Bioaccumulation Risk Assessment Modeling System

Software Presentation and Demonstration

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USACE ERDC Environmental Laboratory
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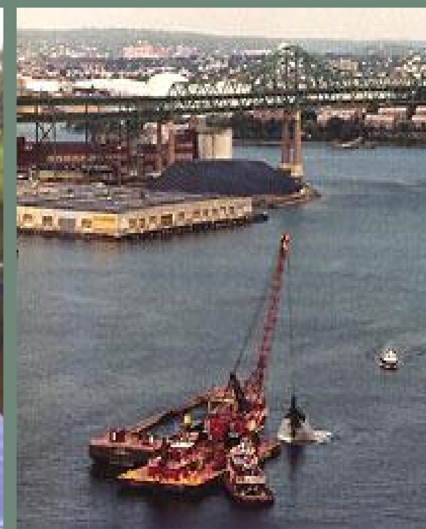


ERDC
Engineer Research and Development Center

US Army Corps of Engineers®

BRAMS Software Suite

Bioaccumulation Risk Assessment Modeling System (BRAMS)

- **BEST** — ***Screening Tool***
- **Trophic Trace** — ***Detailed Model***
- **Fish Rand*** — ***Dynamic Receptors***

Spatially Explicit GIS Data Framework*
(Forthcoming)

**Planned Extensions and Integration*

Outline: BRAMS

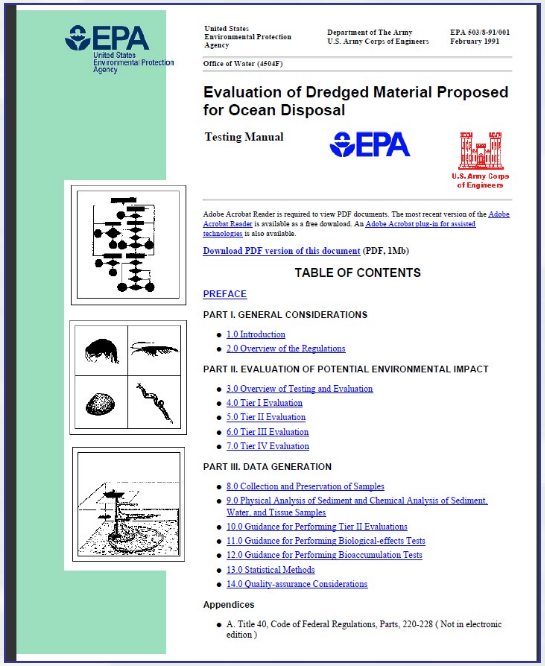
- Scope
  - Dredged Material Disposal Regulations
  - Bioaccumulation
- Introduction to BRAMS
- BEST
  - Technical Approach
  - Software Demonstration
- Trophic Trace
  - Technical Approach
  - Software Demonstration

Dredged Material Management

- Over 200 million cubic yards of sediment are dredged from U.S. waters each year.
- The Marine Protection Research and Sanctuaries Act (MPSA, 1972) prohibits ocean dumping of material that would unreasonably degrade or endanger human health or the marine environment.
- EPA and USACE share the responsibility for regulation of this dredged material.
- The Corps issues permits for dredged material disposal which are subject to EPA review and concurrence before ocean disposal can occur.

Dredged Material Disposal Requirements

- The tiered approach to evaluation of potential environmental impacts of ocean dumping is outlined in the Ocean and Inland Testing Manuals (OTM & ITM)
- BRAMS can be used in Tiers I through IV to provide information about potential risks
- Specific guidance for sampling and testing in accordance with the OTM and ITM is provided in Regional Implementation Manuals


EPA United States Environmental Protection Agency

United States Environmental Protection Agency | Department of The Army U.S. Army Corps of Engineers | EPA 503/8-91/001 February 1991

Office of Water (4504F)

Evaluation of Dredged Material Proposed for Ocean Disposal

Testing Manual

EPA

U.S. Army Corps of Engineers

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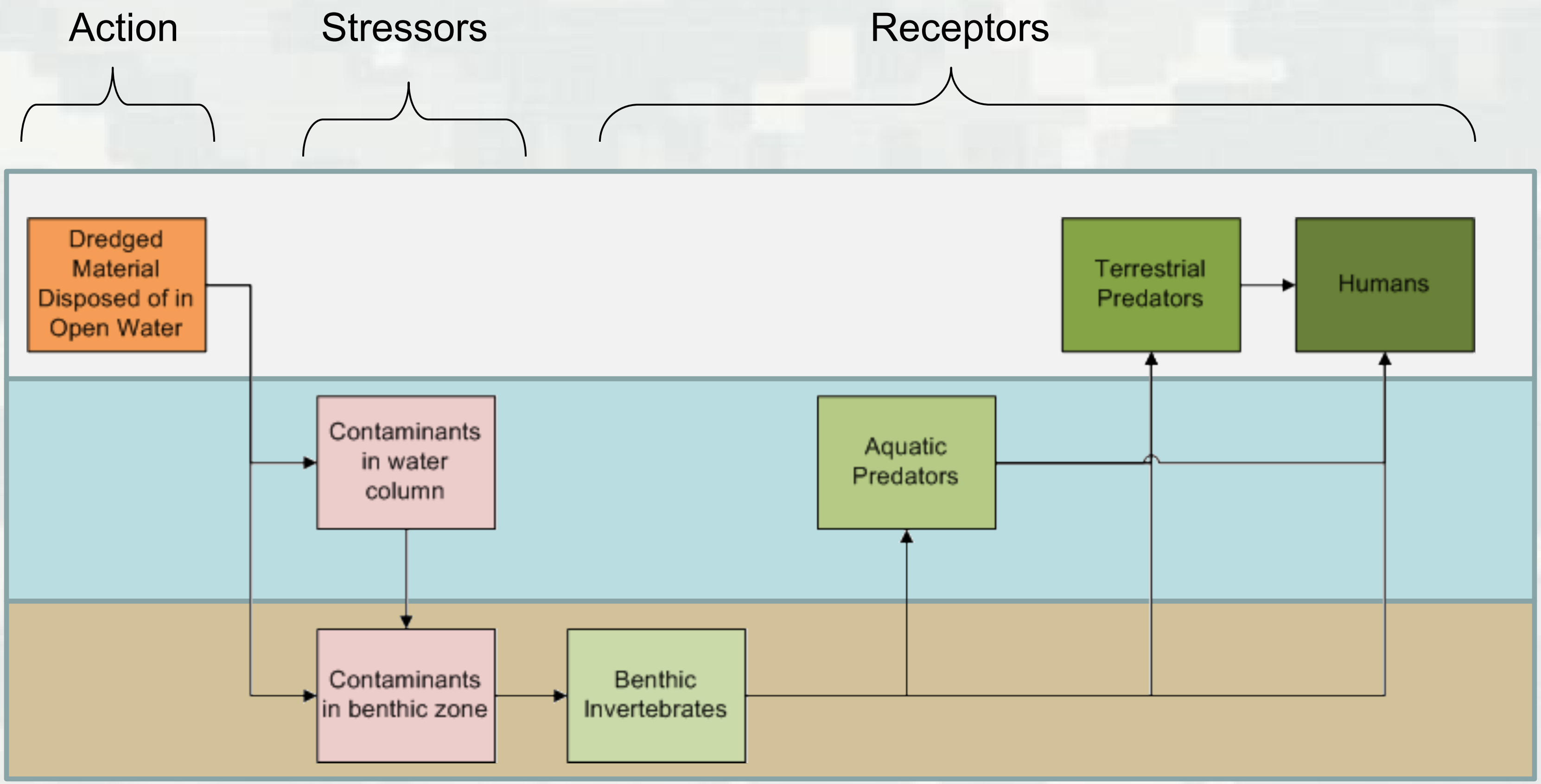
Environmental Impact and Bioaccumulation

- **Primary source of environmental risk associated with dredged sediment disposal:**
  - Sediment-associated contaminants
  - Partially due to bioaccumulation and biomagnification in aquatic food chains

- **Bioaccumulation is included in the required evaluations to:**
  - Indicate biological availability of contaminants in dredged material
  - Assess potential for long-term accumulation of contaminants in aquatic food webs and to levels harmful to consumers

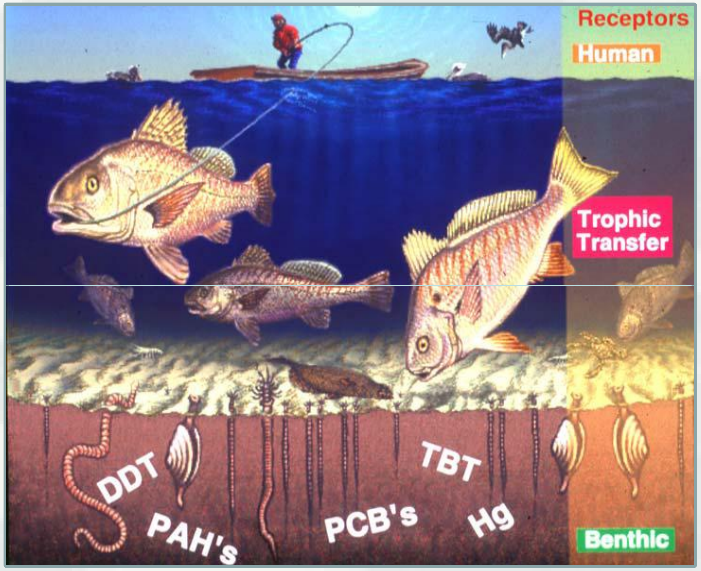
- **Material is potentially unacceptable if:**
  - Animals exposed to dredged material bioaccumulate statistically greater amounts of contaminants than those exposed to reference sediments or higher concentrations than FDA action levels

Bioaccumulation Conceptual Model



Bioaccumulation Modeling

- Designed to estimate bioaccumulation, trophic transfer and risk associated with contaminants in sediment
- Model Components
  - ► Contaminant concentration in water, sediment, and/or tissue
  - ► Site Food Web
  - ► Receptor Exposure Scenarios
  - ► Contaminant uptake, transfer, and toxicity factors
  - ► Environmental conditions



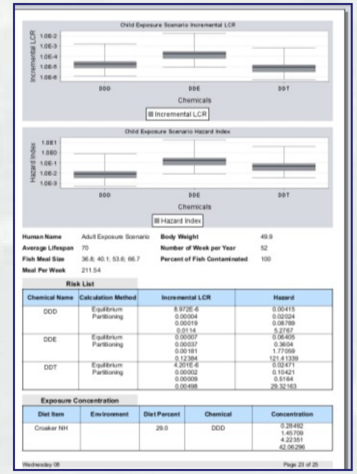
Risk Assessment Process

1. Problem Formulation/Hazard Identification
   - General site characterization
   - Exposure pathway definition (links between contaminant sources and receptors)
2. Exposure Assessment
   - Quantify exposure characteristics of human and ecological receptors
3. Effects or Toxicity Assessment
   - Potential toxicity of contaminants (RfDs, CSFs, TRVs)
4. Risk Characterization
   - Use information from previous steps to calculate dose and risks and compare to established thresholds:

     (ADD, LCR, HI, NOAEL TQ, LOAEL TQ)

Interpreting Results

- **No Potential Risk**
  - Risks below EPA thresholds of concern
  - Conservative, health protective assumptions and bioaccumulation test data used
  - With uncertainty, lowest portion of range of risks still below thresholds of concern



Human Name	Adult Exposure Scenario	**Body Weight**	49.9
Average Lifespan	70	**Number of Week per Year**	52
Fish Meal Size	36.8; 40.1; 53.6; 66.7	**Percent of Fish Contaminated**	100
Meal Per Week	211.54		

Risk List

Chemical Name	Calculation Method	Incremental LCR	Hazard
DDD	Equilibrium Partitioning	8.972E-6 0.00004 0.00019 0.0114	0.00415 0.02024 0.08789 5.2767
DDE	Equilibrium Partitioning	0.00007 0.00037 0.00181 0.12384	0.06405 0.3604 1.77059 121.41339
DDT	Equilibrium Partitioning	4.201E-6 0.00002 0.00009 0.00498	0.02471 0.10421 0.5164 29.32163

Exposure Concentration

Diet Item	Environment	Diet Percent	Chemical	Concentration
Croaker NH		29.0	DDD	0.28492 1.45709 4.22351 42.06296

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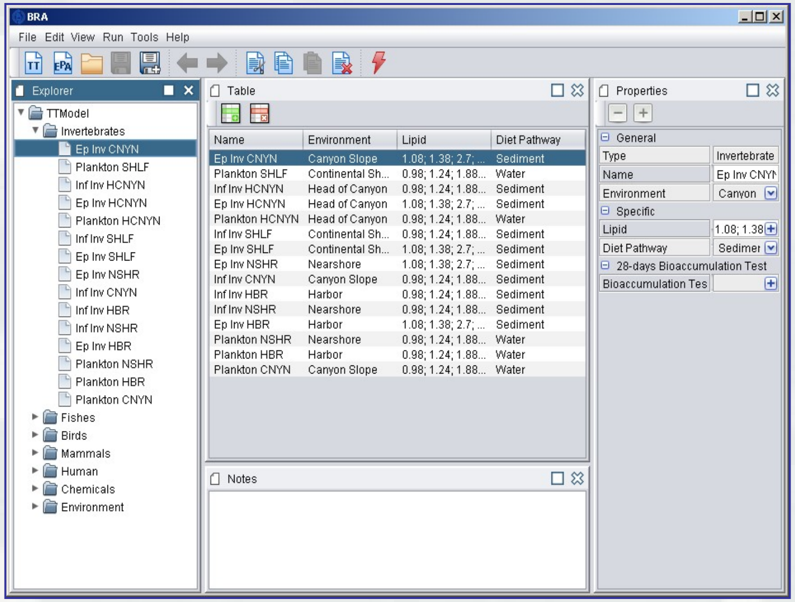
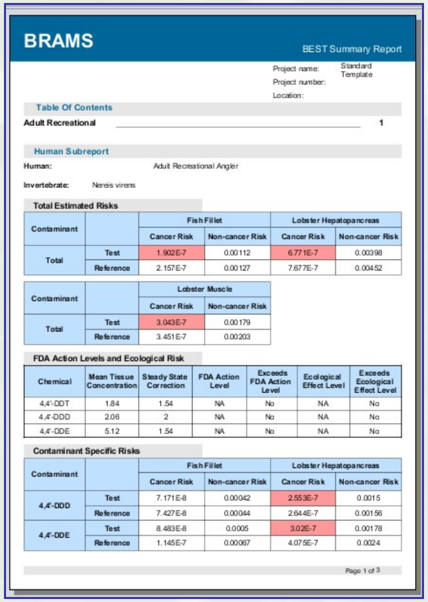
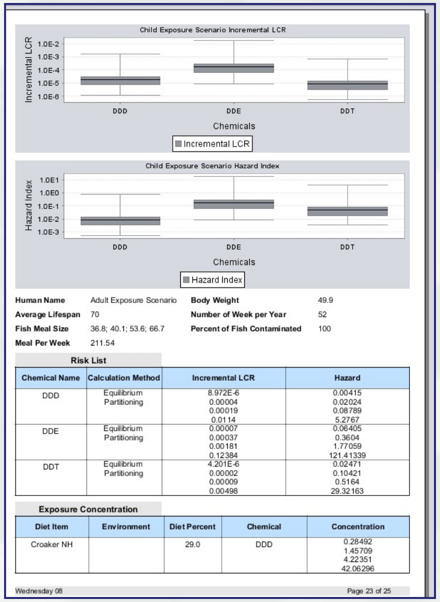
- **Potential Risk**
  - Predicted risks greatly exceed EPA thresholds of concern
  - With uncertainty, lowest portion of range of risks still exceed thresholds
  - Site-specific data and sediment or bioaccumulation test data used

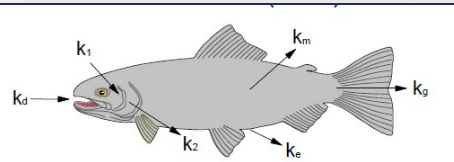
- **Equivocal Risk**
  - Predicted cancer and non-cancer risks above thresholds of concern and NOAEL TQ >1, while LOAEL <1.
  - With uncertainty, lowest portion of range of risks below thresholds
  - Conservative, health protective assumptions and sediment or bioaccumulation test data used

Bioaccumulation Risk Assessment Modeling System (BRAMS)

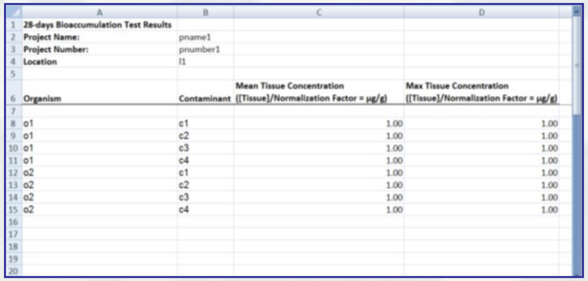








$$C_f = \frac{k_1 * C_{wd} + k_d * C_{diet}}{k_2 + k_e + k_m + k_g}$$



BRAMS Software Suite

Bioaccumulation Risk Assessment Modeling System (BRAMS)

BEST
Screening Tool

Trophic Trace
Detailed Model

Fish Rand*
Dynamic Receptors

Spatially Explicit GIS Data Framework*
(Forthcoming)

**Planned Extensions and Integration*

BRAMS History

- **BEST:**
  - 1999 - EPA Region 1 develops and begins using MS Excel-based risk model to estimate risks of open water disposal from results of bioaccumulation testing
  - 2012 - ERDC moves model framework into BRAMS Java application and adds flexibility to tailor model to specific projects
- **Trophic Trace:**
  - 1999 - Originally developed (as TrophicTrace) by Menzie-Cura & Associates, Inc.
  - 2003 - MS Excel add-in created for the USACE
  - 2004 - Implemented as a desktop application using Adobe (former Macromedia) Flash technology
  - 2012 - Updated by USACE ERDC to a stand-alone Java-based tool that can run on any Java-enabled operating system

Trophic Trace vs. BEST

Trophic Trace

- Mechanistic Bioaccumulation Model
- Tiers I-III, IV (partially)
- Required Input:
  - Sediment, Water, or Tissue Concentrations
- Uncertainty:
  - Interval Analysis or "fuzzy math"

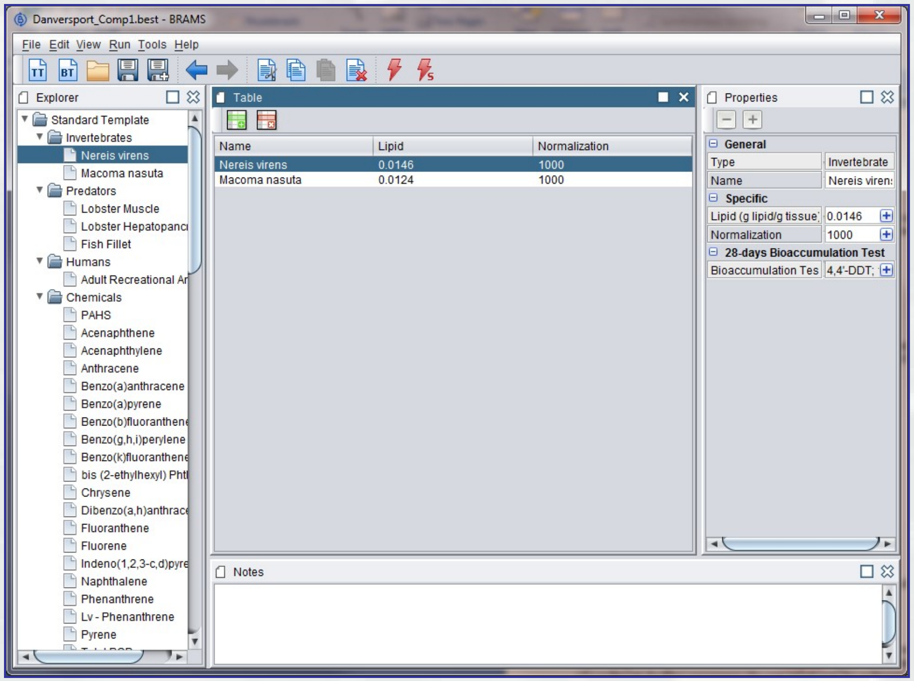
Food Chain:
  - Invertebrates
  - Fish
  - Mammals
  - Birds
  - Humans

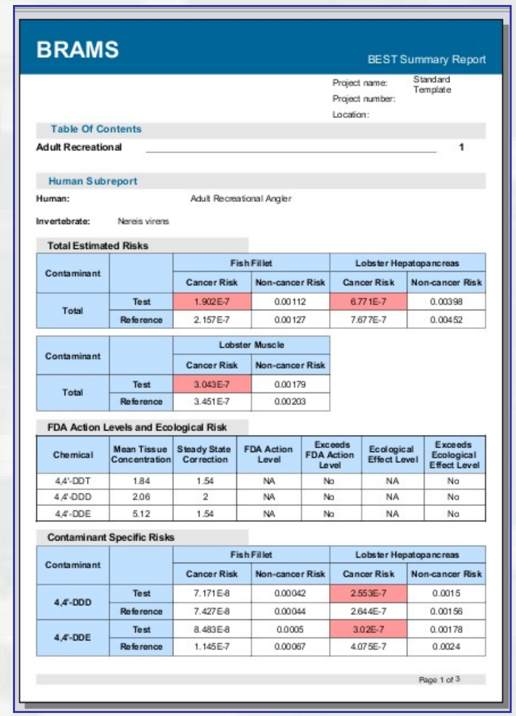
- Trophic Transfer:
  - Equilibrium Partitioning + Gobas Model or BCF
  - 28-bioaccumulation test results (+ TTF) + Gobas Model
- Risk Receptors:
  - Humans
  - Ecological

BEST

- Empirical Screening Tool
- Tier III
- Required Input:
  - Tissue Concentrations
- Uncertainty:
  - None
- Food Chain:
  - Invertebrates
  - Aquatic Predators
  - Humans
- Trophic transfer:
  - 28-day bioaccumulation test results + BMFs
- Risk Receptors:
  - Humans

BEST – Bioaccumulation Evaluation Screening Tool





BRAMS

BEST Summary Report

Project name: Standard Template
Project number:
Location:

Table Of Contents

Human Subreport

Human: Adult Recreational Angler

Invertebrate: Nereis virens

Total Estimated Risks

Contaminant		Fish Fillet		Lobster Hepatopancreas	
		Cancer Risk	Non-cancer Risk	Cancer Risk	Non-cancer Risk
Total	Test	1.902E-7	0.00112	6.771E-7	0.00398
	Reference	2.157E-7	0.00127	7.677E-7	0.00452

Contaminant		Lobster Muscle	
		Cancer Risk	Non-cancer Risk
Total	Test	3.043E-7	0.00179
	Reference	3.451E-7	0.00203

FDA Action Levels and Ecological Risk

Chemical	Mean Tissue Concentration	Steady State Correction	FDA Action Level	Exceeds FDA Action Level	Ecological Effect Level	Exceeds Ecological Effect Level
4,4'-DDT	1.84	1.54	NA	No	NA	No
4,4'-DDD	2.06	2	NA	No	NA	No
4,4'-DDE	5.12	1.54	NA	No	NA	No

Contaminant Specific Risks

Contaminant		Fish Fillet		Lobster Hepatopancreas	
		Cancer Risk	Non-cancer Risk	Cancer Risk	Non-cancer Risk
4,4'-DDD	Test	7.171E-8	0.00042	2.553E-7	0.0015
	Reference	7.427E-8	0.00044	2.644E-7	0.00156
4,4'-DDE	Test	8.483E-8	0.0005	3.02E-7	0.00178
	Reference	1.145E-7	0.00067	4.075E-7	0.0024

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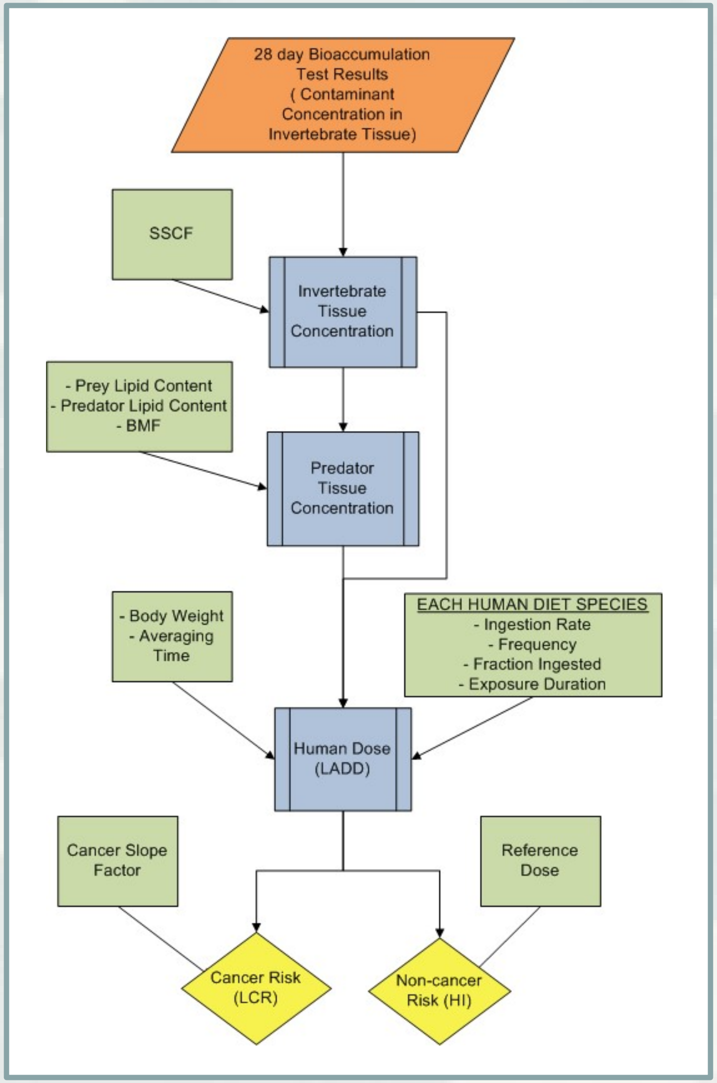
BEST - Technical Approach

- Invertebrate and Predator Body Burdens
  - 28-day Bioaccumulation Test Results
  - SSCF, BMF, Lipid Content
- Human Dose
  - Prey Body Burden
  - Exposure Scenario
- Human Cancer and Non-Cancer Risk
  - LCR = Dose x CSF
  - HI = Dose/ RfD



BEST Model Inputs

Food Web

- Invertebrates
  - Lipid Content
  - 28-day Bioaccumulation Test Results (mean and maximum tissue concentration)
- Predators
  - Lipid Content
  - Diet

Human Exposure

- Body Weight
- Averaging Time
- Each Diet Species
  - Fraction Ingested
  - Frequency
  - Ingestion rate
  - Exposure Duration

Chemicals

- Type
- *Cancer Slope Factor
- *Reference Dose
- Steady State Correction Factor
- Biomagnification Factor
- *Human Toxicity Equivalence Factor
- *FDA Action Level
- *Ecological Effects Level

Project

- Name
- *Number
- *Location
- Risk Thresholds
- *Reference Project

*Optional Input

Invertebrate Tissue Concentration

$$[EdibleTissue_{Invertebrate}] = [C_{\mathrm{Prey}}] \times SSCF$$

Where:
[Edible Tissue $_{\mathrm{Invertebrate}}$] = Concentration of contaminant in edible tissue of invertebrate species (mg/kg)
[C_{Prey}] = Maximum tissue concentration of contaminant in the invertebrate out of five replicates from the 28-day bioaccumulation test data (mg/kg)
SSCF = Steady state correction factor (unitless)

Predator Tissue Concentration

$$[EdibleTissue_{Predator}] = [EdibleTissue_{Invertebrate}] \times BMF \times \left(\frac{Lipid_{Pred}}{Lipid_{Prey}} \right)$$

Where:

$[\text{Edible Tissue}_{\text{Predator}}]$	= Concentration of contaminant in edible tissue of predator (mg/kg)
$[\text{Edible Tissue}_{\text{Invertebrate}}]$	= Concentration of contaminant in edible tissue of invertebrate species (mg/kg)
$\text{Lipid}_{\text{Pred}}$	= Predator mean lipid fraction (g lipid/g tissue)
$\text{Lipid}_{\text{Prey}}$	= Invertebrate mean lipid fraction (g lipid/g tissue)
BMF	= Biomagnification factor (unitless)

Lifetime Average Daily Dose Equation

$$LADD = \frac{ETC \times FI \times F \times IR \times ED}{BW \times AT}$$

Where:

LADD	= Lifetime Average Daily Dose (mg/kg-day)
ETC	= Edible Tissue Concentration of diet species (mg/kg)
FI	= Fraction Ingested (unitless)
F	= Frequency (days/year)
IR	= Fish/shellfish Ingestion Rate (kg/day)
ED	= Exposure Duration (years)
BW	= Body Weight (kg)
AT	= Averaging Time (days)

Standard Risk Equations

$$\text{Cancer Risk} = \text{LADD} \times \text{CSF}$$

Where:
LADD = Lifetime Average Daily Dose (mg/kg-day)
CSF = Oral Cancer Slope Factor (mg/kg)

$$\text{Non-cancer Risk} = \text{LADD}/\text{RfD}$$

Where:
ADD = Lifetime Average Daily Dose (mg/kg-day)
RfD = Oral Reference Dose (mg/kg-day)

Excel Input Templates - Bioaccumulation

	A	B	C	D
1	**28-days Bioaccumulation Test Results**			
2	**Project Name:**	pname1		
3	**Project Number:**	pnumber1		
4	**Location**	l1		
5				
6	**Organism**	**Contaminant**	**Mean Tissue Concentration (Organics = ng/g; Metals = µg/g)**	**Max Tissue Concentration (Organics = ng/g; Metals = µg/g)**
7				
8	o1	c1	1	1
9	o1	c2	1	1
10	o1	c3	1	1
11	o1	c4	1	1
12	o2	c1	1	1
13	o2	c2	1	1
14	o2	c3	1	1
15	o2	c4	1	1
16				
17				
18				
19				

Excel Input Templates - Chemicals

	A	B	C	D	E	F	G	H	I	J	K
1	Chemicals										
2											
3	Name	Chemical Type	Oral Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$	Oral Reference Dose (mg/kg-day)	Biomagnification Factor	Human Toxicity Equivalence Factor	TEF Reference Chemical	TEF Relation	Steady State Correction Factor	FDA Action Level (ppm)	Ecological Effects Level (ppm)
4											
5	c1	Organic	1.00	1.00	1.00	1.00	Y	N/A	1.00	1.00	1.00
6	c2	Organic	1.00	1.00	1.00	0.01	N	c1	1.00	1.00	1.00
7	c3	Metal	1.00	1.00	1.00	N/A	N	N/A	1.00	1.00	1.00
8	c4	Organic	1.00	N/A	1.00	N/A	N	N/A	1.00	1.00	1.00

Chemicals

BEST Reports

Full Report

BRAMS

BEST Model Report

Project name: Standard Template
Project number:
Location:

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General

Human Name	Adult Recreational Angler
Cancer Risk	2.842E-6
Non-Cancer Risk	0.01672

Diet Report

Diet Name	Cancer Risk	Non-Cancer Risk
Fish Fillet	3.842E-7	0.00226
Lobster Muscle	6.147E-7	0.00362
Lobster Hepatopancreas	1.368E-6	0.00805
Macoma nasuta	4.758E-7	0.0028

Prey Report

Prey Name	Diet Name	Cancer Risk	Non-Cancer Risk
Nereis virens	Fish Fillet	1.902E-7	0.00112
Macoma nasuta	Fish Fillet	1.94E-7	0.00114
Nereis virens	Lobster Muscle	3.043E-7	0.00179
Macoma nasuta	Lobster Muscle	3.104E-7	0.00183
Nereis virens	Lobster Hepatopancreas	6.771E-7	0.00398
Macoma nasuta	Lobster Hepatopancreas	6.906E-7	0.00406
Macoma nasuta	Macoma nasuta	4.758E-7	0.0028

Chemical Report

Chemical Name	Diet Name	Edible Tissue Concentration	Average Daily Dose	Cancer Risk	Non-Cancer Risk
4,4'-DDT	Fish Fillet Nereis virens	0.00032	9.901E-8	3.366E-8	0.0002
4,4'-DDD	Fish Fillet Nereis virens	0.00069	2.109E-7	7.171E-8	0.00042
4,4'-DDE	Fish Fillet Nereis virens	0.00082	2.495E-7	8.483E-8	0.0005

Summary Report

BRAMS

BEST Summary Report

Project name: Standard Template
Project number:
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Table Of Contents

Human Subreport

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4,4'-DDE	5.12	1.54	NA	No	NA	No

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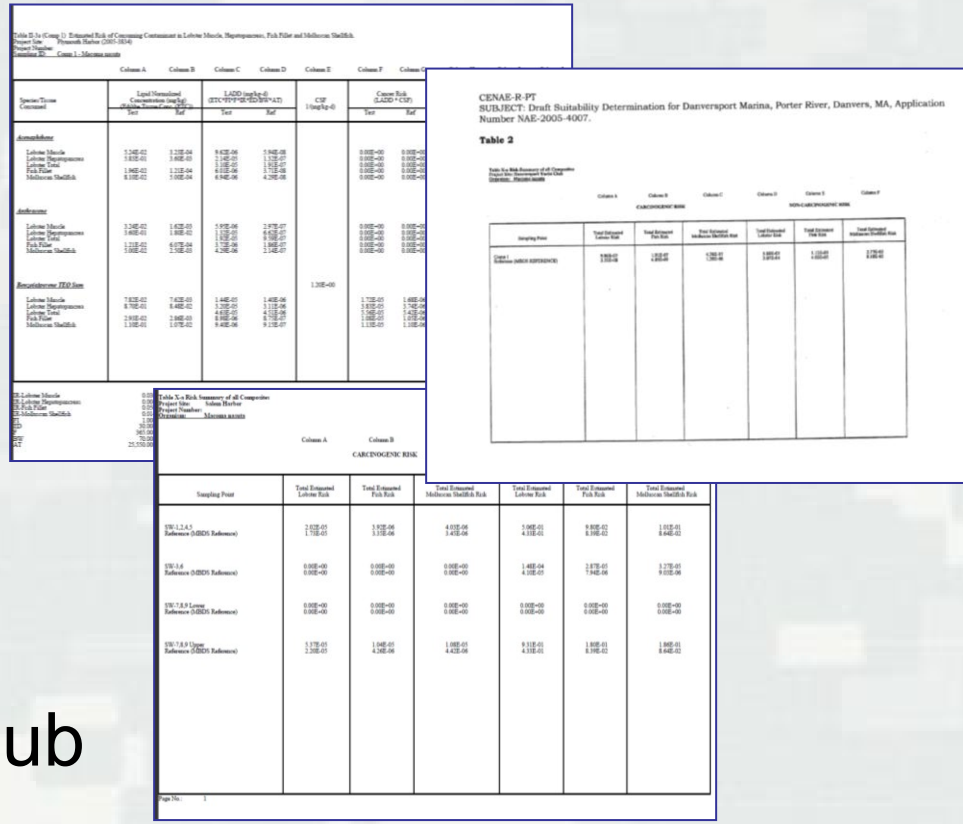
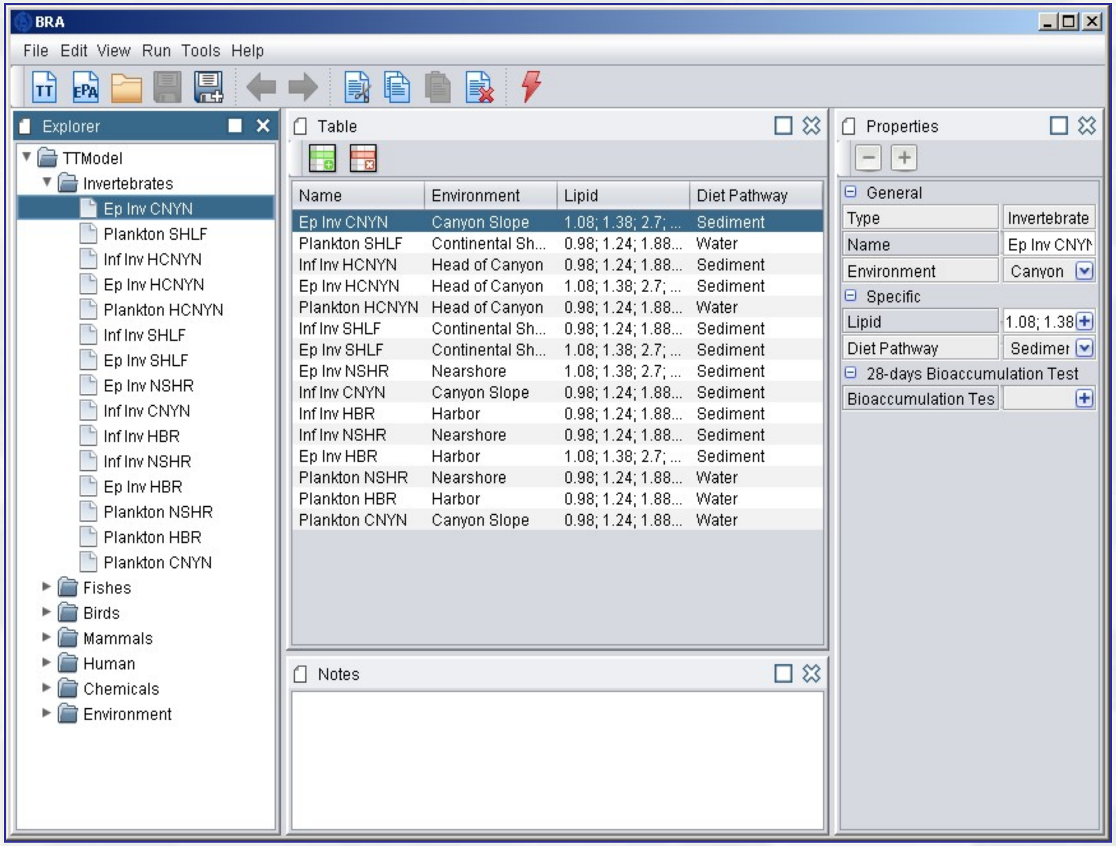
4,4'-DDE	Test	8.483E-8	0.0005	3.02E-7	0.00178
	Reference	1.145E-7	0.00067	4.075E-7	0.0024

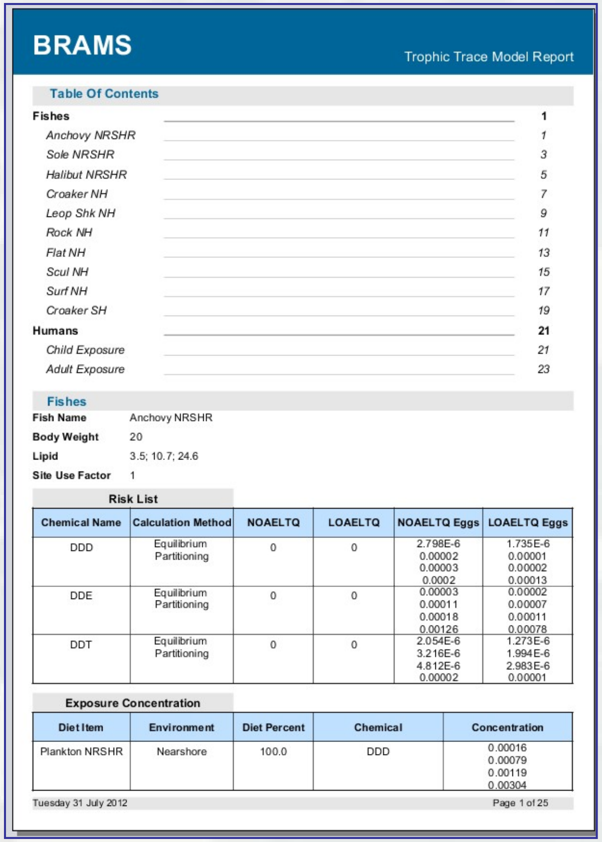
Validation

- Plymouth Harbor
- Salem Harbor
- Danversport Yacht Club


CENAE-R-PT
SUBJECT: Draft Suitability Determination for Danversport Marina, Porter River, Danvers, MA, Application Number NAE-2005-4007.
Table 2

Trophic Trace





BRAMS Trophic Trace Model Report

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Fishes

Fish Name Anchovy NRSHR
Body Weight 20
Lipid 3.5; 10.7; 24.6
Site Use Factor 1

Risk List

Chemical Name	Calculation Method	NOAELTQ	LOAELTQ	NOAELTQ Eggs	LOAELTQ Eggs
DDD	Equilibrium Partitioning	0	0	2.798E-6 0.00002 0.00003 0.0002	1.735E-6 0.00001 0.00002 0.00013
DDE	Equilibrium Partitioning	0	0	0.00003 0.00011 0.00018 0.00126	0.00002 0.00007 0.00011 0.00078
DDT	Equilibrium Partitioning	0	0	2.054E-6 3.216E-6 4.812E-6 0.00002	1.273E-6 1.994E-6 2.983E-6 0.00001

Exposure Concentration

Diet Item	Environment	Diet Percent	Chemical	Concentration
Plankton NRSHR	Nearshore	100.0	DDD	0.00016 0.00079 0.00119 0.00304

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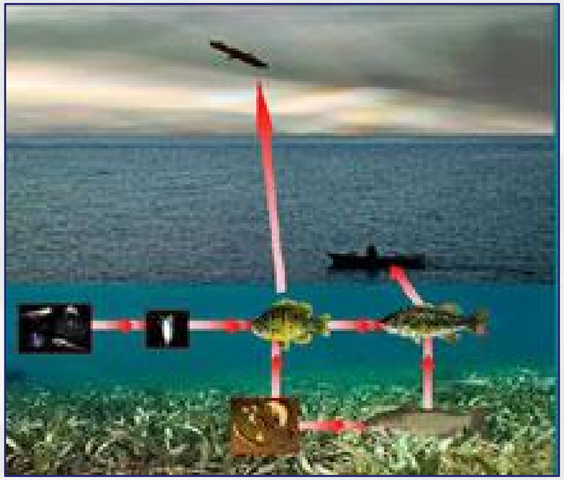
Technical Approach Overview

Depending on inputs, several modeling choices are available:

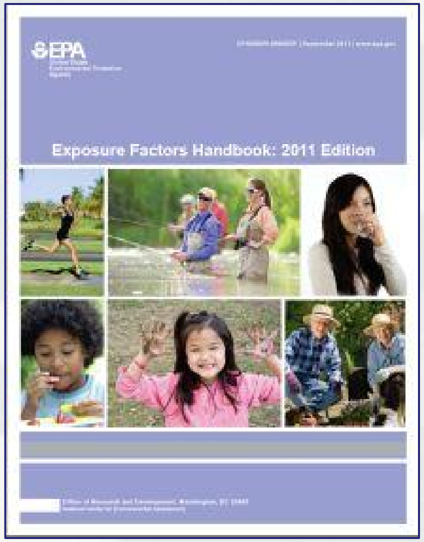
- Freely Dissolved Water Concentration
  - User specified from site specific data
  - Calculated from a subroutine based on whole water concentration
  - Calculated using equilibrium partitioning from a sediment concentration
- Hydrophobic organics
  - Invertebrates Tissue Concentration:
    - BSAF (hydrophobic organics)
    - 28-day Bioaccumulation Testing
  - Fish Burdens:
    - Gobas – steady state uptake model
- Inorganic and hydrophilic organics
  - Fish Burdens:
    - BCF Approach
    - TTF Approach



Technical Approach Overview Continued

- Daily dose:
    - Fish tissue concentrations
    - Exposure assumptions

- Human Health Risk:
    - Incremental Lifetime Cancer Risk (Dose x CSF)
    - Hazard index (Dose/RfD)
- Ecological Risk:
    - NOAEL and LOAEL TQs (Dose/TRV)



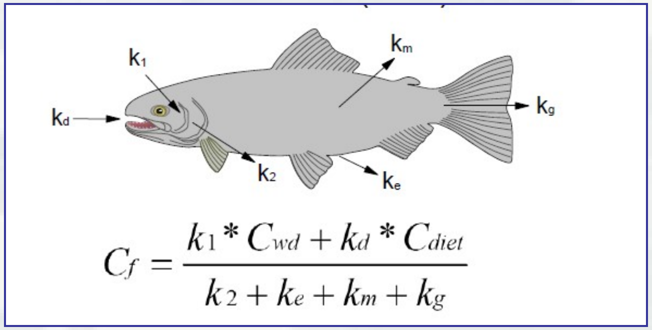
❖ Implements Uncertainty Analysis using Fuzzy Mathematics

Model Structure: Gobas Model

$$C_f = \frac{k_1 \times C_{wd} + k_d \times C_{diet}}{k_2 + k_e + k_m + k_g}$$

Where:

- k_1 = gill uptake rate (L/Kg/d)
- C_{wd} = freely dissolved concentration in water (ng/L)
- k_d = dietary uptake rate (d^{-1})
- C_{diet} = concentration in the diet (μg/kg)
- k_2 = gill elimination rate (d^{-1})
- k_e = fecal egestion rate (d^{-1})
- k_m = metabolic rate (d^{-1})
- k_g = growth rate (d^{-1})
- C_f = concentration in fish (μg/kg)



Gobas Model

- Estimates fish body burdens for hydrophobic organic compounds
- Relies on a steady-state uptake model based on the approach of Gobas (1993 and 1995)
- Several sources provide equations for the rate constants (k_2, k_e, k_m and k_g) detailed in von Stackelberg et al. (2002)

Human Health - Cancer Risk Calculation

$$CancerRisk = \frac{CSF \times IR_f \times C_f \times ED}{BW \times 1000000 \times AT}$$

Where:

- Cancer Risk = incremental lifetime cancer risk
- CSF = cancer slope factor $(mg/kg\text{-}day)^{-1}$
- IR_f = annualized fish ingestion rate (g/day)
- C_f = concentration in fish (μg/kg)
- ED = exposure duration (days)
- BW = body weight (kg)
- AT = averaging time (days)

Human Health - Non-Cancer Risk Calculation

$$HazardIndex = \frac{IR_f \times C_f \times ED}{RfD \times BW \times 1000000 \times AT}$$

Where:
HI = hazard index
IR_f = annualized fish ingestion rate (g/day)
C_f = concentration in fish (µg/kg)
RfD = Reference dose (mg/kg-day)
ED = exposure duration (days)
BW = body weight (kg)
AT = averaging time (days)

Ecological Risk - Toxicity Quotient Calculations

$$TQ = \frac{\sum \left(IR_f \times C_f \times Frac \right)}{TRV \times BW}$$

Where:
TQ = Toxicity Quotient
IR_f = annualized ingestion rate (kg/day)
C_f = concentration in prey (mg/kg)
Frac = fraction in diet
TRV = toxicity reference value (mg/kg/day)
BW = body weight (kg)

Toxicity Quotient Calculations

- Compare predicted contaminant concentrations in tissue and/or daily dose estimates to appropriate toxicity reference values (TRVs).

- TRVs are levels of exposure associated with:
  - Lowest Observed Adverse Effects Levels (LOAELs)
  - No Observed Adverse Effects Levels (NOAELs)

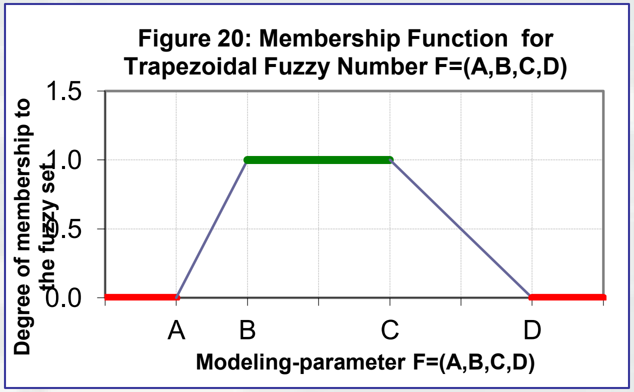
- TRVs are contaminant- and species-specific and are developed based on laboratory or field studies.

Characterizing Parameter Uncertainty Through Interval Analysis or "Fuzzy Math"

- Four numerical values [A, B, C, D] represent the possible and probable range of a parameter.

- The interval [A,D] represents the possible range of the parameter.
  - A is the minimum possible value
  - D is the maximum possible value

- The range [B,C] is the probable range of the parameter.
  - A is the minimum plausible value
  - D is the maximum plausible value

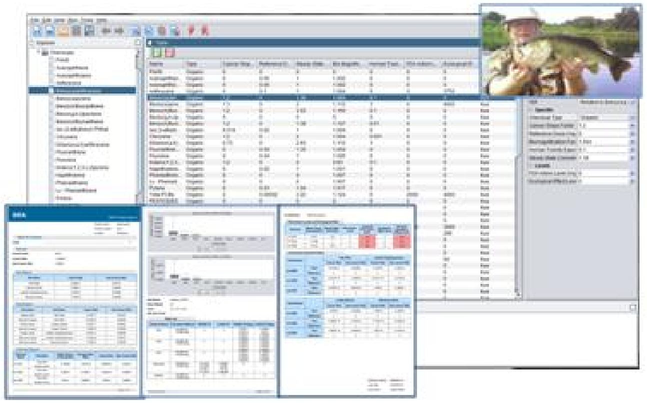


- Fuzzy results yield both "worst case" and
  "best estimates" simultaneously.

User Manual

BIOACCUMULATION RISK ASSESSMENT MODELING SYSTEM (BRAMS)

USERS GUIDE



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