Bioaccumulation Risk Assessment Modeling System
Software Presentation and Demonstration

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Risk and Decision Science Focus Area
USACE ERDC Environmental Laboratory
August 2012
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.
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

- Action: Dredged Material Disposed of in Open Water
- Stressors: Contaminants in water column, Contaminants in benthic zone
- Receptors: Benthic Invertebrates, Aquatic Predators, Terrestrial Predators, Humans
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

- **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)

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

<table>
<thead>
<tr>
<th>Trophic Trace</th>
<th>BEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanistic Bioaccumulation Model</td>
<td>Empirical Screening Tool</td>
</tr>
<tr>
<td>Tiers I-III, IV (partially)</td>
<td>Tier III</td>
</tr>
<tr>
<td>Required Input:</td>
<td>Required Input:</td>
</tr>
<tr>
<td>► Sediment, Water, or Tissue Concentrations</td>
<td>► Tissue Concentrations</td>
</tr>
<tr>
<td>Uncertainty:</td>
<td>Uncertainty:</td>
</tr>
<tr>
<td>► Interval Analysis or “fuzzy math”</td>
<td>► None</td>
</tr>
<tr>
<td>Food Chain:</td>
<td>Food Chain:</td>
</tr>
<tr>
<td>► Invertebrates</td>
<td>► Invertebrates</td>
</tr>
<tr>
<td>► Fish</td>
<td>► Aquatic Predators</td>
</tr>
<tr>
<td>► Mammals</td>
<td>► Humans</td>
</tr>
<tr>
<td>► Birds</td>
<td>►</td>
</tr>
<tr>
<td>► Humans</td>
<td>►</td>
</tr>
<tr>
<td>Trophic Transfer:</td>
<td>Trophic transfer:</td>
</tr>
<tr>
<td>► Equilibrium Partitioning + Gobas Model or BCF</td>
<td>► 28-day bioaccumulation test results + BMFs</td>
</tr>
<tr>
<td>► 28-bioaccumulation test results (+ TTF) + Gobas Model</td>
<td></td>
</tr>
<tr>
<td>Risk Receptors:</td>
<td>Risk Receptors:</td>
</tr>
<tr>
<td>► Humans</td>
<td>► Humans</td>
</tr>
<tr>
<td>► Ecological</td>
<td>►</td>
</tr>
</tbody>
</table>

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**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

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_tropic transfer:_

- Equilibrium Partitioning + Gobas Model or BCF
- 28-bioaccumulation test results (+ TTF) + Gobas Model
BEST – Bioaccumulation Evaluation Screening Tool
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

\[
[\text{Edible Tissue}_{\text{Invertebrate}}] = [C_{\text{Prey}}] \times \text{SSCF}
\]

Where:

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

\[
[\text{Edible Tissue}_{\text{Predator}}] = [\text{Edible Tissue}_{\text{Invertebrate}}] \times \text{BMF} \times \left( \frac{\text{Lipid}_{\text{Pred}}}{\text{Lipid}_{\text{Prey}}} \right)
\]

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

Cancer Risk = LADD × CSF

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

Non-cancer Risk = LADD / RfD

Where:
ADD = Lifetime Average Daily Dose (mg/kg-day)
RfD = Oral Reference Dose (mg/kg-day)
# Excel Input Templates - Bioaccumulation

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-days Bioaccumulation Test Results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Name:</td>
<td>pnamel</td>
<td></td>
</tr>
<tr>
<td>Project Number:</td>
<td>pnumber1</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>l1</td>
<td></td>
</tr>
<tr>
<td>Organism</td>
<td>Contaminant</td>
<td>Mean Tissue Concentration (Organics = ng/g; Metals = μg/g)</td>
</tr>
<tr>
<td>8  o1</td>
<td>c1</td>
<td>1</td>
</tr>
<tr>
<td>9  o1</td>
<td>c2</td>
<td>1</td>
</tr>
<tr>
<td>10 o1</td>
<td>c3</td>
<td>1</td>
</tr>
<tr>
<td>11 o1</td>
<td>c4</td>
<td>1</td>
</tr>
<tr>
<td>12 o2</td>
<td>c1</td>
<td>1</td>
</tr>
<tr>
<td>13 o2</td>
<td>c2</td>
<td>1</td>
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<tr>
<td>14 o2</td>
<td>c3</td>
<td>1</td>
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<tr>
<td>15 o2</td>
<td>c4</td>
<td>1</td>
</tr>
</tbody>
</table>

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**ERDC**

Innovative solutions for a safer, better world
<table>
<thead>
<tr>
<th>Name</th>
<th>Chemical Type</th>
<th>Oral Cancer Slope Factor (mg/kg-day)$^1$</th>
<th>Oral Reference Dose (mg/kg-day)</th>
<th>Biomagnification Factor</th>
<th>Human Toxicity Equivalence Factor</th>
<th>TEF Reference Chemical</th>
<th>TEF Relation</th>
<th>Steady State Correction Factor</th>
<th>FDA Action Level (ppm)</th>
<th>Ecological Effects Level (ppm)</th>
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<tbody>
<tr>
<td>c1</td>
<td>Organic</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00 Y</td>
<td>N/A</td>
<td>NA</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>c2</td>
<td>Organic</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.01 N</td>
<td>c1</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>c3</td>
<td>Metal</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>NA N</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>c4</td>
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<td>NA</td>
<td>1.00</td>
<td>NA N</td>
<td>NA</td>
<td>NA</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

$^1$ Note: mg/kg-day refers to milligrams per kilogram per day.
## BEST Reports

### Full Report

**BRAMS Model Report**

**Table Of Contents**

- Adult Recreational

**General**

- **Human Name**: Adult Recreational Angler
- **Cancer Risk**: 2.842E-6
- **Non-Cancer Risk**: 0.01872

**Diet Report**

<table>
<thead>
<tr>
<th>Diet Name</th>
<th>Cancer Risk</th>
<th>Non-Cancer Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Fillet</td>
<td>3.92E-7</td>
<td>0.00226</td>
</tr>
<tr>
<td>Lobster Muscle</td>
<td>6.14E-7</td>
<td>0.00362</td>
</tr>
<tr>
<td>Lobster Hepatopancreas</td>
<td>1.36E-8</td>
<td>0.00005</td>
</tr>
<tr>
<td>Macoma nasuta</td>
<td>4.75E-7</td>
<td>0.00283</td>
</tr>
</tbody>
</table>

**Prey Report**

<table>
<thead>
<tr>
<th>Prey Name</th>
<th>Diet Name</th>
<th>Cancer Risk</th>
<th>Non-Cancer Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nereis virina</td>
<td>Fish Fillet</td>
<td>1.902E-7</td>
<td>0.00112</td>
</tr>
<tr>
<td>Macoma nasuta</td>
<td>Fish Fillet</td>
<td>1.94E-7</td>
<td>0.00114</td>
</tr>
<tr>
<td>Nereis virina</td>
<td>Lobster Muscle</td>
<td>3.043E-7</td>
<td>0.00179</td>
</tr>
<tr>
<td>Macoma nasuta</td>
<td>Lobster Muscle</td>
<td>3.104E-7</td>
<td>0.00163</td>
</tr>
<tr>
<td>Nereis virina</td>
<td>Lobster Hepatopancreas</td>
<td>6.771E-7</td>
<td>0.00368</td>
</tr>
<tr>
<td>Macoma nasuta</td>
<td>Lobster Hepatopancreas</td>
<td>6.930E-7</td>
<td>0.00406</td>
</tr>
<tr>
<td>Macoma nasuta</td>
<td>Macoma nasuta</td>
<td>4.750E-7</td>
<td>0.00283</td>
</tr>
</tbody>
</table>

**Chemical Report**

<table>
<thead>
<tr>
<th>Chemical Name</th>
<th>Diet Name</th>
<th>Edible Tissue Concentration</th>
<th>Average Daily Dose</th>
<th>Cancer Risk</th>
<th>Non-Cancer Risk</th>
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</thead>
<tbody>
<tr>
<td>4,4'-DDT</td>
<td>Fish Fillet</td>
<td>0.00032</td>
<td>9.901E-8</td>
<td>3.398E-8</td>
<td>0.0002</td>
</tr>
<tr>
<td>Nereis virina</td>
<td>Fish Fillet</td>
<td>0.00039</td>
<td>2.198E-7</td>
<td>7.171E-8</td>
<td>0.00042</td>
</tr>
<tr>
<td>4,4'-DDD</td>
<td>Fish Fillet</td>
<td>0.00082</td>
<td>2.495E-7</td>
<td>8.483E-8</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

### Summary Report

**BRAMS Model Report**

**Table Of Contents**

- Adult Recreational

**Human Subreport**

- **Human**: Adult Recreational Angler
- **Invertebrates**: Nereis virina

**Total Estimated Risks**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Fish Fillet</th>
<th>Lobster Hepatopancreas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancer Risk</td>
<td>Non-Cancer Risk</td>
<td>Cancer Risk</td>
</tr>
<tr>
<td>Test</td>
<td>1.902E-7</td>
<td>0.00125</td>
</tr>
<tr>
<td>Reference</td>
<td>2.107E-7</td>
<td>0.00127</td>
</tr>
</tbody>
</table>

**FDA Action Levels and Ecological Risk**

- **Chemical**: 4,4'-DDT
  - Mean Tissue Concentration: 1.94EA-8
  - Safety Ratio: NA
  - FDA Action Level: NA
  - Ecological Effect Level: NA
  - Expected Ecological Effect Level: NA

**Contaminant Specific Risks**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Fish Fillet</th>
<th>Lobster Hepatopancreas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cancer Risk</td>
<td>Non-Cancer Risk</td>
<td>Cancer Risk</td>
</tr>
<tr>
<td>Test</td>
<td>7.171E-8</td>
<td>0.0002</td>
</tr>
<tr>
<td>Reference</td>
<td>7.427E-8</td>
<td>0.0004</td>
</tr>
<tr>
<td>Test</td>
<td>6.400E-6</td>
<td>0.0000</td>
</tr>
<tr>
<td>Reference</td>
<td>1.142E-7</td>
<td>0.0007</td>
</tr>
</tbody>
</table>
Validation

- Plymouth Harbor
- Salem Harbor
- Danversport Yacht Club
Trophic Trace

Table of Contents
Fishes
- Anthophora NNRSH
  - Body Weight: 20
  - Lipid: 3.9, 10.7, 24.6
  - Site Use Factor: 1
- Chemical Name: Calculation Method
  - NOAEL (LQ), LOAEL (LQ) (Eggs)
    - DDQ: Equilibrium Partitioning
    - DDE: Equilibrium Partitioning
    - DOT: Equilibrium Partitioning

Exposure Concentration
- Date: 31 July 2012
- Chemical: Concentration
  - Plancton NNRSH: Nearshore 100.0 DDQ 0.0010
  - Plancton NNRSH: Nearshore 100.0 DDE 0.0010
  - Plancton NNRSH: Nearshore 100.0 DOT 0.0010

BRAMS - Trophic Trace Model Report
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 \( (k_2, k_e, k_m \text{ and } k_g) \) 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-day)^{-1}
- IR_f = annualized fish ingestion rate (g/day)
- C_f = concentration in fish (\(\mu\)g/kg)
- ED = exposure duration (days)
- BW = body weight (kg)
- AT = averaging time (days)
Human Health - Non-Cancer Risk Calculation

\[
\text{Hazard Index} = \frac{IR_f \times C_f \times ED}{RfD \times BW \times 1000000 \times AT}
\]

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

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

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.

![Figure 20: Membership Function for Trapezoidal Fuzzy Number F=(A,B,C,D)](image)
References


