Bioaccumulation Models and Applications: Setting Sediment Cleanup Goals in the Great Lakes

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Background

The Great Lakes, much of which is within Region 5 of the U.S. Environmental Protection Agency (USEPA), has significant contamination of hydrophobic organic compounds such as PCBs and dioxins. Because much of this contamination is found in sediments, consideration of bioaccumulation is required when making environmental decisions. Regulatory actions that deal with bioaccumulative hydrophobic organic compounds are generally either waterway management (Clean Water Act section 404) decisions or remedial decisions under statutes such as Superfund, and the Resource Conservation and Recovery Act (RCRA). The focus of this talk will be on the latter category of remedial decision-making.

The presentation will discuss the following:

- The need and precedent for the use of bioaccumulation methods in a regulatory setting. Region 5 evaluation of bioaccumulation methodologies using Great Lakes data (sediments to fish workgroup, or S2F).
- S2F-recommended process of using bioaccumulation methods in combination with risk assessment.
- Case studies and lessons learned.

Summary

Environmental decisions often require that sediment cleanup goals be developed. Issues such as what level is safe to leave behind, which sediments need to be removed for it to be safe, and which remedial option offers the best risk reduction, need to be addressed at the many sites with bioaccumulative hydrophobic organic compounds. In general, there are few sediment regulatory levels that directly address human health. PCBs, a frequent contaminant in the Great Lakes, are regulated under the Toxic Substances Control Act at 50 ppm or greater, which is not, however, considered to be health-based. In some cases there are mandates to return to background levels, and there are also the ecological guidelines developed by the Province of Ontario and the National Oceanic and Atmospheric Administration (NOAA). While these are all useful and relevant, there was a perceived gap in having actions that use these as cleanup goals to be protective of human health.

A Regional workgroup was formed that sought to address the issue of how to address bioaccumulative compounds such as PCBs and dioxins in order to be protective of human health. To promote consistency and clarity on the topic, the workgroup developed Regional guidance based on their deliberations. Because of the concern about PCB bioaccumulation, the scope of the workgroup's efforts was always on hydrophobic organic compounds. Because in general it is not appropriate to extrapolate methods or recommendations to other contaminants that behave differently in the environment (such as metals), the workgroup and document only addressed methods appropriate to hydrophobic organic compounds. The workgroup, named Sediments to Fish, or S2F, contained technical staff from several disciplines and areas of the agency. The goal of the workgroup was to: (1) review relevant literature on bioaccumulation; (2) evaluate various methodologies using Great Lakes data and include a discussion of data issues; and (3) recommend how best to develop cleanup goals or, more accurately, how to best use bioaccumulation methodologies in regulatory actions.

A draft guidance document was completed in 1994. The basic structure of the document is:

- Overview.
- Review and discussion of methods.
- Evaluation and validation of methods (includes discussion of data issues).
- Recommended process for how to use the biota-to-sediment accumulation factor (BSAF) method with risk assessment procedures for specific use in a regulatory setting.

The document was reviewed extensively, including Region 5 states, the State of Washington, USEPA

Back

Headquarters, and NOAA. Overall, the reviews were supportive and recommended refining the document further and adding more information. The document has been revised based on this review, and changes include a new appendix on BSAFs found in the literature (values were checked in the primary reference) and additional case studies. Currently, one of the case studies is being revised to incorporate additional data made available recently. When this revision is made, the document will go through academic peer review.

It is clear that the best way to accurately assess bioaccumulation is to use more complex models utilizing pharmacokinetic parameters. However, for purely practical reasons, they were not considered to be useful at present in a regulatory setting where the data needs of these models would not be met and time would also be insufficient. Three methods, then, were analyzed in detail—BCF, BAF, and BSAF. It is useful to note that in general the BCF and BAF methods relate fish tissue levels to the water column, whereas the BSAF method relates fish contamination to sediment (often the medium where levels need to be set and where contamination more likely lies).

Methods were tested by comparing predicted fish levels (using the various methods) with actual fish data. This was done at four locations—Saginaw, Michigan; Buffalo, New York; Ontario, Canada; and Manistique, Michigan. Data needs were considerable for this process; data were needed to input into all methods (water column, sediment, etc.) and a separate data set was needed to determine site-specific BSAFs. Conclusions from this process were as follows:

- When considering all case studies as a whole, BSAF consistently gave the most reliable estimates of fish tissue concentrations relative to other methods. However, for specific case studies, some of the other methods were slightly more or about as accurate (e.g., BAF—using a measured BAF and dissolved values in the Buffalo case; and BCF—using a measured BCF and total concentration values in the Saginaw case).
- In all of the studies, the modified BAF was the least accurate method.
- How data were used was found to have a significant impact. Accuracy in predicting fish levels depended on whether all data were available, how one decided to handle heterogeneously distributed data, and which bioaccumulation factors were used and how they were developed. From this limited review, it appears that site-specific or field-derived bioaccumulation factors improve the accuracy of the results.
- In general, BCF tended to underestimate fish levels and BAF tended to overestimate fish levels.

Another important conclusion from this method validation chapter was how to appropriately use data. Major recommendations are shown in Table 1. Specific results of the data validation using Great Lakes data are shown in Tables 2 through 4.

The document also discusses how to incorporate human health issues, applying the BSAF method, in conjunction with risk assessment. In this way, one can develop options in a regulatory setting such as setting sediment cleanup goals. The general process for setting cleanup goals is shown in Figure 1. Essentially, using the basic exposure and risk equations from the *Risk Assessment Guidance for Superfund* (RAGS), a target level in fish is set. It is important to note that the process shown assumes that the contaminant of concern (PCBs, or other hydrophobic organic compound) is appropriate, and no other compound that would not be assessed in this way is important in making a cleanup decision. It also assumes that the only pathway of concern is ingestion of contaminated fish. (No other pathway is discussed here, such as ingestion of sediment or surface water.) Note, in addition, that setting the target level in fish using risk assessment requires decisions be made regarding acceptable levels of risk (e.g., 10^{-6}). The target fish level can also be a regulatory level such as a threshold for *setting* a fish advisory (e.g., 0.05 ppm).

The target fish level is put into the BSAF equation and solved for concentration in sediment. Important issues to consider when doing this analysis are: (1) choosing a BSAF, which can be site specific or can be chosen from the literature (variations will arise and can have great impact on results); (2) quality of total organic carbon (TOC) data, which can have a great impact on results as well; (3) using appropriate species of fish and keeping species-specific considerations throughout (lipid values, range, etc.); and (4) applying the risk assessment process carefully and considering many options, such as different exposure scenarios for different fishing behaviors.

This process has been applied in several cases in Region 5. Two that will be discussed are Saginaw and Manistique. Results shown were used in decision-making in Saginaw, as part of a Natural Resource Damage Assessment (NRDA). USEPA looked at current health risks, developed cleanup goals, and assessed how a possible action could address human health risk. The lower Saginaw River is characterized as having widespread lower level (less than 5 ppm on average) sediment contamination at the surface and somewhat more contamination at depth in sediment. Site-specific BSAFs were calculated for two species, walleye and carp. Although a range of BSAFs could be calculated depending on data considerations (averaging of sediment data, etc.), they can be summarized as being 0.3 for walleye and 0.6 for carp. This information is contrasted to Manistique, which is characterized as having localized sediment "hot spots" of PCB contamination, the majority of which is not at the surface. Site-specific BSAFs were also calculated although sediment and fish data were somewhat more limited. Again a range of site-specific BSAFs were considered due to possible data handling choices, but they can be summarized as 0.4 for carp and .07 for walleye. Sediment cleanup goals for these two sites obviously follow from the BSAF differences. Saginaw cleanup goals are much lower than those calculated from Manistique, Michigan. A summary is provided in Figure 2.

Table 1. Data Issues and Recommendations for Sediment to Fish Predictive Methods

Data Issue	Recommendation
Averaging of fish or sediment data (geometric vs. arithmetic mean)	Geometric Mean
Use of sediment organic carbon data	Point normalize
Handling of non-detect data	Use one-half the detection limit
Uneven clustering of sediment samples	Surface area weighting
Calculating site specific BSAF value using sediment and fish data	Temporarily matched sediment and fish data
Type of fish sample	Filet (human health endpoint) Whole fish (ecological endpoint)
Bioaccumulation method	BSAF

Table 2. Comparison of Predicted Fish Tissue Concentrations (from draft S2F document)

All values shown are ppm PCBs	Saginaw (walleye)	Buffalo (carp)
BCF (meas./total)	1.4	0.35
BAF (meas./diss.)	38	0.42
BAF (meas./total)	38	3.5
BSAF	1.4	-0.871
Actual	1.5	2.8

(Using geometric means of relevant data)

Table 3. (from draft S2F document)

Manistique, MI	PREDICTED FISH CONCENTRATIONS IN CARP (in mg/kg)				
WATER-TO-FISH OR SEDIMENT-TO-FISH PREDICTIVE MODEL	SAW SEDIMENT; ARITHMETIC MEANS	SAW SEDIMENT; GEOMETRIC MEANS	ARITHMETIC POINT-NORMALIZED SEDIMENT; ARITHMETIC MEANS	ARITHMETIC MEANS FOR ALL PARAMETERS	GEOMETRIC MEANS FOR ALL PARAMETERS
BAF-modified	390 - 550	380 - 550	520 - 740	230 - 330	79 - 110
TBP (pf=4)	88	86	120	52	18
BSAF (value in parentheses is site-specific BSAF used)	9.0 (0.41)	8.6 (0.40)	13 (0.45)	4.6 (0.35)	2.9 (0.64)
Actual Fish Tissue Concentration	6.5	6.2	6.5	6.5	6.2

[1]SAW = surface area weighted

[2]Values in this column are the same regardless if sediment data are normalized before or after calculating geometric means.

Table 4. (from draft S2F document)

Manistique, MI	PREDICTED FISH CONCENTRATIONS IN WALLEYE (in mg/kg)				
WATER-TO-FISH OR SEDIMENT-TO-FISH PREDICTIVE MODEL	SAW SEDIMENT; ARITHMETIC MEANS	SAW SEDIMENT; GEOMETRIC MEANS	ARITHMETIC POINT-NORMALIZED SEDIMENT; ARITHMETIC MEANS	ARITHMETIC MEANS FOR ALL PARAMETERS	GEOMETRIC MEANS FOR ALL PARAMETERS
BAF-modified	200 - 340	180 - 310	270 - 460	120 - 204	37 - 64
TBP (pf=4)	24	22	33	15	4.6
BSAF (value in parentheses is site-specific BSAF used)	0.99 (0.16)	0.87 (0.16)	1.5 (0.18)	0.51 (0.14)	0.29 (0.25)
Actual Fish Tissue Concentration	0.34	0.25	0.34	0.34	0.25

[1]SAW = surface area weighted

[2]Values in this column are the same regardless if sediment data are normalized before or after calculating geometric means.

1) <u>Set acceptable contaminant level in fish</u>
set risk target level (i.e. 10^{-6} cancer, HI=1)
determine appropriate exposure parameters
for fish ingestion pathway
2) <u>Calculate total organic carbon (TOC) in the area</u>
determine fish exposure area
use most recent sediment data
use surface samples
3) <u>Determine fish which are consumed</u>
Consider:
local fish consumption patterns
at least two species to target
species-specific lipid levels
4) <u>Calculate/Select BSAF</u>
use site-specific data to calculate BSAF
and/or
choose literature value from Appendix E
(match species and site)
5) <u>Calculate sediment cleanup goal</u>

$$Cs = \frac{Cf\ (1) \times TOC\ (2)}{BSAF\ (4) \times Lipid\ (3)}$$

Figure 1. Recommended Methodology for Determining Sediment Cleanup Goals.

Cancer Risk Level	Exposure Assumptions	Site	CUGs for PCBs (ppm)
10 E-6	**sport** fisher eating average of **20 g walleye**/day, **25%** from site	Saginaw	0.06
		Manistique	1
10 E-5	**sport** fisher eating average of **15 g walleye**/day, **25%** from site	Saginaw	0.8
		Manistique	13
10 E-4	**subsistence** fisher eating average of **75 g walleye**/day, **50%** from site	Saginaw	0.8
		Manistique	13

Figure 2. Comparison of Saginaw and Manistique Cleanup Goals (CUGs).

Bioaccumulation Models and Applications:
Setting Sediment Clean Up Goals in the Great Lakes

Overview

- need and precedent for use of bioaccumulation methods in regulatory setting (linking sediment levels with health endpoint)
- Region 5 evaluation of bioaccumulation methodologies
- Region 5 recommended process in use of methodology and in linking with risk assessment
- Case Studies/lessons learned

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Bioaccumulation Models and Applications

Need and precedent for bioaccumulation methods for regulatory purposes

- assessing bioaccumulation potential
- setting cleanup goals
- evaluating remedial options
- estimating risks when limited data are available

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Bioaccumulation Models and Applications

Alternative Clean Up Goals/Remedial Targets for Contaminated Sediments

- TSCA (50 ppm for PCBs)
- Ontario Sediment Quality guidelines
- NOAA Sediment Thresholds
- background

☆ gap in having actions protective of human health

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Bioaccumulation Models and Applications

Region 5 Workgroup - Sediments to Fish (S2F)

- multi-media and -division
- focused on hydrophobic organic compounds
  - e.g., PCBs, PCB-like compounds, dioxins
- Guidance document
  -reviewed literature and several methodologies
  -tested methods using Great Lakes data
  -recommended process using BSAF
- draft completed in 1994, reviewed by States and Federal agencies; significant revisions; interim final by end 1996; academic peer review.

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Bioaccumulation Models and Applications

S2F Workgroup:

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Bioaccumulation Models and Applications

Key Questions/Issues that Emerged from S2F

- Which methodology is most accurate in predicting fish tissue concentrations?
- Appropriately handling data
- Science Policy Issues

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Bioaccumulation Models and Applications

Methodologies Available to Assess Bioaccumulation of Contaminated Sediments

- BAF
- BCF

(BAF, BCF) relates fish tissue concentration to water column

- BSAF - relates fish tissue concentration to sediment
- biokinetic models - requires pharmacokinetic parameters

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Bioaccumulation Models and Applications

Testing methodologies

The ability of the various models to accurately predict fish tissue concentrations were tested using actual fish tissue, water column, and sediment data from the following sites:

· Saginaw

· Buffalo

· Ontario

· Manistique

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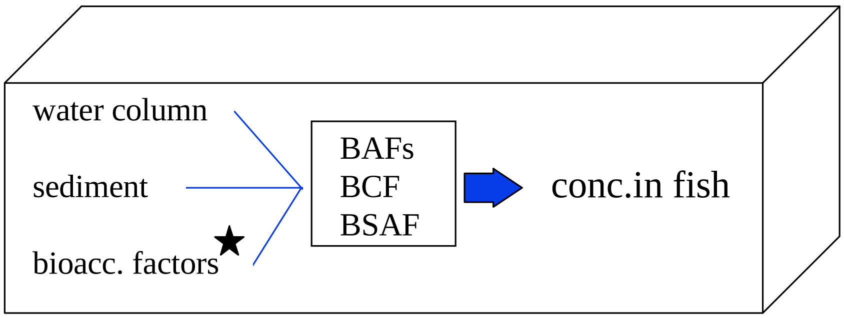
Bioaccumulation Models and Applications

S2F: Testing Methodologies

Data needs were considerable
-need data to input into all methodologies (BAF, BCF, BSAF) and solve for conc. in fish
-compare estimated level in fish to actual fish data



★a separate data set was needed to develop site-specific bioaccumulation factors

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Bioaccumulation Models and Applications

Equations used for Evaluating Bioaccumulation Methods:

$$BCF = \frac{C_f}{C_w}$$

$$BAF = \frac{C_f}{C_w} \qquad \text{Modified BAF} \Rightarrow C_f = \frac{(BCF * FC) * C_s}{f_{oc} * K_{oc}}$$

$$BSAF = \frac{C_f}{C_s}$$

where: C_f = concentration in fish; C_w=concentration in the water column;
C_s =concentration in the sediment; FC=food chain multiplier;
f_{oc} =fraction organic carbon;
K_{oc}= partitioning coefficient (between water and organic carbon)

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Bioaccumulation Models and Applications

Comparison of Predicted Fish Tissue Concentrations

from draft S2F document

all values shown are ppm PCBs	**Saginaw** (walleye)	**Buffalo** (carp)
BCF (meas./total)	**1.4**	.35
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BSAF	**1.4**	**.87-1.7**
Actual	**1.5**	**2.8.**

(Using geometric means of relevant data)

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Bioaccumulation Models and Applications

Predicted PCB carp tissue concentrations for the Manistique River

(from draft S2F document)

WATER-TO-FISH OR SEDIMENT-TO-FISH PREDICTIVE MODEL	PREDICTED FISH CONCENTRATIONS (in mg/kg)				
	SAW[1] SEDIMENT; ARITHMETIC MEANS	SAW SEDIMENT; GEOMETRIC MEANS	ARITHMETIC POINT-NORMALIZED SEDIMENT; ARITHMETIC MEANS	ARITHMETIC MEANS FOR ALL PARAMETERS	GEOMETRIC[2] MEANS FOR ALL PARAMETERS
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Bioaccumulation Models and Applications

Predicted PCB walleye tissue concentrations for the Manistique River

(from draft S2F document)

WATER-TO-FISH OR SEDIMENT-TO-FISH PREDICTIVE MODEL	PREDICTED FISH CONCENTRATIONS (in mg/kg)				
	SAW[1] SEDIMENT; ARITHMETIC MEANS	SAW SEDIMENT; GEOMETRIC MEANS	ARITHMETIC POINT-NORMALIZED SEDIMENT; ARITHMETIC MEANS	ARITHMETIC MEANS FOR ALL PARAMETERS	GEOMETRIC[2] MEANS FOR ALL PARAMETERS
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Bioaccumulation Models and Applications

Data Issues & Recommendations

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Data Issue	Recommendation
Averaging data (geometric vs. arithmetic mean)	Geometric Mean
Use of sediment organic carbon data	Point normalize
Non-detect data	Use one-half the detection limit
Uneven clustering of sediment samples	Surface area weighting
Calculating site specific BSAF	Temporally matched sediment and fish data
Type of fish sample	Fillet (human health endpoint) Whole fish (ecological endpoint)
Bioaccumulation method	BSAF

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Bioaccumulation Models and Applications

Bioaccumulation Method Evaluation Conclusions:

•when evaluating all the case studies as a whole, BSAF consistently gave reliable estimates; although other methods in some cases were slightly more or as accurate as BSAF

•estimates using measured values for bioaccumulation factors were more accurate than those using calculated factors

•accuracy in predicting fish levels strongly depended on data quality, availability, and handling of data (e.g., heterogeneously distributed data)

•in most cases: BAF-modified was least accurate, BCF tended to underestimate, and BAF tended to overestimate

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Bioaccumulation Models and Applications

Recommended Methodology for Determining Sediment Cleanup Goals

1) Set acceptable contaminant level in fish

2) Calculate total organic carbon (TOC) in the area

3) Determine fish which are consumed

4) Calculate/Select BSAF

5) Calculate sediment cleanup goal

$$Cs = \frac{Cf\ (1) \times TOC\ (2)}{BSAF\ (4) \times Lipid\ (3)}$$

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Bioaccumulation Models and Applications

Evaluating Remedial Options

- **Consider several options, for example:**

  -dredge sediments greater than 50 ppm, 10 ppm

  -leave sediment in place

  -other options

- **Calculate surface area weighted sediment concentration for each scenario under evaluation**
  [C_s]

- **Determine BSAF for representative fish species (literature, site specific)**
  [BSAF]

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Bioaccumulation Models and Applications

Evaluating Remedial Options, cont'd

- **Use BSAF to model contaminant concentration in fish under each scenario**

$$C_f = \frac{(BSAF) \times (C_s) \times (Lipid)}{(Organic\ Carbon)}$$

- **Use exposure equation to calculate hu intake of contaminant**

- **Use toxicological risk information (IF calculate human health risk under each s**

Bioaccumulation Models and Applications

Determining an Appropriate BSAF Value
Species Specific Issues

Issue	Consideration
Foraging Range	Consult with fish biologist to help confirm that the average contaminant concentration in the sediment is representative of the fish's range.
Pisciverous vs. Bottom Feeding	Bottom feeding fish will likely have a higher BSAF and thus should be included to represent a more conservative scenario.
Lipid Content	Fatty fish tend to accumulate more contaminants and thus inclusion will add a more conservative scenario.
Presence of Species at Site	Choose a species endpoint that is actually found at the site.
Consumption of Species	Choose a species which is being consumed by the local population.

Bioaccumulation Models and Applications

Critical Science Policy Decisions

- Choice of bioaccumulation model
- Choice of fish species (e.g. pelagic, bottom-feeding)
- Choice of BSAF value
- Determining appropriate sediment concentration term
- Defining fish exposure area/site boundary

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Bioaccumulation Models and Applications

Critical Science Policy Decisions, cont'd

- Handling of "non-detect" data
- Choice of fish consumption rate
- Determination of endpoints of concern
- Accurately estimating TOC

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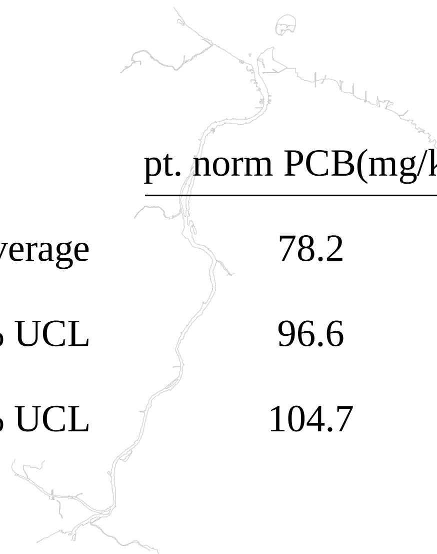
USEPA Region 5

Current Potential Health Risks (MDEQ 1986-1993)

Species	Concentration		Cancer Risk Range		HQ Range	
walleye	0.43		3.04E-05	2.64E-03	0.20	17.11
carp	3.1		2.19E-04	1.90E-02	1.42	123.37
bass	0.21		1.46E-05	1.27E-03	0.10	8.24
whitefish	0.04		2.94E-06	2.55E-04	0.02	1.65
perch	0.13		9.16E-06	7.94E-04	0.06	5.16
pike	0.15		1.07E-05	9.25E-04	0.07	6.01
trout	0.08		5.64E-06	4.89E-04	0.04	3.18

USEPA Region 5

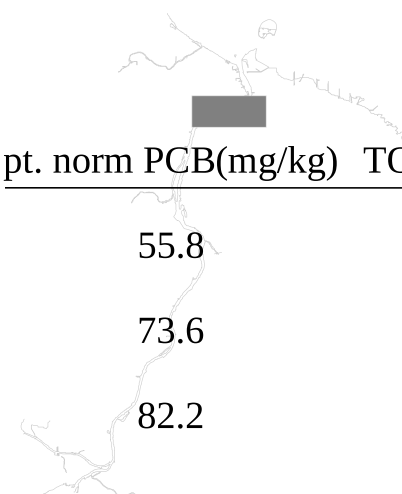
22-Mile Surface- Present



	pt. norm PCB(mg/kg)
Average	78.2
90% UCL	96.6
95% UCL	104.7

USEPA Region 5

22-Mile Surface - Post Dredge



	pt. norm PCB(mg/kg)	TOC(%)
Average	55.8	2.3
90% UCL	73.6	4.1
95% UCL	82.2	4.6

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Calculating Risk-Based Cleanup Goals

- Set Target Fish Tissue Level

Acceptable Risk Level	1.00E-06	1.00E-06	Haz. Index	1	1
cancer slope factor	7.7	7.7	Ref. Dose	2.00E-05	2.00E-05
Body weight (kg)	70	70		70	70
Averaging time (days)	25550	25550		10950	10950
Ingestion rate (kg/day)	0.02	0.13		0.02	0.13
Fraction ingestion (%)	0.25	1		0.25	1
Absorption (%)	1	1		1	1
Exp. frequency (days/year)	365	365		365	365
Exposure duration (years)	9	30		30	30
Concentration in Fish	0.0141	0.0002		0.28	0.0108

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Calculating Risk-Based Cleanup Goals

Input Target Fish Levels into BSAF=>CUGs

	Sediment Cleanup Goal ->			**CS=(toc x CF) /(BSAF x lipid)**								
Cancer (E-6)							Noncancer (HI=1)					
sport	CF	toc	BSAF	lipid	CS		sport	CF	toc	BSAF	lipid	CS
walleye	0.0141414	2.3	0.2813299	1.98	0.0583901		walleye	0.28	2.3	0.2813299	1.96	1.1679221
carp	0.0141414	2.3	0.5319693	12.2	0.0050116		carp	0.28	2.3	0.5319693	1.98	0.6114122
subsis.	CF	toc	BSAF	lipid	CS		subsis.	CF	toc	BSAF	lipid	CS
walleye	0.0001632	2.3	0.2813299	1.98	0.0006737		walleye	0.0107692	2.3	0.2813299	1.98	0.0444663
carp	0.0001632	2.3	0.5319693	12.2	5.783E-05		carp	0.0107692	2.3	0.5319693	1.98	0.0235159

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Post-Remediation Health Risks

- Input Sediment Levels into BSAF=>Resulting Levels in Fish

range walleye	CS	toc	lipid	BSAF	CF	
	0.9	2.3	1.96	0.28	0.2157678	
	1.3	2.3	1.96	0.28	0.1558323	
	55.8	1	0.0196	0.28	0.3076849	(normal.)
	82.2	1	0.0196	0.28	0.4532563	(normal.)
range carp	CS	toc	lipid	BSAF	CF	
	0.9	2.3	12.2	0.53	2.5395752	
	1.3	2.3	12.2	0.53	1.8341377	
	55.8	1	0.122	0.53	3.6214343	(normal.)
	82.2	1	0.122	0.53	5.334801	(normal.)

USEPA Region 5

Post-Remediation Health Risks

Define Exposure Scenarios and Calculate Risk

walleye	Cancer	low	high		N/C	low	high
	CF	0.307685	0.453256		CF	0.307685	0.453256
	BW	70	70		BW	70	70
	AT	25550	25550		AT	25550	25550
	IR	0.02	0.13		IR	0.02	0.13
	FI	0.25	1		FI	0.25	1
	AB	1	1		AB	1	1
	EF	365	365		EF	365	365
	ED	9	30		ED	9	30
	slope	7.7	7.7		RfD	2.00E-05	2.00E-05
	RISK	2.18E-05	2.78E-03		HQ	0.141284	18.03775
carp	Cancer	low	high		N/C	low	high
	CF	3.621434	5.334801		CF	3.621434	5.334801
	BW	70	70		BW	70	70
	AT	25550	25550		AT	25550	25550
	IR	0.02	0.13		IR	0.02	0.13
	FI	0.25	1		FI	0.25	1
	AB	1	1		AB	1	1
	EF	365	365		EF	365	365
	ED	9	30		ED	9	30
	slope	7.7	7.7		RfD	0.00002	0.00002
	RISK	0.000256	0.032695		HQ	1.662903	212.3033

Bioaccumulation Models and Applications

Exposure Assumptions used at Manistique

Variable	Value	
-ingestion rate (kg/day)	.015 - .054 .075 - .130	-recreation "average" - "high end" -subsistence "average" - "high end"
-fraction ingested from area	25 % 50% 100%	-recreation "average" -recr. "high end" & subsis. "avg." -subsistence "high end"
-exposure frequency (days/year)	365	(IR's are daily rates)
-exposure duration (years)	9 30	"average" scenarios "high end" scenarios
-body weight (kg)	70	
-averaging time (days)	3285 10950 25550	"average" noncancer "high-end" noncancer cancer

9/12/96

Bioaccumulation Models and Applications

Manistique Sediment Cleanup Levels Summary (PCBs)

Cancer	**"Average" Scenario**		**"High End" Scenario**	
	risk	target sediment level (ppm)	risk	target sediment level (ppm)
Recreational fishing	10^{-6} 10^{-4}	1.3 130	10^{-6} 10^{-4}	0.0096 0.96
Subsistence fishing	10^{-6} 10^{-4}	0.13 13	10^{-6} 10^{-4}	0.002 0.2

Noncancer (Immuno-toxicity and Reproductive Effects) *Haz. Index = 1*	**"Average" Scenario** target sediment level (ppm)	**"High End" Scenario** target sediment level (ppm)
Recreational fishing	25	0.63
Subsistence fishing	2.5	0.13

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Comparison of Saginaw and Manistique Cleanup Goals (CUGs)

Cancer Risk Level	Exposure Assumptions	Site	CUGs for PCBs (ppm)
10 E-6	**sport** fisher eating average of **20 g walleye**/day, **25%** from site	Saginaw	0.06
		Manistique	1
10 E-5	**sport** fisher eating average of **15 g walleye**/day, **25%** from site	Saginaw	0.8
		Manistique	13
10 E-4	**subsistence** fisher eating average of **75 g walleye**/day, **50%** from site	Saginaw	0.8
		Manistique	13

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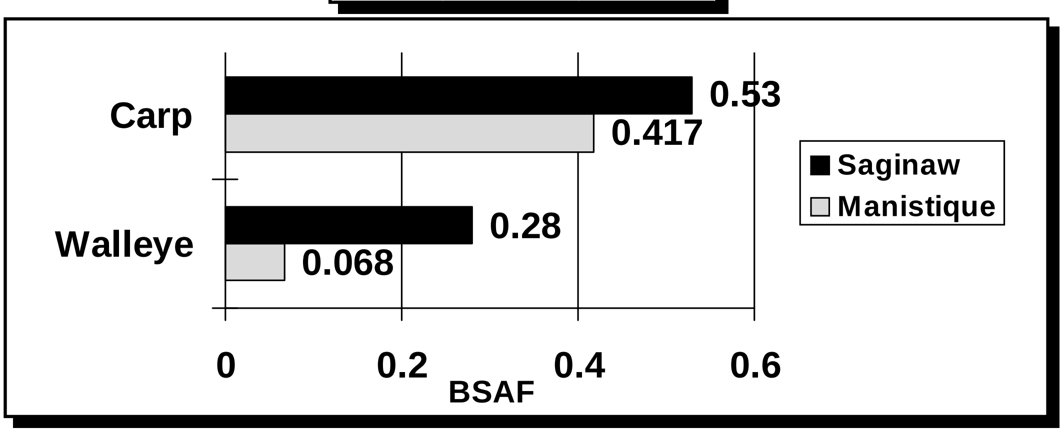
Biota To Sediment Accumulation Factors (BSAFs) in Saginaw and Manistique

Carp	Saginaw	41.6/78.2
	Manistique	102.2/245
Walleye	Saginaw	22/78.2
	Manistique	16.7/245



Bioaccumulation Models and Applications

Conclusions:

-bioaccumulation models applied in a regulatory setting, with careful consideration, appear to provide reasonably accurate results and allow actions to consider human health
[note: models evaluated for hydrophobic organic compounds only]

-data quality and quantity clearly are critical to usability and accuracy

-important considerations include:

- -accurately estimating: TOC, fish species differences (% lipid, range, etc.), concentrations of contaminant at the surface that fish are/were exposed to, and bioaccumulation factors;
- -fish ingestion rates,
- -setting acceptable risk levels (cancer vs noncancer)
- -critically and clearly communicating limitations, assumptions, and uncertainties.

9/12/96

Next