured or estimated concentrations of DDE are at sufficient concentrations to cause, or potentially cause, risk to benthic fish, pelagic fish, insectivorous birds, piscivorous birds, and carnivorous birds.

Benthic and pelagial fish populations appear to be relatively robust throughout lower Green Bay, as evidenced by maintenance of self-reproducing populations of benthic fish and the reintroduction of self-sustaining walleye populations. However, the weight of evidence suggests that while population level impacts do not appear to be occurring, individuals may remain at risk to sublethal effects such as liver tumors.

Insectivorous bird field evaluations showed no discernable effects on nesting behavior, clutch size, hatching success, or deformity.

Chemical levels of organochlorines in piscivorous birds remain sufficiently high to pose risks for at least reproductive impairment and deformities. While the historical levels of PCBs and DDE clearly impacted these birds at the individual and population level, some species (e.g., double-crested cormorants) within the bay have experienced substantial population increases. However, persistence of abnormal development within the area indicates that some level of risk remains for all piscivorous bird species.

Elevated mercury and organochlorine levels in prey continue to pose risk to survival and reproduction of carnivorous birds in zones 1 and 2 of Green Bay. The reproductive rates of nesting bald eagles in these zones appear depressed relative to both inland areas as well as other areas within the Fox River and Green Bay.

Based upon the estimated dietary intakes, PCBs are estimated to be sufficient to cause survival or reproductive impairment to piscivorous mammals.

### 3.2.6 Green Bay Zone 3A

In summary, the results taken in total suggest that concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, benthic fish, pelagic fish, piscivorous birds, carnivorous birds, and piscivorous mammals. There were no data to evaluate insectivorous birds. Mercury concentrations are potentially causing risk to piscivorous birds. Concentrations of dieldrin are a potential risk for carnivorous birds and piscivorous mammals. Concentrations of arsenic, lead, and all o,p'- and p,p'- isomers of DDT and its metabolites were not found to pose risk to any assessment endpoint.

### 3.2.7 Green Bay Zone 3B

In summary, the results taken in total suggest that measured or estimated concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, pelagial fish, piscivorous birds, carnivorous birds, and piscivorous mammals. There are no data to evaluate insectivorous birds. Mercury concentrations are causing or potentially causing risk to benthic invertebrates, pelagial fish, piscivorous birds, and carnivorous birds. DDE concentrations are causing, or potentially causing, risk to pelagial fish, piscivorous birds, and carnivorous birds. Dieldrin concentrations are potentially causing risk to piscivorous mammals. Arsenic and lead concentrations are only of risk to benthic invertebrates.

### 3.2.8 Green Bay Zone 4

In summary, these results taken in total suggest that concentrations of total PCBs are at sufficient levels to cause, or potentially cause, risk to benthic invertebrates, pelagial fish, piscivorous birds, carnivorous birds, and piscivorous mammals. Concentrations of DDE (measured in tissue) are causing or potentially causing risk to pelagial fish and carnivorous birds. Concentrations of mercury are causing or potentially causing risk to piscivorous and carnivorous birds.

### 3.2.9 Ecological Risk Summary for PCBs Mercury, and DDE

Overall, PCBs, mercury, and DDE were the COPCs that most frequently exceeded risk thresholds for all receptors (human and ecological) evaluated and, therefore these three compounds are considered COCs and carried forward in the FS. This section presents selected representative reasonable maximum exposure (RME) HQs developed from the BLRA for PCBs, mercury, and DDE, although, as indicated above, calculated HQs were only one part of the weight of evidence evaluated in the estimation of risk. These risks are summarized in Table 3-1.

HQs exceeding 1.0 for PCBs in the river and bay are presented on Figure 3-4 and Figure 3-5, respectively. For sediment, total PCB HQs in all areas exceeded 1.0. Sediment PCB HQs were greatest in Little Lake Butte des Morts Reach and lowest in Green Bay Zone 4, and generally, sediment HQs in intermediate areas indicated decreasing HQs while moving downstream from the river into the bay. Alternatively, in both benthic and pelagic fish, total PCB HQs increased moving downstream in the river. Total PCB HQs for benthic fish were highest in Green Bay zones 1 and 2, and for pelagic fish they were highest in Green Bay Zone 3B. No benthic fish data were available, however, for Green Bay zones 3B and 4.

Carnivorous and piscivorous bird data were limited to select areas in Green Bay, but did suggest that adverse reproductive risk is occurring. Therefore, because of this potential risk and the limited data, exposure concentrations for areas with no data were estimated through modeling. HQs for piscivorous and carnivorous birds based on exposure modeling suggest that, for both bird types, reproductive risk is greatest for Green Bay zones 1 and 2, followed by Green Bay Zone 3B. No data were available for piscivorous mammals and, therefore, exposure was estimated through modeling dietary intake as was done for piscivorous and carnivorous birds. Similar to the reproductive risk found for birds, the calculated HQs for piscivorous mammals suggest that reproductive risk is greatest for Green Bay zones 1 and 2, followed by Green Bay Zone 3B.

HQs exceeding 1.0 for mercury in all areas evaluated are presented on Figure 3-3. As indicated on this figure, mercury concentrations in sediment are higher in the river than the bay, and the highest sediment concentrations in the river are found in the Little Rapids to De Pere Reach. Mercury HQs for fish only exceeded 1.0 in three areas: Little Rapids to De Pere Reach, Green Bay zones 1 and 2, and Green Bay Zone 3B. Fish concentrations were highest in the Little Rapids to De Pere Reach. Based on exposure modeling, piscivorous bird HQs were highest in Green Bay zones 1 and 2, and all other areas had HQs of similar magnitude. For carnivorous birds, exposure modeling indicated that HQs are highest in Green Bay Zone 3B, followed by Green Bay Zone 4.

HQs exceeding 1.0 for DDT and metabolites in all areas evaluated are presented on Figure 3-6. DDT (in the form of DDE) HQs are highest in the Little Rapids to De Pere reach, and HQs for DDT or its metabolites exceed 1.0 in surface sediment in all other areas evaluated except for Green Bay zones 3A, 3B, and 4. All HQs that exceeded 1.0 for tissues were concentrations of DDE, and all of these HQs were less than 10. DDE HQs for fish only exceeded 1.0 in three areas: Green Bay zones 1 and 2, Green Bay Zone 3B, and Green Bay Zone 4. DDE HQs in piscivorous birds exceeded 1.0 in Green Bay zones 1, 2, and 3B based on both measured and estimated tissue DDE concentrations; and HQs in carnivorous birds exceeded 1.0 in Green Bay zones 1, 2, and 4 based on exposure modeling. Estimated HQs for piscivorous mammals did not exceed 1.0.

## 3.3 Sediment Quality Thresholds

For both human health and ecological risk, the BLRA concludes that the greatest potential risk is from the PCBs that are found in the sediments of the Lower Fox River and Green Bay. For human health, the greatest risk comes from individuals who consume fish caught in the Lower Fox River and Green Bay. For the ecological receptors, the greatest risks were from total PCBs in the surface sediment, as well as PCBs in birds and mammals that rely principally on fish for food. Reducing total PCBs in fish by reducing the levels of total PCBs in the sediments was determined to be the most important means of reducing risks in the Lower Fox River and Green Bay.

The Fox River Bioaccumulation Model (FRFood Model) is a series of mathematical equations that describes a food web and the transfer of bioaccumulating contaminants within that food web. The model includes uptake routes from sediment and water to benthic infauna and ultimately fish, and the model was constructed so that it could be used to either predict fish tissue concentrations from a given sediment concentration, or to predict sediment concentrations from a given fish tissue concentration. The model was validated by running the model "forward;" that is, fish tissue concentrations were predicted from existing sediment concentrations and then compared to measured fish tissue concentrations. When the predicted concentrations were compared to the actual measured concentrations of total PCBs in fish collected in the Lower Fox River and Green Bay, the results were highly comparable. Calibration of the FRFood Model indicated that all predicted fish tissue concentrations were within one-half order of magnitude of observed concentrations of total PCBs, except for yellow perch in the Little Lake Butte des Morts Reach. However, within this reach data were only available for one fish. As a result, the risk analysis carried forward in later sections of the FS focused primarily on walleye and carp, and not on yellow perch.

Human health and ecological SQTs were derived based on conditions present in the De Pere to Green Bay Reach (Green Bay Zone 1) (e.g., sediment organic carbon levels, organism lipid concentrations). As a risk management decision, it is assumed that SQTs derived for Green Bay Zone 1 will be applied to the whole Lower Fox River and Green Bay even if reach-specific or zone-specific water-to-sediment ratios may differ in part because the greatest human health and ecological risks are found in Green Bay Zone 1. Because of the uncertainty associated with the sediment-to-water ratio, SQTs may differ by an order of magnitude. For example, walleye NOAEC SQTs based on a sediment-to-water ratio of $10^{-5}$ are 8 times less than SQTs based on a sediment-to-water ratio of $10^{-6}$ and 25 times less than SQTs based on a sediment-to-water ratio of $10^{-7}$. These derived SQTs are detailed below.

### 3.3.1 Human Health SQTs

To determine SQTs for the protection of human health, sediment concentrations associated with a variety of risk-based fish concentrations (RBFCs) were determined. The RBFCs were calculated for recreational anglers and high-intake fish consumers for reasonable maximum exposure (RME) and central tendency exposure (CTE) scenarios. For recreational anglers, the amount of fish consumed was determined from two studies of Michigan anglers, while for high-intake fish consumers, the amount of fish consumed was determined from a study of low-income minority anglers and a study of Hmong anglers. RBFCs were calculated for a cancer risk level of $10^{-5}$ and a noncancer HI of 1.0 for each receptor. The RBFCs were translated into SQTs using the FRFood Model. These SQTs are presented in Table 3-2.

SQTs for a cancer risk level $10^{-6}$ are 10 times less than the SQTs for the cancer risk level $10^{-5}$, and the SQTs for a cancer risk level of $10^{-4}$ are 10 times greater than the SQTs for the cancer risk level of $10^{-5}$. SQTs for the cancer risk level of $10^{-5}$ ranged from 11 to 677 $\mu$g/kg. Noncancer SQTs ranged from 28 to 1,128 $\mu$g/kg. For SQTs based on cancer and noncancer effects, the minimum SQTs were based on consumption of carp by the high-intake fish consumer under a RME scenario and the maximum SQTs were based on consumption of yellow perch by the recreational angler under a CTE scenario.

### 3.3.2 Ecological SQTs

SQTs calculated for the De Pere to Green Bay Reach (Green Bay Zone 1) are shown in Table 3-3. These SQTs are based upon levels of total PCBs in fish that either cause risk to the fish themselves, or to birds or mink eating the fish, or total PCB concentrations in the sediment that cause risk to benthic invertebrates. The SQTs for no observed adverse effects (NOAEC) to walleye is 176 $\mu$g/kg and for carp is 363 $\mu$g/kg. The only calculated SQTs that were lower than these were the SQT for benthic invertebrates and the SQTs for piscivorous mammals (mink). The benthic invertebrates threshold effect concentration (TEL) is a sediment PCB concentration of 31.6 $\mu$g/kg. The NOAEC SQT for mink is 24. The highest derived SQT is 5,231 $\mu$g/kg and this concentration was derived based on the LOAEC potential for deformity in common terns. SQTs based on NOAECs were up to 10 times lower than SQTs based on LOAECs.

## 3.4 Section 3 Figures and Tables

Figures and tables for Section 3 follow page 3-14 and include:

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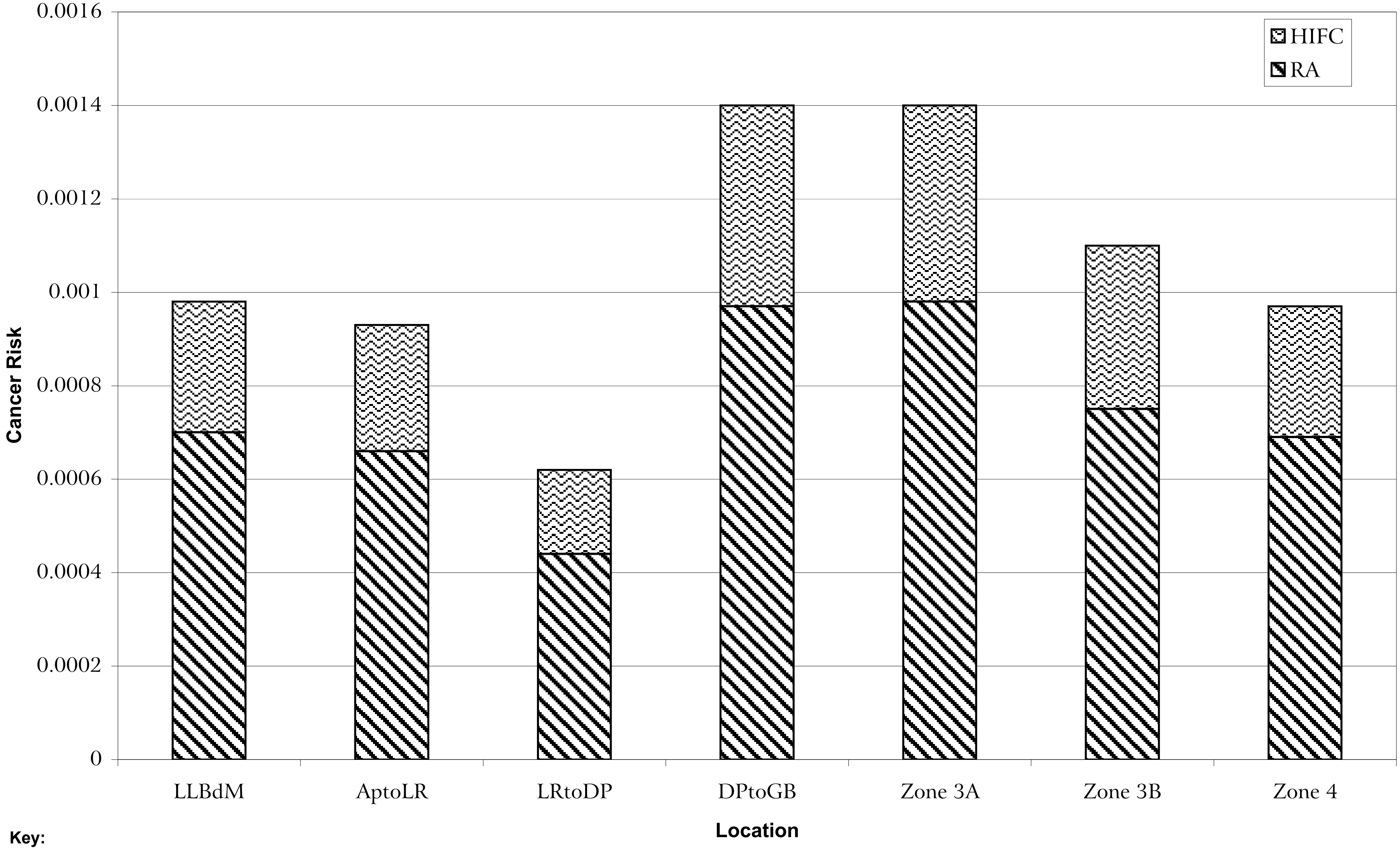
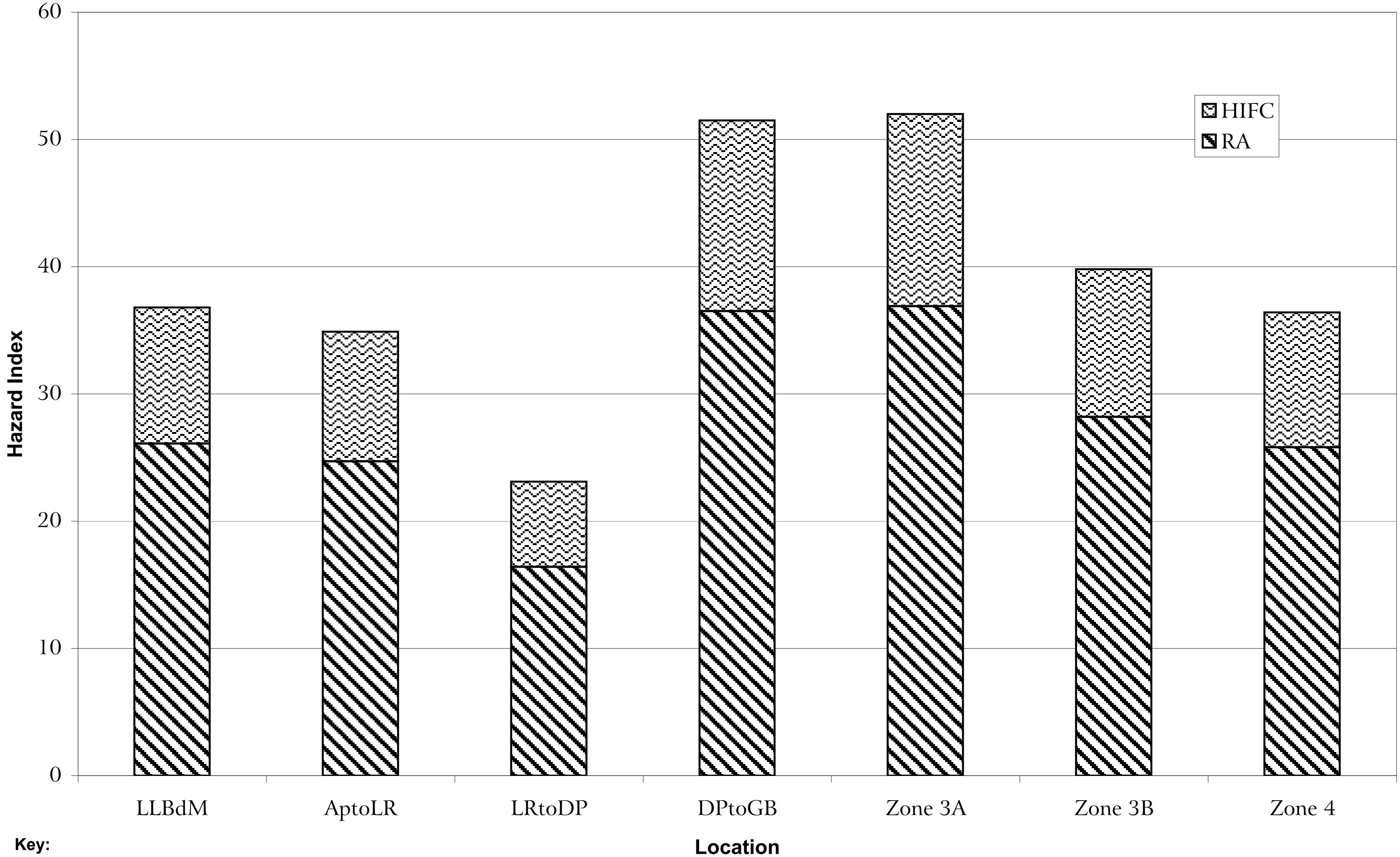
## Figure 3-1 Maximum Cancer Risks for Recreational Anglers and High-intake Fish Consumers




**Key:**

RA - Recreational Angler
HIFC - High Intake Fish Consumer
LLBdM - Little Lake Butte des Morts
AptoLR - Appleton to Little Rapids
LRtoDP - Little Rapids to De Pere
DPtoGB - De Pere to Green Bay
Zone 3A - Zone 3A of Green Bay
Zone 3B - Zone 3B of Green Bay
Zone 4 - Zone 4 of Green Bay

## Figure 3-2 Maximum Hazard Indices for Recreational Anglers and High-intake Fish Consumers




**Key:**

RA - Recreational Angler
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LLBdM - Little Lake Butte des Morts
AptoLR - Appleton to Little Rapids
LRtoDP - Little Rapids to De Pere
DPtoGB - De Pere to Green Bay
Zone 3A - Zone 3A of Green Bay
Zone 3B - Zone 3B of Green Bay
Zone 4 - Zone 4 of Green Bay

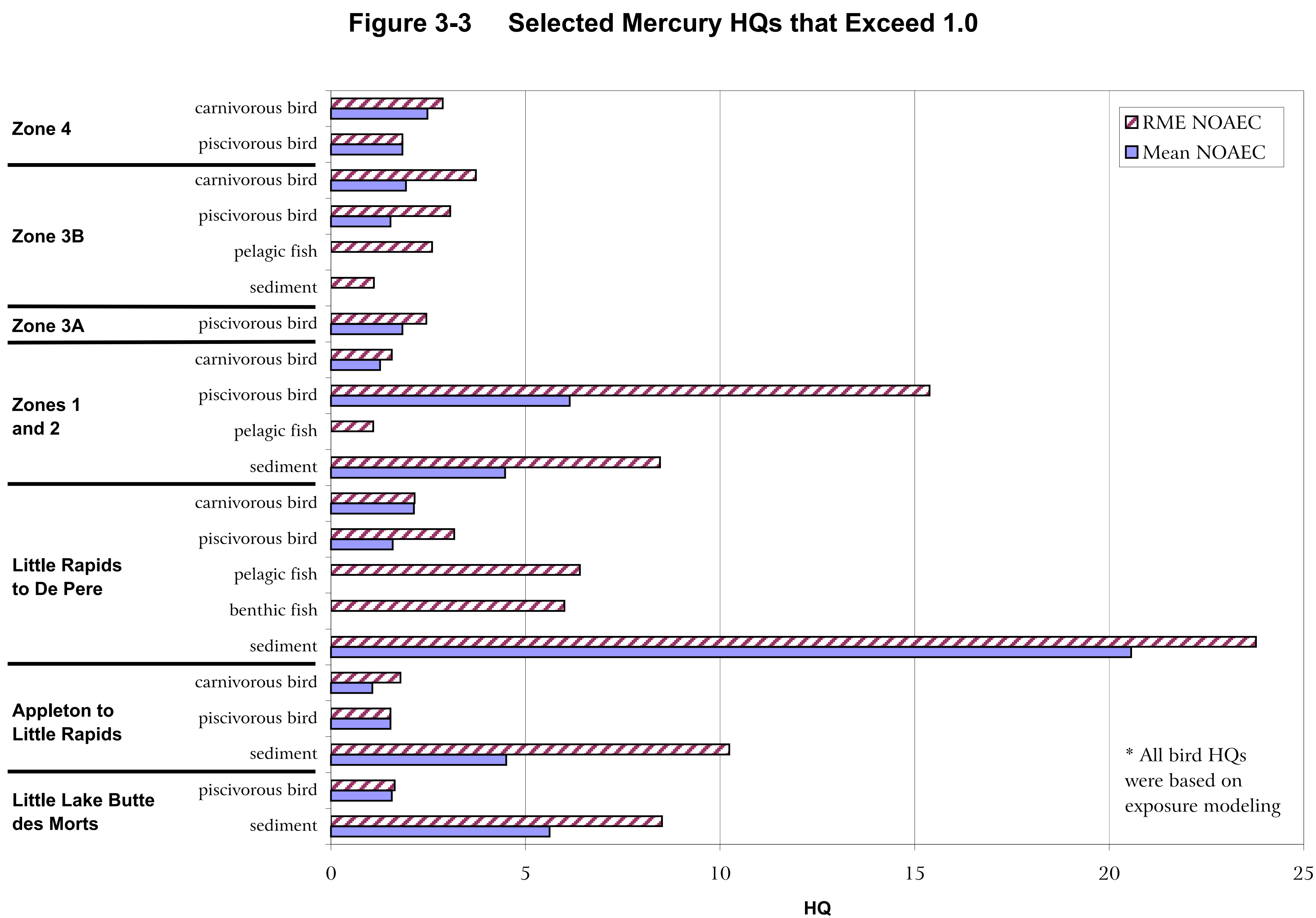
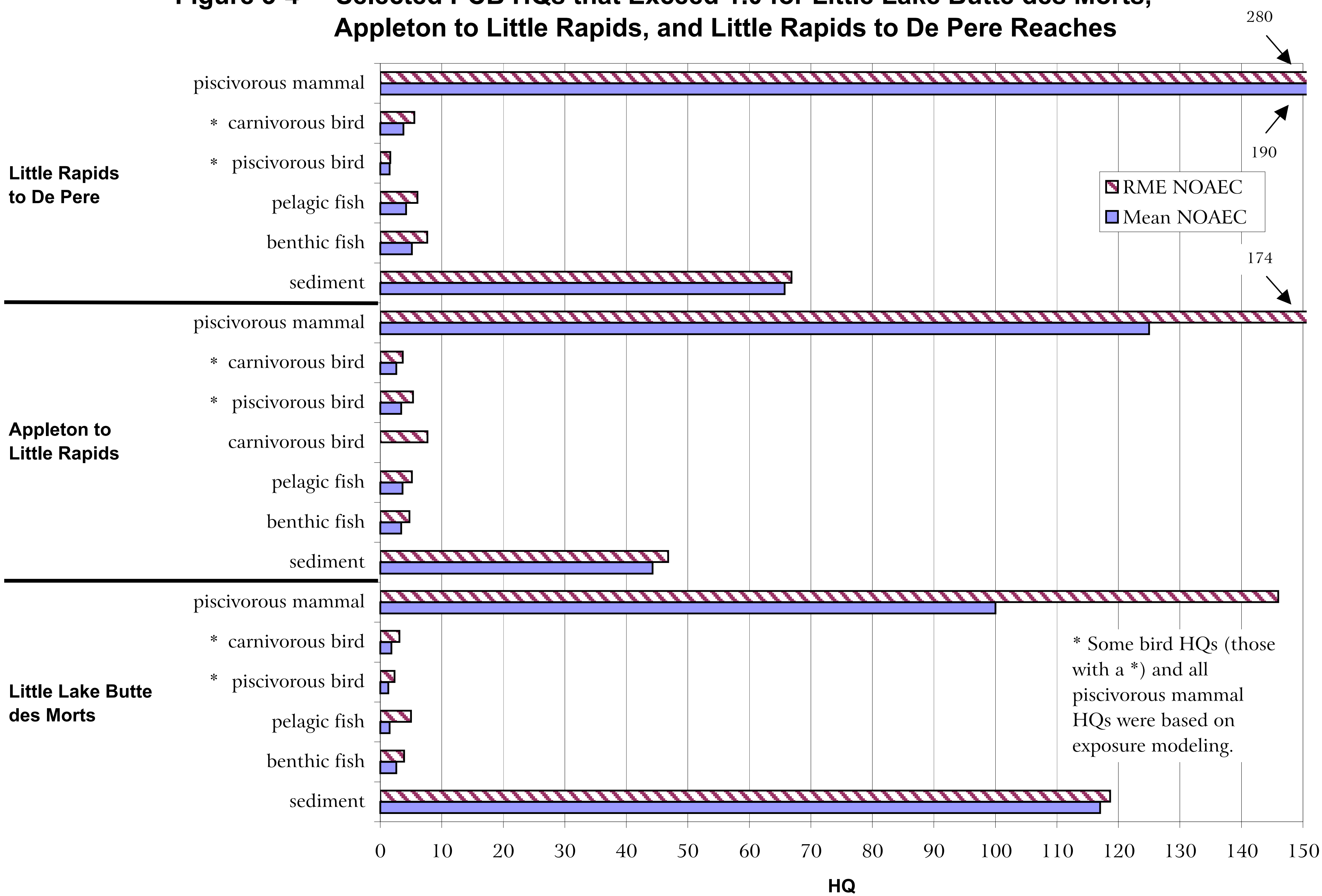
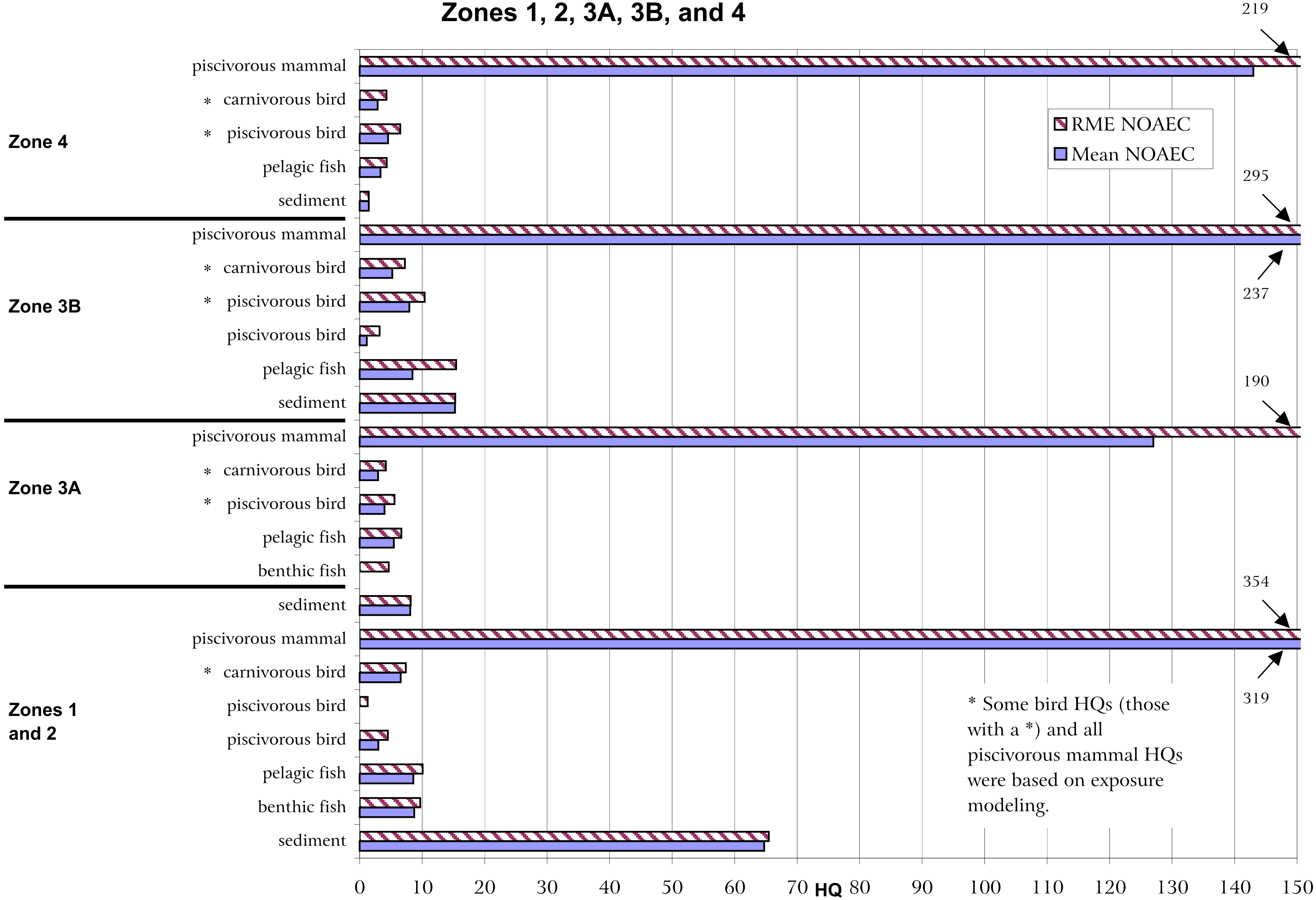


Figure 3-3 Selected Mercury HQs that Exceed 1.0
Zone 4
carnivorous bird
piscivorous bird
Zone 3B
carnivorous bird
piscivorous bird
pelagic fish
sediment
Zone 3A
piscivorous bird
Zones 1 and 2
carnivorous bird
piscivorous bird
pelagic fish
sediment
Little Rapids to De Pere
carnivorous bird
piscivorous bird
pelagic fish
benthic fish
sediment
Appleton to Little Rapids
carnivorous bird
piscivorous bird
sediment
Little Lake Butte des Morts
piscivorous bird
sediment
RME NOAEC
Mean NOAEC
* All bird HQs were based on exposure modeling
0
5
10
15
20
25
HQ

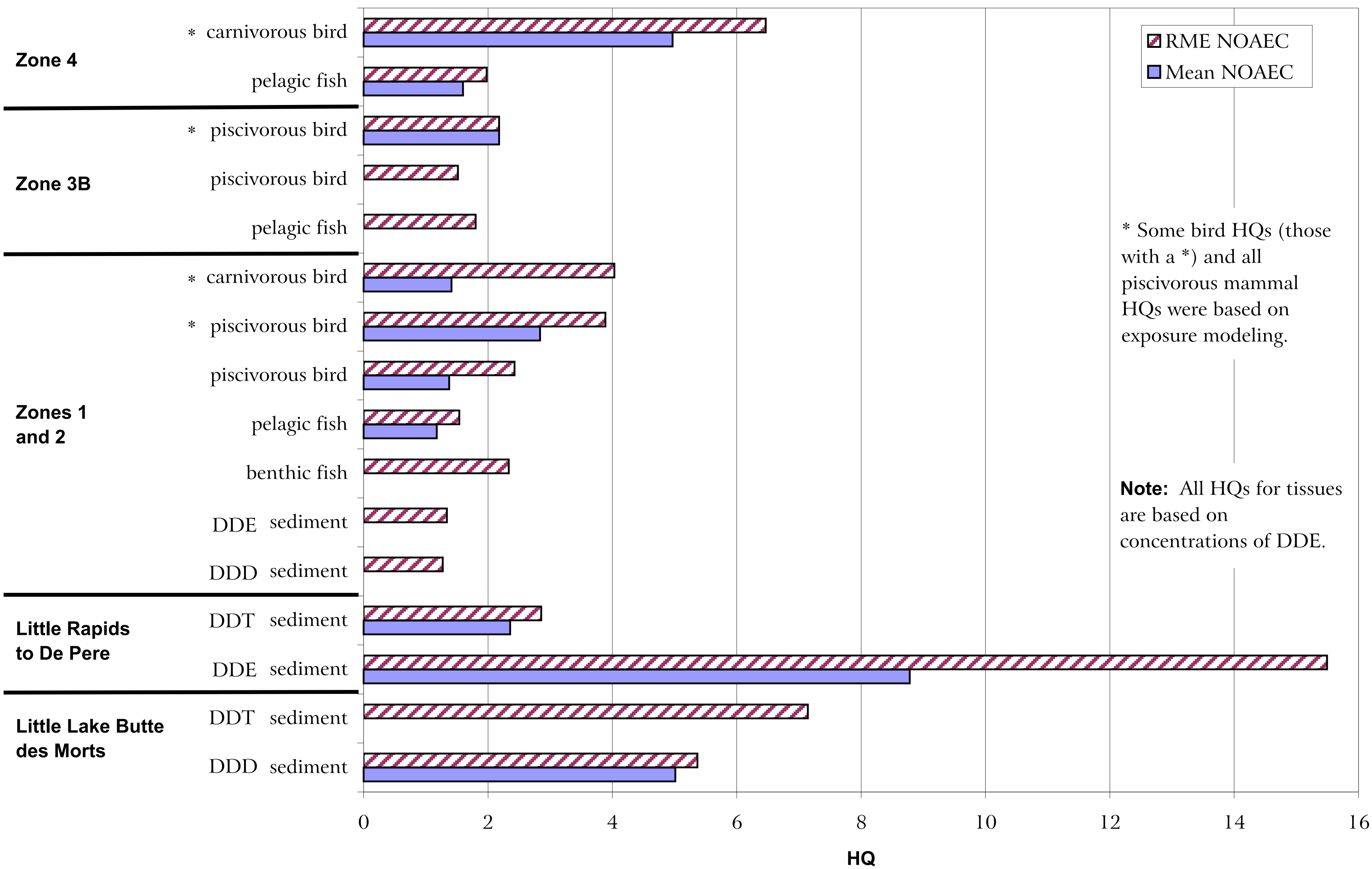
**Figure 3-4 Selected PCB HQs that Exceed 1.0 for Little Lake Butte des Morts, Appleton to Little Rapids, and Little Rapids to De Pere Reaches**



## Figure 3-5 Selected PCB HQs that Exceed 1.0 for Green Bay Zones 1, 2, 3A, 3B, and 4



## Figure 3-6 Selected DDT or Metabolite HQs that Exceed 1.0



# Table 3-1 Ecological Risk Summary Table

| Location | Water Column Invertebrates | Benthic Invertebrates | Benthic Fish | Pelagial Fish | Insectivorous Bird | Piscivorous Bird | Carnivorous Bird | Piscivorous Mammal |
|---|---|---|---|---|---|---|---|---|
| Little Lake Butte des Morts | ● *Mercury*<br>○ *PCBs* | ● *Lead; Mercury; 2,3,7,8-TCDD; PCBs; DDD; DDT* | ○ *PCBs* | ○ *PCBs* | ○ *PCBs* | ○ *Mercury; PCBs* | ○ *PCBs* | ● *PCBs* |
| Appleton to Little Rapids | ○ *PCBs* | ● *Lead; Mercury; PCBs* | ○ *PCBs* | ○ *PCBs* | NA | ○ *Mercury; PCBs* | ● *PCBs*<br>○ *Mercury* | ● *PCBs* |
| Little Rapids to De Pere | ● *Mercury* | ● *Lead; Mercury; 2,3,7,8-TCDD; PCBs; DDE; DDT* | ○ *Mercury; PCBs* | ○ *Mercury; PCBs* | NA | ○ *Mercury; PCBs* | ○ *Mercury; PCBs* | ● *PCBs* |
| Green Bay Zone 1 | ○ *PCBs* | ● *Arsenic; Lead; Mercury; PCBs; DDD; DDE* | ○ *PCBs; DDE* | ○ *Mercury; PCBs; DDE* | ○ *PCBs* | ○ *Mercury; PCBs; Dieldrin; DDE* | ○ *Mercury; PCBs; DDE* | ● *PCBs* |
| Green Bay Zone 2 | ● *Mercury* | ● *Mercury; PCBs* | | | ○ *PCBs; DDE* | | | |
| Green Bay Zone 3A | | ● *PCBs* | ○ *PCBs* | ○ *PCBs* | NA | ○ *Mercury; PCBs* | ● *PCBs*<br>○ *Dieldrin* | ● *PCBs*<br>○ *Dieldrin* |
| Green Bay Zone 3B | | ● *Arsenic; Lead; Mercury; PCBs* | | ● *PCBs*<br>○ *Mercury; DDE* | NA | ● *PCBs*<br>○ *Mercury; Dieldrin; DDE* | ○ *Mercury; PCBs; DDE* | ● *PCBs*<br>○ *Dieldrin* |
| Green Bay Zone 4 | | ● *PCBs* | NA | ○ *PCBs; DDE* | NA | ○ *Mercury; PCBs* | ○ *Mercury; PCBs; DDE* | ● *PCBs* |

**Note:**
NA - No data available.

**Risk Conclusions Based on Hazard Quotients:**
- No risk.
● - Risk.
○ - Potential Risk.

**Risk Conclusions Based on Weight of Evidence:**
- Site-specific receptor data suggest that there is no risk.
- Because of the federal listing of the bald eagle as threatened, it is concluded that potential risk is actual risk.

# Table 3-2 Sediment Quality Thresholds Estimated for Human Health Effects at a $10^{-5}$ Cancer Risk and a Noncancer Hazard Index of 1.0

| | Fish Parameters | Sediment Quality Thresholds | | | |
|---|---|---|---|---|---|
| | Fillet-to-Whole Fish Ratio | Recreational Anglers: Avgerage of Michigan Studies (West *et al.*, 1989; West *et al.*, 1993) | | High-intake Fish Consumers: Average of Low-income Minority Anglers and Hmong Anglers (West *et al.*, 1993 and Hutchison and Kraft, 1994) | |
| | | RME µg/kg | CTE µg/kg | RME µg/kg | CTE µg/kg |
| *Sediment Quality Thresholds for Risk of $10^{-5}$ ** | | | | | |
| Carp | 0.53 | ***16*** | ***180*** | ***11*** | ***57*** |
| Walleye | 0.17 | ***21*** | ***143*** | ***14*** | ***75*** |
| Yellow Perch | 0.17 | ***105*** | ***677*** | ***68*** | ***356*** |
| *Sediment Quality Thresholds for HI of 1.0* | | | | | |
| Carp | 0.53 | ***44*** | ***180*** | ***28*** | ***90*** |
| Walleye | 0.17 | ***58*** | ***238*** | ***37*** | ***119*** |
| Yellow Perch | 0.17 | ***276*** | ***1,128*** | ***175*** | ***564*** |

**Notes:**

* SQTs for cancer risks of $10^{-4}$ and $10^{-6}$ are an order of magnitude higher and lower, respectively.

RME indicates reasonable maximum exposure and CTE indicates central tendency exposure.

Sediment quality thresholds are bolded and in italics.

# Table 3-3 Sediment Quality Thresholds Estimated for Ecological Effects

| Species | Effect | Whole Fish Concentration (µg/kg ww) | Estimated SQT (µg/kg) |
|---|---|---|---|
| Benthic Invertebrates | Threshold Effect Concentration (TEL) | — | 31.6 |
| Walleye | NOAEC - fry growth and mortality<br>LOAEC - fry growth and mortality | 760<br>7,600 | 176<br>1,759 |
| Carp | NOAEC - fry growth and mortality<br>LOAEC - fry growth and mortality | 760<br>7,600 | 363<br>3,633 |
| Common Tern | NOAEC - hatching success<br>LOAEC - hatching success<br>NOAEC - deformity<br>LOAEC - deformity | 2,508<br>4,055<br>427<br>4,269 | 3,073<br>4,969<br>523<br>5,231 |
| Forster's Tern | NOAEC - hatching success<br>LOAEC - hatching success<br>NOAEC - deformity<br>LOAEC - deformity | 2,399<br>3,879<br>408<br>4,083 | 2,940<br>4,753<br>500<br>5,003 |
| Double-crested Cormorant | NOAEC - hatching success<br>LOAEC - hatching success<br>NOAEC - deformity<br>LOAEC - deformity | 814<br>1,317<br>139<br>1,386 | 997<br>1,614<br>170<br>1,698 |
| Bald Eagle | NOAEC - hatching success<br>LOAEC - hatching success<br>NOAEC - deformity<br>LOAEC - deformity | 709<br>1,147<br>121<br>1,207 | 339<br>548<br>58<br>577 |
| Mink | NOAEC - reproduction and kit survival<br>LOAEC - reproduction and kit survival | 50<br>500 | 24<br>239 |

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# 4 Development of Remedial Action Objectives and General Response Actions

This section defines several key cleanup concepts common to all feasibility studies prepared in accordance with CERCLA rules and guidance:

- Remedial action objectives,
- Applicable or relevant and appropriate requirements (ARARs) and information that is "to be considered" (TBC) in the development of remedial alternatives, and
- General response actions (GRAs).

Collectively, these concepts set the stage for developing effective and protective remedial alternatives for cleaning up the Lower Fox River and Green Bay.

RAOs are general cleanup objectives designed to protect human health and the environment. RAOs for the Lower Fox River and Green Bay address the threats site contaminants pose to human and ecological receptors. Risks to biological receptors were characterized and estimated in the BLRA (Section 3).

ARARs and TBCs constitute the body of existing statutes, regulations, ordinances, guidance, and published reports pertaining to any and all aspects of a potential cleanup action in the Lower Fox River and Green Bay. This information typically influences the development of remedial alternatives insofar as the establishment of numeric cleanup levels, permitting, siting, disposal, operating parameters, health and safety, and monitoring. The remedial alternatives developed in Section 7 must, to the extent practicable, meet the requirements of ARARs and address the findings of TBCs.

Lastly, this section presents GRAs for the Lower Fox River and Green Bay. GRAs are broad categories of actions such as treatment, containment, disposal, or combinations of the various categories designed to satisfy one or more of the RAOs. The remedial alternatives developed in Section 7 of this report are a synthesis of the applicable remedial technologies identified in Section 6 and the GRAs presented here.

# 4.1 Media and Chemicals of Concern

Defining the media and chemicals of concern (COCs) in the Lower Fox River and Green Bay is a necessary prerequisite to developing site-specific RAOs and GRAs. RAOs often state what media (e.g., surface water, soil, sediments) must be targeted for cleanup in order to protect human health and the environment. GRAs are also specific to the media and COCs insofar as the physical actions (e.g., removal, disposal) and treatment processes that should be considered. Finally, ARARs and TBC information are generally specified based on media and COCs. For example, identifying surface water as a medium of concern triggers consideration of state and federal clean water regulations.

## 4.1.1 Media of Concern

The RI identified surface water and sediments as the media of concern in the Lower Fox River and Green Bay. Contamination to these media pose risks to human health and ecological receptors. The BLRA (Section 3) determined that the sediments have the greatest impact on improving surface water quality, and thus on reducing risks to humans and wildlife. GRAs presented later in this section describe general cleanup options for COCs contained in sediments only. Cleanup of surface water and reductions in fish tissue COC concentrations will occur naturally once the source of contamination to surface water (i.e., impacted sediments) is removed, treated, or contained.

The vast majority of the mass of COCs is sorbed to sediment particles and is transported through the Fox River and Green Bay in suspended solids. Thus, water quality improvements of the two water bodies must focus on the reservoir of COCs contained in the sediment deposits.

## 4.1.2 Chemicals of Concern

Investigations of sediment and water quality coupled with information on former process operations along the Lower Fox River identified over 300 potential contaminants in the Lower Fox River (WDNR, 1993). *The Lower Green Bay Remedial Action Plan 1993 Update for the Lower Green Bay and Fox River Area of Concern* (WDNR, 1993) and the *Screening Level Risk Assessment* (RETEC, 1998) narrowed this list to eight COPCs for evaluation in the Baseline Risk Assessment (RETEC, 2002b) as follows:

- **COPCs**
  - PCBs (total and/or Aroclor 1242, PCB coplanar congeners),
  - Dioxins (2,3,7,8-TCDD),
  - Furans (2,3,7,8-TCDF),
  - DDT and metabolites (DDE and DDD),
  - Dieldrin,

- Arsenic,
- Lead, and
- Mercury.

A detailed examination of these eight organic and inorganic constituents in the BLRA (Section 3) determined that PCBs pose the greatest human and ecological health risks in both surface water and sediments of the Lower Fox River and Green Bay. Mercury is the single inorganic constituent that presents significant risks. The BLRA also determined that DDE is a concern in sediments and that the risks from this constituent are confined to Green Bay. The COCs identified in the BLRA (RETEC, 2002b) and carried forward in the FS evaluation include:

- **COCs**
  - PCBs (total and coplanar congener),
  - Mercury, and
  - DDE.

However, PCBs are the dominant contributor to risks at the site as a whole. The remedial alternatives developed in this FS focus on the cleanup of sediments containing PCBs at levels considered a threat to human and ecological receptors.

## 4.2 Remedial Action Objectives for Lower Fox River and Green Bay

Protection of human health and the environment in the Lower Fox River and Green Bay can be achieved through fulfillment of the five RAOs discussed below and summarized in Table 4-1.

### 4.2.1 Surface Water Quality

*RAO 1: Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.*

RAO 1 addresses the impacts contaminated sediments in the Lower Fox River and Green Bay have on surface water quality. The primary focus of this FS is on management of sediments. The principal measure of management and/or cleanup success is achieving protective levels of COCs in fish tissue (see Sections 4.2.2 and 4.2.3) as determined in the BLRA. For this reason, water quality criteria are TBCs for all COCs in this FS. However, WDNR recognizes the importance of meeting, to the extent physically practicable, project ARARs and surface water quality TBCs for all COCs. The standards and criteria associated with ARARs and TBCs are discussed in Section 4.3.1. For relative comparison purposes between different remedial alternatives in this FS, expected surface water quality in 30 years following remedy completion is compared to Wisconsin state surface water quality for protection of human and wildlife health.

### 4.2.2 Human Health Risks

*RAO 2: Protect humans who consume fish from exposure to COCs that exceed protective levels.*

The BLRA determined that human exposure to PCBs through ingestion of fish is the exposure pathway leading to the greatest potential for adverse human health effects. Reducing levels and/or exposures of COCs in sediments is the most important means of reducing levels in fish residing in the Lower Fox River and Green Bay. The BLRA also identified ingestion of resident waterfowl by hunters as a significant exposure pathway. However, the health effects associated with this exposure pathway are less than those associated with ingestion of fish. Meeting the RAO for anglers will also protect hunters.

Several key thresholds were carried forward in the FS for relative comparison between alternatives. These thresholds were selected by both WDNR and EPA as important risk evaluation criteria that relate to the human health RAOs for the project:

- Achieve protective levels in 10 years following cleanup for recreational anglers - walleye, whole fish, RME, HI is 1.0 (noncancer) (288 $\mu$g/kg);

- Achieve protective levels in 10 years following cleanup for recreational anglers - walleye, whole fish, RME, $10^{-5}$ cancer risk (106 $\mu$g/kg);

- Achieve protective levels in 30 years following cleanup for high-intake fish consumers - walleye, whole fish RME, HI is 1.0 (noncancer) (181 $\mu$g/kg); and

- Achieve protective levels in 30 years following cleanup for high-intake fish consumers - walleye, whole fish, RME, $10^{-5}$ cancer risk (71 $\mu$g/kg).

  Because many of the recreational angler thresholds are met within 30 years following cleanup without implementation of an active remedy, the high-intake fish consumer threshold was added to the comparative analysis.

WDNR and EPA have established a remedy expectation that recreational anglers will be able to safely consume fish within 10 years following remedy completion, and high-intake fish consumers will be able to safely eat fish within 30 years following remedy completion.

### 4.2.3 Ecological Risks

*RAO 3: Protect ecological receptors from exposure to COCs above protective levels.*

The BLRA established exposure pathways and risks to multiple ecological receptors. At greatest risk from exposure to COCs (primarily PCBs) are:

- The insects and other organisms that live in the sediments and form the base of the food chain;
- Fish; and
- Birds and mammals that rely principally on fish for food.

The BLRA also concluded that reducing levels of COCs or exposures in surface sediments is the most important means of reducing risks to wildlife in the Lower Fox River and Green Bay. WDNR and EPA have established a remedy expectation that safe ecological thresholds will be consistently met within 30 years following remedy completion.

Several key thresholds were carried forward in the FS for relative comparison between alternatives. These thresholds were selected by both WDNR and EPA as important risk evaluation criteria that relate to the ecological health RAOs for the project:

- Achieve protective levels in 30 years following cleanup based on carnivorous bird deformity - NOAEC based on carp, whole fish (121 $\mu$g/kg);
- Achieve protective levels in 30 years following cleanup based on protection of piscivorous mammals (mink) - NOAEC based on carp, whole fish (50 $\mu$g/kg); and
- Achieve surface water quality for the protection of wildlife (0.12 ng/L) in 30 years following cleanup.

### 4.2.4 Transport of Contaminants to Lake Michigan

*RAO 4: Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.*

Contaminant transport from the Lower Fox River to Green Bay and greater Lake Michigan is detrimental to environmental quality in these aquatic systems. Dissolved-phase COCs are transported downstream and along prevailing currents in the water column. Similarly, the movement of COCs adsorbed to resuspended sediments is a concern, particularly during high-flow periods. This RAO is designed to improve environmental conditions in the Lower Fox River and Green Bay as well as in Lake Michigan. The performance evaluation of remedial actions must consider the long-term transport of residual COCs and the potential such transport has to cause adverse human and ecological health effects. For relative comparison purposes between different remedial alternatives in this FS, the PCB loading rates onto Green Bay at the mouth of the Lower Fox River are compared to the combined loading rates of other Green Bay tributaries following remedy completion in the Lower Fox River.

### 4.2.5 Contaminant Releases During Remediation

*RAO 5: Minimize the downstream movement of PCBs during implementation of the remedy.*

This RAO focuses attention on the short-term effectiveness of remedial alternatives. Contaminant releases may occur through various mechanisms, such as volatilization or sediment resuspension (i.e., during dredging). Achieving the goals of this RAO may require incorporation of measures to control contaminant releases during remediation.

## 4.3 Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Information

Section 121(d) of CERCLA stipulates that remedial actions instituted under the Superfund program comply with ARARs. Consideration must also be given to relevant information that, while not legally binding, is collectively referred to as TBC information. ARARs are promulgated cleanup standards and other environmental protection requirements, criteria, or limitations contained within local, state, and federal laws and regulations. TBCs may or may not be promulgated standards and not legally enforceable. Nevertheless, TBCs may contribute to the development and implementation of effective and protective remedial alternatives.

The identification of ARARs and TBCs depends on the media, COCs, site-specific characteristics, and the technologies employed during remediation. ARARs and TBCs that may contribute to defining remedial alternatives for the Lower Fox

River are provided in Tables 4-2 and 4-3 and are grouped into chemical-specific, location-specific, and action-specific categories.

### 4.3.1 Chemical-specific ARARs and TBCs

Chemical-specific ARARs define concentration limits for environmental media. These requirements may be used to set cleanup levels for COCs in sediment and water. For example, the Federal Clean Water Act establishes concentration limits in surface water that are considered protective of human and aquatic life. The principal chemical-specific ARARs and TBCs for sediment cleanup in the Lower Fox River and Green Bay are:

- **Toxic Substances Control Act (TSCA).** TSCA is both a chemical and action ARAR that establishes federal requirements for handling, storage and disposal of materials containing PCBs in excess of 50 ppm.

- **Federal Clean Water Act.** Ambient water quality criteria developed under the Clean Water Act are non-enforceable guidelines that identify protective concentrations of various chemical constituents for surface waters. As non-enforceable guidelines, the ambient water quality criteria are TBCs for the site.

- **State of Wisconsin Water Quality Standards - WAC NR 100 Series.** Wisconsin Administrative Code (WAC) Sections NR 102 through 105 establishes surface water quality standards for the state. The standards are used in making water management decisions and in the control of municipal, business, land development, and agricultural discharges. The WAC NR 140 establishes groundwater quality standards for the state. These standards are used for managing upland disposal facilities. These standards are ARARs for water quality criteria that must be achieved following sediment remediation work in the Lower Fox River and Green Bay. Water quality ARARs related to point discharges are covered under action-specific ARARs.

With respect to establishing sediment cleanup levels, WDNR's sediment guidance (WDNR, 1996) states that state water quality standards are goals to be considered in the development and evaluation of sediment cleanup actions. They are not to be used to develop sediment cleanup values. Although the WDNR's water quality criteria (WQC) are legally promulgated standards, they are not legally enforceable since WDNR does not have a promulgated method for establishing sediment cleanup standards derived from WQC. Protective sediment COC concentrations for the Lower Fox River and Green Bay were developed in the BLRA as discussed in Section 3. This approach is supported by EPA's 1996

Superfund PCB cleanup guidance (EPA, 1996a) which allows for the calculation and use of risk-based sediment cleanup levels as opposed to levels calculated based on equilibrium partitioning between sediments and the overlying water column. Thus, the water quality standards are TBCs for sediment remediation in the Lower Fox River and Green Bay.

### 4.3.2 Location-specific ARARs

Location-specific ARARs place constraints or define requirements for remedial activities that occur in environmentally sensitive areas (e.g., wetlands, floodplains). Location-specific ARARs are used to manage the disposal of sediment-derived wastes in the State of Wisconsin and out-of-state landfills (i.e., preservation of historical sites, navigational constraints). In addition, this category of ARARs defines the siting and permitting requirements for new treatment and disposal facilities (e.g., landfills). The principal location-specific ARARs and TBCs for sediment cleanup in the Lower Fox River and Green Bay are:

- **Wisconsin Statutes Chapter 289.** Prohibits the construction of landfill facilities in floodplains or in open-water areas except by special state permits or legislative authority. Also manages the landfill siting and approval process for upland disposal.

- **Wisconsin Statutes Chapter 30.** Regulates work performed in navigable waters and harbors.

### 4.3.3 Action-specific ARARs

Action-specific ARARs govern the design, performance, or operational aspects of contaminated materials management. For example, action-specific ARARs are used to establish safe concentration levels for discharge of materials during implementation of a remedial action. The National Pollution Discharge Elimination System (NPDES) defines concentration limits on water discharged to surface water from industrial facilities and operations. Discharge limitations would likely apply to sediment cleanups involving the dredging and subsequent discharge of dredge water to surface water. The principal action-specific ARARs and TBCs for sediment cleanup in the Lower Fox River and Green Bay are:

- **State of Wisconsin WAC NR 500 through 520.** These regulations are ARARs that establish standards for collection, handling, transport, storage, and disposal of solid wastes, respectively. These disposal standards apply for both new and existing landfills. Under Wisconsin law, dredged material is considered a solid waste.

- **State of Wisconsin WAC NR 600.** These regulations are ARARs that establish standards for handling and management of hazardous wastes. These disposal standards apply for both new and existing hazardous waste landfills. The NR 600 series would also include hazardous waste management using high-temperature thermal desorption (HTTD) and incinerator units.

- **State of Wisconsin WAC NR 500 and Wisconsin Statute 289.43.** These regulations contain exemptions for the management of solid and low-hazard wastes.

- **State of Wisconsin WAC NR 400.** These regulations are ARARs that establish air quality standards for removal and disposal of hazardous waste. They also set allowable chemical concentration levels for removal and disposal of contaminated sediments. Treatment of sediments by HTTD units would be managed as incinerators under this series by air quality, if TSCA-level materials are treated.

- **State of Wisconsin WAC NR 200 (WPDES program).** These regulations establish water quality effluent limits for discharges during sediment remediation activities. The dewatering ponds/lagoons used for temporary dewatering of dredged material would likely be managed as a wastewater lagoon under the WAC NR 200 series. The WAC NR 213 regulation specifically addresses the requirements for lining of industrial lagoons and design of storage structures regarding effluent limits.

- **Wisconsin Statutes Chapter 30.** This section of the Wisconsin Statutes contains provisions to minimize adverse effects on navigable waterways. The statute specifically bans open-water disposal of dredged material on the beds of navigable waters unless a permit is granted by WDNR pursuant to the statute or the state legislature specifically authorizes an open-water disposal project. It does not, however, prohibit construction of a nearshore confined disposal facility (CDF) and disposal of dredged sediments (less than 50 ppm PCBs) into a newly constructed CDF.

- **Wisconsin Statutes Chapter 289 (Low-hazard Waste Exemption).** This section of the Wisconsin Statutes addresses the permitting and siting requirements for construction of new upland landfills and disposal of solid waste along a river. Under this statute, WDNR has the authority to waive setback requirements for siting disposal facilities.

The low-hazard exemption statute could be used for non-TSCA dredged material disposal sites if no impact to the surrounding environment can be justified.

- **Section 10 - Rivers and Harbors Act.** This federal statute contains provisions for minimizing adverse effects from dredge and fill work conducted within navigable waterways of the United States.

- **Section 404 - Clean Water Act.** This ARAR requires approval from the USACE for discharges of dredge or fill materials into waters of the United States.

- **Federal Clean Water Act.** Surface water quality standards under Section 304 of the Clean Water Act are ARARs for point discharges to the river. Discharges occurring as a part of sediment remediation must comply with this ARAR.

### 4.3.4 To Be Considered Information

TBCs can be grouped into chemical-, location-, or action-specific categories. Important laws, regulations, and guidance that are TBCs for the cleanup of sediments in the Lower Fox River and Green Bay are as follows:

- **State of Wisconsin Surface Water Quality Standards.** The state water quality standards are TBCs for evaluating the effectiveness of sediment remedial alternatives. One of the RAOs for site cleanup is meeting these standards to the extent practicable.

- **Federal Safe Drinking Water Act.** As with water quality standards, drinking water standards are TBCs for sediment cleanup in the Lower Fox River and Green Bay. RAO 1 requires that remedial alternatives meet drinking water standards to the extent practical. These standards are not used to develop sediment cleanup levels.

- **Great Lakes Water Quality Agreement.** This agreement calls for the identification of "Areas of Concern" and the establishment of remedial goals for impacted ports, harbors, and river mouths in the Great Lakes area.

- **Section 303(d) - Clean Water Act.** This portion of the Clean Water Act requires states to formulate and submit to EPA lists of "impaired waterways" that may be subject to watershed planning with respect to total maximum daily loads (TMDL) of various water quality parameters. In December 1996, WDNR submitted its first list of impaired waterways to EPA, which included the Fox River because of the presence of PCBs.

- **Sediment Remediation Implementation Guidance.** Part of the 1995 Strategic Directions Report prepared by WDNR addresses how sediment remediation work should be approached in the State of Wisconsin. The guidance calls for using a risk management process to appraise environmental impacts and assess the technical feasibility and costs of sediment remediation, and states that water quality standards are goals for evaluating sediment impacts to the aquatic environment and for evaluating the performance of various remedial options.

- **Great Lakes Water Quality Initiative.** This initiative sets forth guidance to states bordering the Great Lakes regarding wastewater discharge programs. For remedial actions involving discharges, any lowering of water quality should be minimized to the extent practicable. These concepts are embodied in WAC NR 102 through 106.

### 4.3.5 Numeric Surface Water and Drinking Water TBCs

Table 4-4 lists drinking water and surface water quality standards and criteria for the eight COPCs identified in the SLRA. PCBs, DDE, and mercury are the primary COCs that pose a risk to human health and the environment with respect to impairment of water quality. These values are goals (RAO 1) for ambient water quality following sediment cleanup and ARARs with respect to limiting point discharges during remediation.

## 4.4 Development of General Response Actions (GRAs)

The RAOs, in conjunction with results of the RI and BLRA, establish the basis for identifying general response actions to clean up the Lower Fox River and Green Bay. GRAs are broad categories of actions such as treatment, containment, disposal, or combinations of the various categories. Specific categories of GRAs identified for contamination in the Lower Fox River and Green Bay sediments are as follows:

- No Action,
- Institutional Controls,
- Monitored Natural Recovery,
- Containment,
- Removal,

- *In-situ* Treatment,
- *Ex-situ* Treatment, and
- Disposal.

### 4.4.1 Description of GRAs

#### No Action

Consideration of a "No Action" response is required by the National Contingency Plan (NCP). No action serves as a baseline against which the performance of other remedial alternatives can be compared. This response assumes no active remedial measures are implemented.

#### Institutional Controls

Institutional controls are legal or administrative measures designed to restrict site access or limit site use. The measures reduce exposure to COCs by precluding activities that could lead to exposure. Dredging moratoriums and fish consumption advisories are relevant examples of institutional controls.

#### Monitored Natural Recovery

Natural recovery refers to the processes by which concentrations of COCs in impacted media decline over time by natural processes such as biodegradation, burial, or dilution. While both mercury and PCBs are persistent in the sediment environment, reductions in the concentrations of these constituents over time will occur as a result of these natural processes. However, the time frame required to achieve sufficient reductions in bioavailable concentrations must be calculated and it must be determined whether the time frame is reasonable and acceptable. As discussed in the next section of this report (Section 5), the assumption of natural recovery is central to the development of a range of sediment cleanup action levels that can be used to evaluate varying cleanup time frames for the proposed alternatives.

#### Containment

Containment involves the physical isolation and immobilization of contaminants in sediment. Capping is a common method used in lakes, bays, marine, and riverine environments for containing impacted sediments. No sediment treatment occurs other than by natural processes under the cap surface. Assuming effective cap placement, the bioavailability and mobility of contaminants present in the sediments would be immediately limited.

#### Removal

Sediment removal by dredging or excavation is another common practice for managing contaminated sediments. Following removal, the material is usually relocated to a treatment or disposal facility. Dredging often requires consideration of other unit processes such as:

- In-water controls to minimize contaminant resuspension during removal,
- Dewatering to reduce sediment moisture content,
- Treatment of dredge water before discharge, and
- Disposal and/or treatment of dredged material.

### *In-situ* Treatment

*In-situ* treatment involves chemical or biological methods for reducing contaminant concentrations or bioavailability without first removing the sediment.

### *Ex-situ* Treatment

*Ex-situ* treatment involves the application of treatment technologies to transform, destroy or immobilize COCs following removal of the contaminated sediments. Thermal destruction is one of the more common treatment technologies for PCBs and other chlorinated organics. Metals are commonly treated with cement or other stabilizing materials.

### Disposal

Disposal is the permanent placement of material into an appropriate structure or facility. It is often a significant component of alternatives involving removal of sediments (capacity and cost). Disposal or possible beneficial reuse considerations involve the contaminated media and/or residues from pretreatment and treatment operations.

## 4.4.2 Summary of GRAs and Expectations

Several of the individual GRAs described above likely would not be implemented alone. Rather, they would be implemented in conjunction with other actions. Final selection and design of GRAs will depend on the technological ability to meet the project expectations described in Table 4-5. These expectations are used in this FS to compare the relative risk reduction, costs, and number of years to reach protective thresholds between different alternatives and action levels. Project expectations are a comparative tool and actual implementation of expectations for management of risks will be determined during the design phase. With respect to sediment remediation, the response actions (or combinations) carried forward in this FS are as follows:

- No action,
- Monitored natural recovery and institutional controls,
- Containment (capping),
- Removal and disposal, and
- Removal and *ex-situ* treatment.

Depending on the level of treatment, ARARs, and the physical composition of sediment, treated material may be beneficially used as fill, precluding disposal in a landfill.

In Section 6 of this FS Report, remedial action technologies are identified and screened for each of the aforementioned response actions. In addition, process options within each technology type are identified and screened. The technology types and process options retained after screening are utilized in the development of remedial alternatives (Section 7) for the Lower Fox River and Green Bay.

## 4.5 Section 4 Tables

Tables for Section 4 follow this page and include:

| | |
|---|---|
| Table 4-1 | Remedial Action Objectives for the Lower Fox River and Green Bay |
| Table 4-2 | Potential Federal ARARs and TBCs for the Lower Fox River and Green Bay |
| Table 4-3 | Potential State ARARs and TBCs for the Lower Fox River and Green Bay |
| Table 4-4 | Surface Water Quality Criteria |
| Table 4-5 | Remediation Goals and Project Expectations |

## Table 4-1 Remedial Action Objectives for the Lower Fox River and Green Bay

| Number | Definition |
| --- | --- |
| 1 | *Achieve, to the extent practicable, surface water quality criteria throughout the Lower Fox River and Green Bay.* |
| 2 | *Protect humans who consume fish from exposure to COCs that exceed protective levels.* |
| 3 | *Protect ecological receptors from exposure to COCs above protective levels.*<br>This RAO considers:<br>• Adverse effects to the diversity and reproductive viability of aquatic organisms (fish and insects) in the Lower Fox River and Green Bay,<br>• Adverse effects to fish,<br>• Adverse effects to insect-eating birds through ingestion of fish, and<br>• Adverse effects to fish-eating mammals through ingestion of fish. |
| 4 | *Reduce transport of PCBs from the Lower Fox River into Green Bay and Lake Michigan.* |
| 5 | *Minimize the downstream movement of PCBs during implementation of the remedy.* |

# Table 4-2 Potential Federal ARARs and TBCs for the Lower Fox River and Green Bay

| Program | Requirements | Citation | Description | Application | Comment |
|---|---|---|---|---|---|
| **Clean Water Act** | | 33 U.S.C.A. Sec. 1251–1387 | | | |
| | Ambient Water Quality Criteria | CWA Section 304 Quality Criteria for Water, EPA, 1986 | Establishes non-enforceable guidelines for States to set water quality standards for surface water. Criteria based on protection of aquatic life and human health. | Chemical | Applicable only if concentrations of surface water above sediments exceed these criteria; otherwise becomes a cross-media check. |
| | Water Quality Standards | CWA Section 303<br>40 CFR 131 | Requires states to develop water quality standards based on federal guidelines. | Chemical<br>Action | Applicable only if concentrations of surface water above sediments exceed these criteria; otherwise becomes a cross-media check. |
| | National Pollutant Discharge Elimination System | CWA Section 401 | Requires compliance with permit limitations for discharge to navigable waters, including water quality effluent limits, water quality standards, national performance standards, and toxic and pretreatment effluent standards. | Action | NPDES program is administered by the state. (see Wisconsin NPDES Permit Regulations.) Applicable for actions involving discharges of liquid effluent to surface water. |
| | Effluent Standards - Technology- Based Discharge Requirements | CWA Section 301(b) | Requires all direct discharges to be treated with best control technology prior to discharge. | Action | Applicable if surface water is channeled directly to a surface water body via a ditch, culvert, storm sewer, or other means; or treated water is discharged. |
| | Dredge and Fill Requirements | CWA Section 404 (Inland Testing Manual) | Regulates discharge of dredged or fill material to U.S. waters, including wetlands. Testing manual establishes procedures for determining the potential for contaminant-related impacts associated with discharge of dredged material in inland waters. | Action | Applicable for consideration of any practicable alternatives and may require protection of environmental values of the site. |
| | Proposed Sediment Quality Criteria | CWA Section 304 Sediment Quality Criteria, EPA, 1991 | Establishes sediment quality standards that will not unacceptably affect benthic organisms. | Chemical | Potentially applicable once promulgated. |
| | Great Lakes Critical Program Act of 1990 - Assessment and Remediation of Contaminated Sediments (ARCS) Program | CWA Section 118 (c)(7)<br>40 CFR Part 132 (Appendix E) | Provide environmental managers at AOCs and elsewhere with the tools and information necessary for making informed cost-effective, and environmentally sound decisions in addressing a local contaminated sediment problem. | Location | To be considered in addressing existing and possible pollutant problems in the Great Lakes and their tributaries. |

## Table 4-2 Potential Federal ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

| Program | Requirements | Citation | Description | Application | Comment |
|---|---|---|---|---|---|
| **Resource Conservation and Recovery Act** | | 42 U.S.C.A. 6901–6992k | | | |
| | General Requirements | 40 CFR Parts 172 and 173 | Establishes standards for transporting PCB waste. | Action | Applicable in evaluating transportation and handling of PCB-dredged material. |
| | Definition of Hazardous Waste | 40 CFR 261 | Defines threshold levels and criteria to determine whether material is hazardous waste. | Chemical Action | Applicable in evaluating which wastes would be classified hazardous. These regulations do not set cleanup standards, but would apply during various remedial actions. |
| | Water Resources Development Act | | | | |
| | Toxic Substances Control Act (TSCA) | 40 CFR Parts 750 and 761 | Establishes requirements for handling, storage, and disposal of PCB-containing materials in excess of 50 ppm. | Chemical Action | Applicable to alternatives that address PCB-containing materials in excess of 50 ppm |
| | | 40 CFR Part 761 | Establishes performance standards for disposal technologies (i.e., incinerators, capping). | Action | Air emissions from incineration cannot exceed 0.001 gram of PCBs per kilogram of PCBs treated. |
| | Occupational Safety and Health Administration (OSHA) | 29 CFR Parts 1910.120, 1910.132, 1910.134, 1910.138 | Establishes 8-hour time-weighted average concentrations for protection of worker breathing zones, PPE requirements, medical monitoring requirements, respiratory protection requirements, HAZMAT training requirements. | Action | Applicable for workers near areas of contamination |
| **Clean Air Act** | | 42 U.S.C. 7401–7642 | | | |
| | National Primary and Secondary Ambient Air Quality Standards (NAAQS) | 40 CFR Part 50 | Establishes ambient air quality standards for protection of public health. | Chemical Action | Applicable in evaluating air impacts prior to or during remediation |
| | National Emissions Standards for Hazardous Air Pollutants (NESHAP) | 40 CFR Part 61 | Establishes emission standards for sources emitting benzene, arsenic, asbestos, beryllium, mercury, radionuclides, and vinyl chloride. | Chemical Action | Applicable in evaluating emission standards on treatment technologies. |
| **International Joint Commission (IJC)** | | IJC, 1992 | Protection of fish tissue | Location | To be Considered |
| **Land Disposal of PCB Sediments** | | Valdas Adamkus 1/24/95 EPA Memorandum to WDNR | Outlines requirements for disposal of PCB sediments greater than 50 mg/kg within Wisconsin NR 500-licensed landfills. | Action | Applicable in evaluating disposal options of sediments. This requirement is being renegotiated as of December 2000. |

# Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay

| Program | Requirements | Citation | Description | Application | Comment |
|---|---|---|---|---|---|
| **Wisconsin State Environmental Protection Administrative Code** | | | | | |
| *General* | | *WAC NR 100 Series* | | | |
| | Water Quality Standards for Wisconsin Surface Waters | WAC NR 102–105 | Establishes definition of water use and criteria for protection of public health and enjoyment and protection and propagation of fish, shellfish, and wildlife. | Chemical | Applicable only if concentrations of surface water above sediments exceed these criteria. They are TBCs. |
| | Groundwater Quality | WAC NR 140 | Establishes groundwater quality standards for substances detected or having reasonable probability of entering groundwater resources. | Chemical | Applicable for removal, transport, and disposal of contaminated sediments (impacts to groundwater). |
| | Management of PCBs and Products Containing PCBs | WAC NR 157 | Establishes procedures for the storage, collection, transportation, processing, and final disposal of PCBs and materials containing PCBs at any level. It refers to NR 500 and 600 series. | Action | Applicable for removal, transport, and disposal of contaminated sediments. |
| | Plans and Specifications Review of Projects and Operations | WAC NR 108 | WDNR approval of any reviewable project, general operation and control of specific water/wastewater system. | Action | Applicable for community water systems, sewage systems, and industrial wastewater facilities. |
| *WPDES* | | *WAC NR 200 Series* | | | |
| | Wisconsin Pollutant Discharge Elimination System | WAC NR 200 | Technology-based effluent limits (NR 220–297). Requires compliance with permit limitations for discharge to navigable waters, including water quality effluent limits, water quality standards, national performance standards, and toxic and pretreatment effluent standards. | Action | Applicable action-specific ARAR for remedial alternatives involving discharges. |
| | Water Quality Antidegradation | WAC NR 207 | Establish implementation procedures for the antidegradation policy in s. NR 102.05(1)(a). | Action | Applicable to proposed new or increased discharges. |
| | Water Quality Antidegradation: Waste Load Allocated, Water Quality-related Effluent Standards and Limitations | WAC NR 212–220 | Establishes permit limitations for effluent discharges. | Action | Applicable for remedial alternatives involving effluent discharges. |
| | Lining of Industrial Lagoons and Design of Storage Structures | WAC NR 213 | Requires compliance with permit limitations for discharge to navigable waters from industrial treatment systems. | Action | Potentially applicable for waste management of temporary sediment dewatering and treatment systems. |

## Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

| Program | Requirements | Citation | Description | Application | Comment |
|---|---|---|---|---|---|
| *Water Regulation* | | *WAC NR 300 Series* | | | |
| | Wisconsin's General Permit Program for Certain Water Regulatory Permits | WAC NR 322 | Establishes minimum design standards and specifications for projects permitted under a general permit. | Action | Potentially applicable for implementation of a given remedial alternative. |
| | Dredging Contract Fees | WAC NR 346 | Establishes procedures applicable to the removal of material from the beds of natural lakes and outlying waters for which a contract is required between the state and person desiring to remove bed material. | Action | Potentially applicable for removal, transport, and disposal of sediments. |
| | Sediment Sampling and Analysis, Monitoring Protocol, and Disposal Criteria for Dredging Projects | WAC NR 347 | Establishes procedures and protocols for sediment sampling and analysis, disposal criteria, and monitoring requirements for dredging projects regulated by the State of Wisconsin. | Action | Potentially applicable for removal, transport, and disposal of sediments. |
| *Air Pollution Control* | | *WAC NR 400 Series* | | | |
| | Wisconsin State Air Pollutant Control Regulations | WAC NR 400–499 | Establishes concentration levels, by chemical, for new sources. Manages construction and operation permits. | Action | Applicable action-specific ARAR for removal and disposal of mercury- and PCB-contaminated sediments. |
| *Solid Waste Management* | | *WAC NR 500 Series* | | | |
| | Solid Waste Management | WAC NR 500–520 | Provides definitions, submittal requirements, exemptions and other general information relating to solid waste facilities which are subject to regulations under s. 2789.01(35) Stats. Applicable for off-site siting processes. Applicable to new and existing facilities. | Action | Applicable for implementation of a given remedial alternative. |
| | Beneficial Reuse Solid Waste Exemption | WAC NR 500.08 | Establishes criteria for possible beneficial use of solid wastes after treatment. Applies for on-site reuse options only. | Location<br>Action | Applicable for disposal of treated sediments meeting disposal criteria. |
| *Hazardous Waste Management* | | *WAC NR 600 Series* | | | |
| | Hazardous Waste Management | WAC NR 600–685 | Provides definitions, general permit application information, incorporation by reference citations and general information concerning the hazardous waste management program. Establishes procedures for handling, storage, and disposal of hazardous wastes. | Action | Applicable for removal, transport, and disposal of contaminated sediments. Applicable to treatment units, regulated as incinerators. |
| | Identification and Listing of Hazardous Waste | WAC NR 605 | Establishes criteria for identifying the characteristics of hazardous waste to determine if the waste is subject to regulation. | Action | Applicable for removal, transport, and disposal of contaminated sediments. |

## Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

| Program | Requirements | Citation | Description | Application | Comment |
|---|---|---|---|---|---|
| | *Investigation and Remediation of Environmental* | *WAC NR 700 Series* | | | |
| | Investigation and Remediation of Environmental Contamination | WAC NR 700 | Management of contaminated soil. Establishes standards and procedures that allow for site-specific flexibility, pertaining to the identification, investigation, and remediation of sites and facilities which are subject to regulation under s. 144.442, 144.76, or 144.77, Stats. | Action | Applicable for implementation of a given remedial alternative. |
| | Notification of the Discharge of Hazardous Substances | WAC NR 706 | Notification procedures and responsibilities by discharger of hazardous substances including containment, cleanup, disposal, and restoration. | Action | Applicable for removal, transport, and disposal of contaminated sediments. |
| | Soil Cleanup Standards | WAC NR 720 | Allows for the calculation of site-specific risk-based cleanup standards based on the intended reuse of the property. Generally applied to unsaturated material or soils. | Chemical | Likely managed under NR 500. Potentially applicable if dewatered sediment is considered soil after treatment. |
| | Standards for Selecting Remedial Actions | WAC NR 722 | Establishes standards for selection of remedial actions. Generally applied to soil cleanup programs. | Chemical | Potentially applicable, but likely managed under NR 500. |
| **Dredge and Fill Requirements** | | WDNR 1985, 1990 | Report of the Technical Subcommittee on Determination of Dredge Material Suitability of In-Water Disposal. | Location<br>Action | To be considered for alternatives involving in-water disposal, such as confined aquatic disposal (CAD). |
| **Lower Green Bay Remedial Action Plan** | | WDNR, 1993 | Mercury limits. | Chemical | To be considered. |
| **Local Permits (building, zoning, other)** | | | Construction in floodplain or wetland and miscellaneous construction activities. | Location | To be considered for implementation of a given remedial alternative. |
| **Great Lakes Water Quality Initiative (GLI)** | | WAC 102 and 106<br>EPA 1995 | Sets forth guidance for any remedial action in states bordering the Great Lakes. In general, minimize any lowering of water quality to the extent practicable. | Action | To be considered with regard to remedial alternatives involving wastewater discharge. |

## Table 4-3 Potential State ARARs and TBCs for the Lower Fox River and Green Bay (Continued)

| Program | Requirements | Citation | Description | Application | Comment |
|---|---|---|---|---|---|
| **Wisconsin State Environmental Protection Statutes** | | | | | |
| | Sediment Remediation Implementation Guidance | Strategic Directions Report, WDNR 1995 | Addresses the sediment remediation approach recommended by WDNR for sediment remediation projects. | Action | To be considered in risk management, technological feasibility and cost. |
| | Landfill Siting and Approval Process | Wis. Stats. Ch. 289 | State statute for solid waste facilities. Addresses the upland disposal of solid waste along with in-river disposal options. Landfill facilities are prohibited from shoreland and floodplain zone areas except by permits issued from WDNR. | Location | Applicable for implementation of any given remedial alternative disposal option. |
| | Low-hazard Solid Waste Exemption | Wis. Stats. Ch. 289.43 | Solid waste law that allows issuance of exemption from siting requirements in NR 500–520. Dredged material may be considered "exempt" after treatment if "new" product is created. | Action | Potentially applicable if *ex-situ* treatment option is selected. |
| | Permit in Navigable Waters | Wis. Stats. Ch. 30 | State statute for navigable waters, harbors, and navigation. Substantive provisions that address minimizing adverse effects on navigable waterways resulting from work performed. | Location | Applicable for work performed in navigable waterways. |
| | EPA TSCA Approval Letter for Land Disposal of PCB Sediments | January 24, 1995 (from Valdas Adamkus) | EPA 5-year approval letter allows WDNR to waive disposal requirements in NR 500 landfills and allow disposal of TSCA-level sediments (>50 ppm). | Action | Applicable in evaluating disposal options of sediments. The requirement is being renegotiated with EPA as of December 2000. |

**Note:**

Wisconsin State Administrative Code can be found at website: http://www.legis.state.wi.us/rsb/code/. Table 4-3 last updated from website on December 10, 2000.

# Table 4-4 Surface Water Quality Criteria

| Chemical of Potential Concern | Clean Water Act [1] | | | | Safe Drinking Water Act [2] Standards | | Wisconsin Surface Water Quality [3] | Wisconsin Surface Water (warm water forage, limited forage, and warm water sport fish communities) [3] | |
|---|---|---|---|---|---|---|---|---|---|
| | Freshwater CMC [4] (µg/L) | Freshwater CCC [5] (µg/L) | Human Health for Consumption of Water and Organism (µg/L) | Human Health for Consumption of Organism Only (µg/L) | MCLG (µg/L) | MCL (µg/L) | Wildlife Criteria [3] (µg/L) | Human Threshold Criteria [8] (µg/L) | Human Cancer Criteria [8] (µg/L) |
| Total PCBs | NL | 0.014 | 0.00017 [A] | 0.00017 [A] | 0 | 0.5 | 0.00012 | — | 0.00001 |
| 4,4'-DDT | 1.1 | 0.111 | 0.00059 [A] | 0.00059 [A] | — | — | — | 0.003 | 0.00022 |
| 4,4'-DDE | — | — | 0.00059 [A] | 0.00059 [A] | — | — | — | — | — |
| 4,4'-DDD | — | — | 0.00083 [A] | 0.00084 [A] | — | — | — | — | — |
| Dioxin (2,3,7,8-TCDD) | — | — | 0.000000013 [A] | 0.000000014 [A] | 0 | 3.00E-05 | 3.00E-09 | 1.10E-07 | 1.40E-08 |
| Furan (2,3,7,8-TCDF) | — | — | — | — | — | — | — | — | — |
| Dieldrin | 0.24 | 0.056 | 0.00014 [A] | 0.00014 [A] | NL | NL | — | 0.00059 | 9.10E-06 |
| Arsenic | 340 | 150 | 0.018 [A] | 0.14 [A] | NL | 50 | — | — | 50 |
| Lead | 65 | 2.5 | [B] | [B] | 0 | TT | — | 140 | — |
| Mercury | 1.4 | 0.77 | 0.050 | 0.051 | 2 | 2 | 0.00013 | 0.0015 | — |

**Notes:**

"—" - The chemical of concern was not listed.
NL - No criterion listed for the chemical of concern.
TT - Treatment technique, action level 15 µg/L.
[1] National Recommended Water Quality Criteria - Correction. EPA Office of Water, April 1999. EPA 822-Z-99-01.
[2] Drinking Water Regulations and Health Advisories. EPA Office of Water, October 1996. EPA 822-B-96-002.
[3] Wisconsin Department of Natural Resources, Chapter NR 105, Surface Water Quality and Secondary Values for Toxic Substances.
[4] Criteria Maximum Concentration.
[5] Criterion Continuous Concentration.
[6] Maximum Contaminant Level Goal. A nonenforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.
[7] Maximum Contaminant Level. Maximum permissible level of a contaminant in water which is delivered to any user of a public water system.
[8] Criteria for non-public water supply (µg/L).
[A] Criterion based on carcinogenicity of $10^{-6}$ risk.
[B] EPA has not calculated human health criterion for this contaminant. However, permit authorities should address this contaminant in NPDES permit actions using the state's existing narrative criteria for toxics.

## Table 4-5 Remediation Goals and Project Expectations

| Remedial Action Objective | Valued Endpoint Goal | Remediation Goal | Primary Exposure Pathway | Strategic End Goal and Expectation | Monitoring Metrics |
|---|---|---|---|---|---|
| *FS Section 4* | | *FS Section 5* | *BLRA Section 3* | *Long-term Monitoring Plan (Appendix C)* | |
| Achieve Surface Water Quality | We can eat fish and swim in the water. | Reduce exposure pathway in surface sediments by reducing concentrations in surface water. | Respiration in water, dermal contact | Surface water is ≤ to levels in upstream areas. Water quality meets state and federal criteria. | • Concentrations in surface water |
| Protect Human Health | We can all eat fish and birds. | Minimize exposure pathway in surface sediments by reducing concentrations in fish. | Direct ingestion of fish and waterfowl with COCs | Lift consumption advisories in 10 years for recreational anglers and 30 years for high-intake fish consumers following remedy completion. | • Concentrations in fish tissue<br>• Concentrations in waterfowl tissue |
| Protect Ecological Receptors | Habitats and populations are healthy and diverse in 30 years. | Minimize exposure pathway by reducing or isolating concentrations in surface sediments. | Direct contact with sediment and surface water; ingestion of sediment, water, and fish | Fish tissue levels meet protective thresholds in 30 years following remedy completion. | • Concentrations in fish, bird, and invertebrate tissue<br>• Mink habitat assessment<br>• Bird population and deformity assessment |
| Reduce PCB Transport from Lower Fox River to Green Bay and to Lake Michigan | Protect downstream habitats and water quality. | Reduce or contain contaminant mass that may mobilize during regular storm events. | Dermal contact or ingestion of fish | Surface water and sediment levels are ≤ to upstream areas. Loading estimates to Green Bay are reduced to tributary levels. | • Surface sediment levels<br>• Bathymetry<br>• Flow rates and mass balance |
| Minimize Releases During Active Remediation | Protect downstream habitats. | Contain contaminant mass during remedy implementation through monitoring and physical barriers. | Ingestion of sediment, water, and prey. | <5% of PCBs are transported downstream during remediation. | • Concentration in surface water<br>• Concentration in sediment |

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# 5 Development of PCB Action Levels for the Lower Fox River and Green Bay

This section of the FS puts forward a rational basis for developing remedial action levels from the array of sediment quality thresholds (SQTs) developed earlier in Section 4. An SQT is a risk-based PCB threshold in sediments derived to be protective of specific human health pathways and ecological receptors (fish, avian, or mammal). An action level is a specific PCB cleanup goal carried forward in the FS that considers the level of risk reduction estimated from the SQT thresholds and the variety of PCB concentrations present at the site. Both SQTs and remedial action levels were derived with the assumption that a remedial action targeting PCBs would also capture the other COCs. This section evaluates a series of PCB action levels that brackets the array of SQTs. These action levels result in different volumes/masses of sediment removed, and different levels of risk reduction (Figures 5-1 and 5-2). Unless the most stringent SQT is set as the cleanup goal for the Lower Fox River and Green Bay (correlating to the 125 ppb PCB action level), then some level of risk will remain at the site after remediation. The levels of remaining risk will be discussed and evaluated in Sections 8 and 10 of this FS.

Residual risk in sediments may be quantified in terms of COC concentrations at discrete locations or surface-weighted average concentrations (SWAC) in surface sediments. Cleanup to a higher concentration (absolute concentration or SWAC) may be protective in the long term. The dynamics of the Lower Fox River and Green Bay aquatic systems promote the slow decline of surface sediment concentrations by natural processes (e.g., sedimentation). Thus, actions to remove and isolate or treat sediment to higher levels may be acceptable if natural processes can be relied upon to return sediment COC concentrations to protective levels in a reasonable time frame.

This section presents a rationale for adopting specific PCB action levels central to the evaluation of remedial alternatives that involve sediment removal (dredging) or isolation (capping). As discussed in Section 4, these are often the most important active general response actions to consider for sediment cleanup. Indeed, the alternatives developed and evaluated in Section 7 that involve active remediation arise principally from these two response actions. Valuations are therefore presented for the following key parameters:

- Sediment volume removed or isolated under an active management alternative,

- Mass of PCB removed or isolated in sediments, and

- Residual surface-weighted average concentrations (SWAC) following sediment removal.

Results of the volume, mass, and SWAC calculations are presented for each river reach and for each zone of Green Bay.

## 5.1 Rationale

Action levels are COC concentrations in surface sediments designed to meet project expectations and RAOs. These action levels represent safe thresholds in surface sediment that are protective of both human and ecological receptors. However, action levels that precipitate an active removal or containment action may include or exceed cleanup levels established by chemical-specific ARARs or risk assessment to satisfy project RAOs. In these cases, action levels depend on natural processes capable of further reducing risks in the long term (e.g., sedimentation, degradation, dispersion). Therefore, an evaluation of alternatives at action levels above SQTs necessarily requires a predictive capability. For this site, four fate and transport, and exposure models will be used to determine whether or to what extent cleanup to an action level is capable of meeting RAOs within a reasonable time frame. These computer models include:

- Whole Lower Fox River (wLFR) Sediment Fate and Transport Model,

- Lower Fox River Food Web Model (FRFood),

- Green Bay Toxicity (GBTOXe) Fate and Transport Model, and

- Green Bay Food Web Model (GBFood).

These fate, transport, and exposure models for the Lower Fox River and Green Bay predict the distribution of COCs (in this case PCBs) as a function of time in both sediment and the water column. The evaluation of alternatives (Section 8) compares the relative benefits of short-term risk reduction (immediate attainment of protective concentrations) and longer term natural attainment of protective concentrations following removal or capping to a higher action level.

### 5.1.1 Array of SQTs

The Final Baseline Human Health and Ecological Risk Assessment (RETEC, 2002b) developed SQTs that provide receptor-specific protective PCB concentrations (Section 3). These SQTs were based upon bioaccumulation modeling from tissue concentrations of PCBs in fish that placed human or ecological receptors at risk. The SQTs, and some of the critical receptors they were intended to protect for both the Lower Fox River and Green Bay, are shown on Figures 5-1 and 5-2 for human health and ecological health, respectively. For the purposes of this FS, SQTs are expressed in $\mu$g/kg units. SQTs themselves are not cleanup criteria, but are a good approximation of protective sediment values and can be considered to be "working values" from which to select a remedial action level. SQTs are used to evaluate harmful levels of chemicals that must be addressed, what levels of those chemicals can be safely left behind, and which remedial option offers the best risk reduction. From the array of PCB-SQTs for specific human health and ecological receptors, the response agencies can evaluate risk reduction and select cleanup standards, or remedial action levels for the Lower Fox River and Green Bay, at the conclusion of the feasibility study. Limits on the application of SQTs for predicting future risk are discussed in Section 3.

### 5.1.2 Array of Action Levels

The action levels selected for evaluation (125, 250, 500, 1,000, 5,000, and 10,000 parts per billion [ppb] PCBs) bracket the risk-based SQTs for human and ecological receptors discussed in Section 3 (see Figures 5-1 and 5-2). Action levels carried forward in the FS were selected based on several considerations:

- Select an array of action levels that bracket the human health and ecological SQT values;
- Select lowest action level where residual SWAC is protective of approximately 90 percent of human/ecological receptors (Section 3);
- Select highest action level (minimal protection) where residual SWAC is protective of approximately 10 percent of human/ecological receptors (Section 3);
- Consider the implementability of concentration levels based on precedent set on other sediment remediation projects (i.e., dredging, capping, natural recovery) (Appendices B and C); and
- Select an array of action levels that bracket a commonly implemented action level of 1 ppm PCBs. The array includes multiples of the 1 ppm action level including 10×, 5×, 0.5×, 0.25×, and 0.125×.

For the purposes of this FS, action levels are expressed in ppb units. Action levels are remediation cleanup criteria for sediments that define the size of the dredge prism requiring removal.

The analysis presented here partitions the sediment volumes and associated PCB mass distribution between those that exceed a given action level and those that are below the same action level. Further, the analysis estimates the SWAC for the PCB residual following hypothetical removal of material exceeding the action level. Trends in the relationships between the three parameters (volume, mass, SWAC) can be used to subjectively determine which specific action levels to retain for fate and transport modeling. Ultimately, output from the Fox River and Green Bay models determines how much time is required for fish tissue concentration to reach acceptable levels (Section 8). The relationship between action level and restoration time (i.e., time to reach acceptable fish tissue concentrations) is central to the comparative evaluation of alternatives in Section 10.

## 5.2 Procedures for Estimating Sediment Volume, Mass and SWAC

As part of the Remedial Investigation (RETEC, 2002a), interpolated concentrations of sediment properties through the entire areal and volumetric extent of the Lower Fox River and Green Bay were developed based on data from the Fox River Database (FRDB). The interpolation profiles sediment bed properties (PCB concentration, PCB mass, dry bulk density, and sediment thickness) across the four reaches of the Lower Fox River and the three zones of Green Bay. ArcView GIS software with Spatial Analyst uses the data profiles to compute where sediment quality exceeds the action level and therefore what sediment requires remedial action (removal or isolation). Further, the same software enables calculation of a post-removal or post-isolation SWAC profile. The specific methods for interpolation were summarized in Section 2.4.2 of the FS.

The volume and mass computations use the same basic method of analysis. The interpolated sediment profile was analyzed from bottom to top to determine locations that exceed the action level. Any material that exceeded the action level, or was located above a depth that exceeds the action level, was included in the volume and mass calculation. Locations within layers that do not contain sediment or sediment that is less than half the model layer thickness (i.e., station thickness is only 10 cm in a 30-cm-thick layer) are not included in the volume and mass analyses. Locations that exist outside of the defined "deposits" known as "interdeposit areas" that exceed the selected action level were also included in the PCB mass and volume estimates requiring removal. The specific step-wise procedure for these calculations is provided in Table 5-1.

A similar approach computes the SWAC for material remaining at the surface following hypothetical removal. For undredged areas, the new surface concentration at a location is the same as the concentration in the interpolated surface concentration. In dredged areas, the new surface concentration is taken as the concentration in the layer below the dredged layer. If the bottommost layer is removed, then the new surface concentration is assumed equal to the action level. Areas that do not contain sediment or where sediment thickness is less than half the model layer thickness are assumed to have a PCB concentration of 50 $\mu$g/kg. The SWAC was computed for each river reach by summing the new surface concentration over the entire reach and then dividing by the area of the reach. The step-by-step procedure for the SWAC calculations is provided in Table 5-2. For the purposes of this FS, SWAC values are expressed in $\mu$g/kg units.

## 5.3 Lower Fox River Results

Results of the action level analysis for sediment volumes, associated mass of PCBs, and SWACs are presented in the accompanying tables and figures. Table 5-3 shows the estimated volume and mass values by identified deposits within each reach. As expected from the RI data, the majority of contaminated sediment volume and PCB mass resides in the De Pere to Green Bay Reach. The Appleton to Little Rapids Reach contains the least sediment volume and PCB mass. Table 5-4 presents the calculated SWAC values exposed at the surface after dredging for each reach.

Figure 5-3 presents sediment volume as a function of action level. The percentage values embedded in the graphs represent the percent differences between bracketing volume estimates. For example, there is a 56 percent difference between the calculated sediment volumes at action levels of 125 and 250 ppb in the Appleton to Little Rapids Reach. Figure 5-3 demonstrates the sensitivity of sediment volume to action level across most of the Lower Fox River. With the exception of the De Pere to Green Bay Reach (below 1,000 ppb action level), sediment volumes decline appreciably as a function of action level. This strong dependency of volume to action level bears directly on remedial costs, particularly for cleanup alternatives that involve dredging.

Figure 5-4 relates PCB mass removed to action level. The embedded percentage values, in this case, are the percentages of PCB mass removed relative to the total present at the lowest action level (i.e., 125 ppb). The assumption here is that the PCB mass at 125 ppb is a reasonable estimate of the total mass present that could pose a risk. Figure 5-4 shows that, for the most part, PCB mass is considerably less sensitive to action level than sediment volume at the lower end of the range (e.g., less than 1,000 ppb). Thus, for example, one can remove 96 percent of the PCB mass in the Little Rapids to De Pere Reach at the 500 ppb action level with just 55 percent of the sediment volume (i.e., relative to the estimated volume at the 125 ppb action level).

Figure 5-5 presents the mass and volume calculations in a single graph for each reach. This figure perhaps best illustrates how efficiently the PCB mass and/or sediment volume can be removed or isolated at a selected action level.

Figure 5-6 shows the relationship between SWAC and action level for the four reaches. SWAC is less sensitive to action level in the Appleton to Little Rapids Reach because of the low levels of PCBs found in this section of the river. In the remaining three reaches, SWAC is considerably more sensitive to action level. Note in Figure 5-6 that the 1,000 ppb action level yields a residual SWAC reasonably close (within a factor of 2) to the lowest cleanup action levels (i.e., 125 and 250 ppb) proposed for the FS. The cleanup action level of 5,000 ppb yields a residual SWAC value that is three to four times higher than 250 ppb (the lower action level). Conversely, it should be noted that there is little difference in the residual SWACs between 125 and 250 ppb action levels. These results suggest that 5,000 ppb is a reasonable upper limit action level for evaluating cleanup alternatives considering the time required to reach protective levels (the SQT of 250 $\mu$g/kg) by natural processes following sediment removal or containment actions.

## 5.4 Green Bay Results

Table 5-5 presents sediment volume, PCB mass and SWAC values for Green Bay at action levels of 125, 250, 500, 1,000 and 5,000 ppb. Figure 5-7 presents sediment volume as a function of action level for each zone. Sediment volume is very sensitive to action level, particularly in zones 2A, 3A, and 3B. The lowest two action levels correspond with extraordinarily large sediment volumes (greater than 100,000,000 cubic meters [$m^3$]) most of which reside in zones 3A and 3B. Even at the 1,000 ppb action level, where the impacts are limited to zones 2A and 2B, the calculated sediment volume is in excess of 20,000,000 $m^3$.

PCB mass is not very sensitive to action level in zones 2A and 2B (Figure 5-8). Approximately 90 percent of the total mass of PCBs in zones 2A and 2B (i.e., at concentrations equal to or greater than 125 $\mu$g/kg) can be removed at the 1,000 ppb action level. Further from the mouth of the river (zones 3 and 4) the majority of the mass occurs at concentrations of 250 $\mu$g/kg or less. Figure 5-9 further illustrates these trends by directly relating sediment volume to PCB mass.

Figure 5-10 presents SWAC as a function of action level. SWAC is most sensitive to action level in zones 2A and 2B, where the most significant sediment impacts reside. The SWAC in Zone 3A is slightly above the 250 $\mu$g/kg benchmark at the highest action level, while in Zone 3B the maximum SWAC is a little more than twice as high. The SWAC in Zone 4 is less than one-half the SQT of 250 $\mu$g/kg, regardless of action level.

## 5.5 Selection of Action Levels for Evaluation of Remedial Alternatives

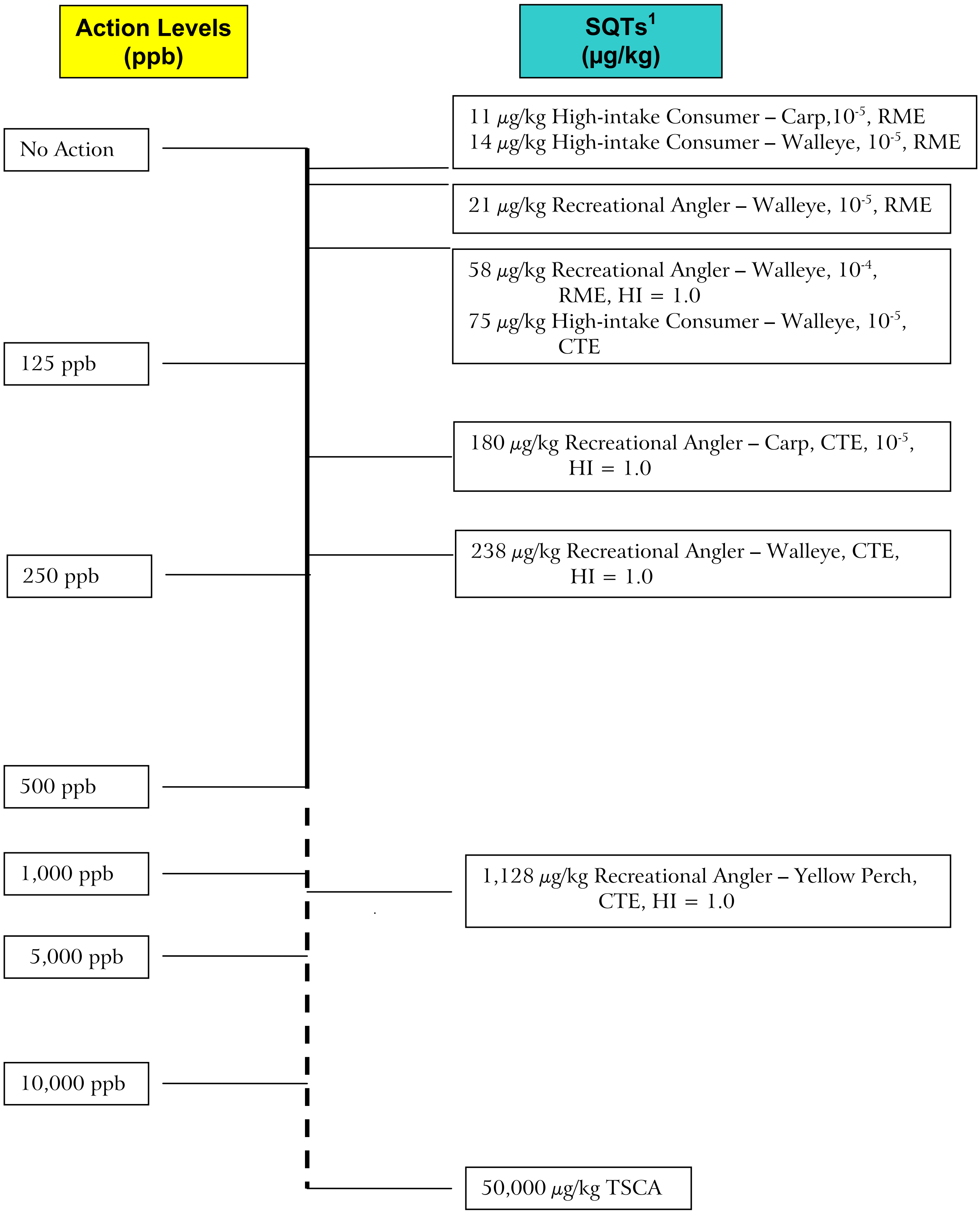
Remedial alternatives for the Lower Fox River that involve containment (capping) or removal (dredging) will be developed for action levels of 125, 250, 500, 1,000, and 5,000 ppb. For Green Bay, containment and removal alternatives will be developed for action levels of 500, 1,000, and 5,000 ppb. The 10,000 ppb action level was eventually dropped from the Lower Fox River evaluation because the bulk of PCB-impacted sediments were addressed at the 5,000 ppb level, and the 10,000 ppb level was not considered adequately protective of valued receptors to warrant further consideration. The 10,000 ppb action level was dropped from the Green Bay evaluation since the maximum detected concentration in Green Bay was below 10,000 $\mu$g/kg. The lowest two action levels were dropped from the Green Bay analysis simply based on the massive volume of sediment requiring removal and disposal. Finding a disposal site with adequate capacity would be technically and administratively challenging and improbable. The corresponding estimates of affected area, sediment volume, PCB mass, and SWAC are central to the development and evaluation of remedial alternatives in subsequent sections of this document (Sections 7, 8, and 9). Following are several key aspects of the cleanup alternatives that are strongly influenced by action level:

- Facility and equipment sizing,
- Siting requirements,
- The duration of active cleanup operations,
- Duration of monitoring and maintenance programs,
- Time to reach protective concentrations through natural processes, and
- Costs.

## 5.6 Section 5 Figures and Tables

Figures and tables for Section 5 follow page 5-8 and include:

## Figure 5-1 Action Levels and Sediment Quality Thresholds for Human Health

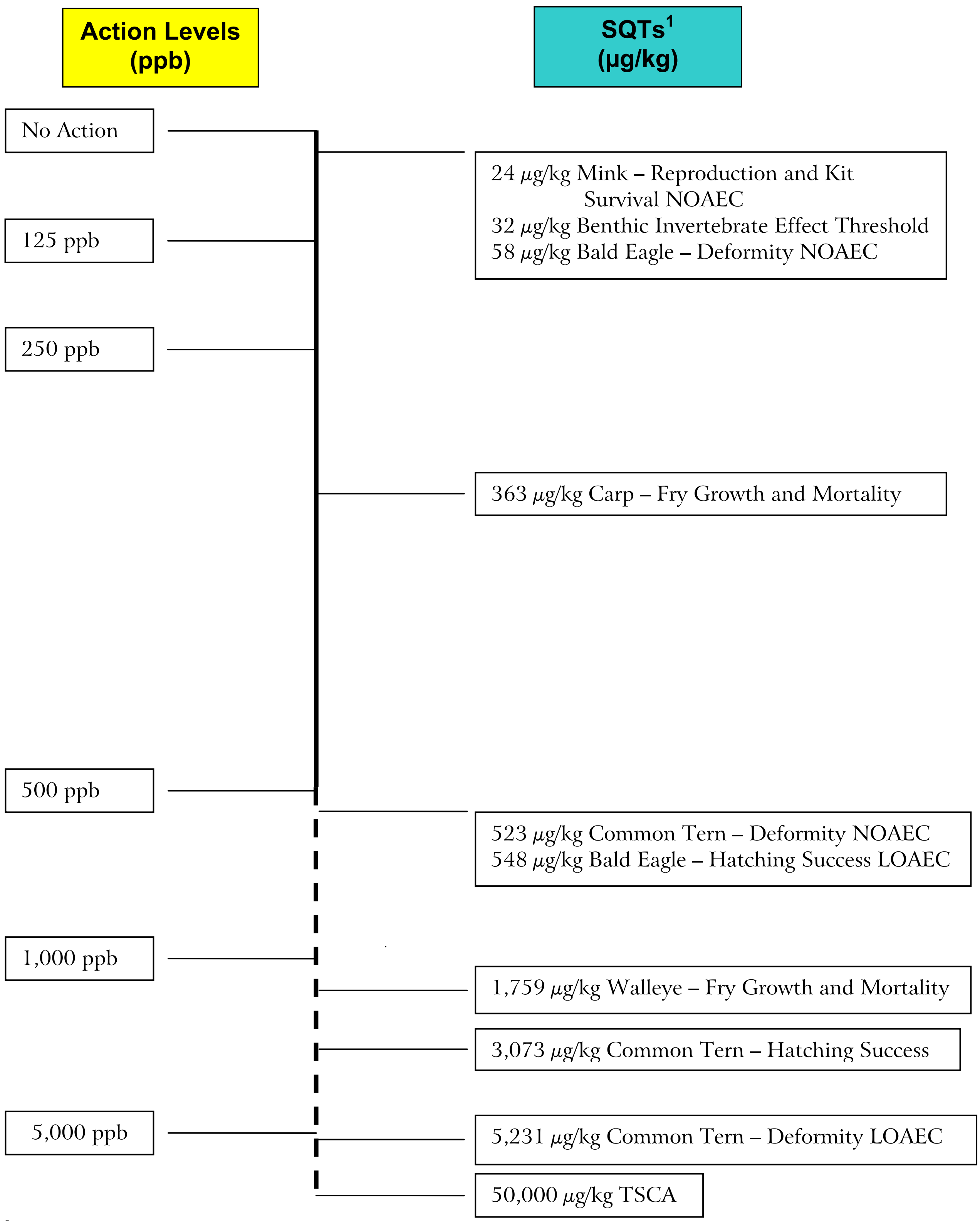



[1] With the exception of the 50,000 µg/kg TSCA number, all values are sediment quality thresholds developed in the *Baseline Human Health and Ecological Risk Assessment* (RETEC, 2002b).

$10^{-5}$ – Risk of one additional cancer in 100,000 people. CTE – Central Tendency Exposure

HI – Hazard Index RME – Reasonable Maximum Exposure

## Figure 5-2 Action Levels and Sediment Quality Thresholds for Ecological Health



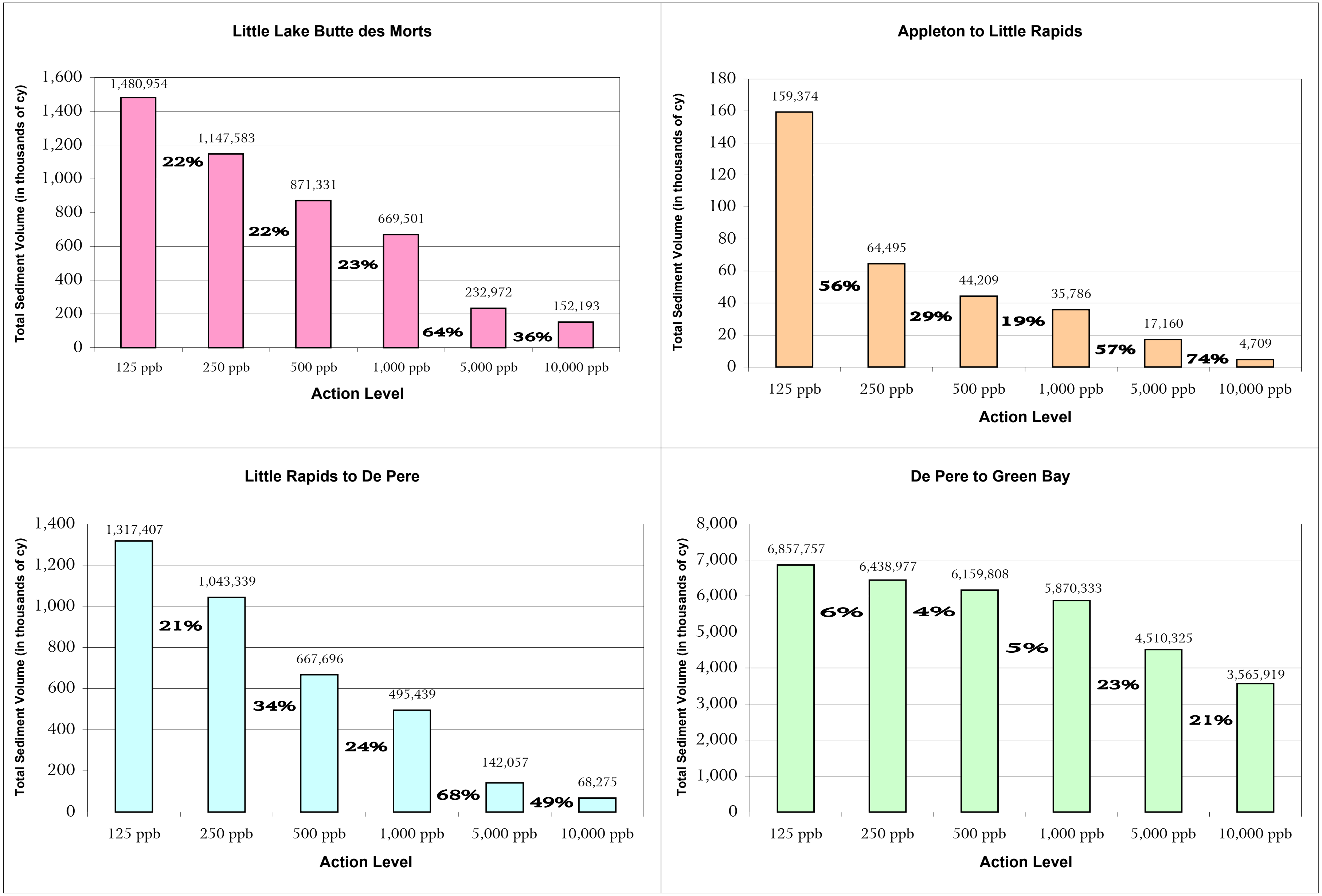

[1] With the exception of the 50,000 µg/kg TSCA number, all values are sediment quality thresholds developed in the *Baseline Human Health and Ecological Risk Assessment* (RETEC, 2002b).

Effect Threshold – A TEL based on *Hyallela azteca* 28-day toxicity test (ARCS, 1996, as cited in RA).

LOAEC – Lowest Observable Adverse Effect Concentration

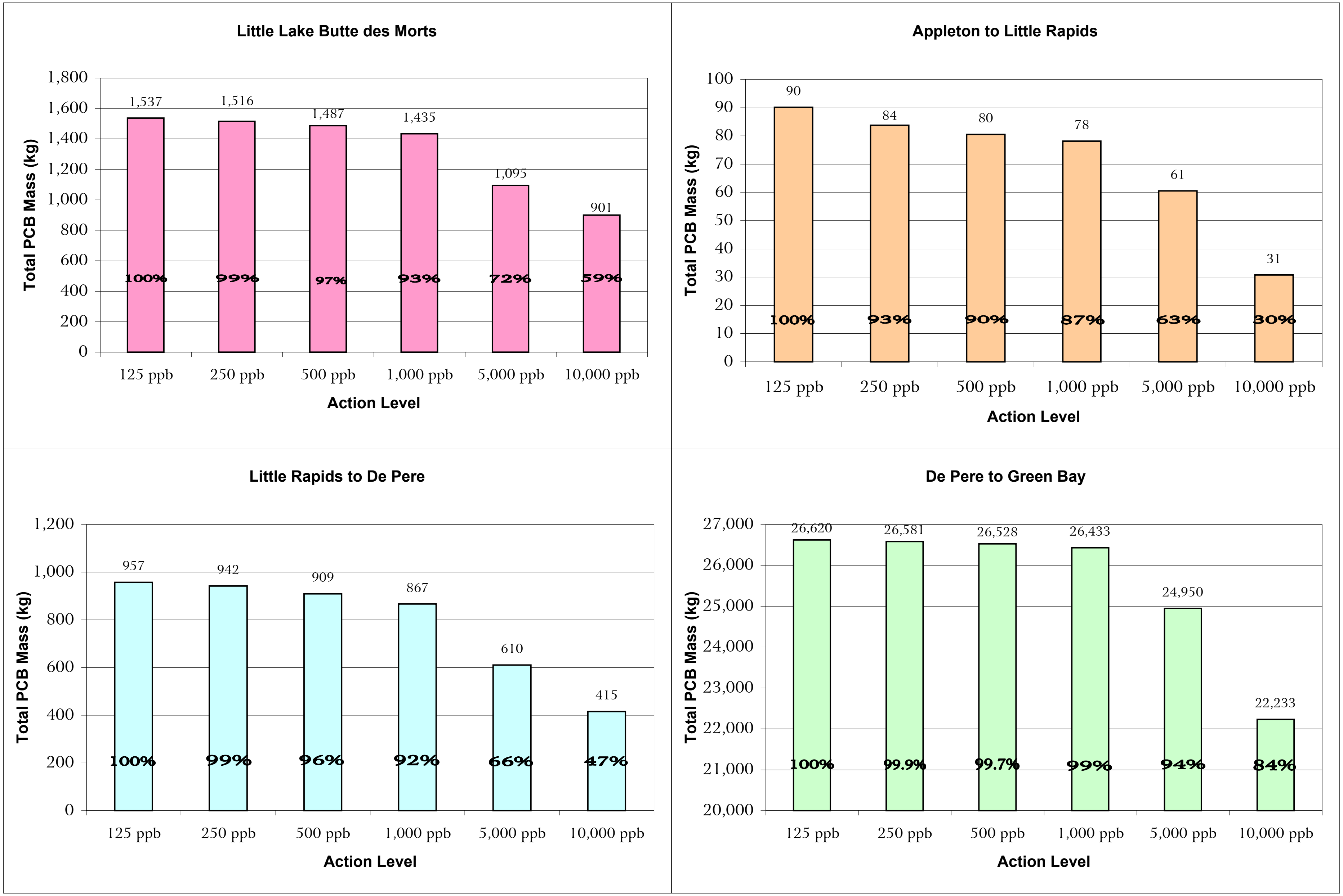
NOAEC – No Observable Adverse Effect Concentration

## Figure 5-3 Total Sediment Volume versus Action Level by Reach in the Lower Fox River



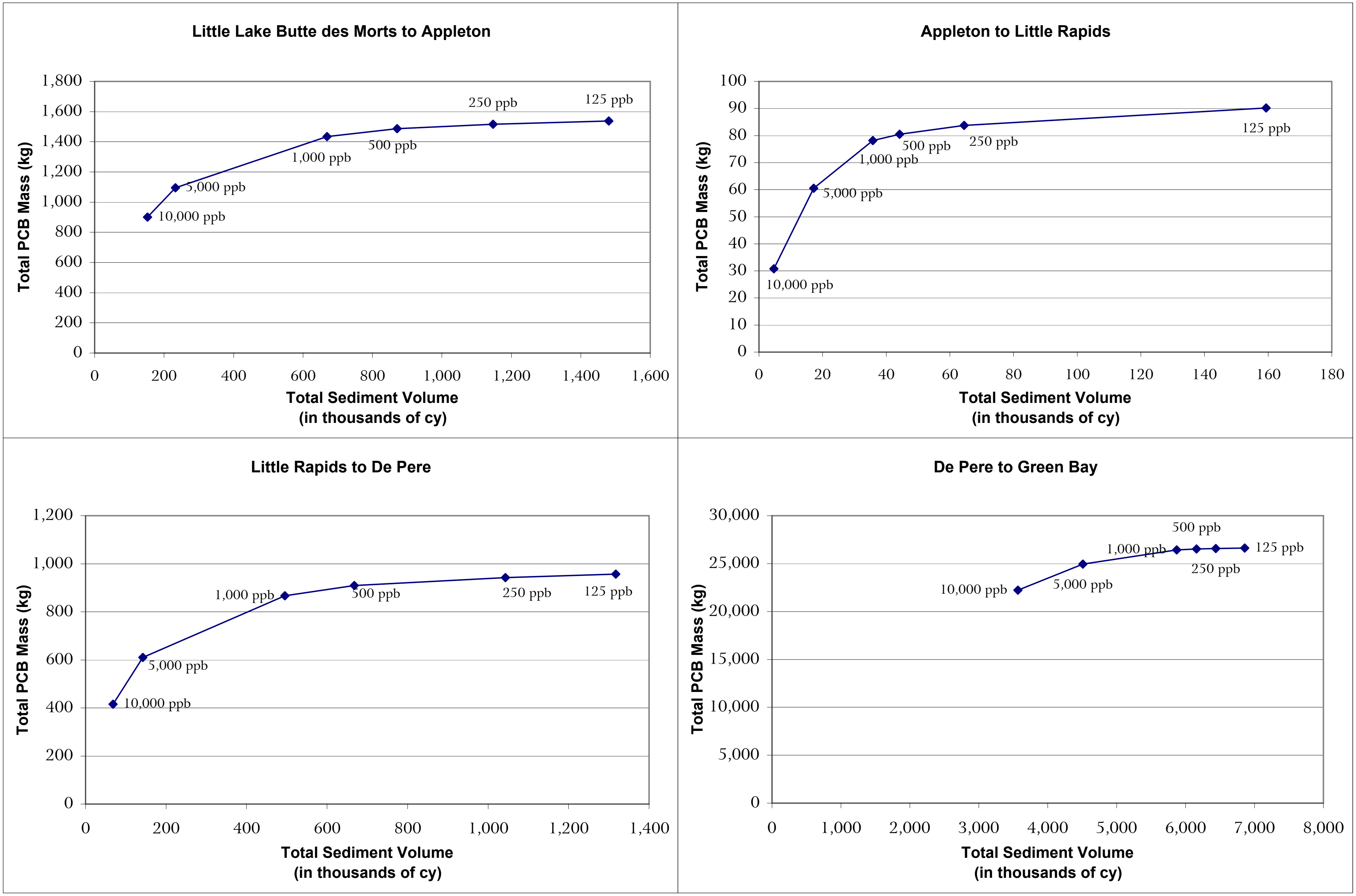

**Note:** The embedded percentage values are the percent differences between the bracketing volumes. For example, there is a 56 percent difference in the sediment volumes removed at action levels of 125 and 250 ppb in the Appleton to Little Rapids Reach.

**Figure 5-4 Total PCB Mass versus Action Level by Reach in the Lower Fox River**

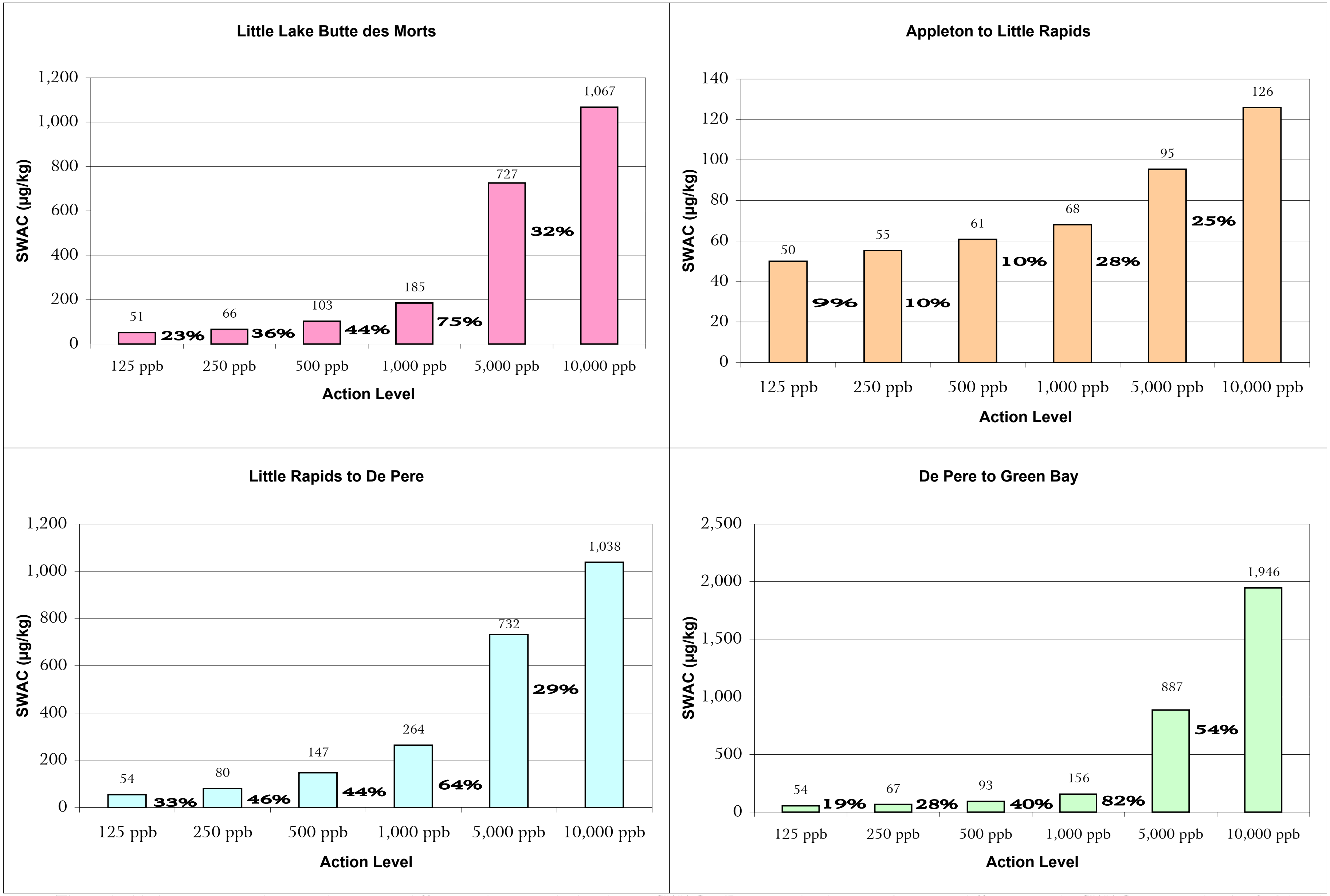



**Note:** Embedded percentages represent the percent of PCB mass theoretically removed at each action level relative to the total estimated mass at 125 ppb.

## Figure 5-5 Total PCB Mass versus Sediment Volume by Reach in the Lower Fox River

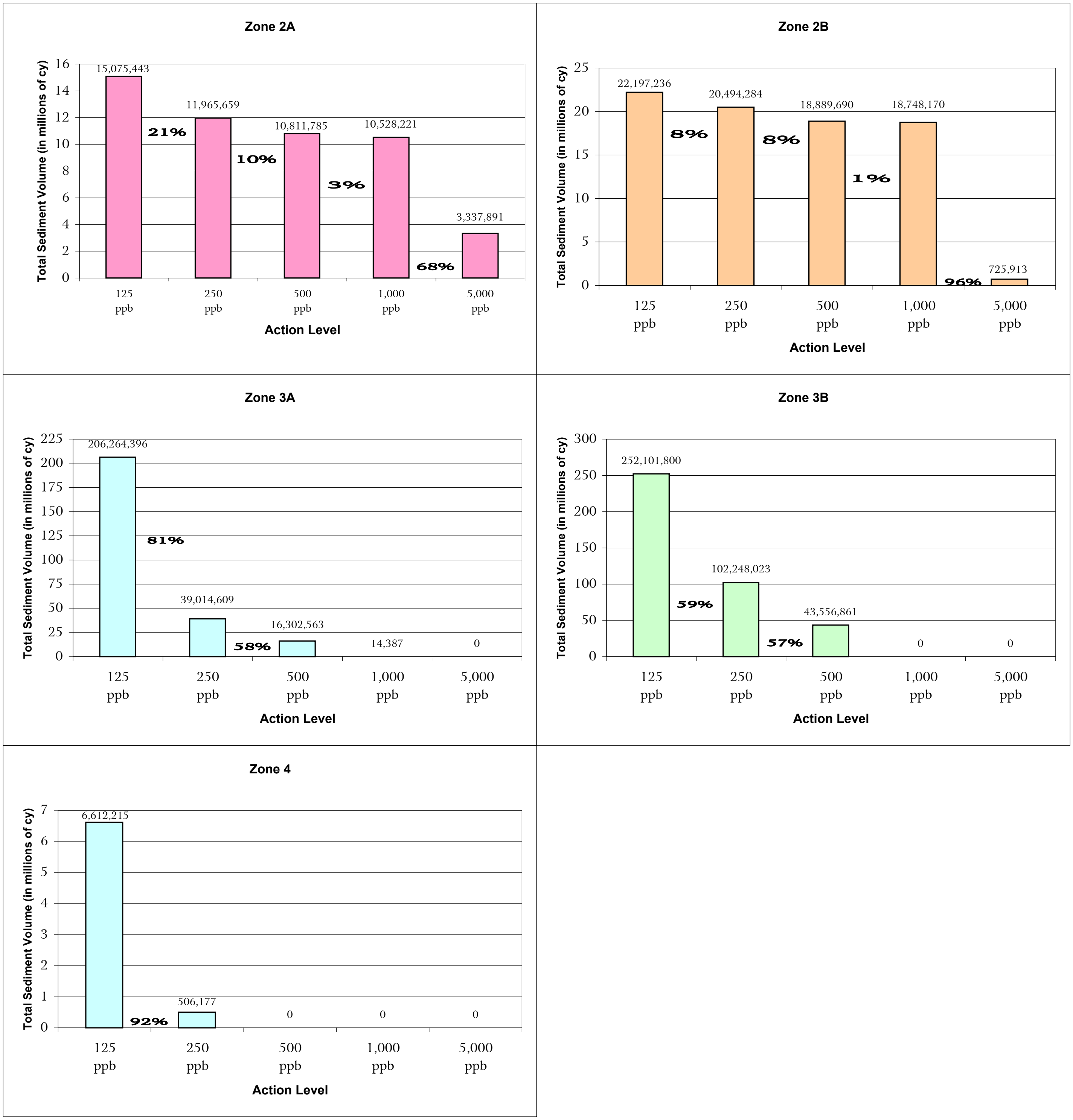


## Figure 5-6 Residual SWAC versus Action Level by Reach in the Lower Fox River



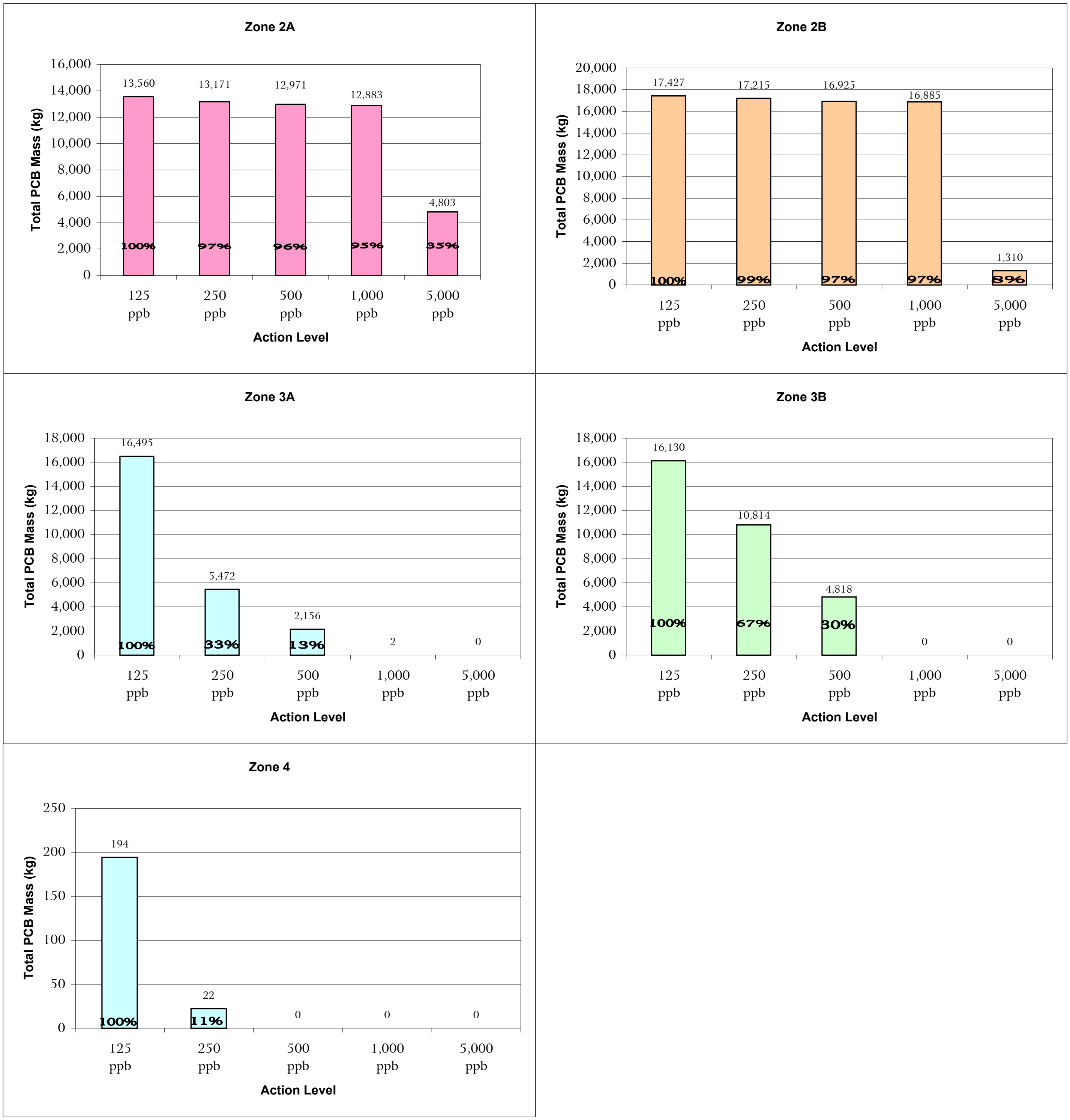

**Note:** The embedded percentage values are the percent differences between the bracketing SWACs. For example, there is a 9 percent difference in the SWAC at action levels of 125 and 250 ppb in the Appleton to Little Rapids Reach.

**Figure 5-7 Total Sediment Volume versus Action Level by Zone in Green Bay**




**Note:** The embedded percentage values are the percent differences between the bracketing volumes. For example, there is a 59 percent difference in the sediment volumes removed at action levels of 125 and 250 ppb in the Zone 3B.

## Figure 5-8 Total PCB Mass versus Action Level by Zone in Green Bay




**Note:** Embedded percentages represent the percent of PCB mass theoretically removed at each action level relative to the total estimated mass at 125 ppb.

**Figure 5-9 Total PCB Mass versus Sediment Volume by Zone in Green Bay**

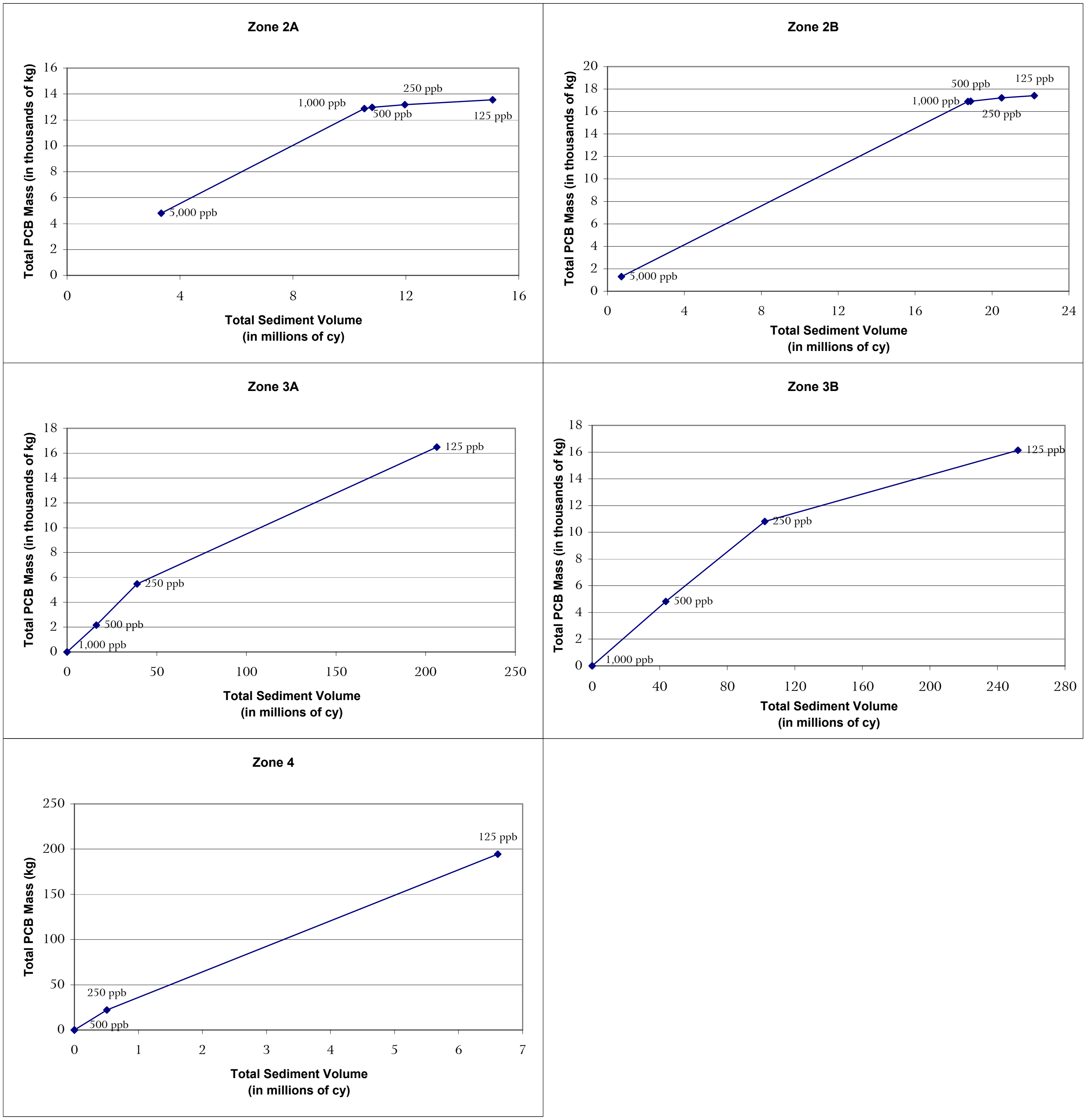
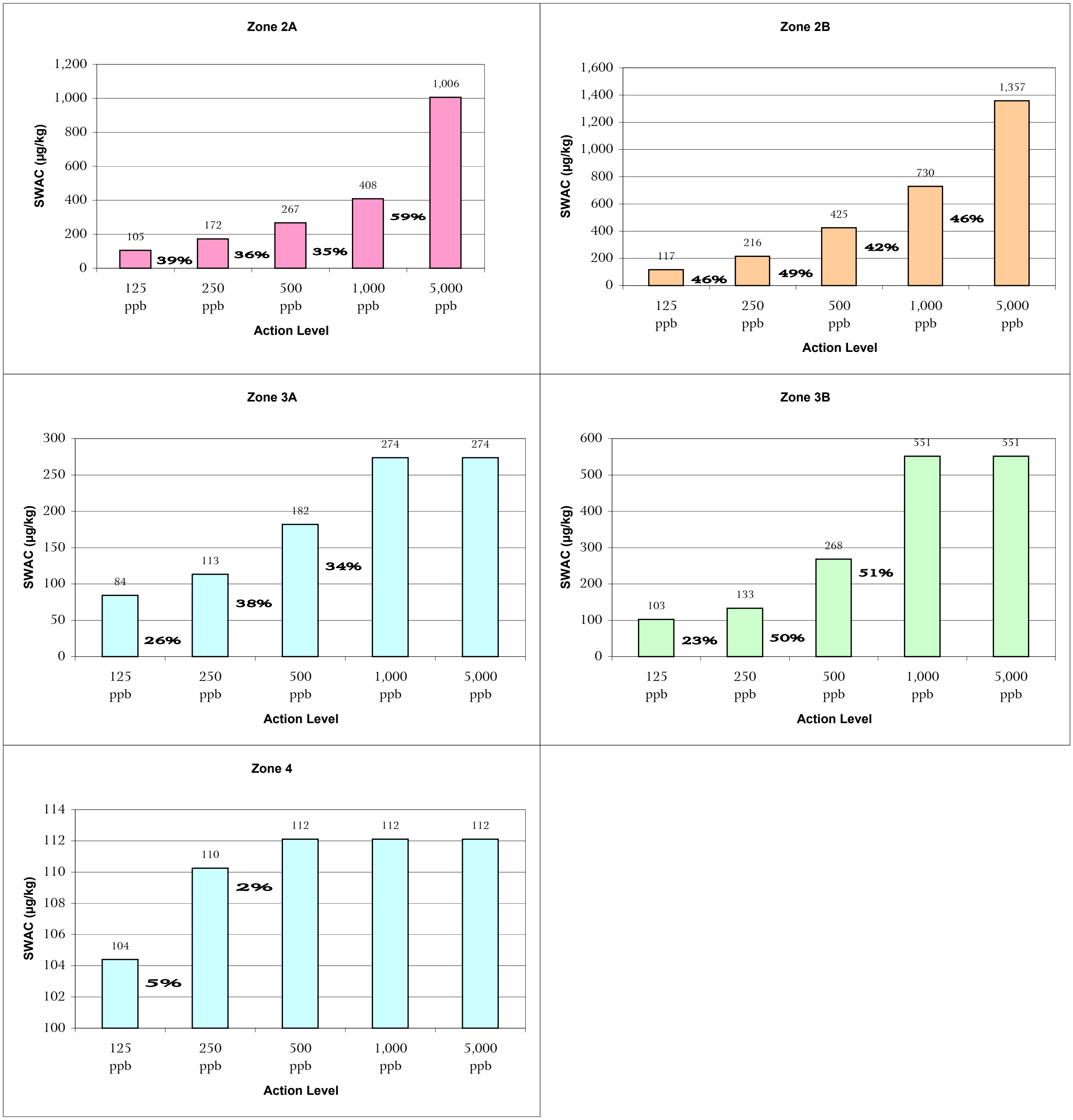


**Figure 5-10 SWAC versus Action Level by Zone in Green Bay**




**Note:** The embedded percentage values are the percent differences between the bracketing SWACs. For example, there is a 39 percent difference in the SWAC at action levels of 125 and 250 ppb in the Zone 2A.

## Table 5-1 Procedure for Computing PCB Mass Removed by Dredging Sediments above Selected Action Levels

| Step | Description | Action |
|---|---|---|
| 1 | Open Mask Grids: 0 for areas with sediment and 1 for areas without sediment. | Loads nine sediment mask grids. |
| 2 | Open PCB interpolated concentration grids: PCB concentration unless outside river footprint or not interpolated based on interpolation criteria. | Loads nine concentration grids. |
| 3 | Starting at bottom layer, identify areas with sediment above action level from bottom up. This will include clean sediments over deeper sediments exceeding an action level. | Generates grid for each layer with 0 if not dredged and 1 if dredged. Areas with no sediment or no interpolated concentration are set at 0. |
| 4 | Load PCB mass grids: Produced by WDNR from concentration and bulk density. | Loads nine grids of PCB mass by layer. |
| 5 | Multiply dredge grid for each layer by mass grid for each layer. | Generates grid for dredged mass in each layer. |
| 6 | Sum over all layers. | Generates single-layer grid of total volume dredged at each cell location. |
| 7 | Save mass results to statistics tables. Results are saved by deposit, by model segment, and by reach. Statistics generated include number of cells, area, minimum, maximum, range, mean, standard deviation, and sum for each category, such as for each river reach. | Generates three output tables for each action level. |
| 8 | Save mass grid from Step 5. | Grid of mass dredged for displaying dredge footprint for each action level. |

**Note:**

Procedure uses interpolated PCB concentration grids, PCB mass grids and grids of presence or absence of sediment (mask grids). PCB concentration, PCB mass, and mask grids prepared by WDNR.

## Table 5-2 Procedure for Computing SWAC for Selected Action

| Step | Description | Action |
|---|---|---|
| 1 | Open Mask Grids: 0 for areas with sediment and 1 for areas without sediment. | Loads nine sediment mask grids. |
| 2 | Open PCB interpolated concentration grids: PCB concentration unless outside river footprint or not interpolated based on interpolation criteria. | Loads nine concentration grids. |
| 3 | Starting at bottom layer, identify areas with sediment above action level from bottom up. This will include clean sediments dredged to remove deeper areas exceeding an action level. | Generates grid for each layer with 0 if not dredged and 1 if dredged. Areas with no sediment or no interpolated concentration are set at 0. |
| 4 | Multiply dredge grid for each layer by thickness of layer and area of cell. | Generates grid for each layer of the volume dredged at each cell location. |
| 5 | Sum over all layers. | Generates single-layer grid of total volume dredged at each cell location. |
| 6 | Save volume results to statistics tables. Results are saved by deposit, by model segment, and by reach. Statistics generated include number of cells, area, minimum, maximum, range, mean, standard deviation, and sum for each category, such as for each river reach. | Generates three output tables for each action level. |
| 7 | Save volume grid from Step 5. | Grid of volume dredged for displaying dredge footprint for each action level. |

**Note:**

SWAC is calculated from interpolated PCB concentration grids and grids of presence or absence of sediment (mask grids). PCB concentration and mask grids prepared by WDNR.

# Table 5-3 PCB Mass and Sediment Volume by Action Level—Lower Fox River

| River Reach | Deposit | Sediment Volume Based on Action Levels (cy) [1] | | | | | | PCB Mass Based on Action Levels (kg) [1] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 10,000 ppb | Total [2] | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 10,000 ppb |
| *Little Lake Butte des Morts* | | | | | | | | | | | | | | |
| | A | 140,801 | 140,539 | 140,487 | 139,964 | 30,841 | 20,744 | 238 | 238 | 237 | 237 | 237 | 135 | 112 |
| | B | 49,951 | 44,784 | 43,856 | 42,835 | 38,035 | 30,423 | 411 | 411 | 410 | 410 | 409 | 396 | 353 |
| | C | 78,098 | 75,691 | 30,174 | 25,989 | 7,468 | 1,256 | 39 | 39 | 39 | 36 | 35 | 20 | 3 |
| | D | 87,136 | 85,305 | 78,215 | 69,858 | 9,718 | 0 | 83 | 83 | 83 | 81 | 78 | 22 | 0 |
| | E | 862,973 | 568,972 | 433,089 | 276,318 | 83,500 | 44,719 | 453 | 450 | 432 | 415 | 373 | 243 | 165 |
| | F | 123,287 | 101,196 | 23,726 | 8,593 | 0 | 0 | 11 | 11 | 10 | 4 | 3 | 0 | 0 |
| | G | 3,662 | 0 | 0 | 0 | 0 | 0 | 0.7 | 0.3 | 0 | 0 | 0 | 0 | 0 |
| | H | 902 | 902 | 902 | 301 | 0 | 0 | 0.7 | 0.7 | 0.7 | 0.7 | 0.4 | 0 | 0 |
| | POG | 134,143 | 130,193 | 120,881 | 105,643 | 63,409 | 55,052 | 305 | 305 | 304 | 303 | 299 | 279 | 267 |
| | Interdeposit Areas | | | | | | | 309 | 276 | | | | | |
| | **Reach Total:** | **1,480,954** | **1,147,583** | **871,331** | **669,501** | **232,972** | **152,193** | **1,850** | **1,813** | **1,516** | **1,487** | **1,435** | **1,095** | **901** |
| *Appleton to Little Rapids* | | | | | | | | | | | | | | |
| | I | 2,668 | 889 | 889 | 0 | 0 | 0 | 0.2 | 0.4 | 0.3 | 0.3 | 0 | 0 | 0 |
| | J | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | K | 209 | 209 | 0 | 0 | 0 | 0 | 0.1 | <0.1 | <0.1 | 0 | 0 | 0 | 0 |
| | L | 249 | 249 | 0 | 0 | 0 | 0 | 0.1 | <0.1 | <0.1 | 0 | 0 | 0 | 0 |
| | M | 1,844 | 1,844 | 615 | 0 | 0 | 0 | 0.2 | 0.3 | 0.3 | 0.1 | 0 | 0 | 0 |
| | N | 6,383 | 6,383 | 6,370 | 6,108 | 3,165 | 2,158 | 30 | 30 | 30 | 30 | 30 | 22 | 19 |
| | O | 3,100 | 3,021 | 2,943 | 1,059 | 0 | 0 | 2 | 2 | 2 | 2 | 0.9 | 0 | 0 |
| | P | 16,742 | 16,742 | 10,045 | 10,045 | 0 | 0 | 5.3 | 5 | 5 | 4 | 4 | 0 | 0 |
| | Q | 275 | 275 | 249 | 196 | 0 | 0 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0 | 0 |
| | R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | S | 2,721 | 2,721 | 2,721 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | T | 6,330 | 6,330 | 6,330 | 6,330 | 3,048 | 0 | 11.3 | 11 | 11 | 11 | 11 | 7 | 0 |
| | U | 785 | 785 | 262 | 0 | 0 | 0 | 0.2 | 0.2 | 0.2 | 0.1 | 0 | 0 | 0 |
| | V | 78 | 78 | 26 | 26 | 0 | 0 | 0 | <0.1 | <0.1 | <0.1 | <0.1 | 0 | 0 |
| | W | 42,862 | 6,592 | 1,256 | 981 | 0 | 0 | 6.8 | 5 | 2 | 0.5 | 0.5 | 0 | 0 |
| | X | 41,305 | 2,080 | 0 | 0 | 0 | 0 | 2.5 | 2 | 0.2 | 0 | 0 | 0 | 0 |
| | Y | 562 | 562 | 0 | 0 | 0 | 0 | 0.3 | 0.1 | 0.1 | 0 | 0 | 0 | 0 |
| | Z | 955 | 955 | 0 | 0 | 0 | 0 | 0.4 | 0.2 | 0.2 | 0 | 0 | 0 | 0 |
| | AA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | BB | 340 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | CC | 4,460 | 1,583 | 1,465 | 0 | 0 | 0 | 0.7 | 0.6 | 0.5 | 0.4 | 0 | 0 | 0 |
| | DD | 27,506 | 13,197 | 11,039 | 11,039 | 10,948 | 2,551 | 34 | 33 | 32 | 31 | 31 | 31 | 12 |
| | Interdeposit Areas | | | | | | | 15 | 45 | | | | | |
| | **Reach Total:** | **159,374** | **64,495** | **44,209** | **35,786** | **17,160** | **4,709** | **110** | **135** | **84** | **80** | **78** | **61** | **31** |

## Table 5-3 PCB Mass and Sediment Volume—Lower Fox River (Continued)

| River Reach / Deposit | Sediment Volume Based on Action Levels (cy) [1] | | | | | | PCB Mass Based on Action Levels (kg) [1] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 10,000 ppb | Total [2] | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 10,000 ppb |
| *Little Rapids to De Pere* | | | | | | | | | | | | | |
| EE | 1,254,456 | 984,246 | 609,401 | 440,675 | 112,745 | 47,217 | 828 | 806 | 791 | 758 | 716 | 492 | 312 |
| FF | 471 | 471 | 0 | 0 | 0 | 0 | 0.1 | <0.1 | <0.1 | 0 | 0 | 0 | 0 |
| GG | 23,962 | 23,308 | 22,981 | 22,850 | 16,232 | 14,374 | 81 | 81 | 81 | 81 | 81 | 72 | 69 |
| HH | 38,519 | 35,315 | 35,315 | 31,914 | 13,080 | 6,684 | 70.2 | 70 | 70 | 70 | 70 | 45 | 35 |
| Interdeposit Areas | | | | | | | 266 | 244 | | | | | |
| **Reach Total:** | **1,317,407** | **1,043,339** | **667,696** | **495,439** | **142,057** | **68,275** | **1,245** | **1,201** | **942** | **909** | **867** | **610** | **415** |
| *De Pere to Green Bay* | | | | | | | | | | | | | |
| Group 20 to 25 | 1,295,316 | 1,213,046 | 1,157,275 | 1,081,270 | 802,716 | 679,088 | | 5,558 | 5,551 | 5,541 | 5,515 | 5,225 | 4,903 |
| Group 26 to 31 | 198,246 | 169,432 | 163,651 | 157,673 | 107,841 | 64,142 | | 761 | 758 | 757 | 754 | 649 | 478 |
| Group 32 to 37 | 289,175 | 281,353 | 257,156 | 250,970 | 202,798 | 116,238 | | 1,174 | 1,173 | 1,167 | 1,165 | 1,099 | 720 |
| Group 38 to 43 | 458,973 | 420,519 | 379,240 | 346,555 | 227,060 | 162,591 | | 1,148 | 1,145 | 1,136 | 1,125 | 987 | 788 |
| Group 44 to 49 | 1,753,007 | 1,704,116 | 1,632,781 | 1,538,713 | 1,169,897 | 887,288 | | 5,213 | 5,209 | 5,197 | 5,170 | 4,833 | 4,065 |
| Group 50 to 55 | 512,651 | 492,535 | 477,114 | 456,266 | 325,758 | 260,295 | | 1,831 | 1,829 | 1,826 | 1,819 | 1,667 | 1,494 |
| Group 56 to 61 | 636,305 | 633,755 | 630,289 | 621,813 | 577,657 | 533,879 | | 5,812 | 5,812 | 5,811 | 5,808 | 5,767 | 5,681 |
| Group 62 to 67 | 249,125 | 246,052 | 240,323 | 231,050 | 163,494 | 109,475 | | 862 | 861 | 861 | 859 | 799 | 711 |
| Group 68 to 73 | 420,689 | 389,900 | 375,565 | 363,676 | 291,869 | 265,527 | | 1,858 | 1,855 | 1,853 | 1,850 | 1,770 | 1,690 |
| Group 74 to 79 | 153,723 | 140,945 | 134,941 | 129,644 | 123,693 | 101,942 | | 429 | 427 | 426 | 425 | 416 | 338 |
| Group 80 to 85 | 184,029 | 123,719 | 98,463 | 91,923 | 62,782 | 39,893 | | 384 | 380 | 374 | 372 | 327 | 241 |
| Group 86 to 91 | 133,123 | 93,610 | 91,099 | 89,464 | 85,932 | 24,197 | | 253 | 249 | 249 | 248 | 245 | 98 |
| Group 92 to 97 | 145,980 | 130,782 | 126,178 | 121,038 | 46,890 | 0 | | 255 | 253 | 251 | 248 | 137 | 0 |
| Group 98 to 103 | 67,307 | 40,821 | 38,859 | 34,151 | 24,720 | 24,720 | | 93 | 90 | 89 | 87 | 79 | 79 |
| Group 104 to 109 | 90,340 | 89,791 | 89,791 | 89,438 | 38,061 | 38,061 | | 150 | 150 | 150 | 150 | 116 | 116 |
| Group 110 to 115 | 269,765 | 268,601 | 267,084 | 266,691 | 259,157 | 258,582 | | 840 | 840 | 839 | 839 | 833 | 832 |
| **Reach Total:** | **6,857,757** | **6,438,977** | **6,159,808** | **5,870,333** | **4,510,325** | **3,565,919** | **26,620** | **26,620** | **26,581** | **26,528** | **26,433** | **24,950** | **22,233** |

**Notes:**

[1] Estimated mass or volume of sediment to be removed or isolated at a specific action level.

[2] Total PCB mass presented above were generated from a GIS map query of the Lower Fox River model layers. The mass contained in each model layer was summed to provide the total mass. Values may differ slightly from those listed in the Fox River Database (FRDB), in Section 2 of the FS, and in the RI Report (generated from the FRDB). Values may differ slightly from those listed in Section 7 of the FS Report since Section 7 includes overburden volumes and PCB mass required for removal. Use the Section 7 volumes and masses for remediation estimates.

## Table 5-4 SWAC Based on Action Levels—Lower Fox River

| River Reach | Residual SWAC (ppb) Based on Action Levels | | | | | |
|---|---|---|---|---|---|---|
| | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 10,000 ppb |
| Little Lake Butte des Morts | 51 | 66 | 103 | 185 | 727 | 1,067 |
| Appleton to Little Rapids | 50 | 55 | 61 | 68 | 95 | 126 |
| Little Rapids to De Pere | 54 | 80 | 147 | 264 | 732 | 1,038 |
| De Pere to Green Bay | 54 | 67 | 93 | 156 | 887 | 1,946 |

**Note:**

Estimated residual surface-weighted average concentration (SWAC) of PCBs in surface sediment after removal.

# Table 5-5 PCB Mass, Volume and SWAC—Green Bay

| Bay Zone | Volume Based on Action Levels (cy) | | | | | PCB Mass Based on Action Levels (kg) | | | | | SWAC Based on Action Levels (ppb) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb | 125 ppb | 250 ppb | 500 ppb | 1,000 ppb | 5,000 ppb |
| Zone 2A | 15,075,443 | 11,965,659 | 10,811,785 | 10,528,221 | 3,337,891 | 13,560 | 13,171 | 12,971 | 12,883 | 4,803 | 105 | 172 | 267 | 408 | 1,006 |
| Zone 2B | 22,197,236 | 20,494,284 | 18,889,690 | 18,748,170 | 725,913 | 17,427 | 17,215 | 16,925 | 16,885 | 1,310 | 117 | 216 | 425 | 730 | 1,357 |
| Zone 2 | 37,272,680 | 32,459,943 | 29,701,474 | 29,276,390 | 4,063,804 | 30,986 | 30,386 | 29,895 | 29,768 | 6,113 | 222 | 388 | 692 | 1,138 | 2,363 |
| Zone 3A | 206,264,396 | 39,014,609 | 16,302,563 | 14,387 | 0 | 16,495 | 5,472 | 2,156 | 2 | 0 | 84 | 113 | 182 | 274 | 274 |
| Zone 3B | 252,101,800 | 102,248,023 | 43,556,861 | 0 | 0 | 16,130 | 10,814 | 4,818 | 0 | 0 | 103 | 133 | 268 | 551 | 551 |
| Zone 4 | 6,612,215 | 506,177 | 0 | 0 | 0 | 194 | 22 | 0 | 0 | 0 | 104 | 110 | 112 | 112 | 112 |

**Notes:**

[1] Estimated mass or volume of sediment to be removed or isolated at a specific action level.

[2] Estimated residual SWAC concentration in surface sediments after removal.

# 6 Identification and Screening of Technologies

The purpose of this section is to identify and screen remedial action technology types and process options that are potentially applicable for management of contaminated sediments in the Lower Fox River and Green Bay. The screening process was conducted in accordance with the EPA RI/FS Guidance (EPA, 1988). First, a list of potentially applicable technologies is prepared based on the general response actions (GRAs) anticipated for site cleanup (identified in Section 4) and on available information on various technologies and processes that either exist or are under development. Next, the list is refined by evaluating each technology for implementability, effectiveness, and relative cost. Technologies are either retained for use in developing remedial alternatives (Section 7) or are dropped from further consideration. The following provides an overview of the review process:

- The initial step involves assembling a comprehensive list of technology types and specific process options applicable to the general response actions developed in Section 4.4 that could be potentially used to manage Lower Fox River and Green Bay sediments (Section 6.1).

- Secondly, criteria are presented to screen the potential technologies based upon their implementability, effectiveness, and relative costs (Section 6.2).

- The results of the technology screening and a brief description of the primary factors that influenced the retention/elimination screening decisions are discussed. The section culminates in a list of retained process options (Section 6.3).

- A detailed description of each of the retained process options that will be carried forward into the detailed reach-specific analysis in Section 7 is provided (Section 6.4). The site-specific factors that will influence implementability or effectiveness (i.e., operational constraints) are also identified here, and will be applied in Section 7.

- Ancillary technologies (i.e., transportation of dredged sediments) that are required to implement specific management options for the Lower Fox River and Green Bay, but do not necessarily require screening, are presented (Section 6.5).

- Additional information on water quality, including protection of the water column during dredging and requirements for discharge of water from sediment handling activities, are presented (Section 6.6).

The literature sources and databases utilized to compile and evaluate a broad list of potentially applicable technology types and process options are provided in Table 6-1. In addition to these sources, available site data, and specific criteria applicable to the process options were used in the screening process.

## 6.1 Identification of Technologies

The first step in the FS process involves the identification of GRAs, remedial action technology types (e.g., dredging, chemical treatment, capping), and remedial action process options (e.g., horizontal auger dredge, electrochemical oxidation, sand cap). Descriptions of GRAs, technology types, and process options include:

- **General Response Actions.** These are selected to address the extent of contamination and the potential for migration of COCs for a given medium. GRAs are described in broad terms in order to encompass all possible remedial actions for achieving the remedial action objectives. By identifying appropriate response actions which apply to contaminated sediments, the list of technologies to be reviewed can be substantially reduced. The GRAs for sediment cleanup in the Lower Fox River and Green Bay are:

    - No Action,
    - Institutional Controls,
    - Monitored Natural Recovery,
    - Containment,
    - Removal,
    - *In-situ* Treatment,
    - *Ex-situ* Treatment, and
    - Disposal.

- **Technology Types.** These are general categories that describe a means for achieving the GRAs (e.g., capping, dredging, dry excavation, or chemical treatment). For example, removal is a GRA that can be achieved by excavation or dredging, while treatment is a GRA that can be achieved using biological or chemical technologies.

- **Process Options.** These are specific processes within each technology type. For example, chemical treatment, which is a technology type, includes such process options as solvent extraction and slurry oxidation. Process options are selected based on an understanding of the characteristics of the medium and technologies that are available to address the medium.

The GRAs describe, in broad terms, remedial actions theoretically capable of achieving the RAOs described in Section 4. The technologies are grouped according to the GRAs discussed in Section 4. One or more technologies and technology process options may be considered within each GRA category. Literature sources used to develop the list of potentially applicable technologies are listed in Table 6-1. A summary of the technologies and process options reviewed and retained within each GRA are listed in Table 6-2. Shaded technologies were retained for further consideration in the development of remedial alternatives for the Lower Fox River and Green Bay.

This section also presents and evaluates several ancillary technologies that, while necessary to the overall implementation of a cleanup program, are secondary to the primary functions embodied by the GRAs. For example, sediment dewatering, water treatment, suspended solids controls during dredging, and monitoring are all discussed in this section as technologies ancillary to the primary GRAs.

The list of technologies evaluated in this section is comprehensive and is supported by numerous published articles, guidance, and technology databases developed over the years for sediment remediation (Table 6-1). Many of the cited publications address technologies and cleanup approaches specific to the Lower Fox River and Green Bay or very similar sites. Finally, site-specific data from the recently completed Site N and 56/57 dredging projects on the Lower Fox River aided the evaluation and selection of dredging, sediment dewatering, and water treatment technologies. A detailed description of the technologies and process options screened in this section are listed in Table 6-3.

## 6.2 Screening of Technologies

The technologies listed in Table 6-2 are screened in this section of the FS to determine which are appropriate for development of sediment remedial alternatives. The screening methodology used is consistent with that presented in the EPA RI/FS Guidance (EPA, 1988). The following subsections describe the process and screening criteria used for the identified technologies.

### 6.2.1 Screening Criteria

The criteria used to evaluate each process option were implementability, effectiveness, and relative cost. These criteria are discussed below.

### Implementability

Technical implementability refers to the technical feasibility of implementing a particular technology. Technologies that are not applicable to site characteristics or the contaminants of concern (COCs) are eliminated from further consideration. Administrative implementability considers permitting and the availability of necessary services and equipment to implement a particular technology.

### Effectiveness

Determining the effectiveness of a technology involves consideration of whether the technology can contain, reduce, or eliminate the COCs and generally achieve the RAOs set forth in Section 4. Effectiveness is evaluated relative to the other technologies identified in the screening. Consideration must also be given to the many aspects of remediation that contribute to a technology's overall effectiveness including:

- How well the technology will handle the estimated areas or volumes of contaminated sediment to be remediated;
- If the RAOs will be met through implementation of the technology;
- How efficiently does the technology reduce or eliminate the COC;
- To what scale (lab-, pilot-, full-) the technology has been tested;
- Timeliness of implementation and availability; and
- How effective is the process option in protecting human health and the environment during the implementation phase of remediation.

The effectiveness evaluation focuses on PCBs as the primary COC. Metals are also considered in the screening of certain process options for treatment.

### Cost

Technologies were evaluated with respect to relative capital and operations and maintenance (O&M) costs. Detailed cost estimates of remedial alternatives are provided in Section 7 of this FS Report. Costs used for this phase of the screening process are defined in terms of high, moderate, and low, rather than a specific dollar amount and are determined on the basis of engineering judgement. The cost of each process option is relative to other process options of the same technology type. Technologies are retained or eliminated based, to a lesser degree, on cost during this phase of the screening (Table 6-4).

### 6.2.2 Screening Process

As specified in the EPA RI/FS Guidance (EPA, 1988), a two-step screening process was used to evaluate each process option listed in Table 6-2, with the exception of technology types or process options associated with the no action GRA. The no action GRA is retained as required by NCP for use as a baseline comparison against other technologies.

In the first step, referred to as the initial screening, process options determined to be technically implementable were retained for further evaluation. Technologies that have no applicability to the COCs, are not ready for full-scale operations, or are otherwise unworkable in the context of sediment remediation were eliminated from further discussion.

In the second step, the final screening of technologies considers effectiveness and cost. In some cases where several technologies are considered similar in approach and performance, a single representative technology is retained for further evaluation. Technologies retained through the screening steps receive extensive coverage in the following subsections. During the detailed analysis of alternatives (Chapter 9 of the FS), technologies evaluated during the screening process and retained are further refined, as appropriate. Technologies and alternatives will be analyzed in detail with respect to short-term impacts associated with implementation, long-term protection of remedy, compliance with ARARs and TBCs, and reduction of toxicity, mobility, and volume of COCs.

## 6.3 Results of Technology Screening

The technologies screened and retained for further consideration in the development of remedial alternatives (Section 7) are shaded in Table 6-2. The following discussion briefly describes the results in advance of the detailed screening that consumes the remainder of this section.

### 6.3.1 No Action

No action was retained, as required by the NCP, for comparing the merits of taking no remedial action whatsoever with other technology-based remedial alternatives (Table 6-4). With a no action alternative, natural restoration is the only means by which sediment quality can improve over time. However, implementation requires no planning, decision making, maintenance, or monitoring. No action does not meet RAOs for the Lower Fox River and Green Bay.

### 6.3.2 Institutional Controls

Institutional controls are administrative actions (e.g., fish consumption advisories, access restrictions, dredging moratoriums) designed to prevent exposure of humans and wildlife to contaminants. Institutional controls are generally effective at limiting human exposure, but are generally ineffective at affording protection to ecological receptors where impacts are ongoing (Table 6-4). In general, institutional controls have no effect on ecological receptors. Nevertheless, institutional controls are important features of many sediment cleanup projects and are retained for further consideration in the development of remedial alternatives (EPA, 1999a).

### 6.3.3 Monitored Natural Recovery

Monitored natural recovery (MNR) refers to the beneficial effects of natural processes that reduce surface sediment concentrations of PCBs. These processes include biodegradation, diffusion, dilution, sorption, volatilization, chemical and biochemical stabilization of contaminants, and burial by natural deposition of cleaner sediments. The primary mechanisms for MNR in the Lower Fox River and Green Bay are desorption and dispersion in the water column (i.e., as a dissolved constituent), burial, and sediment resuspension and transport. Biodegradation is a negligible contributor to the lowering of PCB concentrations and is not a factor for mercury (see Appendix F).

MNR can be an effective alternative under the appropriate conditions. However, for the Lower Fox River it may have limited utility for the Fox River and Green Bay to be protective in a reasonable time frame because of: 1) limitations of natural dechlorination, 2) slow time trend decrease in PCB concentrations in fish and sediment, and 3) substantial fluctuations in sediment bed elevations precluding long-term burial by cleaner sediment. For example, areas of net scour and deposition have measured up to 36 cm of short-term change (annually) and 100 cm of long-term change (several years) in bed elevations (WDNR, 1999c).

MNR is retained for use in developing remedial alternatives for the Lower Fox River and Green Bay (Table 6-4). While MNR alone may not be protective of human health and the environment in heavily impacted areas, natural processes are central to evaluating the long-term performance of technology-based remedial alternatives covering the full range of cleanup action levels.

### 6.3.4 Containment

Various approaches to capping contaminated sediments *in situ* were evaluated (Table 6-4). Capping isolates contaminants from the overlying water column and prevents direct contact with aquatic biota. In addition, capping provides new unimpacted substrate for recolonization by benthic organisms. Capping is considered effective at isolating low-solubility and highly sorbed contaminants like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap designs should minimize the potential for sediment resuspension under normal and extreme (storm) conditions. Cap placement as a remedial alternative assumes source control and minimal potential for recontamination from upstream sources via sediment transport.

Capping is considered both implementable and effective for containing impacted sediments in portions of the Lower Fox River and Green Bay where navigation would not be impeded. The technology is retained for use in developing remedial alternatives in Section 7. Of the various process options, conventional sand cap, armored, and composite cap designs are best suited for consideration. Specific cap materials, thicknesses, and other design parameters are selected based on site-specific conditions and design criteria. Thin-layer and enhanced caps are not appropriate for use at the site based on the time frame selected to meet the project RAOs. This is further explained in Section 6.4.4.

### 6.3.5 Removal

Both hydraulic and mechanical options were retained as removal options (Table 6-4). Despite recent claims that dredging is not an effective remedial alternative for PCB-impacted sediments, dredging is one of the most common remedial alternatives currently used throughout the world. There are supporting data that show that it can effectively reduce total concentrations and contaminant mass. A detailed review of local, national, and international dredging projects (summarized in Section 6.4.2 and in Appendix B) concluded that environmental dredging can feasibly remove contaminated sediments, with many projects showing reductions in surface sediment concentrations. With careful planning, application in appropriate environments, and use of engineering controls, dredging can be an effective tool to remove contaminated sediments. Hydraulic or mechanical dredging can be accomplished with minimal contaminant resuspension and transport during operations. However, removal options require water quality monitoring during and after activities and management of materials following removal.

### 6.3.6 *In-situ* Treatment

*In-situ* treatment of sediments refers to processes that fix, transform, or destroy COCs while leaving the sediments in place (i.e., without first removing the sediment). No *in-situ* technologies were retained for consideration in the development of remedial alternatives (Table 6-5). *In-situ* treatment technologies for PCBs have neither been sufficiently developed nor demonstrated in field applications.

### 6.3.7 *Ex-situ* Treatment

*Ex-situ* treatment refers to technologies that fix, transform, or destroy COCs after first removing sediment from the river or lake bottom. Three *ex-situ* treatment process options, all thermal technologies, were retained (Table 6-5). The elimination of other *ex-situ* treatment options was primarily based on media-specific characteristics (i.e., high water content of sediments), contaminant composition, and the lack of full-scale demonstrations. The retained options are incineration, high-temperature thermal desorption (HTTD) and vitrification.

### 6.3.8 Disposal

Disposal technologies are necessarily coupled with a removal action. Both on-site and off-site disposal technologies were retained for development of remedial alternatives (Table 6-6). The retained on-site disposal options are the level-bottom cap and confined disposal facility (CDF). These technologies involve the relocation and consolidation of dredged sediments in an engineered in-water or nearshore disposal facility. After dewatering and treatment, solids residuals may be taken to an appropriate off-site disposal facility depending upon concentration and management decisions.

### 6.3.9 Ancillary Technologies

Ancillary technologies and processes are essential elements of many remedial alternatives, mostly related to waste management and monitoring. Ancillaries are not subject to the same screening evaluation as remedial alternatives; however, they are discussed in this section as important considerations during selection of remedial process options (Table 6-7). Ancillary technologies and processes described in this section include:

- Dewatering,
- Wastewater treatment,
- Residuals management and disposal,
- Transportation, and
- Water quality management.

Sediment dewatering is a requirement for most disposal and treatment processes. Both passive and mechanical dewatering will be considered in the development of remedial alternatives. Passive dewatering (also referred to as gravity dewatering) involves the gravity separation of water and solids in a sedimentation basin. Mechanical dewatering involves the use of equipment such as centrifuges, hydrocyclones, belt presses, and plate-and-frame filter presses to remove moisture from the sediments. Treatment of wastewater generated during sediment dewatering may be required to meet water quality requirements before discharge back to the river or bay. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal.

Water quality impacts from sediment resuspension during dredging are an issue when planning a sediment removal operation. Operational controls involving modified construction practices, specialized equipment, and containment systems are effective in controlling sediment resuspension and off-site losses.

### 6.3.10 Monitoring

Although monitoring is not part of the technology screening process, monitoring is a key component of sediment remediation to verify project progress and success. For contaminated sediment projects, monitoring can be grouped into five categories: 1) baseline monitoring; 2) short-term monitoring during implementation; 3) verification monitoring immediately following an action; 4) operation and maintenance (O&M) monitoring of disposal sites; and 5) long-term performance monitoring to determine whether RAOs are attained. All five types of monitoring have been included in the FS costs and scope. A proposed model long-term monitoring plan has been developed to determine post-implementation effectiveness of a remedy (Appendix C).

## 6.4 Description and Selection of Retained Process Options

This section provides a detailed description of each of the retained process options and a review of pertinent selection criteria that influenced the screening process. The information presented in the following sections also provides the basis for development of the remedial alternatives in Section 7.

### 6.4.1 No Action

The GRA of no action was retained as required by the NCP for use as a baseline comparison against other technologies. The "no action" alternative requires no human intervention for cleanup. For the no action alternative, natural restoration is the only means of addressing the contaminated sediments in the Lower Fox River and Green Bay. Natural restoration may involve one or more processes that effectively reduce contaminant toxicity, mobility, or volume. These processes include biodegradation, diffusion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants. The no action alternative is unlikely to meet the RAOs, and under this alternative verification of RAOs will not be required. Selection of this process option assumes that no decision-making requirements are involved, nor is a long-term operation and maintenance plan required.

## 6.4.2 Institutional Controls

Institutional controls are administrative actions designed to prevent activities that could expose humans and wildlife to contaminants. The primary controls envisioned for the Lower Fox River and Green Bay are:

- Fish consumption advisories and restrictions,
- Access and use restrictions, and
- Dredging moratoriums.

Consumption advisories warn the general public of risks posed by the consumption of fish caught in affected waters. Access restrictions such as fencing or boating restrictions control human access to contaminated areas. Boating restrictions would likely include "no access" or "no anchoring" restrictions. However, enforcement of these restrictions may be difficult. Dredging moratoriums preclude sediment disturbance or removal in contaminated areas, thereby reducing short-term direct contact and sediment resuspension risks. All of these controls are potentially applicable for use in remedial alternatives.

### Implementability

Implementation of institutional controls for the Lower Fox River and Green Bay requires the cooperation of the implementing agencies, local Indian tribes, and public acceptance. Enforcement of these restrictions and public acceptance may be difficult to achieve. Restrictions would also apply to local Indian tribes.

### Effectiveness

Institutional controls are effective at limiting human exposures, but are generally ineffective at affording protection to ecological receptors where impacts are ongoing. Sediment resuspension and transport from the Lower Fox River to Green Bay continues under natural conditions.

### Costs

Costs for institutional controls are primarily legal and administrative. In general, institutional controls are a low-cost approach to managing the risks posed by contaminated media in comparison with technology-based cleanup options that involve containment, removal, treatment, or disposal.

### Screening Decision

Institutional controls are important features of many sediment cleanup projects and are retained for further consideration in the development of remedial alternatives (Section 7). The management of some remedial systems (e.g., caps, CADs) and management of any residual risk after cleanup to a specified action level above protective concentrations (SQTs) will likely require implementation of institutional controls for a period of time, until the monitored natural recovery goals and project RAOs are achieved. Institutional controls are retained as part of the monitored natural recovery alternative (Table 6-4).

### 6.4.3 Monitored Natural Recovery

Natural recovery refers to the effects of natural processes that lower PCB surface sediment concentrations in the Lower Fox River and Green Bay. Natural recovery involves one or more processes that effectively reduce or isolate contaminant toxicity, mobility, or volume. These processes include physical processes (sediment deposition, mixing and burial, volatilization, diffusion, dilution and transport, and/or dispersion), chemical stabilization (sorption, redox), and biological processes (biodegradation and biotransformation). Monitoring of these processes to determine their effectiveness is commonly referred to as monitored natural recovery (MNR).

Of these potential mechanisms, natural recovery of contaminated sediments primarily occurs through four processes:

1. Loss of contaminants through bacterial biodegradation.

2. Loss of contaminants through diffusion into overlying water. Diffusion and/or volatilization into the atmosphere occur as partitioning mechanisms, especially for PCB congeners with low chlorine content as they tend to be more volatile and also more soluble in water.

3. Burial of contaminated sediments through natural deposition of clean sediments.

4. Mixing of cleaner surface sediments with contaminated deeper sediments by burrowing organisms, ship scour, propeller wash, and natural water currents (i.e., dilution), or downstream dispersion/transport of impacted sediments.

As part of the FS effort, the potential for natural recovery of sediment and fish tissue quality in the Lower Fox River and Green Bay systems was assessed through three lines of inquiry related to the pathways described above. First, available research on the natural biodegradation of PCBs in aquatic systems was summarized to determine whether this mechanism can be expected to significantly influence PCB concentrations over time (located in Appendix F). Second, sediment transport and burial mechanisms were evaluated using fate and transport models, sediment core profiles, and actual changes in sediment bed elevations over time (WDNR, 1999c) (located in the Model Documentation Report). Third, existing sediment and fish tissue PCB concentration data were statistically compared in an analysis of trends over the period of time represented in the FRDB. These statistical changes in PCB-impacted sediment and fish tissue concentrations over time are discussed in the Lower Fox River Time Trends Analysis by The Mountain-Whisper-Light Statistical Consulting (located in Appendix B of the RI Report) (Mountain-Whisper-Light and RETEC, 2002). These three lines of evidence for MNR are discussed below.

**Natural Dechlorination.** Biodegradation of PCBs can occur by bacterial-mediated removal of chlorine atoms from the PCB biphenyl ring (dechlorination, generally anaerobic) or by breaking open the carbon rings of PCBs with low chlorine content through oxidation (aerobic degradation) (Abramowicz, 1990). The most potent PCB congeners are planar and coplanar molecules with non-ortho or mono-ortho substituted PCBs, which chemically resemble and behave like 2,3,7,8-substituted dibenzo-*p*-dioxins (PCDDs). Collectively, these compounds are referred to as planar chlorinated hydrocarbons (PCHs). However, their potencies are structure-dependent (position of the chlorine atoms) and may vary by many orders of magnitude (Walker and Peterson, 1991; Fischer *et al.*, 1998). Conceptually, the dechlorination process given sufficient time, could be considered a viable mechanism to achieve natural recovery. However, the degree of chlorine removal (magnitude) and the rate of chlorine removal (time) are germane to evaluating dechlorination and MNR as a potential remedial alternative.

Most studies of PCB-contaminated sites demonstrate that a threshold PCB concentration must exist before anaerobic dechlorination can occur (discussed in Appendix F). The threshold PCB concentration level is site-specific. At different sites, thresholds have been shown to range between 10 and 50 mg/kg. Dechlorination does occur under anaerobic conditions in nature, but only minor (10 percent or lower) reductions in total PCB concentrations are ever achieved. Little or no reductions from natural anaerobic biodegradation occurs at PCB levels below 30 ppm PCBs. Aerobic degradation of the lower chlorinated PCB congeners has been documented in controlled laboratory studies, but is poorly documented under field conditions. Aerobic degradation is not effective for highly chlorinated PCB congeners.

In the Lower Fox River, natural degradation processes have been observed (McLaughlin, 1994). The threshold concentration PCB concentration level for dechlorinating activity in the Lower Fox River is approximately 30 mg/kg (McLaughlin, 1994). For sediment deposits in the Lower Fox River with average concentrations greater than 30 mg/kg, a 10 percent reduction in PCB mass was estimated due to anaerobic processes (McLaughlin, 1994). No PCB reductions due to anaerobic process for sediments with average PCB concentrations less than 30 mg/kg can be accounted for in the Lower Fox River sediments. No aerobic PCB degradation has been documented in the Lower Fox River or Green Bay (Appendix F).

The observed degradations were attributed mostly to desorptive losses to the water column taking place during sediment transport downstream, rather than aerobic biodegradation (McLaughlin, 1994). Some anaerobic dechlorination has occurred in many deposits along with physical/chemical weathering. The differences in congener distribution between the Lower Fox River and Green Bay sediments have been attributed to chemical and physical processes such as diffusion, solubilization, and resuspension, rather than biological processes such as aerobic degradation or anaerobic dechlorination.

Thus, natural biodegradation can not be relied upon to substantively reduce PCB concentrations over time. The dechlorination of PCBs by anaerobic bacteria is not synonymous with detoxification, as congeners having more carcinogenic activity can be formed through dechlorination (Brown and Wagner, 1990). While PCB dechlorination could contribute to an overall MNR alternative for the Fox River or Green Bay, the actual mass reductions or rates cannot be reliably quantified.

**Sediment Transport and Burial.** Resuspension, transport, and burial of PCB-contaminated sediments are recurring mechanisms that are well documented in the Lower Fox River and Green Bay (WDNR, 1995, 1999a, 1999b, 1999c; Baird and Associates, 2000a; LimnoTech, 1999; BBL, 1999; Velleux *et al.*, 1995). Common methods for estimating the influence and extent of these processes in an aquatic environment include: estimating sedimentation rates through field-collected data, monitoring changes in bed elevations over time, monitoring surface sediment chemistry over time, monitoring surface water quality and sediment loads, and applying fate and transport models to predict sediment transport.

These mechanisms can support the natural recovery process by burial of PCB-contaminated sediments by deposition of cleaner sediments. Alternatively, PCBs in sediments can be resuspended and transported from the river into the bay, and from the bay into Lake Michigan. Burial and transport are functions of the hydraulic conditions in the system, and are reflected as scour or deposition zone. Sediment scour and deposition patterns were evaluated using primarily three lines of evidence including: 1) geochronological sediment dating from radioisotope core data (WDNR, 1995; BBL, 1999), 2) estimated scour depths from episodic storm events and model projections (Baird and Associates, 2000a), and 3) long-term changes in observed bed elevations (WDNR, 1999c). These parameters serve as important input variables to the complex fate and transport and bioaccumulation models used for the Lower Fox River (wLFRM) and Green Bay (GBTOX).

**Radioisotope Vertical Profiling.** Sediment fluxes and resuspension of sediments are important parameters regarding material transport and the potential for natural recovery processes over time. Gross sedimentation rate (net + resuspension) is determined by the flux of settling particulate material which settles through the water column and is deposited on the river bottom (often measured by sediment traps). Net sedimentation flux is determined by the amount of material that remains on the river bottom and is subsequently buried over time (measured by radiological dating of sediment cores). The difference between the gross and net sedimentation rates provides information on the rate at which bottom sediments are resuspended to the overlying water column by physical processes such as ice scour, water currents, or propeller wash from passing vessels where bottom sediments may be subject to transport downstream (advection) or resettling.

Changes in deposition or scour patterns within a deposit or reach are recorded in the sediment profile and can be quantified by measuring changes in levels of atmospherically-deposited radioactive isotopes (i.e., cesium-137 [Cs-137] or lead-210) known as fallout, over time. Anthropogenic inputs of Cs-137 into aquatic systems began in 1950 from atmospheric testing and radioactive releases of nuclear weapons. Peak cesium activity is generally dated at year 1963 with a second sub-peak at year 1959 (Robbins and Edgington, 1975). Cs-137 input levels declined after 1963 following the test ban between the United States and U.S.S.R. Cs-137 profiles (concentration, depth) provide a means of determining the age of a sediment layer. By examining the depth and shape of Cs-137 sediment peaks and correlating theses profiles to the source and time of Cs-137 releases to a system, the profiles can be used to determine if the sediments are being deposited and buried, or scoured and redeposited. Stable depositional zones have stratified cesium levels with discrete horizons preserved in the sediment core. Deposits that are continually disturbed and redeposited, are represented by relatively homogenous cesium levels (no observable peaks) that indicate physical vertical mixing or bioturbation is occurring. Post-depositional redistribution by physical mixing or biological processes can also account for the appearance of Cs137 at greater depths in the core than would be predicted from the inferred sedimentation rate alone (Robbins and Edgington, 1975).

Cs-137 profiles were collected as part of the 1989–1990 Green Bay Mass Balance Study to determine long-term depositional rates (Velleux and Endicott, 1994). In most of the collected cores, the measured cesium levels were consistent with the high resuspension and sediment scour events predicted in the Fox River transport models (WDNR, 1995, 2000b). Of the 24 cores collected upstream of the De Pere dam in 1989/1990, only four cores showed little evidence of sediment diffusion or mixing in the upper layers. Fifteen of the 24 cores were considered inadequate for chronology measurements because of excessive disturbance in the profile. Apparent depths of disturbance ranged from 4 cm down to 40 cm below mudline surface. Geochronological sediment cores were also collected in 1998 as part of the NRDA assessment. The long-term net sedimentation rates were calculated from two usable cores: 1.06 centimeters per year [cm/yr] above the De Pere dam and 1.11 cm/yr below the De Pere dam (BBL, 1999). These rates are consistent with the long-term sedimentation rates of 0.3 to 0.5 cm/yr estimated by USGS based on Cs-137 profiles (as reported in Fitzgerald *et al.*, 2001). The remaining cores were difficult to interpret with evidence of sudden increases in Cs-137 concentrations in surface sediments. These anomalies observed in the profiles are consistent with the 1989/1990 data and likely indicate disturbance events.

The dating method developed for the Great Lakes (Robbins and Edgington, 1975) assumed that the major source of cesium input is via direct deposition from the atmosphere and that watershed inputs of cesium are small. While this condition may be true for the Great Lakes, it is not necessarily true for the Lower Fox River. The radioactive decay process occurs at the same rate regardless of whether a particle with Cs-137 enters river sediments immediately after atmospheric fallout or whether the particle is deposited further upstream in the watershed and takes 20 years to reach the river sediments. As a result, Cs-137 can be a poor tool to "date" sediments because of its long half-life (30 years). However, Cs-137 is a useful tool for showing the vertical extent of sediment disturbance (i.e., resuspension) in the Lower Fox River and Green Bay (ranging from 4 to 40 cm below the sediment-water interface).

Beryllium-7 (Be-7) profiles were used as a tracer to determine short-term (monthly) deposition rates and to refine the predictions of sediment resuspension on a finer scale. Be-7 is produced by cosmic ray spallation of nitrogen and oxygen in the atmosphere and decays rapidly with a half-life of 53 days. In aqueous environments, beryllium strongly sorbs to suspended particles in much the same way as other isotopes and PCBs, and quickly settles to the river bottom. Be-7 was studied in two locations of the Lower Fox River during the summer and fall of 1988 (Fitzgerald *et al.*, 2001). Sediment cores were co-located with sediment trap, Cs-137 profile, and PCB profile data. Be-7 was present in the upper 6 cm, with minimal activity below 6 cm. The profiles predict quiescent periods of low deposition followed by episodic deposition/scour events. The estimated scour depth can be at least 6 cm based on these profiles. The short-term deposition rates recorded at these stations ranged from 0 to 65 cm/yr on a yearly basis (linearly projected from discrete sampling events). These rates are one to two orders of magnitude higher than the long-term predictions by Cs-137 methods. The ratio between the short-term and long-term sedimentation rates represents a measure of the non-steady-state sediment movement into or out of a river deposit over time. This ratio varies from minus 16 cm (erosional episode) to greater than 130 cm (depositional episode) and indicates the contribution of minor resuspension events to mass transport downstream and redeposition over time in these highly dynamic systems.

**Sediment Deposition and Scour Models.** As described in the Model Evaluation Work Plan (WDNR, 1997), the hydrodynamics and sediment transport of the river were examined as part of a series of technical reports located in the Model Documentation Report (WDNR *et al.*, 2001). Hydrodynamic models of the Lower Fox River were developed as part of Technical Memorandum 5c (HydroQual, 2000) and Technical Memorandum 5b (Baird and Associates, 2000a) to examine the structure of river currents. This information was used to estimate shear stresses in the wLFRM. Sediment transport models of the Lower Fox River were also developed as part of Technical Memorandum 5d (Baird and Associates, 2000b) and Technical Memorandum 5b (Baird and Associates, 2000a) to examine aspects of sediment transport. This information was used to help estimate the magnitude and temporal dynamics of settling and resuspension velocities in the wLFRM.

Key findings of the technical memoranda related to sediment deposition and scour are discussed below and state that for any given resuspension event, the particle resuspension flux can be described as a function of the shear stress at the sediment-water interface, which can in turn be approximated as a function of flow. It is generally accepted that flow velocities increase with increasing surface water discharges; and that as flow rates increase, the scour depth and quantity of suspended solids in the water column increase. During a simulated high 100-year flow event of 24,000 cfs (685 $m^3/s$, surface shear stress of 4 to 24 dynes per square centimeter) below the De Pere dam, the predicted bed elevation change varied from 1 to 5 cm depth in the Lower Fox River (Baird and Associates, 2000a). Differences in flow rates at more regular intervals (i.e., 2- and 5-year intervals) are relatively small because the multiple dams and reservoirs throughout the river tend to smooth out the peak flow events.

An additional dimension of the deposition/scour analysis is the spatial scale of the hydrodynamic models applied to the Lower Fox River and Green Bay. All of the models applied to the Fox River are fairly coarse-scale evaluations of average changes in bed elevation over large areas of the riverbed (50 acres). The extrapolation of these coarse-scale model results are likely underpredictive with respect to bed sediment mixing and off-site transport. Finer-scale bed changes within a given model unit that occur from smaller-scale bedform dynamics will not be resolved by the model and will therefore under-predict localized scour and contaminant redistribution. Although these modeled events predict a maximum erosion depth (i.e., elevation loss) per event, the technical memoranda summarize that higher erosional events may occur, shear stresses are likely higher than predicted, and that the models cannot predict the range and magnitude of bed elevation changes observed in USGS monitoring data (discussed below).

**Bed Elevation Changes.** The magnitude of bed elevation changes measured in the De Pere to Green Bay Reach of the Lower Fox River (WDNR, 1999c) were significantly higher than the model-predicted scour depths during short-term storm events. The elevation change for short-term cycles (sub-annual) in the De Pere to Green Bay Reach ranged between 28 and 36 cm for both losses and gains. The elevation change measured over many years (a 25-year period) ranged between a 45-cm increase (net deposition) and 100-cm decrease (net scour). A maximum point change in bed elevation of 200 cm has been observed over a 7-year period (WDNR, 1999c). Flow events and their ability to erode bottom sediments are dependent not only upon the measured stream flow velocities, but also upon the cross-sectional depth of water, lake levels, operation of dams during flood conditions, and wind conditions that produce seiche events near the mouth of the Fox River.

In summary, monitored natural recovery may be appropriate in quiescent areas with net sediment deposition and little erosion potential. In these areas, sediment burial with non-impacted sediments may be possible. Based on radioisotope profiles (Fitzgerald *et al.*, 2001), short-term episodic storm events can expect scouring up to 6-cm depths and greater. In river channel areas with increased stream flow velocities and shear stresses encountered during moderate storm events (a 100-year storm event is not required) resuspension and downstream transport of surface sediment is likely. Additionally, long-term trends in observed bed elevation changes show that significant resuspension and redeposition (up to 100 and 45 cm, respectively) can occur over a period of many years (observed for 25 years) with little spatial or temporal continuity. Finally, these observed trends are based upon the existing hydraulic conditions that are in large part governed by the system of dams on the river. Any MNR alternative considered for a river reach would implicitly require maintenance of the dams, or explicitly require consideration of the effects of dam removal.

**Time Trends Analysis.** PCB concentrations in sediments and fish tissue can be reliable measures of changing conditions since PCBs tend to persist in sediments and bioaccumulate in fish and other animals for long periods of time. The time trends analysis summarized in Section 2.6 presented evidence that concentrations of PCBs in fish tissue and surface sediments have generally declined following the elimination of PCB point source discharges. Statistically significant breakpoints in the decline for most of the fish species examined suggest that the decline has slowed down or, in some cases, that tissue concentrations of PCBs have actually increased.

Data on PCBs in surface sediment samples suggest that PCB concentrations have generally declined over time. Trends in concentrations of PCBs in subsurface sediments are mixed; some deposits show declining trends, while others show trends either close to zero or not significantly different from zero, and yet others show increasing trends. The time trends appear to be quite changeable and confidence intervals for rates are quite wide so that it is not possible to project PCB concentrations into the future for fish or sediment with much confidence.

The time trends analysis was a purely statistical exercise that offered no insight into the mechanism(s) responsible for declining sediment PCB concentrations. The primary attenuating mechanisms for PCBs in the Lower Fox River and Green Bay are sediment resuspension and transport, followed to a lesser degree by desorption and dispersion in the water column (Section 2.5). Biodegradation, resulting from the actions of naturally occurring aerobic and anaerobic microorganisms in the sediments, is believed to be a minor contributor to changes in PCB concentrations.

In summary, much of the Lower Fox River system undergoes both erosional and depositional events, with areas of net deposition, creating areas known as "sediment deposits." However, in net depositional areas where settling exceeds erosion, erosion can still occur. Locating areas of long-term net sediment deposition that are not susceptible to erosional scour events need to be addressed prior to implementing a monitored natural recovery alternative. Transport modeling and bathymetry results indicated that significant erosion is confined to mostly the deeper, mid-channel river sediments (during periods of high flow), while the nearshore sediments are not eroded (Velleux *et al.*, 1995). Both the Be-7 and the Cs-137 data suggest that there are some areas within the Lower Fox River that may be net depositional (i.e., over long periods gross deposition exceeds gross erosion), but that on the aggregate, most deposits are subject to scour and resuspension.

### Implementability

EPA has issued guidance for implementing MNR cleanup remedies at sites involving soil or groundwater contamination (EPA, 1999b). No specific guidance is available for implementing MNR remedies at sediment sites. However, EPA expects that similar natural attenuation considerations for upland sites also apply to sediments (EPA, 1998a).

MNR is an implementable remedy from a technical standpoint, as the means are available for monitoring environmental quality and modeling the rate of natural restoration. In high-energy environments, sediment scour and transport is likely to dominate sediment recovery processes, while in low-energy environments, bioturbation is likely to dominate contaminant movement in the upper layer of sediments. Physical processes such as net burial and isolation of impacted sediments is also likely to dominate the recovery process in low-energy environments. An MNR remedy would require long-term monitoring of Lower Fox River and Green Bay fish tissue, water quality, and sediment quality. This data could be used in conjunction with fate and transport models to determine the rate and extent of natural restoration actually occurring.

## Effectiveness

MNR alone would likely be insufficient to meet project RAOs in the short- or long-term in many portions of the river and bay. Natural recovery may be sufficient in localized nearshore quiescent areas with only minor contamination and accumulating sediments. In areas of the river and bay with higher levels of contaminants and higher potential for scour events, MNR may become an integral component of an active remedy involving some degree of containment or removal. For example, MNR may be effective at reducing residual COC concentrations to acceptable levels over an extended period once the more contaminated sediments are removed. Monitored natural recovery may be an appropriate remedial alternative when:

- Large volumes of contaminated sediment have marginal levels of contamination;
- The area is a low-energy, depositional environment;
- Dredging for navigational needs are not required;
- Site restrictions and institutional controls are acceptable;
- Review of existing data suggest that the system is naturally attenuating and will continue to do so within an acceptable time frame; and
- The cost for an active remedy disproportionately outweighs the risk reduction benefit.

Monitored natural recovery has been selected as the primary remedial alternative at two sediment sites in the United States: 1) James River in Hopewell, Virginia; and 2) the Sangamo Weston/Twelve Mile Creek/Lake Hartwell Superfund site in South Carolina (described in Appendix B). At the Sangamo Weston site, for example, the selected remedy focused on extensive source control of PCB-impacted sediments in Twelve Mile Creek, and monitoring the recovery of sediment and biota in the quiescent, depositional waters of Lake Hartwell over time. Annual monitoring since 1994 has shown measurable decreases in surface sediment concentrations of PCBs. Burial by clean sediment is thought to be the dominant recovery process with measurable contributions from periodic releases by upstream dams. Sediment accumulation rates in Lake Hartwell, estimated from 10 samples collected during 2000 by radioisotope profiling methods, ranged from 0.66 to 19 cm/year. The sediment cores also showed that the PCB congener composition became increasingly dominated by lower chlorinated congeners with sediment depth and corresponding age, resulting in a relative accumulation of ortho-chlorinated congeners and losses of meta- and para-chlorinated congeners. This preliminary evaluation suggests that partial dechlorination in deeper sediments and dissolution/volatilization in surface sediments may also be contributing to the PCB degradation mechanisms at the site. It is possible that a concentration of ortho-substituted congeners at a given site represents the lower limit to the extent of dechlorination achievable at that site (http://www.clu-in.org/Products/NEWSLTRS/TTREND/tt0301.htm). Other case studies regarding the observed extent of biological degradation processes are described in Appendix F.

## Costs

MNR is a generally a low-cost technology because no active sediment remediation occurs that involves containment, removal, or treatment. However, monitoring costs may be significant, extending into the millions of dollars, depending on the term and magnitude of the monitoring program.

Long-term monitoring costs vary widely depending upon the project expectations, media of concern, and residual risks. For the purposes of this FS, sampling costs for sediment, water, bird, fish, and invertebrate tissue are approximately $600,000 per sampling year (every fifth year), with a total present worth monitoring cost of $11.8 million over 40 years for each reach/zone (Appendix C). The *Long-term Monitoring Plan* (LTMP) located in Appendix C will likely be refined and finalized after the remedy has been selected. Elements of the LTMP may differ between locations with residual risk with areas meeting the most protective SQT criteria.

### Screening Decision

MNR is retained for use in developing remedial alternatives for the Lower Fox River and Green Bay (Table 6-4). As discussed above, MNR alone is unlikely to be an effective remedial approach in heavily-impacted areas of the site because of the anticipated time required to reach the project RAOs. In these areas where PCB concentrations exceed the apparent dechlorination threshold of 30 mg/kg described above, dechlorination of the PCB molecule is not a viable process. However, MNR alone may be a viable remedial alternative in areas where the PCB concentrations are moderate, impacted sediments are widely dispersed, and the inventory of PCB mass is relatively low due to historical natural dispersion or burial activities. Natural recovery processes are also critical components to the evaluation of cleanup alternatives over a range of cleanup action levels as described in Section 5.

## 6.4.4 Containment

*In-situ* capping is the containment and isolation of contaminated sediments by the placement of clean materials over the existing substrate. This alternative does not require removal of sediment; clean sediments are placed over old sediments as a barrier, isolating contaminants within the substrate. Capping of subaqueous contaminated sediments has become an accepted engineering option for managing dredged materials of *in-situ* remediation (NRC, 1997; EPA, 1991, 1994a; Palermo *et al.*, 1998). There are multiple references that discuss physical considerations, design, and monitoring requirements for capping. The following references were used in this FS Report to assess the applicability of containment technologies:

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990);

- *Design Requirements for Capping* (Palermo, 1991);

- *Guidance for In Situ Subaqueous Capping of Contaminated Sediments* (Palermo *et al.*, 1998);

- *Placement Techniques for Capping Contaminated Sediments* (Palermo, 1994);

- *Washington State Department of Ecology 1990 Standards for Confined Disposal of Contaminated Sediments Development Document* (Ecology, 1990);

- *Equipment and Placement Techniques for Capping* (USACE, 1991);

- *Monitoring Considerations for Capping* (USACE, 1992);

- *Subaqueous Capping of Contaminated Sediments: Annotated Bibliography* (Zeeman, *et al.*, 1992); and

- *Design Considerations for Capping/Armoring of Contaminated Sediments In-Place* (Maynord and Oswalt, 1993a).

The last two references describe capping design and structural considerations for capping in a riverine environment in the Great Lakes.

## Description of Containment Process Options

Caps may be grouped into three general categories: conventional sand, armored, and composite. Conventional capping includes sand and clay caps. Other miscellaneous capping techniques include thin-layer capping and enhanced capping.

**Conventional Capping.** Conventional caps involve the placement of sand or other suitable cover material (i.e., clay) over the top of contaminated sediments. Material selection and cap thickness are determined based on consideration of contaminant properties and local hydraulic conditions. Sandy soils and sediments are typically preferred as cap materials over fine-grained materials. The latter are more difficult to place evenly, cause a great deal of turbidity during placement, and are more erosive. A cap thickness of 30 to 50 cm is considered sufficient to chemically isolate PCBs and metals (Palermo, 1994).

Capping operations can disturb and displace loose fine-grained bottom sediment, resulting in resuspension losses and mixing of contaminants into the clean capping layer. Physical characteristics, such as solids content, plasticity, shear strength, consolidation, and grain size distribution affect the displacement of sediment. The sediment characteristics will often form the basis for determining the suitability of capping materials and placement options (Palermo, 1991).

A variety of methods are available for constructing conventional caps in riverine environments:

- Hydraulic pipeline delivery of a sand slurry through a floating spreader box or submerged diffuser;

- Physical dispersion of barged capping materials by dozing, clamming, or washing of material that settles through the water column;

- Distribution by controlled discharge from hopper barges;

- Mechanically-fed tremie to the river bottom; and

- High-pressure spraying of a hydraulic sediment-water slurry across the water surface.

The method used to place the cap material must be capable of achieving even placement of material over the target area while limiting the resuspension and loss of contaminated sediment into the water column or the emerging cap layer. Even placement and limited resuspension of contaminated sediment are generally achieved when the capping materials are dispersed and allowed to settle through the water column. The dumping of large, dense masses of capping material (e.g., pushing sands off a barge) or methods that lead to density-driven hydraulic flow should be avoided.

A summary of conventional capping projects in North America is provided in Appendix D.

**Armored Capping.** Armored caps are similar to conventional caps with the exception that the primary capping material (e.g., sand) is covered with stone or other suitable riprap (the armor) to add physical stability in erosive environments. Armored caps are commonly used in environments where high water velocities (i.e., flood flow, propeller wash) threaten the cap integrity. Examples of armored caps from Sheboygan Falls, Wisconsin and Manistique Harbor, Michigan are illustrated on Figure 6-1. However, the Manistique cap was never implemented and is solely based upon preliminary design drawings.

The conventional portion of the cap is placed using one of the previously described methods. Armoring materials (quarried rock or concrete riprap) are then barged to the site and placed using conventional equipment (excavators, cranes). Methods for determining the appropriate armor stone grade and thickness can be found in the *Assessment and Remediation of Contaminated Sediments (ARCS) Sediment Capping Study Final Report* (Maynord and Oswalt, 1993b).

**Composite Capping.** A composite cap generally involves placement of a geotextile or flexible membrane liner directly over the contaminated sediments. Permeable or impermeable liners may be considered, depending upon the migration potential of the chemical(s) of concern, and the potential for methane buildup under the liner in highly organic sediments. The liner is then armored with stone or riprap to ensure the physical integrity of the cap. Composite caps may also include a sand or activated carbon layer to capture any potential diffusive or advective migration of the underlying contaminants. For non-mobile contaminants, such as PCBs, the composite cap would likely only require a liner and armoring. A composite cap was placed at the Manistique River/Harbor site as a temporary containment measure (Figure 6-1).

**Miscellaneous Capping Techniques.** Additional capping approaches, besides those described above, have received attention in the capping literature including thin-layer capping, Aquiblock™, and Claymax™. Thin-layer capping involves the placement of a thin (1- to 3-inch) layer of clean sediments, that is subsequently mixed with the underlying contaminated sediments, to achieve acceptable COC concentrations and/or enhance the natural attenuation process. Mixing occurs naturally as a result of benthic organism activity (bioturbation). This approach is best suited to situations involving contaminants that naturally attenuate over time. However, PCBs do not naturally attenuate to any significant degree and, therefore, thin-layer capping would simply dilute surface sediment PCBs. Thin-layer capping would simply increase the volume of contaminated material albeit at reduced average concentrations. Aquiblock™ technology was used on the Ottawa River, Ohio as a pilot test, and Claymax™ technology was used on floodplain soils for Hudson River sediments.

Enhanced capping involves the incorporation of materials such as activated carbon, iron filings, imbiber beads, or other agents into the base capping material (e.g., sand) to enhance adsorption or *in-situ* chemical reaction. This approach is intended for circumstances in which contaminants are mobile and are expected to migrate through the cap as dissolved constituents in the pore water. These conditions do not exist at the site as PCBs are highly adsorbed to sediments and have a very low potential for migrating in sediment pore water.

## Screening Criteria for Cap Selection

The criteria used for selection of a capping alternative are: presence of sediments with PCB concentrations of 50 ppm or greater (referred to as TSCA-level sediments, where the TSCA level is 50 ppm), site bathymetry, and current speed (median and 100-year flood). The latter two criteria are based upon general design guidance that caps should only be placed in a low-energy environment with little potential for erosion or disturbance of the cap (Palermo *et al.*, 1998).

- **Contaminant Concentration.** *Capping is not considered for sediments where total PCB concentrations exceed the 50 ppm TSCA level, unless the alternative involves removal of all TSCA-level material prior to capping.* Areas with sediment PCB concentrations exceeding the TSCA level of 50 ppm are unlikely to receive regulatory approval for capping. EPA has determined that capping of PCB-contaminated sediments is an action to contain and confine PCBs, though concentrations of 50 ppm or greater may not be approved by EPA (EPA Region 5 letter dated July 15, 1994, provided in Appendix E).

- **Site Bathymetry.** *The final constructed water depth shall be no less than 3 feet*. Site-specific water depth must be considered in selecting a cap as an option. To maintain physical integrity, the cap surface must be sufficiently below the water surface to minimize the potential for ice damage, ice flow scour, wind-induced currents or waves, and vessel draft. Commercial and recreational boating use of an area must also be considered to ensure both adequate draft clearance, as well as the potential damage from anchors or propeller wash. Since the maximum vessel draft, depth of ice scour, and propeller wash depth for recreational boats operating along the Fox River is approximately 2 feet, a minimum water depth of 3 feet should be maintained.

- **Currents.** *Capping is considered an alternative for a given river reach where the average current speed is less than 0.15 feet/second (ft/s), and the maximum (100-year flood) current speed is no greater than 0.7 ft/s.* Currents are important to consider because of their potential to cause scour and physical erosion of the cap. Consideration of currents should include both normal flow, flood events, and dramatic water fluctuation that may result from dam failure or dam drawdown. For a conventional sand cap, the site conditions should generally be non-dispersive in a relatively low-energy environment with low bottom current velocity. In addition, commercial boat-induced currents (propeller wash) should be considered. In the Lower Fox River, flood-flow velocities in the central river channels are expected to be the dominant potential erosional force within the Little Lake Butte des Morts Reach and the Little Rapids to De Pere Reach. Below the De Pere dam, navigation-induced water movement from the wake of a large boat or propeller wash should be considered in any potential capping scenario. Detailed evaluation methods for quantifying erosional potential are given in Palermo *et al.* (1998).

Additional guidance that is applied in this FS concerning the placement of a cap in the Lower Fox River includes the following:

- **Navigation Channels.** Capping is not selected as an alternative within the designated federal navigation channel below the De Pere dam, since periodic maintenance dredging may be required to support vessel draft of large commercial traffic (commercial vessels are limited to below the De Pere dam). While a constructed water depth of greater than 25 feet is sufficient clearance for most vessels, cap placement within the channel would require substantial armoring to protect against erosion by propeller wash, and would result in permanent deed restrictions prohibiting maintenance dredging and/or navigational improvements. In addition, any changes to the navigational channels would require congressional authorization to modify the federally-authorized depth of the navigation channel, assuming a cap placement would limit maintenance to the designated depth.

- **Bottom Sediment Characteristics.** As discussed earlier in this section, specific sediment characteristics will often form the basis for determining the suitability of capping materials and placement options.

- **Capping Materials.** For thin-layer capping, use of clean uniform granular materials (sands, fine gravels) enhances reliable application of the design layer thickness. Clumpy materials (cohesive silts/clays) and/or variable size gravels are more difficult to place evenly, and may only be placed by mechanical means.

- **Placement Method.** Both mechanical and hydraulic methods have been used for cap placement. Mechanical placement of capping material allows for greater placement accuracy while minimizing downstream turbidity. Restrictions to the mechanical application of capping material are related to the draft depths of the material barges, which are generally 8 to 10 feet. Hydraulic placement is not restricted by water depth, and has the advantage of minimizing the resuspension of contaminated sediment losses described above. Conversely, the placement activity itself will result in a temporary increase in downstream suspended solids due to the cap material.

- **Impact to Riverine Habitat and Future Use.** The impact to riverine habitat and long-term use of the site must be considered in selection of a capping option. Creation of a cap will result in change of the site depth, which can significantly change the quality of the aquatic habitat. Conventional, armored, or composite caps result in significant change in substrate type, which can influence the functioning of the benthic community and food chain interactions.

- **Institutional Notifications/Monitoring.** All capping options result in permanent restrictions to future site use, as well as long-term monitoring and maintenance of the cap.

## Implementability

Conventional sand caps and armored sand caps have been successfully placed over contaminated sediments in many in-water lakes (Soda Lake, Wyoming; Hamilton Harbour, Canada) and marine environments (Minamata Bay, Japan; New York Mud Dump; Eagle Harbor, Washington) (Palermo *et al.*, 1998). Other Puget Sound projects that have involved in-place capping of contaminated sediments included Simpson Tacoma Kraft (Commencement Bay), Denny Way (Elliott Bay), and Seattle Ferry Terminal (Elliott Bay). A few caps have been placed in riverine environments, but the number of projects is relatively few (Duwamish River, Washington) when compared to other systems. See Appendix D for a list of capping projects placed over contaminated sediments (metals, PAHs, PCBs). Average cap thickness has ranged from 1 to 5 feet thick and post-cap sediment cores show effective isolation of underlying material in most cases. Geosynthetic liner caps were used at the Minamata Bay, Japan, and Soer Fjord, Norway sites.

Placement of capping material can be accomplished by open-water surface discharge using a split-bottom hopper barge or subsurface discharge using a tremie pipe for more accurate placement. The site considerations listed above (i.e., bathymetry, surface water flow, substrate type) are all important design requirements for successful placement of a containment cap. Long-term chemical stability, erosion, and consolidation potentials should also be examined prior to placement.

*In-situ* sand capping may not be feasible if the bottom sediment is extremely soft where the sediment cannot support a cap, or if water flow conditions would impede accurate placement of sand material.

## Effectiveness

Capping is meant to isolate contaminants from the overlying water column and prevents direct contact with aquatic biota. In addition, capping provides new clean substrate for recolonization by benthic organisms. Capping is considered very effective for low-solubility and highly sorbed contaminants, like PCBs, where the principal transport mechanism is sediment resuspension and deposition. Cap designs must preclude the potential for sediment resuspension under normal and extreme (storm) conditions.

The impact to riverine habitat and long-term use of the site must be considered in selection of a capping option. Impacts include changes to the site depth, navigational and recreational uses, substrate type, and benthic community and food chain interactions. Creation of a cap will result in permanent restrictions and site access limitations in order to ensure adequate protection.

Conventional and armored caps may be effective for containing PCBs and mercury. Use of geotextiles (composite cap) may be an effective substitute for sand or clean sediment, but would likely require some form of armoring. Enhancing the cap medium with carbon or some other reactive agent is not necessary to prevent chemical migration of PCBs and mercury.

### Capping Costs

Costs for capping are moderate with respect to more intensive approaches involving removal, treatment, or disposal. Total cap costs typically range from $30 to $50 per square meter ($300,000 to $500,000 per hectare), depending on cap construction and placement technique (EPA, 1994a).

### Screening Decision

Capping is considered both implementable and effective for containing impacted sediments in portions of the Lower Fox River and Green Bay. The technology is retained for use in development of remedial alternatives in Section 7. Of the various process options, conventional, armored, and composite cap designs are best suited for consideration. Specific cap materials, thicknesses, and other design parameters are selected based on site-specific conditions and design criteria. Armored caps will be retained as the representative process option for in-place containment actions.

## 6.4.5 Removal

Removal refers to excavation or dredging of sediments. The discussion of removal process options herein integrates site knowledge, practical dredging experience, dredging sediment case studies, and demonstrated successful application under similar conditions found throughout the Lower Fox River. Wherever possible, Great Lakes practical experience was utilized to assess the applicability of a specific removal technology. Pilot demonstration dredging projects at Deposit N (in the Appleton to Little Rapids Reach) and SMU 56/57 (in the De Pere to Green Bay Reach) provide site-specific information on the implementability and effectiveness of dredging in the Lower Fox River.

The usefulness of dredging as a viable remedial technology is described, in depth, in the *Sediment Technologies Memorandum* located in Appendix B. This review paper provides a detailed review and summary of many large-scale environmental dredging projects. The major findings of this review and results from the two Lower Fox River demonstration projects (detailed in Appendix B) were used to assess the viability of dredging as a remedial technology. A few guidance documents also provided practical implementation information for sediment remediation projects in the Great Lakes region:

- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA, 1994a);

- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990);

- *Innovations in Dredging Technology: Equipment, Operations, and Management*, USACE DOER Program (McLellan and Hopman, 2000);

- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars *et al.*, 1995); and

- *Guidance for Subaqueous Dredged Material Capping*, USACE (Palermo *et al.*, 1998).

## Description of Removal Process Options

For the purposes of this FS, dredging is defined as the removal of sediment in the presence of overlying water (utilizing mechanical or hydraulic removal techniques). Wet excavation is defined as the in-water removal of sediment using typical earth moving equipment such as excavators and backhoes. Dry excavation is defined as the berming or rerouting of overlying water to create dewatered conditions accessible by upland earth moving equipment. Three categories of removal technologies are commonly considered for sediment removal in "wet" conditions with overlying water:

- Mechanical dredging,
- Excavators, and
- Hydraulic dredging.

All three of these technologies were retained for consideration during the development of remedial alternatives and are described in more detail below.

**Mechanical Dredging.** A mechanical dredge consists of a suspended or manipulated bucket that "bites" the sediment and raises it to the surface (Figure 6-2). The sediment is deposited on a haul barge, as illustrated on Figure 6-3, or other vessel for transport to disposal sites. A mechanical dredge and haul operation is currently used for routine maintenance dredging of the federal navigational channel in the Lower Fox River and Green Bay.

Under suitable conditions, mechanical dredges are capable of removing sediment at near *in-situ* densities, with almost no additional water entrainment in the dredged mass and little free water in the filled bucket. A low water content is important if dewatering is required for ultimate sediment treatment or upland disposal.

Clamshell buckets (open and closed), dragline buckets, dipper dredges, and bucket ladder dredges are all examples of mechanical dredges. Dragline, dipper, and bucket ladder dredges are open-mouthed conveyances and are generally considered unsuitable where sediment resuspension must be minimized to limit the spread of sediment contaminants (EPA, 1994a). Consequently, dragline, dipper, and bucket ladder techniques are not considered further in this FS Report.

The clamshell bucket dredge, or grab-dredge, is widely used in the United States and throughout the world. It typically consists of a barge-mounted floating crane maneuvering a cable-suspended dredging bucket. The crane barge is held in place for stable accurate digging by deployable vertical spuds imbedded into the sediment. The operator lowers the clamshell bucket to the bottom, allowing it to sink into the sediment on contact. The bucket is closed, then lifted through the water column to the surface, swung to the side, and emptied into a waiting haul barge. When loaded, the haul barge is moved to shore where a second clamshell unloads the barge for re-handling and/or transport to treatment or disposal facilities. Clamshell dredges can work in depths over 100 feet, and using advanced positioning equipment (e.g., differential global positioning systems [DGPS]), dredging accuracy is on the order of ± 1 foot horizontally and ± 0.5 foot vertically. Clamshell buckets are designated by their digging capacity when full and range in size from less than 1 cy to more than 50 cy.

A conventional clamshell bucket may not be appropriate for removal of contaminated sediments from some areas of the Lower Fox River. Conventional buckets have a rounded cut that leaves a somewhat cratered sediment surface on the bottom. This irregular bottom surface results in the need to over-dredge to achieve a minimum depth of cut, and can also encourage dense resuspended sediment losses to settle in the craters. Furthermore, the conventional open clamshell bucket is prone to sediment losses over the top during retrieval. Recent innovations in bucket design have reduced the spill and sediment resuspension potential by enclosing the bucket top (Figure 6-2). Also, buckets can be fitted with tongue-in-groove rubber seals to limit sediment losses through the bottom and sides.

A recent alternative bucket demonstrated in several tests and prototype sediment remediation projects is the proprietary Cable Arm® bucket (Figure 6-2). This bucket offers the advantages of a large footprint, a level cut, the capability to remove even layers of sediment, and under careful operating conditions, reduce resuspension losses to the water column as shown on Figure 6-3. The Cable Arm®

bucket has been successfully demonstrated for contaminated sediment removal at a number of sites in the Great Lakes (Cleland, 1997; SEDTEC, 1997), and was used in a removal action in the summer of 1997 at a creosote-contaminated site in Thunder Bay, Ontario.

Production rates for clamshell dredging are highly project-specific. For navigation dredging, a 5-cy bucket might deliver more than 200 cubic yards per hour (cy/hr). This same bucket might only produce 20 to 30 cy/hr in controlled sediment remediation work so as to achieve a thorough removal, limit resuspension, minimize water content, comply with water quality constraints, and limit over-dredging. The presence of large debris requiring separation and re-handling will also slow dredging progress.

**Excavators.** This is a subset of mechanical dredges which includes barge-mounted backhoe and/or excavators, both of which have limited reach capability. Excavators can also be used for dry excavation where the overlying water is removed. Special closing buckets are available to reduce sediment losses and entrained water during excavation. Use of conventional excavating equipment is generally restricted to removal of contaminated sediment and debris in shallow water environments or dry excavations (areas that are bermed, then dewatered for access by land-based equipment). Dewatering of an area for dry dredging involves hydraulic isolation/removal of surface water using: 1) earthen dams, 2) sheet piling, or 3) rerouting the water body using dams. Although normally land-based, excavators can be positioned on floating equipment (e.g., spud-barge) for dredging in shallow environments.

A conventional excavator bucket is open at the top which may contribute to sediment resuspension and loss during dredging, although careful operation can minimize losses. Various improved excavating buckets have been developed which essentially enclose the dredged materials within the bucket prior to lifting through the water column. A special enclosed digging bucket was successfully used on the large excavator “Bonacavor” (C. F. Bean Corp.) for remediation of highly contaminated sediment in Slidell, Louisiana (NRC, 1997). Dredged material removed by backhoe exhibits much the same characteristics as for clamshell dredging, including near *in-situ* densities and limited free water.

**Hydraulic Dredges.** Hydraulic dredges remove and transport dredged materials as a pumped sediment-water slurry. The sediment is dislodged by mechanical agitation, cutterhead, augers, or by high-pressure water or air jets (Figure 6-4). In very soft sediment, it may be possible to remove surface sediment by straight suction and/or by forcing the intake into the sediment without dislodgement. The loosened slurry is essentially then “vacuumed” into the intake pipe by the dredge pump and transported over long distances through the dredge discharge pipeline. Figure 6-5 provides an illustration of a hydraulic dredge with a pipeline to an upland gravity dewatering cell, and Figure 6-6 shows a conceptual layout of a gravity dewatering cell.

Common hydraulic dredges include the conventional round cutterhead, horizontal auger cutterhead, open suction, dust pan, and hopper dredges. The conventional cutterhead and horizontal auger dredges are illustrated on Figure 6-4. Specialty hydraulic dredges are available that limit resuspension losses at the dredge head and increase the solids content of the dredged slurry. These latter include the auger-, cleanup-, and refresher-type dredges. Hydraulic dredges are rated by discharge pipe diameter, and those available in the Great Lakes range from smaller portable machines in the 6- to 16-inch category, to large 24- to 30-inch dredges. The most suitable and available hydraulic dredges for the Lower Fox River project are the open suction, cutterhead, and auger types. These are discussed below.

Suction dredges are open-ended hydraulic pipes that are limited to dredging soft, free-flowing, and unconsolidated material. As suction dredges are not equipped with any kind of cutting devices, they produce very little resuspension of solids during dredging. However, the presence of trash, logs, or other debris in the dredged material will clog the suction and greatly reduce the effectiveness of the dredge (Averett *et al.*, 1990).

The hydraulic pipeline cutterhead suction dredge is commonly used, with approximately 300 operating nationwide. The cutterhead is considered efficient and versatile (Averett *et al.*, 1990). It is similar to the open suction dredge, but is equipped with a rotating cutter surrounding the intake of the suction pipe. The combination of mechanical cutting action and hydraulic suction allows the dredge to work effectively in a wide range of sediment environments. Resuspension of sediments during cutterhead excavation is strongly dependent on operational parameters such as thickness of cut, rate of swing, and cutter rotation rate. Proper balance of operational parameters can result in suspended sediment concentrations as low as 10 mg/L in the vicinity of the cutterhead. More commonly, cutterheads produce suspended solids in the 50 to 150 mg/L range.

The horizontal auger dredge is a relatively small portable hydraulic dredge designed for projects where a small (50 to 120 cy/hr) discharge rate is desired. In contrast to a cutterhead, the auger dredge is equipped with horizontal cutter knives and a spiral auger that cuts the material and moves it laterally toward the center of the auger, where it is picked up by the suction. There are more than 500 horizontal auger dredges in operation. A specialized horizontal auger dredge has been used at the Manistique Harbor Superfund site.

The Toyo pump is a proprietary electrically-driven compact submerged pump assembly that is maneuvered into position using a derrick barge. This pump is capable of high solids production in uncohesive sediment and can be equipped with a rotating cutter or jet-ring to loosen sediment. This is a lower head pump that typically discharges through 6- to 12-inch-diameter pipes and may require a booster pump for long pipeline distances. Typically, slurry discharges are at a density of approximately one-third the *in-situ* density.

The Pneuma® pump is a proprietary pump developed in Italy that uses compressed air and vacuum system to dislodge sediments through a pipeline. It may be suspended from a crane or barge and generally operates like a cutterhead dredge. It was used at the Collingwood, Ontario demonstration dredging project (EPA, 1994a).

An important consideration in hydraulic dredging is the quantity of water needing treatment after dewatering from the dredge slurry. The greater the solids content of the dredge slurry, the better the relative removal efficiency and the less water needing treatment. Typical solids content (wet) for dredge slurry ranges between 5 and 8 percent w/w, but can be less than 5 percent. For the Lower Fox River demonstration projects, the average percent solids was 5 percent w/w with a maximum solids content of about 12 percent w/w. Factors influencing the solids content include dredge type, nature of sediment, condition of equipment, and operator skill and experience.

## Screening Criteria for Dredging

Selection of appropriate dredging technologies and their potential effectiveness is dependent upon more than one variable. It is a formulaic effort considering multiple variables ranging from water depth to disposal sites. Significant operating parameters and constraints considered in selecting and applying the appropriate dredging equipment for the Lower Fox River and Green Bay include:

- **Operating Depths.** *Consider hydraulic dredging in areas with shallow water depths less than 8 feet.* Hydraulic dredging is selected for alternatives in areas where the depth of water is less than 8 feet. Small hydraulic dredges have been successfully utilized in river depths as shallow as 3 feet, whereas mechanical dredges are typically limited to minimum water depths of 8 to 10 feet, principally by the draw of the transport barges required to move the dredged materials to shore. Where water depths are greater than 8 feet, both hydraulic and mechanical dredging options are considered. The method carried forward in the FS depends upon sediment removal volumes (i.e., small hotspot removals of TSCA sediments), upland space capacity for dewatering, and disposal. In shallow areas, dry excavation may be considered.

- **Removal Efficiency.** Efficiency is the capability for removing the target contaminated sediment layer in a single (or minimum number of) pass(es) with the dredge equipment, while minimizing the quantity of over-dredged material to be treated and disposed. Where bedrock underlies contaminated sediments, removal by "over-dredging" to achieve low residual concentrations may be difficult or costly.

- **Contaminant Resuspension.** A major consideration is the capability for removing targeted sediments with minimum amount of sediment resuspension and loss during dredging.

- **Water Management.** Another selection criteria is practicality of managing large volumes of water associated with dredged material that will require collection and treatment prior to discharge of return flow to the river. This ranges from moderate amounts of free water and drainage arising from mechanically-dredged sediment to significant continuous volumes associated with return flow from a hydraulic dredge. Mechanical dredging and dry excavation produce smaller volumes of free water requiring treatment than hydraulic removal methods.

- **Equipment Availability.** Availability of dredging equipment is an important consideration. A number of floating clamshell dredges and small hydraulic dredges are available in the Great Lakes for use at the project site; however, the large quantity of PCB-impacted sediments located in the Lower Fox River and Green Bay may preclude equipment availability for long periods. Large construction backhoes and equipment barges are also available. However, many of the specialty dredges identified in the literature (e.g., pneumatic, refreshers, cleanup, matchbox dredges) are not available locally and/or would require fabrication of new dredging equipment and a period of operating experience.

- **Seasonal Restrictions.** *In-water work will occur within the months of April through October (an approximate 26-week time period).* A significant project constraint is the limited allowable work period for in-water construction activities. Freezing weather in winter will generally limit dredging to the months of April to October. In-water work near residential areas will be restricted to 10-hour work periods in order to minimize disturbance to the residents depending upon the nature of the work. For the purposes of the FS, all costs will be based on a 10-hour in-water work shift. The goal is to complete remediation activities within 10 years after initiation. The combination of sediment removal volume, sizing of pumps and equipment, dewatering facilities, and equipment type will influence the ability to meet the 10-year goal.

- **Work Sequencing.** Sediment removal will generally proceed from upstream to downstream in order to minimize the potential for recontamination of remediated downstream areas due to resuspension from upstream removal activities.

- **Access and Disposal.** Dredging can be limited by the ability to transport, dewater, and dispose of excavated material. A significant limiting constraint for dredging is the availability of on-land real estate for staging and support activities, as well as disposal options. The final destination of the excavated material will influence the type of dredging equipment selected. For example, if a nearshore CDF is considered, then hydraulic dredging and pumping directly into the CDF may be the best option.

- **The Lower Fox River Demonstration Projects.** Results of the Lower Fox River environmental dredging projects are essential considerations. The final selected remedy for a large-scale remediation effort will heavily depend upon the effectiveness of selected dredging equipment, containment systems, and dewatering operations of the pilot projects.

### Implementability

Many regulatory and private interest groups are searching for answers to the same questions of how to cost-effectively manage contaminated sediments while ensuring protection of human health and the environment over the long term (Peterson *et al.*, 1999; Krantzberg *et al.*, 1999; Zarull *et al.*, 1999; SMWG, 1999; SPAC, 1997; Lower Fox River Group, 1998, 1999). Dredging is a common, well-developed technology that can be implemented in the Lower Fox River and Green Bay. Dredging is an effective technology utilized on numerous sites around the world for removing contaminated sediments.

Additionally, results of the Lower Fox River pilot projects demonstrate that dredging techniques can successfully remove a large mass of PCB-impacted sediments as well as achieve reductions in PCB sediment concentrations. Recent advances in dredge head construction and positioning technology enable accurate removal of sediment layers with minimum incidental over-dredging. However, concerns for sediment resuspension, surface recontamination, and downstream transport of impacted-sediments are commonly cited by dredging opponents as short-term limitations of the technology as a viable remedial alternative.

Results of the sediment technology review memo (Appendix B) indicate that dredging can be an implementable and effective method for managing contaminated sediments, provided that the technology is designed and managed appropriately for the site conditions. Expectations and project goals will also influence the perceived success of dredging projects along with a well-designed monitoring plan able to verify achievement of the intended goals. A few of the key concerns and findings are discussed below and detailed in Appendix B.

**Sediment Resuspension.** All removal technologies increase, to varying degrees, suspended solid concentrations in the surrounding waters. This resuspension may adversely impact localized water quality or result in spreading contaminated solids to clean sediment surfaces. Sediment resuspension can be managed by a combination of equipment selection and operational controls, including selection of an appropriate dredge type that best matches site conditions. Operator proficiency in placing and moving the dredge head, reduced dredging rates, and use of silt curtains can be important factors in limiting resuspension and spread of contaminated sediments. Field experience has shown that sediment resuspension by hydraulic dredges can be minimized by careful operation of the dredge (USACE, 1990). This involves controlling the speed of cutterhead rotation, the swing speed, the rate of dredge advance, and depth of cut. Recommendations for minimizing sediment resuspension at the dredge head include maintaining a slow to moderate cutter rotational speed at 15 to 20 revolutions per minute (rpm), a slow swing speed of 0.3 to 0.5 ft/s, and limiting the minimum cut depth to the range of 50 to 100 percent of the suction pipe diameter.

The cutterhead dredge was evaluated for removing contaminated sediment during the New Bedford Harbor Superfund Pilot Study. Compared to two other suction types, the cutterhead was superior for minimizing sediment resuspension (USACE, 1990). Round and horizontal auger cutterhead dredges was also used for removal of Deposit N and SMU 56/57 sediments, respectively.

**Silt Curtains.** Water quality impacts from sediment resuspension at the dredge may be reduced by conducting the dredging within a silt curtain, silt screen, or sheet pile enclosure in order to contain migration of the suspended solids/turbidity plume. A silt curtain is generally constructed of impermeable fabric and is suspended from the surface to the river bottom where it is anchored. A silt curtain can extend completely to the bottom with appropriate fringe weights and anchors.

Gravity settling of the denser sediment plume and loose re-settled solids will seek the lowest point, resulting in some migration beneath the silt curtain. Experience elsewhere indicates that a more than 90 percent reduction in suspended concentrations across the silt curtain can be achieved under favorable conditions. Silt curtains are not effective in current speeds above approximately 0.5 ft/s or in high winds or waves (EPA, 1994a).

In comparison, a silt screen is constructed of permeable fabric designed to pass water, but not the fine-grained resuspended sediment. Either the silt curtain or screen must be placed, managed, and removed with care to avoid resuspension and release of contaminated sediment during operations. Silt curtains and screen placement and operation may be a source of resuspension of bed sediment due to dragging or alteration of local currents. The need for and benefit of containment systems during dredging must be weighed against the utility of and potential disadvantages of these systems.

Maintaining a stable geotextile silt curtain was difficult in soft sediments at the Lower Fox River SMU 56/57 project in 1999. Passing boat traffic disrupted the integrity of the silt curtain, requiring immediate repair during the demonstration project. In 2000, the SMU 56/57 project successfully used silt curtains with sheet pile anchors to provide stability for the dredge. An 80-mil HDPE containment barrier was used at the Lower Fox River Deposit N demonstration project and successfully maintained for the duration of the project.

**Surface Recontamination.** Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), 19 projects had lower maximum post-dredge surface concentrations than maximum pre-dredge conditions. The average percent reduction in maximum detected surface concentration was 84 percent (percent reduction in area average was 97 percent). For a few projects, it is fair to mention that the maximum concentration measured in residual sediments were occasionally higher than the target criteria; however, the majority of subunits measured, on average, were below the chemical criteria.

Surface concentrations should not be the sole measure of dredging success and risk reduction. The percent of surface area coverage with elevated surface concentrations above protective levels would be a more accurate measure of residual risk. For example, the Deposit N project in Wisconsin and GM Foundry project located in New York, collected confirmation samples from the cracks and crevices between the bedrock or bedrock itself because of insufficient sediment volume remaining above the bedrock (in some areas). These values likely biased the “true condition” of residual contaminant distribution among surface sediments. Moreover, focus on short-term residual surface concentrations remaining after dredging may misrepresent site risks. Removal of contaminant mass would likely be reflected in lower bioavailable surface concentrations over the long term as natural processes including sediment deposition and scour events occur over time.

**Contaminant Transport.** The PCB mass balance study conducted during Deposit N dredging activities (Water Resources Institute, 2000), estimated that less than 0.01 percent of PCBs from the slurry concentration was discharged back to the river after treatment. The mass balance model and the river turbidity samples consistently measured TSS below background values during project operations and did not measure an overall increase in mass of particles in the water column during dredging (TSS) when compared to upstream inputs. However, an increased net load of 2.2 kg of PCBs was transported downstream during the active dredging period. The majority of PCB mass excavated from the site (112 pounds) was successfully removed and contained within the treatment process, allowing only 2 percent of the PCB mass to escape the containment system.

Results of the Deposit N mass balance study concluded that surface water quality measures of turbidity or TSS were not accurate measures of PCB mass loading and transport. The Fox River Remediation Advisory Team recommended conducting a mass balance study (deposit mass balance, river transport, and process mass balance) for reliably measuring the transport effect of dredging operations.

## Effectiveness

Effectiveness is described in terms of short-term effectiveness (ability to meet performance criteria) and long-term effectiveness (ability to achieve risk reduction). This evaluation of dredging effectiveness summarizes the finding of the *Sediment Technologies Memorandum* located in Appendix B. It also includes a brief summary of dredging, dewatering, and monitoring performance of the two pilot demonstration projects conducted on the Lower Fox River at Deposit N and SMU 56/57.

**Ability to Meet Short-term Target Goals.** Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), 17 projects met their stated short-term project goals. The target goals were stated as sediment excavation to a chemical concentration, mass, horizon, elevation, or depth compliance criteria. In general, verification criteria that relied on physical features were generally assumed to remove the entire impacted sediment deposit based on site investigations. The two projects that did not meet their stated target goals were GM Foundry (cleanup criteria of 1 ppm PCBs), and Lower Fox River SMU 56/57 (cleanup to an elevation). One project, Manistique (cleanup criteria of 10 ppm PCBs) Harbor, has not been completed yet and therefore, results are undetermined.

Both the GM Foundry and Manistique projects made repeated dredging attempts to remove residual sediments resting on bedrock; however, confirmation samples were higher than the target goals for the maximum concentration detected. For the case of SMU 56/57, the contractor demobilized from the site before reaching the target elevation, thereby exposing the middle of the sediment deposit. This deficit was not a limitation of the dredging equipment; the equipment was capable of reaching the target elevation and removing the entire vertical profile of PCB mass. New contractors returned to the SMU 56/57 site in August 2000 under a different contract to remove the remaining PCB mass (see Appendix B).

**Ability to Achieve Long-term Remedial Objectives.** Achievement of long-term objectives are often measured as improved habitat quality, lower fish tissue concentrations, rescinded consumption advisories, and restoration of a site to beneficial use (e.g., parks, public areas). Of the 20 projects reviewed in the *Sediment Technologies Memorandum* (Appendix B), five projects met their stated long-term project objectives of protecting human health and the environment. Three of these projects (Bayou Bonfouca, Black River, and Minamata Bay) removed the fish consumption advisories listed for the project area within 7 years following remediation. The other two projects (Collingwood Harbour and Sitcum Waterway) were delisted from regulatory status. For Waukegan Harbor, the fish tissue concentrations in carp fillets showed a downward trend from pre-dredge conditions and the fish consumption advisories have been rescinded; however, the data are considered inconclusive because of small sample sizes. The fish tissue concentrations for most of the other projects showed preliminary decreasing trends, but additional sampling over time is required to determine trends. In many cases, the monitoring plans were not well defined nor implemented in order to distinguish site trends, nor has enough time elapsed since implementation to account for fish depuration rates.

**Application to the Lower Fox River.** The two Lower Fox River environmental dredging demonstration projects conducted at Deposit N and SMU 56/57 between 1998 and 2000 provided valuable feedback on the feasibility of dredging and dewatering sediments from the Lower Fox River. A summary of the field activities and performance/construction specifications for Deposit N and SMU 56/57 are summarized in Tables 6-8 and 6-9, respectively, and briefly described below. Detailed descriptions of the project design, implementation, monitoring activities, and lessons learned are presented as case studies in Appendix B.

The Lower Fox River Deposit N pilot demonstration project met the expected goals designed for the project. 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 inches) above bedrock. Approximately 5,475 $m^3$ (7,160 cy) of sediment and 50.3 kg (112 pounds) of PCBs were removed from Deposit N during 1998/1999 (Foth and Van Dyke, 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 (Foth and Van Dyke, 2000).

The PCB mass balance study conducted during dredging activities (Water Resources Institute, 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 PCBs during the active dredging period). Currently, there are no further plans for additional work at Deposit N, now referred to as the former Deposit N.

The Lower Fox River SMU 56/57 pilot demonstration project removed approximately 81,000 cy of dredged material to the target elevations and met the expected goals designed for the project after returning to the site in 2000. Approximately 31,000 cy of dredged material was removed from SMU 56/57 in 1999, leaving a large portion of the contaminated material behind before equipment was demobilized for the winter. 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 of 2000. Additional contaminated sediment (50,000 cy) was removed in 2000 from subunits that were previously disturbed (dredged) during the 1999 pilot project.

In 1999, the target goal of the SMU 56/57 project was to dredge to a design elevation of 565 feet (MSL, National Geodetic Vertical Datum 1929 [NGVD29]). Dredging to this design elevation was expected to remove sediments with PCB concentrations greater than 1 ppm. Confirmation sampling was compared to 1 ppm PCBs. 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 onset 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 4 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). In 1999, the post-dredge average residual PCB concentration was 7.5 ppm (40% reduction from 11.7 ppm average).

Lessons learned during the 1999 removal effort were successfully applied to the 2000 removal effort. For instance, equipment difficulties and large debris was encountered during 1999 dredging which hindered progress and production rates. The auger cutterhead dredge produced a sediment slurry with 4.5 percent solids; much lower than the design specifications. The dredge needed shorter cables, better positioning, and more overlapping transects to remove residual sediment ridges. 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 discontinued use of that pond until the liner could be repaired. Dredging was suspended on December 15, 1999, due to ice on the river and icing of the wastewater treatment system. In 2000, equipment was mobilized to the site 1 month earlier to lengthen the available dredging window before the onset of winter conditions. Land-based excavation equipment conducted a pre-removal of large boulders and debris before mobilization of the hydraulic dredge. The percent solids of the sediment dredge slurry averaged 8.4 percent, almost double the percent solids obtained during 1999. In 2000, a different silt curtain system was used and the passive dewatering equalization basins were eliminated and slurry was pumped directly to holding tanks.

In 2000, the Lower Fox River SMU 56/57 dredging project removed approximately 50,000 cy of sediment to the target elevation of 565 feet MSL. Post-verification surface sediment samples ranged from non-detect to 9.5 ppm (average 2.2 ppm) after one cleanup pass (target goal was less than 10 ppm). A 6-inch cap was placed over areas where surface sediment was above 1 ppm PCBs (no cap necessary if sediment was less than 1 ppm). More cleanup passes were not conducted because the contractor prioritized placement of the cap prior to onset of winter conditions.

### Dredging Costs

As summarized in the *Sediment Technologies Memorandum* (Appendix B), dredging costs range from \$6 to \$500 per cubic yard. Costs are dependent upon understanding site conditions, extent of containment and monitoring, removal volumes, project expectations, and appropriateness of selected technologies. Total project costs including project planning, dredging, treatment, disposal, redevelopment (in some cases), and long-term monitoring can range from \$0.6 million to \$50 million. More detailed dredging and disposal costs are described in Appendix B.

### Screening Decision

Dredging is retained as a removal technology for development of sediment cleanup alternatives (Table 6-4). Dredging has been successfully implemented in the Lower Fox River and elsewhere in the Great Lakes system as a tool for sediment remediation. Hydraulic dredging technologies (round cutterhead and horizontal auger) and process equipment may be effective methods for removing contaminated sediments from the Lower Fox River when properly designed, communicated, and implemented. Mechanical and hydraulic dredges are primary process options likely to be used in sediment removal operations; however, dry excavation may also be retained for shallow areas. Depending on site characteristics, both could be used at different locations within a single reach of the Lower Fox River or section of Green Bay.

## 6.4.6 *In-situ* Treatment

*In-situ* treatment of sediments refers to chemical, physical, or biological techniques for reducing COC concentrations while leaving the impacted sediment mass in place. *In-situ* technologies are commonly employed for cleanup of contaminated soil and groundwater. No successful adaptations of these and other technologies to full-scale sediment cleanup involving PCBs have been reported in the literature. Table 6-3 presents the results of feasibility screening for several potential *in-situ* treatment technologies. None are feasible for implementation in the Lower Fox River and Green Bay (Table 6-5).

## 6.4.7 *Ex-situ* Treatment

*Ex-situ* treatment refers to the processing of dredged sediments to transform or destroy COCs. Table 6-5 screens *ex-situ* treatment technologies based on implementability and effectiveness.

### Description of *Ex-situ* Treatment Process Options

Treatment processes may be classified as biological, chemical, physical, or thermal. *Ex-situ* thermal treatment includes three subcategories: incineration, high-temperature thermal desorption (HTTD), and vitrification. All of these treatment technologies were retained for consideration in the initial FS screening process; however, only thermal treatment was retained for the final screening.

**Biological.** Biological treatment methods involve amendments of nutrients, enzymes, oxygen, or other additives to enhance and encourage biological breakdown of contaminants. Inorganics (metals) and PCBs are not well suited to biological treatment techniques. There are no proven and effective biological techniques for treating PCBs full scale and no reports in the literature of PCB-contaminated sediments biotreated *ex situ*. A pilot-scale biological treatment study was conducted on PCB-impacted sediments from the Sheboygan River, Wisconsin and the Hudson River, New York, but neither the aerobic nor anaerobic treatment had a significant effect (BBL, 1995).

**Chemical.** Chemical treatment methods involve the addition of acids/solvents to extract contaminants or oxidizing agents to encourage conversion to less hazardous compounds. Chemical methods for treating contaminated sediments show little promise. Acid extraction is ineffective for treatment of PCB-contaminated sediments. Solvent extraction is specific to soluble organics (e.g., PCBs) and some organic-complexed metals. Other inorganics remain in the sediments requiring some other form of treatment or disposal. Further, additional treatment is required for the concentrated extract. The literature provides no reports of chemical technologies implemented full-scale for the treatment of sediments.

**Physical.** Physical separation or soil washing refers to the process of classifying sediment into fractions according to particle size or density. Separation may be accomplished by screening, gravity settling, flotation, or hydraulic classification using devices such as hydrocyclones (USACE-DOER, 2000a). Equipment for physical separation is widely available, and the concept has been demonstrated for sediments in both the United States and Europe (USACE-DOER, 2000a); however, physical treatment methods have limited application for removing PCBs from contaminated sediments. Physical separation involving removal of the larger sand and gravel fraction from finer-grained sediment may or may not reduce the residual contaminated sediment mass and/or volume.

Physical treatment can also refer to the solidification/stabilization of dredged material to reduce the mobility of constituents through the use of immobilization additives. Many additives commercially available can immobilize both organic and inorganic constituents. Solidification reagents often include: Type I Portland cement, pozzolan, cement kiln dust, lime kiln dust, lime fines, and other proprietary agents. As described in the *Basis of Design Report for the Lower Fox River SMU 56/57 Project* (Montgomery-Watson, 1998), bench-scale solidification studies using Portland cement and lime dust were tested on dredged material from the Lower Fox River; the lime performed better. In bench-scale studies conducted on PCB-impacted sediments from the Sheboygan River (BBL, 1995), the Portland cement additive provided desirable physical characteristics (i.e., compressive strength) and leachability characteristics.

**Thermal.** Thermal treatment technologies desorb and subsequently destroy organic compounds by combustion. Thermal process options may be grouped into the categories of incineration, thermal desorption, and vitrification. The former two options are widely practiced technologies for treatment of soil containing PCBs and other organics. Vitrification was developed initially for use in treating radioactive mixed wastes and is receiving attention as a cost-competitive thermal option for treating soils and sediments high in sand content. Regardless of the specific technology option, thermal treatment requires that sediments first be dewatered to reduce water content and therefore the amount of heating energy required.

***Incineration.*** Incineration temperatures are typically between 1,400 and 2,200 degrees Fahrenheit (˚F) which is sufficient to volatilize and combust organic chemicals. A common incinerator design is the rotary kiln equipped with an afterburner, a solids quench (to reduce the temperature of the treated material), and an air pollution control system. Incinerator off-gases require treatment to remove particulates and neutralize and remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed-bed scrubbers and spray driers remove acid gases. Incineration facilities are generally fixed-based. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments. Incineration of PAH-contaminated sediment was successfully conducted at the Bayou Bonfouca Superfund site, Louisiana, at a unit cost of $154 per cubic yard. Residual incinerator ash was placed in an on-site landfill.

***High-temperature Thermal Desorption.*** High-temperature thermal desorption (HTTD) is a full-scale technology in which temperatures in the range of 600 to 1,200 ˚F volatilize organic chemicals. HTTD desorption efficiencies for removing PCBs from sediment range between 90 and 99 percent. A carrier gas or vacuum system transports volatilized water and organics to a condenser or a gas treatment system. After sediment desorption in the HTTD unit, volatilized organics are destroyed in an afterburner operating at approximately 2,000 ˚F. This treatment technique has been used successfully at several other sites with PCB contamination. HTTD systems can be both fixed-based and transportable and typically use a rotary kiln. HTTD is a commonly used technology for soils and is readily adapted to sediments. Capacities on the order of 100 tons per hour are available in transportable models.

An anaerobic thermal processor (ATP) extraction system operated by Soil Tech successfully treated PCB-contaminated sediment from the Waukegan Harbor site in Illinois. The ATP system treated sediments with greater than 500 ppm PCBs with an average PCB removal efficiency of 99.98 percent (Appendix B). Air emissions met the 99.9999 percent destruction removal efficiency (DRE) stack emission requirement for final destruction of PCBs.

***Vitrification.*** Vitrification is a process in which high temperatures (2,500 to 3,000 °F) are used to destroy organic chemicals by melting the contaminated soil and sediments into a glass aggregate product. Vitrification units can be operated to achieve 99.9999 percent destruction and removal efficiency requirement for PCBs and dioxin. Trace metals are trapped within the leach-resistant inert glass matrix. Various types of vitrification units exist that utilize different techniques to melt the sediments, including electricity and natural gas, and are discussed in detail below. The following references and project summaries were used in this FS Report to assess the applicability of vitrification technology:

- *Decontamination and Beneficial Reuse of Dredged Estuarine Sediment: The Westinghouse Plasma Vitrification Process* (McLaughlin *et al.*, 1999);

- *Glass Aggregate Feasibility Study - Phase I and II* (Minergy Corporation, 1999);

- *Final Report: Sediment Melter Demonstration Project* (Minergy Corporation, 2002a); and

- *Unit Cost Study for Commercial-Scale Sediment Melter Facility, Supplement to Glass Aggregate Feasibility Study* (Minergy Corporation, 2002b).

***Plasma Vitrification Process.*** This process involves superheating air by passing it through electrodes of the plasma torch. Partially screened and dewatered sediment is injected into the plume of the torch and heated rapidly. After dredging, sediment must be dewatered to approximately 50 percent solids. Additional drying is required to further reduce moisture. Rotary steam-tube dryers or other indirectly heated drying systems are used for this purpose. The high temperature combusts and destroys all the organic contaminants and the mineral phase melts into a glass matrix. Fluxing agents such as calcium carbonate, aluminum oxide, and silica oxide are blended with the sediment, as needed, to obtain the desired molten glass viscosity. The molten glass is quickly quenched, resulting in a product suitable for a wide variety of applications.

***Glass Furnace Technology.*** This process uses a state-of-the-art oxy-fuel-fired glass furnace to vitrify sediment into an inert glass aggregate product. Sediment is dewatered and partially dried before being fed into the glass furnace. The high temperature melts the sediments resulting in a homogenous glassy liquid. Additives such as calcium carbonate, aluminum oxide, and silica oxide are added to obtain the desired viscosity of molten glass. The molten glass is collected and cooled quickly in a water quench to form glass aggregate product. The final glass product has a wide range of industrial applications.

During the comment period of the 2001 draft of the Lower Fox River RI/FS, WDNR completed a project to evaluate the feasibility of a vitrification technology, based on standard glass furnace technology, to treat contaminated river sediment. The sediments treatment demonstration project was completed in 2001 under the EPA's Superfund Innovative Technology Evaluation (SITE) program. A summary of the sediment melter demonstration project with performance and construction specifications is summarized in Table 6-11. Detailed descriptions of the treatment process, process design and construction, observations, and cost estimates are provided in Appendix G.

## Screening Criteria for *Ex-situ* Treatment Selection

This screening evaluation focuses on thermal technologies, as neither biological nor chemical/physical treatments are feasible for application in the Lower Fox River and Green Bay.

## Implementability

Chemical and biological treatment technologies have not been implemented nor proven successful for PCB sediment remediation. Physical separation may be feasible for sediment dredged from the Lower Fox River, but this technology has not been included in the alternatives analysis. Incineration, HTTD, and vitrification are viable thermal technologies for treatment of PCBs in dredged sediment. Incineration and HTTD are well-developed technologies and are commonly used for treatment of PCB-contaminated soil. Vitrification has not been used full scale for treatment of contaminated sediments. However, based on the multi-phased feasibility study conducted by WDNR in 2001, this technology appears to be a viable option for application to sediments in the Lower Fox River.

Many sediment remediation projects in Europe require physical separation of the sand/silt fractions to minimize the sediment volumes requiring disposal, due to limited disposal options. Sediment removal costs and implementability depends upon the contaminant of concern, grain size distribution, and amount of debris in the substrate matrix. Sand reclamation costs for operation of a small plant that handles 150,000 to 200,000 $m^3$ annually costs \$35 per $m^3$ of sediment treated (McLellan and Hopman, 2000). A successful sand reclamation project was implemented at the Port of Rotterdam, Netherlands site (McLellan and Hopman, 2000). Hydrocyclones and "sand peelers" separate sand from the fine fraction and reuse the sand for industrial purposes and preserving disposal capacity at a 100 million $m^3$ nearshore fill. Sand reclamation may be considered during the design phase of the Lower Fox River/Green Bay project, but is not considered in this FS. However, physical treatment expressed as sediment dewatering is required to prepare the sediment solids for treatment and disposal and therefore, is not discussed separately.

Thermal processes must meet TSCA testing and air performance requirements specified in CFR 40 Part 761.70(b) if sediment PCB concentrations exceed 50 ppm. The glass furnace vitrification process evaluated for Lower Fox River sediments requires construction of a new melter facility. The plant size is dependent on the amount of dredged and dewatered sediment available for processing. The sediments feed rate through the melter is limited by the capacity of the facility and moisture content of the sediments. Dewatered sediments need to be mixed with drier materials to achieve optimum moisture content of 37 percent to prevent agglomeration and facilitate easy material handling. The dryer must further reduce the sediment moisture content to 10 percent prior to processing in the melter (Minergy Corporation, 2002a).

### Effectiveness

Thermal desorption systems generally perform at lower destruction/removal efficiency than incineration systems. Thermal desorption removal efficiencies are generally in the neighborhood of 90 to 99 percent (Garbaciak and Miller, 1995). As stated earlier, biological and chemical treatment are likely to have little effect on site sediments. Physical treatment can effectively remove coarse-fractioned solids from dredged material and provide adequate physical characteristics needed for disposal.

River sediments processed during Phase III of the WDNR glass furnace demonstration project conducted in 2001 achieved a PCB destruction of greater than 99.99993 percent. The glass aggregate was subjected to both ASTM water leaching procedures and SPLP testing. The ASTM water leaching procedures and SPLP test did not detect any PCB congeners, SVOCs, or any of the eight heavy metals. Dioxins and furans were not generated during the sediment treatment process. The end product created by the treatment process was very consistent, producing a hard, dark granular material. The resulting glass aggregate has a wide range of industrial applications including roofing shingle granules, industrial abrasives, ceramic floor tile, cement pozzolan, and construction fill (Minergy Corporation, 2002a).

### Treatment Costs

Exclusive of material preparation costs (e.g., dewatering), thermal treatment unit costs can range from $25 to $1,000 per ton (EPA, 1994a). Depending on the size of vitrification unit, unit costs range between $27 and $57 per ton (Minergy Corporation, 2002b). Detailed cost breakdowns and analysis are provided in the *Unit Cost Study for Commercial-Scale Sediment Melter Facility* provided in Appendix G.

### Screening Decision

No biological or chemical treatment technologies are retained for development of remedial alternatives in Section 7. All three thermal technologies (incineration, vitrification, and HTTD) are implementable and effective for treatment of PCBs in sediments. Physical treatment is retained as a dewatering process option (ancillary technology).

## 6.4.8 Disposal Process Options

Disposal is the relocation and placement of removed sediments into a site, structure, or facility (e.g., landfill). Disposal is the most frequent endpoint for sediments in remediation projects that involve removal. PCB-contaminated sediment removed from the Lower Fox River can be disposed of at a number of upland disposal facilities, and depending upon the PCB concentration, in "in-water" contained aquatic disposal (CAD), or level-bottom caps.

### Description of Disposal Process Options

Four general disposal options exist for the disposal of PCB-impacted sediments removed from the Lower Fox River. These are:

- Level-bottom cap;
- Confined aquatic disposal (CAD);
- Existing landfill (in- or out-of-state), construction of new, dedicated landfill; and
- Confined disposal facility (CDF).

**Level-bottom Cap.** Level-bottom capping involves the mounding of contaminated sediment in an area of a water body that has a relatively flat bottom. Capping material is then placed on top of the mounded sediments. The cap must be designed to prevent scour and erosion. Level-bottom caps have typically been constructed in large water bodies such as oceans or lakes. Applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods.

**Confined Aquatic Disposal.** Confined aquatic disposal (CAD) is similar to level-bottom capping, with the exception that the contaminated sediments have lateral sidewall containment from an engineered berm or as a result of excavating a depression at the disposal site (Figure 6-7). As with level-bottom capping, the cap must be designed to prevent scour, erosion, and bioturbation. CAD applications in river systems are uncommon because of water depth requirements for navigation and recreation, as well as the potential scouring that can occur during high-flow periods. Thus, construction of a CAD facility is likely restricted to Green Bay.

The deposit site is prepared either by excavating a depression and using the excavated material for construction of a perimeter berm, or by importing material to construct a perimeter berm on the existing sediment surface. The contaminated sediment is deposited at the specified location and topped with clean sediments.

**Existing or Proposed In-state Landfills.** A landfill is an engineered facility that provides long-term isolation and disposal of waste material, thereby minimizing the potential for release of contaminants to the environment. Landfills are designed to prevent the release of contaminants to groundwater, control runoff to surface water, and limit dispersion into the air.

Landfills in Wisconsin must meet location, hydrogeologic evaluation, and groundwater performance standards (NR 500 WAC). Landfill design requirements in Wisconsin also include: 1) a cover system, 2) a liner system, 3) a leachate collection and treatment system, 4) a water monitoring system, and 5) a gas monitoring system. Landfills cannot accept wastes containing free liquids and sediments must first be dewatered or stabilized before disposal. A total of 13 existing landfills are located within a 40-mile radius of Green Bay, Wisconsin (Figure 6-8).

**Construction of New, Dedicated Landfill.** Contaminated sediment may also be placed within dedicated cells, or monofills, located within landfills. The monofill provides additional assurances that the contaminated sediment will not mix with other solid waste, and provides for more stable long-term control of the material.

**Confined Disposal Facility.** A confined disposal facility (CDF) is an engineered containment structure that provides for dewatering and permanent storage of dredged sediments. In essence, CDFs feature both solids separation and landfill capabilities (EPA, 1994a). Containment of contaminated sediments in CDFs is generally viewed as a cost-effective remedial option at Superfund sites (EPA, 1996b). Recent interest in CDFs for disposal of contaminated dredged sediment has led both the USACE and the EPA to develop detailed guidance documents for construction and management. These include:

- *Engineering and Design - Confined Disposal of Dredged Material* (USACE, 1987);

- *Design, Performance, and Monitoring of Dredged Material Confined Disposal Facilities in Region 5* (EPA, 1996b);
- *Confined Disposal Facility (CDF) Containment Features: A Summary of Field Experience* (USACE-DOER, 2000b);
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program Remediation Guidance Document* (EPA, 1994a);
- *Verification of Procedures for Designing Dredged Material Containment Areas for Solids Retention* (Averett *et al.*, 1988); and
- *Comprehensive Analysis of Migration Pathways (CAMP): Contaminant Migration Pathways at Confined Dredged Material Disposal Facilities* (Brannon *et al.*, 1990).

A CDF may be constructed as an upland or floodplain site, as a nearshore site (one or more sides exposed to water), or as an in-water island containment area. For the purposes of this FS, only the in-water, nearshore and floodplain CDFs are considered. There are approximately 50 completed CDFs in the Great Lakes region. These facilities were constructed primarily for dredged material from navigation projects. Most of the CDFs are in-water lakefills that were constructed using stone retention dikes and simple water return systems. The remainder are upland facilities constructed with earthen dikes, or placed within existing or excavated depressions. Nearshore CDFs have been successfully completed at the Waukegan Harbor, Illinois and Sitcum Waterway, Washington sites for contaminated sediments (Appendix B).

There are two types of designs that are used in the construction of a CDF: solids retention and hydraulic isolation. Solids retention designs for CDFs physically isolate the sediment solids from the environment. Solids retention designs are used when the contaminants in the sediment are tightly bound to the retained solids and are not likely to leach and contaminate the surface or groundwater. Designs for these types of CDFs need only consider retention dikes or configurations such as geosynthetic liners placed between the inner wall of the retention dike and the dredged material. The design of in-water CDFs must consider a final construction height of at least 6 feet above the normal river level (the 100-year flood level) in order to maintain the surface above maximum expected flood height. External dike construction would need to consider the potential for flood- or ice-induced damage. Water treatment consists of settling out the particulates prior to discharge. An example of an in-water CDF is illustrated on Figures 6-9 and 6-10.

In contrast, hydraulic isolation designs isolate the solids and capture the associated water from the contaminated solids. Design of these facilities are similar to those for NR 500 WAC landfills and often employ extensive water recovery and treatment operations. For costing purposes in the FS, we have assumed a 6-foot berm level for all remediation areas, which is the approximate elevation gain increase in lower Green Bay for the 100-year flood event.

## Regulatory Considerations

**Open-water Disposal.** Open-water disposal of contaminated sediments is banned in the waters of Wisconsin (Appendix C). The ban exists in Wisconsin Statutes Chapter 30.12(1)(a). There are, however, certain exceptions to the open-water disposal prohibition. The exceptions include: 1) legislative authorization, 2) lakebed grants, 3) bulkhead lines, and 4) leases. Obtaining any of these exceptions for disposal of dredged material into navigable water may be utilized for remediation of the Lower Fox River (Lynch, 1998), but each could require substantial time to obtain. To obtain an exemption, the activity must still meet the conditions and limitations of the state's responsibilities for protection of water quality and other related issues. This ban applies to level-bottom capping and construction of a CAD or CDF site. Thus, special approval by the state legislature addressing provisions of this ban would be required to implement open-water remedies. This option, by use of a lakebed grant, could be applied to a CDF where the title of a lakebed or bed of a waterway would be transferred from the state to a municipality.

**Placement in an Upland Landfill.** Dredged sediment is classified as solid waste in Wisconsin (Lynch, 1997, 1998). This determination has been made through statute and case law. Wisconsin Statute Chapter 289 and NR 500 through 520 of the WAC provide most of the regulatory framework for handling and disposing of solid waste, and therefore, dredged contaminated sediments. Additionally, in a January 24, 1995 agreement, the EPA gave WDNR the authority to manage the disposal of sediment contaminated with PCBs in concentrations of 50 ppm or greater in NR 500 WAC-approved landfills. Sediments containing PCBs of 50 ppm or greater may be disposed in an NR 500 WAC-approved landfill with EPA concurrence. A copy of the agreement (EPA, 1995b) is included in Appendix C. The agreement also allows WDNR to "select disposal facilities that comply with NR 500 through 520 WAC for the disposal of sediments contaminated with PCBs at concentrations of 50 ppm or greater from sediment remediation projects conducted under the authority and supervision of the WDNR" (EPA, 1995b). Any landfill approved for disposal of contaminated sediment must meet the stringent state requirements for the design, operation, and maintenance of a Subtitle D landfill. In other words, TSCA approval issued from EPA Region 5 is only applicable to landfills that go through the landfill siting and licensing process.

WDNR has the authority to issue exemptions from regulation under Wisconsin Statutes Chapter 289, under some circumstances. The primary exemptions which cover dredged material exist in WAC NR 500.08(3) (Beneficial Reuse). The exemptions may not apply to sediment from the Lower Fox River and Green Bay (Lynch, 1998) because of the large volumes of sediment and the concentrations of PCBs within the sediments.

Other exemptions from solid waste regulations for dredged material are found in the Wisconsin Statutes Chapter 289.43(8), and related NR 500 WAC state codes. The exemption is known as the "Low Hazard Exemption." The Low Hazard Exemption allows exemptions from landfill siting roles and state statutes for either beneficial reuse or disposal. This exemption has been used in the past for nonhazardous dredged material (below TSCA levels *in situ*) generated from the Lower Fox River. The low-hazard waste grant of exemption is a possibility for at least some of the dredged material in the Lower Fox River, either for beneficial reuse or disposal.

**New, Dedicated Upland Landfill.** Construction of a new publically-owned, upland landfill dedicated to the disposal of sediments is a potential option. A dedicated and centrally-located facility would allow reasonable access from all areas of the river. The total capacity required may be up to 5,000,000 cy for the De Pere to Green Bay Reach. Construction requirements for a dedicated landfill would generally be the same as the construction requirements for a municipal landfill. It is important to note that the process of gaining approval for the location of a new landfill (the siting process, as detailed in Wisconsin Statutes Chapter 289) is lengthy and may take many months or years to complete (Huebner, 1996).

A new landfill dedicated to disposal of dredged material (and would not be used for municipal solid wastes) may be exempt from the free liquids and shear strength requirements of solid waste landfills. If the site is designed to accommodate the properties of dredged material (e.g., leachate collection system), then many of the physical requirements of the material may not apply.

**Confined Disposal Facility.** CDFs are disposal facilities located within a floodplain or a waterway and cannot be permitted through the landfill siting process. The mechanisms are available to permit this disposal option if there is a strong rationale to do so. One limitation to this option is the potential long period of time required to obtain the appropriate permits. Wisconsin has banned open-water disposal of dredged material on the bed of all navigable waters for more than 25 years.

In addition to the Wisconsin Statute Chapter 30 ban, NR 504 WAC provides for certain setback requirements when siting disposal facilities. Disposal facilities are required to be set back certain distances from water ways and floodplains. The WDNR has the authority to waive this requirement under Wisconsin Statute Chapter 289.

Floodplain and in-water CDFs can only be designed for nonhazardous solid waste and dredged material generated from non-TSCA-level sediments. In-water CDFs are unlikely to be permitted for sediment with PCB concentrations exceeding the TSCA limit of 50 ppm. As described previously for capping, EPA has not, to date, permitted any permanent in-water containment facilities.

**CERCLA Exemptions.** CERCLA exempts permitting requirements for "on-site" disposal facilities if the EPA is conducting the remediation, or has issued an order or signed a consent decree with the principal responsible parties (PRPs). The exemption does not apply if the State of Wisconsin conducts the work or issues the order or consent decree. For remediation of the Lower Fox River and Green Bay, WDNR's position is that disposal units adjacent to the river or in water could be considered "on-site." Additionally, WDNR does not believe that locational criteria ARARs for on-site disposal units could be exempted or waived even under an EPA-led CERCLA action (Lynch, 1998).

## Screening Criteria for Disposal Selection

The criteria used for selection of a disposal alternative are primarily based on location, capacity, access, and long-term stability. Off-site disposal is considered potentially feasible for all river reach and bay alternatives requiring disposal. Final selection of disposal options will depend upon several criteria (EPA, 1994a):

- Location,
- Upland land use,
- Fill capacity,
- Length and quality of haul route,
- Site setting and design,
- Residential impacts,
- Multiple disposal locations,
- Regulatory considerations,
- Contaminant concentration, and
- Flood and erosion control.

## Implementability

**Level-bottom Cap.** From a technical standpoint, a level-bottom cap is a reasonable disposal option for contaminated sediments in Green Bay. Deep and quiescent areas of Green Bay located away from navigation channels may afford the long-term stability necessary to ensure that COCs are not released back into the aquatic system through erosion.

The effectiveness of level-bottom capping is similar to that of other capping approaches (Section 6.4.4). As long as the design criteria are met, a level-bottom cap contains the contaminated sediments and prevents exposure to humans and aquatic organisms.

**Confined Aquatic Disposal.** From a technical standpoint, a CAD is a reasonable disposal option for contaminated sediments in Green Bay. Deep and quiescent areas of Green Bay located away from navigation channels may afford the long-term stability necessary to ensure that COCs are not released back into the aquatic system through erosion. The short-term impacts of contaminant loss to the water column during placement of the dredged sediments must be considered. Several placement equipment options along with use of engineering controls during placement can reduce losses. Results of empirical tests and computer modeling allows for prediction of contaminant losses during placement and aids in selection of the placement technique.

Monitoring and maintenance (if required) are essential components of a CAD project. Monitoring determines the extent to which CAD performance is matching design expectation in terms of preventing contaminant exposures.

**Landfill.** There are no technical obstacles related to the disposal of dredged sediments in landfills. With the exception of dewatering to an acceptable moisture content, sediment must merely meet the applicable acceptance criteria of the landfill.

If the dredge slurry is pumped directly to a disposal site located a few miles away from the dredge area (i.e., greater than 5 miles), then a detailed engineering design evaluation would be required to successfully pump the slurry large distances. Long slurry pipe runs are technically feasible as demonstrated in White Rock Lake, Dallas, Texas. A 20-mile-long steel, 24-inch-diameter dredge slurry pipe run extended from the dredge area in White Rock Lake through residential and commercial areas directly to a former sand and gravel quarry disposal site (Sosnin, 1998).

**Confined Disposal Facility.** CDFs are implementable from an engineering standpoint. As long as site conditions, placement constraints, and regulatory criteria are satisfied, construction and placement in a CDF is a reasonable disposal option for both the river and bay. A CDF could be technically designed to adequately isolate contaminated sediments over the long term.

## Effectiveness

Disposal at a single location presents a long-term liability at a single facility. Disposal of the sediments at multiple locations may incrementally increase the overall long-term liability of the sediments. By disposing at numerous facilities, there is potential long-term liability associated with the waste disposed at each facility.

**Level-bottom Caps.** The most notable use of level-bottom capping techniques is the open-water multi-user New York Mud Dump Disposal Site operated through the Disposal Area Monitoring System (DAMOS) Program. This program uses level-bottom cap placement and containment technology to confine low- to moderately-contaminated sediments. This site is regularly monitored to ensure compliance within the confines of the program (USACE, 1995).

**Confined Aquatic Disposal.** The long-term effectiveness of a CAD is similar to that of other capping approaches (Section 6.4.4). The primary criteria for success is that the cap thickness required to isolate contaminated material from the environment be placed correctly and maintained. CAD experience demonstrates that proper site selection, design, and construction can eliminate resuspension due to bioturbation and erosion. Further chemical diffusion of contaminants through a properly designed cap is negligible and does not present a long-term risk to the environment.

**Landfills.** Table 6-10 lists municipal and non-municipal landfills located within the Lower Fox River valley and provides information about existing and proposed capacities. Information in the table was derived from WDNR records (WDNR, 1998). Approximately 14 existing and proposed municipal and non-municipal landfills exist within 40 miles of the Lower Fox River. Capacities for all the landfills were not available. Figure 6-8 shows the general location of these landfills.

Waste disposal capacity of landfills located within 40 miles of the river is in excess of 30 million cubic yards. Although several municipalities banned disposal of contaminated sediment in landfills in the past, most local governments have either removed the bans or are in the process of removing the bans, opening the way to additional landfill capacity in the Lower Fox River valley.

Disposal at out-of-state landfills may be an option if in-state disposal facilities have insufficient capacity or cannot be used for other reasons (e.g., permit restrictions). Other disposal locations may become available in the future. Adequate space will most likely exist in municipal and non-municipal landfills within 40 miles of the Lower Fox River to accept all sediments removed from the river, if this option is selected.

Preliminary engineering work has been completed for at least one landfill facility capable of accepting contaminated sediment from the Lower Fox River. The planned facility is located within 20 miles of the Lower Fox River in rural Brown County. The quantity of impacted sediment is compared to typical one-time solid waste disposal projects. The current capacity of landfills will determine the amount of sediment that can be disposed of at any landfill.

**Confined Disposal Facility.** As previously discussed, several CDFs have been constructed for disposal of contaminated sediments and considerable support is available in the literature for design and construction. Over 10 nearshore CDFs have been placed in Puget Sound (West Eagle Harbor, Washington; Sitcum/Milwaukee Waterway, Washington), the Great Lakes region (Calumet Harbor, Chicago; Waukegan Harbor, Illinois), and east coast (New Bedford Harbor, Massachusetts) combined (USACE-DOER, 2000b). Several isolated in-water cells have been placed in Europe and the United States.

Siting, acceptance by the public and regulatory communities, as well as permitting are central to the implementability of this disposal option. In-water CDFs would be limited to areas of the Lower Fox River that are relatively wide with general construction access. Likewise, floodplain CDFs would be limited to large near-river locations that could be permitted for landfill use. In-water CDFs would need to consider site access and potential losses of lake frontage to upland riparian landowners. Other potential uses of the Lower Fox River by upland owners, such as intake or permitted wastewater discharge pipes, and electrical or other cable crossing, must be considered in locating an in-water CDF.

Due to its size, large areas of Green Bay are suitable for siting a CDF.

Floodplain and in-water CDFs would need to meet the substantive requirements for landfills defined in NR 500 WAC. While PCBs alone might be considered particulate-bound contaminants and a simple solids retention design might be suitable, dredged sediments in the Lower Fox River and Green Bay will also contain quantities of other metals, pesticides, and semivolatile organic compounds (i.e., polyaromatic hydrocarbons) that may require some consideration of hydraulic control (i.e., collection of internal leachate; physical isolation).

Disposal of contaminated sediments in CDFs is an effective means of isolating COCs from the surrounding environment. As with other disposal options, CDFs prevent exposure of humans and aquatic organisms to the contaminants.

Migration of COCs out of a CDF over the long term is precluded through design features and the fact that the PCBs are strongly sorbed to the sediment particles.

### Disposal Costs

Level-bottom capping and CAD sites are generally lower in cost than other engineered disposal options such as confined disposal facilities. Level-bottom capping is the lowest-cost disposal option for contaminated sediments as the material is merely deposited in a mound at a specific location and topped with clean sediments. Disposal costs for construction and filling of a CDF is expected to be comparable to landfill disposal (which includes transport). Landfill disposal costs typically range from $25 to $50 per ton exclusive of transportation. Disposal at out-of-state landfills would generally be more costly than disposal at existing local or regional in-state landfills or new dedicated landfills because of increased transportation costs.

Estimated costs to acquire and build the approximately 4 million-cubic-yard landfill currently planned in rural Brown County to accept contaminated sediment is $14 million plus a local siting fee of $5 per ton. Operating costs of the landfill were estimated at $500,000 per year for 10 years. Landfill closure was assumed to consist of a typical cap at $100,000 per acre. Post-closure O&M costs are estimated to be $30,000 per year for 40 years.

### Screening Decision

Level-bottom capping and confined aquatic disposal are viable technologies for disposal of contaminated sediments in Green Bay as long as the statutory restrictions on open-water disposal can be accommodated. Dredged material located in an upland landfill could be subsequently removed for treatment, if desired, and would be more accessible for removal than in-water disposal options. CDFs are appropriate for consideration as a disposal option for dredged sediments of the Lower Fox River and Green Bay as long as the statutory restrictions for nearshore disposal can be accommodated. The disposal of contaminated sediments in landfills is considered an effective and implementable option for purposes of developing cleanup options for the Lower Fox River and Green Bay. However, under CERCLA, landfill disposal in addition to other disposal options mentioned above is not a preferred option primarily because the contaminated materials are merely relocated and the COCs are not destroyed.

## 6.5 Identification of Ancillary Technologies

Additional technologies and process options that are ancillary to the retained process options presented in Section 6.3 may be incorporated in the remedial alternatives. Incorporation of these technologies and process options is dependent on the process options chosen for a particular remedial alternative. For example, if removal and disposal in an off-site landfill is established as a remedial alternative, dewatering prior to transport of materials off site and subsequent treatment of the water generated in the process will take place.

Potential ancillary technologies and process options are not subject to the same screening process described in Section 6.2. However, they are presented here as considerations for the development of remedial alternatives provided in the following sections of this FS Report. A description of ancillary technologies that are a part of certain remedial alternatives are described in following subsections and include:

- Dewatering,
- Wastewater treatment,
- Residuals management and disposal,
- Transportation, and
- Water quality management.

## 6.5.1 Dewatering

Dewatering involves the removal of water from dredged sediment to produce a material more amenable to handling with general construction equipment and that meets landfill disposal criteria (e.g., paint filter test and compaction specifications). Selection of an appropriate dewatering technology depends on the physical characteristics of the material being dredged, the dredging method, and the target moisture level of the dewatered material. Dewatering technologies can be grouped into the following three categories:

- Mechanical dewatering,
- Passive dewatering, and
- Solidification.

### Description of Dewatering Process Options

After removal, the dredged solids typically have moisture contents that must be reduced for effective treatment. Mechanically-dredged sediments typically have a solids content of approximately 50 percent by weight. Hydraulically-dredged sediments are in a slurry with a solids content typically in the range of 6 to 10 percent, with a maximum range of 10 to 12 percent (EPA, 1994a). Dewatering these sediments requires management of the contaminated water, which has direct cost implications.

**Mechanical Dewatering.** Mechanical dewatering equipment physically forces water out of sediment. Four techniques are typically considered for dewatering dredged sediments: centrifugation, diaphragm filter presses, belt presses, and hydrocyclones.

Centrifugation uses centrifugal force to separate liquids from solids. Water and solids are separated based upon density differences. The use of a cloth filter or the addition of flocculent chemicals assists in the separation of fine particles. Typical production rates of a single centrifuge vary from 20 to 500 gallons per minute (gpm). Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, production rates vary from approximately 1 to 21 cy/hr. Centrifuges are suitable for areas along the Lower Fox River where larger dewatering systems (operations) are impractical. The process works well with oily sediments and can be used to thicken or dewater dredge slurries.

Hydrocyclones are continuously-operated devices that use centrifugal force to accelerate the settling rate of particles within water. Hydrocyclones are cone shaped. Slurries enter near the top and spin downward toward the point of the cone. The particles settle out through a drain in the bottom of the cone, while the effluent water exits through a pipe exiting the top of the cone. The production rate and minimum particle size separated are both dependent upon the diameter of the hydrocyclone. Generally, a wider hydrocyclone has a greater production rate, whereas narrower hydrocyclones are better at separating out smaller particles, albeit at lower throughput rates. The production rate of a single unit varies from 50 to 3,500 gpm, depending on equipment diameter. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the production rates vary from approximately 2 to 150 cy/hr. Two hydrocyclones were used during the Deposit N demonstration project to remove +200 sieve material after removal of gravel-sized stones and debris.

Diaphragm filter presses are filter presses with an inflatable diaphragm, which adds an additional force to the filter cake prior to removal of the dewatered sediments from the filter. Filter presses operate as a series of vertical filters that filter the sediments from the dredge slurry as the slurry is pumped past the filters. Once the filter's surface is covered by sediments, the flow of the slurry is stopped and the caked sediments are removed from the filter. Filter presses are available in portable units similar to the centrifuge units. Although very costly and labor intensive, production rates for a single unit vary from 1,200 to 6,000 gpm. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the production rates vary from approximately 50 to 250 cy/hr.

Belt presses use porous belts to compress sediments. Slurries are sandwiched between the belts, resulting in high-pressure compression and shear which promotes the separation. Flocculents are often used to assist the removal of water from the sediments. The overall dewatering process usually involves gravity-draining free water, low-pressure compression, and finally high-pressure compression. Belt presses can be fixed-based or transportable. They are commonly used in sludge management operations at municipal and industrial wastewater treatment plants throughout the Lower Fox River valley.

Belt press efficiencies are dependent upon belt speeds, tension, material composition, feed concentrations, and flocculent dosing. Typical production rates of a single unit vary from 40 to 100 gpm. Assuming a dredged slurry solids content of 4 percent by volume and a dewatered solids content of 30 percent by volume, the typical production rate varies from approximately 2 to 4 cy/hr. A type of belt press, called the recessed chamber filter press, was used for dewatering hydraulically-dredged sediments from Deposit N. The press was used after a gravity-settling stage and polymer conditioning to enhance filter performance. The filter cake produced was sufficiently dewatered for transport and disposal off site.

**Passive Dewatering.** Passive dewatering refers to gravity settling of solids. Passive dewatering can occur on sediment barges, within CDFs, and in specially built lagoons or ponds. The process requires sufficient retention time to allow sediment particles to settle, after which the clarified water may be discharged (or treated and then discharged depending on composition and discharge limitations). Passive dewatering is used for mechanical dredging of the Green Bay navigation channel by the Green Bay Port Authority. Passive dewatering was considered feasible for the SMU 56/57 demonstration project (Montgomery-Watson, 1998).

On-barge dewatering is typically used in conjunction with mechanical dredging. Sediment is deposited inside the dredge-barge and water is allowed to drain by gravity. Typical dredge-barges are equipped with side drains which allow the water to flow from the barge into the water body. Dredge-barges may also be configured with a floor that slopes to a collection sump for collection and treatment of the water before discharge to the water body.

Dewatering in large upland ponds is typically used in conjunction with hydraulic dredging. The dredged sediments are pumped to the pond and allowed to settle. Clarified water is decanted and thickened sediment is removed once the pond fills to a level that reduces settling performance. The addition of baffles to the settling pond increases the effective holding time and separation. Figure 6-6 illustrates the layout of a 4-acre dewatering pond. This type of facility is currently used at Bayport to manage sediments dredged from the Green Bay navigation channel.

An in-river passive dewatering facility may also be considered in the design phase, particularly for the De Pere to Green Bay Reach or Little Lake Butte des Morts. An in-water facility could be constructed using sheet piling and likely requiring about 20 acres of river bottom. Dredge slurry would be pumped into a two-cell (or more) facility, dewatered, then dry excavated with earthmoving equipment. An underlying clay layer or bedrock would be a natural effective liner and would not entail additional construction costs or maintenance. An in-water facility would eliminate the need and cost of locating an upland area.

If temporary passive dewatering ponds are used, the performance requirements of Chapter NR 213 ("Lining of Industrial Lagoons and Design of Storage Structures") may apply. Alternatively, if WDNR decides to regulate passive dewatering ponds as a "solid waste processing facility," the requirements of the NR 500 series of rules may apply.

**Solidification.** Solidification involves mixing a chemical agent with dredged sediments to absorb moisture. Portland cement, pozzolan fly ash, fly ash/Portland cement mixtures, and lime kiln dust are common additives. The chemical agent and sediments may be mixed in a pug mill or in a contained area (e.g., a roll-off box or pit) using an excavator, depending upon sediment production rates and work space areas. Solidification is commonly used for sediments that have been partially dewatered by another means. Mechanically-dredged sediments can sometimes be solidified directly. Solidification is not a practical method for dewatering hydraulically-dredged sediments in the absence of thickening the solids by some other means, as the amount of chemical agent required becomes cost prohibitive. For the purposes of this FS, it was assumed that passively dewatered sediment would require solidification with 10 percent (w/w) lime, based on data provided in the SMU 56/57 Basis of Design Report (Montgomery-Watson, 1998).

## Screening Criteria for Dewatering

The principal criteria used to screen dewatering methods are the type of removal options selected for a given river reach and available land for construction and operation of a passive dewatering facility.

- **Hydraulic Dredging.** *A passive dewatering facility is selected for all hydraulic dredging options where there are greater than 10 to 15 acres of land available for construction and operation of the settling ponds.* At least one alternative will include mechanical dewatering to provide a comparison in costs.

- **Mechanical Dredging.** Passive on-barge dewatering is selected for all mechanical dredging options.

Additional operating parameters and constraints which must be considered in selecting the appropriate dewatering technique for the Lower Fox River include:

- **Production Rate.** The selected dewatering technique should produce dewatered sediments at a rate equivalent to the sediment removal rate. This allows sediment to be removed by the dredges without concern for sediment storage prior to dewatering.

- **Effectiveness.** The selected dewatering technique must be capable of consistently meeting specific the requirements for disposal. This requirement is at least 50 percent solids without the addition of any solidification agents.

- **Dewatering Barge Availability.** Dredge-barges with onboard water collection sumps are not locally available. Such a barge may need to be constructed locally.

- **Siting.** Placing a dewatering pond a significant distance from the river may be impractical from a material handling standpoint. It may also be impractical to remove a large wooded area to install a dewatering pond.

- **Discharge Water Quality.** All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a publicly-owned treatment works (POTW) or to the river. The drain water from standard dredge-barges may not meet WPDES requirements to return to the Lower Fox River without further water treatment.

## Screening Evaluation for Dewatering

**Implementability.** All three dewatering technologies discussed above are implementable for cleanup of sediments in the Lower Fox River and Green Bay. Space availability for settling basins along the Lower Fox River and Green Bay will be a key implementability consideration in the development and evaluation of remedial alternatives (Section 7).

Dredge-barges with onboard water collection sumps are not locally available and therefore may need to be constructed locally.

In all cases, the dewatering operation must be sized so that the production rate is compatible with the sediment removal (dredging) rate.

**Effectiveness.** The water removal technologies discussed here are commonly practiced and effective methods for dewatering sediments. For treatment or disposal, dewatering must be capable of generating a material of at least 50 percent solids without the addition of any solidification agents.

All water removed from the dredged sediments must meet certain regulatory requirements prior to discharge to a POTW or to the river. The drain water from standard dredge-barges may not meet WPDES requirements to return to the Lower Fox River without further water treatment.

### Dewatering Costs

Dewatering costs depend upon the size of the pond, time allowed to settle, physical properties of the material, and disposal requirements. For the Fox River project, passive dewatering costs are relatively low compared to moderately-priced mechanical dewatering options. However, the costs for dewatering are usually inversely proportional to disposal costs.

### Screening Decision

In this FS, passive dewatering in settling basins is assumed for dewatering hydraulically-dredged sediments. This dewatering method requires adequate upland or nearshore space (e.g., greater than 10 to 15 acres) for construction and operation of the settling basins. Passive on-barge dewatering is assumed for mechanical dredging options. Solidification may be useful during some elements of sediment remediation in the Lower Fox River and Green Bay, but is not central to the development of remedial alternatives in Section 7.

For the purposes of this FS, it was assumed that passive dewatering would occur in bermed areas lined with asphalt pavement to allow access by heavy equipment. Due to space limitations and a desire to maximize the settling time, the design storage depth is 8 feet, thereby limiting the land needed to approximately 10 acres for the Little Lake Butte des Morts and Appleton to Little Rapids reaches and 15 acres for the Little Rapids to De Pere Reach. It was further assumed that the dewatered solids content would be 35 percent after dewatering for a period of 3 to 6 months based on data provided in the SMU 56/57 Basis of Design Report (Montgomery-Watson, 1998). In order for the dewatered sediment to be handled and disposed, it was assumed that solidification using 10 percent lime was also necessary.

### 6.5.2 Wastewater Treatment

Water from the dredged sediment dewatering operation must be treated to meet effluent water quality criteria for discharge to the receiving system. The receiving system may be a permitted discharge to the river or bay, a POTW, or an industrial wastewater facility. Water quality may be adversely impacted in and around dredging operations through resuspension and dispersion of contaminated sediments. Therefore, controls on suspended solids are an important consideration in the development of remedial alternatives involving sediment removal. These were discussed with respect to the effectiveness of dredging (Section 6.4.2). Water quality is also an issue in dewatering operations where produced water may require treatment to meet discharge standards.

#### Water Treatment

**Mechanical Dredge Water Treatment.** Free water derived from mechanical dredging is principally within the transfer barges, or at the consolidation (stockpile) facility. Dredged sediment transfer barges are left idle before off-loading to allow for collection of free water at the surface of the load by sediment self-consolidation. The free water can then be decanted and pumped ashore to a water treatment system, if necessary, before unloading the dredged material. An onshore water treatment system may consist of one or several Baker tanks for primary sedimentation of solids, coagulant-aided secondary flocculent settling of remaining suspended solids, and filtration (i.e., sand, mixed media, activated carbon), if needed, to meet water quality requirements.

Shoreside stockpile areas can be graded, bermed, and lined to contain and collect sediment drainage and rainfall runoff. Once sufficiently dewatered, stockpiled material may be treated on site, or loaded onto trucks or rail cars for transport to the treatment or disposal facility.

Water treatment may be required to meet water quality requirements for discharge back to the river. At a minimum, treatment would involve gravity sedimentation and possibly filtration for solids removal. The disposal cell could be designed with a compartment for quiescent settling with or without coagulant addition. Free water present at the surface of the haul barge would be pumped ashore to the disposal cell/water treatment system before off-loading in order to minimize tendency for washout/spillage during the off-load swing. More involved treatment, depending on discharge criteria, could involve the use of standard process options such as:

- Coagulation, flocculation, and settling;
- Filtration (i.e., sand, mixed media);

- Adsorption using granular activated carbon; and
- Ozone, UV/ozone, or UV/peroxide oxidation.

Alternatively, gravity-separated water could be directly discharged to a POTW. The discharge of water to a POTW depends on meeting certain discharge criteria as set by the municipality. In the past, WDNR has authorized a minimum dilution zone for dredge water return flow. For the purposes of this FS Report, it is assumed that acute water quality criteria must be met at the point of discharge and a mixing zone or zone of initial dilution is allowed to satisfy chronic criteria.

**Hydraulic Dredge Water Treatment.** Hydraulic dredging results in a large volume of sediment-water slurry to be managed. Flow rates in small dredges can range from as little as 900 gpm (80 cy/hr) for a 6-inch dredge, to more than 4,000 gpm (354 cy/hr) for a 14-inch dredge. Hydraulic dredging rates in contaminated sediment removal are frequently limited by the capacity and treatment rates of the water quality system.

Conventional separation of solids from the dredged slurry occurs by gravity sedimentation in a suitably-sized, quiescent retention pond. The return flow is decanted over a weir to skim the clarified water from the surface in order to meet water quality requirements before discharge.

Other means of solids removal for hydraulic dredging have been tested (EPA, 1994a; SEDTEC, 1997). In 1995 through 1996, approximately 100,000 cy of hydraulically-dredged contaminated sediment was dewatered by adding a coagulant aid to the slurry stream and routing the flow through a set of two clarifiers for thickening and then through belt presses for landfilling (Ohio River Dredge and Dock, Inc.). A proprietary process (Solomon Venture, Lakewood, Colorado) reports success in using a system of screens and grids to remove particles down to 1-micron size at dredge flows of 1,200 gpm. An emerging solids separation technology uses geomembrane tubes designed to pass water, but not selected sediment sizes. Sandy sediments have been pumped into such tubes for separation of solids. However, the membranes may be subject to blinding (plugging) for high concentrations of fine-grained materials.

Given the physical limitations on ponding cell sizes, it is likely that the hydraulic dredge used for the Lower Fox River in Little Lake Butte des Morts and between Little Rapids and De Pere would be limited to the small dredge sizes: 6 to 10 inches.

Ponding cells would be sized to at least provide the required hydraulic retention capacity. However, the minimum cell size would also need to be balanced with the sediment storage capacity required for deposition of the affected fractions of dredged materials. For Lower Fox River sediment removal, the requirement for cell storage capacity for sediment deposition would dominate the primary cell sizing. A properly designed coagulant-aided solids separation system would be expected to produce return flow effluent with less than 200 mg/L total suspended solids.

An alternative would be a constructed gravity thickener, or clarifier, in place of the above secondary settling cell. As the flocculated sediment settles toward the bottom of the clarifier, the thickened underflow would be collected and pumped to a mechanical filtration system (i.e., belt press) to produce a dewatered solids cake. The withdrawn water is cycled back to the clarifier inflow. Clarifier overflow water (i.e., the clarified dredge flow) is discharged back to the waterway, after meeting water quality requirements. Additional treatment of the effluent may be needed for water quality compliance, and might include sand, mixed media, and/or activated carbon filtration. If needed, such end-stage treatment will be expensive and may result in selecting an alternate dredging/disposal method.

An alternative to gravity sedimentation would be to import or construct a mechanical filtration system on site. Proprietary commercial installations have reported success in solids removal and dewatering the full slurry stream from a small hydraulic dredge (i.e., Solomon Liquids, Lakewood, Colorado; Global Dewatering, Edmonton, Canada.). Such systems can be utilized in tandem to increase overall flow capacity, if needed, for a project of this size (2,000 gpm). A typical system utilizes screens and centrifuges for solids removal, in some cases aided by chemical coagulants and short-term gravity separation. A properly designed and operated system would be expected to produce a return flow with less than 200 mg/L total suspended solids.

A multi-cell settling/treatment pond would allow addition of a coagulating agent to assist in secondary (final) sedimentation before discharge (USACE, 1987). The primary (first) cell would settle and retain the coarser-grained sediment within the first few hours of retention. The overlying suspended fine-grained supernatant would be discharged to the secondary settling cell after mixing with a chemical coagulant to aid in flocculent settling. Addition of the coagulating agent would be mixed by turbulence within the gravity flow discharge pipe(s) from the primary cell into the secondary cell, or a static mixing tank could be added between the cells if the gravity flow energy was not sufficient to result in proper mixing. Final design of the system would require additional testing to identify an optimum coagulant and concentration.

### Other Wastewater Treatment Options

- **Off-site Commercial Treatment.** POTWs can be used for the treatment of effluent water from dredged sediments. This management option allows for the disposal of effluent waters. The discharge of water to a POTW is often dependent upon meeting certain discharge criteria as set by the municipality. This management method may be used in remedial alternatives where sediment dewatering is required.

- **Off-site Disposal of Hazardous Wastes.** Dredged material would be removed from dewatering cells as dewatered solids or filter cake by a rubber-tired front-end loader and loaded to screened refuse containers for transport to a treatment or disposal facility.

- **On-site Treatment of Organic Compound.** Carbon filtration and UV oxidation are commonly used management methods to remove organic compounds from effluent water. Treatment of organic compounds, depending upon concentrations, may be required to discharge effluent water to either a POTW or to the Lower Fox River under a WPDES permit. This management method may be used in remedial alternatives where sediment dewatering is required.

- **On-site Treatment of Suspended Solids and Metals.** Precipitation and froth tanks are commonly used management methods used to remove suspended solids and metals from effluent water. Treatment of suspended solids and metals, depending upon concentrations, may be required to discharge effluent water to either a POTW or the Lower Fox River under a WPDES permit. This management method may be used in remedial alternatives where sediment dewatering is required.

## 6.5.3 Residuals Management and Disposal

Residual management methods will be required for each remedial alternative. Residual management will vary depending upon the chosen remedial alternative. The following provides a description of each of the residual management methods including a summary of the applicability of these methods:

- **Off-site Disposal of Non-Hazardous Wastes.** Wastes such as personal protective equipment (PPE), filtration filters, and construction debris that is not characterized hazardous waste can be disposed of at a local municipal landfill. This management method will be used in all remedial alternatives. The quantity generated will depend upon the remedial alternative.

- **On-site Beneficial Use.** Dewatered and treated sediments may be suitable as soil/sediment construction fill or placed in newly-constructed CDFs as dikes or retaining walls. The feasibility of these disposal techniques depends upon the physical properties of the material, residual concentrations, local needs, and jurisdiction rulings.

No screening evaluation is necessary for residuals management and disposal process options.

### 6.5.4 Transportation

Transportation methods will be needed for any remedial alternative which involves removal of the contaminated sediments. The transportation methods included in each remedial alternative will be based upon the compatibility of that transportation method to the other process options. The following provides a description of each of the transportation methods including a summary of the compatibility of these methods:

- **Truck.** Transport of dewatered sediment over public roadways using dump trucks, roll-off boxes, or trailers. Includes associated loading facilities. This technology applies to transport for short distances, and will be used in remedial alternatives where dewatered sediment is transported to an in-state landfill.

- **Rail.** Transport of dewatered sediment by railroad using open gondolas. Includes associated loading facilities. This technology applies to transport over long distances (greater than 300 miles), and will be used in remedial alternatives where the dewatered sediment is transported to an out-of-state landfill.

- **Barge.** Transport of high-solids sediment through existing navigable waterways using barges. Includes associated unloading facilities on the river shoreline. This technology applies to transport on the river in segments between dams or locks, and will be used in remedial alternatives where sediment removal is conducted using a mechanical dredge.

- **Pipeline.** Transport of low-solids sediment through pipelines directly from dredge equipment to a receiving point on the river shoreline, or to an off-site location using conventional transport. This technology applies to transport on the river and can be conducted along a river segment, or over a dam. Pipeline transport will be used in remedial alternatives where sediment removal is conducted using a hydraulic dredge.

No screening evaluation is necessary for transportation.

### 6.5.5 Water Quality Management

All removal technologies may increase the suspended solid load of the overlying waters, but vary in their overall impact. Solids loss or resuspension may or may not be significant in terms of environmental impact on the water column. In general, environmental impact is related to the magnitude of losses. However, the impact of low losses from environmental dredging are likely to have minimal impact on the waterway (Appendix B). There are operational controls that can further reduce the impacts to water quality during dredging. For selection of the final removal technology(ies), these points must be considered for both environmental protectiveness and cost.

#### Dredge Operator

Water quality impacts can be controlled by the careful selection of dredging equipment as well as using specific operation and technical controls. These can include skilled operators working the dredging units at slower rates, careful placement of the dredging equipment, and use of sediment curtains or booms to control spread of suspended solids.

Field assessments have shown that sediment resuspension by hydraulic dredge can be minimized by careful operation of the dredge (USACE, 1990). This involves controlling the speed of cutterhead rotation, the swing speed, the rate of dredge advance, and depth of cut. Recommendations for minimizing sediment resuspension at the dredge head include maintaining a slow to moderate cutter rotational speed at 15 to 20 rpm, a slow swing speed of 0.3 to 0.5 ft/s, and limiting the minimum cut depth to the range of 50 to 100 percent of the suction pipe diameter.

#### Containment Barriers

Water quality impacts from sediment resuspension at the dredge can also be reduced by conducting the dredging within a silt curtain, silt screen, or sheet piling enclosure in order to contain migration of the suspended solids or turbidity plume. The silt curtain is generally constructed of impermeable fabric and is suspended from the surface to the river bottom where it is anchored. The silt curtain can extend completely to the bottom with appropriate fringe weights and anchors. Gravity settling of the denser sediment plume and loose re-settled solids will seek the lowest point, resulting in some migration beneath the silt curtain. Experience elsewhere indicates more than 90 percent reduction in suspended concentrations across the silt curtain can be achieved under favorable conditions. Silt curtains are not effective in current speeds above approximately 0.5 ft/s or in high winds or waves (EPA, 1994a).

In comparison, the silt screen is constructed of permeable fabric designed to pass water, but not fine-grained resuspended sediment. Either the silt curtain or screen must be placed, managed, and removed with care to avoid resuspension and release of contaminated sediment during operations. Silt curtains and screen placement and operation may be a source of resuspension of bed sediment due to dragging or alteration of local currents. The need for and benefit of containment systems during dredging must be weighed against the utility of and potential disadvantages of these systems.

Sheet piling may be selected when site conditions such as stray currents, high winds, changing water levels, excessive ship traffic and wave height, or drifting ice and debris preclude use of silt curtains/screens. Sheet piles are generally constructed of impermeable, interlocking steel plates that are driven below mudline into an underlying clay layer. If bedrock underlies the dredge prism, then piles can be connected to the bedrock using driving pins. Sheet piles can be expensive to install, difficult to remove without disturbing neighboring structures, and may be most practical in areas where "excessive" resuspension is expected.

## 6.6 Monitoring

Monitoring is a key control and assessment technology for sediment remediation. Numerous guidance documents confirm the necessity for monitoring to measure the effectiveness, stability, and integrity of source control measures, and to verify achievement of project RAOs (EPA, 1998a, 1994a; Krantzberg *et al.*, 1999). For contaminated sediment projects, monitoring can be grouped into five categories:

- Baseline monitoring,
- Short-term monitoring during implementation,
- Verification monitoring immediately following an action,
- Long-term operation and maintenance monitoring of storage sites, and
- Long-term performance monitoring to determine whether RAOs are attained.

### 6.6.1 Baseline Monitoring

Baseline monitoring establishes a statistical basis for comparing conditions before and after the cleanup action. The RI for the Lower Fox River and Green Bay presents a large body of data on the site. However, the database consists of information derived from numerous investigations that utilized varying methodologies. Further, the investigations cover a considerable time frame. Before implementing a specific cleanup action, baseline sampling and analysis of sediment and tissue samples will be required. The sampling design will be sufficiently rigorous to allow statistical comparison of conditions before, during, and following the cleanup action.

### 6.6.2 Implementation Monitoring

Short-term monitoring during remediation is used to evaluate whether the project is being implemented in accordance with specifications (i.e., performance of contractor, equipment, barriers, environmental controls). For removal or capping operations, short-term monitoring evaluates water quality near operations to determine whether contaminant resuspension and downgradient movement is being adequately controlled (e.g., with silt curtains). Water quality monitoring generally consists of surface water samples and frequent turbidity measurements. As demonstrated in the Deposit N pilot project, a PCB mass balance approach can be an effective method for tracking PCB mass management and loss through every phase. Bathymetric monitoring evaluates whether target sediments are being removed in dredging operations, or whether cap materials are being placed in the design location and at the design thickness. Bathymetry surveys are generally required during dredging operations to track removal progress and payment terms for contractors. Poling surveys are often used to ground-truth the bathymetry measurements. Other process monitoring may also be required depending on the remedial alternative. For example, sediment removal rates and slurry percent solids are important parameters to measure during hydraulic dredging operations.

### 6.6.3 Verification Monitoring

Verification monitoring evaluates post-removal surface and subsurface sediment conditions in dredging areas to confirm compliance with project specifications.

### 6.6.4 Operation and Maintenance Monitoring

Long-term maintenance monitoring of containment and/or disposal sites (i.e., nearshore fills, CAD sites, conventional *in-situ* caps) will be required to ensure adequate source control and continued stability of the structure. These O&M costs are included in the disposal (or containment) construction costs. The monitoring program will likely include surface and subsurface sediment and water quality monitoring, but the scope will be finalized during the remedial design phase.

### 6.6.5 Long-term Monitoring

Long-term monitoring evaluates sediment and tissue quality at the site for an extended period following the remedial action. In addition, disposal facilities are monitored for structural integrity and to ensure that the COCs continue to be contained. The scope of the former component of long-term monitoring (i.e., sediment and tissue sampling) is largely independent of the specific remedial action, although sampling locations and frequency can vary. The scope of the latter component depends on the location, type, and configuration of the disposal facility. A comprehensive *Long-term Monitoring Plan* for sediment and tissue quality for the Lower Fox River and Green Bay is detailed in Appendix C. Facility-specific monitoring is discussed in the context of remedial alternatives developed in Section 7.

No screening evaluation is necessary for monitoring options.

## 6.7 Section 6 Figures and Tables

Figures and tables for Section 6 follow page 6-74 and include:

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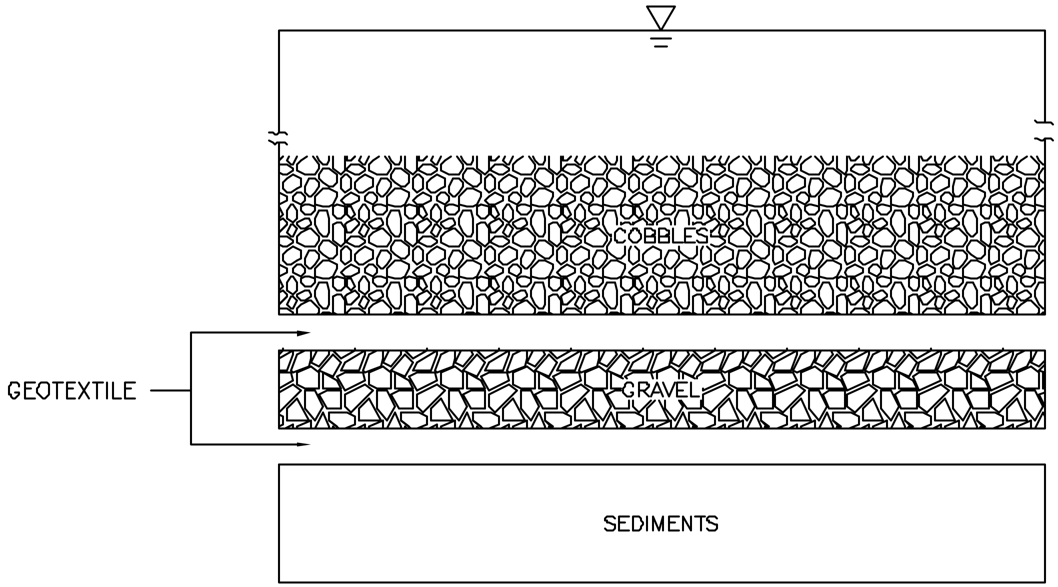
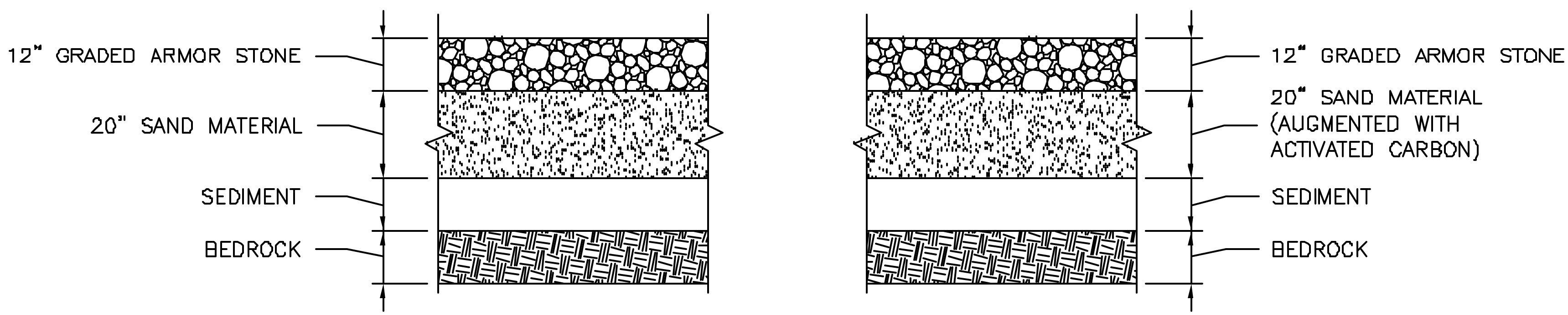



SHEBOYGAN FALLS, WI




MANISTIQUE HARBOR, MI

ThermoRetec

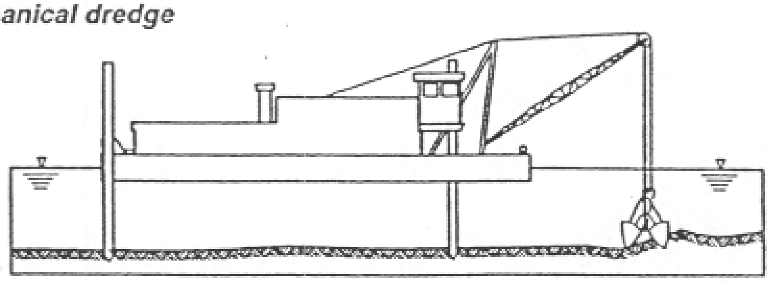
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

**EXAMPLES OF ARMORED CAPS**

DATE: 09/15/00 | DRWN: N.S. | FILE: 14414G001

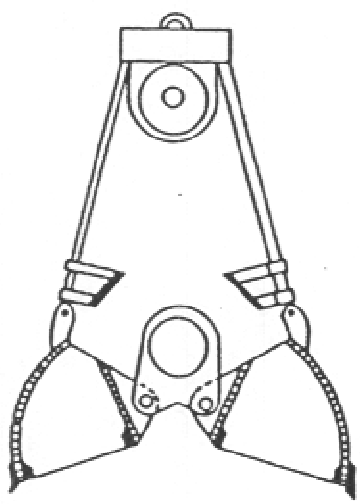
**FIGURE 6-1**

*Mechanical dredge*



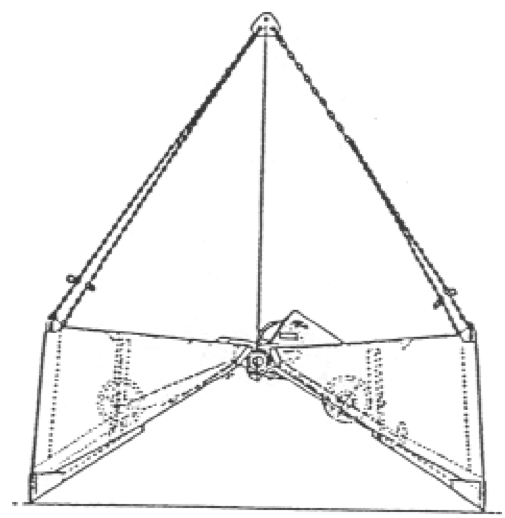
Source: USACE/USEPA (1992)

*Enclosed Bucket*



Source: Herbich and Brahme (1991).

*Cable Arm Bucket*



Source: Cable Arm, Inc.

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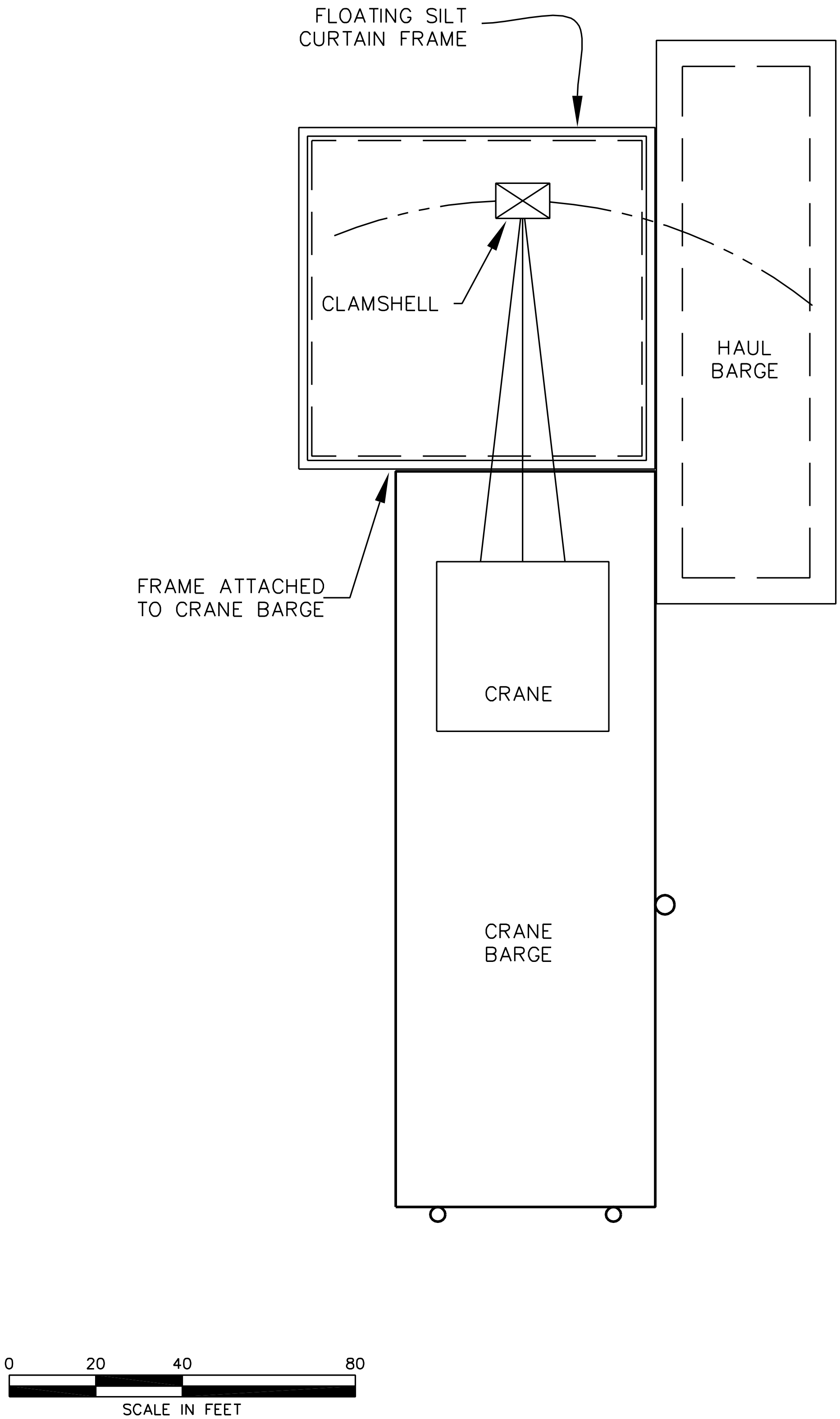
| | |
|---|---|
| LOWER FOX RIVER<br>FEASIBILITY STUDY<br>3-3584-900 | **EXAMPLES OF<br>MECHANICAL DREDGES** |
| CURRENT DATE 01-13-99 CADD FILE | **FIGURE 6-2** |

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LOWER FOX RIVER
FEASIBILITY STUDY
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**TYPICAL MECHANICAL DREDGE OPERATIONS**

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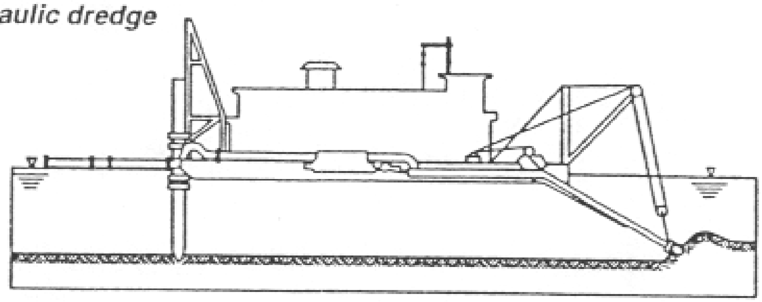
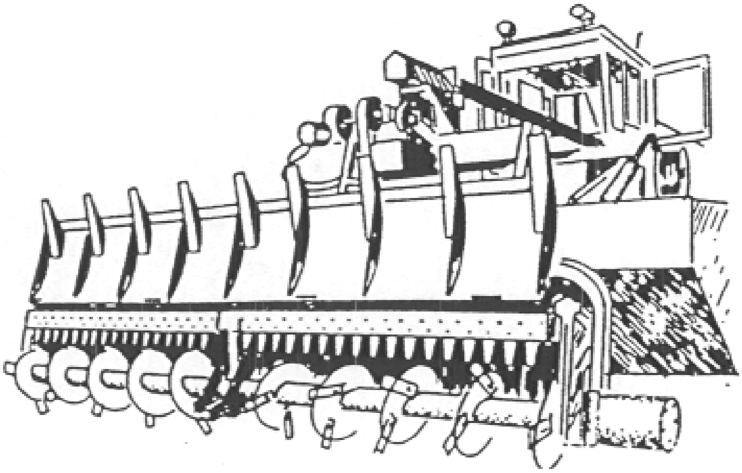
**FIGURE 6-3**

Hydraulic dredge

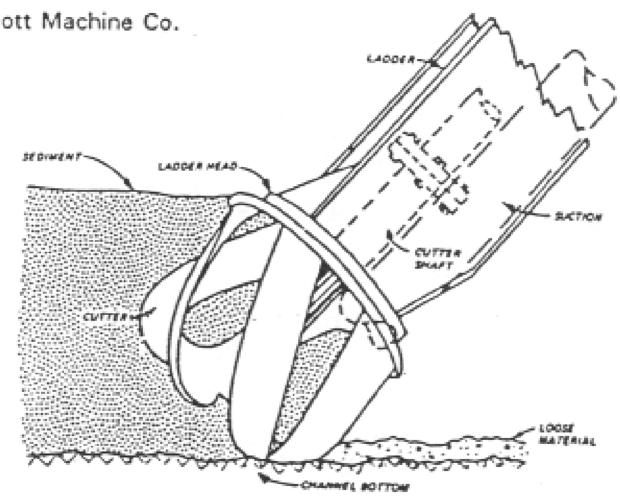


Source: USACE/USEPA (1992)



Horizontal Auger Dredge

Source: Ellicott Machine Co.




Conventional (Open Basket) Dredgehead

Source: Zappi and Hayes (1991)

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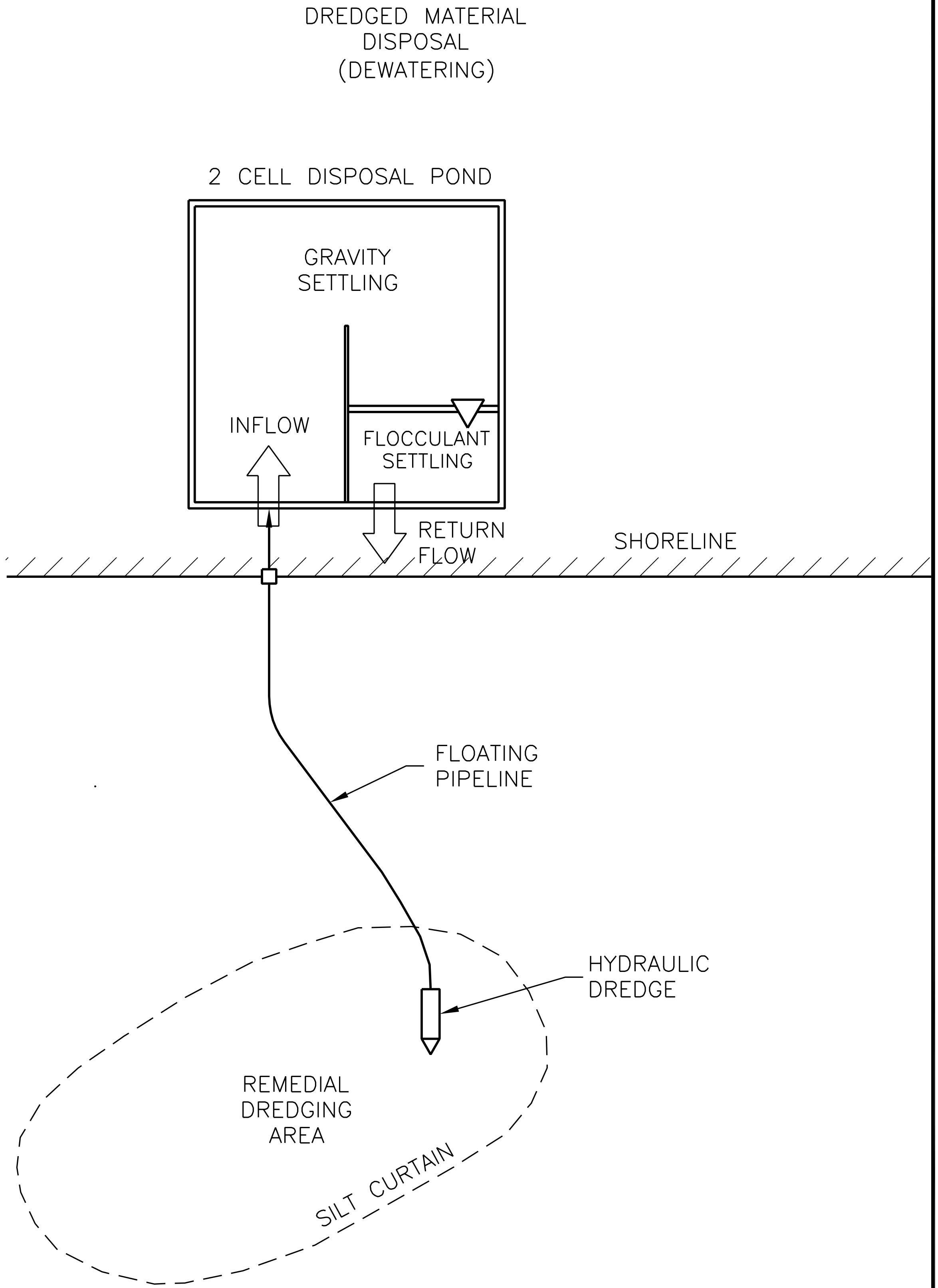
| LOWER FOX RIVER FEASIBILITY STUDY 3-3584-900 | EXAMPLES OF HYDRAULIC DREDGES |
|---|---|
| CURRENT DATE 01-13-99 CADD FILE | FIGURE 6-4 |

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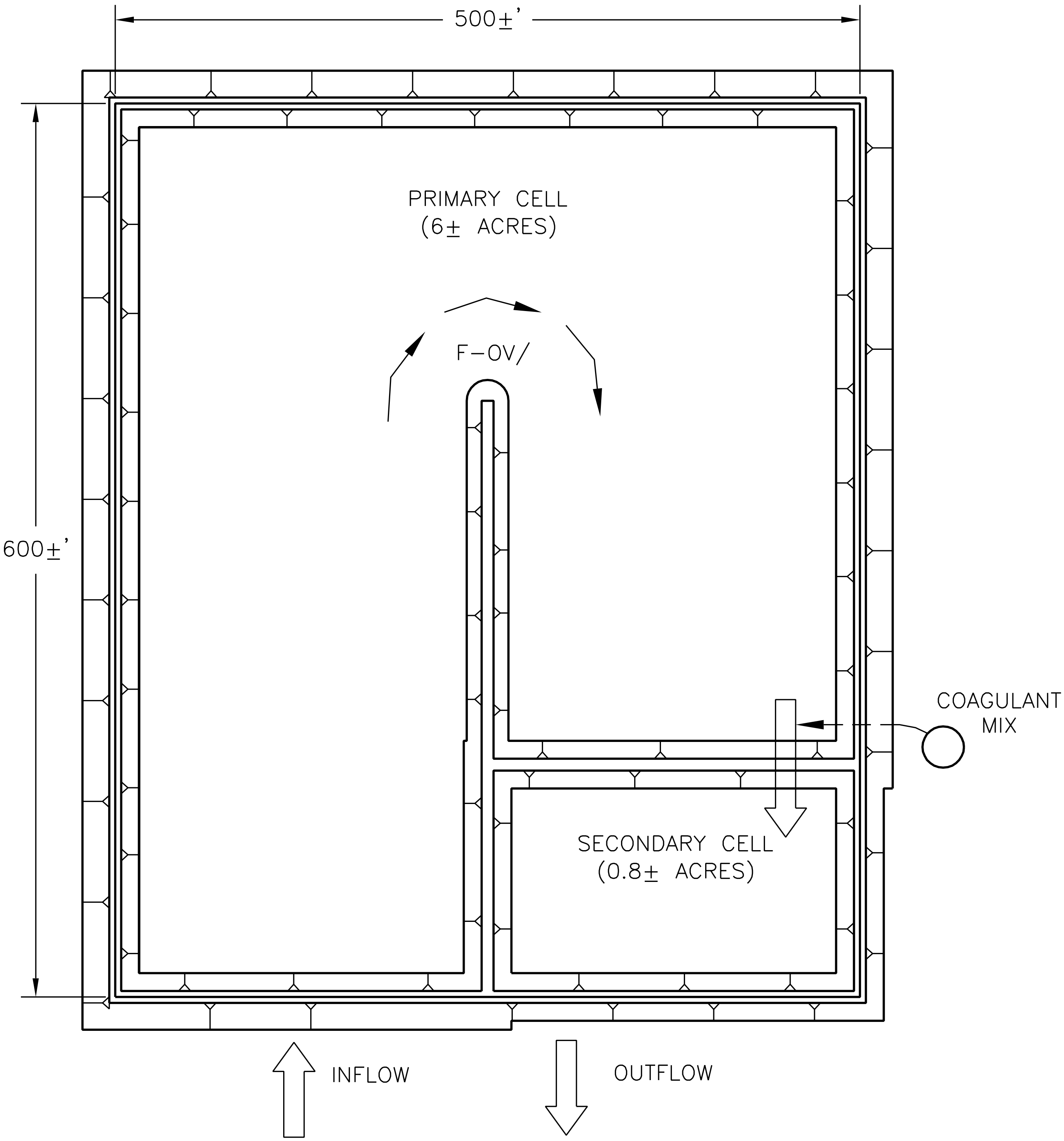
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

**CONCEPTUAL HYDRAULIC DREDGING TO DEWATERING POND**

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D003

**FIGURE 6-5**



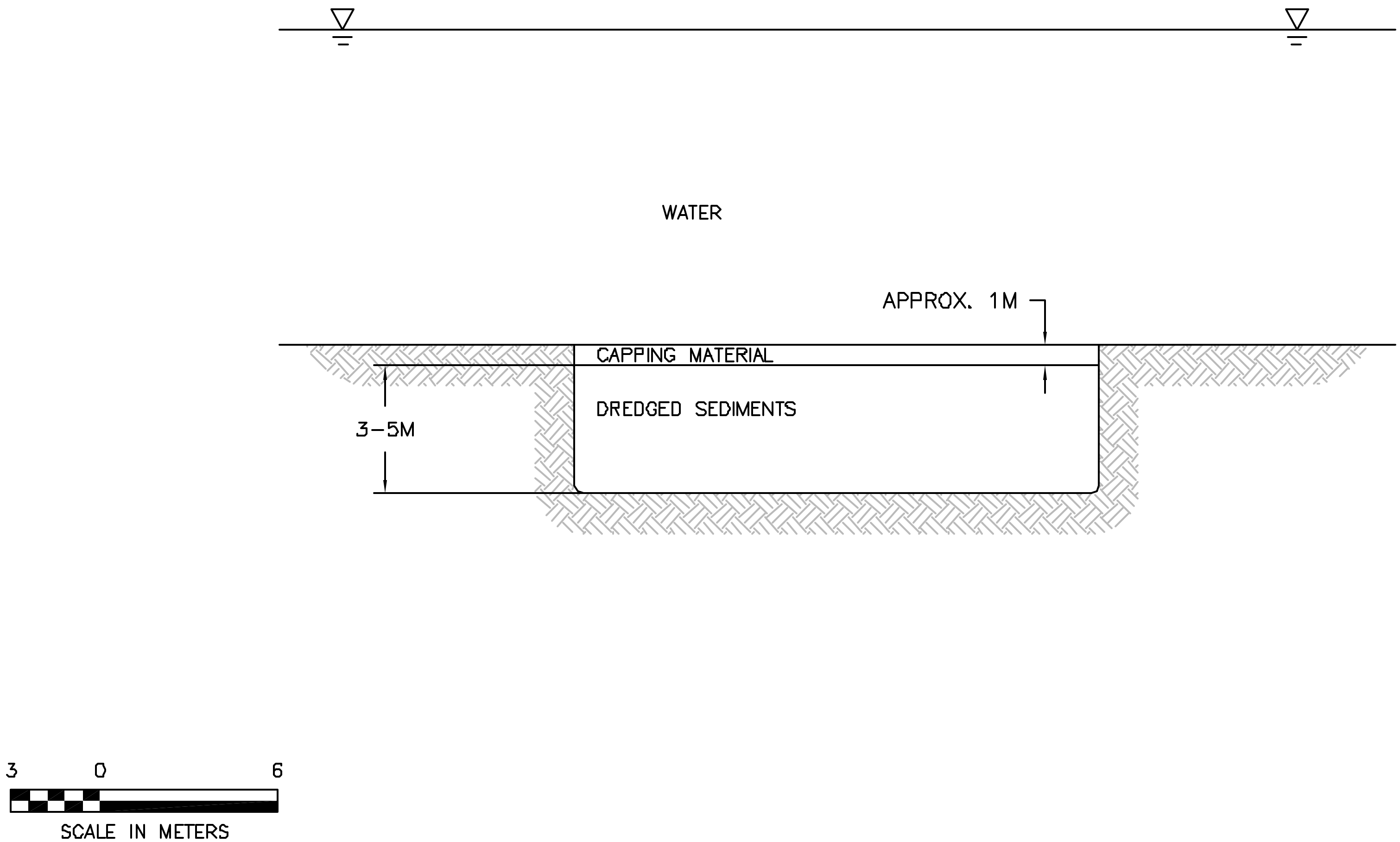

ThermoRetec

LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

**CONCEPTUAL LAYOUT OF A GRAVITY DEWATERING POND**

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D005

**FIGURE 6-6**

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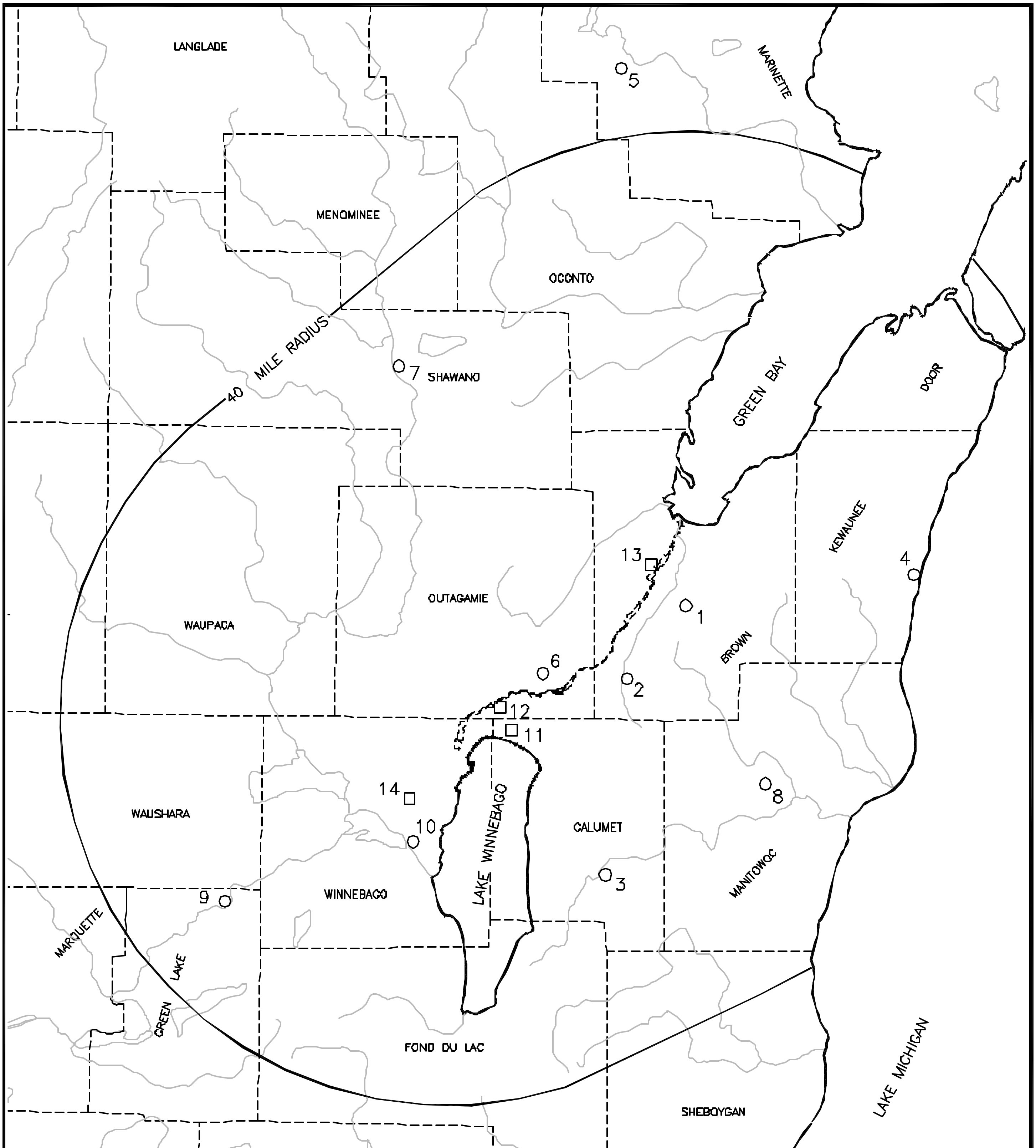
LOWER FOX RIVER
FEASIBILITY STUDY
WISCN-14414-535

DATE: 04/19/01 | DRWN: S.E. | FILE: 14414G002

**CROSS-SECTION OF CONFINED AQUATIC DISPOSAL**

**FIGURE 6-7**




# LOWER FOX RIVER GENERAL LANDFILL LOCATION MAP

N W E S

LEGEND

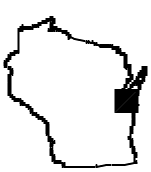
3500' 0 7000'

SCALE 1"=7000'

○ 21 GENERAL LOCATION MUNICIPAL LANDFILL

□ 15 GENERAL LOCATION NON MUNICIPAL LANDFILL

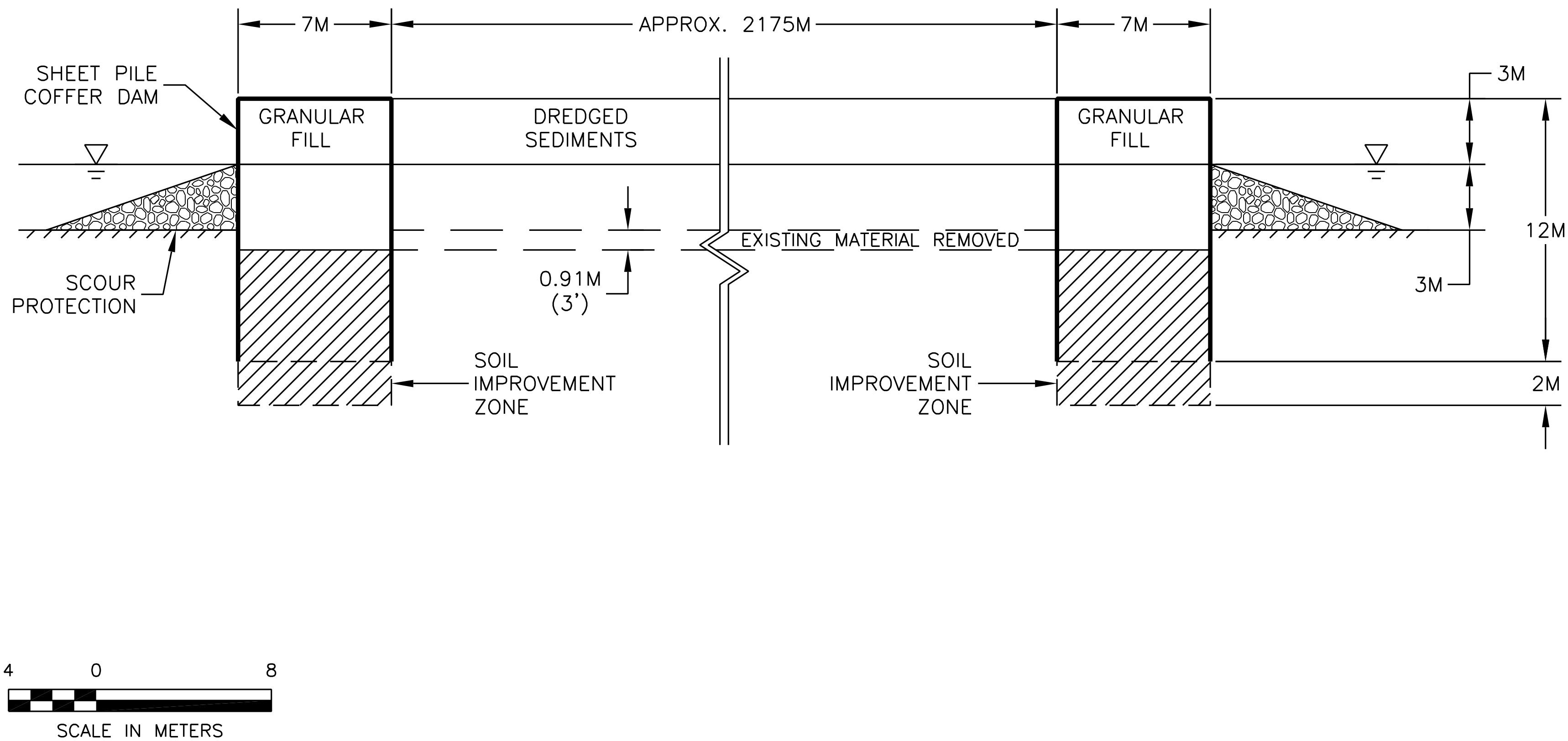
(NUMBERS CORRESPOND TO LANDFILLS LISTED ON TABLE 6-17 OF FEASIBILITY STUDY)



LOCATION KEY

ThermoRetec

| LOWER FOX RIVER FEASIBILITY STUDY WISCN-14414-535 | | GENERAL LANDFILL LOCATION MAP | |
|---|---|---|---|
| CURRENT DATE | 04/19/01 | CADD FILE | 14414s019 |
| | | | FIGURE 6-8 |

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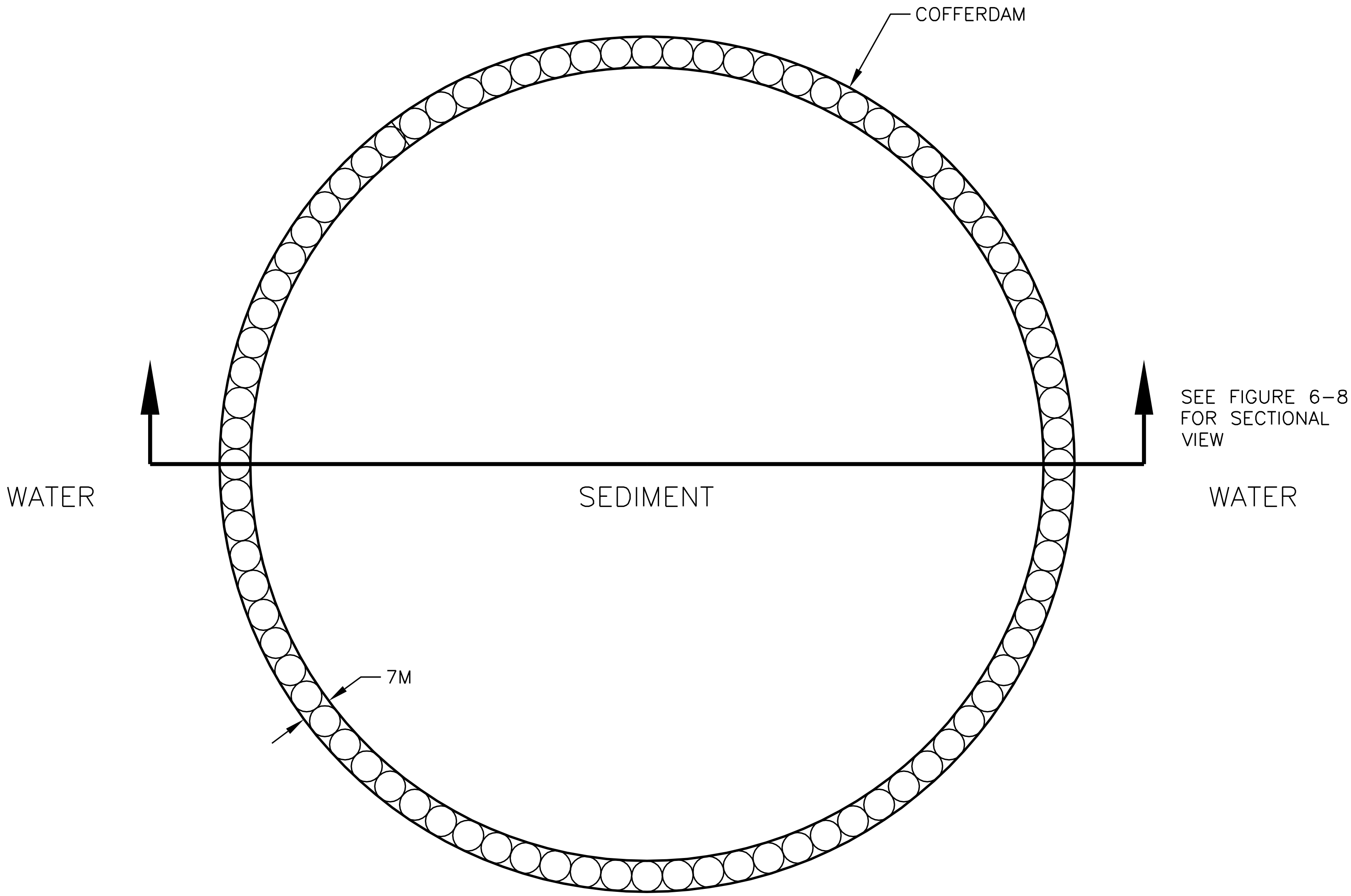
DATE: 07/26/00 | DRWN: N.S. | FILE: 14414D001

**CROSS-SECTION OF CELLULAR COFFERDAM CDF**

**FIGURE 6-9**




NOT TO SCALE

ThermoRetec

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FEASIBILITY STUDY
WISCN-14414-535

DATE: 07/12/01 | DRWN: N.S. | FILE: 14414D002

**PLAN VIEW OF WASTE CELLULAR COFFERDAM CDF**

**FIGURE 6-10**

## Table 6-1 Guidance and Literature Resources Used to Develop the List of Potentially Applicable Technologies for Cleanup of the Lower Fox River and Green Bay

- *Remediation Technologies Screening Matrix and Reference Guide, Second Edition* (DOD, 1994)
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Final Summary Report* (EPA, 1994a)
- *Assessment and Remediation of Contaminated Sediments (ARCS) Program, Remediation Guidance Document* (EPA, 1994a)
- *Review of Removal, Containment and Treatment Technologies for Remediation of Contaminated Sediment in the Great Lakes* (Averett *et al.*, 1990)
- *Dredging, Remediation, and Containment of Contaminated Sediments* (Demars *et al.*, 1995)
- *SEDTEC: A Directory of Contaminated Sediment Removal and Treatment Technologies* (SEDTEC, 1997)
- *Record of Decision, Sheboygan River and Harbor, Sheboygan, Wisconsin* (EPA, 2000a)
- *Remedial Investigation Report for Contaminated Sediment Deposits on the Fox River: Little Lake Butte des Morts to the De Pere Dam* (GAS/SAIC, 1996)
- *Feasibility Study Report for Deposits POG and N on the Fox River* (GAS/SAIC, 1997)
- *Remedial Investigation/Feasibility Study - Little Lake Butte des Morts - Sediment Deposit A* (Blasland & Bouck Engineers, P.C., 1993)
- *Engineering Evaluation/Cost Analysis: Manistique River and Harbor* (BBL, 1994)
- *Sheboygan River and Harbor Feasibility Study* (BBL, 1998)
- *Feasibility Study Report - Deposit A Little Lake Butte des Morts* (EWI Engineering Associates, Inc., 1992)
- Dredging Dallas' White Rock Lake in *World Dredging Mining and Construction,* April 1998. Describing a 20-mile-long slurry pipe run to disposal site (Sosnin, 1998).

## Table 6-2 Summary of Technologies Reviewed and Retained[3]

| General Response Action | Remedial Technology | Process Option |
|---|---|---|
| No Action | None | Not Applicable |
| Institutional Controls | Physical, Engineering or Legislative Restrictions | Consumption Advisories<br>Access Restriction<br>Dredging Moratorium |
| Monitored Natural Recovery | Physical Degradation | Combination of Desorption, Diffusion, Dilution, Volatilization, Resuspension, and Transport |
| | Biological Degradation | Dechlorination (aerobic and anaerobic) |
| | Physical Burial | Sedimentation |
| Containment | Capping | Conventional Sand Cap<br>Sediment Clay Cap<br>Armored Cap<br>Composite Cap<br>Thin-layer Cap<br>Enhanced Cap |
| | Rechannelization | Construct New Channels |
| Removal | Dredging | Hydraulic Dredging<br>Mechanical Dredging |
| | Dry Excavation | Excavator (for specific conditions) |
| *In-situ* Treatment | Biological | *In-situ* Slurry Biodegradation<br>*In-situ* Aerobic Biodegradation<br>*In-situ* Anaerobic Biodegradation |
| | Chemical | *In-situ* Slurry Oxidation<br>Aqua MecTool™ Oxidation<br>*In-situ* Oxidation<br>Electrochemical Oxidation |
| | Physical Extractive Processes | Sediment Flushing<br>SVE/Thermally Enhanced SVE/Bioventing<br>Air Sparging |
| | Physical-Immobilization | Air Sparging MecTool™ Stabilization<br>Vitrification<br>Imbiber Beads™<br>Ground Freezing |

3 **Note:** Shading designates technologies that were retained in developing remedial alternatives.

## Table 6-2 Summary of Technologies Reviewed and Retained (Continued) [3]

| General Response Action | Remedial Technology | Process Option |
|---|---|---|
| *Ex-situ* Treatment | Biological | Landfarming/Composting<br>Biopiler<br>Fungal Biodegradation<br>Slurry-phase Biological Treatment<br>Enhanced Biodegradation |
| | Chemical | Acid Extraction<br>Solvent Extraction<br>Slurry Oxidation<br>Reduction/Oxidation |
| | Chemical/Physical | Dehalogenation<br>Sediment Washing<br>Radiolytic Dechlorination |
| | Physical | Separation<br>Solar Detoxification<br>Solidification |
| | Thermal | Incineration<br>High-temperature Thermal Desorption<br>Low-temperature Thermal Desorption<br>Pyrolysis<br>Thermal Destruction<br>Vitrification<br>High-pressure Oxidation |
| Disposal | On Site | Level Bottom Cap<br>Confined Aquatic Disposal (CAD)<br>Confined Disposal Facility (CDF)<br>Nearshore Biofiltration Cell<br>Upland Confined Fill |
| | Off Site | Existing Upland Landfill<br>Dedicated New Landfill<br>TSCA Landfill<br>Upland Confined Fill (commercial)<br>Upland Fill (residential) |

[3] **Note:** Shading designates technologies that were retained in developing remedial alternatives.

# Table 6-3 Description of Potential Remedial Technologies

| GRA | Technology | Process Option | Description |
|---|---|---|---|
| **No Action** | *None* | Not Applicable | No active remedy (i.e., passive remediation by natural processes). |
| **Institutional Controls** | *Physical, Engineering, or Legislative Restrictions* | Consumption Advisories | Advisories to indicate that consumption of fish in the area may present a health risk. |
| | | Access Restrictions | Constraints, such as fencing and signs, placed on property access. |
| | | Dredging Moratorium | Restricts dredging operations. |
| **Monitored Natural Recovery** | *Physical Degradation* | Combination | Desorption, diffusion, dilution, volatilization, resuspension, and transport. |
| | *Biological - Degradation* | Dechlorination (aerobic and anaerobic) | Chlorine atoms are removed from PCB molecule by bacteria, however, toxicity reduction is not directly correlated to dechlorination. |
| | *Physical - Burial* | Sedimentation | Impacted sediments are buried to deeper intervals which are not in the biologically active zone. |
| **Containment** | *Capping* | Conventional Sand Cap | Placement of clean sand over existing contaminated bottom to physically isolate contaminants. |
| | | Conventional Sediment/Clay Cap | Use of dredged fine-grained sediments or commercially-obtained clay materials to achieve contaminant isolation. |
| | | Armored Cap | Cobbles, pebbles or larger material are incorporated into the cap to prevent erosion in high-energy environments, or to prevent cap breaching by bioturbators (example: membrane gabions). |
| | | Composite Cap | Soil, media and geotextile cap over contaminated material to inhibit contaminated pore water migration and/or inhibit bioturbators. |
| | | Thin Layer Cap | Application of a thin (1"–3") layer of clean sediments and allowing natural resorting or bioturbation to mix the contaminated and clean sediments, which results in a surface layer of impacted material within acceptable levels. |
| | | Enhanced Cap | Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding or destruction of contaminants migrating in pore water. |
| | *Rechannelization* | Construction of New Channels | Construction of new channels to reroute surface water through non-impacted sediments or soils. |
| **Removal** | *Dredging* | Hydraulic Dredging | A rotating cutterhead loosens sediment at the suction mouth, where a centrifugal pump draws the sediment/water slurry through the pipeline. Performs efficiently in most sediments. Resuspension losses can be minimized by operational controls. |
| | *Dry Excavation* | Mechanical Dredging | A mechanical dredge consists of a barge-mounted floating crane that maneuvers a cable-suspended dredging bucket. The bucket is lowered into the sediment, and when withdrawn the cable closes the jaws of the bucket, retaining dredged material. |
| | | Excavator | This removal option includes erecting sheet piles, or a cofferdam, around the contaminated sediments to dewater. Removal would then involve conventional excavation (backhoe) equipment. |
| ***In-situ* Treatment** | *Biological* | *In-situ* Slurry Biodegradation | Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen levels, nutrients, and pH are controlled to enhance degradation. Would require sheet piling around entire area and slurry treatment would be performed using aerators and, possibly, mixers. |
| | | *In-situ* Aerobic Biodegradation | Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen levels, nutrients, and pH are controlled to enhance degradation. |

## Table 6-3 Description of Potential Remedial Technologies (Continued)

| GRA | Technology | Process Option | Description |
|---|---|---|---|
| *In-situ* Treatment (Continued) | *Biological (Continued)* | *In-situ* Anaerobic Biodegradation | Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients, and pH are controlled to enhance degradation. |
| | *Chemical* | *In-situ* Slurry Oxidation | Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton's Reagent. |
| | | Aqua MecTool™ Oxidation | A caisson (18' × 18') is driven into the sediment and a rotary blade is used to mix sediment and add oxidizing agents such as ozone, peroxide, or Fenton's Reagent. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated. |
| | | *In-situ* Oxidation | An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics. |
| | | Electrochemical Oxidation | Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics. |
| | *Physical-Extractive Processes* | Sediment Flushing | Water or other aqueous solution is circulated through impacted sediment. An injection or infiltration process introduces the solution to the impacted area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled. |
| | | SVE/Thermally Enhanced SVE/ Bioventing | An array of extraction and injection wells is used to physically strip volatile contaminants or to stimulate biodegradation in unsaturated soil. Oxygen levels, nutrients, and pH can be controlled in bioventing applications. Removal may be enhanced by heating the system. |
| | | Air Sparging | An array of injection wells is used to physically strip volatile contaminants or to stimulate biodegradation in unsaturated soil. Oxygen levels, nutrients, and pH can be controlled to enhance biological activity. |
| | *Physical-Immobilization* | Aqua MecTool™ Stabilization | A caisson (18' × 18') is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated. |
| | | Vitrification | Uses and electric current to melt soil or other earthen materials at extremely high temperatures (2,900˚–3,650 ˚F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis. *In-situ* applications use graphite electrodes to heat soil. |
| | | Imbiber Beads™ | A "cover blanket" of Imbiber Beads™ placed over contaminated sediments to enhance anaerobic microbial degradation processes and allow exchange of gases between sediments and surface water. The beads are spherical plastic particles that would absorb PCB vapors generated. |
| | | Ground Freezing | An array of pipes is placed in the ground and brine at a temperature of -20˚ to -40 ˚C is circulated to freeze soil. Is only recommended for short-duration applications and to assist with excavation. |
| *Ex-situ* Treatment | *Biological* | Landfarming/ Composting | Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using a windrow composter, conventional tilling equipment, or other means to provide aeration. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems. |
| | | Biopiles | Excavated sediments are mixed with amendments and placed in aboveground enclosures. It is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. |

# Table 6-3 Description of Potential Remedial Technologies (Continued)

| GRA | Technology | Process Option | Description |
|---|---|---|---|
| *Ex-situ* Treatment (Continued) | *Biological (Continued)* | Fungal Biodegradation | Fungal biodegradation refers to the degradation of a wide variety of organopollutants by using their lignin-degrading or wood-rotting enzyme system (example: white rot fungus). |
| | | Slurry-phase Biological Treatment | An aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors). |
| | | Enhanced Biodegradation | Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation. Use of heat to break carbon-halogen bonds and to volatilize light organic compounds (example: D-Plus [Sinre/DRAT]). |
| | *Chemical* | Acid Extraction | Waste-contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use. |
| | | Solvent Extraction | Waste-contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process). |
| | | Slurry Oxidation | The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton's Reagent. |
| | | Reduction/ Oxidation | Reduction/oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide. |
| | *Chemical/ Physical* | Dehalogenation | Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition or BCD) or potassium polyethylene glycol (APEG). The mixture is heated to above 630 ˚F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride. |
| | | Sediment Washing | Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals. |
| | | Radiolytic Dechlorination | Sediment is placed in alkaline isopropanol solution and gamma irradiated to a dose of <10 (~1% solution). Products of this dechlorination process are biphenyl, acetone, and inorganic chloride. Process must be carried out under inert atmosphere. |
| | *Physical* | Separation | Contaminated fraction of solids are concentrated through gravity, magnetic or sieving separation processes. |
| | | Solar Detoxification | Through photochemical and thermal reactions, the ultraviolet energy in sunlight destroys contaminants. |
| | | Solidification | The mobility of constituents in a "solid" medium are reduced through addition of immobilization additives. |
| | *Thermal* | Incineration | Temperatures greater than 1,400˚ F are used to volatilize and combust organic chemicals. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system. |

# Table 6-3 Description of Potential Remedial Technologies (Continued)

| GRA | Technology | Process Option | Description |
|---|---|---|---|
| *Ex-situ* Treatment (Continued) | *Thermal (Continued)* | High-temperature Thermal Desorption (HTTD) | Temperatures in the range of 600˚–1,200 ˚F are used to volatilize organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions. |
| | | Low-temperature Thermal Destruction | Temperatures in the range of 200˚–600 ˚F are used to volatilize and combust organic chemicals. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions. |
| | | Pyrolysis | Chemical Decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash. |
| | | Thermal Desorption | Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system (examples: X*TRAX™, DAVES, Tacuik Process and Holoflite™ Dryer). |
| | | Vitrification | Uses an electric current to melt soil or other earthen materials at extremely high temperatures (2.900˚–3,650 ˚F). |
| | | High-pressure Oxidation | High temperature and pressure used to break down organic compounds. Operating temperatures Range from 150˚–600 ˚C and pressures range from 2,000–22,300 MPa (examples: wet air oxidation and supercritical water oxidation). |
| Disposal | *On-site Disposal* | Level-bottom Cap | Relocation of impacted sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water. Relocation of impacted sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water. |
| | | Confined Aquatic Disposal (CAD) | Place untreated sediment within a lateral containment structure (i.e., bottom depression or subaqueous berm) and cap with clean sediment. |
| | | Confined Disposal Facility (CDF) | Place untreated sediment in a nearshore confined disposal facility that is separated from the river by an earthen berm or other physical barrier and capped to prevent dermal contact. |
| | | Nearshore Biofiltration Cell | Contaminated sediment is placed in a nearshore confined treatment facility (CTF) where the contents are manipulated to enhance naturally-occurring biodegradation. |
| | | Upland Confined Fill | Place treated sediment at an on-site location. Location may require cap or other containment devices based on analytical data. |
| | *Off-site Disposal* | NR 500 WAC Landfill (county, private, industrial landfills) | Off-site disposal at a licensed commercial facility that can accept nonhazardous dewatered sediment. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation. |
| | | Dedicated New Upland Landfill | A new dedicated landfill designed to contain all PCB-impacted sediments removed from the Lower Fox River. |
| | | TSCA Subtitle C Landfill | Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment. Depends on analytical data from dredged sediment. Dewatering required to reduce water content for transportation. |
| | | Upland Confined Fill (commercial/-industrial) | Place treated or untreated sediment at an off-site location. Location may require cap or other containment devices based on analytical data. |
| | | Upland Fill (residential/clean) | Place treated sediment at an off-site location. Requires that sediment be treated to a level that allows no restriction reuse. |

# Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal

| GRA | Technology | Process Option | Initial Screening | | Final Screening | | |
|---|---|---|---|---|---|---|---|
| | | | **Implementability** | **Screening Decision** | **Effectiveness** | **Cost** | **Screening Decision** |
| **No Action** | *None* | Not Applicable | Potentially applicable. | Retained | Retainment required. | Low | Retained |
| **Institutional Controls** | *Physical, Engineering, or Legislative Restrictions* | Consumption Advisories | Potentially applicable. | Retained | Provides limited protection. | Low | Retained |
| | | Access Restrictions | Potentially applicable. | Retained | Provides limited protection. | Low | Retained |
| | | Dredging Moratorium | Potentially applicable. | Retained | Provides limited protection. | Low | Retained |
| **Monitored Natural Recovery** | *Physical Degradation* | Desorption, Diffusion, Dilution, Volatilization | Potentially applicable. | Retained | Surface sediment concentrations are generally decreasing over time, but not at depth. PCB volatilization in Green Bay indicates degradation is occurring. | Low | Retained |
| | *Biological - Degradation* | Dechlorination (aerobic and anaerobic) | Potentially applicable. | Retained | Relatively successful for sediments with high PCB levels, but little degradation occurs at lower PCB levels. | Low | Retained |
| | *Physical Processes* | Sedimentation Burial | Potentially applicable. | Retained | Deposition and reburial is occurring, but based on bed elevation changes over time, much of the sediment is resuspended. | Low | Retained |
| | | Resuspension and Transport | Potentially applicable. | Retained | Bed elevation changes over time indicate transport is occurring. | Low | Retained |
| **Containment** | *Capping* | Conventional Sand Cap | Easily applied *in-situ*, however, scouring must be considered. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation. | Retained | Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Modeling will be necessary to determine if a thin-layer cap will provide adequate protection of the water column from dissolved PCBs. | Low | Retained |

## Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal (Continued)

| GRA | Technology | Process Option | Initial Screening | | Final Screening | | |
|---|---|---|---|---|---|---|---|
| | | | Implementability | Screening Decision | Effectiveness | Cost | Screening Decision |
| Containment (Continued) | *Capping (Continued)* | Conventional Sediment/Clay Cap | Placement of cap within the waterway may require special engineering controls. Difficult to place clay portion of a cap. Minimizes cap thickness in areas with shallow water depth. | Retained | Sediment with silt and clay is effective in limiting diffusion of contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Clay caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption. These properties increase dissolution to the overlying water column and/or recontamination of sediment within the bioactive zone (upper 10 cm). | Low | Retained |
| | | Armored Cap | Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation. | Retained | Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Armoring minimizes scouring. | Low to Moderate | Retained for limited use in high-energy sections of river |
| | | Composite Cap (geotextile) | Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation. | Retained | Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Use of geotextiles may not be necessary for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. | Low to Moderate | Retained |
| | | Thin-layer Cap | Minimizes reduction in water depth that may limit future use of river and may impact flooding, stream bank erosion, navigation, and recreation. | Retained | Effective for contaminants that are amenable to natural attenuation. PCBs are not amenable to natural attenuation. | Low | Eliminated |

# Table 6-4 Screening of Potential Remedial Technologies - No Action, Containment, and Removal (Continued)

| GRA | Technology | Process Option | Initial Screening: Implementability | Initial Screening: Screening Decision | Final Screening: Effectiveness | Final Screening: Cost | Final Screening: Screening Decision |
|---|---|---|---|---|---|---|---|
| Containment (Continued) | *Capping (Continued)* | Enhanced Cap | Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation and recreation. | Retained | Provides similar direct contact protection as sand cap, but additives are designed to increase retention time in the cap or treat pore water. Additives used for the purpose of increasing retention time and treating pore water would have little effect on PCBs with low solubility and high sorption. | Low to Moderate | Eliminated |
| Containment (Continued) | *Rechan-nelization* | Construction of New Channels | Rerouting channels is often not feasible for the Lower Fox River. | Eliminated | | | |
| Removal | *Dredging* | Hydraulic Dredging | Produces low slurry density and results in high water treatment costs. Limited ability to remove debris. | Retained | Can effectively dredge all types of materials. Superior in minimizing sediment resuspension compared to other dredges. Low slurry density. | Low | Retained |
| Removal | *Dredging* | Mechanical Dredging | Readily available in the U.S. Vessel draft precludes operations in water with depths less than 6'. May be difficult to implement upstream of the De Pere dam due to barge access/construction issues. | Retained | Can be operated to produce low suspended solids in the water column, thereby reducing water quality impacts. Level cut and low suspended solids also provide less opportunity for recontamination of dredged areas. | Low | Retained |
| Removal | *Dry Excavation* | Excavator | An enclosed and drained berm or sheet pile wall would need to be constructed to be water-impervious and water needs to be removed or diverted. Difficult to implement in deeper water or areas with bedrock. | Retained | Sheet pile isolates contaminated area during removal activities to minimize contamination of nearby sediments and water. | Moderate to High | Retained |

# Table 6-5 Screening of Potential Remedial Technologies - Treatment

| GRA | Technology | Process Option | Initial Screening | | Final Screening | | |
|---|---|---|---|---|---|---|---|
| | | | Implementability | Screening Decision | Effectiveness | Cost | Screening Decision |
| *In-situ* Treatment | *Biological* | *In-situ* Slurry Biodegradation | Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Biodegradation has not been demonstrated to effectively remediate PCBs. No known full-scale applications. | Eliminated | | | |
| | | *In-situ* Aerobic Biodegradation | Work performed to date has only been performed in the laboratory. Some contaminants (e.g., PCBs) generally not amenable to aerobic degradation. Has not been effective for PCBs in field demonstrations. | Eliminated | | | |
| | | *In-situ* Anaerobic Biodegradation | Work performed to date has only been performed in the laboratory. Laboratory testing data has indicated only minor removal is achievable. Has not been effective for PCBs in field demonstrations. | Eliminated | | | |
| | *Chemical* | *In-situ* Slurry Oxidation | Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications. | Eliminated | | | |
| | | Aqua MecTool™ Oxidation | May have difficulty injecting high air flows into caisson with standing water while preventing generation of TSS. No known completed full- or pilot-scale projects. | Eliminated | | | |
| | | *In-situ* Oxidation | Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications. | Eliminated | | | |
| | | Electrochemical Oxidation | Applicability for use in water is not known. No demonstrated sediment application. | Eliminated | | | |
| | *Physical-Extractive Processes* | Sediment Flushing | Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. No known full-scale applications. | Eliminated | | | |
| | | SVE/Thermally Enhanced SVE/ Bioventing | Technology is applicable to vadose zone soil or dewatered soil. | Eliminated | | | |

# Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

| GRA | Technology | Process Option | Initial Screening: Implementability | Initial Screening: Screening Decision | Final Screening: Effectiveness | Final Screening: Cost | Final Screening: Screening Decision |
|---|---|---|---|---|---|---|---|
| *In-situ* Treatment (Continued) | *Physical-Extractive Processes (Continued)* | Air Sparging | Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles. Possible generation of exceedances through leakage from sheet pile. Targets VOCs and other readily degradable organics rather than PCBs. No known sediment applications. | Eliminated | | | |
| | *Physical-Immobilization* | Aqua MecTool™ Stabilization | Proprietary technology that has been used in a pilot-scale application in Wisconsin with coal tar-contaminated sediments. Previous trials with this technology created water treatment problems inside the caisson. | Eliminated | | | |
| | | Vitrification | Requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications. | Eliminated | | | |
| | | Imbiber Beads™ | Not well demonstrated for remediation of bottom sediments. Removal and disposal of the blanket is not well demonstrated. | Eliminated | | | |
| | | Ground Freezing | Application in presence of standing water has not been tested. Standing water likely provides a significant sink for cold temperatures and would substantially increase cost. | Eliminated | | | |
| *Ex-situ* Treatment | *Biological* | Landfarming/ Composting | Requires a large amount of space. Contaminants generally not amenable to aerobic degradation. Inorganic contaminants will not be degraded. | Eliminated | | | |
| | | Biopiles | Requires large upland area. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Contaminants generally not amenable to aerobic degradation. | Eliminated | | | |

# Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

| GRA | Technology | Process Option | Initial Screening: Implementability | Initial Screening: Screening Decision | Final Screening: Effectiveness | Final Screening: Cost | Final Screening: Screening Decision |
|---|---|---|---|---|---|---|---|
| ***Ex-situ* Treatment (Continued)** | Biological (Continued) | Fungal Biodegradation | No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale. | Eliminated | | | |
| | | Slurry-phase Biological Treatment | Large volume of tankage required. No known full-scale applications. Contaminants generally not amenable to biodegradation. Inorganic constituents will not be degraded. | Eliminated | | | |
| | | Enhanced Biodegradation | Not available on a commercial scale. PCB not amenable to biodegradation. Inorganic constituents will not be degraded. | Eliminated | | | |
| | *Chemical* | Acid Extraction | Commercial-scale units are in operation. Suitable for sediments contaminated with heavy metals. Not applicable to PCB-impacted sediment. | Eliminated | | | |
| | | Solvent Extraction | At least one commercial unit available. Effective for treating sediments containing PCBs. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. The process is sensitive to sediment characteristics (i.e., clay content, pH). PCBs are not destroyed and may require further treatment by another technology. | Eliminated | | | |
| | | Slurry Oxidation | Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost. | Eliminated | | | |
| | | Reduction/ Oxidation | Target contaminant group for chemical redox is inorganics. Less effective against nonhalogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides. Not cost-effective for high contaminant concentrations because of large amounts of oxidizing agent required. | Eliminated | | | |

## Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

| GRA | Technology | Process Option | Initial Screening: Implementability | Initial Screening: Screening Decision | Final Screening: Effectiveness | Final Screening: Cost | Final Screening: Screening Decision |
|---|---|---|---|---|---|---|---|
| *Ex-situ* Treatment (Continued) | *Chemical/ Physical* | Dehalogenation | Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is generally not cost-effective for large volumes. | Retained | Effective for treating sediments containing PCBs. The presence of metals may affect performance. High moisture content adversely effects treatment. The process is sensitive to sediment characteristics (i.e., clay content, pH). The APEG process often needs to cycle numerous times to achieve the desired results and may cause the formation of dioxins and furans. | Moderate | Eliminated |
| | | Sediment Washing/ Fractionation | Not an easily-accessible commercial process (limited use in the United States). Process has difficulty with fine-grained sediment. Not effective for PCBs. | Eliminated | | | |
| | | Radiolytic Dechlorination | Only bench-scale testing has been performed. Difficult and expensive to create inert atmosphere for full-scale project. | Eliminated | | | |
| | *Physical* | Separation | Not effective on fine-grained sediment and in presence of high moisture content. Target compounds are SVOCs, fuels, and inorganics. Previous tests on Fox River sediments have shown no benefit in reducing contaminated sediment volumes, but it has been demonstrated as effective in improving the efficiencies of the dewatering process. | Retained | Effective for dewatering dredged material. Recent PCB mass balance studies conducted on Deposit N Fox River sediments have shown 96% of PCB mass is contained in filter cake after dewatering. | Moderate | Retained |
| | | Solar Detoxification | The process has been successfully demonstrated at pilot scale. The target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. Some heavy metals may be removed. Only effective during daytime with normal intensity of sunlight. | Eliminated | | | |

## Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

| GRA | Technology | Process Option | Initial Screening: Implementability | Initial Screening: Screening Decision | Final Screening: Effectiveness | Final Screening: Cost | Final Screening: Screening Decision |
|---|---|---|---|---|---|---|---|
| *Ex-situ* Treatment (Continued) | *Physical* | Solidification | Bench-scale studies have added immobilizing reagents ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents with varying success. Dependent on sediment characteristics and water content. | Retained | Lime was successfully added to dewatered dredged material from the Lower Fox River demonstration projects. Considered for use during the dewatering operation to remove excess water and prepare material for disposal. | Moderate | Retained |
| | *Thermal* | Incineration | Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments. May require an acid gas scrubber for treatment of air emissions. | Retained | High temperatures result in generally complete decomposition of PCBs and other organic chemicals. Effective across wide range of sediment characteristics. At a minimum, consider use for TSCA-level sediments. | Very High | Retained as high-cost alternative |
| | | High-temperature Thermal Desorption (HTTD) then Destruction | Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments. | Retained | Thermal desorption and combustion is effective with a range of SVOCs. Target contaminants for HTTD are SVOCs, PAHs, PCBs and pesticides. Destruction of organic compounds occurs within an off-gas chamber or unit that is integrated into the thermal desorption system. | High | Retained |
| | | Low-temperature Thermal Desorption | Technology readily available as mobile units which would need to be set up at a fixed location in close proximity to the contaminated sediments. Thermal desorption and combustion is effective with a range of SVOCs. Typically not employed with chlorinated compounds or VOCs. | Eliminated | | | |
| | | Pyrolysis | High moisture content increases treatment cost. Generates air and coke waste streams. Target contaminant groups are SVOCs and pesticides. It is not effective in either destroying or physically separating inorganics from the contaminated medium. Limited performance data are available for pyrolytic systems treating hazardous wastes containing PCBs, dioxins, and other organics. | Eliminated | | | |

## Table 6-5 Screening of Potential Remedial Technologies - Treatment (Continued)

| GRA | Technology | Process Option | Initial Screening: Implementability | Initial Screening: Screening Decision | Final Screening: Effectiveness | Final Screening: Cost | Final Screening: Screening Decision |
|---|---|---|---|---|---|---|---|
| *Ex-situ* Treatment (Continued) | *Thermal (Continued)* | Thermal Desorption | Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas. | Retained | Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment as well. | Low | Retained |
| | | Vitrification | Requires less than 60% water content. Thermally treats PCBs and stabilizes metals, but at a much higher cost. | Retained | Destroys PCBs and immobilizes metals. Fundamentally, the process thermally treats PCBs and stabilizes metals. High moisture content adversely effects the treatment. Residuals are produced that must be treated and/or disposed. Recent pilot studies on Fox River sediments have shown that the process can be effective. Volume reduction to glass pellets is approximately 10:1. | High | Retained |
| | | High-pressure Oxidation | Predominantly for aqueous-phase contaminants. Wet air oxidation is a commercially-proven technology for municipal wastewater sludges and destruction of PCBs is poor. Supercritical water oxidation has demonstrated success for PCB destruction in bench- and pilot-scale testing. | Eliminated | | | |

# Table 6-6 Screening of Potential Remedial Technologies - Disposal

| GRA | Technology | Process Option | Initial Screening | | Final Screening | | |
|---|---|---|---|---|---|---|---|
| | | | Implementability | Screening Decision | Effectiveness | Cost | Screening Decision |
| Disposal | *On-site Disposal* | Level-bottom Cap | Decreased water depth may limit future use of river and may impact flooding, stream bank erosion, navigation, and recreation. | Retained | Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Effective for contaminants such as PCBs with low solubility and high sorption where the main concern is resuspension and direct contact. Releases from impacted sediment may occur during consolidation. | Moderate | Retained |
| | | Confined Aquatic Disposal (CAD) | CAD may not be implemented due to ban on open-water disposal in the Great Lakes, but carried forward in FS as feasible for Green Bay. | Retained | CAD sites have been successfully constructed in many urban bays. Effective for isolating contaminants such as PCBs. | Moderate | Retained |
| | | Confined Disposal Facility (CDF) | Portion of river to be used must be expendable. Potential impacts on flooding, stream bank erosion, navigation, and recreation. Requires USACE 404 permit. | Retained | Risk of discharge to river or bay through outer berm or containment wall. | Moderate | Retained |
| | | Nearshore Biofiltration Cell | Portion of river to be used must be expendable. Potential impacts on flooding, stream bank erosion, navigation, and recreation. Requires USACE 404 permit. Engineering design of a full-scale system may be difficult to implement due to the potential need for oxygen additions. Demonstration project on Sheboygan River sediments resulted in incomplete degradation of PCBs and concerns about full-scale engineering design. | Eliminated | | | |
| | | Upland Confined Fill | Standard construction techniques. Requires available upland space. | Retained | Standard construction techniques. Requires available upland space. Long-term successful storage. | Moderate | Retained |

## Table 6-6 Screening of Potential Remedial Technologies - Disposal (Continued)

| GRA | Technology | Process Option | Initial Screening | | Final Screening | | |
|---|---|---|---|---|---|---|---|
| | | | Implementability | Screening Decision | Effectiveness | Cost | Screening Decision |
| Disposal (Continued) | *Off-site Disposal* | NR 500 WAC Landfill (county, private, industrial landfills) | Sediment must pass strength test and be able to support slopes for disposal, especially with large quantities. WDNR has authority to dispose of PCB sediment in NR 500 WAC facilities (re-approval pending). | Retained | EPA waiver allows WDNR to regulate disposal of PCB-contaminated sediments in NR 500 WAC landfills; however, TSCA sediments must pass paint filter test for transport and disposal. Some non-municipal landfills may require upgrades to meet NR 500 criteria. | Low to Moderate | Retained |
| | | Dedicated New Upland Landfill | Construction requirements for a dedicated landfill would generally be the same as the construction requirements for a municipal landfill. Time required to site, design and construct the landfill is a consideration. If dredge slurry is pumped long distances directly to landfill, engineering and community concerns need to be addressed. | Retained | EPA waiver allows WDNR to regulate disposal of PCB-contaminated sediments in NR 500 WAC landfills. The dedicated landfill could be centrally located in an area to allow access from all areas of the river. | Moderate to High | Retained |
| | | TSCA Subtitle C Landfill | Sediment must pass paint filter test for transport and disposal sediment must also pass strength test and be able to support slopes for disposal, especially with large quantities. WDNR has authority to dispose of PCB sediment in NR 500 WAC facilities. | Retained | Commercial permitted landfill. | High | Retained |
| | | Upland Confined Fill (commercial/-industrial) | Standard construction techniques. Treatment to Wisconsin commercial/industrial criteria. | Retained | Sediments must be treated to commercial/industrial criteria. May require liner and cap depending on constituent concentrations. | Low to Moderate | Eliminated |
| | | Upland Fill (residential/clean) | Standard construction techniques. Treatment to Wisconsin clean fill criteria. | Retained | Sediment must meet residential fill criteria. | Low | Retained |

# Table 6-7 Ancillary Technologies

| Technology | Process Option | Description | Implementability and Effectiveness | Cost | Screening Decision |
|---|---|---|---|---|---|
| *Passive Dewatering* | On-barge | Mechanically-dredged sediments are placed within a barge which either allows excess water to flow into river, or to accumulate in an on-board sump where it is removed and treated. | Water drained from sediment on barge into river may not meet NPDES discharge standards. Gravity-drained water may contain high concentrations of TSS. Not all river segments may be accessible to a barge. Sediments could require additional treatment to pass paint filter test. | Low | Retained |
| | Dewatering Lagoons/Ponds | Dredged sediments are placed within constructed lagoons where sediments are allowed to gravity settle. | Construction of ponds near river may involve removal of wooded areas. Construction costs may involve contingencies to address potential spills and leaks. Effluent water may contain high concentrations of TSS. Average annual rainfall and evaporation approximately equal. Retention time affects production rates. Based on Fox River design estimates, dewatered sediments would likely require solidification to pass paint filter test. | Low to Moderate | Retained |
| | Solidification | Dredged sediments are mixed with amendments (e.g., Portland cement, lime, and/or fly ash mixture) to produce a product which passes regulatory requirements (e.g., paint filter test). | Staging, mixing, and curing areas required. Solidified sediments have increased mass of unsolidified sediments. Most effective on partially-dewatered/high-solid sediments. | Moderate | Retained |
| *Mechanical Dewatering* | Centrifugation | Rapidly rotates fluid mixture to separate the components based upon mass. Flocculents are often used to increase effectiveness. | Production rate is based on size and quantity of centrifuges used to dewater. Typical production rate of a single centrifuge is 20–500 gpm. Due to handling issues, more effective on dredge spoils containing a low percent of solids. | Moderate | Retained |
| | Belt Press | Uses belts that compress sediments against rollers to achieve high-pressure compression and shear to remove water from dredged sediments. | Production rate is based on the size and quantity of belt presses used. Typical production rate of a single belt press is 40–100 gpm. Sediments are initially gravity-drained which could produce high concentration of TSS. PCB mass balance studies conducted on Fox River sediments have shown 96% of mass is retained in dewatered filter cake. | Moderate to High | Retained |
| | Hydrocyclone | Continuous operating cone-shaped device which uses centrifugal force to accelerate settling. | Production rate and minimum separation size depended upon size of hydrocyclone (larger capacity provides a larger minimum separation size). Typical production rate of a single hydrocyclone is 50–3,500 gpm. | Moderate | Retained |
| | Diaphragm Filter Press | Dewaters dredged sediments by passing slurry through a vertical filter. Uses inflatable diaphragms to increase pressures on sediments prior to removing sediments from filter. | Production rate is based on the size and quantity of filter presses used. Typical production rate of a single filter press is 1,200–6,000 gpm. Due to nature of operation, does not allow for continuous operation. | Moderate to High | Retained |

# Table 6-7 Ancillary Technologies (Continued)

| Technology | Process Option | Description | Implementability and Effectiveness | Cost | Screening Decision |
|---|---|---|---|---|---|
| *Wastewater Treatment (for mechanical dredging)* | Sedimentation | Passive physical separation in a dewatering cell to remove solids. | Basic form of primary treatment used at wastewater treatment facilities. Gravity settling is used the most extensively. | Low | Retained |
| | Filtration | Water is fed through sand or mixed-media filter for solids retention. Gravity or pressure pumped. | Filtration media is commonly used in CDFs. Most organic compounds, especially hydrophobic ones, are generally removed with the solids. | Low | Retained |
| | Coagulation Aid, Flocculation and Settling | Coagulant aid added to slurry stream then flowed through clarifiers for thickening. | Coagulant and polymer flocculents used in pilot projects to promote removal of silty clay. Limited full-scale application. | Low to Moderate | Eliminated |
| | Adsorption Carbon Filter | Uses activated granular carbon. | Useful for removing organic substances. Spent carbon must be frequently discarded and disposed of. The Fox River demonstration projects met effluent water quality criteria without the use of carbon filters, however, carbon use should be considered. | Low to Moderate | Eliminated (but possibly add later) |
| | Oxidation | Oxidation of organic molecules to carbon dioxide and water by chemical or ultraviolet oxidation. | Technology is effective for removing organic compounds including PCBs. | High | Eliminated |
| | Mechanical | Discussed under Dewatering Process Options. | | | |
| *Solid Residuals Management* | Sediment | Discussed under Disposal Technologies. | | | |
| | Water | Discussed above and returned to site or transported to POTW for treatment and disposal. | | | |
| | Air Emissions | Treated on site and discharged at generation site. | | | |
| | Other Solids (i.e., PPE) | To local municipal landfill. | | | |

# Table 6-7 Ancillary Technologies (Continued)

| Technology | Process Option | Description | Implementability and Effectiveness | Cost | Screening Decision |
|---|---|---|---|---|---|
| *Transportation* | Truck | After dewatering, stockpiled solids placed in sealed trucks by backhoes. | Portable and flexible. Readily available. | High | Retained |
| | Rail | Sediment placed in railcars for hauling long distances. | Limited availability. Difficult loading/unloading logistics. | High | Eliminated |
| | Barge | High-solids dredged material mechanically placed in barge. After dewatering, offloaded using backhoe and trucks. | Used with mechanical dredging operations. Consider dewatering limitations on barge. | Moderate | Retained |
| | Pipeline | Transports dredged material in slurry form directly to disposal site or treatment site if necessary. | Preferred for hydraulic dredging and transport over short distances (<3 km). Booster pumps need consideration. Must be hydraulically linked. A 20-mile-long slurry pipe run was successfully implemented over 1 year in White Rock Lake, Texas. Requires sufficient land space near dredging operations to serve as slurry transfer station between the dredge and pipeline. | Moderate | Retained |
| *Water Quality* | Containment Structures | Placement of physical barriers (silt screens, curtains, sheet pile walls) to lower TSS transport. | Mixed effectiveness. Highly dependent on site conditions. | Moderate | Retained (but not costed) |
| | Operator Modifications | Use slower dredging rates and speeds. | Effective, but requires monitoring. Selection of a qualified dredge operator may have the largest influence on dredge or cap implementation. | Low | Retained |

## Table 6-8 Deposit N Demonstration Project Summary

| Parameter | Specification |
|---|---|
| Dredge Equipment | Hydraulic round cutterhead (Moray/Ultra)<br>Rotating, variable speed<br>8" pump and 8" double-walled pipeline (single in 1999) |
| Dredge Period | November 26 to December 31, 1998<br>August 20 to October 14, 1999<br>(104 days) |
| Production Rate | 80 cubic yards per day (average) |
| Hours of Operation | Treatment: 24 hours/day in 1998;<br>7 days/week, 10 hours/day in 1999 |
| Area | 3 acres |
| Water Depth | 8' (average) |
| Volume/Mass | 8,175 cy (112 pounds PCBs) |
| Percent Solids | 0.4%–6% (average is 2%) dredge slurry |
| Dewatering Method | ⅜" shaker screen to 12,000-gallon V-bottom tank<br>Augered to 2- hydrocyclones, to<br>4 - 20,000-gallon mixing tanks, to<br>2 - 200-cf filter presses, then stockpiled |
| Water Treatment | Bag filters, sand filters, and liquid-phase carbon adsorbers |
| Disposal | Wayne Disposal Landfill (TSCA material)<br>Winnebago County Landfill (non-TSCA material) |
| Environmental Controls | Perimeter turbidity barriers (80-mil HDPE)<br>Silt curtain<br>Deflection barrier (80-mil HDPE)<br>Real-time in-river water quality monitoring |
| WPDES Effluent Limits | Mercury: 1.7 $\mu$g/L daily maximum, 0.0013 pounds/day weekly average<br>PCBs: 1.2 $\mu$g/L daily maximum, 0.0036 pounds/day monthly average |
| Monitoring | Daily water quality, air, diver-collected surface sediment, mass balance study, hourly and daily flow rates compiled from USGS |
| Limitations | Coal and large boulders resting on river bed nearshore—this area not dredged. Additional dredging in west lobe (3" to bedrock) produced very low percent slurry solids. |
| Removal Goals | Dredge sediment to within 3 inches and 6 inches of bedrock<br>Conduct verification sampling of residuals<br>Also removed sediment from Deposit O |
| Dredge Costs | $20.73 per cy dredged |
| Total Costs | $3.9 million ($540 per cy) |

# Table 6-9 SMU 56/57 Demonstration Project Summary

| Year 1999 Parameter | Year 1999 Specification |
|---|---|
| Dredge Equipment | Hydraulic round cutterhead—used only a few days<br>Hydraulic horizontal auger (IMS 5012 Versi dredge) 9'<br>12" pump and 12" single- and double-walled pipeline |
| Dredge Period | September 10 to December 12, 1999<br>(96 of 108 days) |
| Production Rate | 60 cy/hr (average)<br>294 cy/day (average)<br>Goal: 200 cy/hr and 900 cy/day |
| Hours of Operation | Treatment: 24 hours/day and 7 days/week<br>Dredge: 4.3 hours/day (average) |
| Area | NA |
| Water Depth | 2' nearshore to 14' mid-channel |
| Volume/Mass | 31,346 cy (1,326 pounds PCBs) |
| Percent Solids | 4.4% (average) in dredge slurry<br>Goal: 7.5% |
| Dewatering Method | Passive dewatered in equalization basins,<br>Horizontal augered/piped to shaker screens, to<br>7 - 20,000-gallon mixing feed tanks, to<br>4 - 100-cf and 2 - 200-cf filter presses, then stockpiled |
| Water Treatment | Equalization basin, sand/gravel filters, granular activated carbon (GAC) filter - 75,256,500 gallons treated<br>Peak capacity 1,100 gpm<br>$0.26/gallon or $64/cy of sediment |
| Disposal | On-site industrial landfill at Fort James Corp.<br>26,927 wet tons (11,696 dry tons)<br>$68/cy |
| Environmental Controls | Anchored silt curtain (8" closed cell foam wrapped in PVC-coated fabric) in adjoining panels |
| WPDES Effluent Limits | Mercury: 1.7 $\mu$g/L daily maximum, 0.0026 pounds/day weekly average<br>PCBs: 1.2 $\mu$g/L daily maximum, 0.0072 pounds/day weekly average |
| Monitoring | Daily water quality, real-time turbidity, pre- and post-sediment cores, dewatered sediment, dredge slurry, and effluent testing (mass balance study), daily flow rates compiled from USGS |
| Limitations | Lower percent solids than predicted |
| Removal Goals | Remove all material within dredge prism to a design elevation of 565'<br>Collect verification samples of surface residuals (only 1 of 19 subunits achieved target depth) |
| Dredge Costs | $27/cy dredged |
| Total Costs | $8.97 million ($286 per cy) |

**Note:**
NA - Not available.

## Table 6-9 SMU 56/57 Demonstration Project Summary (Continued)

| Year 2000 Parameter | Year 2000 Specification |
|---|---|
| Target Goal | Remove 50,000 cy of sediment, assuming that remaining sediments have <1 ppm PCBs. |
| Dredge Equipment | 3 hydraulic horizontal augers with submersible pumps |
| Dredge Period | August 23 to November 8, 2000 |
| Production Rate | 833 cy/day (average) |
| Hours of Operation | Treatment: 24 hours/day and 7 days/week<br>Dredge: 24 hours/day and 7 days/week |
| Area | NA |
| Water Depth | Same in 1999/2000 |
| Volume/Mass | 50,316 cy (670 pounds PCBs; total PCBs removed 2,111 pounds) |
| Percent Solids | 8.4% (average) in dredge slurry |
| Dewatering Method | Dredge slurry piped to a booster pump, then pumped to land-based facility through to vibrating shaker screens on V-bottom tank,<br>to hydrocyclones,<br>to a 20,000-gallon agitated pump tank,<br>to plate-and-frame mechanical presses (2 - 200 cf) |
| Water Treatment | Water surge tank, cloth bag filters, sand filters, carbon absorption system, cloth bag filters<br>66,329,000 gallons treated |
| Disposal | Trucked to on-site industrial landfill at Fort James Corp. Cell 12A (6 miles away)<br>51,613 dry tons with 59% solids (average) |
| Environmental Controls | Anchored silt curtains around perimeter<br>additional silt curtains to separate dredge areas and avoid recontamination |
| WPDES Effluent Limits | Mercury: 1.7 $\mu$g/L daily maximum, 0.0026 pounds/day weekly average<br>PCBs: 1.2 $\mu$g/L daily maximum, 0.0072 pounds/day weekly average |
| Monitoring | Every other day water quality, real-time turbidity, pre- and post-sediment cores, filter cake, dredge slurry, effluent testing, daily flow rates compiled from USGS |
| Limitations | Dredge area covered with 8" sand cap (required for surface sediments between 1 and 10 ppm PCBs) after one cleanup pass to ensure protection before onset of winter<br>Added larger filter presses and one additional dredge (total 3) to increase production rates |
| Removal Goals | Remove 50,000 cy of sediment within dredge prism<br>Collect verification samples of surface residuals |
| Dredge Costs | NA |
| Total Costs | Actual dredge and on-site disposal cost $8.18 million ($159 per cy) value<br>Cost for management and value of on-site Cell 12A ($296 per cy) |

**Note:**
NA - Not available.

# Table 6-10 Summary of Selected Wisconsin Landfills Within Approximately 40 Miles of the Lower Fox River

| Facility Name | No.[4] | County | Status | | Remaining Capacity[3] (cubic yards) | Notes |
|---|---|---|---|---|---|---|
| | | | Existing Landfill | Proposed Landfill | | |
| *Municipal* [1] | | | | | | |
| Brown County East | 1 | Brown | ✓ | | 934,875 | |
| Brown County South | 2 | Brown | | ✓ | 8,025,000 | b |
| Superior Services - Hickory Meadows | 3 | Calumet | | ✓ | 7,500,000 | |
| Kewaunee County Southwest | 4 | Kewaunee | ✓ | | 259,367 | d |
| Mar-Oco | 5 | Marinette | ✓ | | 1,080,754 | |
| Outagamie County Southwest Division | 6 | Outagamie | ✓ | | 5,600,000–6,600,000 | a |
| Shawano County Phase 2 | 7 | Shawano | ✓ | | 716,500 | a |
| W M W I - Ridgeview Recycling | 8 | Manitowoc | ✓ | | 4,770,000 | a |
| W M W I - Valley Trail | 9 | Green Lake | ✓ | | 4,905,300 | a |
| Winnebago County - Sunnyview | 10 | Winnebago | ✓ | | 5,015,557 | |
| *Non-Municipal* [2] | | | | | | |
| Appleton Papers, Inc. Tn of Harrison | 11 | Calumet | ✓ | | unknown | |
| Appleton Papers, Inc. - Locks MI | 12 | Outagamie | ✓ | | 65,800 | c |
| Fort James Corp. - Green Bay West | 13 | Brown | ✓ | | 3,972,984 | |
| Wisconsin Tissue Mills North | 14 | Winnebago | ✓ | | 312,569 | |

**Notes:**

[1] Landfill is operated for the disposal of municipal solid waste and some industrial waste. May be either publicly or privately owned.

[2] Landfill is operated for the disposal of industrial waste and is privately owned.

[3] Remaining capacity as of January 1998 and proposed capacity.

[4] Landfill identification for Figure 6-7, Lower Fox River Feasibility Study.

a. Proposed or existing facilities which are expansions to an existing facility.

b. A 3,700,000-cubic-yard monofill was approved as part of this site's Feasibility Study, but this monofill is not proposed or being developed at this time.

c. Not an NR 500-approved facility; landfill modifications required prior to the acceptance of sediments.

d. Facility is a balefill; landfill modifications required prior to the acceptance of sediments.

## Table 6-11 Sediment Melter Demonstration Project Summary

| Parameter | Specification |
|---|---|
| Target Goal | Evaluate the feasibility of a vitrification technology based on standard glass furnace technology to treat contaminated Lower Fox River sediments. |
| Pilot Melter Equipment | Refractory lined rectangular melter measuring 10 square feet. |
| Vitrification Period | June 16–23, 2001 and August 11–18, 2001 on a 24-hour/day time frame. |
| Dryer Equipment | Bench-scale Holoflite® dryer. Drying analysis performed at Hazen Research, Inc., Golden, Colorado. |
| Sediments Volume | 60 tons of dredged and dewatered sediments from Lower Fox River. |
| Percent Solids | 50% by weight. |
| Dryer Efficiency | Dryer equipment dried sediments to 10% moisture. |
| Metal Separation | 13 bar magnets used to recover significant amounts of magnetic material. |
| Flux Material | 5% sodium sulfate by weight. |
| Melter Temperature | Ranged between 2,600 and 2,900 ˚F. |
| Percent Moisture (feed sediments) | Ranged between 5% and 20%. |
| Pilot Melter Processing Rate | 2 tons/day or 170 pounds of river sediment/hour. |
| Environmental Controls | Air quality control equipment for treating air emissions. |
| Removal Efficiency | Dioxins and furans are not generated during the treatment process. |
| Limitations | Moisture content of river sediment affect feed rates and material handling. Moisture content greater than 20% tended to bridge in the charger and cake around the auger of the melter. Downstream end of the pilot melter system experienced plugging due to accumulation of particulates and sulfates, primarily due to use of sodium sulfate as flux. |
| Glass Aggregate Testing | Performed ASTM water leach test and SPLP test. The tests did not detect any dioxins, furans, PCB congeners, SVOCs, or any of the eight heavy metals in the glass aggregate. |
| Total Costs | Not applicable. Unit costs were developed for full-scale melter facilities. Unit cost analysis for full-scale melter units are presented in Appendix G. |