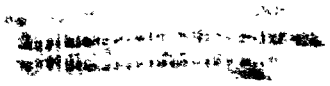
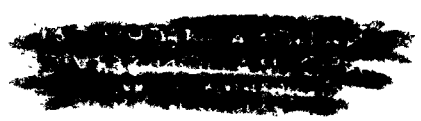
GREAT LAKES WATER QUALITY INITIATIVE

TECHNICAL SUPPORT DOCUMENT FOR

THE PROCEDURE TO DETERMINE BIOACCUMULATION FACTORS

(March 1993 Draft)





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This document provides the technical information and rationale in support of the proposed procedures to determine bioaccumulation factors. Bioaccumulation factors, together with the quantity of aquatic organisms eaten, determine the extent to which people and wildlife are exposed to chemicals through the consumption of aquatic organisms.

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GREAT LAKES WATER QUALITY INITIATIVE

TECHNICAL SUPPORT DOCUMENT FOR

THE PROCEDURE TO DETERMINE BIOACCUMULATION FACTORS

I. INTRODUCTION

A. Purpose and Scope

The purpose of this document is to provide the technical information and rationale in support of the proposed procedures to determine bioaccumulation factors. Bioaccumulation factors, together with the quantity of aquatic organisms eaten, determine the extent to which people and wildlife are exposed to chemicals through the consumption of aquatic organisms. The more bioaccumulative a pollutant is, the more important the consumption of aquatic organisms becomes as a potential source of contaminants to humans and wildlife.

Bioaccumulation factors are needed to determine both human health and wildlife tier I water quality criteria and tier II values. Also, they are used to define Bioaccumulative Chemicals of Concern among the the Great Lakes Initiative universe of pollutants. Bioaccumulation factors range from less than one to several million.

B. Overview of Bioaccumulation and Bioconcentration

Aquatic organisms in nature absorb and retain some water-borne chemicals in their tissues at levels greater than the concentrations of these chemicals in the surrounding water. This process is bioaccumulation. Bioaccumulation can be viewed simply as the result of competing rates of chemical uptake and depuration. However, bioaccumulation is a very dynamic process, affected by the physical and chemical properties of the chemical, the physiology and biology of the organism, environmental conditions, and the amount and source of the chemical. When uptake and depuration are equal, the ratio of the concentration of the chemical in the organism's tissue to the concentration of the chemical in the water is the steady state bioaccumulation factor (BAF). Thus:

$$BAF = \frac{Cff}{Cwf} \qquad (1)$$

Where: Cff = concentration of chemical in the fish in the field

Cwf = concentration of chemical in the water in the field

The Cff is expressed on a mass per mass basis and the Cwf is expressed in a mass per volume basis. For example, the Cff and Cwf may be in mg/kg and mg/L respectively; the BAF is expressed in L/kg. Most Cwf values available in the current literature are total concentrations. BAFs would be more accurate if the Cwf is limited to that portion of the total concentration that is available to the organism for uptake. For example, the bioavailable fraction can be estimated by measuring the concentration in a filtered sample (dissolved analysis).

Bioaccumulation refers to uptake by aquatic organisms of a chemical from all sources such as diet and bottom sediments as well as the water. Measured BAFs are based on field measurements of tissue and water concentrations.

Bioconcentration refers to uptake of a chemical by aquatic organisms exposed only from the water. A bioconcentration factor (BCF) is, as is the BAF, the ratio between the concentration of the chemical in the organism's tissues and the concentration in the water. BCFs are measured in laboratory experiments and have the same units as BAFs. They are determined as follows:

$$BCF = \frac{Cfl}{Cwl} \qquad (2)$$

Where: Cfl = concentration of chemical in the fish in the laboratory
Cwl = concentration of chemical in the water in the laboratory

BCFs, measured in the laboratory, are not always determined under steady state conditions; i.e., conditions under which the tissue and the surrounding water concentrations, and therefore the BCF, are stable over a period of time. Only steady state BCFs, either measured directly or projected based on the data, are useful for the determination of BAFs. Steady state conditions are implied for the BAFs and BCFs referenced throughout this document.

C. Outline of the BAF Procedure

BAFs are determined in three ways listed below from most preferred to least preferred.

1. A BAF measured in the field, preferably on fish in the Great Lakes living at or near the top of the food chain.

2. A BCF measured in the laboratory, preferably on a fish species, times the appropriate Food Chain Multiplier.

3. A BCF predicted from the log of the octanol-water partition coefficient times the appropriate Food Chain Multiplier.

Field measured BAFs, preferred because they reflect bioaccumulation in nature, are available for relatively few chemicals. BCFs have been measured for many more pollutants but a BCF may underestimate bioaccumulation. The BCF data base for organic chemicals can be utilized to derive a BAF through the application of a Food Chain Multiplier. When neither a measured BAF nor BCF is available for an organic chemical, a BCF can be predicted from the chemical's hydrophobicity. BAFs for inorganic chemicals must be based on measured BAFs or BCFs.

II. DATA REQUIREMENTS AND EVALUATION

BAFs and BCFs are obtained from EPA criteria documents, published papers, the AQUIRE data base, and other reliable sources. Data should be screened for acceptability using the criteria in The U.S. Environmental Protection Agency (EPA) guidelines for deriving aquatic life criteria (Stephan et al. 1985), and American Society for Testing and Materials guidance (practice E 1022-84) detailing methods for conducting a flow-through bioconcentration test (ASTM 1990).

In general, the Great Lakes Initiative (GLI) BAF procedures follow closely the EPA guidance (Stephan et al. 1985) with the addition of the Food Chain Multiplier. The EPA recently published draft guidance on the control of bioaccumulative pollutants in surface waters which recommends the use of food chain multipliers (USEPA 1991A).

No guidance can cover all the variations of experimental design and data presentation found in the literature concerning BAFs and BCFs. Professional judgment is needed throughout the BAF development process to select the best available information.

III. DETERMINATION OF BAFs FOR ORGANIC CHEMICALS

A. Bioaccumulation-Lipid Relationship

A fundamental assumption made in the determination of BAFs for organic chemicals is that bioaccumulation can be defined by the partitioning of the chemical between the water and lipid phase of the aquatic animal. Making this assumption means, 1) BCFs can be predicted from the partitioning of an organic chemical between octanol and water phases, and 2) BAFs can be derived from BAF or BCF data from a variety of species and tissues by normalizing the BAFs or BCFs on a lipid basis. This assumption has been extensively evaluated in the literature (e.g. Mackay 1982, Connell 1988, Barron, 1990), and is generally accepted. It is

part of the EPA guidance on bioaccumulation (Stephan et al. 1985, USEPA 1991A), and is included in the GLI BAF procedure.

It is important to note, however, that some researchers report little basis for expressing contaminant concentrations on a lipid basis (Schmitt et al. 1990, Borgmann and Whittle 1991). Schmitt et al. (1990) and Randall et al. (1991) suggest that solvent extracted lipid material represents a very complex mixture of compounds, and organic chemicals may not be distributed uniformly among the extractable lipids. Consistent with these observations, it has been shown that the analytical method used to determine percent lipid can affect lipid values because different solvent systems extract different fractions of total lipids (Randall et al. 1991). Percent lipid is determined gravimetrically. The tissue sample is extracted with an organic solvent; the extract is placed in a tared beaker, allowed to air dry, and then heated to 85 to 100 degrees C for one hour. The sample is reweighed and the percent lipid calculated. Resulting percent lipid values can vary by as much a factor of four depending on the solvent system used (Randall et al. 1991). Specifically, the chloroform-methanol method (Bligh and Dyer 1959) results in lipid values about two times larger than methods using some other solvent systems (Randall et al. 1991).

Lipid content of fish tissue is affected by the age, sex and diet of the fish, and by the season the fish are sampled, and differing environmental conditions. Therefore, it is generally necessary to determine an average percent lipid value for the test organisms.

The GLI proposes to normalize BAFs and BCFs reported in the literature to one percent lipid, and adjust them to the percent lipid selected to represent the Great Lakes community to be protected. Since BAFs are used to calculate both human health and wildlife criteria, a standard percent lipid value was needed for each. GLI criteria are applicable to both the Great Lakes and the inland waters of the Great Lakes basin. To assure protection of the Great Lakes the lipid values proposed are based on the lipid content of Great Lakes fish.

Percent lipid data from the fish contaminant monitoring programs in Michigan, Wisconsin, Ohio, Indiana, New York and Minnesota provided lipid data for edible tissues (e.g. muscle) of fish from each of the Great Lakes (Appendix A). Most lipid data are for skin-on fillets. Skin-on fillets are the accepted tissue sample used by most of the Great Lakes fish consumption advisory programs. These data were used to determine the proposed standardized lipid value of 5.0 percent for human health BAFs. Whole fish lipid data from the the U.S. Fish and Wildlife Service national contaminant biomonitoring program and the Canada Department of Fisheries and Oceans were used to determine the proposed standardized lipid value of 7.9 percent for wildlife BAFs. (Appendix B).

A variety of solvents were used by the programs providing lipid data as shown in Table 1. However, the methods used all measure a subset of total lipids. None used the more exhaustive chloroform-methanol method, and the resulting variability in lipid measurements should be within an acceptable range. (As previously mentioned, the exhaustive chloroform-methanol method resulted in lipid values two times larger than those results from the other solvent systems.

Table 1

Organic Solvents Used to Extract Lipids from Fish Tissue By State and Federal Contaminant Programs

	Program	Solvent
Edible Tissue Samples	Indiana	Hexane
	Michigan	Ethyl ether Petroleum ether
	Minnesota	Hexane
	New York	Hexane
	Ohio	Petroleum ether
	Wisconsin	Dichloromethane
Whole Fish Samples	U.S. Fish & Wildlife Service	
	Canada Dept. of Fisheries and Oceans	Hexane

The GLI Technical Work Group also reviewed the edible portion percent lipid data weighted by human fish consumption patterns on the Great Lakes to determine if this would significantly change the proposed lipid value. Creel survey and game fish harvest data from the sources listed below were used in this analysis. The harvest data in percent of total catch by species was combined with data for the typical weights of game fish species (from the same sources), to determine a consumption weighting "factor". This factor was applied to the edible portion species mean lipid data discussed above to calculate a consumption weighted lipid value (Appendix A, Table A4). The overall mean of the consumption weighted lipid values for the Great Lakes is 4.7 percent. It was felt by the Technical Work Group that this value was not substantially different from the non-weighted mean of 5.0, and elected to retain the proposed value of 5.0 percent.

	Program	Lakes Represented
Creel Survey Data	Michigan	Superior, Huron, Michigan and Erie
	Minnesota	Superior
	New York	Erie and Ontario

Wisconsin Superior and Michigan

A standardized lipid value for wildlife BAFs was determined using the whole fish lipid data from the two federal programs mentioned above, plus some additional whole fish values from the New York Department of nvironmental Conservation. Species mean lipid values for all fish species, both game and non-game, were calculated. The mean of these values is 7.9 percent lipid (Appendix B). The proposed value of 9 percent for wildlife BAFs is based on an errcneous mean value of 8.9 from an earlier calculation.

B. Bioconcentration and Octanol-Water Partitioning

The widely used surrogate for the lipid-water system in fish is the partitioning of organic chemicals between octanol and water. The log of the octanol-water partition coefficient (log K_{ow}) has been shown empirically to be related to the bioconcentration of organic chemicals, with certain limitations.

A relationship between bioconcentration and the lipid content of fish was suggested by Hamelink et al. (1971) in their investigation of the increase in DDT bioaccumulation in successive trophic levels. Subsequently, Neely et al. (1974) with eight chemicals and Veith et al. (1979) with 55 chemicals demonstrated a linear correlation between the log BCF and the log K_{ow}.

The relationship of Veith et al. (1979) can be expressed as follows:

$$\log BCF = 0.85 \log K_{ow} - 0.70 \qquad (3)$$

$N = 55$

$r^2 = 0.897$

Where: $\log K_{ow} = \log_{10}$ of the octanol-water partition coefficient

Equation 3 was used by EPA to predict BCFs in the absence of measured BCFs, for the calculation of the 1980 human health criteria. Veith and Kosian (1983) expanded the number of chemicals upon which the relationship is based to 122 by including data for 12 species of freshwater and saltwater fish in addition to the fathead minnow data used to determine the relationship expressed in equation 3. The correlation from the larger data set is expressed as follows:

$$\log BCF = 0.79 \log K_{ow} - 0.40 \qquad (4)$$

$N = 122$

$r^2 = 0.86$

This equation has been adopted by EPA to predict BCFs in the absence of measured values (USEPA 1991A), and is the model used in the computerized Quantitative Structure-Activity Relationships (QSAR) database to predict BCFs. Equation 4 is proposed for the GLI procedures for the estimation of BCFs.

The ability to predict the bioconcentration potential of a wide range of organic chemicals is very useful in toxicology, and the log K_{ow} model has been widely used for this purpose. However, as with any model, it is important to understand its limitations. Some of these are discussed below and in section III.E.

Veith and Kosian (1983) indicate that the BCFs estimated with equation 4 have 95 percent confidence limits of about one order of magnitude. For example, a predicted BCF of 100 would have confidence limits ranging from about 10 to 1000. Also, the accuracy of BCF prediction is likely to be even less for super lipophilic chemicals; i.e., chemicals with log K_{ow} values greater than 6.5. Veith and Kosian (1983) caution the use of their model for chemicals with molecular weights greater than 600. As organic molecules increase in size and molecular weight, membrane permeability apparently is inhibited which limits bioaccumulation (Veith and Kosian 1983, Oliver and Niimi 1985). A ceiling of 100,000 is used for QSAR estimated BCFs for super lipophilic organic chemicals. Equation 4 equates a BCF of 100,000 to a log K_{ow} value of about 6.8 at 7.6 percent lipid. The GLI procedure proposes a cap of 100,000 (at 7.6 % lipid) for predicted BCFs.

Bioconcentration models based on other factors such as water solubility (Metcalf et al. 1975), other physicochemical factors (Schuuman and Klein 1988), or both biological and physicochemical factors (Barber et al. 1988, Barber et al. 1991) have been proposed, but so far none has gained the wide acceptance of the log K_{ow} model.

C. Food Chain Biomagnification

The importance of uptake of chemicals through the diet and the potential for a stepwise increase in bioaccumulation from one trophic level to the next in natural systems has been recognized for many years (Hamelink et al. 1971). This pathway, involving transfer of a chemical in food through successive trophic levels, is called biomagnification. Many researchers have noted that the bioaccumulation factors of some chemicals in nature exceed the bioconcentration factors measured in the laboratory or estimated by log K_{ow} models (e.g. Oliver and Niimi 1983, Oliver and Niimi 1988, Niimi 1985, Swackhammer and Hites 1988). Chemicals

exhibiting this phenomenon are typically highly lipophilic, have low water solubilities, and are resistant to being metabolized by aquatic organisms (Metcalf et al. 1975).

Some researchers have modeled bioaccumulation and uptake through the food chain. Oliver and Niimi (1988) correlated BAFs for PCBs and other chlorinated organics with log K_{ow} values similar to what others have done with BCFs and log K_{ow}. The resulting equation is:

$$\log BAF = 1.07 \log K_{ow} - 0.21 \qquad (5)$$

$$n = 18$$

$$r^2 = 0.86$$

BAFs calculated with equation 5 in a range of log K_{ow} values of 4 to 6.5 are about 15 to 70 times larger than BCFs calculated using equation 4 as shown in Table 2. The factor in Table 2 represents the predicted ratio of uptake through water plus food to uptake through water only (a food chain multiplier). Consideration of uptake only from water, or use of unadjusted BCFs, could substantially underestimate bioaccumulation for highly lipophilic chemicals.

Table 2

Comparison of BAFs from Equation 5 (Oliver and Niimi 1988) to BCFs from equation 4 (Veith and Kosian 1983)

Normalized to 1 Percent Lipid

Log Kow	BAF Equation 6	BCF Equation 4	Factor (BAF/BCF)
4.0	1,068	76	14
4.5	3,661	188	19
5.0	12,549	467	27
5.5	43,014	1,159	37
6.0	147,437	2,879	51
6.5	505,368	7,148	71

Connolly and Pedersen (1988) examined the transfer gradients (fugacity) of chemicals between water and biota. Fugacity ratios between water and fish increase with log K_{ow} from one at log K_{ow} of 4 to three or four at log K_{ow} of 6. This basic food chain model indicates that for chemicals with log K_{ow} values less than 4, uptake of the chemical from food is not important. At higher log K_{ow} values and fugacity ratios greater than one, uptake through food becomes increasingly important because the animal becomes less able to depurate the assimilated chemical (Connolly and Pedersen 1988). Thomann and Connolly (1984) modeled the uptake of PCBs through the food chain using concentrations measured in Lake Michigan alewife and lake trout to calibrate the model. The model predicts order of magnitude greater PCB concentration in juvenile lake trout when food uptake is included over uptake from water only. The ratio increases to two orders of magnitude for older trout, which is probably partially explained by the greater lipid content of older trout. The predicted BCF for PCBs using a log K_{ow} of 6.72 and equation 4 is four to five times lower than the measured and modeled BAFs (Thomann and Connolly 1984).

D. Food Chain Multipliers

Food chain multipliers (FCM) for organic chemicals were derived using the model of Thomann (1989). Thomann's model is a four trophic level pelagic food chain as follows:

Trophic level 1	phytoplankton
Trophic level 2	zooplankton
Trophic level 3	small fish
Trophic level 4	top predator fish

The model predicts tissue residue concentrations at each trophic level as a result of chemical uptake from water and contaminated food in the food chain.

Thomann's model was programmed in Fortran on a VAX computer at the EPA Environmental Research Laboratory in Duluth. The required input data for the model was taken from Table II in Thomann's paper. The required input data consists of: a) weights of organisms for trophic levels 2, 3, and 4, b) respiration parameters, c) growth parameters, d) lipid fraction of trophic levels 2, 3, and 4, and e) food assimilation efficiencies.

Thomann (1989) evaluated four different sets of model assumptions, and all four provide similar predictions for chemicals with log K_{ow} values less than approximately 6.5. Model set C was selected to derive the food chain multipliers. Model C assumes that the phytoplankton BCF equals the K_{ow} of the chemical and that the assimilation efficiency of the chemical is a function of the chemical's K_{ow}.

Using the data from Table II of Thomann and the assumptions of model C, the computer model was run using log K_{ow} values of 3.5, 3.6, 3.7, ..., 6.3, 6.4, and 6.5; and BCFs and BAFs were calculated for each trophic level for each log K_{ow} value. Food chain multipliers were calculated using the following equations:

For trophic level 2: $FCM = BAF_2/BCF_2$
For trophic level 3: $FCM = BAF_3/BCF_2$
For trophic level 4: $FCM = BAF_4/BCF_2$

where BCF_2 is the bioconcentration factor for trophic level 2 organisms and BAF_2, BAF_3, and BAF_4 are the bioaccumulation factors for trophic levels 2, 3, and 4, respectively.

In calculating the FCMs for each trophic level, the BCF of trophic level 2 was used since, in many cases, measured BCFs have

been determined using smaller organisms such as guppies, fathead minnows, and Daphnia. The resulting FCMs for trophic levels 2, 3 and 4 are shown in Table 3. FCMs for trophic level 4 increase above 1 starting at log K_{ow} equals 4 and reach a maximum of 100 at log K_{ow} equals 6.5. Thomann compared predicted BAFs for trophic level 4 with measured BAFs from the Great Lakes and concluded that, within an order of magnitude, model predicted BAFs were a reasonable representation of the observed data for chemicals with log K_{ow} values in the range of 3.5 to 6.5.

For chemicals with log K_{ow} values greater than 6.5, Thomann's model is very sensitive to the input parameters and model assumptions. In addition, other factors not accounted for in the model such as metabolism of the chemical can affect bioaccumulation of these highly lipophilic chemicals, and the risk of over estimating the BAF is great. Therefore, FCMs for log K_{ow} values greater than 6.5 are given as a range; 0.1 to 19, 0.1 to 45, and 0.1 to 100 for trophic levels 2, 3 and 4, respectively. USEPA (1991A and 1991B) indicates that the FCM may be as low as 0.1 at log K_{ow} values greater than 6.5. Super lipophilic chemicals will be evaluated individually to determine the appropriate FCM to use within the range of 0.1 to 100. If chemical-specific data are not available, the GLI Steering Committee decided that a FCM of 1 should be used. In conclusion, the FCM model works best for lipophilic chemicals with log K_{ow} values in the range of 4.5 to 6.5 that are poorly metabolized by aquatic organisms.

In application, FCMs for trophic level 4 are used to determine BAFs for calculating human health criteria because most game fish consumed by people are top, or near top, carnivore fish. FCMs for trophic levels 3 and 4 are used to determine BAFs for calculating wildlife criteria because wildlife consume aquatic organisms over a range of trophic levels. The FCMs in Table 3 are the same FCMs included in EPA's draft guidance on the control of bioconcentratable pollutants (USEPA 1991A), and the technical support document for setting water quality-based effluent limitations (USEPA 1991B).

The bioaccumulation work of several researchers indicates that FCMs up to 100 are consistent with the differences between measured BAFs in the Great Lakes compared to their respective BCFs for highly lipophilic and persistent chemicals (Oliver and Niimi 1988 and Table 2). Oliver and Niimi (1985) reported field BAFs up to 220 times larger that laboratory BCFs for some chlorinated hydrocarbons.

Rasmussen et al. 1990 reported a 3.5 factor increase in biomagnification of PCBs with each trophic level in lake trout in Ontario lakes. When corrected for the 1.5 percent increase in trout lipid content with each additional trophic level below the trout, the factor becomes 2.3. This factor agrees well with the ratios of trophic level 4 to 3 FCMs in Table 3, which range from

about 2 to 3.2, for chemicals with log K_{ow} values between 5.5 to 6.5.

Table 3

Food Chain Multipliers

Log Kow	Trophic Levels* 2	3	4
<3.9	1.0	1.0	1.0
4.0	1.1	1.0	1.0
4.1	1.1	1.1	1.1
4.2	1.1	1.1	1.1
4.3	1.1	1.1	1.1
4.4	1.2	1.1	1.1
4.5	1.2	1.2	1.2
4.6	1.2	1.3	1.3
4.7	1.3	1.4	1.4
4.8	1.4	1.5	1.6
4.9	1.5	1.8	2.0
5.0	1.6	2.1	2.6
5.1	1.7	2.5	3.2
5.2	1.9	3.0	4.3
5.3	2.2	3.7	5.8
5.4	2.4	4.6	8.0
5.5	2.8	5.9	11
5.6	3.3	7.5	16
5.7	3.9	9.8	23
5.8	4.6	13	33
5.9	5.6	17	47
6.0	6.8	21	67
6.1	8.2	25	75
6.2	10	29	84
6.3	13	34	92
6.4	15	39	98
6.5	19	45	100
>6.5	**	**	**

*Trophic level: 2 is zooplankton
3 is small fish
4 is piscivorous fish including top predators

**For chemicals with log K_{ow} values greater than 6.5 a FCM can range from 0.1 to 100. Such chemicals should be evaluated individually to determine the appropriate FCM. In the absence of chemical-specific information, a FCM of 1 should be used.

Measured "food chain multipliers" were recently reported for a plankton, "Mysis/Pontoporeia", sculpin food chain in Lakes Michigan and Ontario (Evans et al. 1991). It is useful to compare the measured increase in bioaccumulation through the trophic levels of this food chain to FCMs calculated from the Thomann model. The measured and predicted increase in biomagnification show good agreement between trophic levels 3 and 4 for the three organic pollutants studied (Table 4).

Table 4

Comparison of Measured to Predicted Ratios
Of Trophic Level 3 to Trophic Level 2 Tissue Residues

Pollutant	Log K_{ow}*	Trophic level 3/2		
		Observed**		Predicted***
		L. Michigan	L. Ontario	
Total DDT	6.4	2.8	2.1	2.6
Total PCBs	6.3	2.5	3.5	2.6
Toxaphene	5.0	3.7	-	1.3

* Log K_{ow} values are those used by the GLI to estimate BAFs

Log K_{ow} for DDE used for DDT because DDE accounted for over 75% of total DDT in Lake Michigan.

Log K_{ow} for total PCBs from the following aroclor specific values:

Aroclor 1016	5.58
1242	5.58
1248	6.11
1254	6.72

** Observed ratios: Sculpin to mysid/amphipod from Evans et al. 1991; adjusted for lipid content: Sculpin, 8 % and mysid/amphipod, 3 % from Oliver and Niimi, 1988.

*** Predicted values based on food chain biomagnification model in Thomann 1989.

E. Factors Affecting Bioaccumulation of Organic Chemicals

The steady state BAF for an organic chemical is the result of very complex and dynamic chemical, physical and biological interactions. Whereas some factors enhance bioaccumulation, others can inhibit or reduce bioaccumulation below levels predicted by log K_{ow} based BCF and FCM models. Some of these factors were mentioned previously in Section III B.

Low chemical absorption efficiencies from water to the gill and the ability of organisms to rapidly metabolize chemicals can effectively lower bioaccumulation. Niimi et al. (1989) reported that BCFs for chloronitrobenzenes (mono to penta) ranged from 69 to 1362, but the measured BCFs did not significantly increase as log K_{ow} increased. Predicted BCFs for these chemicals based on measured log K_{ow} values (Niimi et al. 1989) and equation 4 range from 34 to 2581 (8.4 % lipid). The predicted BCFs for the chloronitrobenzenes as a group, while larger than the measured BCFs, are well within the expected range of variability for BAF and BCF data. However, the measured BCF for pentachloronitrobenzene is 171 (Niimi et al. 1989). Compared to a predicted BCF of 2581 [(log Kow 4.77) 2335 x 8.4/7.6 (lipid adjustment) = 2581], bioconcentration is overestimated by a factor of 15.

The potential disparity between measured and predicted BAFs or BCFs becomes more important for chemical groups with log K_{ow} values in the 5 to 7 range. Bioaccumulation studies on polycyclic aromatic hydrocarbons (PAHs) indicate that dietary uptake is not a major pathway of bioaccumulation for many PAHs in most fish species tested (Niimi and Dookhran 1989). Log K_{ow} predicted BCFs for the more water soluble PAHs, without considering dietary uptake, often exceed field measured BAFs by a factor of two (Niimi and Dookhran 1989). This is usually attributed to the rapid metabolism of these chemicals in fish, or their poor absorption efficiency, or both. Predicted BAFs and BCFs for chemicals with these characteristics will probably substantially overestimate true bioaccumulation in nature.

Several researchers have discussed other physicochemical and biological properties that can inhibit bioaccumulation of super lipophilic chemicals (log K_{ow} > 6.5). Very low water solubility and large molecular size can limit molecular transport (McKim et al. 1985, Oliver and Niimi 1985). Ellgehausen et al. (1980) found that depuration rate and half-life, which were correlated with log K_{ow} values, were important factors related to bioaccumulation. Gobas et al. (1989) examined the importance of reduced bioavailability and slow chemical uptake rates of super lipophilic chemicals in the inhibition of bioaccumulation in nature. As discussed under food chain multipliers, the ability to predict food chain bioaccumulation is poor for super lipophlic chemicals (Thomann 1989).

IV. DETERMINATION OF BAFs FOR INORGANIC CHEMICALS

The lipid-BAF relationship does not apply to the determination of BAFs for inorganic chemicals. BAF and BCF data for inorganics are not as transferable from one species, or one tissue, to another as organic data. Bioaccumulation of some trace metals is substantially greater in internal organs than muscle tissue. For example, BCFs for rainbow trout liver, kidney, gut and skin, and muscle exposed to cadmium for 178 days were about 325, 75, 7, and 1 respectively (Giles 1988). Merlini and Pozzi (1977) reported that lead bioconcentrated 30 times more in bluegill liver than in bluegill muscle tissue after eight days. They reported a BCF for muscle tissue of 0.46.

Because bioaccumulation can differ dramatically between tissues, BAFs or BCFs for edible tissue should be used for BAFs to calculate human health criteria. Similarly, BAFs or BCFs for whole body fish should be used for the BAFs used to calculate wildlife criteria.

BAFs or BCFs for inorganic chemicals measured in plants or invertebrate animals might be one or more orders of magnitude greater than BAFs or BCFs for the edible tissue of fish (see Table 5 in the EPA criteria documents for cadmium, copper, lead and nickel; USEPA 1985A, USEPA 1985B, USEPA 1985C, and USEPA 1986). For this reason plant or invertebrate BAFs and BCFs should not be used to calculate GLI human health criteria and values. If site-specific conditions warrant, and the resulting criteria are more stringent, plant or invertebrate BAFs or BCFs could be used to calculate wildlife criteria.

Mercury and certain other metals are subject to methylation through microbial action in nature. The organo-metalic form of the metal, especially methyl mercury, is highly bioaccumulative in the muscle tissue of fish (Grieb et al. 1990).

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APPENDIX A

TABLE A1

LIPID CONTENT OF EDIBLE PORTIONS OF GREAT LAKES FISH

Species Mean Values from Each Source

LAKE	SPECIES	PERCENT LIPID Xg	Xa	N	PORTION	SOURCE
SUPERIOR	Bloater Chub		10.27	3	F	WDNR
	Brown Trout		6.40	11	F	WDNR
	Carp		7.84	9	F	WDNR
	Chinook		3.35	10	Fs	MDNR
	Chinook		2.95	4	F	WDNR
	Chinook		2.96	5	F	MPCA
	Chinook		2.68	14	F	MPCA
	Coho		7.50	3	F	WDNR
	Coho		1.39	8	F	MPCA
	Coho		1.56	5	F	MPCA
	Herring		9.20	1	F	WDNR
	Herring		4.58	6	D	MPCA
	Lake Trout		11.42	44	F	WDNR
	Lake Trout		10.46	71	F	MPCA
	Lake Trout		9.21	28	F	MPCA
	Lake Trout	11.34		71	F	MDNR
	Rainbow Smelt		0.90	3	D	MPCA
	Rainbow Trout		2.13	3	F	WDNR
	Rainbow Trout		1.24	8	F	MPCA
	Walleye		1.91	33	F	WDNR
	Whitefish	7.85		10	F	MDNR
	Whitefish		7.15	2	F	MPCA
	Yellow Perch		0.92	8	F	WDNR
MICHIGAN	Black Bullhead		1.80	1	Fs	WDNR
	Bloater Chub		14.75	92	F	WDNR
	Brook Trout		4.33	68	F	WDNR
	Brown Trout		11.96	170	F	WDNR
	Brown Trout	5.68		46	F	MDNR
	Brown Trout		11.19	21	A	IDEM
	Brown Trout		11.22	6	D	IDEM
	Brown Trout		3.88	5	Fs	IDEM
	Brown Trout		6.70	9	F	IDEM
	Carp		20.43	2	F	IDEM
	Carp	6.82		16	Fs	MDNR
	Carp		10.68	47	F	WDNR
	Channel Catfish		8.92	11	Fs	WDNR
	Chinook		4.20	275	F	WDNR
	Chinook		4.92	30	A	IDEM
	Chinook		2.60	4	D	IDEM
	Chinook		1.45	5	Fs	IDEM

Chinook		2.46	28	F	IDEM
Chinook	1.79		71	F	MDNR
Chinook-trim	0.99		10	0	MDNR
Coho		5.96	19	A	IDEM
Coho		6.51	8	D	IDEM

TABLE AI (continued)

LAKE	SPECIES	PERCENT LIPID Xg	Xa	N	PORTION	SOURCE
MICHIGAN (continued)	Coho		1.95	2	Fs	IDEM
	Coho		2.80	18	F	IDEM
	Coho	2.42		36	F	MDNR
	Coho		3.82	164	F	WDNR
	Lake Trout		17.25	156	A	IDEM
	Lake Trout		16.58	13	D	IDEM
	Lake Trout		8.81	3	Fs	IDEM
	Lake Trout		12.01	9	F	IDEM
	Lake Trout	16.67		60	F	MDNR
	Lake Trout		12.71	311	F	WDNR
	Lake Trout-trim	9.19		10	0	MDNR
	Longnose Sucker		5.45	2	A	IDEM
	Longnose Sucker		4.95	3	F	IDEM
	Longnose Sucker	5.59		10	F	MDNR
	Northern Pike		3.00	2	A	IDEM
	Northern Pike	0.57		10	Fs	MDNR
	Rainbow Trout	3.76		25	F	MDNR
	Steelhead		11.09	17	A	IDEM
	Steelhead		7.10	3	D	IDEM
	Steelhead		2.77	2	Fs	IDEM
	Steelhead		5.62	6	F	IDEM
	Walleye	1.63		11	F	MDNR
	Walleye		1.45	9	Fs	MDNR
	Walleye		2.19	9	F	WDNR
	Whitefish		9.00	1	A	IDEM
	White Sucker		2.45	2	A	IDEM
	White Sucker	1.61		10	F	MDNR
	Yellow Perch		3.00	1	A	IDEM
	Yellow Perch		1.55	6	D	IDEM
	Yellow Perch		1.06	9	F	IDEM
	Yellow Perch	0.82		10	F	MDNR
	Yellow Perch		0.95	24	F	WDNR
MICHIGAN (Green Bay)	Black Bullhead		1.10	8	Fs	WDNR
	Brook Trout		4.97	9	F	WDNR
	Brown Trout		9.44	106	F	WDNR
	Carp		8.17	48	F	WDNR
	Channel Catfish		4.75	15	Fs	WDNR
	Chinook		4.63	46	F	WDNR
	Coho		7.70	1	F	WDNR
	Lake Trout		11.88	28	F	WDNR
	Rainbow Trout		6.39	45	F	WDNR
	Smallmouth Bass		1.34	10	F	WDNR
	Walleye		2.71	67	F	WDNR
	White Bass		3.76	18	F	WDNR
	Yellow Perch		0.76	26	F	WDNR

HURON	Brown Trout	7.54	20	F	MDNR
	Carp	11.37	9	Fs	MDNR
	Channel Catfish	10.69	1	Fs	MDNR
	Chinook	1.72	44	F	MDNR
	Coho	3.96	8	F	MDNR
	Lake Trout	14.12	80	F	MDNR
	Walleye	1.62	10	F	MDNR

TABLE A1 (continued)

LAKE	SPECIES	PERCENT LIPID Xg	Xa	N	PORTION	SOURCE
ERIE	Carp	3.44		8	Fs	MDNR
	Chinook		3.88	21	F	NYDEC
	Channel Catfish	7.11		10	Fs	MDNR
	Coho		4.50	22	F	NYDEC
	Lake Trout		13.00	5	F	NYDEC
	Smallmouth Bass		1.99	19	F	NYDEC
	Walleye	2.56		40	F	MDNR
	Walleye		1.98	9	Fs	OEPA
	White Bass		4.42	8	Fs	OEPA
	Whitefish		8.75	4	Fs	OEPA
ONTARIO	Brown Trout		10.40	91	F	NYDEC
	Channel Catfish		12.80	47	Fs	NYDEC
	Chinook		2.75	45	F	NYDEC
	Coho		3.38	98	F	NYDEC
	Lake Trout		14.53	120	F	NYDEC
	Rainbow Trout		9.04	57	F	NYDEC
	Smallmouth Bass		1.85	161	F	NYDEC
	White Perch		5.64	33	F	NYDEC

Key to Abbreviations

Percent Lipid:
- Xg = geometric mean, contributing program (source) used geometric means to summarize data
- Xa = arithmetic mean, contributing program (source) used arithmetic means to summarize data

N = Number of fish sampled

Portion:
- F = filet, skin on
- Fs = filet, skin off
- A = Anterior section through fish
- D = dressed (gutted, head removed)
- 0 = filet, skin off, visible fat removed (trimmed)

Source:
- MDNR = Michigan Department of Natural Resources. Fish Contaminant Monitoring Program, Data for Lakes Erie, Huron, Michigan and Superior 1986-1989.
- MPCA = Minnesota Pollution Contol Agency. Minnesota Fish Consumption Advisory Program, Data for Lake Superior.
- IDEM = Indiana Department of Environmental Management, OWM-Biological Studies, Data for Lake Michigan.

OEPA = Ohio Environmental Protection Agency. Ohio Dept. of Natural Resources, Data for Lake Erie.
WDNR = Wisconsin Department of Natural Resources. Data for Lakes Michigan and Superior.
NYDEC = New York Department of Environmental Conservation. Data for Lakes Erie and Ontario.

TABLE A2

GREAT LAKES INITIATIVE

LIPID CONTENT OF FISH EDIBLE PORTIONS, SPECIES MEAN VALUES BY LAKE

Lake/Species	Percent Lipid	
	Mean	n*
LAKE SUPERIOR		
Salmonids (excluding Siscowet) x = 5.65 n = 7		
lake trout	10.61	4
herring	6.89	2
whitefish	7.50	2
brown trout	6.40	1
chinook	2.99	4
coho	3.48	3
rainbow trout	1.69	2
Nonsalmonids x = 1.42 n = 2		
walleye	1.91	1
yellow perch	0.92	1
Nongame fish x = 6.34 n = 3		
bloater chub	10.27	1
carp	7.84	1
rainbow smelt	0.90	1
All fish x = 5.12 n = 12		
LAKE HURON		
Salmonids x = 6.84 n = 4		
lake trout	14.12	1
brown trout	7.54	1
chinook	1.72	1
coho	3.96	1
Nonsalmonid fish x = 6.16 n = 2		
walleye	1.62	1
channel catfish	10.69	1
All nongame fish (carp)	11.37	1
All fish x = 7.29 n = 7		

LAKE MICHIGAN (including Green Bay)

Salmonids x = 7.09 n = 7		
brook trout	4.65	2
brown trout	8.58	7
rainbow trout (steelhead)	6.12	6
chinook	3.15	7
coho	4.45	7
lake trout	13.70	7
whitefish	9.00	1

* Number of state programs reporting data for a species.

TABLE A2 (continued)

Lake/Species	Percent Lipid Mean	n*
LAKE MICHIGAN (including Green Bay) (continued)		
Nonsalmonid x = 2.65 n = 7		
black bullhead	1.45	2
northern pike	1.79	2
walleye	2.00	4
yellow perch	1.36	6
channel catfish	6.84	2
smallmouth bass	1.34	1
white bass	3.76	1
All nongame fish x = 8.41 n = 4		
bloater chub	14.75	1
carp	11.53	4
longnose sucker	5.33	3
white sucker	2.03	2
All fish x = 5.61 n = 18		
LAKES ST. CLAIR AND ERIE		
Salmonids x = 7.53 n = 4		
lake trout	13.00	1
whitefish	8.75	1
chinook	3.88	1
coho	4.50	1
Nonsalmonid fish x = 3.95 n = 4		
walleye	2.27	2
channel catfish	7.11	1
smallmouth bass	1.99	1
white bass	4.42	1
Nongame fish (carp)	3.44	1
All fish x = 5.48 n = 9		
LAKE ONTARIO		
Salmonids x = 8.02 n = 5		
Lake trout	14.53	1
brown trout	10.40	1
coho	3.38	1
chinook	2.75	1
rainbow trout	9.04	1
Nonsalmonid fish x = 7.33 n = 2		
smallmouth bass	1.85	1

channel catfish	12.80	1
Nongame fish (excluding american eel)		
white perch	5.64	1

All fish x = 7.55 n = 8

SPECIES MEAN LIPID VALUES, POOLED FOR ALL GREAT LAKES

SALMONIDS	MEAN(n*)	NONSALMONID GAME FISH	MEAN(n*)	NONGAME FISH	MEAN(n*)
Brook trout	4.65(1)	Black bullhead	1.45(1)	Bloater chub	12.51(2)
Brown trout	8.23(4)	Channel catfish	9.36(4)	Carp	8.55(4)
Chinook	2.90(5)	Northern pike	1.79(1)	Longnose sucker	5.33(1)
Coho	3.95(5)	Smallmouth bass	1.73(3)	Rainbow smelt	0.90(1)
Herring	6.89(1)	Walleye	1.95(4)	White perch	5.64(1)
Lake trout	13.19(5)	White bass	4.09(2)	White sucker	2.03(1)
Rainbow trout	5.62(3)	Yellow perch	1.14(2)		
Whitefish	8.42(3)				
OVER ALL MEANS	6.73		3.07		5.83
Std. Dev.	3.27		2.93		4.27
N	8		7		6

	ALL GAME FISH	ALL FISH
OVER ALL MEANS	5.02	5.25
Std.Dev.	3.55	3.68
N	15	21

* Number of lakes for which data are available

APPENDIX B
TABLE BI

LIPID CONTENT OF WHOLE FISH FROM THE GREAT LAKES

Species Mean Values By Lake

SPECIES	LAKE*						CDF&O**	MEAN
	Sup.	Mich.	Hur.	St.C	Erie	Ont.		
Salmonids								
Bloater	13.1	22.3						17.7
Brown trout						12.2	15.44	13.8
Coho salmon							8.45	8.5
Lake herring						6.0		
Lake trout	16.6	17.0	20.5			15.3#	17.25	17.3
Lake Whitefish	10.5		10.0					10.3
Pink salmon							1.78	1.8
Rainbow trout							7.59	7.6

Skipjack herring	9.8						9.8
Spake						10.12	10.1
SALMONID MEAN							10.28
Nonsalmonid Game Fish							
Brown bullhead					6.1	3.58	4.8
Channel catfish		18.7			11.7		15.2
Northern pike						2.17	2.2
Rock bass					4.8		4.8
Walleye			8.1	11.4		8.01	1.2
White bass			9.6	9.8		10.16	9.9
Yellow perch	7.4	4.1		4.2	5.6	5.95	5.5
NONSALMONID GAME FISH MEAN							7.35
Nongame Fish							
Alewife						9.73	9.7
Bluntnose minnow					1.5#		1.5
Common carp		10.5	9.5	11.0	5.8	8.59	9.1
Emerald shiner				1.6#	2.7#		2.2
Freshwater drum				8.4			8.4
Rainbow smelt						4.78	4.8
Redhorse				6.4			6.4
Slimy sculpin						6.95	7.0
Spottail shiner				2.0#	1.8#		1.9
White perch .					10.2#		10.2
White sucker	6.8	6.0		4.9		5.15	5.7
NONGAME FISH MEAN							6.07

MEAN, ALL FISH	7.90
Std. Dev.	4.43
N	28

TABLE B1 (continued)

Footnotes

* Data for the individual lakes from U.S. Fish and Wildlife Service National Contaminant Biomonitoring Program 1976-1984.
** CDF&O = Canada Department of Fisheries and Oceans. Percent lipid data for unspecified Great Lakes. These data are averaged together with the lake-specific data from the U.S. Fish and Wildlife Service.
# Value includes data from the New York State Department of Environmental Conservation.

Data Sources:

Canada Department of Fisheries and Oceans, Great Lakes Contaminant Surveillance Program, 1977-1985.

New York Department of Environmental Conservation

Schmitt, C.J., J.L. Zajicek and P.H. Peterman. 1990. National contaminant biomonitoring program: residues of organochlorine chemicals in U.S. freshwater fish, 1976-1984. Arch. Environ. Contam. Toxicol. 19: 748-781.

TABLE A4. CALCULATION OF A CONSUMPTION WEIGHTED PERCENT LIPID VALUE FOR THE GREAT LAKES EDIBLE PORTION PERCENT LIPID

LAKE/SPECIES	MEAN % LIPID	PERCENT MICH.	CATCH WISC.	MINN.	N.Y.	MEAN %	MICH.	WEIGHT WISC.	grams MINN.	N.Y.	MEAN WT. KG.	FACTOR	WTED % LIPID
LAKE SUPERIOR													
siscowet	27.38	none	none	0.08		0.080	none	1690	3406		2.548		
lake trout	10.61	73.3	45.92	72.78		64.000	3116	2802	1447		2.455	157.120	1667.043
herring	6.89	none	none	none			none	none	none				
whitefish	7.5	18.42	none	none		18.420	none	none	none				
brown trout	6.4	none	5.41	0.1		2.755	2349	1997	1715		2.020	5.566	35.623
chinook	2.99	0.79	7.92	6.87		5.193	5512	4569	2913		4.331	22.494	67.257
coho	3.48	3.77	28.84	15.94		16.183	2463	2310	1079		1.951	31.568	109.858
rainbow trout	1.69	0.72	1.12	3.75		1.863	3019	2178	1551		2.249	4.191	7.083
walleye	1.91	0.3	none	none		0.300	1734	1007	none		1.371	0.411	0.785
yellow perch	0.92	2.09	none	none		2.090	254	171	none		0.213	0.444	0.409
bloater chub	10.27	none	none	none			none	none	none				
carp	7.84	none	none	none			none	none	none				
rainbow smelt	0.9	none	none	none			none	none	none				
SUM						110.885						221.795	1888.058
WTED. MEAN % LIPID													8.513

TABLE A4. CALCULATION OF A CONSUMPTION WEIGHTED PERCENT LIPID VALUE FOR THE GREAT LAKES EDIBLE PORTION PERCENT LIPID

LAKE/SPECIES	MEAN % LIPID	PERCENT CATCH				MEAN %	WEIGHT grams				MEAN WT. KG.	FACTOR	WTED % LIPID
		MICH.	WISC.	MINN.	N.Y.		MICH.	WISC.	MINN.	N.Y.			
LAKE HURON													
lake trout	14.12	0.57				0.570					2.959	1.687	23.815
brown trout	7.54	0.02				0.020					2.173	0.043	0.328
chinook	1.72	0.34				0.340					5.041	1.714	2.948
coho	3.96	0.02				0.020					2.387	0.048	0.189
walleye	1.62	4.14				4.140					1.371	5.674	9.192
channel catfish	10.69	1.78				1.780					0.822	1.463	15.641
carp	11.37	none											
yellow perch	0.92	91.69				91.690					0.213	19.484	17.925
SUM						98.560						30.113	70.038
WTED. MEAN % LIPID													2.326

TABLE A4. CALCULATION OF A CONSUMPTION WEIGHTED PERCENT LIPID VALUE FOR THE GREAT LAKES EDIBLE PORTION PERCENT LIPID

LAKE/SPECIES	MEAN % LIPID	PERCENT CATCH MICH.	WISC.	MINN.	N.Y.	MEAN %	MICH.	WEIGHT grams WISC.	MINN.	N.Y.	MEAN WT. KG.	FACTOR	WTED % LIPID
LAKE ONTARIO													
lake trout	14.53				6.77	6.770				2350	2.350	15.910	231.165
brown trout	10.4				9.02	9.020				2223	2.223	20.051	208.535
coho	3.38				4.11	4.110				2395	2.395	9.843	33.271
chinook	2.75				11.01	11.010				7952	7.952	87.552	240.767
rainbow trout	9.04				5.85	5.850				2654	2.654	15.526	140.354
smallmouth bass	1.85				8.57	8.570				645.5	0.646	5.532	10.234
channel catfish	12.8				none					822	0.822		
white perch/bass	5.64				1.93	1.930				401	0.401	0.774	4.365
yellow perch	1.14				34.5	34.500				212.5	0.213	7.331	8.358
walleye	1.95				0.08	0.080				1370.5	1.371	0.110	0.214
panfish	0.74				15.48	15.480				217	0.217	3.359	2.486
american eel	27.9												
SUM						97.320					.	165.988	879.748
WTED. MEAN % LIPID													5.300

TABLE A4. CALCULATION OF A CONSUMPTION WEIGHTED PERCENT LIPID VALUE FOR THE GREAT LAKES EDIBLE PORTION PERCENT LIPID

LAKE/SPECIES	MEAN % LIPID	PERCENT CATCH				MEAN %	WEIGHT grams				MEAN WT. KG.	FACTOR	WTED % LIPID
		MICH.	WISC.	MINN.	N.Y.		MICH.	WISC.	MINN.	N.Y.			
LAKE MICHIGAN													
brook trout	4.65	none	0.11			0.110	none	505			0.505	0.056	0.258
brown trout	8.58	1.03	2.02			1.525	2349	1997			2.173	3.314	28.433
rainbow trout	6.12	1.57	1.07			1.320	3019	2178			2.599	3.430	20.992
chinook	2.88	4.43	5.73			5.080	5512	4569			5.041	25.606	73.745
coho	4.45	3.93	2.17			3.050	2463	2310			2387	7.279	32.391
lake trout	13.14	4.51	1.21			2.860	3116	2802			2.959	8.463	111.200
whitefish	9	0.77	none			0.770	1386	none			1.386	1.067	9.605
black bullhead	1.45	0.04	none			0.040	437	none			0.437	0.017	0.025
northern pike	1.79	0.19	0.19			0.190	1795	none			1.795	0.341	0.610
walleye	2	2.12	0.94			1.530	1734	1007			1.371	2.097	4.194
yellow perch	1.36	76.26	86.09			81.175	254	171			0.213	17.250	23.460
channel catfish	6.84	0.87	0.07			0.070	822	none			0.822	0.058	0.394
smallmouth bass	1.34	1.05	0.43			0.740	728	563			0.646	0.478	0.640
white bass	3.76	none	none				none	401			0.401		
bloater chub	14.75	none	none				none	none					
carp	11.53	none	none				none	none					
longnose sucker	5.33	none	none				none	none					
white sucker	2.03	0.01	none			0.010	1321	none			1.321	0.013	0.027
SUM						98.470						69.467	305.973
WTED. MEAN % LIPID													4.405

TABLE A4. CALCULATION OF A CONSUMPTION WEIGHTED PERCENT LIPID VALUE FOR THE GREAT LAKES EDIBLE PORTION PERCENT LIPID

LAKE/SPECIES	MEAN % LIPID	PERCENT CATCH				MEAN %	WEIGHT grams				MEAN WT. KG.	FACTOR	WTED % LIPID
		MICH.	WISC.	MINN.	N.Y.		MICH.	WISC.	MINN.	N.Y.			
LAKES ST. CLAIR AND ERIE													
lake trout	13	none			0.29	0.290				2530	2.530	0.734	9.538
whitefish	8.75	none											
chinook	3.88	none			1.35	1.350				3189	3.189	4.305	16.704
coho	4.5	none			9.4	9.400				1473	1.473	13.846	62.308
walleye	2.27	42.83			7.38	25.105				1557	1.557	39.088	88.731
channel catfish	7.11	5.15				5.150							
smallmouth bass	1.99	0.02			11.22	5.620				839	0.839	4.715	9.383
white bass	4.42	11.19			4.12	7.655				401	0.401	3.070	13.568
carp	3.4	none											
rainbow trout	5.62				4.25	4.250				1025	1.025	4.356	24.482
brown trout	8.23				0.79	0.790				1487	1.487	1.175	9.668
yellow perch	1.14				41.03	41.030				225	0.225	9.232	10.524
SUM						100.640						80.521	244.906
WTED. MEAN % LIPID													3.042
OVERALL ARITHMETIC MEAN:				4.717									
STD. DEV.				2.417									
N				5									