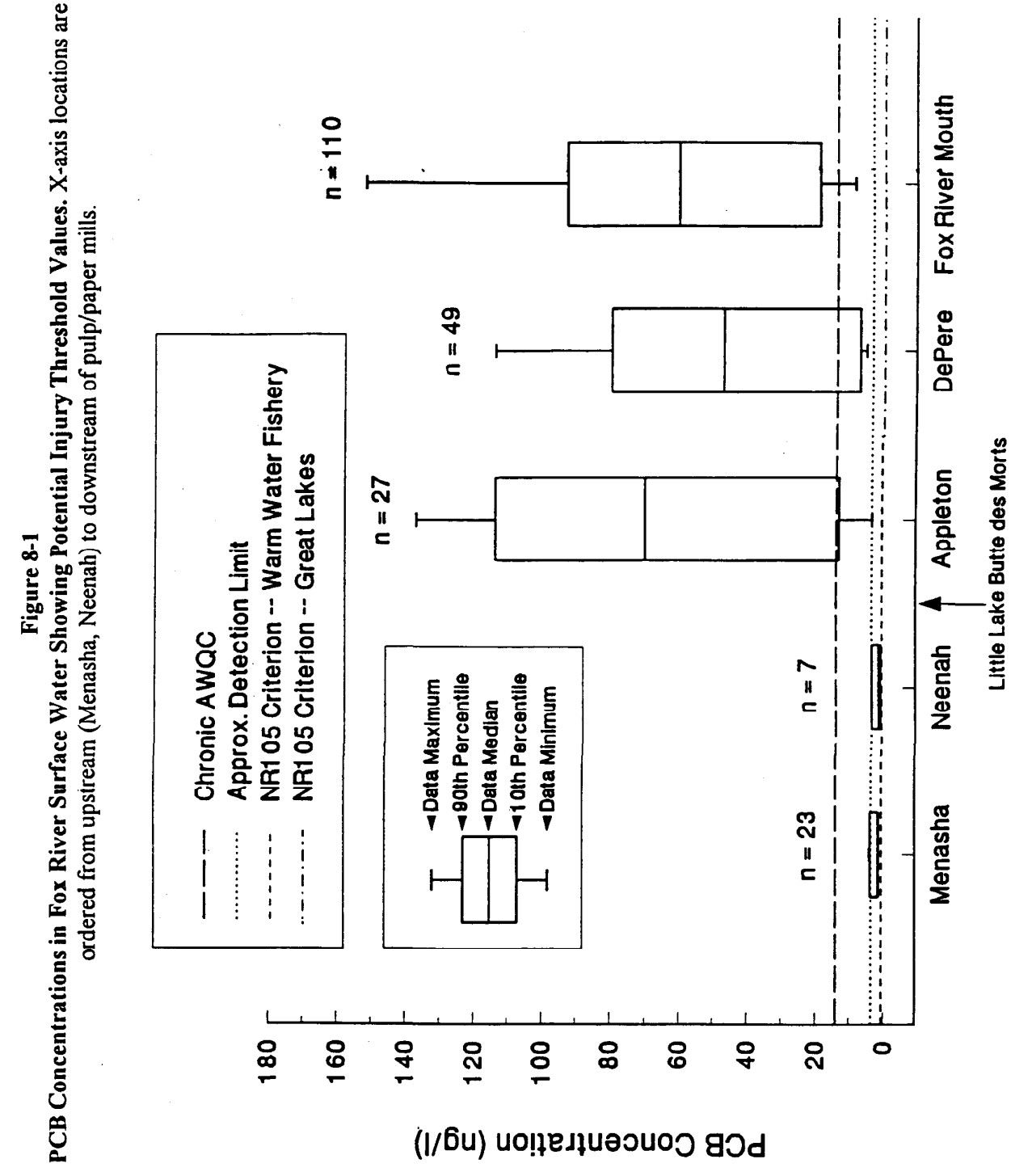
Figure 8-1
PCB Concentrations in Fox River Surface Water Showing Potential Injury Threshold Values. X-axis locations are ordered from upstream (Menasha, Neenah) to downstream of pulp/paper mills.



of 110 kg. Another model simulation estimates that over a 25 year time period, 2,000 kg of PCBs would be resuspended from sediments in the Fox River between Lake Winnebago and Green Bay (U.S. EPA, 1993a). These mass balance modeling results were based on detailed studies and simulations that included hydraulic parameters, sediment characteristics and loads, bathymetry, bottom sediment concentrations, and mobility of PCBs in the system (Bierman et al., 1992). These and other data may be utilized to evaluate pathways of hazardous substances to surface water resources. If necessary, additional studies may be undertaken to supplement existing data on pathways to exposed surface water resources in the assessment area.

8.3.1.4 Injury Quantification Approaches

Quantification of injuries to surface water resources will include evaluation of:

- the spatial extent of injuries throughout the assessment area
- the temporal extent of injuries throughout the assessment area.

For example, existing data suggest that surface water concentrations of PCBs have exceeded the NR 105 HCC of 0.49 ng/l for warm water fisheries for at least 24 years (Table 6-1; Figure 8-2). Preliminary evaluation of the spatial extent of potential injuries indicates that surface water concentrations of PCBs in the Lower Fox River from Little Lake Butte des Morts to the mouth of the Fox River have exceeded the NR 105 HCC for warm water fisheries and for Great Lakes waters (Figure 8-3). Further data analysis will be conducted in the assessment to quantify surface water injuries.

8.3.2 Sediments

8.3.2.1 Injury Definitions

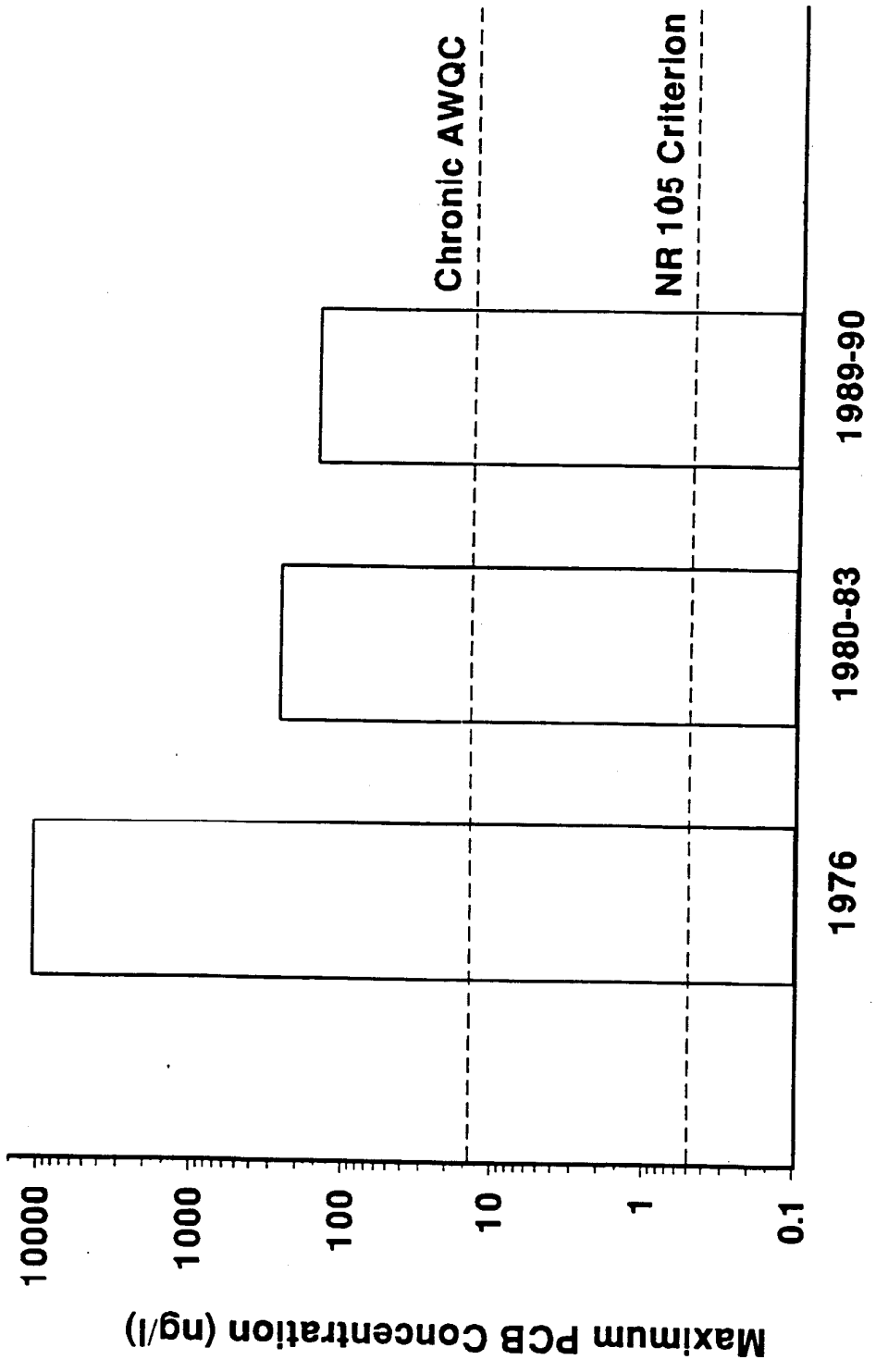
Relevant definitions of injury to sediments that may be evaluated by the trustees include:

- concentrations of PCBs sufficient to cause injury to biological or surface water resources that are exposed to sediments [43 CFR §11.62(b)(1)(v); 11.62(e)(11)].

8.3.2.2 Injury Determination Approaches

The definitions of injury presented in Section 8.3.2.1 contain several components. Table 8-4 summarizes the components of each definition and the evaluation approaches that may be used by the trustees in assessing each component.

Figure 8-2
Maximum PCB Concentrations in Surface Water at the Mouth of the Fox River, from 1976 to 1990, Compared to Potential Injury Threshold Values (concentrations plotted on a logarithmic scale)



Sources: WDNR, 1995b; Marti and Armstrong, 1990; House et al., 1993.

Figure 8-3
Map Showing Locations of 1976-1990 Surface Water Samples in the Fox River/Lower Green Bay Assessment Area that Equal or Exceed Surface Water Criteria

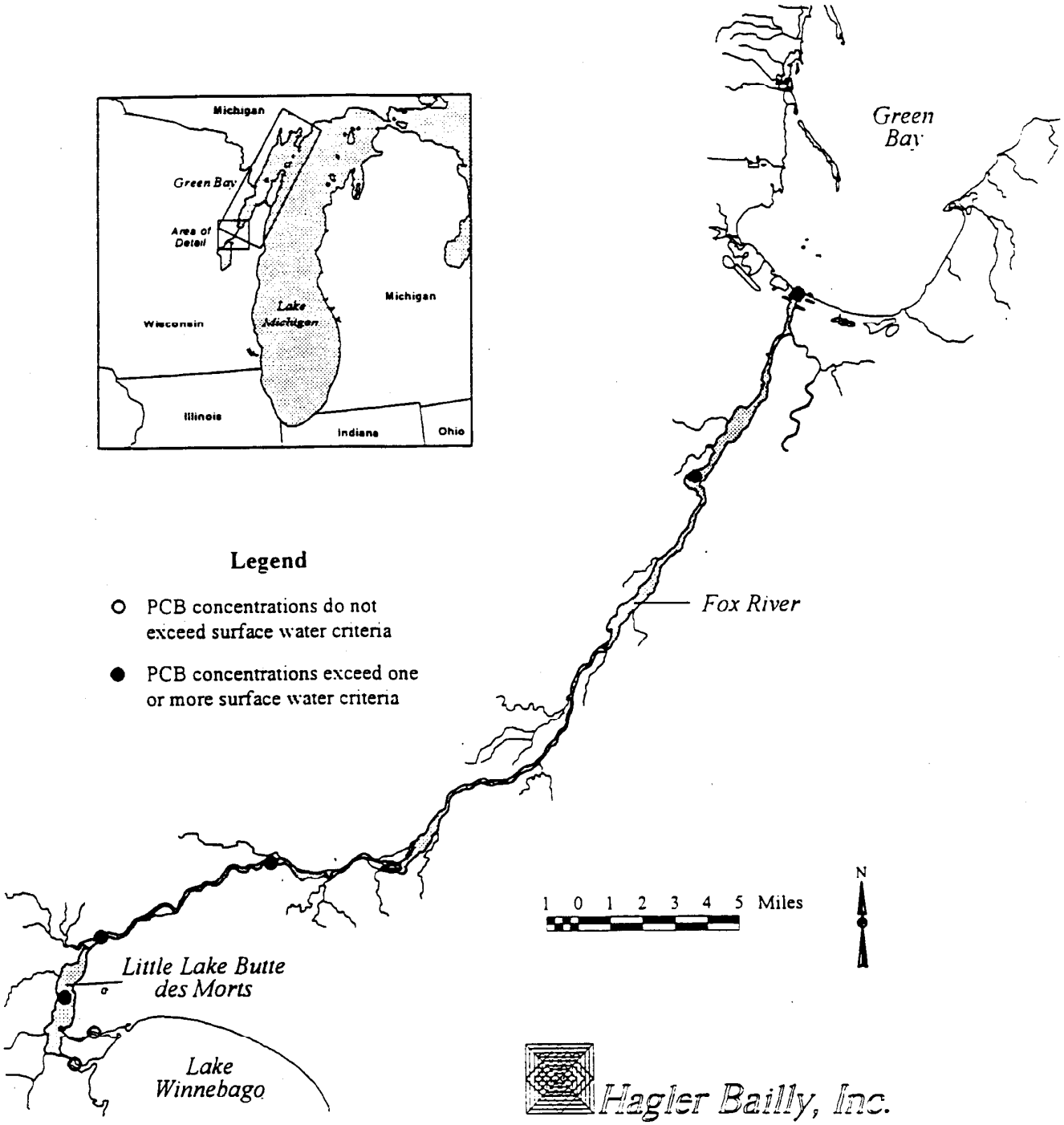


Table 8-4
Components of Relevant Sediment Injury Definitions

Injury Definition	Definition Components	Evaluation Approach
Biological or surface water resources are injured when exposed to sediments [43 CFR §§ 11.62(b)(1)(iv)-(v)]	Biological or surface water resources are injured when exposed to sediments.	Determine whether biota or surface water have been injured as a result of exposure to sediments. Quantify concentrations of PCBs in sediments sufficient to cause injuries.

The WDNR (1993) evaluated several models for estimating the PCB concentrations in sediments that are likely to cause injury to surface water and biota. The sediment models were based on several protection endpoints, including surface water regulatory criteria, fish tissue PCB accumulation, and protection of benthic invertebrates. Table 8-5 summarizes the results of the WDNR's evaluation, which may be used for evaluation of the injury to sediment resources by the second injury test listed in Section 8.3.2.1.

The 18 threshold PCB sediment concentrations presented in Table 8-5 range from 0.0002 to 3.409 mg/kg, depending on the protection endpoint and the type of model used. Most of the threshold concentrations are substantially less than 1.0 mg/kg.

Much of the sediment PCB data collected from the Fox River/Green Bay area come from sediment cores, providing PCB concentrations at various depths. PCBs in sediments cause injury to other natural resources primarily through sediment resuspension and near-surface exposure of biota. The WDNR (1993) concluded that "the top 15 cm of bedded sediment would generally be the strata where the greatest interchange of PCBs will take place between the sediment phases and the overlying water column." Therefore, initially, PCB concentrations in the top 15 cm will be considered for sediment injury determination, although further evaluation of the active sediment zone and the potential for sediment resuspension during high flow events may be performed during the assessment phase.

Figure 8-4 presents a preliminary example of an application of the injury determination approach. As shown in the figure, all of the sediment samples downstream of Fox River paper and pulp mills exceeded at least two injury thresholds. Four out of nine downstream sediment samples also exceeded the 50 mg/kg threshold for hazardous chemical disposal under the Toxic Substances Control Act (TSCA) [40 CFR § 761.60(a)(5)].

Table 8-5
Summary of Potential Sediment PCB Injury Thresholds
(numerical thresholds from WDNR, 1993)

Injury Endpoint	Type of Model	Threshold Sediment PCB Concentration (mg/kg)
Causes surface water concentrations to exceed 0.49 ng/l (NR 105 HCC — warm water fisheries)	Equilibrium partitioning	0.004-0.020
Causes surface water concentrations to exceed 3.0 ng/l (NR 105 Wild and Domestic Animal criterion)	Equilibrium partitioning	0.022-0.123
Causes PCB concentrations in edible fish fillets to exceed 2 mg/kg FDA action level for protection of human health	Accumulation Relative to Sediments (ARS)	0.20-1
	Thermodynamic Equilibrium Model	0.188-1.038
	Bioconcentration Model	0.616-3.409
	Food Chain Multiplier Model	0.035-0.104
Causes whole fish PCB concentrations to exceed 0.100 mg/kg International Joint Commission (IJC) objective for protection of piscivorous birds and mammals	ARS	0.010-0.050
	Thermodynamic Equilibrium Model	0.0045-0.026
	Bioconcentration Model	0.015-0.082
	Food Chain Multiplier Model	0.0009-0.0026
Causes PCB concentrations in whole fish to exceed 0.023 mg/kg GLWQG for protection of piscivorous wildlife	ARS	0.002-0.012
	Thermodynamic Equilibrium Model	0.001-0.006
	Bioconcentration Model	0.004-0.020
	Food Chain Multiplier Model	0.0002-0.0006
Causes surface water PCB concentrations to exceed 14 ng/l U.S. EPA chronic AWQC for protection of aquatic life	Equilibrium Partitioning Model	0.070-0.554
Exceeds lowest effect level (LEL) for protecting 95% of benthic invertebrate species from Aroclor 1248 — Ontario Ministry of the Environment	Organic Carbon- and Aroclor-Dependent Model	0.030-0.240
Exceeds apparent effects threshold (AET) for protecting marine invertebrates — State of Washington sediment standards	Organic Carbon-Dependent; based on lab bioassays	0.120-0.960
Exceeds AET for protecting marine invertebrates — NOAA (National Oceanic and Atmospheric Administration)	Data from Equilibrium Partitioning models and spiked-sediment toxicity tests	0.370

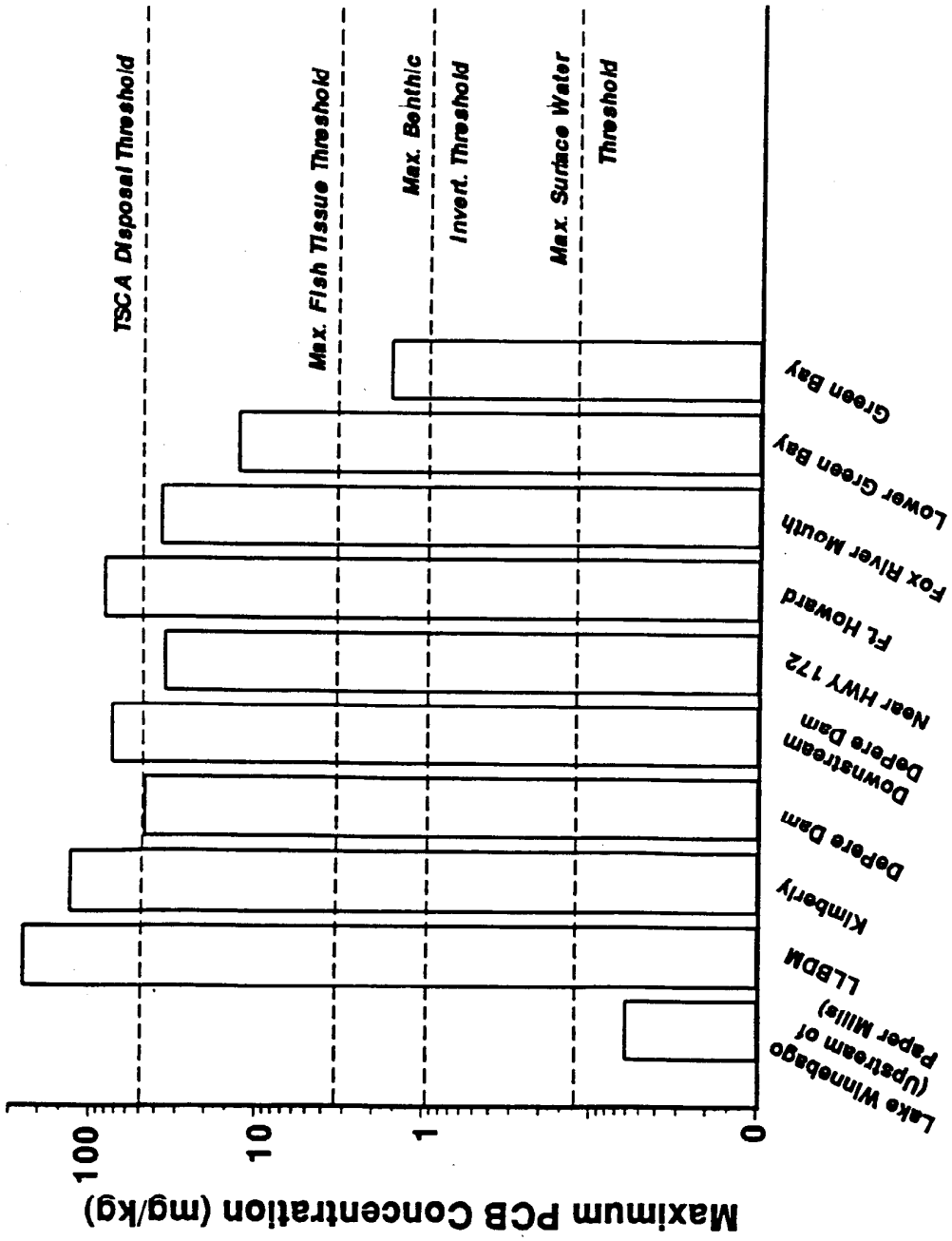


Figure 8-4
Maximum PCB Concentrations Measured in Lower Fox River and Green Bay Sediments Compared to Potential Injury Threshold Values and the TSCA Disposal Threshold Value. Sampling locations ordered from upstream to downstream.
Note: Concentrations are plotted on a logarithmic scale.

Sediment PCB concentrations in Green Bay are also elevated. In 1977, the WDNR (1978, in Lohr, 1988) collected 12 sediment samples from the bay. The highest concentration found was 11 mg/kg, over three times higher than the highest threshold shown in Table 8-5. Four of the 12 samples reported in Lohr (1988) exceed 3.4 mg/kg, the highest threshold concentration in Table 8-5, including samples from Green Bay Harbor and one sample from southeast of Point Au Sable. In 1984, the U.S. ACOE (1985, in Lohr, 1988) collected four sediment samples from Green Bay near Grassy Island. One of these samples contained 13 mg/kg PCBs.

Data on Green Bay sediment PCB concentrations were summarized by Manchester (1993). Based on these data, it appears that the PCB concentrations averaged over all sampled depths ranged approximately between 0.1 and 1 mg/kg. Concentrations of PCBs at 1 mg/kg exceed the high range of 12 of the 18 potential injury thresholds shown in Table 8-5. Further data analysis will be conducted in the assessment to evaluate sediment injuries.

8.3.2.3 Pathway Evaluation

Once released into the environment, the low water solubility of PCBs dominates their environmental fate and transport. In the environment, PCBs are strongly adsorbed onto soils, sediments, and particulates; the highest environmental concentrations typically accumulate in aquatic sediments containing microparticulates and high organic or clay content (Eisler, 1986). In aquatic systems, sediments are a primary transport mechanism and sink for PCBs (Thomann and Connolly, 1984; Ram and Gillett, 1993). Consequently, important pathways to injured sediments include the settling of PCBs from contaminated surface water and resuspension of contaminated sediments. Data on sediment concentrations and distributions, coupled with physical transport data and models, will be used to evaluate pathways. If necessary, additional studies may be undertaken to supplement existing data on pathways to exposed sediment resources in the assessment area.

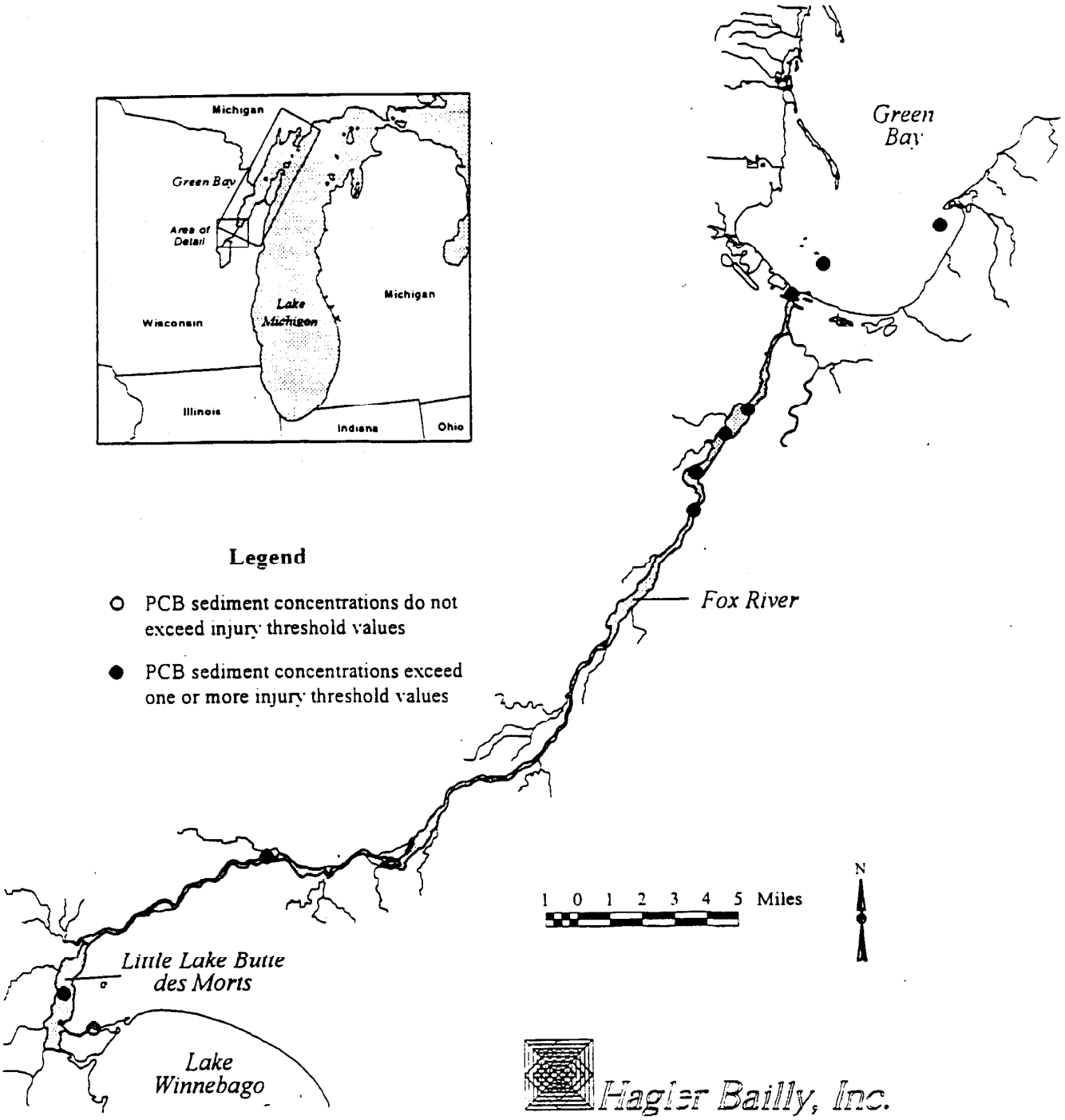
8.3.2.4 Injury Quantification Approaches

Quantification of injuries to sediment resources will include an evaluation of:

- the spatial extent of injuries throughout the assessment area
- the temporal extent of injuries throughout the assessment area.

For example, existing data indicate that sediment concentrations of PCBs in the Lower Fox River and Green Bay have exceeded sediment PCB injury thresholds (Tables 8-4, 8-5) for at least 16 years (Table 6-2). Preliminary evaluation of the spatial extent of potential injuries indicates that concentrations of PCBs in sediment deposits from Little Lake Butte des Morts to mid-Green Bay have exceeded PCB injury thresholds (Figures 8-4, 8-5). Further data analysis will be performed in the assessment to quantify injuries.

Figure 8-5
Map Showing Locations of 1977-1993 Sediment Samples in the Fox River/Lower Green Bay Assessment Area that Meet or Exceed Potential Sediment PCB Injury Thresholds



8.4 AQUATIC BIOTA RESOURCES

8.4.1 Injury Definitions

Relevant biological injuries defined by DOI regulations [43 CFR § 11.62(f)(1)] may include the following:

- concentrations of a hazardous substance sufficient to exceed action or tolerance levels established under section 402 of the Food, Drug and Cosmetic Act, 21 U.S.C. 342, in edible portions of organisms [43 CFR § 11.62(f)(1)(ii)]

- concentrations of a hazardous substance sufficient to exceed levels for which an appropriate State health agency has issued directives to limit or ban consumption of such organism [43 CFR § 11.62(f)(1)(iii)]

- concentrations of a hazardous substance sufficient to cause the biological resource or its offspring to have undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62(f)(1)(i)]

8.4.2 Injury Determination Approaches

The injury definitions in Section 8.4.1 contain several components. Table 8-6 summarizes the components of each definition and the approaches that may be used by the trustees in assessing each component.

As shown in Figures 6-2 to 6-5, PCB fillet concentrations in fish from the Fox River and Green Bay have been sufficiently high since 1976 to trigger fish consumption advisories by the WDHHS for many sport and commercially exploited fish species. Fish consumption advisories are still in effect for specified sizes of most species (WDNR, 1976 to 1994) (Table 6-3). PCB contamination has been sufficient to prompt closure of commercial fisheries. The large-scale commercial carp fishery in Green Bay was suspended from interstate commerce in 1975, and closed entirely in 1984 because of PCB contamination (Kleinert, 1976; Allen et al., 1987). Further data analysis of consumption advisories will be performed in the assessment to evaluate these potential injuries.

PCBs also can adversely affect fish viability by causing mortality, decreased reproductive success (Table 3-7), and increased incidence of fry deformities (Eisler, 1986). Other documented effects of PCBs on fish include edema; hemorrhages; arrested growth and development; liver enlargement; calcium, magnesium, and cholesterol metabolism disruption; decreased coordination; anemia; and hyperglycemia (Eisler, 1986; Peterson et al., 1993). In addition, PCBs can also cause inhibition of immune functions, tumor formation, and neurotoxicity (Safe, 1994).

Table 8-6
Components of Relevant Biological Resources Injury Definitions

Injury Definition	Definition Components	Evaluation Approach
Food, Drug, and Cosmetic Act exceedences [43 CFR § 11.62 (f)(1)(ii)]	Tissue concentrations of a hazardous substance in edible portions of organisms exceed applicable standards.	Compare organism tissue concentrations to applicable Food and Drug Administration (FDA) standards.
Consumption advisory exceedences [43 CFR § 11.62 (f)(1)(iii)]	Tissue concentrations of a hazardous substance exceed levels for which a state has issued directives to limit or ban consumption.	Compare organism tissue concentrations to consumption advisories.
Adverse changes in viability [43 CFR § 11.62 (f)(1)(i)]	The biological resource or its offspring has undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations.	Determine whether the measured biological response satisfies the criteria for indicating an adverse change in viability.

Table 8-7
Egg-Concentration Values for Reproductive Effects from Existing Literature

Species	Egg PCB Concentration (mg/kg)	Effect	Reference
Rainbow Trout	2.7	75% mortality by day 30 post-hatch	Hogan and Brauhn, 1975
Atlantic Salmon	0.6 to 1.9	46 to 100% mortality of eggs and fry	Johansson, 1970 (cited in Niimi, 1983)
Lake Trout	2.0 (estimated)	decreased hatching success	Mac and Schwartz, 1992
Chinook Salmon	3.0	decreased hatching success	Ankley et al., 1991

Early life stages in fish are more sensitive to PCB toxicity than are adult fish (Eisler, 1986). Adverse effects such as reduced egg hatchability, fry mortality, and developmental deformities occur at PCB concentrations orders of magnitude less than concentrations causing adult mortality (Nebeker et al., 1974; Eisler, 1986). Fish embryos can acquire PCB burdens both by uptake from water and via maternal transfer during oogenesis (Broyles and Noveck, 1979; Niimi, 1983; Ankley et al., 1989; Noguchi and Hesselberg, 1991; Spitsbergen, 1991, as cited in Walker and Peterson, 1991). In the embryo, PCBs accumulate in the lipid-rich yolk to concentrations that are typically much greater than those in the surrounding water (Broyles and Noveck, 1979) and may be greater than those in the maternal fish (Niimi, 1983). Many of the adverse effects of PCBs on fry generally occur during yolk sac absorption, suggesting that the toxicity of PCBs to early life stages is associated with uptake of PCBs from the yolk sac by the developing embryo (Mac, 1988; Harris et al., 1994).

PCBs in Great Lakes fish have been implicated as a causal factor in the low reproductive success of fish throughout the region (Willford et al., 1981). Some studies have investigated the possibility that PCBs are responsible for the limited natural reproduction of lake trout and salmon in Lake Michigan, and for the occasionally high mortality in eggs collected from feral Great Lakes fish and incubated in fish hatcheries (e.g., Stauffer, 1979; Willford et al., 1981; Mac, 1988; Walker and Peterson, 1991). Several investigators have posited a relationship between PCB concentrations in feral lake trout eggs and mortality (Ankley et al., 1991; Mac and Schwartz, 1992).

Adverse changes in viability may be assessed through further data analysis and by evaluating potential toxicological effects of PCBs on assessment area fish, such as described below in Section 8.6.

8.4.3 Pathway Determination

Exposure pathways to biological resources in the assessment area include direct exposure through physical contact with hazardous substances in surface water and sediments as well as indirect exposure through food chain processes. Data on PCB concentrations in surface water, sediments, and fish prey will be used to evaluate exposure pathways. If necessary, additional studies may be undertaken to supplement existing data on pathways to exposed aquatic biota resources in the assessment area.

8.4.4 Injury Quantification Approaches

Quantification of injuries to aquatic biota resources will include evaluation of:

- the spatial extent of injuries throughout the assessment area
- the temporal extent of injuries throughout the assessment area.

For example, existing data suggest that elevated concentrations of PCBs in aquatic biota have resulted in a restriction on the commercial carp fishery since 1975 (Kleinert, 1976), and in consumption advisories for sport fish since 1976 (WDNR, 1976-1994). Preliminary evaluation of the spatial extent of injury indicates that PCB concentrations in fish collected from inner to outer Green Bay exceed consumption advisory thresholds (Figure 6-4). Further data analysis will be performed to quantify injuries to aquatic biota.

8.5 TERRESTRIAL BIOTA RESOURCES

8.5.1 Injury Definitions

Relevant biological injuries defined by DOI regulations may include:

- concentrations of a hazardous substance sufficient to exceed action or tolerance levels established under section 402 of the Food, Drug and Cosmetic Act, 21 U.S.C. 342, in edible portions of organisms [43 CFR § 11.62(f)(1)(ii)]

- concentrations of a hazardous substance sufficient to exceed levels for which an appropriate State health agency has issued directives to limit or ban consumption of such organism [43 CFR § 11.62(f)(1)(iii)]

- concentrations of a hazardous substance sufficient to cause the biological resource or its offspring to have undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations [43 CFR § 11.62(f)(1)(i)].

8.5.2 Injury Determination Approaches

The injury definitions in Section 8.5.1 contain several components. Table 8-8 summarizes the components of each definition and the approaches that may be used by the trustees in assessing each component.

Laboratory studies have shown that concentrations of PCBs in bird eggs in the range of 5-10 mg/kg may be associated with embryotoxicity (e.g., Britton and Huston, 1973; Brunstrom and Reutergardh, 1986; Kubiak et al., 1989; Peakall et al., 1972; Wiemeyer et al., 1984; Yamashita et al., 1993). Table 6-5 shows that PCBs in eggs of numerous bird species throughout the assessment area greatly exceed that concentration.

As shown in Tables 8-9 and 8-10, studies of birds nesting on Green Bay or the Lower Fox River demonstrate a pattern of adverse effects, including the following:

Table 8-8
Components of Relevant Biological Resources Injury Definitions

Injury Definition	Definition Components	Evaluation
Food, Drug, and Cosmetic Act exceedences [43 CFR § 11.62 (f)(1)(ii)]	Tissue concentrations of a hazardous substance in edible portions of organisms exceed applicable standards.	Compare organism tissue concentrations to applicable FDA standards.
Consumption advisory exceedences [43 CFR § 11.62 (f)(1)(iii)]	Tissue concentrations of a hazardous substance exceed levels for which a state has issued directives to limit or ban consumption.	Compare organism tissue concentrations to consumption advisories.
Adverse changes in viability [43 CFR § 11.62 (f)(1)(i)]	The biological resource or its offspring has undergone at least one of the following adverse changes in viability: death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunctions in reproduction), or physical deformations.	Determine whether the measured biological response satisfies the criteria for indicating an adverse change in viability.

- reduced reproductive success, including reduced hatching success in Forster's terns (Kubiak et al., 1989), common terns (Hoffman et al., 1993), double-crested cormorants (Tillitt et al., 1992; Larson et al., 1996), and bald eagles (C. Dykstra, unpublished data)
- physical deformations, including head and neck edema, and bill and leg deformities in double-crested cormorants (Larson et al., 1996), black-crowned night-herons (Hoffman et al., 1993), common terns (Hoffman et al., 1993), and Forster's terns (Kubiak et al., 1989)
- "wasting" of Forster's tern chicks, i.e., failure to put on weight during nestling development usually followed by death prior to fledgling (Harris et al., 1993)
- reduced Forster's tern parental attentiveness during incubation (Kubiak et al., 1989)
- reduced colony tenacity in Caspian terns (Mora et al., 1993).

Further data analysis will be performed to evaluate injuries to terrestrial biota.

Table 8-9
Comparisons of Hatching Success/Productivity and Embryo & Nestling Deformity Rates among Birds Nesting on Green Bay/Lower Fox River (impact area) and Control Areas

Species	Hatching Success/Productivity		Deformity Rate		Reference
	Impact	Control	Impact	Control	
Forster's Tern	37% hs[1]	75% hs	33%	12%	Kubiak et al., 1989
Common Tern	71% hs	85% hs	11%	0%	Hoffman et al., 1993
Double-Crested Cormorant	55-65% hs	64-76% hs	0.76%	0.06%	Larson et al., 1996
Bald Eagle	0.39 young/pair	1.09 young/pair	—	—	C. Dykstra unpublished data

1. hs = hatching success.

8.5.3 Pathway Determination

Exposure pathways to biological resources in the assessment area include direct exposure through physical contact with hazardous substances in surface water and sediments as well as indirect exposure through food chain processes. For example, PCB residue data from bottom- and sediment-dwelling organisms exposed directly to PCBs in water and sediments can be used to determine areal dispersion of PCBs. PCB residue data from indicator species can be used to represent the exposure of a particular trophic level in a food chain. If necessary, additional studies may be undertaken to supplement existing data on pathways to exposed wildlife resources in the assessment area.

8.5.4 Injury Quantification Approaches

Quantification of injuries to terrestrial biota resources will include evaluation of:

- the spatial extent of injuries throughout the assessment area
- the temporal extent of injuries throughout the assessment area.

For example, existing data indicate that elevated concentrations of PCBs in eggs of numerous bird species throughout the assessment area have exceeded since the early 1970s concentrations demonstrated in laboratory exposure and field studies to cause injuries. Preliminary evaluation of the spatial extent of potential injuries indicates that bird injuries have been observed at several