Ref 28

44

JUL 29

DOCUMENT FOR DEVELOPMENT OF SEDIMENT QUALITY OBJECTIVE CONCENTRATIONS FOR PCBS IN DEPOSIT A LITTLE LAKE BUTTE DES MORTS

CONTENT

053278

4.1 Use of an equilibrium partitioning model to derive Sediment Quality Objective Concentrations to protect benthic organisms exposed to PCBs in sediment pore water.

4.2 Review of literature, regulatory criteria and guidelines for establishing Sediment Quality Objective Concentrations for PCBs to protect benthic organisms.

4.2.1 Ontario Ministry of the Environment Sediment Quality Guidelines.
4.2.2 State of Washington Sediment Standards.
4.2.3 National Oceanic and Atmospheric Administration (NOAA) Sediment Quality Guidelines.
4.2.4 Sediment quality assessment approach application to determine biological effect levels to benthic organisms from PCBs.
4.2.5 Summary of approaches and effect levels to benthic organisms.
4.2.6 Benthic community studies on the Lower Fox River.

5.0 Consideration of toxic PCB congeners.

6.0 Preliminary Results From Wisconsin Department of Natural Resources biomonitoring studies of Deposit A, summer of 1992.

4.1 Use of an equilibrium partitioning model to derive Sediment Quality Objective Concentrations to protect benthic organisms exposed to PCBs in sediment pore water.

4.2 Review of literature, regulatory criteria and guidelines for establishing Sediment Quality Objective Concentrations for PCBs to protect benthic organisms.

4.2.1 Ontario Ministry of the Environment Sediment Quality Guidelines.
4.2.2 State of Washington Sediment Standards.
4.2.3 National Oceanic and Atmospheric Administration (NOAA) Sediment Quality Guidelines.
4.2.4 Sediment quality assessment approach application to determine biological effect levels to benthic organisms from PCBs.
4.2.5 Summary of approaches and effect levels to benthic organisms.
4.2.6 Benthic community studies on the Lower Fox River.

5.0 Consideration of toxic PCB congeners.

6.0 Preliminary Results From Wisconsin Department of Natural Resources biomonitoring studies of Deposit A, summer of 1992.

1.0 Summary of Sediment Quality Objective Concentrations for PCBs in Deposit A Sediments

Wisconsin Department of Natural Resources' (WDNR) Sediment Management and Remediation Techniques Program (SMART) goal for sediment remediation is to restore contaminated systems to conditions that are protective to the maximum extent possible of the aquatic ecosystem and human uses. This goal is tempered by a number of factors, however, one of which is the understanding that remedial actions should not be expected to reduce sediment contaminant concentrations to levels below background. A background PCB concentration as used herein is a statistically defined maximum probable concentration found in surficial sediments based on samples from representative unimpacted reference sites. Based on this framework, sediments in Deposit A should be remediated to achieve a concentration of total PCBs in sediment no greater than the higher of

(1) sediment concentrations protective of a range of biological endpoints; or
(2) background sediment concentrations.

Based on the protective levels discussed below and review of the limited data available on background PCB concentrations in Fox River system sediments, WDNR preliminarily identifies the sediment quality objective concentration (SQOC) for PCBs in Deposit A sediments to be the maximum probable background PCB concentration. The data currently available (five samples) indicate that maximum probable background concentration, and the SQOC for PCBs in sediment, will be approximately 40 to 90 μg/kg (all sediment chemical concentrations in the following document are expressed on a dry weight basis).

This summary and the following document describe WDNR's approaches to determining protective and background concentrations of PCBs in Deposit A sediments.

Sediment PCB Concentrations Protective of Biological Endpoints

A number of approaches were used to establish protective concentrations of PCBs in Deposit A sediments in Little Lake Butte des Morts:

(1) Partitioning-based estimates of sediment quality that will protect established biological (including human health) endpoints;

(2) Review of sediment quality criteria and guidelines established by other regulatory agencies or discussed in the literature; and
(3) Consideration of studies in the Lower Fox River that related PCBs to biological effects were reviewed and pertinent information used.

Partitioning-Based Estimates of Sediment Quality Protective of Biological Endpoints

WDNR's partitioning-based estimates of sediment quality considered a number of biological endpoints, including (1) water quality criteria related to protection of human health and wildlife, (2) fish tissue residue criteria and objectives, and (3) water quality criteria related to

053276

protection of aquatic organisms that spend all or part of their life cycles associated with sediments, sediment pore waters, and/or the sediment-water column interface.

A number of partitioning models were applied to attempt to relate and predict PCB distribution between the water, sediment, and biotic environmental compartments. These models used data specific to Deposit A (including total organic carbon levels in the sediment and type of Aroclor present), Aroclor-specific partitioning coefficients (K_{ow} and K_{oc}), and assumed fish lipid contents.

Most of the Sediment Quality Objective Concentrations (SQOC) for PCBs developed by the partitioning approach are expressed on an organic carbon normalized basis, that is, to protect each biological endpoint, a maximum ug PCB/g organic carbon is allowed. This normalization reflects the assumption that the organic carbon of sediments is the depository and primary determinant of the bioavailability of nonpolar organic compounds such as PCBs associated with sediments. To facilitate communication of the levels of PCBs in sediments that are protective of various biological endpoints, the concentrations are generally presented in dry weight bulk chemical terms - μg PCB/kg dry sediment in the following document.

A number of partitioning models currently available to relate sediment levels of PCBs to fish tissue levels were applied. Four different models were used to establish SQOC based on protection of three different fish tissue residue levels-U.S. Food and Drug Administration (FDA), International Joint Commission (IJC), and proposed Great Lakes Water Quality Initiative-related level (GLWQI).

Sediment Quality Criteria and Guidelines Established Elsewhere

In addition to the partitioning approaches, protective sediment concentrations were also identified from sediment quality criteria and guidelines for PCBs established by other regulatory agencies and in the literature. The focus of WDNR's review of the criteria and guidelines was on criteria that relate to effects on benthic organisms and communities.

Summary of Sediment PCB Concentrations Protective of Biological Endpoints

A summary of the resulting SQOC to protect the various biological endpoints is given below. Details of the rationale and considerations made at arriving at the objective concentrations are discussed in the attached development document.

052275

Summary of Sediment Quality Objective Concentrations
To Protect Various Biological Endpoints

Biological Endpoint, Criteria, or Objectives to Be Met or Protected		Sediment Quality Objective Concentrations For PCBs to Protect Biological Endpoints (ug PCB/kg Sediment)
Water Quality Criteria		
Equilibrium Partitioning Model		
NR 105 Human Cancer Criterion		4 - 20
NR 105 Wild and Domestic Animal Criterion		22 - 123
Fish Tissue Residue Criteria/Objectives		
ARS Model	FDA	200 - 1,000
	IJC	10 - 50
	GLWQI	2 - 12
Thermodynamic Equilibrium Model	FDA	188 - 1,038
	IJC	4.5 - 26
	GLWQI	1 - 6
Bioconcentration Model	FDA	616 - 3,409
	IJC	15 - 82
	GLWQI	4 - 20
Food Chain Multiplier Model	FDA	35 - 104
	IJC	0.9 - 2.6
	GLWQI	0.2 - 0.6

Protection of Benthic Organisms
Equilibrium Partitioning Model
U.S. EPA Chronic Water Quality Criteria ____ 70 - 554
Regulatory Guidelines and Criteria
Ontario Sediment Quality Guidelines ____ 30 - 240
State of Washington Sediment Standards ____ 120 - 960
NOAA Effects Range-Low ____ 23 - 180
Literature
Chapman-Comparison of Four Approaches To Develop Sediment Quality Criteria. Minimal or no Effect Level ____ 100

Reference Site Sediment PCB Concentrations

Range	14.1 - 90
Average	42.2

Reference Site Sediment PCB Concentrations in the Lower Fox River System

A number of the calculated methods and referenced criteria result in SQOC below what appear to be the concentrations of PCBs in surficial sediments at unimpacted reference sites along the lower Fox River. Other SQOC, especially those based on the lower TOC contents, are less than or equal to the maximum observed reference site concentrations of 90 ug PCB/kg sediment along the Lower Fox River. To provide protection to the maximum extent possible of all the biological end points, criteria, and objectives in all environmental compartments, and to protect ecosystem integrity, any remediation of PCB contaminated sediments should be driven by clean-up to background levels of PCBs. Background is defined as the maximum probable background concentration (MPBC) of PCBs found at unimpacted reference sites along the river. An adequate number of samples taken at appropriate reference sites are needed to statistically define a MPBC. Five available samples of reference sites to date have resulted in a maximum observed value of 90 ug PCB/kg sediment. This limited amount of information does not support complete characterization of background PCB levels.

Toxic PCB Congeners

Development of SQOC for 11 planar PCB congeners is also discussed in the following development document. SQOC development for the congeners is based on protecting the proposed ambient water quality criteria for the congeners presently established in the Great Lakes Water Quality Initiative. It appears PCB congener 77 (IUPAC numbering system) may be contributing the greatest amount of 2, 3, 7, 8-TCDD toxic equivalency of all the toxic congeners in Deposit A sediments based primarily on the concentration present. Congener 77 has a lower toxic equivalency factor to 2, 3, 7, 8-TCDD compared to congeners 105 or 126, but because of 77's larger concentrations in the sediments, it results in the largest contribution to the total toxic equivalency. More information is needed on the fate, partitioning, transport, and TCDD-toxic equivalency concentration of this group of 11 toxic congeners in the Deposit A sediments and other sediments along the Lower Fox River.

2.0 Introduction

The basic concepts and rationale used for the development of Sediment Quality Objectives Concentrations (SQOC) for PCBs are established in a Wisconsin Department of Natural Resources (WDNR) July 10, 1992 memo from Schuettpelz to Giesfeldt. A copy of the memo (hereafter the July 10 memo will be referenced as the Sheboygan Memo) was provided earlier to Blasland and Bouck Engineers, the contractor for the P.H. Glatfelter Company, based on the signed agreement between the Department and the company. The memo contained Water Resource Management's (WRM) listing of applicable criteria, guidelines, procedures, and policies as Applicable or Relevant and Appropriate Requirements (ARARs) and to be considered (TBC) criteria for use in establishing clean-up levels for surface water, sediment, and floodplain soils at the Sheboygan River Superfund site.

Using the basic tenets in the Sheboygan Memo and considering site specific factors associated with Deposit A in Little Lake Butte des Morts (LLBM), SQOC are established in this document. Site specific factors considered in SQOC development were the Total organic carbon (TOC) values associated with Deposit A sediments, the specific Aroclor make-up in the sediments, and any Lower Fox River studies involving assessments of PCBs in the sediments, water column, and biotic environmental compartments.

The protection of an array of biological objectives or endpoints using a number of tools or approaches is considered during development of SQOC for PCBs. Multiple approaches and objectives contribute to a weight-of-evidence approach to developing an appropriate SQOC to be protective of the most sensitive endpoint(s).

The objectives and approaches to develop SQOC to protect those objectives are discussed below. A narrow focus on only a singular objective such as lowering fish tissue residues of PCBs to below the Food and Drug Administration (FDA) criterion of 2 ppm for human consumption does not address all the hazards of PCBs in the river on a broader ecosystem basis. The SQOCs are established based solely on biological endpoint protection and scientific information. Remediation and cleanup of sediments should be designed to achieve the SQOC as closely as is practicable. Practicality in achieving SQOC is defined by considering the factors of net environmental effects, natural recovery rates, engineering feasibility, and costs when determining site cleanup standards.

Within the following discussion, the terms Sediment Quality Objective Concentrations, Sediment Quality Criteria, Sediment Quality Objective Values, and sediment safe levels are used interchangeably.

2.1 Identification of PCB Aroclor Make-Up of Deposit A

Based on the results of Task 2: Sediment Characterization/Mapping of Deposit A, Technical Memorandum (EWI Engineering, 1991), the PCB samples from Deposit A most closely resemble the congener distribution of Aroclor 1242. The minimum, maximum, and weighted average of PCB concentrations in the top 15 cm of the Deposit A sediments are 1.71 ug/g, 177 ug/g and 50.3 ug/g, respectively (EWI, 1991).

In the various partitioning models discussed in SQOC development, octanol-water (K_{ow}) and organic-carbon (K_{oc}) partitioning coefficients associated with Aroclor 1242 were used. Because the K_{oc} for Aroclor 1242 varied depending on the reference used and method of derivation, all SQOC calculations were made using minimum (26,300 L/Kg), maximum (1,949,844 L/Kg), and average (494,808 L/Kg) partitioning coefficient values.

The partitioning coefficient for an Aroclor is an average of the partitioning coefficients of the individual congeners making up the Aroclor. Because partitioning coefficients are derived based on manufactured Aroclors whose congener patterns change once the Aroclor is released to the environment (due to physicochemical and biological weathering and other factors), it is appropriate to consider the uncertainty in estimating partitioning coefficients in SQOC determinations by using a range of K_{oc} values. K_{ow} values which were used to derive K_{oc} values were derived from MacKay et al. (1983), Kadeg and Pavlov (1989), U.S. EPA (1989), U.S. EPA (1990), and Kenega and Goring (1978).

Where it was necessary to convert K_{ow} values to K_{oc}, the following regression equation was used (based on Di Toro, 1985):

$$K_{oc} = 0.00028 + 0.983 * \mathrm{Log}_{10} K_{ow}$$

This equation is used by U.S. EPA (Di Toro et al., 1992) in the development document for establishing sediment quality criteria for nonpolar organic compounds.

The predicted partitioning coefficients are based on a two phase partioning model (free or dissolved PCBs and PCBs sorbed to particulate organic carbon). A third phase, dissolved organic carbon (DOC), may play a role in bioavailability of PCBs in interstitial and overlying surface waters. Eadie et al. (1992) reported that the binding of hydrophobic organic chemicals to DOC in Green Bay water is small, and on average, the amount associated with this phase is less than 10%. Partitioning to this phase or relationship with bioavailability was not considered in this SQOC development document.

2.2 Toxicity Considerations Of Aroclor 1242

In the following SQOC development, Aroclor 1242 concentrations equate with total PCB concentrations contained in criteria or objectives to be protected. NR 105 does not distinguish any relative toxicities of the different Aroclors. Wisconsin's application of the FDA (2 ppm) tissue residue objectives for PCBs used in issuing fish advisories is based on total PCB concentrations in fish and also does not distinguish any relative toxicities of the Aroclors.

EPA classifies all PCBs as carcinogenic. They recognize that toxicities of Aroclors may vary, but they also indicate that there is only limited information on calculating separate cancer potency estimates for each PCB mixture. Their policy is to evaluate carcinogenic risk posed by PCBs as if they have the carcinogenic potency of Aroclor 1260. Also, there is commonality of some PCB congeners between different Aroclors and no data to definitively link specific congeners to animal tumorigenicity. Once released to the environment, the congeners of concern may be more persistent and bioavailable than other congeners in the

Aroclor mix. Given these uncertainties, the assumption of all environmental PCB mixtures having the carcinogenicity of Aroclor 1260 is appropriate.

The congener make-up of manufactured formulations of Aroclors changes once released to the environment due to physical, chemical, and biological processes. The relative concentration of congeners will vary among environmental compartments, between sediment depositional areas, and over time. Changes in congener make-up may mean changes in toxicity in the environment from that measured in manufactured formulations. For example, more recent studies have observed that there is greater toxicity to mink fed Great Lakes fish containing PCBs than was observed in earlier studies where mink were fed comparable levels of technical grade PCBs in their diet. In addition, there is evidence that much smaller concentrations of PCBs in the tissues of Great Lakes fish may be harmful to fish predators.

The activities of several commercial Aroclors as inducers of microsomal Aryl Hydrocarbon Hydroxylase (AHH) and the Ethoxyresorufin O-Deethylase (EROD) in mammalian cells was found to be dependent on the chlorine contents (and congener distribution) of the mixtures. The induction potencies of Aroclors 1242, 1248, 1254 were higher than 1221 and 1268. The enzyme activities corresponded to the number of active congeners in the tetra- to hexachlorobiphenyl homolog groups. Based on *in vitro* AHH and EROD induction assays, Aroclor 1242 is a more potent inducer than Aroclors 1254, 1260, or 1268 (Sawyer et al., 1984; Smith et al., 1990). Aroclor 1242 had a higher relative ability to induce EROD activity than any of the other Aroclors in the Smith et al. (1990) study.

In an examination of the toxicity of Aroclors 1242, 1248, 1254, and 1260 to rainbow trout, bluegill, and channel catfish, Mayer et al. (1977) found that Aroclor 1248 was the most toxic mixture closely followed by Aroclor 1242. Kannan et al. (1987) found that the content of congener 77 was highest in Aroclor 1248 and next highest in Aroclor 1242. The relative concentrations of congener 77 in Aroclors are consistent with the above fish toxicity reported for Aroclor mixtures (Kannan et al., 1987).

2.3 Total Organic Carbon (TOC) Content of Deposit A Sediments

In the various partitioning models used to develop SQOC, representative TOC values of the bedded sediments of Deposit A were utilized. Based on the EWI Engineering Technical Memorandum (1991), the organic carbon content of the top 15 cm (6 in) of Deposit A sediment ranges from 1.5%-11.7% and averages 8.27% (n=46). The organic carbon normalized PCB concentrations in the top 15 cm of Deposit a range from approximately 60-1600 ug PCB/g Organic Carbon (OC) and averages 650 ug PCB/g OC.

The top 15 cm was used because it is the most biologically active zone in the sediments. Organisms that burrow in or remain at the sediment surface have their greatest exposure to the PCBs associated with sediment particulate matter, pore water, or food items in this strata. Also, depending on sediment characteristics such as bulk density, bed porosity, and amount of disturbance, the top 15 cm of the 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.

053270

In calculating SQOC where TOC is a component of a partitioning model, the minimum, maximum, and average TOC values for the Deposit A sediments were used. Where applicable, SQOC values are expressed on a TOC normalized basis for PCBs (μg PCB/g of TOC). The SQOC are made site specific by consideration of the TOC values in the Deposit A sediments.

2.4 Reference Site Concentrations of PCB in Sediments

Some of the calculated PCB SQOC values protective of various endpoints are relatively low. Practicality dictates that the cleanup criteria of contaminated sediments can be established at levels no more stringent than identified representative watershed-related unimpacted reference site concentrations. The Sheboygan Memo reviews background concentrations for PCBs in sediments at various sites. On the Lower Fox River, the data from three sample sites is available for use in establishing reference site levels of total PCB in sediments. Two sediment samples were with taken a tube corer in the Menasha channel at the outlet of Lake Winnebago by WDNR in 1990. Two samples were taken with a Ponar dredge by WDNR in September, 1991. One sample was taken in 1988 from sediments in the East River as part of the study by Call, et al. (1991). The East River sampling location was used as reference site for sediment quality evaluations in the Lower Fox River in the study. The results of the sampling from the two sources for reference or background values for PCBs in surficial sediments are:

Sampling Sites	Total PCB Concentrations in Sediment ug/Kg (dry weight)	% TOC	OC Normalized ug PCB/g OC
East River	90	1.46	6.16
Menasha Channel			
47-1	33.8	7.48	0.45
47-2	14.1	9.64	0.15
47-1-A	44	7.2	0.61
47-1-B	29.1	6.7	0.43
Average	42.2		1.56

Further sampling at representative unimpacted reference sites associated with the lower Fox River system is needed to determine the variability of total PCBs and certain PCB congeners in surficial sediment samples. Sediments also need to be analyzed for TOC content to establish organic carbon normalized PCB concentrations at the reference sites.

3.0 Sediment Quality Objective Concentrations to Protect Various Biological Endpoints

3.1 Development of Sediment Quality Objective Concentrations to Protect Water Quality Criteria and Objectives

053269

Table 1 lists the NR 105 ambient water quality criteria protective of human health and wildlife that were used to drive SQOC development based on a simple partitioning model. The calculated SQOC values to protect human health and wildlife and the partitioning model used are shown in Tables 2 and 3, respectively.

The partitioning model described in the notes to the tables serves as the basis for U.S. EPA's development of proposed sediment quality criteria for nonpolar compounds (Di Toro, 1992). Assuming comparable sensitivity of water column and sediment dwelling organisms, U.S. EPA uses water quality criteria for fish and aquatic life to protect sensitive benthic organisms exposed to a contaminant in sediment pore water from chronic toxicity. The partitioning model calculates the amount of contaminant that can be associated with the organic carbon of sediments such that a concentration is not partitioned to the sediment pore water to a level that exceeds the chronic water quality criteria.

The application of the partitioning model in Tables 2 and 3 assumes an equilibrium is reached between PCBs associated with sedimentary organic carbon, sediment pore water, and the overlying water column. This also assumes that once PCBs are released from sediments and sediment pore water to the overlying water column, that residence time is relatively long and mixing and dilution are small. The reduction in concentration of dissolved PCBs from pore water to the overlying surface water is site-specific depending on flows, water circulation, water column residence time, and sediment turnover. Preliminary runs of the Green Bay Mass Balance Model Study show a reduction of dissolved PCB concentrations from the sediment pore water to the overlying surface water by up to two orders of magnitude (personal communication, Jeff Steuer) in the area of Deposit A. Inflow of uncontaminated Lake Winnebago water to the area of Deposit A, low water column velocity over and little resuspension of Deposit A sediments, may be reasons for the predicted pore water to surface water concentration reductions. In sediment deposits farther downstream that are in higher energy areas subject to greater amounts of sediment resuspension and where all upstream PCB releases are accumulating and being carried in the water column, the reduction of dissolved PCBs from the pore water to water column is predicted to be one order of magnitude based on the Green Bay Mass Balance Model.

A one order of magnitude reduction of dissolved PCB concentrations from pore water to surface water could potentially mean the SQOC calculated in Tables 2 and 3 could increase by one order of magnitude. For example, the SQOC calculated to be protective of NR 105 human health criteria (based on ave. TOC and KOC) could increase from 20 ug/kg to 200 ug/kg. However, because the partitioning model used to calculate the SQOC values in the tables only accounts for the dissolved fraction, it underestimates of the total PCBs released to the water column. Water column organisms can ingest particulate-sorbed PCBs. Also it has been shown that as suspended particle concentrations increase, PCBs in the dissolved phase increase (Di Toro, 1985).

The Green Bay Mass Balance Model estimates that 20-40% of the PCBs in the water column over Deposit A are associated with particulate matter. For sites downstream, particulate PCBs may contribute 70% of the total PCBs, except during winter. The PCB criteria in NR 105 are based on the total of dissolved and particulate associated PCBs in the water column, so consideration needs to be given to the particulate PCBs in determining SQOC

053268

appropriateness. Also, while the model used to calculate the SQOC values does not account for dilution, attenuation or degradation factors, it also does not account for factors such as bioturbation, advective pumping, gas convection, bed porosity, irregularity of sediment bed surfaces and near bed sediment particle concentrations that can contribute to total PCBs transported across the sediment-water interface. While equilibrium may not be attained in many environmental situations, it is the driving force for the movement of dissolved and vapor phase compounds between environmental compartments.

The low SQOC that are calculated by the model shown in Table 2 are also protective of benthic organisms. These levels reduce/minimize the exposure and accumulation of PCBs from sediment pore water, and ingestion of PCB sediment particles and food items. Benthic invertebrates and emerging insects are a potential biotic pathway for transferring sediment associated PCBs to upper food chain levels in aquatic and terrestrial ecosystems. Using the Table 2 SQOC values also minimizes exposure of bottom dwelling fish such as carp, small forage fish, and bullheads to PCBs released from sediments to the lower portion of the water column.

Table 1, box 4, contains the water quality criteria for PCBs proposed under the Great Lakes Water Quality Initiative (GLWQI) as part of the Great Lakes Critical Programs Act of 1990. The proposed criteria will be published in the Federal Register in the near future. If adopted, Wisconsin will have two years to revise NR 105 to incorporate the methodology for development of the criteria. The methodology would be used to revise the PCB criteria for Great Lakes communities as well as cold water and warm water stream classifications. Table 1, box 5, shows the proposed total PCBs criteria for a Warm Water Sports Fish Community stream classification applicable to the segment of the Fox River that contains Deposit A, using the proposed GLWQI methodology. The GLWQI wildlife criteria will apply to all stream classifications.

The proposed GLWQI methodology results in water quality criteria that are approximately two orders of magnitude lower than the PCB criteria presently in NR 105 for both human health and wildlife protection. This is due primarily to more current toxicity data, and more field and laboratory data that have led to a more accurate bioaccumulation factor for PCBs. Use of the proposed GLWQI Criteria would reduce the SQOC calculated in Tables 2 and 3 by two orders of magnitude.

Based on the above reasoning, the SQOC values in Tables 2 and 3 appear to be appropriately protective of human health and wildlife. The SQOC values for protection of water quality criteria should be no greater than the Table 2 and 3 values based on site-specific average TOC and Aroclor 1242 average K_{oc} values.

Table 4 shows a comparison of the water column concentrations of PCBs in LLBM and the Fox River at Appleton, with the ambient water quality criteria in NR 105 and proposed in the GLWQI. An exceedance factor has been calculated by dividing the water column concentration by the criteria. A total of the average dissolved PCBs and particulate associated PCBs in the Neenah channel (1.49 ng/L) was taken as ambient background concentrations in the river. The value was subtracted from the maximum and average values for PCB in water samples from Little Lake Butte des Morts and Appleton before calculation

053267

of the exceedance factors in Table 4. The resulting values represent baseline contributions of PCBs from these two sampling locations.

3.2 Development of Sediment Quality Objective Concentrations to Protect Fish Tissue Residue Criteria and Objectives

Table 5 provides three sources of fish tissue residue criteria or objectives developed for the protection of humans or wildlife that consume fish. From the FDA objective (2000 ug/kg), the levels decrease by two orders of magnitude with the lowest being PCB levels in fish needed to protect wildlife (23 ug/kg) based on the proposed GLWQI water quality criteria development document.

The FDA objective is based on a quantitative human health risk analysis and involves a judgmental cost-benefit analysis. Fish above this level cannot enter interstate commerce. The FDA objective of 2 ppm PCB in fish tissue applies to skin-on fillets. The 2 ppm objective in the development of SQOC uses the 2 ppm to apply to the PCB concentration in the whole body fresh weight of the fish. Generally the PCB concentration in the whole body fresh weight is greater than the concentration in the fillet. The ratio of whole body concentration to edible concentrations depends on the species and age of the fish. Applying the 2 ppm to whole body fresh weight of the fish may derive conservative SQOC concentrations to be protective of PCB concentrations in the edible fillet portions. The FDA number does not consider the impacts of PCBs at other ecosystem levels. While fish tissue PCB levels may be maintained at less than 2 ppm in fillets to protect humans, the potential for environmental impacts on the contaminated organisms or their non-human predators is not considered. Also, the 2 ppm total PCB tissue residue criterion does not take into account the presence and quantity of toxicologically significant PCB congeners.

There is a general feeling that the Food and Drug Administration (FDA) guidelines currently used by many of the Great Lakes states are not appropriate for regular consumers of sport caught fish. Advisory protocol also varies from state to state. These inconsistencies have led to confusion among the fish consuming public. The Council of Great Lakes Governors created the Fish Advisory Task Force to deal with the inconsistent advice being given to fish consumers. The goal of the Task Force, which is made up of a representative from each state's health and environmental agencies, is to create a consistent fish advisory protocol for all the great Lakes states. The Task Force has been pursuing a direction that would be more scientifically founded and appropriate for consumers of sport fish from the Great Lakes basin based on their eating habits. A new protocol for issuing consumption advisories is currently under review by each of the Great Lakes states.

The Task Force spent considerable time reviewing and discussing the selection of the adverse health endpoints to use as a reference for the advisory. Infant neuro-development was chosen as the most appropriate endpoint based on consideration of both human experience and controlled laboratory animal studies. In most cases, PCBs would be used as the surrogate contaminant for placing fish into consumption categories. Under the proposed protocol, fish advisories may be initiated at concentrations approximately two orders of magnitude lower (i.e. 0.05 ppm) than the current action level of 2.0 ppm. The advisory would be separated by site, species and sizes as is currently employed. Average PCB concentrations would be used to place the fish into five easily understood consumption frequencies. Since this advisory is based on reproductive/developmental effects, there would not be separate consumption advice given for women and children. It should be noted that this is still a proposal. Final state approval is currently being sought by the Task Force with the goal for implementation in 1994.

For fish there is little published data that relates sublethal effects to tissue residue concentrations of PCBs. The data base for establishing quantitative residue effects relationships is very limited. Eisler (1986) indicates that among sensitive species of fish, total PCB residues (in ug/kg fresh weight) in excess of 500 in diets, 400 in whole body, and 300 in eggs were demonstrated to be harmful, and should be considered presumptive evidence of significant PCB contamination. Gibson et al. (1984) reviewed the published papers reporting the sublethal effects of chlorinated contaminants on marine and esturaine animals. Based on their review, the general guidance they formulated for whole body tissue residue levels of concern associated with potential adverse sublethal effects to fish from chlorinated organic contaminants were:

Level of Concern	Tissue Concentrations (wet wt.)
Low	< 100 ug/kg
Medium	100 - 1,000 ug/kg
High	> 1,000 ug/kg

The IJC fish tissue residue objective for PCBs of 100 ug/kg is based on the protection of birds and animals that consume fish. Maack (1988) notes that the mink study used to derive the 100 ug/kg value is dated (1973) and more recent studies have observed that the toxicity from Great Lakes fish fed to mink was greater than observed in earlier studies with mink fed comparable levels of technical grade PCBs. Gagnon et al. (1990) note there is evidence that PCB concentrations less than 100 ug/kg in fish may be harmful to fish predators. Gagnon et al. suggest a revision of the IJC objectives based on congener mixtures actually found in nature, new knowledge about toxicity of individual congeners, and their biomagnification in the food chain.

Females of some species of fish transfer as much as 30% of their PCB body burdens to the developing eggs which puts developing fish larvae at risk. (Sijm et al., 1992; Miller, in press). Rainbow trout containing 400 ug PCB/kg fresh wt. produced eggs with low hatchability and numerous fry deformities (U.S. EPA, 1980).

Fish in the Lower Fox River are continuously exposed to PCBs along the reaches of the entire river which has multiple PCB contaminated sediment deposits and PCB releases from the deposits along the river reaches. The fish generally do not have the ability to spend time in clean reaches. In trying to relate sediment concentrations of PCBs in Deposit A to fish tissue levels, no attempt was made to derive an area use factor or estimation of how much time the fish are in the area of Deposit A relative to their home range. Based on the water quality data in Table 4, fish off-site could be exposed to elevated concentrations of PCB in the water column downstream because all deposit releases are accumulating in the water column. An assumption is made that fish are capable of receiving PCB exposures from the sediment, food sources, or water in all reaches of the river making up their home range. Because of fish mobility, their exposure is integrated over the entire area making up their home range. Based on this, attempts to distinguish site-by-site contributions to exposure in the partitioning model application were not attempted.

Table 6 presents the mean and range of percent lipid content of various fish species sampled by the WDNR in Little Lake Butte des Morts. Generally, fish lipid values of 4% and 8% were used in establishing SQOC to protect fish tissue residue objectives using various partitioning models. The 4% value is associated with sport fish consumed by humans and the 8% value is associated with the higher lipid values in site fish that are consumed by wildlife.

3.2.1 Use of Data From Studies On the Lower Fox River

Fish tissue analysis for PCBs was performed by Call et al. (1991) by analyzing fathead minnows exposed to collected river sediment in a 30-day laboratory bioaccumulation study and field-collected black bullheads. Ten sediment samples were collected in the lower Fox River below the De Pere dam and two in Green Bay. One site was sampled in the East River as a reference site. Black bullheads were collected in the vicinity of seven of the sediment sampling sites. Laboratory bioaccumulation tests were run on sediments collected from all 13 sites. Table 11 shows the PCB and TOC concentrations in the sediment at the sampling sites in the Call et al. (1991) study. Both PCB and TOC concentrations are on the lower end of the range of what are found in the Deposit A sediments. The PCB mixture present in the Call study sediment samples was comprised mainly of the tri- and tetrachlorohomolog groups, and resembled the Aroclor 1242 and 1248 commercial mixtures. The presence of Aroclor 1242 in these lower river sediments has a commonality with the Aroclor 1242 in Deposit A sediments. The East River sediment reference site has more of the penta-, hexa-, and heptachloro-isomers, which is similar to the patterns exhibited in commercial mixtures of Aroclor 1254 and 1260.

In regard to the PCB chloro-isomer content in the field collected black bullhead and laboratory exposed fathead minnow, Call et al. (1991) found the following:

1. While the sediment was predominated by trichlorobiphenyls, the bullhead tissues contained tetrachlorobiphenyls in the greatest amount.

2. Tetra-, penta-, and hexachlorobiphenyl are selectively accumulated in bullhead tissue relative to their concentration in the sediment. [Note: This is also supported by Walleye data collected during the Green Bay Mass Balance Study.]

3. It is noteworthy that the tetra-, penta-, and hexachlo homolog groups were accumulated in tissue, especially the penta- series (which contains congeners 105 and 126). PCB congeners in these homolog groups have been linked to reproductive impairment in fish eating birds in Green Bay (Kubiak et al., 1989).

4. The black bullheads contained total concentrations of the highly toxic tetra- and pentachlorobiphenyl congeners (IUPAC numbers 77, 84, 105, 114 and 118) ranging from 25 to 110 ug/Kg (considering an equal distribution between co-eluting

compounds). Only trace amounts (0.61 to 1.90 ug/Kg) of #156 were found in the tissue (assuming even distribution of co-eluting compounds).

5. As with black bullheads, tetrachloro homologs predominated in fathead minnow tissue from the laboratory bioaccumulation study. Pentachloro homologs comprised the second largest percentage of total PCB in minnow tissue comparable to the black bullheads.

6. The PCB residues in fish and invertebrates are of definite concern regarding their likely roles in causing mortalities and reduced reproductive success in sensitive avian and mammalian consumers.

3.2.2 Application of Partitioning Models to Develop Sediment Quality Objective Concentrations for Fish Tissue Residue Level Protection

Relating fish tissue PCB residue concentrations to concentrations in sediment can be done based on two general types of sediment bioaccumulation models: equilibrium-based and kinetic approaches. The approaches and models under each are:

Equilibrium-Based

1. Site-specific measurements of sediment-fish partition coefficients or bioaccumulation factors

2. Thermodynamic partitioning model based on sediment organic carbon and fish lipid normalized values

3. Sediment-water-fish tissue partitioning model.

Kinetic Based

1. Bioenergetically based toxicokinetic models

2. Kinetic process models

The equilibrium-based approaches assume steady-state conditions between the organisms and the environment. The kinetic approaches describe bioaccumulation as the net effect of rate processes (Lee, 1992).

The first three listed models are a simplified expression of contaminant distribution between environmental compartments in aquatic systems. To address the true complexity and multitude of environmental factors bearing on compartmental distributional relationships of contaminants and food chain transfers, sophisticated models requiring large amounts of measured input data would be needed (MacKay et al., 1983). Information is limited to demonstrate that kinetic models are better predictors than equilibrium models. There are few data to evaluate the accuracy of kinetic models with sediment contaminants (Landrum et al., 1992).

053263

Partitioning constants have not been developed to a great extent and they must evolve from in-field or laboratory bioaccumulation studies. The Call et al. (1991) study discussed above looked at bioaccumulation of PCBs in fish when exposed to sediments in the Lower Fox River below the De Pere Dam. Ankley et al. (1992) expanded on data collected in the Call et al. study in regard to bioaccumulation of PCBs.

3.2.3 Accumulation in Fish Relative to Sediments (ARS Factor)

Table 7 shows the sediment and tissue PCB concentrations from the Call et al. (1991) study as a result of the 30-day bioaccumulation test using fathead minnows. The tissue concentrations in Table 7 are expressed on a dry-weight basis. The concentrations have been converted from a wet-weight basis reported by Call et al. to a dry weight basis assuming a dry-weight to wet-weight ratio of 0.2, or that the fish are 80 percent water. The 80 percent value is based on Seelye et al. (1982) who used juvenile yellow perch in a bioaccumulation study and Oliver and Niimi (1988), who studied PCB uptake by field-collected sculpins in Lake Michigan. Other species and older fish may have lower percent water content in tissue. Conversion to a dry-weight basis in tissues allows a comparison with available literature bioaccumulation studies. The simplest bioaccumulation model is the ratio between PCB concentrations in fish tissue and sediment. An accumulation in fish tissue relative to sediment (ARS) for PCBs was calculated in Table 7 for the bioaccumulation results at each sample site in the Call study based on the formula given at the bottom of the table. The ARS factors range from 0.53 to 4.03 and have an average of 1.35. On average, PCBs in fish tissue are 1.35 times as concentrated as PCBs in sediment on a dry-weight basis. It should be noted that site 3, with the lowest sediment PCB concentration (306.15 μg/kg), had the maximum ARS factor. The high ARS factor at a low PCB sediment concentration may be an indication that the degree of sediment contamination is less a determinant of actual bioaccumulation than are the physical, chemical, and biological processes affecting bioavailablity at particular sites and sediment deposits along the river.

Table 8 shows the same calculations on the black bullheads collected in the field near the sediment sampling stations. Since the bullheads are mobile they did not spend all of their daily or seasonal use periods in the immediate vicinity of the sampling stations, although black bullheads range less than other fish species (Ankley et al., 1992). It is noted that the maximum ARS factor (17.26) for the black bullheads was at site 3, the same site that had the maximum ARS factor for the laboratory exposed minnows. The average ARS factor for the field collected fish was 4.43, greater than the average laboratory ARS factor of 1.35. Ankley et al. (1992) note that use of fathead minnow in laboratory sediment tests may result in significant underprediction of the exposure of indigenous fishes to bioaccumulable contaminants.

Wilford et al. (1987) and others note that 10 or 30-day laboratory exposures of fish to sediment may not enable measurement of final steady state concentrations in organisms. For some chlorinated hydrocarbons, 10-day exposures are believed to reach 30-50 percent of steady state conditions. Months may be required to reach a steady state condition under a laboratory situation. Based on water exposures only, lower chlorinated congeners may reach only 50-80% of their steady state concentrations in fish after 96 days (Oliver et al., 1985).

Higher chlorinated congeners may reach less than 10% of their steady state concentrations in this same time period.

In comparing caged fathead minnows to resident fatheads in a confined disposal facility to assess PCB bioaccumulation, Rathbun et al. (1988) (as cited in Mac et al., 1992) found that in an 8-day exposure:

a) low K_{ow} di- and trichlorobiphenyls in tissues had reached nearly 100% of concentrations in resident fish.

b) the percentage of uptake has decreased to 50% for the tetrachlorobiphenyls and 30% for pentachlorobiphenyls.

c) concentrations of all biphenyls with 6 or more chlorines were less than 20% of those in resident fish.

Constant laboratory test system temperatures compared to variable ambient field temperatures also need to be considered in evaluating PCB uptake by fish. Spigarelli et al. (1983) exposed brown trout to a food source containing a constant set level of PCBs and Lake Michigan water at varying temperature regimes. While sediment was not available as a source of PCBs in the Spigarelli study, the implications of temperature influence on PCB uptake is important. Spigarelli et al. estimated that PCB uptake under constant conditions in the laboratory could be lower by a factor of 2-4 than those actually experienced by fish in nature, solely due to the effect of temperature fluctuations. Differences in uptake by laboratory exposed and field-collected fish may also be due to lack of exposure via contaminated food in the laboratory fish (Ankley et al., 1992). Relative uptake of PCB by laboratory fish is from the water and ingestion of contaminated sediment. Bioavailability to fish in laboratory tests is enhanced by suspension of contaminated sediments (McFarland et al. 1985). In field exposures, fish in cages placed on sediment accumulated more PCBs in tissue than those held in cages suspended in the water column above the sediment (Mac et al., 1985).

Table 9 summarizes the results of some bioaccumulation studies conducted in the laboratory and in the field. The Mac et al. (1985) results under B. in Table 9 are based on exposures to sediments from Green Bay. Exposure of caged fish placed on the sediments yielded a maximum ARS factor of 6.2 in the Mac et al. study.

Other studies that report distribution ratios comparably derived as the above ARS factors are:

1. Beak consultants (1987) reviewed a number of studies and used 25 as a typical ARS factor.

2. Evans et al. (1987) in a study that looked at biomagnification of PCBs in a Lake Michigan offshore food web found a biomagnification or ARS factor from sediment to sculpin of approximately 50.

0S2261

3. Smith et al. (1985) analyzed carp and duck from sections of the Detroit River that had PCB sediment concentrations on the order of 630 μg/kg (wet wt.). The median distribution coefficients or carp/sediment and duck/sediment chlorohomolog ratios were as follows:

Chlorohomolog Group	Carp/Sediment ARS Value	Ducks/Sediment ARS Value
Trichloro-	11	6
Tetrachloro-	18	5
Pentachloro-	26	8
Hexachloro-	37	27
Octachloro-	47	43

Body burdens of PCBs in ducks ranged from 2.7 to 20 mg/kg in the carcass and from 38 to 89 mg/kg in the lipid fraction.

Table 10 illustrates sediment safe levels of PCBs to protect each of the three fish tissue residue objectives with varying assumptions of ARS values and fish moisture content. The left hand column provides a range of ARS factors from which a value or a range of values must be selected for application to the site. The ARS values which are calculated on a dry-weight basis, must be corrected for whole body wet weight of the fish because the objectives for the fish tissue residue for PCB are on a wet-weight basis. The body of the table has a range of sediment quality objectives expressed in μg PCB/kg sediment on a dry-weight basis. Based on the review of the site-specific and literature ARS factors above, an ARS factor range of 10-20 would appear appropriate for the Deposit A site in the Lower Fox River. This would yield the following range of SQOC for PCBs to be protective of the three objectives:

Fish Tissue Objective	SQOC Range ugPCB/kg Sediment
FDA	200 - 1000
IJC	10 - 50
GLWQI	2 - 12

Some field validation of the 200-1000 μg/kg SQOC to protect the FDA objective of 2 ppm from other sites is provided by the State of Indiana's observation that fish generally do not exceed the FDA objective where PCB sediment levels are 500 μg/kg or less (IJC, 1988). Also, the Ontario Ministry of the Environment reported that total PCB concentrations in the St. Clair River sediments between 1976 and 1978 averaged 490 μg/kg and that average concentrations in fish from the river were at or near the US FDA action level. In the time frame given, the FDA number was 5 ppm for PCBs in fish tissue. If 490 μg/kg of PCB in sediments was resulting in fish tissue levels at or near 5 ppm, it would follow that the lower level of 200 μgPCB/kg sediment may be needed to be protective of a 2 ppm level.

053260

3.2.4 Application of an Equilibrium Partition Model for Predicting Bioaccumulation of PCBs in Fish Tissue.

Sediment organic carbon (as measured by TOC) is the primary storage compartment for neutral organic chemicals in sediment and is the primary environmental factor influencing partitioning and bioavailability. Organic carbon behaves as though it were an organic solvent in competition with the lipid of organisms for containment of any nonpolar organic chemicals, such as PCBs, that are present. For a given concentration of chemical in sediment, low TOC favors increased bioaccumulation and high TOC favors the reverse (Clarke et al., 1991).

Normalizing PCB concentrations to sediment organic carbon content and lipid content of fish allows calculation of a preference factor of PCBs for lipids over organic carbon. Through normalization, an estimate of the amount of chemical in sediment that is actually available to organisms can be made. Normalizing reduces site-to-site variability of PCB exposures and allows inter-species bioaccumulation comparisons. Preference factors are calculated by determining the ratio of lipid normalized concentration in fish or other aquatic organisms to the organic carbon normalized PCBs concentrations in sediment.

The Equilibrium Partitioning model is a simple, fugacity-based model which has been shown to be useful for predicting the bioaccumulation potential of hydrophobic nonpolar organic compounds in sediments (Ferraro et al., 1991). The model assumes chemical equilibrium or steady state between PCBs in organic carbon and lipids. The basic partitioning model used to estimate sediment safe levels for PCBs to protect a fish tissue residue objective is:

$$SQOC = \frac{(TRC)\ (foc)}{(FSAF)\ (fl)}$$

Where:

TRC = fish tissue residue objectives for PCBs (FDA, IJC, or GLWQI) expressed as μg/kg in whole body wet-weight

foc = Total organic carbon in sediment expressed as a decimal weight fraction

SQOC = Sediment Quality Objective Concentration to protect fish tissue residue objective, expressed as μg PCB/kg sediment (dry weight).

fL = fish lipid expressed as decimal weight fraction of whole body wet-weight

FSAF = Fish-Sediment Accumulation Factor expresses the preference of PCBs for fish lipids over sediment organic carbon. Ratio of lipid normalized PCB concentration to organic carbon normalized concentrations. Based on site specific data if available.

052259

The equilibrium partitioning model for predicting bioaccumulation of nonpolar organic compounds is thought to be the most applicable for predicting the first level transfer of nonpolar organics from sediments to infaunal organisms. Various studies have found preference factors for nonpolar organic chemicals (which include PCBs) of from 1 to 4 with the value generally being less than 2 (US EPA, 1990; Clarke et al., 1991; and Lake et al., 1990). Thus, multiplying the organic carbon normalized PCB concentration in sediment by 2 predicts the lipid-normalized PCB tissue concentrations.

Some studies suggest that the simple equilibrium partitioning approach may be applicable to contaminant bioaccumulation in fish (Lake et al., 1990). Preference factors of nonpolar organic chemicals in fish have been found to range from 1.5 (Karickhoff et al., 1979) to 4 (McKay, 1982). Clarke, McFarland, and Dorkin (1988); as referenced in Clarke et al. (1991), found preference factors ranging from 1.48 to 4.45 (mean 2.98) for crayfish and eight species of fish collected inside a confined disposal facility. No differences were found in PCB concentrations of crayfish and fish after long term infield exposures.

Bierman (1990) reviewed the equilibrium partitioning theory (EPT) and biomagnification of organic chemicals in benthic animals based on field studies. The EPT is based on the assumption that:

1. The operative distribution volumes for the chemical are sediment organic carbon, animal lipid, and the aqueous phase in the interstitial water,

2. The system is in a state of equilibrium,

3. There are no steric hindrances to the uptake of the chemical, and

4. There are no significant degrees of degradation or metabolism of the chemical.

The assumptions do not preclude uptake from both food and water, provided that the food consists only of contaminated sediment particles that are in equilibrium with the associated aqueous-phase chemical concentration. Bierman concludes that the body burdens of organic chemicals in smaller, younger, forage fish was not significantly different from those in benthic macroinvertebrates. The levels were expected based on the EPT mechanism. He notes, however, that this does not prove that the EPT is the sole mechanism determining body burdens of organic chemicals in forage fish. He found that body burdens of organic chemicals in carp were significantly higher than expected on the basis of EPT, indicating biomagnification was occurring. If biomagnification of PCBs occurs in fish, then simple equilibrium partitioning may underestimate the accumulations by higher trophic level predator fish. The equilibrium partitioning model assumes sediment is the only source of PCBs to the organisms and does not take food chain uptake into account nor does it adjust for organism growth (Clarke et al. 1991).

Clarke et al. (1991) state that a review of recent literature assigns a greater role to contaminated food as a major pathway for bioaccumulation of contaminants, particularly in pelagic fishes. Dietary bioaccumulation is favored when the food an organism consumes is highly contaminated relative to the water it respires. Also, the relative importance of the various environmental compartments as PCB sources for uptake can change over the life cycle of the organism when the organism occupies different trophic levels or habitats during different stages of development.

In a review of PCB contamination in fishes from Wisconsin waters of Lake Michigan. Clarke et al. (1992) found that highest mean PCB concentrations occurred in some top predators and some bottom-feeding species, suggesting that food chain biomagnification and partitioning from contaminated sediments may both be important mechanisms for PCB bioaccumulation in Lake Michigan fishes. For pelagic species studied, the food chain is very important. Carp, on the other hand "skip" a portion of the food chain by their direct contact with sediment. They also tend to have higher concentrations than any of the other top-level piscivorous species indicating that, while the food chain is definitely very important, direct uptake of sediments, ingestion, and absorption in the gut may be even more important. For some forage fish species, interspecific differences in PCB body burdens are related to the habitat occupied (surface feeder or benthivore) and ecological processes associated with that habitat which regulate the bioavailability and uptake of PCBs (Hebert et al., 1991). Interspecific differences were associated with compounds with high Log K_{ow} values, becoming more pronounced with Log $K_{ow} > 6.0$. Benthivore forage fish species had higher accumulation factors than surface-feeding species (Herbert et al., 1991).

Preference factors or Fish-Sediment Accumulation Factors (FSAF), were calculated for the laboratory exposed fathead minnows and field-collected black bullheads based on Call et al. (1991) and Ankley et al. (1992). (Tables 11 and 12, respectively). The FSAF factors are based on a ratio of lipid normalized PCB concentrations over organic carbon normalized sediment concentrations. The average FSAF values for the laboratory exposed fathead minnows was 0.30 with a range of 0.17 to 0.59. The average FSAF values for the black bullheads was 1.91 with a range of 0.74-4.77. Total PCB concentration per unit lipid in the black bullheads was on average six times greater than the laboratory exposed fathead minnows. Differences in the laboratory versus field bioaccumulation results may be due to the factors discussed earlier. This study suggests that laboratory results may underestimate the actual uptake of PCBs under field conditions.

Table 13 shows, within the body of the table, SQOC expressed as μg PCB/kg sediment (dry-weight basis) to protect the three fish tissue residue objectives with consideration given to combinations of variables at a specific site (i.e. TOC, percent lipid of fish, and of site specific FSAF value). Given the above discussions and site-specific data, FSAF values appropriate to the Deposit A site range from 2 to 4. A FSAF of 4 was used to calculate SQOC for Deposit A. Using assumed lipid concentrations of 4% for fish related to the FDA criterion and 8% for fish related to the IJC and GLWQI, the following SQO values apply to a range of TOCs from 1.5% to 8.3%:

053257

Fish Tissue Objective	SQOC Range (μgPCB/kg Sediment		
	% Lipid	TOC 1.5%	TOC 8.3%
FDA	4	188	1038
IJC	8	4.5	26
GLWQI	8	1	6

The higher lipid values are appropriate to the IJC and GLWQI criteria because they are based on wildlife consumption of whole fish of all species. Humans would be consuming sportfish of lower lipid content. However, some humans may consume fish species of higher lipid content such as carp. Consideration of this higher lipid content in relation to the FDA value would lower the SQOC values calculated above.

3.2.5 Consideration of Bioconcentration Factors in an Equilibrium Partitioning Model to Develop SQOC to Protect Fish Tissue Residue Criteria.

Van Der Kooij et al. (1991) summarized an approach recently proposed in the Netherlands to use the equilibrium partitioning approach method to derive a set of quality criteria for aquatic systems including criteria for organic compounds in sediment based on product standards (organism residue criteria). The basic equation for deriving sediment criteria from tissue residue criterion is:

$$SQOC = \left(\frac{TRC}{BCF}\right) (f_{oc}) (K_{oc})$$

Where:

SQOC = Sediment Quality Objective Concentration in μg PCB/kg sediment (dry-weight) needed to protect the fish tissue residue criterion

TRC = fish tissue residue criterion for PCBs (FDA, IJC, and GLWQI) expressed as μg/kg in whole body wet weight.

f_{oc} = total organic carbon in sediments expressed as a decimal weight fraction.

K_{oc} = organic carbon partitioning coefficient for Aroclor 1242

K_{oc} Range-26,300-1,949,844 L/kg

K_{oc} Average-494,808 L/kg

052256

BCF = the bioconcentration factor for Aroclor 1242. BCF is derived from K_{ow} values using the regression equation in the NR 105 development document. The equation is:

$$Log_{10}\ BCF = 0.79\ Log_{10}\ K_{ow} - 0.40.$$

The BCF regression equation predicts the BCF for tissue with 7.6 percent lipid content (U.S. EPA, 1991). To normalize the BCF to 1 percent lipid, the BCF calculated in the above formula is divided by 7.6. The maximum K_{ow} for Aroclor 1242, based on the literature values discussed above, was used in the formula to derive a BCF value. The maximum K_{ow} of 2,511,886 L/kg yields a BCF of 45,290. On a lipid normalized basis, the BCF is 5,959 L/Kg/1 percent lipid. In the above model to calculate SQOC values, BCFs associated with 1 percent (5959 L/kg), 4 percent (23,826 L/kg), and 8 percent (47,672 L/kg) lipids were used.

Tables 14, 15, and 16 show the SQOC expressed as µg PCB/kg sediment, based on various combinations of variables at the site (TOC, fish lipids, and K_{oc}), to be protective of the FDA, IJC, and GLWQI objectives, respectively. Utilizing the minimum and average TOC content of sediment, average K_{oc}, and lipid contents of 4 and 8 percent, the SQOC recommended to be protective of the residue objectives are as follows:

Fish Tissue Objective	SQOC Range (µgPCB/kg Sediment		
	% Lipid	TOC 1.5%	TOC 8.3%
FDA	4	616	3409
IJC	8	15	82
GLWQI	8	4	20

The above laboratory derived BCFs are a conservative estimate of the PCB tissue residues likely to occur in the environment. PCB tissue residues may arise both from bioconcentration of PCBs from the water through the gills and other membranes and from ingestion and absorption of contaminated food sources. An attempt was made to calculate a site specific BCF based on a caged fish study conducted by WDNR during August, 1992. The preliminary study results are discussed in the last section of this development document. Fathead minnows were exposed for 10 days in cages placed on sediments at the Menasha Channel reference site, at Deposit A, and downstream one-half mile below the Highway 441 bridge.

Since no concurrent water column sampling was done during the period of cage placement, water column data collected for the Green Bay Mass Balance study were used. A location at Appleton sampled during Aguust of 1989 was the nearest site to Deposit A (approximately 5.5 miles downstream of Deposit A). Some water column samples were taken at the Chicago and Northwestern Railroad bridge which is one-mile downstream of Deposit A. However, the samples were not taken in August to match the seasonal period of cage placement. When the sampling events at the Appleton site and the railroad bridge were simultaneous, the results indicated comparable water column concentrations of PCBs. This may indicate the water column concentration of PCBs at the Appleton site are reflective of upstream concentrations as far as Deposit A during all months of the year. The average dissolved concentration of PCBs at Appleton during August was 16.6 ng/L. Utilizing this value and the results of the caged fish studies, whole body and normalized to 1% Lipid BCF values were calculated as follows:

	Menasha Channel Reference Site	Deposit A	Downstream Site Hwy 441 Bridge
Sediment Concentrations of PCB	0.030 ug/g (Ave. of four samples from Menasha Channel)	Ave. 50.3 ug/g	Ave. 1.6 ug/g
Water Column Dissolved PCB Concentration (ng/L) @ Appleton	2.25 ng/L	16.6 ng/L	16.6 ng/L
Ave. Whole Body PCB Concentration Wet Weight	No detects for any of the 74 congeners analyzed	9462 ug/kg (Ave. of 3 replicates)	216.63 ug/kg (Ave. of 3 replicates)
Whole Body Bioconcentration Factor	—	570,000 L/kg	13,050 L/kg
Ave. Lipid Content	2.3%	2.8%	2.4%
BCF Normalized to 1% Lipid	—	203,571 L/kg	5438 L/kg
Assume tissue levels are only 50% of a steady state concentration. Concentration at steady state	—	18,924 ug/kg	433.26 ug/kg
BCF Normalized To 1% Lipid at "steady state"	—	407,143 L/kg	9,321 L/kg

The BCF value normalized to 1% lipids at the downstream site (5438) is comparable to the value (5959) derived from the BCF regression equation. However, the BCF normalized value calculated for the Deposit A exposed caged fish is approximately 37 times the downstream BCF value. Some considerations of this BCF value are:

1. The caged fish at Deposit A are exposed to dissolved PCBs in the water column and also to contaminated sediments and particulate matter that enter the cage perforations because the cages were set on the sediment surface. The minnows may ingest these particles and PCBs are absorbed from the gut contents. Because the contaminated sediments represent another route of uptake, the lipid normalized BCF value of 203,571 calculated above is more of a bioaccumulation factor than a BCF which is based only on exposures to dissolved PCBs in the water column. At the downstream caged fish site, the sediment PCB concentration are considerably less than in Deposit A sediments. The sediment sampling site nearest to the Hwy. 441 caged fish site had an average of 1.6 ug/g of PCBs in the sediments versus an average of approximately 50 ug/g in Deposit A sediments. Any sediment particles ingested by fish at the Hwy. 441 site have considerably less PCBs associated with them. The fish were

continuously exposed to an average of 16.6 ng/L of dissolved PCBs in the water column.

2. The 10 day caged fish exposure duration did not allow fish tissue concentrations to reach a steady state condition. Assuming only 50% of steady state concentrations have been achieved, the potential "BCFs" normalized to 1% Lipid for Deposit A and the Hwy. 441 site are 407,143 and 9,321 respectively, utilizing fish tissue levels at two times those measured.

3. The actual water column concentrations of PCBs above the Deposit A sediments at the location of the caged fish placement may be greater than the concentration found downstream at Appleton. A higher water column concentration in the vicinity of the cages would lower the site-specific "BCF" values calculated above.

4. Substituting the site specific "BCF" value (203,571 @ 1% Lipid) from the caged fish study, for the BCF value derived from the K_{ow} value (5959 L/kg @ 1% Lipid), would yield much lower SQOC values to be protective of FDA, IJC, and GLWQI fish tissue objectives.

3.2.6 Consideration of Bioaccumulation Factors in an Equilibrium Partitioning Model to Develop SQOC to Protect Fish Tissue Residue Criteria

For chemicals with Log K_{ow} values below 5.0, Bioaccumulation Factors (BAFs) and BCFs are equal regardless of the ecosystem structure. For these chemicals, the bioconcentration process from water is more important than the bioaccumulation process from food (U.S. EPA, 1991). For chemicals with Log K_{ow} values ranging from 5.0 to 7.0, bioaccumulation from food becomes more important with increasing log K_{ow} value and complexity of the food chain (Thomann, 1989). The Log K_{ow} values for Aroclor 1242 used in the partitioning models in this SQOC development discussion include lower and upper values of 4.5 to 6.4 and an average value of 5.8.

To attempt to address both bioconcentration of PCBs from water to fish and uptake from food, especially for higher level predator fish, a food chain multiplier (FCM) can be applied to the BCF (U.S. EPA, 1991). The bioaccumulation and bioconcentration factors for a chemical are related as follows in approximating a BAF value:

$$BAF = BCF * FCM$$

Using U.S. EPA's (1991) guidance, the FCMs for trophic levels 3 and 4 based on an average Log K_{ow} value of 5.8 are 12.7 and 33.3 respectively. The FCMs for a maximum Log K_{ow} value of 6.4 are 39.3 and 98.4, respectively. The FCM factor is placed in the SQOC formula such that:

052253

$$SQOC = \left(\frac{TRC}{BCF * FCM}\right)(f_{oc})(K_{oc})$$

Trophic level 4 of the food chain generally consists of predator fish used for sportfishing. Trophic level 3 are generally small forage fish. Based on considerations of the maximum and average Log K_{ow} values, BCFs associated with different lipid contents, and different trophic levels, the BAFs used are as follows:

		Bioaccumulation Factors			
	Trophic Level	3		4	
	Lipid Content	4%	8%	4%	8%
Log K_{ow} Aroclor 1242	5.8 Average	302,590	605,434	793,406	1,587,478
	6.4 Maximum	936,362	1,873,510	2,344,478	4,690,925
	Total PCBs GLWQI 6.21167	490,754	981,508	1,421,488	2,842,976

Also placed on the above table are the BAF values from the GLWQI Methodology for Development of Bioaccumulation Factors. The GLWQI BAF is based on field and laboratory data that has led to a more accurate estimation of the bioaccumulation factor for PCBs. The normalized BAF for total PCBs is 355,372 in the GLWQI. The BAF values calculated from the maximum and average Log K_{ow} for Aroclor 1242 bracket the GLWQI BAFs based on a "typical normalized BAF" for total PCBs.

In considering a lipid of 4% and 8% as appropriate, an average f_{oc} of 8.3%, an average K_{oc} of 494,808 and using the BAF values calculated above, the following are the SQOC related to protecting the three fish tissue residue objectives;

Fish Tissue Objective		SQOC (μg PCB/kg Sediment)			
		Maximum Kow		Average Kow	
		Trophic Level		Trophic Level	
	Lipid	4	3	4	3
FDA	4%	35	88	104	274
IJC	8%	0.9	2.2	2.6	7
GLWQI	8%	0.2	0.5	0.6	1.6

Using the above model, SQOC on the lower end of the above ranges would be needed to protect the trophic level 4 organisms consumed by humans. Wildlife would be consuming both trophic level 3 and 4 fish.

053252

4.0 Development of Sediment Quality Objectives to Protect Aquatic Organisms Associated with Deposited Sediments

Organisms associated with the benthic community spend all or part of their life cycles burrowing in or associated with the sediment surface. Epibenthic organisms, such as Daphnia, spend time in the water column and also settle on the sediment surface where they spend a significant amount of time filter feeding and ingesting particulate-bound PCBs. Some of the most sensitive stages of aquatic organisms, developing eggs and larvae, become exposed to PCBs through sediment contact.

Routes of exposure and uptake of PCBs to benthic organisms include respiration and epithelial contact, and ingestion of sediment pore water, sediment particulates, detritus and food items. Because benthic invertebrates are relatively non-mobile they are subject to long term, chronic exposure to PCBs associated with sediment phases.

As reviewed by Clarke et al. (1989) in regard to PCB toxicity to aquatic biota:

1. Ecotoxic effects of sediment PCB contamination appear most likely to be sublethal and chronic.

2. The effects would be manifested at the population level in aquatic biota.

3. Physiological functions that are controlled by steroid hormones may be altered by the exposure of organisms to PCBs.

4. Growth, molting, and reproduction are primary functions that have been shown to be affected by the exposures of aquatic organisms to PCBs.

5. The ability of organisms to eliminate foreign organic compounds or endogenous waste products may also be affected.

6. Steroid biosynthesis and degradation and transformation of xenobitic compounds are metabolic activities that are strongly influenced by oxidase activities of the microsomal cytochrome P-450 systems (also referred to as mixed function oxygenase [MFO] systems). These activities occur in fish and invertebrates as well. The total and specific MFO activity is lower and more variable in fish compared to mammals. Aquatic invertebrates exhibit even lower MFO activities. Some PCB congeners are inducers of MFO in aquatic invertebrates.

7. It is primarily through effects on these enzyme systems that toxicities attributable to low concentrations of PCBs typical of environmental systems are thought to occur.

There are some findings that acute toxicity may be a simple function of the aqueous solubility of individual PCB congeners. As molecular weight decreases, solubility increases and toxicity increases. (Abernathy et al. 1986 as cited in Dillon et al. 1991).

4.1 Use of the Equilibrium Partitioning Model to Derive Sediment Quality Objective Concentrations to Protect Benthic Organisms Exposed to PCBs in Sediment Pore Water

Based on the principles in U.S. EPA's Sediment Quality Criteria Development document (Di Toro et al., 1992) and U.S. EPA's (1980) Chronic Water Quality Criterion for PCBs, Table 17 shows the SQOC calculated based on the 0.014 ug/L chronic value. The 0.014 ug/L is based on a Final Residue Value for protecting the uses of aquatic life. There is an insufficient data base to derive a Final Chronic Value to protect aquatic life from chronic toxicity. The lowest concentration at which adverse effects to aquatic life have been reported from water-only exposures to PCBs range from 0.2 - 9.0 ug/L for fish and invertebrates (U.S. EPA, 1980). This effects range considers Aroclors 1242 and 1248 which have relatively large contributions of the lower chlorinated homolog groups (di- to tetrachlorobiphenyls) in the PCB mixture.

Following the method of Pavlou (1984), a sediment safe level for PCBs is established based on using one-half the lowest concentration causing adverse biological effects or one half of 0.2 ug/L which equals 0.1 ug/L. Pavlou uses the approach as an interim attempt to estimate the concentration at which a water quality criterion may eventually be established. Because the lowest concentration causing adverse effects is based on a very limited toxicological data base, the estimated "criterion" of 0.1 ug/L may be inadequate to ensure protection of freshwater aquatic life. The 0.1 ug/L value is greater than the chronic value of 0.014 ug/L based on a Final Residue Value. Since benthic organisms in sediment are subject to exposure from pore water and may also be in direct contact with contaminated sediments, and ingest contaminated particulate matter and food items, their total exposure may be underestimated by considering water exposure only. Therefore using a water concentration less than 0.1 ug/L may be appropriate to derive sediment safe levels for PCBs. Based on a minimum and average TOC content of 1.5% and 8.3%, respectively, in the deposited sediments and an average K_{oc}, the SQOC in Table 17 range from 104 to 573 ug PCB/kg sediment.

4.2 Review of Literature, Regulatory Criteria, and Guidelines for Establishing Sediment Quality Objective Concentrations for PCBs

Formulation of sediment quality criteria and guidelines by other regulatory agencies and studies have linked biological effects to benthic organisms from the presence of PCB compounds in sediment. Key criteria, guidelines, and studies relating PCB sediment levels to biological effects are summarized below.

4.2.1 Ontario Ministry of the Environment Sediment Quality Guidelines

The Ontario Ministry of the Environment developed guidelines for use in evaluating sediments throughout Ontario. Sediment quality guidelines (SQG) are intended to provide guidance during decision making in relationship to sediment issues ranging from preventative to remedial action (Persaud et al., 1990). The Ontario SQG for total PCBs is based on an approach to develop sediment quality assessment values called the Screening Level Concentration (SLC) approach. The SLC approach uses field data on the co-occurrence in sediments of benthic infaunal species and different concentrations of contaminants. The SLC is an estimate of the highest concentration of total PCBs and some Aroclors that can be tolerated by 95% of the benthic infaunal species. The guidelines define two levels of exotoxic effects applicable to total PCBs and PCB Aroclors:

a. Lowest Effect Level (LEL) indicating a level of sediment contamination that can be tolerated by 95% of benthic organisms.

b. Limit of Tolerance (LTL) or Severe Effect Level (SEL) indicating the level at which pronounced disturbance of the sediment benthic community can be expected. At the SEL concentration, the majority of benthic species may be detrimentally impacted.

Concentration values associated with the above levels of effects for total PCBs and PCB Aroclors in sediments in the Ontario SQGs are shown in Table 18. At an average TOC of 8% in sediment, the Lowest Effect Level for total PCBs in the Ontario guidelines is 560 ug/kg. Individual Aroclors have lower guideline values. There are no sediment values for Aroclor 1242 in the Ontario guidelines. There are sediment guideline values for Aroclor 1248. In the range of 1% to 8% TOC in sediments, the Lowest Effect Level for Aroclor 1248 is between 30 and 240 ug/kg.

4.2.2 State of Washington Sediment Standards

Washington recently adopted a new rule known as the Sediment Management Standards, Chapter 173-204 of the Washington Administrative Code. The rule establishes a set of narrative, chemical, and biological criteria as sediment quality standards. The Sediment Management Standards were developed using the Apparent Effects Threshold (AET) and Equilibrium Partitioning (EP) Method and were developed for Puget Sound initially. The AET and EP approaches associate the chemical concentrations in sediments with adverse biological responses. The AET values for Puget Sound were determined on a chemical-specific basis using acute bioassays (lethal and sublethal) and endogenous biota analysis for as many as four biological indicators. The specific biological tests that have been used to derive Puget Sound AET values include bioassays for amphipod mortality, oyster larvae abnormality, and Microtox™ bioluminescence, and in situ abundances of macroinvertebrates. The chemical-specific criteria are established such that there are no significant effects on any of the biological organisms used to establish the standard. A criteria represents the lowest biological effects level and risk level to human health. It is recognized that the local conditions may influence the bioavailability of chemical contaminants. The State of Washington standards establish specific guidance for performing biological testing and biological test interpretation criteria to confirm the level of adverse effects due to the presence of PCB concentrations in sediments that exceed the chemical criteria at specific locations. Results of the site-specific biological testing govern the final decision regarding the quality of the sediments. The chemical-specific sediment quality guidelines for PCBs are shown in Table 19. In the range of 1% to 8% TOC in sediments, the Sediment Quality Standards are 120 and 960 ug PCB/kg sediment. The Sediment Quality Standards are cleanup objectives. A second sediment standard, the Minimum Cleanup Level, acts as an upper bound or ceiling on cleanup decisions. Between these two standards, cleanup decisions consider engineering feasibility, costs, net environmental effects, and natural recovery rates.

Applicability of the Washington sediment guidelines that are based on effects to salt water and estuarine benthic organisms to freshwater organisms is not known. Based on Clarke et al. (1991), salinity has some of the following effects on bioavailability and bioaccumulation:

1. Salinity influences desorption and solubility, osmoregulation, membrane permeability, and respiration rates and volume.

2. Factors other than salinity are usually more important in effecting bioaccumulation.

3. Increasing salinity tends to decrease the water solubility of neutral organic chemicals, and also decreases the concentration of particulate and dissolved organic carbon. The decrease in organic carbon in increasing salinity may under some conditions actually enhance bioavailability of neutral organic compounds to organisms.

4.2.3 National Oceanic and Atmospheric Administration (NOAA) Sediment Quality Guidelines

NOAA has developed guidelines that are intended to provide an estimate of the potential for adverse biological effects of sediment-associated contaminants on benthic organisms. The guidelines employ a preponderance of evidence assembled from a variety of approaches and from data gathered in many geographic areas from analysis performed on multiple species and/or biological communities. Reliance is put on tests of acute and chronic toxicity and from analyses of benthic community structure.

The database NOAA has compiled contains information generated by investigators using three major approaches to establishing effects-based sediment quality guidelines (Long and Morgan, 1991). The approaches were applied in marine, estuarine, and freshwater habitats. The data from the following three basic approaches were evaluated by NOAA: (a) equilibrium partitioning, (b) spiked-sediment toxicity tests, and (c) various approaches that rely on matching synoptically collected sediment chemistry and biological effects data. Candidate data sets were screened for the assessment methods used in each study, the type and magnitude of biological endpoint measured, and the degree of concordance between the chemical and biological data. The chemical concentrations observed in each of the above approaches that were associated with biological effects that pass screening were sorted. The lower 10 percentile in the data was identified as an Effects Range - Low (ER-L) and was considered to represent a lower threshold value. The ER-L indicated the low end of the range of concentrations above which adverse effects may begin or are predicted among sensitive life stages and/or species. The Effects Range - Median (ER-M) is a concentration equivalent to the 50 percentile point in the screened available data. The ER-M value is the concentration above which biological effects were frequently or always observed or predicted among most organisms.

The NOAA guidelines are used to rank and prioritize sites with regard to the relative potential for contaminant-induced effects in coastal marine, estuarine and freshwater environments throughout the United States. It is indicated that the ER-L and ER-M values are not to be interpreted as NOAA standards or criteria, although the ER-L and EL-M concentrations may be used by others as guidance in evaluating sediment contamination data. The ER-L and ER-M guideline values for total PCBs derived from the NOAA study compilation and evaluation are shown in Table 20a. The Effects Range - Low and Effects Range - Medium identified in the evaluation are 50 ug/kg and 400 ug/kg, respectively.

MacDonald (Long et al., 1992) added a substantial amount of new data from field studies and laboratory spiked-sediment bioassays to the Long and Morgan (1992) data base. The ER-L and ER-M values based on the larger MacDonald data base are shown in Table 20b.

Long et al. (1992) indicate that the NOAA approach can be applied equally to any sediment type that occurs in freshwater, estuarine, and marine environments. The NOAA guidelines are considered to be widely applicable because the data base that supports the guidelines contains information from a wide variety of sediment types.

4.2.4 Sediment Quality Assessment Approach Application to Determine Biological Effects Levels To Benthic Organisms from PCBs

Application of different assessment approaches by Chapman et al. (1987) and Chapman (1986) yielded similar levels of PCBs in sediments related to biological effects. The assessments were done in marine and estuarine habitats. Generally no or minimal biological effects are associated with less than 100 ug/kg PCBs in sediment in the approaches being compared (Table 21).

4.2.5 Summary of Approaches and Effects

In summary, the following PCB sediment concentrations are associated with biological effects to benthic organisms based on the above approaches:

	Sediment Quality Objectives ug PCB/kg Sediment TOC	
	1%	8%
Chronic Toxicity Application of EPA Ambient WQC To Pore Water	70	554
Ontario Sediment Guidelines Lowest Effect Level Aroclor 1248	30	240
State of Washington	120	960
NOAA - Effects Range Low	23	180
Chapman - Four Approaches Compared. Not TOC Normalized. Minimum or No Effect Level	100	

053247

The sediment safe levels in the different guidelines are based on a number of approaches and biological endpoints but generally arrive at comparable values. Generally it would appear that PCB concentrations in sediments at 8% TOC must be less than 500 ug/kg to minimize detrimental biological effects to benthic organisms including mortality and reduction in growth and reproduction. As the TOC content of the sediment decreases the sediment safe levels for PCBs appear to decrease accordingly. At 1% TOC, PCBs in sediments should be at the level of approximately 70 ug/kg or less (based on averaging the effect levels associated with the lowest TOC concentrations).

In establishing sediment safe levels for PCBs, to protect benthic and water column organisms, some additional consideration needs to be given to the following (Eisler, 1986; Moore et al., 1984):

1. Toxicity of PCBs increases with increasing exposure. Benthic organisms are relatively non-mobile and are subject to long term, chronic exposures.

2. Among invertebrates, crustaceans (Daphnia and Gammarus) are sensitive to PCB exposure.

3. Lower chlorinated biphenyls were more toxic than higher chlorinated biphenyls.

4. Juvenile/immature stages of many invertebrate species are more sensitive to PCBs than adults.

5. Aroclor 1242 appears to be particularly toxic to freshwater algae.

6. PCBs reduce photosynthesis and carbon uptake in sensitive species of algae at concentrations of 0.1 - 1.0 ug/L.

   Comparably low concentrations have been known to alter the community structure and species composition of natural algal populations.

7. The relative toxicity of Aroclors (3 week LC_{50}) to Daphnia magna was in the following order: 1242 > 1260 > 1254 > 1248.

4.2.6 Benthic Community Studies On the Lower Fox River

The diversity values and relative abundance of benthos determined by Ankley et al. (1992) suggests that sites along the Lower Fox River are adversely impacted. The benthic community is dominated by chironomids and oligochaetes. It is uncertain whether the impact is due to toxic contaminants, poor habitat, adverse water quality conditions (e.g., low dissolved oxygen) or some combination of these factors. Toxicity testing suggests that one chemical contributing to the impact on benthos is ammonia (Ankley et al., 1990). Based on the observed effects using the Microtox bioassay on sediment pore water from the lower Fox River, Hoke et al. (1992) found that while un-ionized ammonia accounted for a large part of the observed toxicity, metals and possibly unidentified organic compounds also appear to contribute to the observed toxicity.

Based on analysis from laboratory bioassays and field collected invertebrates, Call et al. (1991) found the following PCB accumulations in tissues (ug/kg wet weight):

	Field Collected Invertebrates			
	Reference Site Exposure	PCB Impacted Sites		
		Avg.	Min.	Max.
Annelids	___	376.87	284.38	474.30
Chironomids	14.97	351.32	158.52	1,148.22

	Laboratory Exposed Invertebrates			
	Reference Site Exposure	**PCB Impacted Sites**		
		Avg.	**Min.**	**Max.**
Lumbriculus Variegatus	108.99	345.91	73.24	747.48
Chironomus riparius	812.02	795.39	392.65	1,518.75
Hexagenia limbata	196.97	1,462.78	427.04	4,174.24
Hyalella azteca	421.59	652.81	459.61	980.31

In the Call study, the PCB chlorohomolog pattern in annelids and chironomids from the Lower Fox River and Green Bay and in laboratory bioassay annelids and mayflies exposed to sediments was dominated by tetrachlorobiphenyls. Trichlorobiphenyls generally make up the next largest chlorohomolog group followed by pentachlorobiphenyls. In field collected and laboratory bioassay annelids and field collected chironomids, the tetra- to heptachlorohomolog groups are preferentially accumulated in tissue compared to percentage contribution of the groups to the total PCB concentration in sediments. In bioassay annelids, the tetra- and pentachlorohomolog groups are preferentially accumulated. Both homolog groups may include potentially toxic coplaner and mono-ortho coplaner congeners in them (congener 77 in tetrachlorobiphenyl group and 105, 114, 118, 123, and 126 in the pentachlorobiphenyl group).

Call et al. (1991), indicated that the PCB tissue levels they measured in laboratory bioassays of *Hyalella* were below adverse effects levels attributed to PCB tissue levels in the literature. There is concern regarding the likely transfer of PCBs in invertebrates to higher trophic levels in the food chain. There is some indication that *Hexagenia* populations are returning to the lower Fox River system after being eliminated by pollution (Cochran, 1992). Emerging insects are a potential biotic transport route for PCBs in sediments to the aquatic and terrestrial ecosystem.

5.0 Consideration of Toxic PCB Congeners

The Sheboygan Memo discusses concerns with the presence of toxic PCB congeners in sediments, water, and biota. Environmental criteria based on concentrations of total PCB or Aroclor mixtures without consideration of specific congeners may not address the total toxicity of the PCB mixture the organism is exposed to. From a toxicological and ecological perspective, some PCBs are of more concern than others, especially those that have structural and toxicokinetic properties similar to 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). Based on these properties, the proposed GLWQI contains water quality criteria for 11 toxic coplanar and mono-ortho coplanar congeners related to 2,3,7,8-TCDD, to protect wildlife consuming fish.

The equilibrium partitioning model applied above was used to derive SQOC for the 11 congeners contained in the GLWQI. The considerations made in developing these SQOC are discussed in the Sheboygan Memo. To deal with the 11 congeners included in the class criteria, a Hazard Index Approach and a back-calculation method that predicts the total concentration of congeners in water released from sediment based on measured concentrations in sediment are also discussed in the Sheboygan Memo.

There have been a number of site specific studies conducted on the Lower Fox River and Green Bay that suggest the majority of toxic effects of PCB/Furan/Dioxin mixtures on biota, especially reproductive impairments to fish eating birds, is due to the dioxin-like activity of planar PCBs such as congeners 77, 105, and 126. (Kubiak et al., 1989; Ankley et al., 1992; Tillett et al., 1992; Harris et al., unpublished). Kubiak et al. (1989) calculated biomagnification factors of 0.17, 64, and 176 for congeners 77, 126, and 169, respectively based on the ratio of median tern egg concentration/small forage fish concentration. Data also suggest that TCDD-related activities of congeners 77, 105, and 126 may be related to observed adverse impacts in lake trout and Chinook salmon from Lake Michigan (Walker et al. 1991; Ankley et al., 1991).

Table 22 shows the results of sediment samples taken by WDNR from Deposit A and in the Menasha channel at the outlet of Lake Winnebago. Analysis was done by U.S. EPA - Duluth. The sediments were analyzed for toxic PCB congeners, 2,3,7,8-TCDD, 2,3,7,8-TCDF, and total PCBs. The weight percent contribution of congener 77 (0.96%) to the total PCBs in sediments appears to be 1.9x to 2.7x greater than would be expected from the weight percent contribution of congener 77 in a commercial Aroclor 1242 mixture (Table 22). Assuming the Aroclor source of PCBs to Deposit A was 1242, this may indicate congener 77 is more persistent and less mobile compared to other congeners. The relatively high weight percent contribution of congener 77 in the Deposit A sediments does not appear to agree with the findings of Brown et al. (1987) that indicated congener 77 was preferentially lost by anaerobic dechlorination in sediments. Also placed in Table 22 are more recent results for congener 118 concentrations in Deposit A and Menasha channel sediments based on WDNR's biomonitoring study. The 385 ug/kg concentration of 118 in Deposit A sediments represents an average of two sample results (350 and 420 ug/kg).

Table 23 shows the congener concentrations converted to 2,3,7,8-TCDD equivalents (TCDD-EQ) expressed as pg TCDD Toxic Equivalents/g PCB based on the toxicity equivalency factors (TEF) of Safe et al. (1990). Also in Table 23 are the TCDD-EQ of the congeners calculated for other sites around the state for comparison. Table 24 shows the TCDD-EQ for congeners in 8 sample sites along the Sheboygan River which is a Superfund site because of PCB contaminated sediments. The TCDD-EQ at Deposit A for the PCB congeners exceeds the TCDD-EQ for 7 of the 8 sites along the Sheboygan River.

In Deposit A, the low total PCB concentration in the sediments (18.4 ug/g) has a relatively high TCDD-EQ concentration (1947.67 pg/g) from PCB congeners associated with it compared with other sites. 91% of the TCDD-EQ is due to congener 77 in the Deposit A sample. The reference site sediments in the Menasha Channel had a TCDD-EQ of 4.82 pg/g.

At other sediment sampling sites below the DePere dam and in Green Bay, concentrations of congener 77, ranged from 1.28 ug/kg to 48.15 ug/kg; congener 105 from 3.28 ug/kg to 15.3 ug/kg; and congener 126 from 0.024 ug/kg to 0.73 ug/kg (Ankley et al., 1992). The concentration of the three congeners in Deposit A sediments are greater than the highest values found in the downstream sample sites based on the above results. For congener 77, the concentrations are 3.7x higher.

The SQOC for the 11 toxic congeners based on the GLWQI criteria are in Table 5 of the Sheboygan Memo with qualifications for use as if single and not mixtures of congeners are present. Mixtures of congeners lowers the SQOC for individual congeners. At 1.5% and 8.3% TOC in the sediments, the following are the SQOC for the toxic congeners discussed above compared with reference site and Deposit A concentrations.

Congener	Reference Site ug/kg Menasha Channel	Deposit A ug/kg	Sediment Quality Objectives Concentrations ug/kg	
			1.5%	8.3%
#77	0.211	176.67	0.03	0.166
#105	1.31	39.97	0.45	2.49
#126	0.013	1.41	0.008	0.042
#169	0.002	N.D.	0.045	0.249
#118	1.24	385.0	0.56	3.07

The concentration of congener 77 in Deposit A sediment exceeds the SQOC by 3 orders of magnitude; congener 105 exceeds the SQOC by one order of magnitude, and congener 126 exceeds by two orders of magnitude. Congener 118 exceeds the SQOC by approximately two orders of magnitude.

Additional sampling of Deposit A sediments for the remaining toxic congeners for which SQOC have been developed is needed. Generally these remaining congeners have lower TEF values and would result in lower TCDD-EQ contributions than congeners 77, 126, and 169 unless present at very high concentrations.

6.0 Preliminary Results from WDNR Biomonitoring Studies of Deposit A, Summer of 1992

Preliminary results are available from the WDNR caged fish studies and field collection of oligochaetes from Deposit A, an upstream reference site, and a downstream site. The fish and oligochaete tissues were analyzed for PCBs on a congener basis. Seventy-three individual or co-eluting congeners were analyzed for. Levels of detection ranged from 0.3-3.0 ng/g for the congeners. Preliminary results of the tissue analysis are shown in Table 25.

Hatchery-reared *Pimphales promelas* (fathead minnow) were placed in aluminum cages at 3 sites. The aluminum cages were 16" x 16" x 18" in size made of perforated aluminum sheets with 5/32" hole diameter and 63% open area. At each of the 3 sites, 3 replicate cages were placed on the sediment surface. A location in the Menasha channel served as the reference site. Cages were placed in the southwest corner of Deposit A. The downstream site was 1/3 of a mile north of the Highway 441 bridge, along the east bank of the river. Caged fish were placed at each site for 10 days. Oligochaetes were collected at each site for a PCB congener analysis of the tissue.

Table 25 shows the chlorobiphenyl isomer distribution in the fish and oligochaetes compared to the distribution in manufactured Aroclor 1242. The relative proportions of the pentachlorobiphenyls and hexachlorobiphenyls are greater in the fish and oligochaetes compared to the commercial mix. The penta- and hexachloro homolog proportions are greater in tissues downstream at the Highway 441 bridge site compared to the Deposit A site. The trichloro-homolog contribution is lower at the Highway 114 site compared to Deposit A. The actual chlorohomolog makeup in the sediments may differ from the manufactured Aroclor mix. Also, the homolog proportions may change over longer periods of exposure.

In 10 days of exposure, the fathead minnows at Deposit A accumulated an average of 9.46 $\mu g/g$. Since the fish may not have reached a steady state concentration in this short exposure time, longer exposure would result in greater PCB tissue concentrations. Given that 10 day laboratory exposures only achieve 30-50 percent of the steady state concentrations, it is possible longer exposure of caged fish could double or triple the tissue concentrations. Tissue accumulations at the downstream Highway 441 site were approximately 2 percent of the Deposit A accumulation in fish. On a lipid normalized basis, site-to-site differences are not as great in comparing fish and oligochaete PCB accumulations.

The bottom of Table 25 shows analysis for 8 of the 11 toxic PCB congeners included under the proposed Great Lakes Water Quality Initiative because of identified effects to wildlife consuming fish. A number of the congeners were not found above the indicated level of detection. The State Laboratory of Hygiene (SLOH) currently does not have analytical capability for congeners 114, 167, or 189.

Congeners 126 and 169 have been detected in spottail shiners in the Lower Fox River in concentrations of 0.06 ng/g and 0.007 ng/g respectively (Kubiak et. al., 1989), compared to the limit of detection achieved by the SLOH of 0.5 ng/g. Because of the relatively high Toxicity Equivalency Factors based on Safe et. al. (1990) assigned to congeners 126 and 169, they can make significant contributions to the total TCDD-EQ if present at concentrations less than 0.5 ng/g. The spottail shiners in the Kubiak study had 3.2 ng/g of congener 77 in their tissues. The minnows in the caged fish study over Deposit A had tissue levels of 19.0 ng/g. The TCDD-EQ of the detected PCB congeners in Deposit A caged fish was 281.6 pg/g, with 68 percent and 26 percent of the total TCDD-EQ of PCBs being contributed by 77 and 118, respectively.

053241

TABLE 1 **Water Quality Criteria, Proposed Criteria, and Water Quality Objectives for Consideration at the Little Lake Butte des Morts (LLBDM) Site**		
Source of Criteria or Objective	Biological Endpoint Protected	Criteria or Objective Concentration
1. NR 102 and 104, Wis. Adm. Code	The Fox River at the LLBDM site is classified as a Warmwater Sport Fish Community, Non-public water supply	
2. NR 105.09, Wis. Adm. Code	Maximum concentration of PCBs established to protect humans from unreasonable incremental risk of cancer resulting from contact or ingestion of surface waters or aquatic organisms taken from surface waters of the state	0.49 ng/L Total PCBs
3. NR 105.07, Wis. Adm. Code	Concentration that protects Wisconsin's wild and domestic animals from adverse effects resulting from ingestion of surface waters or aquatic organisms	3.0 ng/L Total PCBs
4. Proposed Water Quality Criteria Under the Great Lakes Initiative Total PCBs	Human Health Criteria Human Cancer Value Human Non-Cancer Value Wildlife Criteria	 0.003 ng/L 0.01 ng/L 0.015 ng/L
5. Potential Water Quality Criteria in NR 105 for Protection of Human Health, Warmwater Sport Fish Community Stream Classification Using Values in Chemical Criteria Documents Developed Under the Great Lakes Water Quality Initiative	Human Health Criteria Human Cancer Criterion Human Non-Cancer Criterion	 0.013 ng/L 0.06 ng/L
6. Great Lakes Water Quality Agreement of 1978 as Amended	Water quality objective to protect the most sensitive user	1 ng/L Total PCBs (Proposed)

053240

TABLE 2
Total PCB Sediment Quality Objective Concentrations
For Little Lake Butte des Morts -
Deposit A

Objective: Protection of NR 105.09, Wisconsin Administrative Code, Human Cancer Criteria. Water Quality Criteria - 0.49 ng/L Total PCBs

	Organic Carbon Normalized Total PCB Critiera[1] ug PCB/Kg Organic Carbon (OC)		
	Minimum	Average	Maximum
Organic Carbon Partitioning Coefficient $(k_{oc})^3$ L/Kg	26,303	494,808	1,949,844
ug PCB/Kg OC	12.89	242.46	955.42

		Site Specific Sediment Criteria[2] ug PCB/Kg Sediment (SED)		
		Minimum	Average	Maximum
Organic Carbon Partitioning Coefficient (K_{oc}) L/Kg		26,303	494,808	1,949,844
	%TOC[4]			
ug PCB/Kg SED	Min. 1.5	0.19	3.64	14.33
	2.0	0.26	4.85	19.11
	3.0	0.38	7.27	28.66
	4.0	0.51	9.70	38.22
	5.0	0.64	12.12	47.77
	6.0	0.77	14.55	57.32
	7.0	0.90	16.97	66.88
	Ave. 8.27	1.07	20.05	79.01
	9.0	1.16	21.82	85.99
	10.0	1.29	24.25	95.54
	11.0	1.42	26.67	105.09
	Max. 11.7	1.51	28.37	111.78

053239

Table 2 (Continued)

Notes:

1. SQC_{OCN} = WQC x K_{oc}

   Where:

   SQC_{OCN} = Organic Carbon Normalized Sediment Quality Criteria expressed as ug PCB/Kg OC

   WQC = Water Quality criteria in ug/L

   K_{oc} = Organic Carbon Partitioning Coefficient for Aroclor 1242

2. SQC_{SED} = WQC x K_{oc} x foc

   Where:

   SQC_{SED} = Site Specific Sediment Quality Critiera Expressed as ug PCB/Kg Sediment

   WQC = As above

   K_{oc} = As above

   foc = Total organic carbon content of the sediment expressed as a decimal weight fraction of dry sediment.

3. K_{oc} values are based on organic carbon partitioning characteristics of Aroclor 1242, the predominant Aroclor identified in the Deposit A sediments.

4. TOC percentages represent the range and average value found in the top 6 inches (15cm) of Deposit A sediments.

v:\9304\wr9llbd1.tpj

053238

TABLE 3
Total PCB Sediment Quality Objective Concentrations
For Little Lake Butte des Morts -
Deposit A

Objective: Protection of NR 105.07, Wisconsin Administrative Code, Wild and Domestic Animal Criteria. Water Quality Criteria - 3 ng/L Total PCBs

	Organic Carbon Normalized Total PCB Criteria[1] ug PCB/Kg Organic Carbon (OC)		
Organic Carbon Partitioning Coefficient (K_{oc})[3] L/Kg	Minimum	Average	Maximum
	26,303	494,808	1,949,844
ug PCB/Kg OC	78.91	1496.42	5,849.53

		Site Specific Sediment Criteria[2] ug PCB/Kg Sediment (SED)		
Organic Carbon Partitioning Coefficient (K_{oc}) L/Kg		Minimum	Average	Maximum
		26,303	494,808	1,949,844
	% TOC[4]			
ug PCB/Kg SED	Min. 1.5	1.18	22.27	87.74
	2.0	1.58	29.69	116.99
	3.0	2.37	44.53	175.49
	4.0	3.16	59.38	233.98
	5.0	3.94	74.22	292.47
	6.0	4.73	89.07	350.97
	7.0	5.52	103.90	409.47
	Ave. 8.27	6.53	122.76	483.76
	9.0	7.10	133.60	526.46
	10.0	7.89	148.44	584.95
	11.0	8.68	163.29	643.45
	Max. 11.7	9.23	173.68	684.40

053237

Table 3 (Continued)

Notes:

1. SQC_{OCN} = WQC x KOC

   Where:

   SQC_{OCN} = Organic Carbon Normalized Sediment Quality Criteria expressed as ug PCB/Kg OC

   WQC = Water Quality Criteria in ug/L

   K_{oc} = Organic Carbon Partitioning Coefficient for Aroclor 1242

2. SQC_{SED} = WQC x K_{oc} x foc

   Where:

   SQC_{SED} = Site Specific Sediment Quality Criteria expressed as ug PCB/Kg Sediment

   WQC = As above

   K_{oc} = As above

   foc = Total organic carbon content of the sediment expressed as a decimal weight fraction of dry sediment

3. K_{oc} values are based on organic carbon partitioning characteristics of Aroclor 1242, the predominant Aroclor identified in the Deposit A sediments.

4. TOC percentages represent the range and average value found in the top 6 inches (15cm) of Deposit A sediments.

Table 4
Exceedance Factors of Surface Water Column Concentrations of PCBs With Existing and Proposed Ambient Water Quality Criteria

	NR 105 Water Quality Criteria		Proposed Great Lakes Initiative	
Little Lake Butte des Morts n = 3	Human Cancer Criteria 0.49 ng/L	Wildlife 3 ng/L	Human Cancer Criterion Value 0.013 ng/L	Wildlife 0.015 ng/L
Minimum (1.29 ng/L)	2.5 x	–	99.2 x	86 x
Average (1.44 ng/L)	2.9 x	–	110.8 x	96 x
Maximum (3.64 ng/L)	7.4 x	1.2 x	280 x	242.7 x
Appleton n = 24				
Minimum (2.11 ng/L)	4.3 x	–	162.3 x	140.7 x
Average (25.75 ng/L)	52.6 x	8.6 x	1980.8 x	1716.7 x
Maximum (50.19 ng/L)	102.4 x	16.7 x	3860.8 x	3346 x

PCB water column data based on Table 2-1 of Comments on WDNRs Evaluation for the Remediation of Deposit A Sediments, Draft Final Prepared by Blasland and Bouck. Submitted by Wisconsin Paper Council, June 1992. Values represent a total of dissolved PCBs and particulate associated. Average concentration of PCBs at the upstream Neenah sampling site were subtracted from the average and maximum concentrations found at the Deposit A and Appleton sites.

v:\9304\wr9llb17.tpj

053225

TABLE 5 Fish Tissue Residue Action Levels and Objectives for the Protection of Human Health and Wildlife that Consume Fish		
Source of Criteria or Objective	Biological Endpoint Protected	Action Level or Objective Tissue Concentrations in Fish
1. U.S. Food and Drug Administration (FDA) Action Levels	Human Health	2 μg/g (ppm) Based on fillet with skin on
2. Great Lakes Water Quality Agreement (International Join Commission [IJC] Objective)	Protection of birds and animals which consume fish	0.1 μg/g Whole fish wet weight basis
3. Great Lakes Water Quality Initiative. The fish tissue value was derived from the chemical criteria documents for wildlife protection	Wildlife that consume fish as a primary component of their diet	0.023 μg/g Whole fish wet weight basis

v:\9304\wr911bd4.tpj

053234

Table 6. Percent Lipid content in Fillets and Whole Fish Sampled from Little Lake Butte des Morts.

Fillets	Mean Lipid Content	Range	Number of Fish
White Bass	3.53	2.9 - 4.0	6
Northern Pike	1.28	0.3 - 2.9	13
Walleye	1.62	0.3 - 6.4	27
Carp	6.19	1.0 - 16.9	31
Yellow Perch	1.77	0.2 - 9.0	28
White Suckers	3.05	0.6 - 10.0	19

Whole Fish	Mean Lipid Content	Range	Number of Fish
Northern Pike	5.50		1
Brown Bullheads	5.14	4.7 - 5.8	5
Carp	11.20	11.0 - 11.4	2
Yellow Perch	3.82	3.0 - 6.0	6
White Suckers	5.57	3.9 - 7.4	3

053233

Table 7
Calculation of PCB Accumulation in Fathead Minnow Tissue Relative to Sediment Concentrations. Based on 30 day Laboratory Bioaccumulation Testing from Call et al. 1991.

	Sediment Concentration ug/kg	Tissue Concentration[1] ug/kg	ARS[2]
East River-Reference	90.51	258.00	2.85
Fox River			
Site 1	6,751.41	3,796.0	0.56
Site 2	2,401.54	1,257.90	0.53
Site 3	306.15	1,235.30	4.03
Site 4	2,650.90	1,266.95	0.48
Site 5	4,007.11	1,425.75	0.36
Site 6	3,057.04	1,457.10	0.48
Site 7	414.07	723.85	1.75
Site 8	1,241.04	1,868.30	1.51
Site 9	2,297.26	2,115.95	0.92
Site 10	1,828.90	2,797.05	1.53
Green Bay			
Site 11	811.32	1,647.20	2.03
Site 12	707.09	1,383.40	1.96
		Ave. for sites	1.46

Fish from all sites contained a mean lipid content of 3.04%

1 Converted to a dry weight basis from a reported wet weight concentration utilizing a dry weight to wet weight ratio of 0.2.

2 Accumulation Relative to Sediment (ARS) = Dry weight concentration of PCB in fish tissue (ug PCB/kg dry tissue weight) / Dry weight concentration of PCB in sediment (ug PCB/kg dry sediment)

053232

Table 8
Calculation of PCB Accumulation In Field
Collected Black Bullhead Tissue From Call et al. 1991.

	Sediment Concentration ug/kg	Tissue Concentration[1] ug/kg	ARS[2]
Site 1	6,751.41	12,521.05	1.86
Site 2	2,401.54	4,744.80	1.98
Site 3	306.15	5,283.40	17.26
Site 4	2,650.90	5,372.65	2.03
Site 6	3,057.04	2,524.10	0.83
Sites 8 & 9	1,769.02	4,651.35	2.62
		Ave. for sites	4.43

Fish contained a mean lipid content of 1.65%

[1] Converted to a dry weight basis from a reported wet weight concentration utilizing a dry weight to wet weight ratio of 0.2.

[2] Accumulation Relative to Sediment (ARS) = $\frac{\text{Dry weight concentration of PCB in fish tissue (ug PCB/kg dry tissue weight)}}{\text{Dry weight concentration of PCB in sediment (ug PCB/kg dry sediment)}}$

[3] Based on average of PCB sediment concentrations found at site 8 (1241.04 ug/kg) and site 9 (2,297.26 ug/kg)

Table 9
Review of Literature For Fish Tissue Accumulation of PCBs Relative To Sediment Concetrations

A. Wilford et al., 1987

Fathead Minnow	Sediment Concentration ug/kg	Tissue Concentration ug/kg	ARS
Laboratory Exposure	94	640	6.8
	210	2,030	9.7
	650	1,490	2.3
	2,030	2,270	1.1
	31,700	45,400	1.4

B. Mac et al., 1985

Fathead Minnow		Sediment Concentration ug/kg	Tissue Concentration ug/kg	ARS
Field Exposure	Site 1	2,030	1,624 (Suspended Cage)	0.8
			2,639 (Bottom Cage)	1.3
	Site 2	650	2,275 (Suspended Cage)	3.5
			4,030 (Bottom Cage)	6.2
Laboratory Exposures	Site 1	2,030	4,669	2.3
	Site 2	650	3,835	5.9

C. U.S. EPA, 1984

Laboratory Exposure			Sediment Concentration ug/kg	Tissue Concentration ug/kg	ARS
Laboratory Exposure		% Lipids			
Fathead Minnow	Preexposure	8.5		1,000	
	Control	8.1	16	1,400	
	Test	8.1	31,720	45,400	1.4
Yellow Perch	Preexposure	4.9		1,600	
	Control	3.9	13	2,000	
	Test	3.6	12,780	8,900	0.57

053230

D. WDNR, 1990 (Unpublished)
Laboratory Exposure, Sheboygan River Sediment, Fathead Minnow

Sediment Deposit	Sediment Concentration ug/g	Tissue Concentration ug/g	ARS
#3	2,800	7,500	2.68
#28	132	593	4.49
#23	19	175	9.2
#26	9.20	45	4.89
CTH A	2.60	19	7.31

E. Beak Consultants, 1987
Preview of studies relating PCB levels in bottom dwelling fish to sediments levels. Typical ARS factor.

ARS
25

v:\9304\wr9llbd5.tpj

Table 10
Use of Accumulation Relative to Sediment (ARS) Factors and Fish Tissue Objectives to Derive Sediment Quality Objectives for PCBs (ug/kg) To Protect Fish Tissue Objectives

	FDA Action Level 2000 ug/kg wet wt.		IJC Objective 100 ug/kg wet wt		Great Lakes Water Quality Initiative 23 ug/kg	
	% Water in Tissue		% Water in Tissue		% Water in Tissue	
	50%	80%	50%	80%	50%	80%
	Dry Wt. Concen.		Dry Wt. Concen.		Dry Wt. Concen.	
ARS Factor	4000 ug/kg	10,000 ug/kg	200 ug/kg	500 ug/kg	46 ug/kg	115 ug/kg
0.5	8,000	20,000	400	1,000	92	230
1.0	4,000	10,000	200	500	46	115
2.0	2,000	5,000	100	250	23	58
3.0	1,333	3,333	67	167	15	38
4.0	1,000	2,500	50	125	12	29
5.0	800	2,000	40	100	9	23
10.0	400	1,000	20	50	5	12
15.0	267	667	13	33	3	8
20.0	200	500	10	25	2	6
30.0	133	333	7	17	1.5	4
40.0	100	250	5	13	1.0	3
50.0	80	200	4	10	0.9	2

Sediment Quality Objectives expressed as PCBs (Total) ug/kg dry wt.
ARS Factor = Accumulation Relative to Sediment

v:\9304\wr9llb18.tpj

053228

TABLE 11

Calculations of Fish-Sediment Accumulation Factors (FSAF) For PCBs In Fish Based on Normalization to Percent Lipid and Total Organic Carbon Site Values Laboratory Exposure - Fathead Minnow

	Sediment			Fish Tissue			FSAF
	PCB µg/kg (dry wt.)	Percent Organic Carbon	µg PCB/g OC	PCB µg/kg (Wet wt.)	Percent Lipid	µg PCB/g Lipid	
East River Reference	91.51	1.46	6.27	51.6	3.04	1.70	0.27
Site 1	6751.41	7.36	91.73	759.20	↑	24.97	0.27
2	2401.54	6.70	35.84	251.58		8.28	0.23
3	306.15	2.28	13.43	242.06		7.96	0.59
4	2650.90	5.39	49.18	253.19		8.33	0.17
5	4007.11	8.28	48.40	285.15		9.38	0.19
6	3057.04	7.37	41.48	291.42		9.59	0.23
7	414.07	1.26	32.86	144.77		4.76	0.14
8	1241.04	2.81	44.17	373.66		12.29	0.28
9	2297.26	5.57	41.24	423.19		13.92	0.33
10	1828.90	3.31	55.25	559.41		18.40	0.33
Green Bay							
11	811.32	2.70	300.49	329.44	↓	10.84	0.36
12	707.09	4.37	161.81	276.68	3.04	9.10	0.56
Average FSAF							0.30

1. Fish-Sediment Accumulation Factor (FSAF) =

$$\frac{\text{Wet wt. concentration of PCB in fish tissue } (\mu g/g) \; / \; \text{\% Lipid } (g/g \text{ wet weight})}{\text{Dry wt. concentration of PCB in sediment } (\mu g/g) \; / \; \text{\% Total Organic Carbon in Sediment } (g/g \text{ dry weight})}$$

Data from Call et al. 1991

052227

TABLE 12

Calculations of Fish-Sediment Accumulation Factors (FSAF) For PCBs In Fish Based on Normalization to Percent Lipid and Total Organic Carbon Site Values Field-Collected Black Bullheads

	Sediment			Fish Tissue			FSAF[1]
	PCB µg/kg (dry wt.)	Percent Organic Carbon	µg PCB/g OC	PCB µg/kg (Wet wt.)	Percent Lipid	µg PCB/g Lipid	
Site 1	6751.41	7.36	91.72	2504.21	1.65	151.76	1.65
2	2401.54	6.70	35.84	948.96	▲	57.45	1.60
3	306.15	2.28	13.43	1056.68		64.00	4.77
4	2650.90	5.39	49.18	1074.53		65.09	1.32
6	3057.04	7.37	41.48	504.82	▼	30.55	0.74
Sites 8&9	1769.15	4.19	42.22	930.27	1.65	56.36	1.33
				Average FSAF			1.91

1. Fish-Sediment Accumulation Factor (FSAF) =

$$\frac{\text{Wet wt. concentration of PCB in fish tissue } (\mu g/g) \;/\; \text{\% Lipid (g/g wet weight)}}{\text{Dry wt. concentration of PCB in sediment } (\mu g/g) \;/\; \text{\% Total Organic Carbon in Sediment (g/g dry weight)}}$$

The PCB and Total Organic Carbon values represent the average of concentration found at sites 8 & 9.

Data from Call et al. 1991

052226

TABLE 13. Sediment Quality Objectives To Prevent Exceedances of Fish Tissue Residue Objective Based on Site-Specific Fish-Sediment Accumulation Factors (FSAF)

	Organic Carbon Normalized PCB Sediment Quality Objectives µg PCB/g Organic Carbon (at 1% Lipid, Fish-Sediment Accumulation Factor of 4)																	
	FDA Action Level 2 ppm						IJC Objective 0.1 ppm						Proposed Great Lakes Water Quality Initiative Based 0.023 ppm					
	50						2.5						0.6					
	Site Specific Sediment Quality Objectives (µg PCB/kg Sediment)																	
	FDA Action Level 2000 µg/kg wet wt.						IJC Objectives 100 µg/kg wet wt.						Great Lakes Water Quality Initiative 23 µg/kg					
% Lipid	1%			4%			1%			4%			1%			4%		
% TOC	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	1
FSAF Factor 0.1	30,000	166,000	234,000	7,500	41,500	58,500	1,500	8,300	11,700	375	2,075	2,925	345	1,909	2,691	86	477	
0.25	12,000	66400	93,600	3,000	16,600	23,400	600	3,320	4,680	150	830	1,170	138	764	1,076	35	191	
0.5	6,000	33200	46,800	1,500	8,300	11,700	300	1,660	2,340	75	415	585	69	382	538	17	95	
0.75	4,000	28,133	31,200	1,000	5,533	7,800	200	1,107	1,560	50	277	390	46	255	359	12	64	
1.00	3,000	16,600	23,400	750	4,150	5,850	150	830	1,170	38	208	293	35	191	269	9	48	
1.50	2,000	11,067	15,600	500	2,767	3,900	100	553	780	25	138	195	23	127	179	6	32	
2.00	1,500	8,300	11,700	375	2,075	2,925	75	415	585	19	104	146	17	95	135	4	24	
3.00	1,000	5,533	7,800	250	1,383	1,950	50	277	390	13	69	98	12	64	90	3	16	
4.00	750	4,150	5,850	188	1,038	1,463	38	208	293	9	52	73	9	48	67	2	12	
5.00	600	3,320	4,680	150	830	1,170	30	166	234	8	42	59	7	38	54	1.7	10	
6.00	500	2,767	3,900	125	692	975	25	138	195	6	35	49	6	32	45	1.4	8	
7.00	429	2,371	3,343	107	593	836	22	119	167	5	30	42	5	27	38	1.2	7	
8.00	375	2,075	2,925	94	519	731	19	104	146	4	26	37	4	24	34	1.1	6	

\9301\wr9lll[illegible]tpj

052925

Table 14. Sediment Quality Objectives to Prevent Exceedance of FDA Fish Tissue Residue Criteria (2 ppm) Based on Consideration of Sediment-Water-Fish Partitioning of PCBs

Organic Carbon Partition Coefficient (Koc) L/Kg	Organic Carbon Normalized Total PCB Sediment Quality Objective ug PCB/g Organic Carbon (OC) — Based on 1% Lipid in Fish Tissue
26,300	8.83
494,808	166.06
1,949,844	654.37

	Site Specific Sediment Quality Objectives ug PCB/Kg Sediment (dry weight)								
% TOC	1.5%			8.3%			11.7%		
% Lipid	1%	4%	8%	1%	4%	8%	1%	4%	8%
Organic Carbon Partition Coefficient Aroclor 1242 Koc (L/Kg)									
26,300	132.4	32.7	16.6	733.5	181.2	91.7	1,032.6	255.4	129.2
494,808	2,490.9	616.0	311.7	13,799	3,408.7	1,724.9	19,428.7	4,805.1	2,431.5
1,949,844	9,815.5	2,427.6	1,228.4	54,377.4	13,432.5	6,797.2	76,561	18,934.9	9,581.5

Table 15. Sediment Quality Objectives to Prevent Exceedance of IJC Fish Tissue Residue Criteria Objectives (0.1 ppm) Based on Consideration of Sediment-Water-Fish Partitioning of PCBs

Organic Carbon Partition Coefficient (Koc) L/Kg	Organic Carbon Normalized Total PCB Sediment Quality Objective ug PCB/g Organic Carbon (OC) Based on 1% Lipid in Fish Tissue
26,300	0.45
494,808	8.41
1,949,844	33.15

	Site Specific Sediment Quality Objectives ug PCB/Kg Sediment (dry weight)								
% TOC	1.5%			8.3%			11.7%		
% Lipid	1%	4%	8%	1%	4%	8%	1%	4%	8%
Organic Carbon Partition Coefficient Aroclor 1242 Koc (L/Kg)									
26,300	6.7	1.6	0.8	37.1	8.7	4.4	4.4	12.3	6.2
494,808	126.2	29.7	14.8	698.2	164.3	82.1	82.1	231.6	115.8
1,949,844	497.2	117.0	58.5	2,751.22	647.3	323.7	323.7	912.5	456.3

Table 16. Sediment Quality Objectives to Prevent Exceedance of Proposed Great Lakes Water Quality Initiative-Based Fish Tissue Residues (0.023 ppm) to Protect Wildlife. Based on Consideration of Sediment-Water-Fish Partitioning of PCBs

	Organic Carbon Normalized Total PCB Sediment Quality Objective ug PCB/g Organic Carbon (OC)
Organic Carbon Partition Coefficient (Koc) L/Kg	Based on 1% Lipid in Fish Tissue
26,300	0.10
494,808	1.91
1,949,844	7.53

	Site Specific Sediment Quality Objectives ug PCB/Kg Sediment (dry weight)								
% TOC	1.5%			8.3%			11.7%		
% Lipid	1%	4%	8%	1%	4%	8%	1%	4%	8%
Organic Carbon Partition Coefficient Aroclor 1242 Koc (L/Kg)									
26,300	1.5	0.4	0.2	8.4	2.1	1.0	11.9	2.9	1.5
494,808	28.7	7.2	3.6	158.5	39.8	19.7	223.5	56.2	27.8
1,949,844	112.9	28.4	14.0	624.7	157.0	77.7	880.6	221.3	109.5

v:\9304\wr9llb15.tpj

Table 17
Sediment Quality Objective Concentrations for
Little Lake Butte des Morts, Deposit A

Objective: Protection of aquatic organisms that spend all or part (as eggs or larvae) of their life cycles burrowing in or on the surface of sediments deposited in water bodies. USEPA Ambient Water Quality Criteria to Protect Freshwater Aquatic Life - 0.014 ug/L. (Represents a final residue value to protect wildlife consuming fish. See discussion in text).

	Organic Carbon Normalized Total PCB Criteria ug PCB/Kg Organic Carbon (OC)		
Organic Carbon Partitioning Coefficient (Koc) L/Kg	Minimum 26,303	Average 494,808	Maximum 1,949,844
ug PCB/kg OC	362.24	6,927.31	27,297.82

Organic Carbon Partitioning Coefficient (Koc) L/Kg		Site Specific Sediment Criteria ugPCB/Kg Sediment (SED)		
		Minimum 26,303	Average 494,808	Maximum 1,949,844
	% TOC			
ugPCB/Kg SED	Min. 1.5	5.43	103.91	409.47
	2.0	7.24	138.55	545.96
	3.0	10.87	207.82	818.94
	4.0	14.49	277.09	1,091.91
	5.0	18.11	346.37	1,364.89
	6.0	21.73	415.64	1,637.87
	7.0	25.35	484.91	1,910.85
	Ave. 8.27	29.96	572.89	2,257.53
	9.0	32.60	623.46	2,456.80
	10.0	36.22	692.73	2,729.78
	11.0	39.85	762.00	3,002.76
	Max. 11.7	42.38	810.49	3,193.84

See notes for Table 2 above for partitioning model used.

v:\9304\wr9llb19.tpj

053221

Table 18
Guidelines and Objectives for the Protection of Benthic Aquatic Organisms

Ontario Sediment Quality Guidelines (Persaud et al. 1990; Jaagumagi, 1990)

	Organic Carbon Normalized PCB Guidelines ug PB/Kg Organic Carbon		
	No Effect Level	Lowest Effect Level	Severe Effect Level
PCB (Total)	–	7,000	530,000
PCB 1016	–	700	53,000
PCB 1248	–	3,000	150,000
PCB 1254	–	6,000	34,000
PCB 1260	–	500	24,000

	Site Specific PCB Sediment Guidelines ug PCB/Kg Sediment				
	No Effect Level	Lowest Effect Level		Severe Effect Level	
		% TOC		% TOC	
		1	8	1	8
PCB (Total)	20	70	560	5,300	42,400
PCB 1016	No Value Given	7	56	530	4,240
PCB 1248	No Value Given	30	240	1,500	12,000
PCB 1254	No Value Given	60	480	340	2,720
PCB 1260	No Value Given	5	40	240	1,920

The No Effect Level Guidelines for Total PCBs derived from the Equilibrium Partitioning method to protect Ontario's water quality objectives fell below the background value of 20 ug/Kg, therefore Ontario uses the latter value as the No Effect Level.

Based on Ontario's approach to developing Sediment Quality Guidelines, their data shows the total organic carbon content of the sediment by itself may have biological effects at levels above 1%. Elevated levels of TOC and organic or inorganic contaminants when present in mixtures in sediments may be impacting benthic organisms.

053219

Table 19.
Washington Department of Ecology Sediment Management Standards Adopted September 1990.

	Organic Carbon Normalized PCB Criteria ug PCB/Kg Organic Carbon
PCB (Total)	12,000

	Site Specific PCB Marine Sediment Quality Standards ug/PCB/Kg Sediment	
	% TOC	
	1	8
PCB (Total)	120	960

Represents a level where there are no significant effects to any of the biological organisms used to establish the standard.

053218

Table 20a.
Potential For Biological Effects of Sediment Sorbed PCBs Tested in the National Status and Trends Program.
Based on Long and Morgan 1991

	Effects Range-Low Concentration ug/Kg	Effects Range-Median Concentration ug/Kg	Overall Apparent Effects Threshold ug/Kg
PCB (TOTAL)	50	400	370

Subjective degree of confidence in Effects Range - Low/Effects Range - Medium Values - Moderate/Moderate.

Table 20b.
Potential For Biological Effects of Sediment Sorbed PCBs Based On Expanded Database of MacDonald

	Effects Range-Low Concentration	Effects Range-Median Concentration
PCB (TOTAL)	22.7	180

053217

Table 21.
Sedimen Quality Criteria Developed by Different Approaches To Protect Benthic Organisms in Marine Habitats[1]

	Approach	Criteria PCB(Total) ug/Kg
No or minimal biological effects at or below these values.	Triad	100
	Screening Level Concentrations	60
Significant biological effects at or above these values	Apparent Effects Threshold	130
	Triad	≥ 800
Significant biological effects determined in San Francisco Bay at these minimum values		160

Notes

1. From: Chapman, P.M., R.C. Barrick, J.M. Neff, and R.C. Swartz. 1987. Four Independent Approaches to Developing Sediment Quality Criteria Yield Similar Values for Model Contaminants. Environ. Toxicol. Chem. 6:723-725.

Chapman, P.M., 1986. Sediment Quality Criteria From the Sediment Quality Triad: An Example.Environ. Toxicol Chem. 5:957-964.

053216

Table 22. Coplanar PCB Concentrations in Sediments of Deposit A and Lake Winnebago.

Coplanar PCB (IUPAC No.)	Sediment Concentration (ug/kg)	
	Menasha Channel 47-2 *	Deposit A Site 48-1
77	0.211	176.67
105	1.31	39.97
126	0.013	1.41
169	0.002	N.D.
Total PCBs	14	18,397
118	1.24	385

Weight Percent of Coplanar PCBs in Deposit
A Sediment and Weight Percent in Manufactured Aroclor 1242

Deposit A Sediments		[1]Schultz et.al 1989	[2]Chantry 1989	[3]Duinker et.al 1988
77	0.96	0.45	0.35	0.50
105	0.22	0.86	0.31	0.33
126	0.008	----	----	< 0.01
169	----	----	----	< 0.01

* Background Site - Sample Taken in Menasha Channel, Outlet for Lake Winnebago.

1. Schulz D.E., G. Petrick, and J.C. Duinker. 1989. Complete Characterization of Polychlorinated Biphenyl Congeners in Commercial Aroclor and Clophen Mixtures by Multidimensional Gas Chromatography - Electron Capture Detection. Environ. Sci. Technol. 23: 852-859.

2. Chantry, W.A. 1989. Biodegradation of PCBs Solved to Sewerage Sludge Lagoon Sediments in an Aerobic Digester. 201 Facilities Planning Update Madison Metropolitan Sewerage District.

3. Duinker, J.C., D.E. Schultz, and G. Petrick. 1988. Multidimensional Gas Chromatography With Electron Capture Detection for the Determination of Toxic Congeners Polychlorinated Biphenyl Mixtures. Anal. Chem. 60: 478-482.

TABLE 23

2,3,7,8-TCDD "EQUIVALENTS"[1] DEVELOPED FROM ACTUAL CONCENTRATIONS OF PCB CONGENERS FOUND IN SEDIMENTS FROM SEVERAL SITES ASSOCIATED WITH COASTAL ZONE STUDY (WDNR 1992)

SITE	PCB Congener (IUPAC Number)[2] TCDD-EQ pg/g				TCDD Equivalents From PCBs pg/g	Total PCB in Sample µg/g	2,3,7,8 TCDF pg/g	2,3,7,8 TCDD pg/g
	77	105	126	169				
Little Lake Butte Des Mort 48-1 Deposit A	1766.7	39.97	141.0	--[3]	1947.67	18.4	333	25.1
Menasha Channel Outlet Lake Winnebago 47-2	2.11	1.31	1.3	0.1	4.82	0.034	4.5	--
Cedar Creek Ruck Pond 78-1	176.86	5.53	--	2.81	185.2	39.70	23.5	1.4
Menominee River Marinette 41-1	8.14	4.32	4.9	0.19	17.55	0.089	33.7	--
Kewaunee Harbor 55-2	25.31	7.22	4.9	--	37.43	0.304	--	--
Oconto River 90-2	4.63	3.47	2.8	--	10.9	0.047	6	1.1

[1] Toxicity Equivalency Factors (TEF) for determining "2,3,7,8-TCCD equivalents" for isoteric compounds of 2,3,7,8-TCDD by relative ability to induce aryl hydrocarbon hydroxylase (AHH) enzyme activity taken from Safe et al. (1990). TCDD equivalents = sum of each congeners TCDD equivalent (actual concentration of each congener in pg/g x conversion factor). The induction potency factors are derived from mammalian systems.

[2] International Union of Pure and Applied Chemists (IUPAC) PCB Congener number.

[3] "--" indicates congener not detected. Analysis done by EPA-Duluth.

v:\93021wr9congl.tpj

Table 24. 2,3,7,8-TCDD "Equivalents" Developed From Actual Concentrations of PCB Congeners Found in Sheboygan River Sediments by Sonzogni, et al. (1991)

	PCB Cogener (IUPAC Number)[1] TCDD-EQ Pg/g								Total TCDD Equivalents[2] From PCBs pg/g	Total PCB in Sample ug/g
Site	77	81	105	114	118	126	167	169		
1	310	___[3]	80	___	140	___	44	___	574	50.3
2	972	3600	490	11	1480	1,000	80	950	7600	1,050
3	240	___	27	___	129	900	___	450	1746	76.9
4	210	___	41	___	318	___	___	___	569	97.8
5	460	0.7	15	___	395	___	___	___	870	256
6	50	___	11	___	103	___	___	___	164	73.4
7	110	___	6	___	162	___	___	550	828	97.5
8	160	0.4	11	___	86	___	___	___	257	124

[1] International Union of Pure and Applied Chemists (IUPAC) PCB Congener Number.

[2] Toxicity Equivalency Factors (TEF) for determining "2,3,7,8-TCDD equivalents" for isoteric compounds of 2,3,7,8-TCDD by relative ability to induce Aryl Hydrocarbon Hydroxylase (AHH) enzyme activity taken from Safe, et al. (1990). 2,3,7,8-TCDD equivalents = sum of each congeners TCDD equivalent (actual concentration of each congener in pg/g X conversion factor). The induction potency factors are derived from mammalian systems. Toxic equivalents expressed in units of pg 2,3,7,8-TCDD equivalents/g. TEF factors used for congeners 81 and 114 taken from Smith et al. (1990).

[3] "___" indicates congener not detected (concentration less than 1 ng/kg).

v:\9302\wr9shebg.tpj

Table 25. Preliminary Results from WDNR Caged Fish Studies and Field - Collected Oligochaetes From Deposit A, and Reference and Downriver Sites

	Percent Composition of PCB Chlorohomolog Groups in Minnow and Oligochaetes						
	Caged Fathead Minnow			Field - Collected Oligochaetes			
	Menasha Channel	Deposit A	441 Bridge	Menasha Channel	Deposit A	441 Bridge	Commercial 1242
Chlorohomolog Groups							
Dichloro	N.D.	9.5	6.7	N.D.	9.8	3.3	17.7
Trichloro	N.D.	43.9	32.7	100	41.3	28.5	44.7
Tetrachloro	N.D.	33.3	38.7	N.D.	31.9	35.8	30.2
Pentachloro	N.D.	9.7	19.3	N.D.	11.3	23.7	4.4
Hexachloro	N.D.	2.8	5.8	N.D.	3.8	8.7	0.9
Heptachloro	N.D.	0.7	0	N.D.	1.2	N.D.	0.6
Octachloro	N.D.	0.1	0	N.D.	0.7	N.D.	0.2
Total PCBs (Summed Congeners) ug/kg Wet Wt.	–	9461.77	216.63	0.85	930.17	166.8	
Lipid Normalized ug PCB/g Lipid	–	338.57	8.99	0.12	186.03	20.85	
% Lipid	2.3	2.8	2.4	0.7	0.5	0.8	
Congener Number	Concentration of Toxic PCB Congeners In Minnow and Oligochaetes (ng/g)						
77	<0.5	19	0.54	<0.5	2.7	<0.5	
126	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
169	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
105	<0.3	9.2	1.1	<0.3	1.1	1.0	
114	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
123	<0.4	6.3	0.44	<0.40	0.74	0.4	
118	<0.80	72	4.3	<0.8	8.6	4.1	
156	<0.3	3	<0.3	<0.3	0.42	<0.3	
157	<0.4	1.1	<0.4	<0.40	<0.4	<0.4	
167	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
189	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
	Total TCDD - EQ (Pg/g based on the TEF Factors of Safe (1990)						
TCDD-EQ (pg/g)	–	281.6	11.24	–	37.86	5.51	

v:\9302\wr9llb40.tpj

052212

References

Ankley, G.T., A. Katko, and J.W. Arthur. 1990. Identification of Ammonia as and Important Sediment - Associated Toxicant In the Lower Fox River and Green Bay, Wisconsin. Environ. Toxicol. Chem. 9:313-322.

Ankley, G.T., D.E. Tillitt, J.P. Giesy, P.D. Jones, and D.A. Verbrugge. 1991. Bioassay - Derived 2, 3, 7, 8 - Tetrachloro-dibenzo-p-Dioxin Equivalents In PCB - Containing Extracts From the Flesh and Eggs of Lake Michigan Chinook Salmon *Oncorhynchus tshawytscha*) and Possible Implications for Reproduction. Can. J. Fish. Aquat. Sci. 48:1685-1690.

Ankley, G.T., K. Lodge, D.J. Call, M.D. Balcer, L.T. Brooke, P.M. Cook, R.G. Kreis, Jr., A.R. Carlson, R.D. Johnson, G.J. Niemi, R.A. Hoke, C.W. West, J.P. Giesy, P.D. Jones, and Z.C. Fuying, 1992. Integrated Assessment of Contaminated Sediments in the Lower Fox River and Green Bay, Wisconsin. Ecotoxicology and Environmental Safety. 23: 46-63

Ankley, G.T., P.M. Cook, A.R. Carlson, D.J. Call, J.A. Sevenson, H.F. Corcoran and R.A. Hoke. 1992. Bioaccumulation of PCBs from Sediments by Oligochaetes and Fishes: Comparison of Laboratory and Field Studies. Can. J. Fish Aquat. Sci. 49: 2080-2085.

Abernethy, S., A.M. Bobra, W.R. Shiu, P.G. Wells, and D. MacKay. 1986. Acute Lethal Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to Two Planktonic Crustaceans: The Key Role of Organism - Water Partitioning. Aquat. Toxicol. 8: 163-174.

Bierman, V.J. 1990. Equilibrium Partitioning and Biomagnification of Organic Chemicals In Benthic Animals. Environ. Sci. Technol. 24: 1407-1412.

Brown, J.F. Jr., D.L. Bedard, M.J. Brennan, J.C. Carnahan, H. Feng, and R.E. Wagner. 1987. Polychlorinated Bihenyl Dechlorination in Aquatic Sediments. Science. 236:709-712.

Call, D.J., M.D. Balcer, L.T. Brooke, S.J. Lozano, and D.D. Vaishnav. 1991. Sediment Quality Evaluation In the Lower Fox River and Southern Green Bay of Lake Michigan. Report by the Center for Lake Superior Environmental Studies of the U.W.-Superior. U.S. EPA Cooperative Agreement No. CR-815232.

Chapman, P.M. 1986. Sediment Quality Criteria From the Sediment Quality Triad: An Example. Environ. Toxicology and Chemistry. 5:957-964.

Chapman, P.M., R.C. Barrick, J.M. Neff, and R.C. Swartz. 1987. Four Independent Approaches to Developing Sediment quality Criteria Yield Similar Values for Model Contaminants. Environ. Toxicology and Chemistry. 6: 723-725.

053211

Clarke, J.U., V.A. McFarland, and J. Dorkin. 1988. Evaluating Bioavailability of Neutral Organic Chemicals in Sediments -- A Confined Disposal Facility Case Study. Proceedings of the Seminar, Water Quality 1988. R.G. Wiley, ed., Hydrologic Engineering Research Center, Davis, CA. pp. 251-268.

Clarke, J.U., V.A. McFarland, B.D. Pierce. 1989. Preliminary Recommendations For a Congener - Specific PCB Analysis In Regulatory Evaluation of Dredged Material. Miscellaneous Paper D-89-2. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Clarke, J.U. and V.A. McFarland. 1991. Assessing Bioaccumulation In Aquatic Organisms Exposed to Contaminated Sediments. Miscellaneous Paper D-91-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Clarke, Joan U., P.L. Whitman, and J. Dorkin. 1992. Trends in PCB Contamination In Fishes from Wisconsin Waters of Lake Michigan, 1978-1986. Miscellaneous Paper D-92-3. Vicksburg, MS. U.S. Army Engineer Waterways Experiment Station.

Cochran, P.A. 1992. The Return of Hexagenia (Ephemeroptera: Ephemeridae) to the Lower Fox River, Wisconsin. The Great Lakes Entomologist. 25:79-81.

Di Toro, D.M. 1985. A Particle Interaction Model of Reversible Organic Chemical Sorption. Chemosphere. 14(10):1503-1538.

Di Toro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, M.A. Thomas, and P.R. Paquin. 1991. Technical Basis for Establishing Sediment Quality Criteria for Nonionic Organic Chemicals Using Equilibrium Partitioning. Environ. Tox. and Chemistry. 10:1541-1582.

Dillon, T.M., W.H. Benson, R.A. Stackhouse, and A.M. Crider. 1990. Effects of Selected PCB Congeners On Survival, Growth, and Reproduction In *Daphnia Magna*. Environ. Toxicol. Chemistry. 9:1317-1326.

Dillon, T.M. and W.D.S. Burton. 1991. Acute Toxicity of PCB Congeners to *Daphnia magna* and *Pimephales promelas*. Bull. Environ. Contam. Toxicol. 46:208-215.

Eadie, B.J. 1992. J. Great Lakes Research. 18:91-97

Eisler, R. 1986. Polychlorinated Biphenyl Hazards to Fish, Wildlife, and Invertebrates. A Synoptic Review. U.S. Fish and Wildlife Service. Biological Report 85(1.7).

Evans, M.S., G.E. Noguchi, and O.P. Rice. 1991. The Biomagnification of Polychlorinated Biphenyls, Toxaphene, and DDT Compounds in a Lake Michigan Offshore Food Web. Arch. Environ. Contam. Toxicol. 20: 87-93.

EWI Engineering Associates, Inc. 1991. Draft Technical Memorandum, Task 2: Sediment Characterization Mapping. Deposit A Little Lake Butte des Morts. Prepared for Wisconsin Department of Natural Resources. Project No. 15605.

Ferraro, S.P., H. Lee II, L.M. Smith, R.J. Ozretich, and D.T. Specht. 1991. Accumulation Factors for Eleven Polychlorinated Biphenyl Congeners. Bull Environ. Contam. Toxicol. 46: 276-283.

Gagnon, M.M., J.J. Dodson, M.C. Comba, and K.L. Kaiser. 1990. Congener - Specific Analysis of the Accumulation of Polychlorinated Biphenyls (PCBs) by Aquatic Organisms In the Maximum Turbidity Zone of the St. Lawrence Estuary, Quebec, Canada. The Science of the Total Environment 97/98: 739-759.

Gibson, A.B. and T.M. Dillion. 1989. Bioaccumulation of Chlorinated Contaminants and Concomitant Sublethal Effects in Marine Animals: An Assessment of Current Literature. Environmental Effects of Dredging Technical Notes. U.S. Army Waterways Experiment Station. Vicksburg, MS.

Harris, H.J., T.C. Erdman, K.B. Lodge, and G.T. Ankley. Measures of Reproductive Success and Contaminant Concentration In Forster's Term on Green Bay, Lake Michigan - 1988. Manuscript in preparation.

Hebert, C.E. and G.D. Haffner. 1991. Habitat Partitioning and Contaminant Exposure in Cyprinids. J. Fish. Aquat. Sci. 48:261-266.

Hoke, R.A., J.P. Giesy, and G. Kreis, Jr. 1992. Sediment Pore Water Toxicity Identification in the Lower Fox River and Green bay, Wisconsin, using Microtox Assay. Ecotoxicology and Environmental Safety. 23:343-354.

IJC (International Joint Commission). 1988. Procedures for the Assessment of Contaminated Sediment Problems in the Great Lakes. Report to the Great Lakes Water Quality Board. Sediment Subcommittee and its Assessment Work Group.

Kadeg, R.D. and S.P. Pavlou. 1989. Sediment Toxicity Handbook. Prepared for U.S. EPA Office of Superfund, Hazardous Site Control Division and Office of Water, Criteria and Standards Division by Envirosphere Company. Bellvue, WA.

Kannan, N., S. Tanabe. T. Wakimoto, and R. Tatsukawa. 1987. A Simple Method For Determining non-ortho substituted PCBs in Kanechlors, Aroclors and Environmental Samples. Chemosphere. 16:1631.

Karickhoff, S.W., D.S. Brown, and T.A. Scott. 1979. Sorption of Hydrophobic Pollutants On Natural Sediments Water. Res. 13:241-248.

Kenega, E.E. and C.A.I. Goring. 1978. Relationship Between Water Solubility, Soil Sorption, Octanol - Water Partitioning, and Concentration of Chemicals In Biota. In: Aquatic Toxicology. ASTM Special Technical Publication 707.

053209

Kubiak T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D.E. Docherty, and T.C. Erdman. 1989. Microcontaminants and Reproductive Impairment of the Forster's Tern On Green Bay, Lake Michigan-1983. Arch. Environ. Contam. Toxicol. 18: 706-727.

Lake, J.L., N.I. Rubinstein, H. Lee II, C. Lake, J. Heltshe, and S. Pavignano. 1990. Equilibrium Partitioning and Bioaccumulation of Sediment-Associated Contaminants By Infaunal Organisms. Environ. Toxicology Chem. 9: 1095-1106.

Landrum, P.F., H. Lee II, M.J. Lydy. 1992. Toxicokinetics In Aquatic Systems: Model Comparisons and Use In Hazard Assessment. Environ. Toxicol. Chem. 11:1709-1725.

Lee, H.II. 1992. Models, Muddles, and Mud: Predicting Bioaccumulation of Sediment - Associated Pollutants. Pgs. 267-293. In: Sediment Toxicity Assessment. Ed. G. Allen Burton. Lewis Publishers.

Long, E.R. and D.D. MacDonald. 1992. National Status and Trends Program. Chapter 14 in Sediment Classification Methods Compendium. U.S. EPA, Office of Water. EPA 823-R-92-0006.

Long, E.R. and L.G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. National Oceanic and Atmospheric Administration. National Ocean Service, Seattle, Wash. NOAA Technical Memorandum NOS OMA 52.

Maack, L. 1988. Sheboygan RAP. PCB Information. Correspondence Memorandum to R. Kazmierczak. April 22, 1988.

Mayer, F.L., P.M. Mehrle, and H.O. Sanders. 1977. Residue Dynamics and Biological Effects of Polychlorinated Biphenyls In Aquatic Systems. Arch. Environ. Contam. and Toxicol. 5: 501-511.

Mac, M., C. Edsall, and R. Hesselberg. 1985. Accumulation of PCBs and Hg by Fish and Earthworms During Field and Laboratory Exposures to Green Bay Sediments. Admin. Report No. 85-4. USFWS-GLFL/AR-85-4.

Mac, M.J. and C.J. Schmitt. 1992. Sediment Bioaccumulation Testing With Fish. In: Sediment Toxicity Assessment. Ed: G.A. Burton, Jr. Lewis Publishers. Ann Arbor.

Mackay, D., W.Y. Shiu, J. Billington, and G.L. Huang. 1983. Physical Chemical Properties of Polychlorinated Biphenyls. In: Physical Behavior of PCBs In the Great Lakes. Ed. D. Mackay, S. Paterson, S.L. Eisenneich, and M.S. Simmons. Ann Arbor Science. pgs. 59-69.

053208

Mackay, D. 1982. Correlation of Bioconcentration Factors. Environ. Sci. Technol. 16: 274-278.

Mackay, D., S. Patterson, and M. Joy. 1983. Application of Fugacity Models to the Estimation of Chemical Distribution and Persistence in the Environment. In: Fate of Chemicals In the Environment. Compartmental and Multimedia Models for Predictions. Ed. R.L. Swann and A. Eschenroeder. American Chemical Society Symposium Series. 225.

McFarland, V.A., J.U. Clarke, and A.B. Gibson. 1985. Bioaccumulation of Polychlorinated Biphenryls (PCBs) from Sheboygan Harbor Wisconsin Sediments In Laboratory Exposures. U.S. Army Corps. of Engineers Waterways Experiment Station. Unpublished Report U.S. ACOE.

Miller, M.A. (in press). Maternal Transfer of Organochlorine Compounds In Salmonines To Their Eggs. Can. J. Fish. Sci. Aquat.

Moore, J.W. and S. Ramamoorthy. 1984. Organic Chemicals In Natural Waters. Applied Monitoring and Impact Assessment. Springer-Verlag. New York.

Oliver, B.G. and A.J. Niimi. 1985. Bioconcentration Factors of Some Halogenated Organics For Rainbow Trout: Limitations In Their Use For Prediction of Environmental Residues. Environ. Sci. Technol. 19:842-849.

Oliver, B.G. and A.J. Niimi. 1988. Trophodynamic Analysis of Polychlorinated Biphenyl Congeners and Other Chlorinated Hydrocarbons in the Lake Ontario Ecosystem. Environ. Sci. Technol. 22: 388-397.

Pavlou, S.P. 1984. The Use of The Equilibrium Partitioning Approach in Determining Safe Levels of Contaminants in Marine Sediments. In: Fate and Effects of Sediment - bound Chemicals In Aquatic Systems. Ed. K.L. Dickson, A.W. Maki, and W.A. Brungs. Proceedings of Sixth Pellston Workshop.

Persaud D., R. Jaagumagi, and A. Hayton. 1990. Provincial Sediment Quality Guidelines. Water Resources Branch, Ontario Ministry of the Environment.

Rathbum, J.E., R.G. Kreis, Jr., E.L. Lancaster, M.J. Mac, and M.J. Zabik. 1988 (unpublished). Pilot Confined Disposal Facility Biomonitoring Study: Channel/Shelter Island Diked Facility, Saginaw Bay, 1987. U.S. EPA Lange Lakes Research Station, ERL - Duluth.

Safe, S. and D. Phil. 1990. Polychlorinated Biphenyls (PCBs), Dibenzo-p-Dioxins (PCDDs), Dibenzofurans (PCDFs), and Related Compounds: Environmental and Mechanistic Considerations Which Support the Development of Toxic Equivalency Factors (TEFs). Critical Reviews In Toxicology. 21:51-88.

U53207

Sawyer T.W., A.D. Vatcher, and S. Safe. 1984. Comparative Aryl Hydrocarbon Hydroxylase Induction Activities of Commercial PCBs In Wistar Rats and Rat Hepatoma H-4-II E Cells in Culture. Chemosphere. 13(7): 695-701.

Seelye, J. G., R.J. Hesselberg, and M.J. Mac. 1982. Accumulation by Fish of Contaminants Released from Dredged Sediments. Environ. Sci. Technol. 16: 459-464.

Sijm, D.T.H.M., W. Seinen, and A. Opperhuizen. 1992. Life-Cycle Biomagnification Study in Fish. Environ. Sci. Technol. 26:2162-2174.

Smith, V.E., J.M. Spurr, J.C. Filkins, and J.J. Jones. 1985. Organochlorine Contaminants of Wintering Ducks Foraging On Detroit River Sediments. J. Great Lakes Res. 11(3): 231-246.

Smith, L.M., T.R. Schwartz, K. Feltz, and T.J. Kubiak. 1990. Determination and Occurrence of AHH-Active Polychlorinated Biphenyls, 2,3,7,8 - Tetrachloro-p-Dioxin and 2,3,7,8 - Tetrachlorodibenzofuran In Lake Michigan Sediment and Biota. The Question of Their Relative Toxicological Significance. Chemosphere. 9: 1063-1085.

Sonzogni, W.C. 1990. L. Maack, T. Gibson, and J. Lawrence. 1991. Toxic Polychlorinated Biphenyl Congeners In Sheboygan River (USA) Sediments. Bull. of Environ. Contamination and Toxicology. 47:398-405.

Spigarelli, S.A., M.M. Thommes, and W. Prepejchal. 1983. Thermal and Metabolic Factors Affecting PCB Uptake by Adult Brown Trout. Environ. Sci. Technol. 17: 88-94.

Tillett, D.E., G.T. Ankley, J.P. Giesy, J.P. Ludwig, H. Kurita-Matsuba, D.V. Weseloh, P.S. Ross, C.A. Bishop, L. Sileo, K.L. Stromberg, J. Larson, T.J. Kubiak. 1992. Polychlorinated Biphenyl Residues and Egg Mortality In Double-Crested Cormorants From the Great Lakes. Environ. Toxicol. and Chemistry. 11: 1281-1288.

Thomann, R.V. 1989. Bioaccumulation Model of Organic Chemical Distribution in Aquatic Food Chains. Environ. Sci. Technol. 23: 699-707.

U.S. EPA. 1980. Ambient Water Quality Criteria for Polychlorinated Biphenyls. EPA 440/5-80-068.

U.S. EPA. 1989. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish. EPA-503/8-89-002.

U.S. EPA. 1990. Draft Ecological Evaluation of Proposed Discharge of Dredged Material Into Ocean Waters. EPA-503-8-90/002.

053206

U.S. EPA. 1990. Guidance On Remedial Actions for Superfund Sites With PCB Contamination. EPA/540/6-90/007.

U.S. EPA. 1991. Guidance On Assessment and Control of Bioconcentratable Contaminants In Surface Waters. Draft. Office of Water. Wash. D.C.

Van Der Kooij, L.A., D. Van De Meent, C.J. Van Leeuwen, and W.A. Bruggeman. 1991. Deriving Quality Criteria For Water and Sediment From the Results of Aquatic Toxicity Tests and Product Standards: Application of the Equilibrium Partitioning Method. Water Research. 6: 697-705.

Walker, M.K. and R.E. Peterson. 1991. Potencies of Polychlorinated Dibenzo-p-Dioxin, Dibenzofuran, and Biphenyl Congeners, Relative to 2,3,7,8-tetrachlorodibenzo-p-Dioxin, For Producing Early Life Stage Mortality In Rainbow Trout (*Oncorhynchus mykiss*). Aquatic Toxicology. 21:219-238.

Wilford, W.A., M.J. Mac, and R.J. Hesselberg. 1987. Assessing the Bioaccumulation of Contaminants From Sediments By Fish and Other Aquatic Organisms. Hydrobiologia. 149: 107-111.

v:\9305\wr9llb99.tpj

053205

SCHUETTPELZ

Ref 28

Development of
Sediment Quality Objective Concentrations
for PCBs in Deposit A
Little Lake Butte des Morts

Wisconsin Department of Natural Resources
Bureau of Water Resources Management
Sediment Management and Remediation Techniques Program

February 1993

JUL 29 [illegible]

053280

WISCONSIN
DEPT. OF NATURAL RESOURCES

State of Wisconsin \ DEPARTMENT OF NATURAL RESOURCES

George E. Meyer
Secretary

101 South Webster Street
Box 7921
Madison, Wisconsin 53707
TELEPHONE 608-266-2621
TELEFAX 608-267-3579
TDD 608-267-6897

SUBJECT: Establishment of Sediment Quality Objective Concentrations for Polychlorinated Biphenyls (PCBs) in Deposit A, Little Lake Butte des Morts, Winnebago County, WI.

Dear Reader:

This document contains the Department of Natural Resources' determination of the Sediment Quality Objective Concentrations (SQOC) for PCBs in Deposit A, a specific sediment deposition area in Little Lake Butte des Morts. This development document was prepared by the Bureau of Water Resources Management - Sediment Management and Remediation Techniques (SMART) program staff with technical assistance from the Water Quality Standards Unit.

The SQOC for PCBs in this document are specific to Deposit A, based on a number of considerations which include: site specific total organic carbon content of the sediment; PCB Aroclor and congeners present; and data and information available from Fox River studies.

Sediment Quality Objective Concentrations are based on protecting a variety of biological endpoints including water quality criteria as contained in NR 105, Wis. Adm. Code, fish tissue residue values protective of human and animal health and benthic organisms and communities. The procedures used in this development document are generally applicable to other sites, but site-specific information and data are needed to develop SQOC for any particular site.

Remediation options for Deposit A sediment should be designed to achieve the SQOC as closely as is practicable. Practicability in achieving the SQOC is defined by considering net environmental effects, including protection of health,safety and welfare, natural recovery rates, engineering feasibility, costs and compliance with applicable laws and regulations.

Please direct any questions regarding the use of the attached document to Lee Liebenstein, SMART Program Unit Supervisor (608-266-0164) or Tom Sheffy, Project Manager for the Little Lake Butte des Morts Contaminated Sediment Remediation Demonstration activity (608-267-7648).

Sincerely,

3/2/93

Duane Schuettpelz, Chief
Surface Water Standards and Monitoring Section
Bureau of Water Resources Management

053279

DOCUMENT FOR DEVELOPMENT OF SEDIMENT QUALITY OBJECTIVE CONCENTRATIONS FOR PCBS IN DEPOSIT A LITTLE LAKE BUTTE DES MORTS

CONTENT

053278

4.1 Use of an equilibrium partitioning model to derive Sediment Quality Objective Concentrations to protect benthic organisms exposed to PCBs in sediment pore water.

4.2 Review of literature, regulatory criteria and guidelines for establishing Sediment Quality Objective Concentrations for PCBs to protect benthic organisms.

4.2.1 Ontario Ministry of the Environment Sediment Quality Guidelines.
4.2.2 State of Washington Sediment Standards.
4.2.3 National Oceanic and Atmospheric Administration (NOAA) Sediment Quality Guidelines.
4.2.4 Sediment quality assessment approach application to determine biological effect levels to benthic organisms from PCBs.
4.2.5 Summary of approaches and effect levels to benthic organisms.
4.2.6 Benthic community studies on the Lower Fox River.

5.0 Consideration of toxic PCB congeners.

6.0 Preliminary Results From Wisconsin Department of Natural Resources biomonitoring studies of Deposit A, summer of 1992.

4.1 Use of an equilibrium partitioning model to derive Sediment Quality Objective Concentrations to protect benthic organisms exposed to PCBs in sediment pore water.

4.2 Review of literature, regulatory criteria and guidelines for establishing Sediment Quality Objective Concentrations for PCBs to protect benthic organisms.

4.2.1 Ontario Ministry of the Environment Sediment Quality Guidelines.
4.2.2 State of Washington Sediment Standards.
4.2.3 National Oceanic and Atmospheric Administration (NOAA) Sediment Quality Guidelines.
4.2.4 Sediment quality assessment approach application to determine biological effect levels to benthic organisms from PCBs.
4.2.5 Summary of approaches and effect levels to benthic organisms.
4.2.6 Benthic community studies on the Lower Fox River.

5.0 Consideration of toxic PCB congeners.

6.0 Preliminary Results From Wisconsin Department of Natural Resources biomonitoring studies of Deposit A, summer of 1992.

1.0 Summary of Sediment Quality Objective Concentrations for PCBs in Deposit A Sediments

Wisconsin Department of Natural Resources' (WDNR) Sediment Management and Remediation Techniques Program (SMART) goal for sediment remediation is to restore contaminated systems to conditions that are protective to the maximum extent possible of the aquatic ecosystem and human uses. This goal is tempered by a number of factors, however, one of which is the understanding that remedial actions should not be expected to reduce sediment contaminant concentrations to levels below background. A background PCB concentration as used herein is a statistically defined maximum probable concentration found in surficial sediments based on samples from representative unimpacted reference sites. Based on this framework, sediments in Deposit A should be remediated to achieve a concentration of total PCBs in sediment no greater than the higher of

(1) sediment concentrations protective of a range of biological endpoints; or
(2) background sediment concentrations.

Based on the protective levels discussed below and review of the limited data available on background PCB concentrations in Fox River system sediments, WDNR preliminarily identifies the sediment quality objective concentration (SQOC) for PCBs in Deposit A sediments to be the maximum probable background PCB concentration. The data currently available (five samples) indicate that maximum probable background concentration, and the SQOC for PCBs in sediment, will be approximately 40 to 90 μg/kg (all sediment chemical concentrations in the following document are expressed on a dry weight basis).

This summary and the following document describe WDNR's approaches to determining protective and background concentrations of PCBs in Deposit A sediments.

Sediment PCB Concentrations Protective of Biological Endpoints

A number of approaches were used to establish protective concentrations of PCBs in Deposit A sediments in Little Lake Butte des Morts:

(1) Partitioning-based estimates of sediment quality that will protect established biological (including human health) endpoints;

(2) Review of sediment quality criteria and guidelines established by other regulatory agencies or discussed in the literature; and
(3) Consideration of studies in the Lower Fox River that related PCBs to biological effects were reviewed and pertinent information used.

Partitioning-Based Estimates of Sediment Quality Protective of Biological Endpoints

WDNR's partitioning-based estimates of sediment quality considered a number of biological endpoints, including (1) water quality criteria related to protection of human health and wildlife, (2) fish tissue residue criteria and objectives, and (3) water quality criteria related to

053276

protection of aquatic organisms that spend all or part of their life cycles associated with sediments, sediment pore waters, and/or the sediment-water column interface.

A number of partitioning models were applied to attempt to relate and predict PCB distribution between the water, sediment, and biotic environmental compartments. These models used data specific to Deposit A (including total organic carbon levels in the sediment and type of Aroclor present), Aroclor-specific partitioning coefficients (K_{ow} and K_{oc}), and assumed fish lipid contents.

Most of the Sediment Quality Objective Concentrations (SQOC) for PCBs developed by the partitioning approach are expressed on an organic carbon normalized basis, that is, to protect each biological endpoint, a maximum ug PCB/g organic carbon is allowed. This normalization reflects the assumption that the organic carbon of sediments is the depository and primary determinant of the bioavailability of nonpolar organic compounds such as PCBs associated with sediments. To facilitate communication of the levels of PCBs in sediments that are protective of various biological endpoints, the concentrations are generally presented in dry weight bulk chemical terms - μg PCB/kg dry sediment in the following document.

A number of partitioning models currently available to relate sediment levels of PCBs to fish tissue levels were applied. Four different models were used to establish SQOC based on protection of three different fish tissue residue levels-U.S. Food and Drug Administration (FDA), International Joint Commission (IJC), and proposed Great Lakes Water Quality Initiative-related level (GLWQI).

Sediment Quality Criteria and Guidelines Established Elsewhere

In addition to the partitioning approaches, protective sediment concentrations were also identified from sediment quality criteria and guidelines for PCBs established by other regulatory agencies and in the literature. The focus of WDNR's review of the criteria and guidelines was on criteria that relate to effects on benthic organisms and communities.

Summary of Sediment PCB Concentrations Protective of Biological Endpoints

A summary of the resulting SQOC to protect the various biological endpoints is given below. Details of the rationale and considerations made at arriving at the objective concentrations are discussed in the attached development document.

052275

Summary of Sediment Quality Objective Concentrations
To Protect Various Biological Endpoints

Biological Endpoint, Criteria, or Objectives to Be Met or Protected		Sediment Quality Objective Concentrations For PCBs to Protect Biological Endpoints (ug PCB/kg Sediment)
Water Quality Criteria		
Equilibrium Partitioning Model		
NR 105 Human Cancer Criterion		4 - 20
NR 105 Wild and Domestic Animal Criterion		22 - 123
Fish Tissue Residue Criteria/Objectives		
ARS Model	FDA	200 - 1,000
	IJC	10 - 50
	GLWQI	2 - 12
Thermodynamic	FDA	188 - 1,038
Equilibrium	IJC	4.5 - 26
Model	GLWQI	1 - 6
Bioconcentration	FDA	616 - 3,409
Model	IJC	15 - 82
	GLWQI	4 - 20
Food Chain	FDA	35 - 104
Multiplier Model	IJC	0.9 - 2.6
	GLWQI	0.2 - 0.6

Protection of Benthic Organisms

Equilibrium Partitioning Model

U.S. EPA Chronic Water Quality Criteria ____ 70 - 554

Regulatory Guidelines and Criteria

Ontario Sediment Quality Guidelines ____ 30 - 240

State of Washington Sediment Standards ____ 120 - 960

NOAA Effects Range-Low ____ 23 - 180

Literature

Chapman-Comparison of Four Approaches To Develop Sediment Quality Criteria.

Minimal or no Effect Level ____ 100

Reference Site Sediment PCB Concentrations

Range	14.1 - 90
Average	42.2

Reference Site Sediment PCB Concentrations in the Lower Fox River System

A number of the calculated methods and referenced criteria result in SQOC below what appear to be the concentrations of PCBs in surficial sediments at unimpacted reference sites along the lower Fox River. Other SQOC, especially those based on the lower TOC contents, are less than or equal to the maximum observed reference site concentrations of 90 ug PCB/kg sediment along the Lower Fox River. To provide protection to the maximum extent possible of all the biological end points, criteria, and objectives in all environmental compartments, and to protect ecosystem integrity, any remediation of PCB contaminated sediments should be driven by clean-up to background levels of PCBs. Background is defined as the maximum probable background concentration (MPBC) of PCBs found at unimpacted reference sites along the river. An adequate number of samples taken at appropriate reference sites are needed to statistically define a MPBC. Five available samples of reference sites to date have resulted in a maximum observed value of 90 ug PCB/kg sediment. This limited amount of information does not support complete characterization of background PCB levels.

Toxic PCB Congeners

Development of SQOC for 11 planar PCB congeners is also discussed in the following development document. SQOC development for the congeners is based on protecting the proposed ambient water quality criteria for the congeners presently established in the Great Lakes Water Quality Initiative. It appears PCB congener 77 (IUPAC numbering system) may be contributing the greatest amount of 2, 3, 7, 8-TCDD toxic equivalency of all the toxic congeners in Deposit A sediments based primarily on the concentration present. Congener 77 has a lower toxic equivalency factor to 2, 3, 7, 8-TCDD compared to congeners 105 or 126, but because of 77's larger concentrations in the sediments, it results in the largest contribution to the total toxic equivalency. More information is needed on the fate, partitioning, transport, and TCDD-toxic equivalency concentration of this group of 11 toxic congeners in the Deposit A sediments and other sediments along the Lower Fox River.

2.0 Introduction

The basic concepts and rationale used for the development of Sediment Quality Objectives Concentrations (SQOC) for PCBs are established in a Wisconsin Department of Natural Resources (WDNR) July 10, 1992 memo from Schuettpelz to Giesfeldt. A copy of the memo (hereafter the July 10 memo will be referenced as the Sheboygan Memo) was provided earlier to Blasland and Bouck Engineers, the contractor for the P.H. Glatfelter Company, based on the signed agreement between the Department and the company. The memo contained Water Resource Management's (WRM) listing of applicable criteria, guidelines, procedures, and policies as Applicable or Relevant and Appropriate Requirements (ARARs) and to be considered (TBC) criteria for use in establishing clean-up levels for surface water, sediment, and floodplain soils at the Sheboygan River Superfund site.

Using the basic tenets in the Sheboygan Memo and considering site specific factors associated with Deposit A in Little Lake Butte des Morts (LLBM), SQOC are established in this document. Site specific factors considered in SQOC development were the Total organic carbon (TOC) values associated with Deposit A sediments, the specific Aroclor make-up in the sediments, and any Lower Fox River studies involving assessments of PCBs in the sediments, water column, and biotic environmental compartments.

The protection of an array of biological objectives or endpoints using a number of tools or approaches is considered during development of SQOC for PCBs. Multiple approaches and objectives contribute to a weight-of-evidence approach to developing an appropriate SQOC to be protective of the most sensitive endpoint(s).

The objectives and approaches to develop SQOC to protect those objectives are discussed below. A narrow focus on only a singular objective such as lowering fish tissue residues of PCBs to below the Food and Drug Administration (FDA) criterion of 2 ppm for human consumption does not address all the hazards of PCBs in the river on a broader ecosystem basis. The SQOCs are established based solely on biological endpoint protection and scientific information. Remediation and cleanup of sediments should be designed to achieve the SQOC as closely as is practicable. Practicality in achieving SQOC is defined by considering the factors of net environmental effects, natural recovery rates, engineering feasibility, and costs when determining site cleanup standards.

Within the following discussion, the terms Sediment Quality Objective Concentrations, Sediment Quality Criteria, Sediment Quality Objective Values, and sediment safe levels are used interchangeably.

2.1 Identification of PCB Aroclor Make-Up of Deposit A

Based on the results of Task 2: Sediment Characterization/Mapping of Deposit A, Technical Memorandum (EWI Engineering, 1991), the PCB samples from Deposit A most closely resemble the congener distribution of Aroclor 1242. The minimum, maximum, and weighted average of PCB concentrations in the top 15 cm of the Deposit A sediments are 1.71 ug/g, 177 ug/g and 50.3 ug/g, respectively (EWI, 1991).

In the various partitioning models discussed in SQOC development, octanol-water (K_{ow}) and organic-carbon (K_{oc}) partitioning coefficients associated with Aroclor 1242 were used. Because the K_{oc} for Aroclor 1242 varied depending on the reference used and method of derivation, all SQOC calculations were made using minimum (26,300 L/Kg), maximum (1,949,844 L/Kg), and average (494,808 L/Kg) partitioning coefficient values.

The partitioning coefficient for an Aroclor is an average of the partitioning coefficients of the individual congeners making up the Aroclor. Because partitioning coefficients are derived based on manufactured Aroclors whose congener patterns change once the Aroclor is released to the environment (due to physicochemical and biological weathering and other factors), it is appropriate to consider the uncertainty in estimating partitioning coefficients in SQOC determinations by using a range of K_{oc} values. K_{ow} values which were used to derive K_{oc} values were derived from MacKay et al. (1983), Kadeg and Pavlov (1989), U.S. EPA (1989), U.S. EPA (1990), and Kenega and Goring (1978).

Where it was necessary to convert K_{ow} values to K_{oc}, the following regression equation was used (based on Di Toro, 1985):

$$K_{oc} = 0.00028+0.983*\text{Log}_{10} K_{ow}$$

This equation is used by U.S. EPA (Di Toro et al., 1992) in the development document for establishing sediment quality criteria for nonpolar organic compounds.

The predicted partitioning coefficients are based on a two phase partioning model (free or dissolved PCBs and PCBs sorbed to particulate organic carbon). A third phase, dissolved organic carbon (DOC), may play a role in bioavailability of PCBs in interstitial and overlying surface waters. Eadie et al. (1992) reported that the binding of hydrophobic organic chemicals to DOC in Green Bay water is small, and on average, the amount associated with this phase is less than 10%. Partitioning to this phase or relationship with bioavailability was not considered in this SQOC development document.

2.2 Toxicity Considerations Of Aroclor 1242

In the following SQOC development, Aroclor 1242 concentrations equate with total PCB concentrations contained in criteria or objectives to be protected. NR 105 does not distinguish any relative toxicities of the different Aroclors. Wisconsin's application of the FDA (2 ppm) tissue residue objectives for PCBs used in issuing fish advisories is based on total PCB concentrations in fish and also does not distinguish any relative toxicities of the Aroclors.

EPA classifies all PCBs as carcinogenic. They recognize that toxicities of Aroclors may vary, but they also indicate that there is only limited information on calculating separate cancer potency estimates for each PCB mixture. Their policy is to evaluate carcinogenic risk posed by PCBs as if they have the carcinogenic potency of Aroclor 1260. Also, there is commonality of some PCB congeners between different Aroclors and no data to definitively link specific congeners to animal tumorigenicity. Once released to the environment, the congeners of concern may be more persistent and bioavailable than other congeners in the

Aroclor mix. Given these uncertainties, the assumption of all environmental PCB mixtures having the carcinogenicity of Aroclor 1260 is appropriate.

The congener make-up of manufactured formulations of Aroclors changes once released to the environment due to physical, chemical, and biological processes. The relative concentration of congeners will vary among environmental compartments, between sediment depositional areas, and over time. Changes in congener make-up may mean changes in toxicity in the environment from that measured in manufactured formulations. For example, more recent studies have observed that there is greater toxicity to mink fed Great Lakes fish containing PCBs than was observed in earlier studies where mink were fed comparable levels of technical grade PCBs in their diet. In addition, there is evidence that much smaller concentrations of PCBs in the tissues of Great Lakes fish may be harmful to fish predators.

The activities of several commercial Aroclors as inducers of microsomal Aryl Hydrocarbon Hydroxylase (AHH) and the Ethoxyresorufin O-Deethylase (EROD) in mammalian cells was found to be dependent on the chlorine contents (and congener distribution) of the mixtures. The induction potencies of Aroclors 1242, 1248, 1254 were higher than 1221 and 1268. The enzyme activities corresponded to the number of active congeners in the tetra- to hexachlorobiphenyl homolog groups. Based on *in vitro* AHH and EROD induction assays, Aroclor 1242 is a more potent inducer than Aroclors 1254, 1260, or 1268 (Sawyer et al., 1984; Smith et al., 1990). Aroclor 1242 had a higher relative ability to induce EROD activity than any of the other Aroclors in the Smith et al. (1990) study.

In an examination of the toxicity of Aroclors 1242, 1248, 1254, and 1260 to rainbow trout, bluegill, and channel catfish, Mayer et al. (1977) found that Aroclor 1248 was the most toxic mixture closely followed by Aroclor 1242. Kannan et al. (1987) found that the content of congener 77 was highest in Aroclor 1248 and next highest in Aroclor 1242. The relative concentrations of congener 77 in Aroclors are consistent with the above fish toxicity reported for Aroclor mixtures (Kannan et al., 1987).

2.3 Total Organic Carbon (TOC) Content of Deposit A Sediments

In the various partitioning models used to develop SQOC, representative TOC values of the bedded sediments of Deposit A were utilized. Based on the EWI Engineering Technical Memorandum (1991), the organic carbon content of the top 15 cm (6 in) of Deposit A sediment ranges from 1.5%-11.7% and averages 8.27% (n=46). The organic carbon normalized PCB concentrations in the top 15 cm of Deposit a range from approximately 60-1600 ug PCB/g Organic Carbon (OC) and averages 650 ug PCB/g OC.

The top 15 cm was used because it is the most biologically active zone in the sediments. Organisms that burrow in or remain at the sediment surface have their greatest exposure to the PCBs associated with sediment particulate matter, pore water, or food items in this strata. Also, depending on sediment characteristics such as bulk density, bed porosity, and amount of disturbance, the top 15 cm of the 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.

053270

In calculating SQOC where TOC is a component of a partitioning model, the minimum, maximum, and average TOC values for the Deposit A sediments were used. Where applicable, SQOC values are expressed on a TOC normalized basis for PCBs (μg PCB/g of TOC). The SQOC are made site specific by consideration of the TOC values in the Deposit A sediments.

2.4 Reference Site Concentrations of PCB in Sediments

Some of the calculated PCB SQOC values protective of various endpoints are relatively low. Practicality dictates that the cleanup criteria of contaminated sediments can be established at levels no more stringent than identified representative watershed-related unimpacted reference site concentrations. The Sheboygan Memo reviews background concentrations for PCBs in sediments at various sites. On the Lower Fox River, the data from three sample sites is available for use in establishing reference site levels of total PCB in sediments. Two sediment samples were with taken a tube corer in the Menasha channel at the outlet of Lake Winnebago by WDNR in 1990. Two samples were taken with a Ponar dredge by WDNR in September, 1991. One sample was taken in 1988 from sediments in the East River as part of the study by Call, et al. (1991). The East River sampling location was used as reference site for sediment quality evaluations in the Lower Fox River in the study. The results of the sampling from the two sources for reference or background values for PCBs in surficial sediments are:

Sampling Sites	Total PCB Concentrations in Sediment ug/Kg (dry weight)	% TOC	OC Normalized ug PCB/g OC
East River	90	1.46	6.16
Menasha Channel			
47-1	33.8	7.48	0.45
47-2	14.1	9.64	0.15
47-1-A	44	7.2	0.61
47-1-B	29.1	6.7	0.43
Average	42.2		1.56

Further sampling at representative unimpacted reference sites associated with the lower Fox River system is needed to determine the variability of total PCBs and certain PCB congeners in surficial sediment samples. Sediments also need to be analyzed for TOC content to establish organic carbon normalized PCB concentrations at the reference sites.

3.0 Sediment Quality Objective Concentrations to Protect Various Biological Endpoints

3.1 Development of Sediment Quality Objective Concentrations to Protect Water Quality Criteria and Objectives

053269

Table 1 lists the NR 105 ambient water quality criteria protective of human health and wildlife that were used to drive SQOC development based on a simple partitioning model. The calculated SQOC values to protect human health and wildlife and the partitioning model used are shown in Tables 2 and 3, respectively.

The partitioning model described in the notes to the tables serves as the basis for U.S. EPA's development of proposed sediment quality criteria for nonpolar compounds (Di Toro, 1992). Assuming comparable sensitivity of water column and sediment dwelling organisms, U.S. EPA uses water quality criteria for fish and aquatic life to protect sensitive benthic organisms exposed to a contaminant in sediment pore water from chronic toxicity. The partitioning model calculates the amount of contaminant that can be associated with the organic carbon of sediments such that a concentration is not partitioned to the sediment pore water to a level that exceeds the chronic water quality criteria.

The application of the partitioning model in Tables 2 and 3 assumes an equilibrium is reached between PCBs associated with sedimentary organic carbon, sediment pore water, and the overlying water column. This also assumes that once PCBs are released from sediments and sediment pore water to the overlying water column, that residence time is relatively long and mixing and dilution are small. The reduction in concentration of dissolved PCBs from pore water to the overlying surface water is site-specific depending on flows, water circulation, water column residence time, and sediment turnover. Preliminary runs of the Green Bay Mass Balance Model Study show a reduction of dissolved PCB concentrations from the sediment pore water to the overlying surface water by up to two orders of magnitude (personal communication, Jeff Steuer) in the area of Deposit A. Inflow of uncontaminated Lake Winnebago water to the area of Deposit A, low water column velocity over and little resuspension of Deposit A sediments, may be reasons for the predicted pore water to surface water concentration reductions. In sediment deposits farther downstream that are in higher energy areas subject to greater amounts of sediment resuspension and where all upstream PCB releases are accumulating and being carried in the water column, the reduction of dissolved PCBs from the pore water to water column is predicted to be one order of magnitude based on the Green Bay Mass Balance Model.

A one order of magnitude reduction of dissolved PCB concentrations from pore water to surface water could potentially mean the SQOC calculated in Tables 2 and 3 could increase by one order of magnitude. For example, the SQOC calculated to be protective of NR 105 human health criteria (based on ave. TOC and KOC) could increase from 20 ug/kg to 200 ug/kg. However, because the partitioning model used to calculate the SQOC values in the tables only accounts for the dissolved fraction, it underestimates of the total PCBs released to the water column. Water column organisms can ingest particulate-sorbed PCBs. Also it has been shown that as suspended particle concentrations increase, PCBs in the dissolved phase increase (Di Toro, 1985).

The Green Bay Mass Balance Model estimates that 20-40% of the PCBs in the water column over Deposit A are associated with particulate matter. For sites downstream, particulate PCBs may contribute 70% of the total PCBs, except during winter. The PCB criteria in NR 105 are based on the total of dissolved and particulate associated PCBs in the water column, so consideration needs to be given to the particulate PCBs in determining SQOC

053268

appropriateness. Also, while the model used to calculate the SQOC values does not account for dilution, attenuation or degradation factors, it also does not account for factors such as bioturbation, advective pumping, gas convection, bed porosity, irregularity of sediment bed surfaces and near bed sediment particle concentrations that can contribute to total PCBs transported across the sediment-water interface. While equilibrium may not be attained in many environmental situations, it is the driving force for the movement of dissolved and vapor phase compounds between environmental compartments.

The low SQOC that are calculated by the model shown in Table 2 are also protective of benthic organisms. These levels reduce/minimize the exposure and accumulation of PCBs from sediment pore water, and ingestion of PCB sediment particles and food items. Benthic invertebrates and emerging insects are a potential biotic pathway for transferring sediment associated PCBs to upper food chain levels in aquatic and terrestrial ecosystems. Using the Table 2 SQOC values also minimizes exposure of bottom dwelling fish such as carp, small forage fish, and bullheads to PCBs released from sediments to the lower portion of the water column.

Table 1, box 4, contains the water quality criteria for PCBs proposed under the Great Lakes Water Quality Initiative (GLWQI) as part of the Great Lakes Critical Programs Act of 1990. The proposed criteria will be published in the Federal Register in the near future. If adopted, Wisconsin will have two years to revise NR 105 to incorporate the methodology for development of the criteria. The methodology would be used to revise the PCB criteria for Great Lakes communities as well as cold water and warm water stream classifications. Table 1, box 5, shows the proposed total PCBs criteria for a Warm Water Sports Fish Community stream classification applicable to the segment of the Fox River that contains Deposit A, using the proposed GLWQI methodology. The GLWQI wildlife criteria will apply to all stream classifications.

The proposed GLWQI methodology results in water quality criteria that are approximately two orders of magnitude lower than the PCB criteria presently in NR 105 for both human health and wildlife protection. This is due primarily to more current toxicity data, and more field and laboratory data that have led to a more accurate bioaccumulation factor for PCBs. Use of the proposed GLWQI Criteria would reduce the SQOC calculated in Tables 2 and 3 by two orders of magnitude.

Based on the above reasoning, the SQOC values in Tables 2 and 3 appear to be appropriately protective of human health and wildlife. The SQOC values for protection of water quality criteria should be no greater than the Table 2 and 3 values based on site-specific average TOC and Aroclor 1242 average K_{oc} values.

Table 4 shows a comparison of the water column concentrations of PCBs in LLBM and the Fox River at Appleton, with the ambient water quality criteria in NR 105 and proposed in the GLWQI. An exceedance factor has been calculated by dividing the water column concentration by the criteria. A total of the average dissolved PCBs and particulate associated PCBs in the Neenah channel (1.49 ng/L) was taken as ambient background concentrations in the river. The value was subtracted from the maximum and average values for PCB in water samples from Little Lake Butte des Morts and Appleton before calculation of the exceedance factors in Table 4. The resulting values represent baseline contributions of PCBs from these two sampling locations.

3.2 Development of Sediment Quality Objective Concentrations to Protect Fish Tissue Residue Criteria and Objectives

Table 5 provides three sources of fish tissue residue criteria or objectives developed for the protection of humans or wildlife that consume fish. From the FDA objective (2000 ug/kg), the levels decrease by two orders of magnitude with the lowest being PCB levels in fish needed to protect wildlife (23 ug/kg) based on the proposed GLWQI water quality criteria development document.

The FDA objective is based on a quantitative human health risk analysis and involves a judgmental cost-benefit analysis. Fish above this level cannot enter interstate commerce. The FDA objective of 2 ppm PCB in fish tissue applies to skin-on fillets. The 2 ppm objective in the development of SQOC uses the 2 ppm to apply to the PCB concentration in the whole body fresh weight of the fish. Generally the PCB concentration in the whole body fresh weight is greater than the concentration in the fillet. The ratio of whole body concentration to edible concentrations depends on the species and age of the fish. Applying the 2 ppm to whole body fresh weight of the fish may derive conservative SQOC concentrations to be protective of PCB concentrations in the edible fillet portions. The FDA number does not consider the impacts of PCBs at other ecosystem levels. While fish tissue PCB levels may be maintained at less than 2 ppm in fillets to protect humans, the potential for environmental impacts on the contaminated organisms or their non-human predators is not considered. Also, the 2 ppm total PCB tissue residue criterion does not take into account the presence and quantity of toxicologically significant PCB congeners.

There is a general feeling that the Food and Drug Administration (FDA) guidelines currently used by many of the Great Lakes states are not appropriate for regular consumers of sport caught fish. Advisory protocol also varies from state to state. These inconsistencies have led to confusion among the fish consuming public. The Council of Great Lakes Governors created the Fish Advisory Task Force to deal with the inconsistent advice being given to fish consumers. The goal of the Task Force, which is made up of a representative from each state's health and environmental agencies, is to create a consistent fish advisory protocol for all the great Lakes states. The Task Force has been pursuing a direction that would be more scientifically founded and appropriate for consumers of sport fish from the Great Lakes basin based on their eating habits. A new protocol for issuing consumption advisories is currently under review by each of the Great Lakes states.

The Task Force spent considerable time reviewing and discussing the selection of the adverse health endpoints to use as a reference for the advisory. Infant neuro-development was chosen as the most appropriate endpoint based on consideration of both human experience and controlled laboratory animal studies. In most cases, PCBs would be used as the surrogate contaminant for placing fish into consumption categories. Under the proposed protocol, fish advisories may be initiated at concentrations approximately two orders of magnitude lower (i.e. 0.05 ppm) than the current action level of 2.0 ppm. The advisory would be separated by site, species and sizes as is currently employed. Average PCB concentrations would be used to place the fish into five easily understood consumption frequencies. Since this advisory is based on reproductive/developmental effects, there would not be separate consumption advice given for women and children. It should be noted that this is still a proposal. Final state approval is currently being sought by the Task Force with the goal for implementation in 1994.

For fish there is little published data that relates sublethal effects to tissue residue concentrations of PCBs. The data base for establishing quantitative residue effects relationships is very limited. Eisler (1986) indicates that among sensitive species of fish, total PCB residues (in ug/kg fresh weight) in excess of 500 in diets, 400 in whole body, and 300 in eggs were demonstrated to be harmful, and should be considered presumptive evidence of significant PCB contamination. Gibson et al. (1984) reviewed the published papers reporting the sublethal effects of chlorinated contaminants on marine and esturaine animals. Based on their review, the general guidance they formulated for whole body tissue residue levels of concern associated with potential adverse sublethal effects to fish from chlorinated organic contaminants were:

Level of Concern	Tissue Concentrations (wet wt.)
Low	< 100 ug/kg
Medium	100 - 1,000 ug/kg
High	> 1,000 ug/kg

The IJC fish tissue residue objective for PCBs of 100 ug/kg is based on the protection of birds and animals that consume fish. Maack (1988) notes that the mink study used to derive the 100 ug/kg value is dated (1973) and more recent studies have observed that the toxicity from Great Lakes fish fed to mink was greater than observed in earlier studies with mink fed comparable levels of technical grade PCBs. Gagnon et al. (1990) note there is evidence that PCB concentrations less than 100 ug/kg in fish may be harmful to fish predators. Gagnon et al. suggest a revision of the IJC objectives based on congener mixtures actually found in nature, new knowledge about toxicity of individual congeners, and their biomagnification in the food chain.

Females of some species of fish transfer as much as 30% of their PCB body burdens to the developing eggs which puts developing fish larvae at risk. (Sijm et al., 1992; Miller, in press). Rainbow trout containing 400 ug PCB/kg fresh wt. produced eggs with low hatchability and numerous fry deformities (U.S. EPA, 1980).

Fish in the Lower Fox River are continuously exposed to PCBs along the reaches of the entire river which has multiple PCB contaminated sediment deposits and PCB releases from the deposits along the river reaches. The fish generally do not have the ability to spend time in clean reaches. In trying to relate sediment concentrations of PCBs in Deposit A to fish tissue levels, no attempt was made to derive an area use factor or estimation of how much time the fish are in the area of Deposit A relative to their home range. Based on the water quality data in Table 4, fish off-site could be exposed to elevated concentrations of PCB in the water column downstream because all deposit releases are accumulating in the water column. An assumption is made that fish are capable of receiving PCB exposures from the sediment, food sources, or water in all reaches of the river making up their home range. Because of fish mobility, their exposure is integrated over the entire area making up their home range. Based on this, attempts to distinguish site-by-site contributions to exposure in the partitioning model application were not attempted.

Table 6 presents the mean and range of percent lipid content of various fish species sampled by the WDNR in Little Lake Butte des Morts. Generally, fish lipid values of 4% and 8% were used in establishing SQOC to protect fish tissue residue objectives using various partitioning models. The 4% value is associated with sport fish consumed by humans and the 8% value is associated with the higher lipid values in site fish that are consumed by wildlife.

3.2.1 Use of Data From Studies On the Lower Fox River

Fish tissue analysis for PCBs was performed by Call et al. (1991) by analyzing fathead minnows exposed to collected river sediment in a 30-day laboratory bioaccumulation study and field-collected black bullheads. Ten sediment samples were collected in the lower Fox River below the De Pere dam and two in Green Bay. One site was sampled in the East River as a reference site. Black bullheads were collected in the vicinity of seven of the sediment sampling sites. Laboratory bioaccumulation tests were run on sediments collected from all 13 sites. Table 11 shows the PCB and TOC concentrations in the sediment at the sampling sites in the Call et al. (1991) study. Both PCB and TOC concentrations are on the lower end of the range of what are found in the Deposit A sediments. The PCB mixture present in the Call study sediment samples was comprised mainly of the tri- and tetrachlorohomolog groups, and resembled the Aroclor 1242 and 1248 commercial mixtures. The presence of Aroclor 1242 in these lower river sediments has a commonality with the Aroclor 1242 in Deposit A sediments. The East River sediment reference site has more of the penta-, hexa-, and heptachloro-isomers, which is similar to the patterns exhibited in commercial mixtures of Aroclor 1254 and 1260.

In regard to the PCB chloro-isomer content in the field collected black bullhead and laboratory exposed fathead minnow, Call et al. (1991) found the following:

1. While the sediment was predominated by trichlorobiphenyls, the bullhead tissues contained tetrachlorobiphenyls in the greatest amount.

2. Tetra-, penta-, and hexachlorobiphenyl are selectively accumulated in bullhead tissue relative to their concentration in the sediment. [Note: This is also supported by Walleye data collected during the Green Bay Mass Balance Study.]

3. It is noteworthy that the tetra-, penta-, and hexachlo homolog groups were accumulated in tissue, especially the penta- series (which contains congeners 105 and 126). PCB congeners in these homolog groups have been linked to reproductive impairment in fish eating birds in Green Bay (Kubiak et al., 1989).

4. The black bullheads contained total concentrations of the highly toxic tetra- and pentachlorobiphenyl congeners (IUPAC numbers 77, 84, 105, 114 and 118) ranging from 25 to 110 ug/Kg (considering an equal distribution between co-eluting

compounds). Only trace amounts (0.61 to 1.90 ug/Kg) of #156 were found in the tissue (assuming even distribution of co-eluting compounds).

5. As with black bullheads, tetrachloro homologs predominated in fathead minnow tissue from the laboratory bioaccumulation study. Pentachloro homologs comprised the second largest percentage of total PCB in minnow tissue comparable to the black bullheads.

6. The PCB residues in fish and invertebrates are of definite concern regarding their likely roles in causing mortalities and reduced reproductive success in sensitive avian and mammalian consumers.

3.2.2 Application of Partitioning Models to Develop Sediment Quality Objective Concentrations for Fish Tissue Residue Level Protection

Relating fish tissue PCB residue concentrations to concentrations in sediment can be done based on two general types of sediment bioaccumulation models: equilibrium-based and kinetic approaches. The approaches and models under each are:

Equilibrium-Based

1. Site-specific measurements of sediment-fish partition coefficients or bioaccumulation factors

2. Thermodynamic partitioning model based on sediment organic carbon and fish lipid normalized values

3. Sediment-water-fish tissue partitioning model.

Kinetic Based

1. Bioenergetically based toxicokinetic models

2. Kinetic process models

The equilibrium-based approaches assume steady-state conditions between the organisms and the environment. The kinetic approaches describe bioaccumulation as the net effect of rate processes (Lee, 1992).

The first three listed models are a simplified expression of contaminant distribution between environmental compartments in aquatic systems. To address the true complexity and multitude of environmental factors bearing on compartmental distributional relationships of contaminants and food chain transfers, sophisticated models requiring large amounts of measured input data would be needed (MacKay et al., 1983). Information is limited to demonstrate that kinetic models are better predictors than equilibrium models. There are few data to evaluate the accuracy of kinetic models with sediment contaminants (Landrum et al., 1992).

053263

Partitioning constants have not been developed to a great extent and they must evolve from in-field or laboratory bioaccumulation studies. The Call et al. (1991) study discussed above looked at bioaccumulation of PCBs in fish when exposed to sediments in the Lower Fox River below the De Pere Dam. Ankley et al. (1992) expanded on data collected in the Call et al. study in regard to bioaccumulation of PCBs.

3.2.3 Accumulation in Fish Relative to Sediments (ARS Factor)

Table 7 shows the sediment and tissue PCB concentrations from the Call et al. (1991) study as a result of the 30-day bioaccumulation test using fathead minnows. The tissue concentrations in Table 7 are expressed on a dry-weight basis. The concentrations have been converted from a wet-weight basis reported by Call et al. to a dry weight basis assuming a dry-weight to wet-weight ratio of 0.2, or that the fish are 80 percent water. The 80 percent value is based on Seelye et al. (1982) who used juvenile yellow perch in a bioaccumulation study and Oliver and Niimi (1988), who studied PCB uptake by field-collected sculpins in Lake Michigan. Other species and older fish may have lower percent water content in tissue. Conversion to a dry-weight basis in tissues allows a comparison with available literature bioaccumulation studies. The simplest bioaccumulation model is the ratio between PCB concentrations in fish tissue and sediment. An accumulation in fish tissue relative to sediment (ARS) for PCBs was calculated in Table 7 for the bioaccumulation results at each sample site in the Call study based on the formula given at the bottom of the table. The ARS factors range from 0.53 to 4.03 and have an average of 1.35. On average, PCBs in fish tissue are 1.35 times as concentrated as PCBs in sediment on a dry-weight basis. It should be noted that site 3, with the lowest sediment PCB concentration (306.15 μg/kg), had the maximum ARS factor. The high ARS factor at a low PCB sediment concentration may be an indication that the degree of sediment contamination is less a determinant of actual bioaccumulation than are the physical, chemical, and biological processes affecting bioavailablity at particular sites and sediment deposits along the river.

Table 8 shows the same calculations on the black bullheads collected in the field near the sediment sampling stations. Since the bullheads are mobile they did not spend all of their daily or seasonal use periods in the immediate vicinity of the sampling stations, although black bullheads range less than other fish species (Ankley et al., 1992). It is noted that the maximum ARS factor (17.26) for the black bullheads was at site 3, the same site that had the maximum ARS factor for the laboratory exposed minnows. The average ARS factor for the field collected fish was 4.43, greater than the average laboratory ARS factor of 1.35. Ankley et al. (1992) note that use of fathead minnow in laboratory sediment tests may result in significant underprediction of the exposure of indigenous fishes to bioaccumulable contaminants.

Wilford et al. (1987) and others note that 10 or 30-day laboratory exposures of fish to sediment may not enable measurement of final steady state concentrations in organisms. For some chlorinated hydrocarbons, 10-day exposures are believed to reach 30-50 percent of steady state conditions. Months may be required to reach a steady state condition under a laboratory situation. Based on water exposures only, lower chlorinated congeners may reach only 50-80% of their steady state concentrations in fish after 96 days (Oliver et al., 1985).

053262

Higher chlorinated congeners may reach less than 10% of their steady state concentrations in this same time period.

In comparing caged fathead minnows to resident fatheads in a confined disposal facility to assess PCB bioaccumulation, Rathbun et al. (1988) (as cited in Mac et al., 1992) found that in an 8-day exposure:

a) low K_{ow} di- and trichlorobiphenyls in tissues had reached nearly 100% of concentrations in resident fish.

b) the percentage of uptake has decreased to 50% for the tetrachlorobiphenyls and 30% for pentachlorobiphenyls.

c) concentrations of all biphenyls with 6 or more chlorines were less than 20% of those in resident fish.

Constant laboratory test system temperatures compared to variable ambient field temperatures also need to be considered in evaluating PCB uptake by fish. Spigarelli et al. (1983) exposed brown trout to a food source containing a constant set level of PCBs and Lake Michigan water at varying temperature regimes. While sediment was not available as a source of PCBs in the Spigarelli study, the implications of temperature influence on PCB uptake is important. Spigarelli et al. estimated that PCB uptake under constant conditions in the laboratory could be lower by a factor of 2-4 than those actually experienced by fish in nature, solely due to the effect of temperature fluctuations. Differences in uptake by laboratory exposed and field-collected fish may also be due to lack of exposure via contaminated food in the laboratory fish (Ankley et al., 1992). Relative uptake of PCB by laboratory fish is from the water and ingestion of contaminated sediment. Bioavailability to fish in laboratory tests is enhanced by suspension of contaminated sediments (McFarland et al. 1985). In field exposures, fish in cages placed on sediment accumulated more PCBs in tissue than those held in cages suspended in the water column above the sediment (Mac et al., 1985).

Table 9 summarizes the results of some bioaccumulation studies conducted in the laboratory and in the field. The Mac et al. (1985) results under B. in Table 9 are based on exposures to sediments from Green Bay. Exposure of caged fish placed on the sediments yielded a maximum ARS factor of 6.2 in the Mac et al. study.

Other studies that report distribution ratios comparably derived as the above ARS factors are:

1. Beak consultants (1987) reviewed a number of studies and used 25 as a typical ARS factor.

2. Evans et al. (1987) in a study that looked at biomagnification of PCBs in a Lake Michigan offshore food web found a biomagnification or ARS factor from sediment to sculpin of approximately 50.

0SC261

3. Smith et al. (1985) analyzed carp and duck from sections of the Detroit River that had PCB sediment concentrations on the order of 630 μg/kg (wet wt.). The median distribution coefficients or carp/sediment and duck/sediment chlorohomolog ratios were as follows:

Chlorohomolog Group	Carp/Sediment ARS Value	Ducks/Sediment ARS Value
Trichloro-	11	6
Tetrachloro-	18	5
Pentachloro-	26	8
Hexachloro-	37	27
Octachloro-	47	43

Body burdens of PCBs in ducks ranged from 2.7 to 20 mg/kg in the carcass and from 38 to 89 mg/kg in the lipid fraction.

Table 10 illustrates sediment safe levels of PCBs to protect each of the three fish tissue residue objectives with varying assumptions of ARS values and fish moisture content. The left hand column provides a range of ARS factors from which a value or a range of values must be selected for application to the site. The ARS values which are calculated on a dry-weight basis, must be corrected for whole body wet weight of the fish because the objectives for the fish tissue residue for PCB are on a wet-weight basis. The body of the table has a range of sediment quality objectives expressed in μg PCB/kg sediment on a dry-weight basis. Based on the review of the site-specific and literature ARS factors above, an ARS factor range of 10-20 would appear appropriate for the Deposit A site in the Lower Fox River. This would yield the following range of SQOC for PCBs to be protective of the three objectives:

Fish Tissue Objective	SQOC Range ugPCB/kg Sediment
FDA	200 - 1000
IJC	10 - 50
GLWQI	2 - 12

Some field validation of the 200-1000 μg/kg SQOC to protect the FDA objective of 2 ppm from other sites is provided by the State of Indiana's observation that fish generally do not exceed the FDA objective where PCB sediment levels are 500 μg/kg or less (IJC, 1988). Also, the Ontario Ministry of the Environment reported that total PCB concentrations in the St. Clair River sediments between 1976 and 1978 averaged 490 μg/kg and that average concentrations in fish from the river were at or near the US FDA action level. In the time frame given, the FDA number was 5 ppm for PCBs in fish tissue. If 490 μg/kg of PCB in sediments was resulting in fish tissue levels at or near 5 ppm, it would follow that the lower level of 200 μgPCB/kg sediment may be needed to be protective of a 2 ppm level.

053260

3.2.4 Application of an Equilibrium Partition Model for Predicting Bioaccumulation of PCBs in Fish Tissue.

Sediment organic carbon (as measured by TOC) is the primary storage compartment for neutral organic chemicals in sediment and is the primary environmental factor influencing partitioning and bioavailability. Organic carbon behaves as though it were an organic solvent in competition with the lipid of organisms for containment of any nonpolar organic chemicals, such as PCBs, that are present. For a given concentration of chemical in sediment, low TOC favors increased bioaccumulation and high TOC favors the reverse (Clarke et al., 1991).

Normalizing PCB concentrations to sediment organic carbon content and lipid content of fish allows calculation of a preference factor of PCBs for lipids over organic carbon. Through normalization, an estimate of the amount of chemical in sediment that is actually available to organisms can be made. Normalizing reduces site-to-site variability of PCB exposures and allows inter-species bioaccumulation comparisons. Preference factors are calculated by determining the ratio of lipid normalized concentration in fish or other aquatic organisms to the organic carbon normalized PCBs concentrations in sediment.

The Equilibrium Partitioning model is a simple, fugacity-based model which has been shown to be useful for predicting the bioaccumulation potential of hydrophobic nonpolar organic compounds in sediments (Ferraro et al., 1991). The model assumes chemical equilibrium or steady state between PCBs in organic carbon and lipids. The basic partitioning model used to estimate sediment safe levels for PCBs to protect a fish tissue residue objective is:

$$SQOC = \frac{(TRC)\ (foc)}{(FSAF)\ (fl)}$$

Where:

TRC = fish tissue residue objectives for PCBs (FDA, IJC, or GLWQI) expressed as µg/kg in whole body wet-weight

foc = Total organic carbon in sediment expressed as a decimal weight fraction

SQOC = Sediment Quality Objective Concentration to protect fish tissue residue objective, expressed as µg PCB/kg sediment (dry weight).

fL = fish lipid expressed as decimal weight fraction of whole body wet-weight

FSAF = Fish-Sediment Accumulation Factor expresses the preference of PCBs for fish lipids over sediment organic carbon. Ratio of lipid normalized PCB concentration to organic carbon normalized concentrations. Based on site specific data if available.

053259

The equilibrium partitioning model for predicting bioaccumulation of nonpolar organic compounds is thought to be the most applicable for predicting the first level transfer of nonpolar organics from sediments to infaunal organisms. Various studies have found preference factors for nonpolar organic chemicals (which include PCBs) of from 1 to 4 with the value generally being less than 2 (US EPA, 1990; Clarke et al., 1991; and Lake et al., 1990). Thus, multiplying the organic carbon normalized PCB concentration in sediment by 2 predicts the lipid-normalized PCB tissue concentrations.

Some studies suggest that the simple equilibrium partitioning approach may be applicable to contaminant bioaccumulation in fish (Lake et al., 1990). Preference factors of nonpolar organic chemicals in fish have been found to range from 1.5 (Karickhoff et al., 1979) to 4 (McKay, 1982). Clarke, McFarland, and Dorkin (1988); as referenced in Clarke et al. (1991), found preference factors ranging from 1.48 to 4.45 (mean 2.98) for crayfish and eight species of fish collected inside a confined disposal facility. No differences were found in PCB concentrations of crayfish and fish after long term infield exposures.

Bierman (1990) reviewed the equilibrium partitioning theory (EPT) and biomagnification of organic chemicals in benthic animals based on field studies. The EPT is based on the assumption that:

1. The operative distribution volumes for the chemical are sediment organic carbon, animal lipid, and the aqueous phase in the interstitial water,

2. The system is in a state of equilibrium,

3. There are no steric hindrances to the uptake of the chemical, and

4. There are no significant degrees of degradation or metabolism of the chemical.

The assumptions do not preclude uptake from both food and water, provided that the food consists only of contaminated sediment particles that are in equilibrium with the associated aqueous-phase chemical concentration. Bierman concludes that the body burdens of organic chemicals in smaller, younger, forage fish was not significantly different from those in benthic macroinvertebrates. The levels were expected based on the EPT mechanism. He notes, however, that this does not prove that the EPT is the sole mechanism determining body burdens of organic chemicals in forage fish. He found that body burdens of organic chemicals in carp were significantly higher than expected on the basis of EPT, indicating biomagnification was occurring. If biomagnification of PCBs occurs in fish, then simple equilibrium partitioning may underestimate the accumulations by higher trophic level predator fish. The equilibrium partitioning model assumes sediment is the only source of PCBs to the organisms and does not take food chain uptake into account nor does it adjust for organism growth (Clarke et al. 1991).

Clarke et al. (1991) state that a review of recent literature assigns a greater role to contaminated food as a major pathway for bioaccumulation of contaminants, particularly in pelagic fishes. Dietary bioaccumulation is favored when the food an organism consumes is highly contaminated relative to the water it respires. Also, the relative importance of the various environmental compartments as PCB sources for uptake can change over the life cycle of the organism when the organism occupies different trophic levels or habitats during different stages of development.

In a review of PCB contamination in fishes from Wisconsin waters of Lake Michigan, Clarke et al. (1992) found that highest mean PCB concentrations occurred in some top predators and some bottom-feeding species, suggesting that food chain biomagnification and partitioning from contaminated sediments may both be important mechanisms for PCB bioaccumulation in Lake Michigan fishes. For pelagic species studied, the food chain is very important. Carp, on the other hand "skip" a portion of the food chain by their direct contact with sediment. They also tend to have higher concentrations than any of the other top-level piscivorous species indicating that, while the food chain is definitely very important, direct uptake of sediments, ingestion, and absorption in the gut may be even more important. For some forage fish species, interspecific differences in PCB body burdens are related to the habitat occupied (surface feeder or benthivore) and ecological processes associated with that habitat which regulate the bioavailability and uptake of PCBs (Hebert et al., 1991). Interspecific differences were associated with compounds with high Log K_{ow} values, becoming more pronounced with Log $K_{ow} > 6.0$. Benthivore forage fish species had higher accumulation factors than surface-feeding species (Herbert et al., 1991).

Preference factors or Fish-Sediment Accumulation Factors (FSAF), were calculated for the laboratory exposed fathead minnows and field-collected black bullheads based on Call et al. (1991) and Ankley et al. (1992). (Tables 11 and 12, respectively). The FSAF factors are based on a ratio of lipid normalized PCB concentrations over organic carbon normalized sediment concentrations. The average FSAF values for the laboratory exposed fathead minnows was 0.30 with a range of 0.17 to 0.59. The average FSAF values for the black bullheads was 1.91 with a range of 0.74-4.77. Total PCB concentration per unit lipid in the black bullheads was on average six times greater than the laboratory exposed fathead minnows. Differences in the laboratory versus field bioaccumulation results may be due to the factors discussed earlier. This study suggests that laboratory results may underestimate the actual uptake of PCBs under field conditions.

Table 13 shows, within the body of the table, SQOC expressed as μg PCB/kg sediment (dry-weight basis) to protect the three fish tissue residue objectives with consideration given to combinations of variables at a specific site (i.e. TOC, percent lipid of fish, and of site specific FSAF value). Given the above discussions and site-specific data, FSAF values appropriate to the Deposit A site range from 2 to 4. A FSAF of 4 was used to calculate SQOC for Deposit A. Using assumed lipid concentrations of 4% for fish related to the FDA criterion and 8% for fish related to the IJC and GLWQI, the following SQO values apply to a range of TOCs from 1.5% to 8.3%:

052257

Fish Tissue Objective	SQOC Range (μgPCB/kg Sediment		
	% Lipid	TOC 1.5%	TOC 8.3%
FDA	4	188	1038
IJC	8	4.5	26
GLWQI	8	1	6

The higher lipid values are appropriate to the IJC and GLWQI criteria because they are based on wildlife consumption of whole fish of all species. Humans would be consuming sportfish of lower lipid content. However, some humans may consume fish species of higher lipid content such as carp. Consideration of this higher lipid content in relation to the FDA value would lower the SQOC values calculated above.

3.2.5 Consideration of Bioconcentration Factors in an Equilibrium Partitioning Model to Develop SQOC to Protect Fish Tissue Residue Criteria.

Van Der Kooij et al. (1991) summarized an approach recently proposed in the Netherlands to use the equilibrium partitioning approach method to derive a set of quality criteria for aquatic systems including criteria for organic compounds in sediment based on product standards (organism residue criteria). The basic equation for deriving sediment criteria from tissue residue criterion is:

$$SQOC = \left(\frac{TRC}{BCF}\right)(f_{oc})(K_{oc})$$

Where:

SQOC = Sediment Quality Objective Concentration in μg PCB/kg sediment (dry-weight) needed to protect the fish tissue residue criterion

TRC = fish tissue residue criterion for PCBs (FDA, IJC, and GLWQI) expressed as μg/kg in whole body wet weight.

f_{oc} = total organic carbon in sediments expressed as a decimal weight fraction.

K_{oc} = organic carbon partitioning coefficient for Aroclor 1242

K_{oc} Range-26,300-1,949,844 L/kg

K_{oc} Average-494,808 L/kg

BCF = the bioconcentration factor for Aroclor 1242. BCF is derived from K_{ow} values using the regression equation in the NR 105 development document. The equation is:

$$\text{Log}_{10}\,\text{BCF} = 0.79\,\text{Log}_{10}\,K_{ow} - 0.40.$$

The BCF regression equation predicts the BCF for tissue with 7.6 percent lipid content (U.S. EPA, 1991). To normalize the BCF to 1 percent lipid, the BCF calculated in the above formula is divided by 7.6. The maximum K_{ow} for Aroclor 1242, based on the literature values discussed above, was used in the formula to derive a BCF value. The maximum K_{ow} of 2,511,886 L/kg yields a BCF of 45,290. On a lipid normalized basis, the BCF is 5,959 L/Kg/1 percent lipid. In the above model to calculate SQOC values, BCFs associated with 1 percent (5959 L/kg), 4 percent (23,826 L/kg), and 8 percent (47,672 L/kg) lipids were used.

Tables 14, 15, and 16 show the SQOC expressed as μg PCB/kg sediment, based on various combinations of variables at the site (TOC, fish lipids, and K_{oc}), to be protective of the FDA, IJC, and GLWQI objectives, respectively. Utilizing the minimum and average TOC content of sediment, average K_{oc}, and lipid contents of 4 and 8 percent, the SQOC recommended to be protective of the residue objectives are as follows:

Fish Tissue Objective	SQOC Range (μgPCB/kg Sediment		
	% Lipid	TOC 1.5%	TOC 8.3%
FDA	4	616	3409
IJC	8	15	82
GLWQI	8	4	20

The above laboratory derived BCFs are a conservative estimate of the PCB tissue residues likely to occur in the environment. PCB tissue residues may arise both from bioconcentration of PCBs from the water through the gills and other membranes and from ingestion and absorption of contaminated food sources. An attempt was made to calculate a site specific BCF based on a caged fish study conducted by WDNR during August, 1992. The preliminary study results are discussed in the last section of this development document. Fathead minnows were exposed for 10 days in cages placed on sediments at the Menasha Channel reference site, at Deposit A, and downstream one-half mile below the Highway 441 bridge.

Since no concurrent water column sampling was done during the period of cage placement, water column data collected for the Green Bay Mass Balance study were used. A location at Appleton sampled during Aguust of 1989 was the nearest site to Deposit A (approximately 5.5 miles downstream of Deposit A). Some water column samples were taken at the Chicago and Northwestern Railroad bridge which is one-mile downstream of Deposit A. However, the samples were not taken in August to match the seasonal period of cage placement. When the sampling events at the Appleton site and the railroad bridge were simultaneous, the results indicated comparable water column concentrations of PCBs. This may indicate the water column concentration of PCBs at the Appleton site are reflective of upstream concentrations as far as Deposit A during all months of the year. The average dissolved concentration of PCBs at Appleton during August was 16.6 ng/L. Utilizing this value and the results of the caged fish studies, whole body and normalized to 1% Lipid BCF values were calculated as follows:

	Menasha Channel Reference Site	Deposit A	Downstream Site Hwy 441 Bridge
Sediment Concentrations of PCB	0.030 ug/g (Ave. of four samples from Menasha Channel)	Ave. 50.3 ug/g	Ave. 1.6 ug/g
Water Column Dissolved PCB Concentration (ng/L) @ Appleton	2.25 ng/L	16.6 ng/L	16.6 ng/L
Ave. Whole Body PCB Concentration Wet Weight	No detects for any of the 74 congeners analyzed	9462 ug/kg (Ave. of 3 replicates)	216.63 ug/kg (Ave. of 3 replicates)
Whole Body Bioconcentration Factor	—	570,000 L/kg	13,050 L/kg
Ave. Lipid Content	2.3%	2.8%	2.4%
BCF Normalized to 1% Lipid	—	203,571 L/kg	5438 L/kg
Assume tissue levels are only 50% of a steady state concentration. Concentration at steady state	—	18,924 ug/kg	433.26 ug/kg
BCF Normalized To 1% Lipid at "steady state"	—	407,143 L/kg	9,321 L/kg

The BCF value normalized to 1% lipids at the downstream site (5438) is comparable to the value (5959) derived from the BCF regression equation. However, the BCF normalized value calculated for the Deposit A exposed caged fish is approximately 37 times the downstream BCF value. Some considerations of this BCF value are:

1. The caged fish at Deposit A are exposed to dissolved PCBs in the water column and also to contaminated sediments and particulate matter that enter the cage perforations because the cages were set on the sediment surface. The minnows may ingest these particles and PCBs are absorbed from the gut contents. Because the contaminated sediments represent another route of uptake, the lipid normalized BCF value of 203,571 calculated above is more of a bioaccumulation factor than a BCF which is based only on exposures to dissolved PCBs in the water column. At the downstream caged fish site, the sediment PCB concentration are considerably less than in Deposit A sediments. The sediment sampling site nearest to the Hwy. 441 caged fish site had an average of 1.6 ug/g of PCBs in the sediments versus an average of approximately 50 ug/g in Deposit A sediments. Any sediment particles ingested by fish at the Hwy. 441 site have considerably less PCBs associated with them. The fish were

053254

continuously exposed to an average of 16.6 ng/L of dissolved PCBs in the water column.

2. The 10 day caged fish exposure duration did not allow fish tissue concentrations to reach a steady state condition. Assuming only 50% of steady state concentrations have been achieved, the potential "BCFs" normalized to 1% Lipid for Deposit A and the Hwy. 441 site are 407,143 and 9,321 respectively, utilizing fish tissue levels at two times those measured.

3. The actual water column concentrations of PCBs above the Deposit A sediments at the location of the caged fish placement may be greater than the concentration found downstream at Appleton. A higher water column concentration in the vicinity of the cages would lower the site-specific "BCF" values calculated above.

4. Substituting the site specific "BCF" value (203,571 @ 1% Lipid) from the caged fish study, for the BCF value derived from the K_{ow} value (5959 L/kg @ 1% Lipid), would yield much lower SQOC values to be protective of FDA, IJC, and GLWQI fish tissue objectives.

3.2.6 Consideration of Bioaccumulation Factors in an Equilibrium Partitioning Model to Develop SQOC to Protect Fish Tissue Residue Criteria

For chemicals with Log K_{ow} values below 5.0, Bioaccumulation Factors (BAFs) and BCFs are equal regardless of the ecosystem structure. For these chemicals, the bioconcentration process from water is more important than the bioaccumulation process from food (U.S. EPA, 1991). For chemicals with Log K_{ow} values ranging from 5.0 to 7.0, bioaccumulation from food becomes more important with increasing log K_{ow} value and complexity of the food chain (Thomann, 1989). The Log K_{ow} values for Aroclor 1242 used in the partitioning models in this SQOC development discussion include lower and upper values of 4.5 to 6.4 and an average value of 5.8.

To attempt to address both bioconcentration of PCBs from water to fish and uptake from food, especially for higher level predator fish, a food chain multiplier (FCM) can be applied to the BCF (U.S. EPA, 1991). The bioaccumulation and bioconcentration factors for a chemical are related as follows in approximating a BAF value:

$$BAF = BCF * FCM$$

Using U.S. EPA's (1991) guidance, the FCMs for trophic levels 3 and 4 based on an average Log K_{ow} value of 5.8 are 12.7 and 33.3 respectively. The FCMs for a maximum Log K_{ow} value of 6.4 are 39.3 and 98.4, respectively. The FCM factor is placed in the SQOC formula such that:

053253

$$SQOC=\left(\frac{TRC}{BCF*FCM}\right)(f_{oc})(K_{oc})$$

Trophic level 4 of the food chain generally consists of predator fish used for sportfishing. Trophic level 3 are generally small forage fish. Based on considerations of the maximum and average Log K_{ow} values, BCFs associated with different lipid contents, and different trophic levels, the BAFs used are as follows:

		Bioaccumulation Factors			
	Trophic Level	3		4	
	Lipid Content	4%	8%	4%	8%
Log K_{ow} Aroclor 1242	5.8 Average	302,590	605,434	793,406	1,587,478
	6.4 Maximum	936,362	1,873,510	2,344,478	4,690,925
	Total PCBs GLWQI 6.21167	490,754	981,508	1,421,488	2,842,976

Also placed on the above table are the BAF values from the GLWQI Methodology for Development of Bioaccumulation Factors. The GLWQI BAF is based on field and laboratory data that has led to a more accurate estimation of the bioaccumulation factor for PCBs. The normalized BAF for total PCBs is 355,372 in the GLWQI. The BAF values calculated from the maximum and average Log K_{ow} for Aroclor 1242 bracket the GLWQI BAFs based on a "typical normalized BAF" for total PCBs.

In considering a lipid of 4% and 8% as appropriate, an average f_{oc} of 8.3%, an average K_{oc} of 494,808 and using the BAF values calculated above, the following are the SQOC related to protecting the three fish tissue residue objectives;

Fish Tissue Objective		SQOC (μg PCB/kg Sediment)			
		Maximum Kow		Average Kow	
		Trophic Level		Trophic Level	
	Lipid	4	3	4	3
FDA	4%	35	88	104	274
IJC	8%	0.9	2.2	2.6	7
GLWQI	8%	0.2	0.5	0.6	1.6

Using the above model, SQOC on the lower end of the above ranges would be needed to protect the trophic level 4 organisms consumed by humans. Wildlife would be consuming both trophic level 3 and 4 fish.

053252

4.0 Development of Sediment Quality Objectives to Protect Aquatic Organisms Associated with Deposited Sediments

Organisms associated with the benthic community spend all or part of their life cycles burrowing in or associated with the sediment surface. Epibenthic organisms, such as Daphnia, spend time in the water column and also settle on the sediment surface where they spend a significant amount of time filter feeding and ingesting particulate-bound PCBs. Some of the most sensitive stages of aquatic organisms, developing eggs and larvae, become exposed to PCBs through sediment contact.

Routes of exposure and uptake of PCBs to benthic organisms include respiration and epithelial contact, and ingestion of sediment pore water, sediment particulates, detritus and food items. Because benthic invertebrates are relatively non-mobile they are subject to long term, chronic exposure to PCBs associated with sediment phases.

As reviewed by Clarke et al. (1989) in regard to PCB toxicity to aquatic biota:

1. Ecotoxic effects of sediment PCB contamination appear most likely to be sublethal and chronic.

2. The effects would be manifested at the population level in aquatic biota.

3. Physiological functions that are controlled by steroid hormones may be altered by the exposure of organisms to PCBs.

4. Growth, molting, and reproduction are primary functions that have been shown to be affected by the exposures of aquatic organisms to PCBs.

5. The ability of organisms to eliminate foreign organic compounds or endogenous waste products may also be affected.

6. Steroid biosynthesis and degradation and transformation of xenobitic compounds are metabolic activities that are strongly influenced by oxidase activities of the microsomal cytochrome P-450 systems (also referred to as mixed function oxygenase [MFO] systems). These activities occur in fish and invertebrates as well. The total and specific MFO activity is lower and more variable in fish compared to mammals. Aquatic invertebrates exhibit even lower MFO activities. Some PCB congeners are inducers of MFO in aquatic invertebrates.

7. It is primarily through effects on these enzyme systems that toxicities attributable to low concentrations of PCBs typical of environmental systems are thought to occur.

There are some findings that acute toxicity may be a simple function of the aqueous solubility of individual PCB congeners. As molecular weight decreases, solubility increases and toxicity increases. (Abernathy et al. 1986 as cited in Dillon et al. 1991).

4.1 Use of the Equilibrium Partitioning Model to Derive Sediment Quality Objective Concentrations to Protect Benthic Organisms Exposed to PCBs in Sediment Pore Water

Based on the principles in U.S. EPA's Sediment Quality Criteria Development document (Di Toro et al., 1992) and U.S. EPA's (1980) Chronic Water Quality Criterion for PCBs, Table 17 shows the SQOC calculated based on the 0.014 ug/L chronic value. The 0.014 ug/L is based on a Final Residue Value for protecting the uses of aquatic life. There is an insufficient data base to derive a Final Chronic Value to protect aquatic life from chronic toxicity. The lowest concentration at which adverse effects to aquatic life have been reported from water-only exposures to PCBs range from 0.2 - 9.0 ug/L for fish and invertebrates (U.S. EPA, 1980). This effects range considers Aroclors 1242 and 1248 which have relatively large contributions of the lower chlorinated homolog groups (di- to tetrachlorobiphenyls) in the PCB mixture.

Following the method of Pavlou (1984), a sediment safe level for PCBs is established based on using one-half the lowest concentration causing adverse biological effects or one half of 0.2 ug/L which equals 0.1 ug/L. Pavlou uses the approach as an interim attempt to estimate the concentration at which a water quality criterion may eventually be established. Because the lowest concentration causing adverse effects is based on a very limited toxicological data base, the estimated "criterion" of 0.1 ug/L may be inadequate to ensure protection of freshwater aquatic life. The 0.1 ug/L value is greater than the chronic value of 0.014 ug/L based on a Final Residue Value. Since benthic organisms in sediment are subject to exposure from pore water and may also be in direct contact with contaminated sediments, and ingest contaminated particulate matter and food items, their total exposure may be underestimated by considering water exposure only. Therefore using a water concentration less than 0.1 ug/L may be appropriate to derive sediment safe levels for PCBs. Based on a minimum and average TOC content of 1.5% and 8.3%, respectively, in the deposited sediments and an average K_{oc}, the SQOC in Table 17 range from 104 to 573 ug PCB/kg sediment.

4.2 Review of Literature, Regulatory Criteria, and Guidelines for Establishing Sediment Quality Objective Concentrations for PCBs

Formulation of sediment quality criteria and guidelines by other regulatory agencies and studies have linked biological effects to benthic organisms from the presence of PCB compounds in sediment. Key criteria, guidelines, and studies relating PCB sediment levels to biological effects are summarized below.

4.2.1 Ontario Ministry of the Environment Sediment Quality Guidelines

The Ontario Ministry of the Environment developed guidelines for use in evaluating sediments throughout Ontario. Sediment quality guidelines (SQG) are intended to provide guidance during decision making in relationship to sediment issues ranging from preventative to remedial action (Persaud et al., 1990). The Ontario SQG for total PCBs is based on an approach to develop sediment quality assessment values called the Screening Level Concentration (SLC) approach. The SLC approach uses field data on the co-occurrence in sediments of benthic infaunal species and different concentrations of contaminants. The SLC is an estimate of the highest concentration of total PCBs and some Aroclors that can be tolerated by 95% of the benthic infaunal species. The guidelines define two levels of exotoxic effects applicable to total PCBs and PCB Aroclors:

a. Lowest Effect Level (LEL) indicating a level of sediment contamination that can be tolerated by 95% of benthic organisms.

b. Limit of Tolerance (LTL) or Severe Effect Level (SEL) indicating the level at which pronounced disturbance of the sediment benthic community can be expected. At the SEL concentration, the majority of benthic species may be detrimentally impacted.

Concentration values associated with the above levels of effects for total PCBs and PCB Aroclors in sediments in the Ontario SQGs are shown in Table 18. At an average TOC of 8% in sediment, the Lowest Effect Level for total PCBs in the Ontario guidelines is 560 ug/kg. Individual Aroclors have lower guideline values. There are no sediment values for Aroclor 1242 in the Ontario guidelines. There are sediment guideline values for Aroclor 1248. In the range of 1% to 8% TOC in sediments, the Lowest Effect Level for Aroclor 1248 is between 30 and 240 ug/kg.

4.2.2 State of Washington Sediment Standards

Washington recently adopted a new rule known as the Sediment Management Standards, Chapter 173-204 of the Washington Administrative Code. The rule establishes a set of narrative, chemical, and biological criteria as sediment quality standards. The Sediment Management Standards were developed using the Apparent Effects Threshold (AET) and Equilibrium Partitioning (EP) Method and were developed for Puget Sound initially. The AET and EP approaches associate the chemical concentrations in sediments with adverse biological responses. The AET values for Puget Sound were determined on a chemical-specific basis using acute bioassays (lethal and sublethal) and endogenous biota analysis for as many as four biological indicators. The specific biological tests that have been used to derive Puget Sound AET values include bioassays for amphipod mortality, oyster larvae abnormality, and Microtox™ bioluminescence, and in situ abundances of macroinvertebrates. The chemical-specific criteria are established such that there are no significant effects on any of the biological organisms used to establish the standard. A criteria represents the lowest biological effects level and risk level to human health. It is recognized that the local conditions may influence the bioavailability of chemical contaminants. The State of Washington standards establish specific guidance for performing biological testing and biological test interpretation criteria to confirm the level of adverse effects due to the presence of PCB concentrations in sediments that exceed the chemical criteria at specific locations. Results of the site-specific biological testing govern the final decision regarding the quality of the sediments. The chemical-specific sediment quality guidelines for PCBs are shown in Table 19. In the range of 1% to 8% TOC in sediments, the Sediment Quality Standards are 120 and 960 ug PCB/kg sediment. The Sediment Quality Standards are cleanup objectives. A second sediment standard, the Minimum Cleanup Level, acts as an upper bound or ceiling on cleanup decisions. Between these two standards, cleanup decisions consider engineering feasibility, costs, net environmental effects, and natural recovery rates.

Applicability of the Washington sediment guidelines that are based on effects to salt water and estuarine benthic organisms to freshwater organisms is not known. Based on Clarke et al. (1991), salinity has some of the following effects on bioavailability and bioaccumulation:

1. Salinity influences desorption and solubility, osmoregulation, membrane permeability, and respiration rates and volume.

2. Factors other than salinity are usually more important in effecting bioaccumulation.

3. Increasing salinity tends to decrease the water solubility of neutral organic chemicals, and also decreases the concentration of particulate and dissolved organic carbon. The decrease in organic carbon in increasing salinity may under some conditions actually enhance bioavailability of neutral organic compounds to organisms.

4.2.3 National Oceanic and Atmospheric Administration (NOAA) Sediment Quality Guidelines

NOAA has developed guidelines that are intended to provide an estimate of the potential for adverse biological effects of sediment-associated contaminants on benthic organisms. The guidelines employ a preponderance of evidence assembled from a variety of approaches and from data gathered in many geographic areas from analysis performed on multiple species and/or biological communities. Reliance is put on tests of acute and chronic toxicity and from analyses of benthic community structure.

The database NOAA has compiled contains information generated by investigators using three major approaches to establishing effects-based sediment quality guidelines (Long and Morgan, 1991). The approaches were applied in marine, estuarine, and freshwater habitats. The data from the following three basic approaches were evaluated by NOAA: (a) equilibrium partitioning, (b) spiked-sediment toxicity tests, and (c) various approaches that rely on matching synoptically collected sediment chemistry and biological effects data. Candidate data sets were screened for the assessment methods used in each study, the type and magnitude of biological endpoint measured, and the degree of concordance between the chemical and biological data. The chemical concentrations observed in each of the above approaches that were associated with biological effects that pass screening were sorted. The lower 10 percentile in the data was identified as an Effects Range - Low (ER-L) and was considered to represent a lower threshold value. The ER-L indicated the low end of the range of concentrations above which adverse effects may begin or are predicted among sensitive life stages and/or species. The Effects Range - Median (ER-M) is a concentration equivalent to the 50 percentile point in the screened available data. The ER-M value is the concentration above which biological effects were frequently or always observed or predicted among most organisms.

The NOAA guidelines are used to rank and prioritize sites with regard to the relative potential for contaminant-induced effects in coastal marine, estuarine and freshwater environments throughout the United States. It is indicated that the ER-L and ER-M values are not to be interpreted as NOAA standards or criteria, although the ER-L and EL-M concentrations may be used by others as guidance in evaluating sediment contamination data. The ER-L and ER-M guideline values for total PCBs derived from the NOAA study compilation and evaluation are shown in Table 20a. The Effects Range - Low and Effects Range - Medium identified in the evaluation are 50 ug/kg and 400 ug/kg, respectively.

MacDonald (Long et al., 1992) added a substantial amount of new data from field studies and laboratory spiked-sediment bioassays to the Long and Morgan (1992) data base. The ER-L and ER-M values based on the larger MacDonald data base are shown in Table 20b.

Long et al. (1992) indicate that the NOAA approach can be applied equally to any sediment type that occurs in freshwater, estuarine, and marine environments. The NOAA guidelines are considered to be widely applicable because the data base that supports the guidelines contains information from a wide variety of sediment types.

4.2.4 Sediment Quality Assessment Approach Application to Determine Biological Effects Levels To Benthic Organisms from PCBs

Application of different assessment approaches by Chapman et al. (1987) and Chapman (1986) yielded similar levels of PCBs in sediments related to biological effects. The assessments were done in marine and estuarine habitats. Generally no or minimal biological effects are associated with less than 100 ug/kg PCBs in sediment in the approaches being compared (Table 21).

4.2.5 Summary of Approaches and Effects

In summary, the following PCB sediment concentrations are associated with biological effects to benthic organisms based on the above approaches:

	Sediment Quality Objectives ug PCB/kg Sediment TOC	
	1%	8%
Chronic Toxicity Application of EPA Ambient WQC To Pore Water	70	554
Ontario Sediment Guidelines Lowest Effect Level Aroclor 1248	30	240
State of Washington	120	960
NOAA - Effects Range Low	23	180
Chapman - Four Approaches Compared. Not TOC Normalized. Minimum or No Effect Level	100	

053247

The sediment safe levels in the different guidelines are based on a number of approaches and biological endpoints but generally arrive at comparable values. Generally it would appear that PCB concentrations in sediments at 8% TOC must be less than 500 ug/kg to minimize detrimental biological effects to benthic organisms including mortality and reduction in growth and reproduction. As the TOC content of the sediment decreases the sediment safe levels for PCBs appear to decrease accordingly. At 1% TOC, PCBs in sediments should be at the level of approximately 70 ug/kg or less (based on averaging the effect levels associated with the lowest TOC concentrations).

In establishing sediment safe levels for PCBs, to protect benthic and water column organisms, some additional consideration needs to be given to the following (Eisler, 1986; Moore et al., 1984):

1. Toxicity of PCBs increases with increasing exposure. Benthic organisms are relatively non-mobile and are subject to long term, chronic exposures.

2. Among invertebrates, crustaceans (Daphnia and Gammarus) are sensitive to PCB exposure.

3. Lower chlorinated biphenyls were more toxic than higher chlorinated biphenyls.

4. Juvenile/immature stages of many invertebrate species are more sensitive to PCBs than adults.

5. Aroclor 1242 appears to be particularly toxic to freshwater algae.

6. PCBs reduce photosynthesis and carbon uptake in sensitive species of algae at concentrations of 0.1 - 1.0 ug/L.

   Comparably low concentrations have been known to alter the community structure and species composition of natural algal populations.

7. The relative toxicity of Aroclors (3 week LC_{50}) to Daphnia magna was in the following order: 1242 > 1260 > 1254 > 1248.

4.2.6 Benthic Community Studies On the Lower Fox River

The diversity values and relative abundance of benthos determined by Ankley et al. (1992) suggests that sites along the Lower Fox River are adversely impacted. The benthic community is dominated by chironomids and oligochaetes. It is uncertain whether the impact is due to toxic contaminants, poor habitat, adverse water quality conditions (e.g., low dissolved oxygen) or some combination of these factors. Toxicity testing suggests that one chemical contributing to the impact on benthos is ammonia (Ankley et al., 1990). Based on the observed effects using the Microtox bioassay on sediment pore water from the lower Fox River, Hoke et al. (1992) found that while un-ionized ammonia accounted for a large part of the observed toxicity, metals and possibly unidentified organic compounds also appear to contribute to the observed toxicity.

Based on analysis from laboratory bioassays and field collected invertebrates, Call et al. (1991) found the following PCB accumulations in tissues (ug/kg wet weight):

	Field Collected Invertebrates			
	Reference Site Exposure	PCB Impacted Sites		
		Avg.	Min.	Max.
Annelids	___	376.87	284.38	474.30
Chironomids	14.97	351.32	158.52	1.148.22

	Laboratory Exposed Invertebrates			
	Reference Site Exposure	PCB Impacted Sites		
		Avg.	Min.	Max.
Lumbriculus Variegatus	108.99	345.91	78.24	747.48
Chironomus riparius	812.02	795.39	392.65	1,518.75
Hexagenia limbata	196.97	1,462.78	427.04	4,174.24
Hyalella azteca	421.59	652.81	459.61	980.31

In the Call study, the PCB chlorohomolog pattern in annelids and chironomids from the Lower Fox River and Green Bay and in laboratory bioassay annelids and mayflies exposed to sediments was dominated by tetrachlorobiphenyls. Trichlorobiphenyls generally make up the next largest chlorohomolog group followed by pentachlorobiphenyls. In field collected and laboratory bioassay annelids and field collected chironomids, the tetra- to heptachlorohomolog groups are preferentially accumulated in tissue compared to percentage contribution of the groups to the total PCB concentration in sediments. In bioassay annelids, the tetra- and pentachlorohomolog groups are preferentially accumulated. Both homolog groups may include potentially toxic coplaner and mono-ortho coplaner congeners in them (congener 77 in tetrachlorobiphenyl group and 105, 114, 118, 123, and 126 in the pentachlorobiphenyl group).

Call et al. (1991), indicated that the PCB tissue levels they measured in laboratory bioassays of *Hyalella* were below adverse effects levels attributed to PCB tissue levels in the literature. There is concern regarding the likely transfer of PCBs in invertebrates to higher trophic levels in the food chain. There is some indication that *Hexagenia* populations are returning

053245

to the lower Fox River system after being eliminated by pollution (Cochran, 1992). Emerging insects are a potential biotic transport route for PCBs in sediments to the aquatic and terrestrial ecosystem.

5.0 Consideration of Toxic PCB Congeners

The Sheboygan Memo discusses concerns with the presence of toxic PCB congeners in sediments, water, and biota. Environmental criteria based on concentrations of total PCB or Aroclor mixtures without consideration of specific congeners may not address the total toxicity of the PCB mixture the organism is exposed to. From a toxicological and ecological perspective, some PCBs are of more concern than others, especially those that have structural and toxicokinetic properties similar to 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). Based on these properties, the proposed GLWQI contains water quality criteria for 11 toxic coplanar and mono-ortho coplanar congeners related to 2,3,7,8-TCDD, to protect wildlife consuming fish.

The equilibrium partitioning model applied above was used to derive SQOC for the 11 congeners contained in the GLWQI. The considerations made in developing these SQOC are discussed in the Sheboygan Memo. To deal with the 11 congeners included in the class criteria, a Hazard Index Approach and a back-calculation method that predicts the total concentration of congeners in water released from sediment based on measured concentrations in sediment are also discussed in the Sheboygan Memo.

There have been a number of site specific studies conducted on the Lower Fox River and Green Bay that suggest the majority of toxic effects of PCB/Furan/Dioxin mixtures on biota, especially reproductive impairments to fish eating birds, is due to the dioxin-like activity of planar PCBs such as congeners 77, 105, and 126. (Kubiak et al., 1989; Ankley et al., 1992; Tillett et al., 1992; Harris et al., unpublished). Kubiak et al. (1989) calculated biomagnification factors of 0.17, 64, and 176 for congeners 77, 126, and 169, respectively based on the ratio of median tern egg concentration/small forage fish concentration. Data also suggest that TCDD-related activities of congeners 77, 105, and 126 may be related to observed adverse impacts in lake trout and Chinook salmon from Lake Michigan (Walker et al. 1991; Ankley et al., 1991).

Table 22 shows the results of sediment samples taken by WDNR from Deposit A and in the Menasha channel at the outlet of Lake Winnebago. Analysis was done by U.S. EPA - Duluth. The sediments were analyzed for toxic PCB congeners, 2,3,7,8-TCDD, 2,3,7,8-TCDF, and total PCBs. The weight percent contribution of congener 77 (0.96%) to the total PCBs in sediments appears to be 1.9x to 2.7x greater than would be expected from the weight percent contribution of congener 77 in a commercial Aroclor 1242 mixture (Table 22). Assuming the Aroclor source of PCBs to Deposit A was 1242, this may indicate congener 77 is more persistent and less mobile compared to other congeners. The relatively high weight percent contribution of congener 77 in the Deposit A sediments does not appear to agree with the findings of Brown et al. (1987) that indicated congener 77 was preferentially lost by anaerobic dechlorination in sediments. Also placed in Table 22 are more recent results for congener 118 concentrations in Deposit A and Menasha channel sediments based on WDNR's biomonitoring study. The 385 ug/kg concentration of 118 in Deposit A sediments represents an average of two sample results (350 and 420 ug/kg).

Table 23 shows the congener concentrations converted to 2,3,7,8-TCDD equivalents (TCDD-EQ) expressed as pg TCDD Toxic Equivalents/g PCB based on the toxicity equivalency factors (TEF) of Safe et al. (1990). Also in Table 23 are the TCDD-EQ of the congeners calculated for other sites around the state for comparison. Table 24 shows the TCDD-EQ for congeners in 8 sample sites along the Sheboygan River which is a Superfund site because of PCB contaminated sediments. The TCDD-EQ at Deposit A for the PCB congeners exceeds the TCDD-EQ for 7 of the 8 sites along the Sheboygan River.

In Deposit A. the low total PCB concentration in the sediments (18.4 ug/g) has a relatively high TCDD-EQ concentration (1947.67 pg/g) from PCB congeners associated with it compared with other sites. 91% of the TCDD-EQ is due to congener 77 in the Deposit A sample. The reference site sediments in the Menasha Channel had a TCDD-EQ of 4.82 pg/g.

At other sediment sampling sites below the DePere dam and in Green Bay, concentrations of congener 77, ranged from 1.28 ug/kg to 48.15 ug/kg; congener 105 from 3.28 ug/kg to 15.3 ug/kg; and congener 126 from 0.024 ug/kg to 0.73 ug/kg (Ankley et al., 1992). The concentration of the three congeners in Deposit A sediments are greater than the highest values found in the downstream sample sites based on the above results. For congener 77, the concentrations are 3.7x higher.

The SQOC for the 11 toxic congeners based on the GLWQI criteria are in Table 5 of the Sheboygan Memo with qualifications for use as if single and not mixtures of congeners are present. Mixtures of congeners lowers the SQOC for individual congeners. At 1.5% and 8.3% TOC in the sediments, the following are the SQOC for the toxic congeners discussed above compared with reference site and Deposit A concentrations.

Congener	Reference Site ug/kg Menasha Channel	Deposit A ug/kg	Sediment Quality Objectives Concentrations ug/kg	
			1.5%	8.3%
#77	0.211	176.67	0.03	0.166
#105	1.31	39.97	• 0.45	2.49
#126	0.013	1.41	0.008	0.042
#169	0.002	N.D.	0.045	0.249
#118	1.24	385.0	0.56	3.07

The concentration of congener 77 in Deposit A sediment exceeds the SQOC by 3 orders of magnitude; congener 105 exceeds the SQOC by one order of magnitude, and congener 126 exceeds by two orders of magnitude. Congener 118 exceeds the SQOC by approximately two orders of magnitude.

Additional sampling of Deposit A sediments for the remaining toxic congeners for which SQOC have been developed is needed. Generally these remaining congeners have lower TEF values and would result in lower TCDD-EQ contributions than congeners 77, 126, and 169 unless present at very high concentrations.

6.0 Preliminary Results from WDNR Biomonitoring Studies of Deposit A, Summer of 1992

Preliminary results are available from the WDNR caged fish studies and field collection of oligochaetes from Deposit A, an upstream reference site, and a downstream site. The fish and oligochaete tissues were analyzed for PCBs on a congener basis. Seventy-three individual or co-eluting congeners were analyzed for. Levels of detection ranged from 0.3-3.0 ng/g for the congeners. Preliminary results of the tissue analysis are shown in Table 25.

Hatchery-reared *Pimphales promelas* (fathead minnow) were placed in aluminum cages at 3 sites. The aluminum cages were 16" x 16" x 18" in size made of perforated aluminum sheets with 5/32" hole diameter and 63% open area. At each of the 3 sites, 3 replicate cages were placed on the sediment surface. A location in the Menasha channel served as the reference site. Cages were placed in the southwest corner of Deposit A. The downstream site was 1/3 of a mile north of the Highway 441 bridge, along the east bank of the river. Caged fish were placed at each site for 10 days. Oligochaetes were collected at each site for a PCB congener analysis of the tissue.

Table 25 shows the chlorobiphenyl isomer distribution in the fish and oligochaetes compared to the distribution in manufactured Aroclor 1242. The relative proportions of the pentachlorobiphenyls and hexachlorobiphenyls are greater in the fish and oligochaetes compared to the commercial mix. The penta- and hexachloro homolog proportions are greater in tissues downstream at the Highway 441 bridge site compared to the Deposit A site. The trichloro-homolog contribution is lower at the Highway 114 site compared to Deposit A. The actual chlorohomolog makeup in the sediments may differ from the manufactured Aroclor mix. Also, the homolog proportions may change over longer periods of exposure.

In 10 days of exposure, the fathead minnows at Deposit A accumulated an average of 9.46 μg/g. Since the fish may not have reached a steady state concentration in this short exposure time, longer exposure would result in greater PCB tissue concentrations. Given that 10 day laboratory exposures only achieve 30-50 percent of the steady state concentrations, it is possible longer exposure of caged fish could double or triple the tissue concentrations. Tissue accumulations at the downstream Highway 441 site were approximately 2 percent of the Deposit A accumulation in fish. On a lipid normalized basis, site-to-site differences are not as great in comparing fish and oligochaete PCB accumulations.

The bottom of Table 25 shows analysis for 8 of the 11 toxic PCB congeners included under the proposed Great Lakes Water Quality Initiative because of identified effects to wildlife consuming fish. A number of the congeners were not found above the indicated level of detection. The State Laboratory of Hygiene (SLOH) currently does not have analytical capability for congeners 114, 167, or 189.

Congeners 126 and 169 have been detected in spottail shiners in the Lower Fox River in concentrations of 0.06 ng/g and 0.007 ng/g respectively (Kubiak et. al., 1989), compared to the limit of detection achieved by the SLOH of 0.5 ng/g. Because of the relatively high Toxicity Equivalency Factors based on Safe et. al. (1990) assigned to congeners 126 and 169, they can make significant contributions to the total TCDD-EQ if present at concentrations less than 0.5 ng/g. The spottail shiners in the Kubiak study had 3.2 ng/g of congener 77 in their tissues. The minnows in the caged fish study over Deposit A had tissue levels of 19.0 ng/g. The TCDD-EQ of the detected PCB congeners in Deposit A caged fish was 281.6 pg/g, with 68 percent and 26 percent of the total TCDD-EQ of PCBs being contributed by 77 and 118, respectively.

TABLE 1 **Water Quality Criteria, Proposed Criteria, and Water Quality Objectives for Consideration at the Little Lake Butte des Morts (LLBDM) Site**		
Source of Criteria or Objective	Biological Endpoint Protected	Criteria or Objective Concentration
1. NR 102 and 104, Wis. Adm. Code	The Fox River at the LLBDM site is classified as a Warmwater Sport Fish Community, Non-public water supply	
2. NR 105.09, Wis. Adm. Code	Maximum concentration of PCBs established to protect humans from unreasonable incremental risk of cancer resulting from contact or ingestion of surface waters or aquatic organisms taken from surface waters of the state	0.49 ng/L Total PCBs
3. NR 105.07, Wis. Adm. Code	Concentration that protects Wisconsin's wild and domestic animals from adverse effects resulting from ingestion of surface waters or aquatic organisms	3.0 ng/L Total PCBs
4. Proposed Water Quality Criteria Under the Great Lakes Initiative Total PCBs	Human Health Criteria Human Cancer Value Human Non-Cancer Value Wildlife Criteria	 0.003 ng/L 0.01 ng/L 0.015 ng/L
5. Potential Water Quality Criteria in NR 105 for Protection of Human Health, Warmwater Sport Fish Community Stream Classification Using Values in Chemical Criteria Documents Developed Under the Great Lakes Water Quality Initiative	Human Health Criteria Human Cancer Criterion Human Non-Cancer Criterion	 0.013 ng/L 0.06 ng/L
6. Great Lakes Water Quality Agreement of 1978 as Amended	Water quality objective to protect the most sensitive user	1 ng/L Total PCBs (Proposed)

053240

TABLE 2
Total PCB Sediment Quality Objective Concentrations
For Little Lake Butte des Morts -
Deposit A

Objective: Protection of NR 105.09, Wisconsin Administrative Code, Human Cancer Criteria. Water Quality Criteria - 0.49 ng/L Total PCBs

	Organic Carbon Normalized Total PCB Critiera[1] ug PCB/Kg Organic Carbon (OC)		
Organic Carbon Partitioning Coefficient (k_{oc})[3] L/Kg	Minimum	Average	Maximum
	26,303	494,808	1,949,844
ug PCB/Kg OC	12.89	242.46	955.42

			Site Specific Sediment Criteria[2] ug PCB/Kg Sediment (SED)		
Organic Carbon Partitioning Coefficient (K_{oc}) L/Kg			Minimum	Average	Maximum
			26,303	494,808	1,949,844
	%TOC[4]				
ug PCB/Kg SED	Min.	1.5	0.19	3.64	14.33
		2.0	0.26	4.85	19.11
		3.0	0.38	7.27	28.66
		4.0	0.51	9.70	38.22
		5.0	0.64	12.12	47.77
		6.0	0.77	14.55	57.32
		7.0	0.90	16.97	66.88
	Ave.	8.27	1.07	20.05	79.01
		9.0	1.16	21.82	85.99
		10.0	1.29	24.25	95.54
		11.0	1.42	26.67	105.09
	Max.	11.7	1.51	28.37	111.78

Table 2 (Continued)

Notes:

1. SQC_{OCN} = WQC x K_{oc}

Where:

SQC_{OCN} = Organic Carbon Normalized Sediment Quality Criteria expressed as ug PCB/Kg OC

WQC = Water Quality criteria in ug/L

K_{oc} = Organic Carbon Partitioning Coefficient for Aroclor 1242

2. SQC_{SED} = WQC x K_{oc} x foc

Where:

SQC_{SED} = Site Specific Sediment Quality Critiera Expressed as ug PCB/Kg Sediment

WQC = As above

K_{oc} = As above

foc = Total organic carbon content of the sediment expressed as a decimal weight fraction of dry sediment.

3. K_{oc} values are based on organic carbon partitioning characteristics of Aroclor 1242, the predominant Aroclor identified in the Deposit A sediments.

4. TOC percentages represent the range and average value found in the top 6 inches (15cm) of Deposit A sediments.

v:\9304\wr9llbd1.tpj

053238

TABLE 3
Total PCB Sediment Quality Objective Concentrations
For Little Lake Butte des Morts -
Deposit A

Objective: Protection of NR 105.07, Wisconsin Administrative Code, Wild and Domestic Animal Criteria. Water Quality Criteria - 3 ng/L Total PCBs

	Organic Carbon Normalized Total PCB Criteria[1.] ug PCB/Kg Organic Carbon (OC)		
	Minimum	Average	Maximum
Organic Carbon Partitioning Coefficient (K_{oc})[3.] L/Kg	26,303	494,808	1,949,844
ug PCB/Kg OC	78.91	1496.42	5,849.53

		Site Specific Sediment Criteria[2.] ug PCB/Kg Sediment (SED)		
		Minimum	Average	Maximum
Organic Carbon Partitioning Coefficient (K_{oc}) L/Kg		26,303	494,808	1,949,844
	% TOC[4.]			
	Min. 1.5	1.18	22.27	87.74
	2.0	1.58	29.69	116.99
	3.0	2.37	44.53	175.49
	4.0	3.16	59.38	233.98
	5.0	3.94	74.22	292.47
ug PCB/Kg SED	6.0	4.73	89.07	350.97
	7.0	5.52	103.90	409.47
	Ave. 8.27	6.53	122.76	483.76
	9.0	7.10	133.60	526.46
	10.0	7.89	148.44	584.95
	11.0	8.68	163.29	643.45
	Max. 11.7	9.23	173.68	684.40

Table 3 (Continued)

Notes:

1. SQC_{OCN} = WQC x KOC

   Where:

   SQC_{OCN} = Organic Carbon Normalized Sediment Quality Criteria expressed as ug PCB/Kg OC

   WQC = Water Quality Criteria in ug/L

   K_{oc} = Organic Carbon Partitioning Coefficient for Aroclor 1242

2. SQC_{SED} = WQC x K_{oc} x foc

   Where:

   SQC_{SED} = Site Specific Sediment Quality Criteria expressed as ug PCB/Kg Sediment

   WQC = As above

   K_{oc} = As above

   foc = Total organic carbon content of the sediment expressed as a decimal weight fraction of dry sediment

3. K_{oc} values are based on organic carbon partitioning characteristics of Aroclor 1242, the predominant Aroclor identified in the Deposit A sediments.

4. TOC percentages represent the range and average value found in the top 6 inches (15cm) of Deposit A sediments.

Table 4
Exceedance Factors of Surface Water Column Concentrations of PCBs With Existing and Proposed Ambient Water Quality Criteria

	NR 105 Water Quality Criteria		Proposed Great Lakes Initiative	
Little Lake Butte des Morts n = 3	Human Cancer Criteria 0.49 ng/L	Wildlife 3 ng/L	Human Cancer Criterion Value 0.013 ng/L	Wildlife 0.015 ng/L
Minimum (1.29 ng/L)	2.5 x	--	99.2 x	86 x
Average (1.44 ng/L)	2.9 x	--	110.8 x	96 x
Maximum (3.64 ng/L)	7.4 x	1.2 x	280 x	242.7 x
Appleton n = 24				
Minimum (2.11 ng/L)	4.3 x	--	162.3 x	140.7 x
Average (25.75 ng/L)	52.6 x	8.6 x	1980.8 x	1716.7 x
Maximum (50.19 ng/L)	102.4 x	16.7 x	3860.8 x	3346 x

PCB water column data based on Table 2-1 of Comments on WDNRs Evaluation for the Remediation of Deposit A Sediments, Draft Final Prepared by Blasland and Bouck. Submitted by Wisconsin Paper Council, June 1992. Values represent a total of dissolved PCBs and particulate associated. Average concentration of PCBs at the upstream Neenah sampling site were subtracted from the average and maximum concentrations found at the Deposit A and Appleton sites.

v:\9304\wr9llb17.tpj

053225

TABLE 5 **Fish Tissue Residue Action Levels and Objectives for the Protection of Human Health and Wildlife that Consume Fish**		
Source of Criteria or Objective	Biological Endpoint Protected	Action Level or Objective Tissue Concentrations in Fish
1. U.S. Food and Drug Administration (FDA) Action Levels	**Human Health**	2 μg/g (ppm) Based on fillet with skin on
2. Great Lakes Water Quality Agreement (International Join Commission [IJC] Objective)	**Protection of birds and animals which consume fish**	0.1 μg/g Whole fish wet weight basis
3. Great Lakes Water Quality Initiative. The fish tissue value was derived from the chemical criteria documents for wildlife protection	**Wildlife that consume fish as a primary component of their diet**	0.023 μg/g Whole fish wet weight basis

v:\9304\wr911bd4.tpj

053234

Table 6. Percent Lipid content in Fillets and Whole Fish Sampled from Little Lake Butte des Morts.

Fillets	Mean Lipid Content	Range	Number of Fish
White Bass	3.53	2.9 - 4.0	6
Northern Pike	1.28	0.3 - 2.9	13
Walleye	1.62	0.3 - 6.4	27
Carp	6.19	1.0 - 16.9	31
Yellow Perch	1.77	0.2 - 9.0	28
White Suckers	3.05	0.6 - 10.0	19

Whole Fish	Mean Lipid Content	Range	Number of Fish
Northern Pike	5.50		1
Brown Bullheads	5.14	4.7 - 5.8	5
Carp	11.20	11.0 - 11.4	2
Yellow Perch	3.82	3.0 - 6.0	6
White Suckers	5.57	3.9 - 7.4	3

053233

Table 7
Calculation of PCB Accumulation in Fathead Minnow Tissue Relative to Sediment Concentrations. Based on 30 day Laboratory Bioaccumulation Testing from Call et al. 1991.

	Sediment Concentration ug/kg	Tissue Concentration[1] ug/kg	ARS[2]
East River-Reference	90.51	258.00	2.85
Fox River			
Site 1	6,751.41	3,796.0	0.56
Site 2	2,401.54	1,257.90	0.53
Site 3	306.15	1,235.30	4.03
Site 4	2,650.90	1,266.95	0.48
Site 5	4,007.11	1,425.75	0.36
Site 6	3,057.04	1,457.10	0.48
Site 7	414.07	723.85	1.75
Site 8	1,241.04	1,868.30	1.51
Site 9	2,297.26	2,115.95	0.92
Site 10	1,828.90	2,797.05	1.53
Green Bay			
Site 11	811.32	1,647.20	2.03
Site 12	707.09	1,383.40	1.96
		Ave. for sites	1.46

Fish from all sites contained a mean lipid content of 3.04%

1 Converted to a dry weight basis from a reported wet weight concentration utilizing a dry weight to wet weight ratio of 0.2.

2 Accumulation Relative to Sediment (ARS) = Dry weight concentration of PCB in fish tissue (ug PCB/kg dry tissue weight) / Dry weight concentration of PCB in sediment (ug PCB/kg dry sediment)

Table 8
Calculation of PCB Accumulation In Field
Collected Black Bullhead Tissue From Call et al. 1991.

	Sediment Concentration ug/kg	Tissue Concentration[1] ug/kg	ARS[2]
Site 1	6,751.41	12,521.05	1.86
Site 2	2,401.54	4,744.80	1.98
Site 3	306.15	5,283.40	17.26
Site 4	2,650.90	5,372.65	2.03
Site 6	3,057.04	2,524.10	0.83
Sites 8 & 9	1,769.02	4,651.35	2.62
		Ave. for sites	4.43

Fish contained a mean lipid content of 1.65%

[1] Converted to a dry weight basis from a reported wet weight concentration utilizing a dry weight to wet weight ratio of 0.2.

[2] Accumulation Relative to Sediment (ARS) = $\frac{\text{Dry weight concentration of PCB in fish tissue (ug PCB/kg dry tissue weight)}}{\text{Dry weight concentration of PCB in sediment (ug PCB/kg dry sediment)}}$

[3] Based on average of PCB sediment concentrations found at site 8 (1241.04 ug/kg) and site 9 (2,297.26 ug/kg)

Table 9
Review of Literature For Fish Tissue Accumulation of PCBs Relative To Sediment Concetrations

A. Wilford et al., 1987

Fathead Minnow	Sediment Concentration ug/kg	Tissue Concentration ug/kg	ARS
Laboratory Exposure	94	640	6.8
	210	2,030	9.7
	650	1,490	2.3
	2,030	2,270	1.1
	31,700	45,400	1.4

B. Mac et al., 1985

Fathead Minnow		Sediment Concentration ug/kg	Tissue Concentration ug/kg	ARS
Field Exposure	Site 1	2,030	1,624 (Suspended Cage)	0.8
			2,639 (Bottom Cage)	1.3
	Site 2	650	2,275 (Suspended Cage)	3.5
			4,030 (Bottom Cage)	6.2
Laboratory Exposures	Site 1	2,030	4,669	2.3
	Site 2	650	3,835	5.9

C. U.S. EPA, 1984

Laboratory Exposure			Sediment Concentration ug/kg	Tissue Concentration ug/kg	ARS
Laboratory Exposure		% Lipids			
Fathead Minnow	Preexposure	8.5		1,000	
	Control	8.1	16	1,400	
	Test	8.1	31,720	45,400	1.4
Yellow Perch	Preexposure	4.9		1,600	
	Control	3.9	13	2,000	
	Test	3.6	12,780	8,900	0.57

053230

D. WDNR, 1990 (Unpublished)
Laboratory Exposure, Sheboygan River Sediment, Fathead Minnow

Sediment Deposit	Sediment Concentration ug/g	Tissue Concentration ug/g	ARS
#3	2,800	7,500	2.68
#28	132	593	4.49
#23	19	175	9.2
#26	9.20	45	4.89
CTH A	2.60	19	7.31

E. Beak Consultants, 1987
Preview of studies relating PCB levels in bottom dwelling fish to sediments levels. Typical ARS factor.

ARS
25

v:\9304\wr9llbd5.tpj

Table 10
Use of Accumulation Relative to Sediment (ARS) Factors and Fish Tissue Objectives to Derive Sediment Quality Objectives for PCBs (ug/kg) To Protect Fish Tissue Objectives

	FDA Action Level 2000 ug/kg wet wt.		IJC Objective 100 ug/kg wet wt		Great Lakes Water Quality Initiative 23 ug/kg	
	% Water in Tissue		% Water in Tissue		% Water in Tissue	
	50%	80%	50%	80%	50%	80%
	Dry Wt. Concen.		Dry Wt. Concen.		Dry Wt. Concen.	
ARS Factor	4000 ug/kg	10,000 ug/kg	200 ug/kg	500 ug/kg	46 ug/kg	115 ug/kg
0.5	8,000	20,000	400	1,000	92	230
1.0	4,000	10,000	200	500	46	115
2.0	2,000	5,000	100	250	23	58
3.0	1,333	3,333	67	167	15	38
4.0	1,000	2,500	50	125	12	29
5.0	800	2,000	40	100	9	23
10.0	400	1,000	20	50	5	12
15.0	267	667	13	33	3	8
20.0	200	500	10	25	2	6
30.0	133	333	7	17	1.5	4
40.0	100	250	5	13	1.0	3
50.0	80	200	4	10	0.9	2

Sediment Quality Objectives expressed as PCBs (Total) ug/kg dry wt.
ARS Factor = Accumulation Relative to Sediment

v:\9304\wr9llb18.tpj

053228

TABLE 11

Calculations of Fish-Sediment Accumulation Factors (FSAF) For PCBs In Fish Based on Normalization to Percent Lipid and Total Organic Carbon Site Values Laboratory Exposure - Fathead Minnow

	Sediment			Fish Tissue			FSAF
	PCB µg/kg (dry wt.)	Percent Organic Carbon	µg PCB/g OC	PCB µg/kg (Wet wt.)	Percent Lipid	µg PCB/g Lipid	
East River Reference	91.51	1.46	6.27	51.6	3.04	1.70	0.27
Site 1	6751.41	7.36	91.73	759.20	↑	24.97	0.27
2	2401.54	6.70	35.84	251.58		8.28	0.23
3	306.15	2.28	13.43	242.06		7.96	0.59
4	2650.90	5.39	49.18	253.19		8.33	0.17
5	4007.11	8.28	48.40	285.15		9.38	0.19
6	3057.04	7.37	41.48	291.42		9.59	0.23
7	414.07	1.26	32.86	144.77		4.76	0.14
8	1241.04	2.81	44.17	373.66		12.29	0.28
9	2297.26	5.57	41.24	423.19		13.92	0.33
10	1828.90	3.31	55.25	559.41		18.40	0.33
Green Bay					↓		
11	811.32	2.70	300.49	329.44		10.84	0.36
12	707.09	4.37	161.81	276.68	3.04	9.10	0.56
Average FSAF							0.30

1. Fish-Sediment Accumulation Factor (FSAF) =

$$\frac{\text{Wet wt. concentration of PCB in fish tissue } (\mu g/g) \;/\; \text{\% Lipid } (g/g \text{ wet weight})}{\text{Dry wt. concentration of PCB in sediment } (\mu g/g) \;/\; \text{\% Total Organic Carbon in Sediment } (g/g \text{ dry weight})}$$

Data from Call et al. 1991

TABLE 12
Calculations of Fish-Sediment Accumulation Factors (FSAF) For PCBs
In Fish Based on Normalization to Percent
Lipid and Total Organic Carbon Site Values
Field-Collected Black Bullheads

	Sediment			Fish Tissue			FSAF[1]
	PCB µg/kg (dry wt.)	Percent Organic Carbon	µg PCB/g OC	PCB µg/kg (Wet wt.)	Percent Lipid	µg PCB/g Lipid	
Site 1	6751.41	7.36	91.72	2504.21	1.65	151.76	1.65
2	2401.54	6.70	35.84	948.96	▲	57.45	1.60
3	306.15	2.28	13.43	1056.68	|	64.00	4.77
4	2650.90	5.39	49.18	1074.53	|	65.09	1.32
6	3057.04	7.37	41.48	504.82	▼	30.55	0.74
Sites 8&9	1769.15	4.19	42.22	930.27	1.65	56.36	1.33
Average FSAF							1.91

1. Fish-Sediment Accumulation Factor (FSAF) = [Wet wt. concentration of PCB in fish tissue (µg/g) / % Lipid (g/g wet weight)] ÷ [Dry wt. concentration of PCB in sediment (µg/g) / % Total Organic Carbon in Sediment (g/g dry weight)]

$$\text{FSAF} = \frac{\text{Wet wt. concentration of PCB in fish tissue } (\mu g/g) \,/\, \%\text{ Lipid } (g/g \text{ wet weight})}{\text{Dry wt. concentration of PCB in sediment } (\mu g/g) \,/\, \%\text{ Total Organic Carbon in Sediment } (g/g \text{ dry weight})}$$

The PCB and Total Organic Carbon values represent the average of concentration found at sites 8 & 9.

Data from Call et al. 1991

053226

TABLE 13. Sediment Quality Objectives To Prevent Exceedances of Fish Tissue Residue Objective Based on Site-Specific Fish-Sediment Accumulation Factors (FSAF)

Organic Carbon Normalized PCB Sediment Quality Objectives µg PCB/g Organic Carbon (at 1% Lipid, Fish Sediment Accumulation Factor of 4)		
FDA Action Level 2 ppm	IJC Objective 0.1 ppm	Proposed Great Lakes Water Quality Initiative Based 0.023 ppm
50	2.5	0.6

Site Specific Sediment Quality Objectives (µg PCB/kg Sediment)	FDA Action Level 2000 µg/kg wet wt						IJC Objectives 100 µg/kg wet wt.						Great Lakes Water Quality Initiative 23 µg/kg					
% Lipid	1%			4%			1%			4%			1%			4%		
% TOC	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	11.7	1.5	8.3	[illegible]
FSAF Factor 0.1	30,000	166,000	234,000	7,500	41,500	58,500	1,500	8,300	11,700	375	2,075	2,925	345	1,909	2,691	86	477	
0.25	12,000	66400	93,600	3,000	16,600	23,400	600	3,320	4,680	150	830	1,170	138	764	1,076	35	191	
0.5	6,000	33200	46,800	1,500	8,300	11,700	300	1,660	2,340	75	415	585	69	382	538	17	95	
0.75	4,000	28,133	31,200	1,000	5,533	7,800	200	1,107	1,560	50	277	390	46	255	359	12	64	
1.00	3,000	16,600	23,400	750	4,150	5,850	150	830	1,170	38	208	293	35	191	269	9	48	
1.50	2,000	11,067	15,600	500	2,767	3,900	100	553	780	25	138	195	23	127	179	6	32	
2.00	1,500	8,300	11,700	375	2,075	2,925	75	415	585	19	104	146	17	95	135	4	24	
3.00	1,000	5,533	7,800	250	1,383	1,950	50	277	390	13	69	98	12	64	90	3	16	
4.00	750	4,150	5,850	188	1,038	1,463	38	208	293	9	52	73	9	48	67	2	12	
5.00	600	3,320	4,680	150	830	1,170	30	166	234	8	42	59	7	38	54	1.7	10	
6.00	500	2,767	3,900	125	692	975	25	138	195	6	35	49	6	32	45	1.4	8	
7.00	429	2,371	3,343	107	593	836	22	119	167	5	30	42	5	27	38	1.2	7	
8.00	375	2,075	2,925	94	519	731	19	104	146	4	26	37	4	24	34	1.1	6	

\9301\wr9III\tpj

0532925

Table 14. Sediment Quality Objectives to Prevent Exceedance of FDA Fish Tissue Residue Criteria (2 ppm) Based on Consideration of Sediment-Water-Fish Partitioning of PCBs

	Organic Carbon Normalized Total PCB Sediment Quality Objective ug PCB/g Organic Carbon (OC)
Organic Carbon Partition Coefficient (Koc) L/Kg	Based on 1% Lipid in Fish Tissue
26,300	8.83
494,808	166.06
1,949,844	654.37

	Site Specific Sediment Quality Objectives ug PCB/Kg Sediment (dry weight)								
% TOC	1.5%			8.3%			11.7%		
% Lipid	1%	4%	8%	1%	4%	8%	1%	4%	8%
Organic Carbon Partition Coefficient Aroclor 1242 Koc (L/Kg)									
26,300	132.4	32.7	16.6	733.5	181.2	91.7	1,032.6	255.4	129.2
494,808	2,490.9	616.0	311.7	13,799	3,408.7	1,724.9	19,428.7	4,805.1	2,431.5
1,949,844	9,815.5	2,427.6	1,228.4	54,377.4	13,432.5	6,797.2	76,561	18,934.9	9,581.5

Table 15. Sediment Quality Objectives to Prevent Exceedance of IJC Fish Tissue Residue Criteria Objectives (0.1 ppm) Based on Consideration of Sediment-Water-Fish Partitioning of PCBs

Organic Carbon Partition Coefficient (Koc) L/Kg	Organic Carbon Normalized Total PCB Sediment Quality Objective ug PCB/g Organic Carbon (OC) Based on 1% Lipid in Fish Tissue
26,300	0.45
494,808	8.41
1,949,844	33.15

	Site Specific Sediment Quality Objectives ug PCB/Kg Sediment (dry weight)								
% TOC	1.5%			8.3%			11.7%		
% Lipid	1%	4%	8%	1%	4%	8%	1%	4%	8%
Organic Carbon Partition Coefficient Aroclor 1242 Koc (L/Kg)									
26,300	6.7	1.6	0.8	37.1	8.7	4.4	4.4	12.3	6.2
494,808	126.2	29.7	14.8	698.2	164.3	82.1	82.1	231.6	115.8
1,949,844	497.2	117.0	58.5	2,751.22	647.3	323.7	323.7	912.5	456.3

Table 16. Sediment Quality Objectives to Prevent Exceedance of Proposed Great Lakes Water Quality Initiative-Based Fish Tissue Residues (0.023 ppm) to Protect Wildlife. Based on Consideration of Sediment-Water-Fish Partitioning of PCBs

Organic Carbon Partition Coefficient (Koc) L/Kg	Organic Carbon Normalized Total PCB Sediment Quality Objective ug PCB/g Organic Carbon (OC) Based on 1% Lipid in Fish Tissue
26,300	0.10
494,808	1.91
1,949,844	7.53

	Site Specific Sediment Quality Objectives ug PCB/Kg Sediment (dry weight)								
% TOC	1.5%			8.3%			11.7%		
% Lipid	1%	4%	8%	1%	4%	8%	1%	4%	8%
Organic Carbon Partition Coefficient Aroclor 1242 Koc (L/Kg)									
26,300	1.5	0.4	0.2	8.4	2.1	1.0	11.9	2.9	1.5
494,808	28.7	7.2	3.6	158.5	39.8	19.7	223.5	56.2	27.8
1,949,844	112.9	28.4	14.0	624.7	157.0	77.7	880.6	221.3	109.5

v:\9304\wr9llb15.tpj

Table 17
Sediment Quality Objective Concentrations for
Little Lake Butte des Morts, Deposit A

Objective: Protection of aquatic organisms that spend all or part (as eggs or larvae) of their life cycles burrowing in or on the surface of sediments deposited in water bodies. USEPA Ambient Water Quality Criteria to Protect Freshwater Aquatic Life - 0.014 ug/L. (Represents a final residue value to protect wildlife consuming fish. See discussion in text).

	Organic Carbon Normalized Total PCB Criteria ug PCB/Kg Organic Carbon (OC)		
Organic Carbon Partitioning Coefficient (Koc) L/Kg	Minimum 26,303	Average 494,808	Maximum 1,949,844
ug PCB/kg OC	362.24	6,927.31	27,297.82

Organic Carbon Partitioning Coefficient (Koc) L/Kg		Site Specific Sediment Criteria ugPCB/Kg Sediment (SED)		
		Minimum 26,303	Average 494,808	Maximum 1,949,844
	% TOC			
ugPCB/Kg SED	Min. 1.5	5.43	103.91	409.47
	2.0	7.24	138.55	545.96
	3.0	10.87	207.82	818.94
	4.0	14.49	277.09	1,091.91
	5.0	18.11	346.37	1,364.89
	6.0	21.73	415.64	1,637.87
	7.0	25.35	484.91	1,910.85
	Ave. 8.27	29.96	572.89	2,257.53
	9.0	32.60	623.46	2,456.80
	10.0	36.22	692.73	2,729.78
	11.0	39.85	762.00	3,002.76
	Max. 11.7	42.38	810.49	3,193.84

See notes for Table 2 above for partitioning model used.

v:\9304\wr9llb19.tpj

053221

Table 18
Guidelines and Objectives for the Protection of Benthic Aquatic Organisms

Ontario Sediment Quality Guidelines (Persaud et al. 1990; Jaagumagi, 1990)

	Organic Carbon Normalized PCB Guidelines ug PB/Kg Organic Carbon		
	No Effect Level	Lowest Effect Level	Severe Effect Level
PCB (Total)	–	7,000	530,000
PCB 1016	–	700	53,000
PCB 1248	–	3,000	150,000
PCB 1254	–	6,000	34,000
PCB 1260	–	500	24,000

	Site Specific PCB Sediment Guidelines ug PCB/Kg Sediment				
	No Effect Level	Lowest Effect Level		Severe Effect Level	
		% TOC		% TOC	
		1	8	1	8
PCB (Total)	20	70	560	5,300	42,400
PCB 1016	No Value Given	7	56	530	4,240
PCB 1248	No Value Given	30	240	1,500	12,000
PCB 1254	No Value Given	60	480	340	2,720
PCB 1260	No Value Given	5	40	240	1,920

The No Effect Level Guidelines for Total PCBs derived from the Equilibrium Partitioning method to protect Ontario's water quality objectives fell below the background value of 20 ug/Kg, therefore Ontario uses the latter value as the No Effect Level.

Based on Ontario's approach to developing Sediment Quality Guidelines, their data shows the total organic carbon content of the sediment by itself may have biological effects at levels above 1%. Elevated levels of TOC and organic or inorganic contaminants when present in mixtures in sediments may be impacting benthic organisms.

053219

Table 19.
Washington Department of Ecology Sediment Management Standards
Adopted September 1990.

	Organic Carbon Normalized PCB Criteria ug PCB/Kg Organic Carbon
PCB (Total)	12,000

	Site Specific PCB Marine Sediment Quality Standards ug/PCB/Kg Sediment	
	% TOC	
	1	8
PCB (Total)	120	960

Represents a level where there are no significant effects to any of the biological organisms used to establish the standard.

053218

Table 20a.
Potential For Biological Effects of Sediment Sorbed PCBs Tested in the National Status and Trends Program. Based on Long and Morgan 1991

	Effects Range-Low Concentration ug/Kg	Effects Range-Median Concentration ug/Kg	Overall Apparent Effects Threshold ug/Kg
PCB (TOTAL)	50	400	370

Subjective degree of confidence in Effects Range - Low/Effects Range - Medium Values - Moderate/Moderate.

Table 20b.
Potential For Biological Effects of Sediment Sorbed PCBs Based On Expanded Database of MacDonald

	Effects Range-Low Concentration	Effects Range-Median Concentration
PCB (TOTAL)	22.7	180

053217

Table 22. Coplanar PCB Concentrations in Sediments of Deposit A and Lake Winnebago.

Coplanar PCB (IUPAC No.)	Sediment Concentration (ug/kg)	
	Menasha Channel 47-2 *	Deposit A Site 48-1
77	0.211	176.67
105	1.31	39.97
126	0.013	1.41
169	0.002	N.D.
Total PCBs	14	18,397
118	1.24	385

Weight Percent of Coplanar PCBs in Deposit A Sediment and Weight Percent in Manufactured Aroclor 1242

Deposit A Sediments		[1]Schultz et.al 1989	[2]Chantry 1989	[3]Duinker et.al 1988
77	0.96	0.45	0.35	0.50
105	0.22	0.86	0.31	0.33
126	0.008	----	----	< 0.01
169	----	----	----	< 0.01

* Background Site - Sample Taken in Menasha Channel, Outlet for Lake Winnebago.

1. Schulz D.E., G. Petrick, and J.C. Duinker. 1989. Complete Characterization of Polychlorinated Biphenyl Congeners in Commercial Aroclor and Clophen Mixtures by Multidimensional Gas Chromatography - Electron Capture Detection. Environ. Sci. Technol. 23: 852-859.

2. Chantry, W.A. 1989. Biodegradation of PCBs Solved to Sewerage Sludge Lagoon Sediments in an Aerobic Digester. 201 Facilities Planning Update Madison Metropolitan Sewerage District.

3. Duinker, J.C., D.E. Schultz, and G. Petrick. 1988. Multidimensional Gas Chromatography With Electron Capture Detection for the Determination of Toxic Congeners Polychlorinated Biphenyl Mixtures. Anal. Chem. 60: 478-482.

053215

TABLE 23

2,3,7,8-TCDD "EQUIVALENTS"[1] DEVELOPED FROM ACTUAL CONCENTRATIONS OF PCB CONGENERS FOUND IN SEDIMENTS FROM SEVERAL SITES ASSOCIATED WITH COASTAL ZONE STUDY (WDNR 1992)

SITE	PCB Congener (IUPAC Number)[2] TCDD-EQ pg/g				TCDD Equivalents From PCBs pg/g	Total PCB in Sample µg/g	2,3,7,8 TCDF pg/g	2,3,7,8 TCDD pg/g
	77	105	126	169				
Little Lake Butte Des Mort 48-1 Deposit A	1766.7	39.97	141.0	--[3]	1947.67	18.4	333	25.1
Menasha Channel Outlet Lake Winnebago 47-2	2.11	1.31	1.3	0.1	4.82	0.034	4.5	--
Cedar Creek Ruck Pond 78-1	176.86	5.53	--	2.81	185.2	39.70	23.5	1.4
Menominee River Marinette 41-1	8.14	4.32	4.9	0.19	17.55	0.089	33.7	--
Kewaunee Harbor 55-2	25.31	7.22	4.9	--	37.43	0.304	--	--
Oconto River 90-2	4.63	3.47	2.8	--	10.9	0.047	6	1.1

[1] Toxicity Equivalency Factors (TEF) for determining "2,3,7,8-TCCD equivalents" for isoteric compounds of 2,3,7,8-TCDD by relative ability to induce aryl hydrocarbon hydroxylase (AHH) enzyme activity taken from Safe et al. (1990). TCDD equivalents = sum of each congeners TCDD equivalent (actual concentration of each congener in pg/g x conversion factor). The induction potency factors are derived from mammalian systems.

[2] International Union of Pure and Applied Chemists (IUPAC) PCB Congener number.

[3] "--" indicates congener not detected. Analysis done by EPA-Duluth.

v:\9302\wr9congl.tpj

Table 24. 2,3,7,8-TCDD "Equivalents" Developed From Actual Concentrations of PCB Congeners Found in Sheboygan River Sediments by Sonzogni, et al. (1991)

Site	PCB Cogener (IUPAC Number)[1] TCDD-EQ Pg/g								Total TCDD Equivalents[2] From PCBs pg/g	Total PCB in Sample ug/g
	77	81	105	114	118	126	167	169		
1	310	___[3]	80	___	140	___	44	___	574	50.3
2	972	3600	490	11	1480	1,000	80	950	7600	1,050
3	240	___	27	___	129	900	___	450	1746	76.9
4	210	___	41	___	318	___	___	___	569	97.8
5	460	0.7	15	___	395	___	___	___	870	256
6	50	___	11	___	103	___	___	___	164	73.4
7	110	___	6	___	162	___	___	550	828	97.5
8	160	0.4	11	___	86	___	___	___	257	124

[1] International Union of Pure and Applied Chemists (IUPAC) PCB Congener Number.

[2] Toxicity Equivalency Factors (TEF) for determining "2,3,7,8-TCDD equivalents" for isoteric compounds of 2,3,7,8-TCDD by relative ability to induce Aryl Hydrocarbon Hydroxylase (AHH) enzyme activity taken from Safe, et al. (1990). 2,3,7,8-TCDD equivalents = sum of each congeners TCDD equivalent (actual concentration of each congener in pg/g X conversion factor). The induction potency factors are derived from mammalian systems. Toxic equivalents expressed in units of pg 2,3,7,8-TCDD equivalents/g. TEF factors used for congeners 81 and 114 taken from Smith et al. (1990).

[3] "___" indicates congener not detected (concentration less than 1 ng/kg).

v:\9302\wr9shebg.tpj

Table 25. Preliminary Results from WDNR Caged Fish Studies and Field - Collected Oligochaetes From Deposit A, and Reference and Downriver Sites							
	Percent Composition of PCB Chlorohomolog Groups in Minnow and Oligochaetes						
	Caged Fathead Minnow			Field - Collected Oligochaetes			
	Menasha Channel	Deposit A	441 Bridge	Menasha Channel	Deposit A	441 Bridge	Commercial 1242
Chlorohomolog Groups							
Dichloro	N.D.	9.5	6.7	N.D.	9.8	3.3	17.7
Trichloro	N.D.	43.9	32.7	100	41.3	28.5	44.7
Tetrachloro	N.D.	33.3	38.7	N.D.	31.9	35.8	30.2
Pentachloro	N.D.	9.7	19.3	N.D.	11.3	23.7	4.4
Hexachloro	N.D.	2.8	5.8	N.D.	3.8	8.7	0.9
Heptachloro	N.D.	0.7	0	N.D.	1.2	N.D.	0.6
Octachloro	N.D.	0.1	0	N.D.	0.7	N.D.	0.2
Total PCBs (Summed Congeners) ug/kg Wet Wt.	–	9461.77	216.63	0.85	930.17	166.8	
Lipid Normalized ug PCB/g Lipid	–	338.57	8.99	0.12	186.03	20.85	
% Lipid	2.3	2.8	2.4	0.7	0.5	0.8	
Congener Number	Concentration of Toxic PCB Congeners In Minnow and Oligochaetes (ng/g)						
77	<0.5	19	0.54	<0.5	2.7	<0.5	
126	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
169	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
105	<0.3	9.2	1.1	<0.3	1.1	1.0	
114	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
123	<0.4	6.3	0.44	<0.40	0.74	0.4	
118	<0.80	72	4.3	<0.8	8.6	4.1	
156	<0.3	3	<0.3	<0.3	0.42	<0.3	
157	<0.4	1.1	<0.4	<0.40	<0.4	<0.4	
167	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
189	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	
	Total TCDD - EQ (Pg/g based on the TEF Factors of Safe (1990)						
TCDD-EQ (pg/g)	–	281.6	11.24	–	37.86	5.51	

v:\9302\wr9llb40.tpj

053212

References

Ankley, G.T., A. Katko, and J.W. Arthur. 1990. Identification of Ammonia as and Important Sediment - Associated Toxicant In the Lower Fox River and Green Bay, Wisconsin. Environ. Toxicol. Chem. 9:313-322.

Ankley, G.T., D.E. Tillitt, J.P. Giesy, P.D. Jones, and D.A. Verbrugge. 1991. Bioassay - Derived 2, 3, 7, 8 - Tetrachloro-dibenzo-p-Dioxin Equivalents In PCB - Containing Extracts From the Flesh and Eggs of Lake Michigan Chinook Salmon *Oncorhynchus tshawytscha*) and Possible Implications for Reproduction. Can. J. Fish. Aquat. Sci. 48:1685-1690.

Ankley, G.T., K. Lodge, D.J. Call, M.D. Balcer, L.T. Brooke, P.M. Cook, R.G. Kreis, Jr., A.R. Carlson, R.D. Johnson, G.J. Niemi, R.A. Hoke, C.W. West, J.P. Giesy, P.D. Jones, and Z.C. Fuying, 1992. Integrated Assessment of Contaminated Sediments in the Lower Fox River and Green Bay, Wisconsin. Ecotoxicology and Environmental Safety. 23: 46-63

Ankley, G.T., P.M. Cook, A.R. Carlson, D.J. Call, J.A. Sevenson, H.F. Corcoran and R.A. Hoke. 1992. Bioaccumulation of PCBs from Sediments by Oligochaetes and Fishes: Comparison of Laboratory and Field Studies. Can. J. Fish Aquat. Sci. 49: 2080-2085.

Abernethy, S., A.M. Bobra, W.R. Shiu, P.G. Wells, and D. MacKay. 1986. Acute Lethal Toxicity of Hydrocarbons and Chlorinated Hydrocarbons to Two Planktonic Crustaceans: The Key Role of Organism - Water Partitioning. Aquat. Toxicol. 8: 163-174.

Bierman, V.J. 1990. Equilibrium Partitioning and Biomagnification of Organic Chemicals In Benthic Animals. Environ. Sci. Technol. 24: 1407-1412.

Brown, J.F. Jr., D.L. Bedard, M.J. Brennan, J.C. Carnahan, H. Feng, and R.E. Wagner. 1987. Polychlorinated Bihenyl Dechlorination in Aquatic Sediments. Science. 236:709-712.

Call, D.J., M.D. Balcer, L.T. Brooke, S.J. Lozano, and D.D. Vaishnav. 1991. Sediment Quality Evaluation In the Lower Fox River and Southern Green Bay of Lake Michigan. Report by the Center for Lake Superior Environmental Studies of the U.W.-Superior. U.S. EPA Cooperative Agreement No. CR-815232.

Chapman, P.M. 1986. Sediment Quality Criteria From the Sediment Quality Triad: An Example. Environ. Toxicology and Chemistry. 5:957-964.

Chapman, P.M., R.C. Barrick, J.M. Neff, and R.C. Swartz. 1987. Four Independent Approaches to Developing Sediment quality Criteria Yield Similar Values for Model Contaminants. Environ. Toxicology and Chemistry. 6: 723-725.

053211

Clarke, J.U., V.A. McFarland, and J. Dorkin. 1988. Evaluating Bioavailability of Neutral Organic Chemicals in Sediments -- A Confined Disposal Facility Case Study. Proceedings of the Seminar, Water Quality 1988. R.G. Wiley, ed., Hydrologic Engineering Research Center, Davis, CA. pp. 251-268.

Clarke, J.U., V.A. McFarland, B.D. Pierce. 1989. Preliminary Recommendations For a Congener - Specific PCB Analysis In Regulatory Evaluation of Dredged Material. Miscellaneous Paper D-89-2. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Clarke, J.U. and V.A. McFarland. 1991. Assessing Bioaccumulation In Aquatic Organisms Exposed to Contaminated Sediments. Miscellaneous Paper D-91-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Clarke, Joan U., P.L. Whitman, and J. Dorkin. 1992. Trends in PCB Contamination In Fishes from Wisconsin Waters of Lake Michigan, 1978-1986. Miscellaneous Paper D-92-3. Vicksburg, MS. U.S. Army Engineer Waterways Experiment Station.

Cochran, P.A. 1992. The Return of Hexagenia (Ephemeroptera: Ephemeridae) to the Lower Fox River, Wisconsin. The Great Lakes Entomologist. 25:79-81.

Di Toro, D.M. 1985. A Particle Interaction Model of Reversible Organic Chemical Sorption. Chemosphere. 14(10):1503-1538.

Di Toro, D.M., C.S. Zarba, D.J. Hansen, W.J. Berry, R.C. Swartz, C.E. Cowan, S.P. Pavlou, H.E. Allen, M.A. Thomas, and P.R. Paquin. 1991. Technical Basis for Establishing Sediment Quality Criteria for Nonionic Organic Chemicals Using Equilibrium Partitioning. Environ. Tox. and Chemistry. 10:1541-1582.

Dillon, T.M., W.H. Benson, R.A. Stackhouse, and A.M. Crider. 1990. Effects of Selected PCB Congeners On Survival, Growth, and Reproduction In *Daphnia Magna*. Environ. Toxicol. Chemistry. 9:1317-1326.

Dillon, T.M. and W.D.S. Burton. 1991. Acute Toxicity of PCB Congeners to *Daphnia magna* and *Pimephales promelas*. Bull. Environ. Contam. Toxicol. 46:208-215.

Eadie, B.J. 1992. J. Great Lakes Research. 18:91-97

Eisler, R. 1986. Polychlorinated Biphenyl Hazards to Fish, Wildlife, and Invertebrates. A Synoptic Review. U.S. Fish and Wildlife Service. Biological Report 85(1.7).

Evans, M.S., G.E. Noguchi, and O.P. Rice. 1991. The Biomagnification of Polychlorinated Biphenyls, Toxaphene, and DDT Compounds in a Lake Michigan Offshore Food Web. Arch. Environ. Contam. Toxicol. 20: 87-93.

EWI Engineering Associates, Inc. 1991. Draft Technical Memorandum, Task 2: Sediment Characterization Mapping. Deposit A Little Lake Butte des Morts. Prepared for Wisconsin Department of Natural Resources. Project No. 15605.

Ferraro, S.P., H. Lee II, L.M. Smith, R.J. Ozretich, and D.T. Specht. 1991. Accumulation Factors for Eleven Polychlorinated Biphenyl Congeners. Bull Environ. Contam. Toxicol. 46: 276-283.

Gagnon, M.M., J.J. Dodson, M.C. Comba, and K.L. Kaiser. 1990. Congener - Specific Analysis of the Accumulation of Polychlorinated Biphenyls (PCBs) by Aquatic Organisms In the Maximum Turbidity Zone of the St. Lawrence Estuary, Quebec, Canada. The Science of the Total Environment 97/98: 739-759.

Gibson, A.B. and T.M. Dillion. 1989. Bioaccumulation of Chlorinated Contaminants and Concomitant Sublethal Effects in Marine Animals: An Assessment of Current Literature. Environmental Effects of Dredging Technical Notes. U.S. Army Waterways Experiment Station. Vicksburg, MS.

Harris, H.J., T.C. Erdman, K.B. Lodge, and G.T. Ankley. Measures of Reproductive Success and Contaminant Concentration In Forster's Term on Green Bay, Lake Michigan - 1988. Manuscript in preparation.

Hebert, C.E. and G.D. Haffner. 1991. Habitat Partitioning and Contaminant Exposure in Cyprinids. J. Fish. Aquat. Sci. 48:261-266.

Hoke, R.A., J.P. Giesy, and G. Kreis, Jr. 1992. Sediment Pore Water Toxicity Identification in the Lower Fox River and Green bay, Wisconsin, using Microtox Assay. Ecotoxicology and Environmental Safety. 23:343-354.

IJC (International Joint Commission). 1988. Procedures for the Assessment of Contaminated Sediment Problems in the Great Lakes. Report to the Great Lakes Water Quality Board. Sediment Subcommittee and its Assessment Work Group.

Kadeg, R.D. and S.P. Pavlou. 1989. Sediment Toxicity Handbook. Prepared for U.S. EPA Office of Superfund, Hazardous Site Control Division and Office of Water, Criteria and Standards Division by Envirosphere Company. Bellvue, WA.

Kannan, N., S. Tanabe. T. Wakimoto, and R. Tatsukawa. 1987. A Simple Method For Determining non-ortho substituted PCBs in Kanechlors, Aroclors and Environmental Samples. Chemosphere. 16:1631.

Karickhoff, S.W., D.S. Brown, and T.A. Scott. 1979. Sorption of Hydrophobic Pollutants On Natural Sediments Water. Res. 13:241-248.

Kenega. E.E. and C.A.I. Goring. 1978. Relationship Between Water Solubility, Soil Sorption, Octanol - Water Partitioning, and Concentration of Chemicals In Biota. In: Aquatic Toxicology. ASTM Special Technical Publication 707.

Kubiak T.J., H.J. Harris, L.M. Smith, T.R. Schwartz, D.L. Stalling, J.A. Trick, L. Sileo, D.E. Docherty, and T.C. Erdman. 1989. Microcontaminants and Reproductive Impairment of the Forster's Tern On Green Bay, Lake Michigan-1983. Arch. Environ. Contam. Toxicol. 18: 706-727.

Lake, J.L., N.I. Rubinstein, H. Lee II, C. Lake, J. Heltshe, and S. Pavignano. 1990. Equilibrium Partitioning and Bioaccumulation of Sediment-Associated Contaminants By Infaunal Organisms. Environ. Toxicology Chem. 9: 1095-1106.

Landrum, P.F., H. Lee II, M.J. Lydy. 1992. Toxicokinetics In Aquatic Systems: Model Comparisons and Use In Hazard Assessment. Environ. Toxicol. Chem. 11:1709-1725.

Lee, H.II. 1992. Models, Muddles, and Mud: Predicting Bioaccumulation of Sediment - Associated Pollutants. Pgs. 267-293. In: Sediment Toxicity Assessment. Ed. G. Allen Burton. Lewis Publishers.

Long, E.R. and D.D. MacDonald. 1992. National Status and Trends Program. Chapter 14 in Sediment Classificatio n Methods Compendium. U.S. EPA, Office of Water. EPA 823-R-92-0006.

Long, E.R. and L.G. Morgan. 1991. The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program. National Oceanic and Atmospheric Administration. National Ocean Service, Seattle, Wash. NOAA Technical Memorandum NOS OMA 52.

Maack, L. 1988. Sheboygan RAP. PCB Information. Correspondence Memorandum to R. Kazmierczak. April 22, 1988.

Mayer, F.L., P.M. Mehrle, and H.O. Sanders. 1977. Residue Dynamics and Biological Effects of Polychlorinated Biphenyls In Aquatic Systems. Arch. Environ. Contam. and Toxicol. 5: 501-511.

Mac, M., C. Edsall, and R. Hesselberg. 1985. Accumulation of PCBs and Hg by Fish and Earthworms During Field and Laboratory Exposures to Green Bay Sediments. Admin. Report No. 85-4. USFWS-GLFL/AR-85-4.

Mac, M.J. and C.J. Schmitt. 1992. Sediment Bioaccumulation Testing With Fish. In: Sediment Toxicity Assessment. Ed: G.A. Burton, Jr. Lewis Publishers. Ann Arbor.

Mackay, D., W.Y. Shiu, J. Billington, and G.L. Huang. 1983. Physical Chemical Properties of Polychlorinated Biphenyls. In: Physical Behavior of PCBs In the Great Lakes. Ed. D. Mackay, S. Paterson, S.L. Eisenneich, and M.S. Simmons. Ann Arbor Science. pgs. 59-69.

053208

Mackay, D. 1982. Correlation of Bioconcentration Factors. Environ. Sci. Technol. 16: 274-278.

Mackay, D., S. Patterson, and M. Joy. 1983. Application of Fugacity Models to the Estimation of Chemical Distribution and Persistence in the Environment. In: Fate of Chemicals In the Environment. Compartmental and Multimedia Models for Predictions. Ed. R.L. Swann and A. Eschenroeder. American Chemical Society Symposium Series. 225.

McFarland, V.A., J.U. Clarke, and A.B. Gibson. 1985. Bioaccumulation of Polychlorinated Biphenryls (PCBs) from Sheboygan Harbor Wisconsin Sediments In Laboratory Exposures. U.S. Army Corps. of Engineers Waterways Experiment Station. Unpublished Report U.S. ACOE.

Miller, M.A. (in press). Maternal Transfer of Organochlorine Compounds In Salmonines To Their Eggs. Can. J. Fish. Sci. Aquat.

Moore, J.W. and S. Ramamoorthy. 1984. Organic Chemicals In Natural Waters. Applied Monitoring and Impact Assessment. Springer-Verlag. New York.

Oliver, B.G. and A.J. Niimi. 1985. Bioconcentration Factors of Some Halogenated Organics For Rainbow Trout: Limitations In Their Use For Prediction of Environmental Residues. Environ. Sci. Technol. 19:842-849.

Oliver, B.G. and A.J. Niimi. 1988. Trophodynamic Analysis of Polychlorinated Biphenyl Congeners and Other Chlorinated Hydrocarbons in the Lake Ontario Ecosystem. Environ. Sci. Technol. 22: 388-397.

Pavlou, S.P. 1984. The Use of The Equilibrium Partitioning Approach in Determining Safe Levels of Contaminants in Marine Sediments. In: Fate and Effects of Sediment - bound Chemicals In Aquatic Systems. Ed. K.L. Dickson, A.W. Maki, and W.A. Brungs. Proceedings of Sixth Pellston Workshop.

Persaud D., R. Jaagumagi, and A. Hayton. 1990. Provincial Sediment Quality Guidelines. Water Resources Branch, Ontario Ministry of the Environment.

Rathbum, J.E., R.G. Kreis, Jr., E.L. Lancaster, M.J. Mac, and M.J. Zabik. 1988 (unpublished). Pilot Confined Disposal Facility Biomonitoring Study: Channel/Shelter Island Diked Facility, Saginaw Bay, 1987. U.S. EPA Lange Lakes Research Station, ERL - Duluth.

Safe, S. and D. Phil. 1990. Polychlorinated Biphenyls (PCBs), Dibenzo-p-Dioxins (PCDDs), Dibenzofurans (PCDFs), and Related Compounds: Environmental and Mechanistic Considerations Which Support the Development of Toxic Equivalency Factors (TEFs). Critical Reviews In Toxicology. 21:51-88.

Sawyer T.W., A.D. Vatcher, and S. Safe. 1984. Comparative Aryl Hydrocarbon Hydroxylase Induction Activities of Commercial PCBs In Wistar Rats and Rat Hepatoma H-4-II E Cells in Culture. Chemosphere. 13(7): 695-701.

Seelye, J. G., R.J. Hesselberg, and M.J. Mac. 1982. Accumulation by Fish of Contaminants Released from Dredged Sediments. Environ. Sci. Technol. 16: 459-464.

Sijm, D.T.H.M., W. Seinen, and A. Opperhuizen. 1992. Life-Cycle Biomagnification Study in Fish. Environ. Sci. Technol. 26:2162-2174.

Smith, V.E., J.M. Spurr, J.C. Filkins, and J.J. Jones. 1985. Organochlorine Contaminants of Wintering Ducks Foraging On Detroit River Sediments. J. Great Lakes Res. 11(3): 231-246.

Smith, L.M., T.R. Schwartz, K. Feltz, and T.J. Kubiak. 1990. Determination and Occurrence of AHH-Active Polychlorinated Biphenyls, 2,3,7,8 - Tetrachloro-p-Dioxin and 2,3,7,8 - Tetrachlorodibenzofuran In Lake Michigan Sediment and Biota. The Question of Their Relative Toxicological Significance. Chemosphere. 9: 1063-1085.

Sonzogni, W.C. 1990. L. Maack, T. Gibson, and J. Lawrence. 1991. Toxic Polychlorinated Biphenyl Congeners In Sheboygan River (USA) Sediments. Bull. of Environ. Contamination and Toxicology. 47:398-405.

Spigarelli, S.A., M.M. Thommes, and W. Prepejchal. 1983. Thermal and Metabolic Factors Affecting PCB Uptake by Adult Brown Trout. Environ. Sci. Technol. 17: 88-94.

Tillett, D.E., G.T. Ankley, J.P. Giesy, J.P. Ludwig, H. Kurita-Matsuba, D.V. Weseloh, P.S. Ross, C.A. Bishop, L. Sileo, K.L. Stromberg, J. Larson, T.J. Kubiak. 1992. Polychlorinated Biphenyl Residues and Egg Mortality In Double-Crested Cormorants From the Great Lakes. Environ. Toxicol. and Chemistry. 11: 1281-1288.

Thomann, R.V. 1989. Bioaccumulation Model of Organic Chemical Distribution in Aquatic Food Chains. Environ. Sci. Technol. 23: 699-707.

U.S. EPA. 1980. Ambient Water Quality Criteria for Polychlorinated Biphenyls. EPA 440/5-80-068.

U.S. EPA. 1989. Assessing Human Health Risks from Chemically Contaminated Fish and Shellfish. EPA-503/8-89-002.

U.S. EPA. 1990. Draft Ecological Evaluation of Proposed Discharge of Dredged Material Into Ocean Waters. EPA-503-8-90/002.

053206

U.S. EPA. 1990. Guidance On Remedial Actions for Superfund Sites With PCB Contamination. EPA/540/6-90/007.

U.S. EPA. 1991. Guidance On Assessment and Control of Bioconcentratable Contaminants In Surface Waters. Draft. Office of Water. Wash. D.C.

Van Der Kooij, L.A., D. Van De Meent, C.J. Van Leeuwen, and W.A. Bruggeman. 1991. Deriving Quality Criteria For Water and Sediment From the Results of Aquatic Toxicity Tests and Product Standards: Application of the Equilibrium Partitioning Method. Water Research. 6: 697-705.

Walker, M.K. and R.E. Peterson. 1991. Potencies of Polychlorinated Dibenzo-p-Dioxin, Dibenzofuran, and Biphenyl Congeners, Relative to 2,3,7,8-tetrachlorodibenzo-p-Dioxin, For Producing Early Life Stage Mortality In Rainbow Trout (*Oncorhynchus mykiss*). Aquatic Toxicology. 21:219-238.

Wilford, W.A., M.J. Mac, and R.J. Hesselberg. 1987. Assessing the Bioaccumulation of Contaminants From Sediments By Fish and Other Aquatic Organisms. Hydrobiologia. 149: 107-111.

v:\9305\wr9llb99.tpj

053205