VIRTUAL WQS ACADEMY

AQUATIC LIFE WATER QUALITY CRITERIA FOR TOXICS

Ecological Risk Assessment Branch
Health and Ecological Criteria Division
Office of Science and Technology
Office of Water

DISCLAIMER

- This Presentation does not:
  - Impose any binding requirements
  - Determine the obligation of the regulated community
  - Change or substitute for any statutory provision or regulatory requirement
  - Change or substitute for any Agency policy or guidance
  - Control in any case of conflict between this discussion and statute, regulation, policy, or guidance

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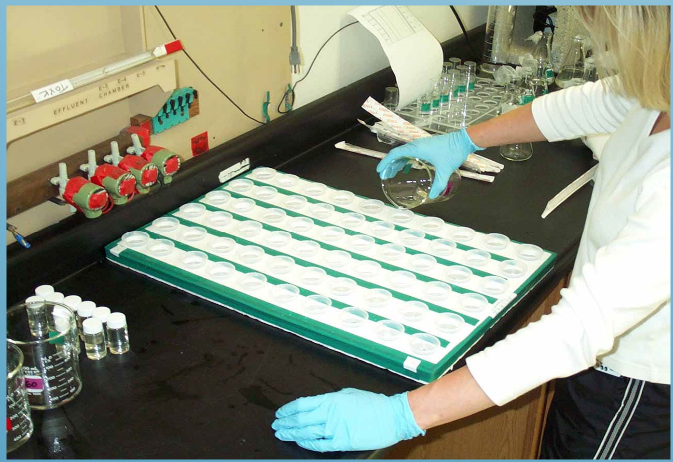
PRESENTATION

- Aquatic Life Criteria Overview
- Process for Deriving Criteria Values
  - Water-Based Criteria
  - Tissue-Based Criteria
- Quiz and Aquatic Life Exercise

AQUATIC LIFE PROTECTION

- States have both:
  - Chemical-specific criteria
  - Toxicity testing approach - often called Whole Effluent Toxicity (WET) testing
- For chemical-specific criteria, states can choose either a narrative form, such as “no toxics in toxic amounts,” or numerical values (both acute and chronic)
- This module describes the chemical-specific aquatic life criteria derivation process for toxics



WATER QUALITY CRITERIA REQUIREMENTS

- States/Tribes can adopt numeric criteria based on:
  - EPA's 304(a) criteria recommendations
  - 304(a) recommendations modified to reflect site specific conditions
  - Other scientifically defensible methods
- States/Tribes can adopt narrative criteria:
  - Where numeric criteria cannot be established
  - Or to supplement numeric criteria

CHEMICAL SELECTION PROCESS

- Select new chemicals of national concern where no criteria exists
  - Stakeholder input/public interest (e.g., States and Tribes)
- Select existing criteria needing re-evaluation for several possible reasons
  - New science (e.g., selenium)
  - New data (e.g., cadmium)
  - New approach (e.g., BLM to MLR)
  - Stakeholder input (e.g., States and Tribes)
  - Legal action

“The Guidelines”

PB85-227049

Guidelines for Deriving Numerical National Water Quality Criteria for the Protection Of Aquatic Organisms and Their Uses

by Charles E. Stephen, Donald I. Mount, David J. Hansen, John R. Gentile, Gary A. Chapman, and William A. Brungs

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Environmental Research Laboratories
Duluth, Minnesota
Narragansett, Rhode Island
Corvallis, Oregon

KEY COMPONENTS OF THE GUIDELINES

- Development of the Problem Formulation
- All information related to aquatic toxicity and bioaccumulation is collected, reviewed for acceptability (a lot of effort!), and sorted for evaluation.
  - Require high quality data to support quality decisions
- Criteria undergo internal Agency and external peer review and public comment.

304(a) NUMERIC WATER QUALITY CRITERIA

- Scientifically determined numeric values, or concentrations which establish "safe" chemical concentrations
- 3 aspects:
  - **Magnitude**: Concentration (e.g., 1 mg/L)
    - Most criteria are for water column concentrations
    - Some bioaccumulative pollutants have tissue criteria
  - **Duration**: Maximum period of time that a concentration can occur (e.g., 1-hour for acute criteria, 4 or 30 days for chronic criteria)
  - **Frequency**: How often a concentration can be exceeded (e.g., once in 3 or 10 years)
- Some criteria are adjusted to reflect the impacts of water chemistry on toxicity (e.g., metals and pH effects)
- Narrative criteria can also be adopted

DERIVING AQUATIC LIFE CRITERIA: WATER-BASED CRITERIA

June 2024

WATER QUALITY CRITERIA

- **Example numeric criteria**: "To protect Aquatic Life, Dissolved Zinc shall not exceed ***90 micrograms per liter*** as a ***one hour average*** more than ***once every three years***."

SHORT-TERM AND LONG-TERM CRITERIA

Two types of criteria related to short or long-term exposure protection

- **Acute**:
  - Effects of short-term, higher concentration exposures
  - Death resulting from 24-96 hour exposures
    - LC50: a concentration that is lethal to 50% of the test organisms
- **Chronic:**
  - Effects of longer-term, lower concentration exposures
  - Decreased growth, reproduction, or longer-term survival from 7 to 60-day exposures
    - EC10 or 20: a concentration that affects 10 or 20% of test organisms
    - Other measurements: No Effect Level (NOEC) or Lowest Effect Level (LOEC)

TOXICITY TEST DATA SOURCES

- Data are collected from ecological toxicity database (ECOTOX, maintained by ORD)
- This is updated, on a compound-specific basis, from literature
- Data may also be collected from other sources to ensure all available data are obtained (e.g., web search)

AQUATIC LIFE CRITERIA SYSTEMATIC REVIEW

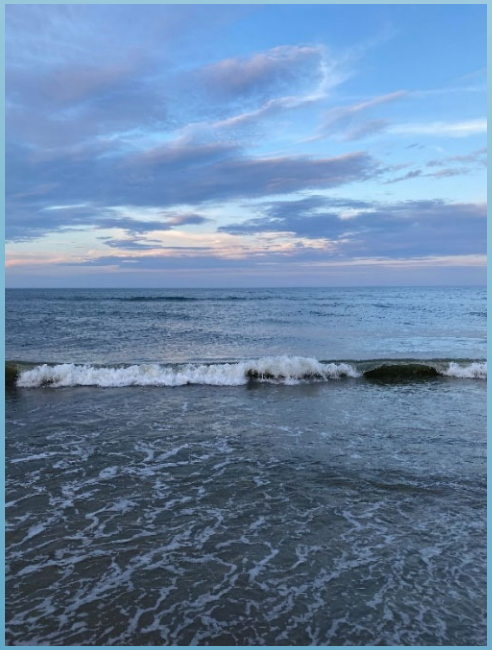
- EPA's Office of Water (OW) has documented its long-standing process in a **Systematic Review Standard Operating Procedure (SOP)** and fillable **Data Evaluation Record (DER)** templates to capture toxicity data
  - OW compared its current DERs and harmonized, as appropriate, with the approaches of EPA's Office of Pesticide Program and Office of Pollution Prevention and Toxics
- EPA OW collaborated with EPA's Office of Research and Development
  - Automated capture of data from publications into DERs to streamline and expedite review process

SOP FOR SYSTEMATIC REVIEW OF ECOTOXICITY DATA FOR CRITERIA

- SOP details are rigorous:
  - ***Screening Process*** – general screening of papers (e.g., applicable or not),
    - OW uses ORD's ECOTOX as its primary source to obtain ecotoxicological studies for criteria development
    - Begins with a comprehensive chemical-specific literature search of the open literature
  - ***Reviewing Process*** – for reviewing studies that pass the screening process to determine a study's usability in criteria development (e.g., quantitative, qualitative, and unused)
  - ***Documenting Process*** – to support efficient and consistent documenting of the review process

SOP FOR SYSTEMATIC REVIEW OF ECOTOXICITY DATA FOR CRITERIA

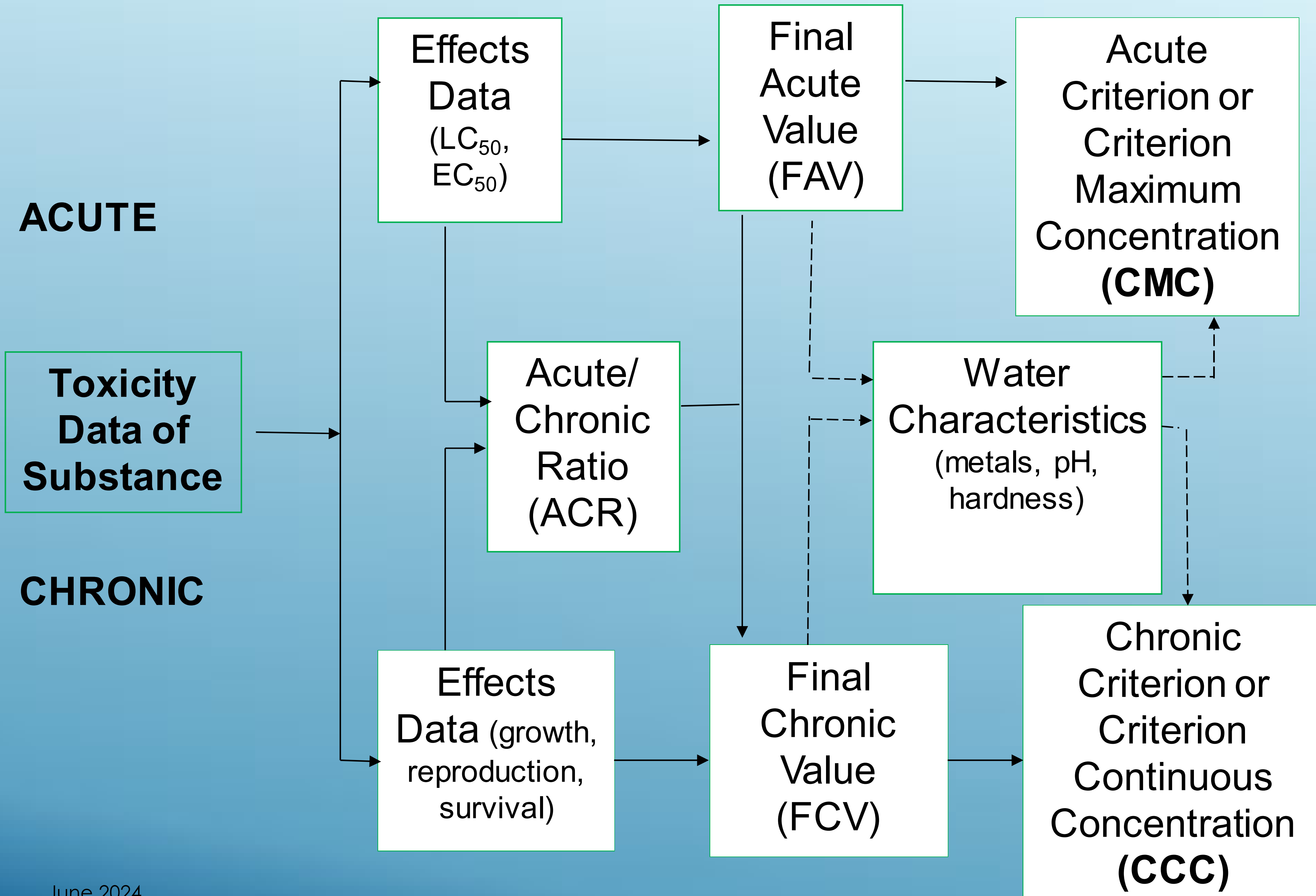
- Documentation Process:
  - Study review documentation is captured via a species-specific DER
  - Purpose of is to ensure a transparent and consistent process for conducting reviews of studies
  - The SOP is accompanied by DER templates for
    - Fish
    - Aquatic invertebrates
    - Aquatic plants
    - Amphibians
    - Aquatic-dependent bird species



CRITERIA DEVELOPMENT PROCESS OVERVIEW

- All Aquatic Life Criteria for toxics undergo rigorous scientific development and review
  - Develop criteria document draft
  - Intra-agency peer review process
  - Independent external peer review
  - Revisions based on external peer review
    - Intra-agency review of draft criteria document
  - Release to the public in draft form to obtain scientific views
    - Revisions considering public comments
    - Intra-agency review of final criteria document
  - Publication of final criteria document
- Long and complex process, so we prioritize completion of important criteria for environmental protection

CRITERIA DERIVATION OVERVIEW



MINIMUM DATASET FOR FRESHWATER CRITERIA DERIVATION

1. SALMONID: Rainbow trout

2. SECOND FISH FAMILY:

Bluegill

3. CHORDATA

Fish or amphibians

4. PLANKTONIC CRUSTACEAN:

Daphnia

5. BENTHIC CRUSTACEAN:

Crayfish, amphipod,etc.

6. INSECT: Mayfly

7. OTHER: ROTIFERA, ANNELIDA, MOLLUSCA

8. OTHER INSECT OR MOLLUSCA

Clam

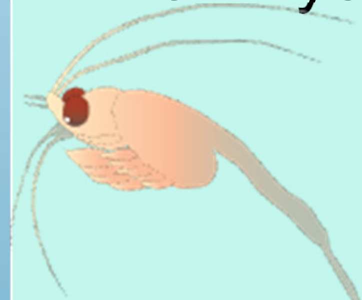
MINIMUM DATASET FOR SALTWATER CRITERIA DERIVATION

Family in
Chordata

Family in
Chordata

Family other than Arthropoda or Chordata

Either Mysidae or Penaeidae



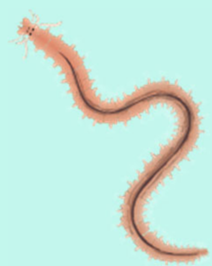
3 other families not in the phylum Chordata:

Bivalves

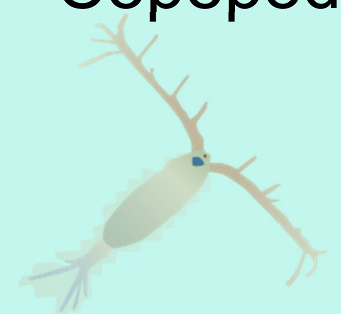
June 2024

Barnacles

Polychaetes



Copepods



TOXICITY DATA REQUIREMENTS

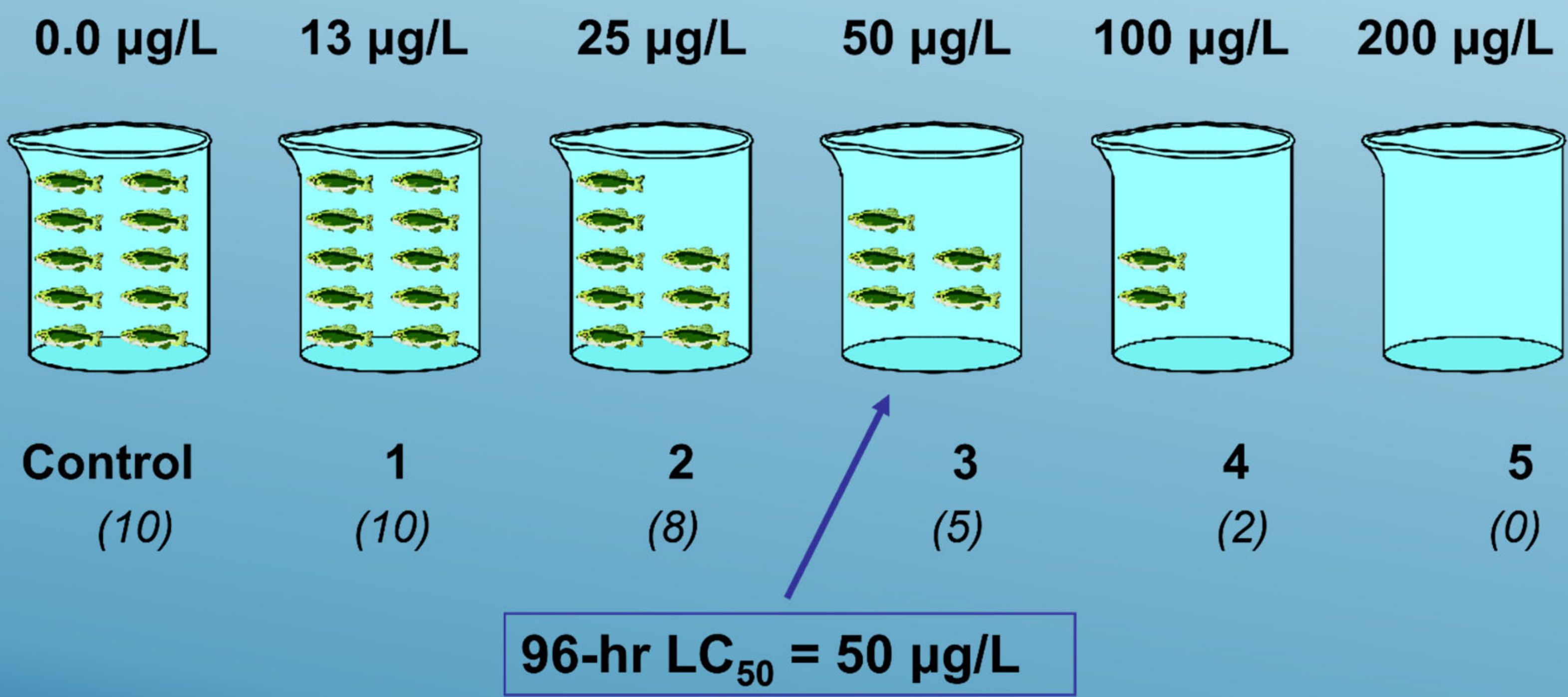
Data from the most sensitive life stage is used

Most Sensitive?

ACUTE TEST DATA HANDLING

96-hour LC_{50} values from the literature

Concentration:



FAV CALCULATION OVERVIEW

Step 1. Calculate Species Mean Acute Values (SMAVs) - geometric mean of all acceptable acute values for species

Step 2. Calculate Genus Mean Acute Values (GMAVs) - geometric mean of all SMAVs for genus

Step 3. Rank GMAVs - from most sensitive (#1 = lowest concentration to see an effect) to least sensitive (n)

Step 4. Calculate Final Acute Value Using 4 Lowest GMAVs(or those GMAVs closest to the 5th percentile)

CALCULATION OF GMAV

Step 1 – Calculate each SMAV (*Daphnia magna*)

Daphnia magna EC_{50}	25 µg/L
Daphnia magna EC_{50}	30 µg/L
Daphnia magna EC_{50}	35 µg/L
Daphnia magna EC_{50}	28 µg/L

SMAV = 29 µg/L

Step 2 – Calculate the GMAV (*Daphnia*)

Daphnia magna	SMAV	29 µg/L
Daphnia pulex	SMAV	38 µg/L
Daphnia ambigua	SMAV	42 µg/L

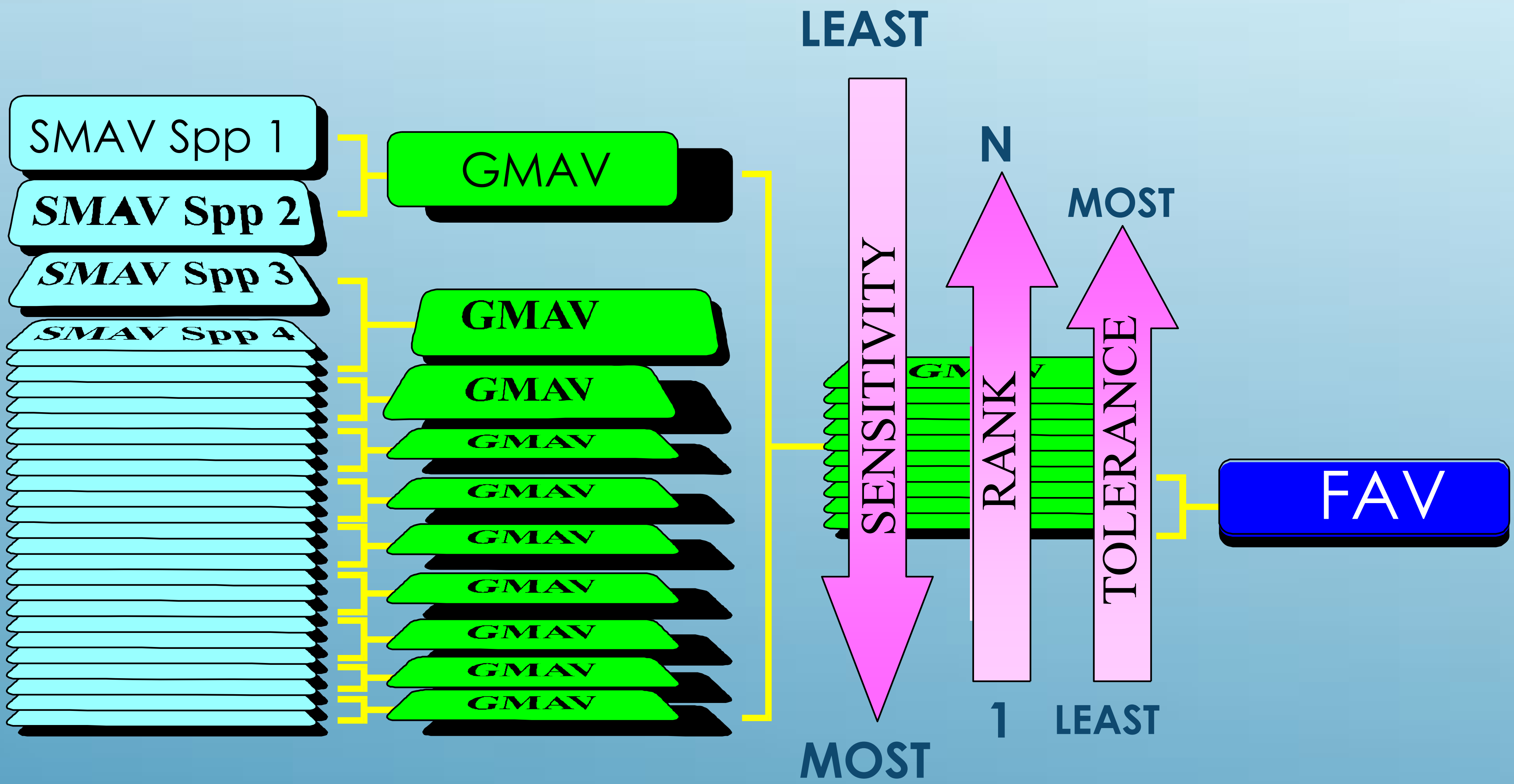
GMAV = 36 µg/L

FAV CALCULATION - RANKING

Step 3 – Rank (Percentile) Ordering by Sensitivity

Rank	GMAV	Species	SMAV
4	100	*Oncorhynchus mykiss*	100
3	36	*Daphnia ambigua*	42
		Daphnia pulex	38
		Daphnia magna	29
2	25	*Gammarus pseudolimnaeus*	25
1	19	*Hyalella azteca*	19

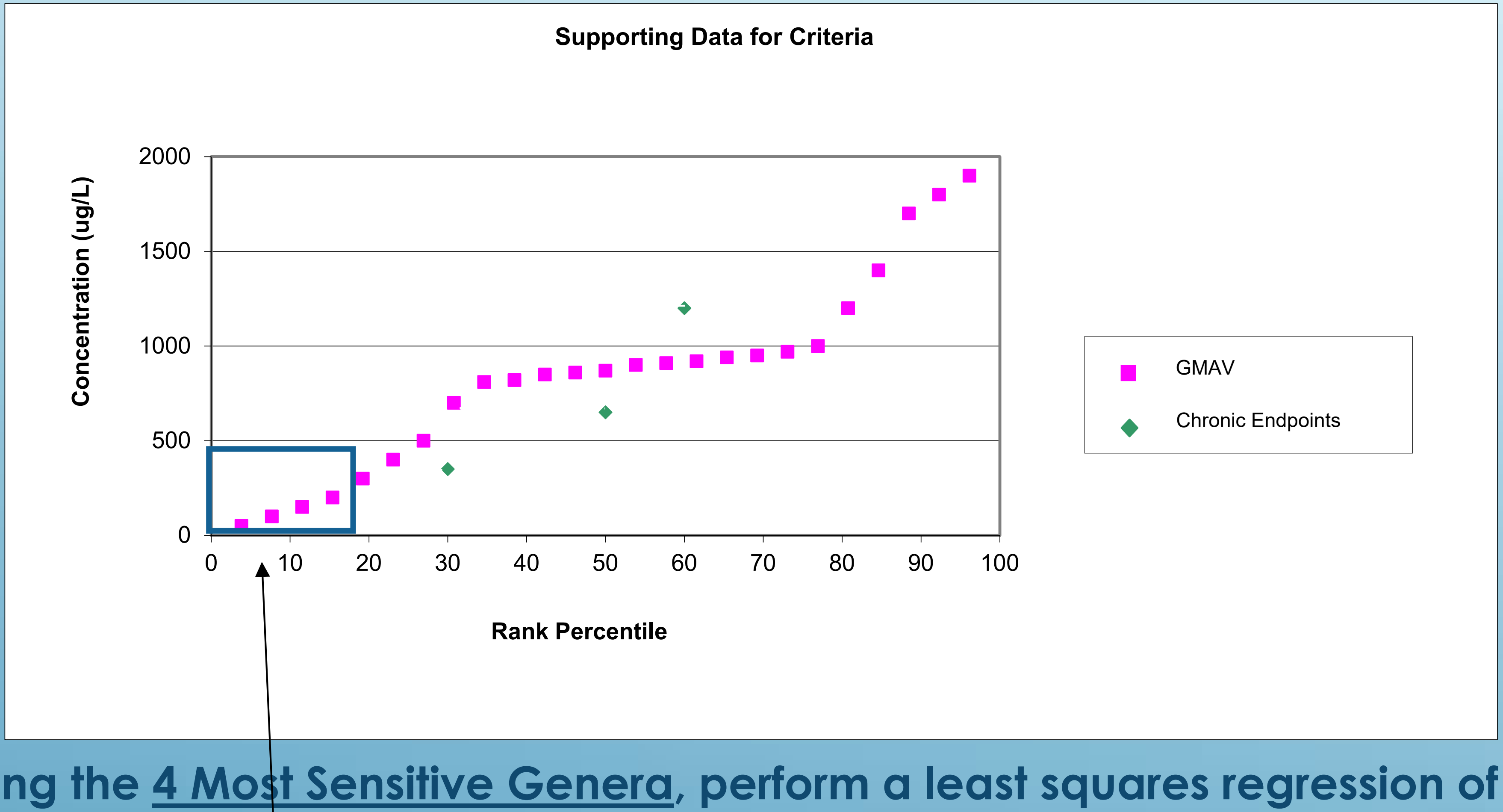
AQUATIC LIFE CRITERIA DERIVATION



LOG TRIANGULAR DISTRIBUTION

- Assume the available GMAVs follow a log-triangular distribution
- Use the Rank Order the GMAVs – least to most sensitive
- Assign Ranks (1 to N); Calculate Cumulative Probability - $P = R/(N+1)$
- Select the 4 GMAVs closest to 0.05 (often the lowest 4 GMAVs) – those are used to define the slope of the toxic response

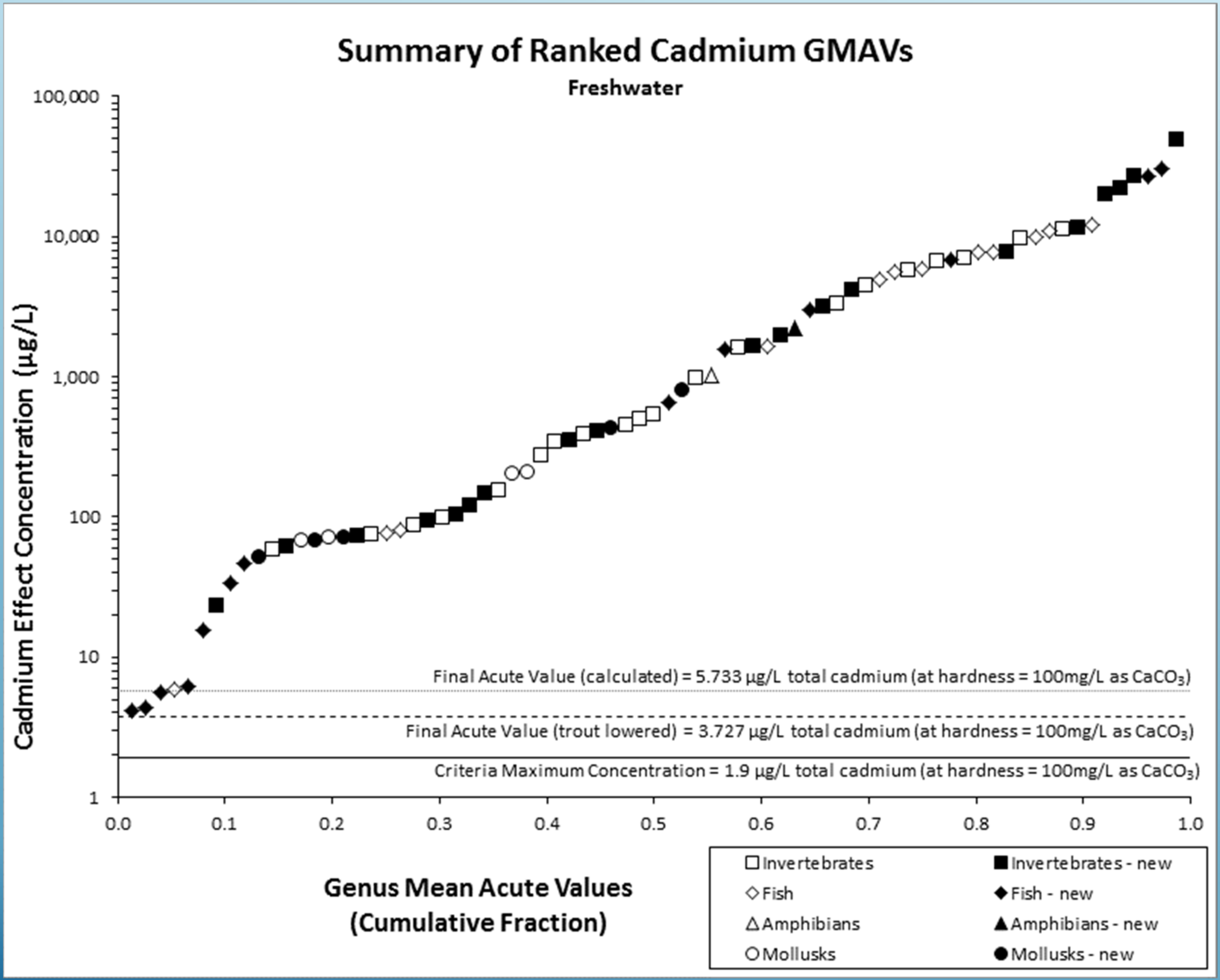
AQUATIC LIFE CRITERIA CALCULATION



Using the <u>4 Most Sensitive Genera</u>, perform a least squares regression of the log of genus values on the percentile ranks focused around the lowest 5% of genera. The total number of genera ("N") is also part of the calculation

Aquatic life criteria are intended to protect approximately 95% of genera

EXAMPLE: ACUTE CRITERIA FRESHWATER CADMIUM SENSITIVITY DISTRIBUTION



ACUTE AQUATIC LIFE CRITERIA: FINAL OVERVIEW

1. Is Toxicity related to WQ Characteristic? → Yes → Develop Equation & Adjust

   No ↓

2. **Check Agreement within Species (if <10x difference proceed)**
3. **Check Sensitive Life Stages (use most sensitive life stage)**
4. **Calculate Species Mean Acute Values (SMAVs)**
5. **Calculate Genus Mean Acute Values (GMAVs)**
6. **Rank GMAVs**
7. **Calculate Cumulative Probability**
8. **Calculate Final Acute Value (FAV)**
9. **Calculate CMC (CMC = FAV/2)**

CHRONIC CRITERIA TEST ENDPOINTS

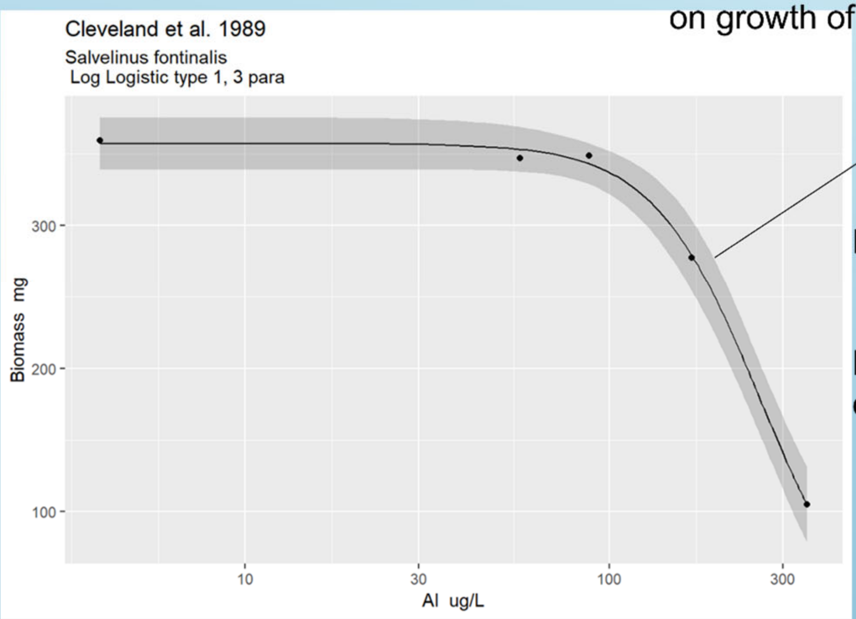
- Species-appropriate test durations
  - Including full life cycle, early-life stage tests, etc. as appropriate

- Toxicity Endpoints include long term mortality, growth and reproduction
  - Or other endpoints that can be linked to those apical responses quantitatively

- Effects Measurements include:
  - NOECs, LOECs, MATCs (hypothesis testing), and
  - EC20s or EC10s (regression analysis)

EFFECTS CONCENTRATION: EC10 OR EC20

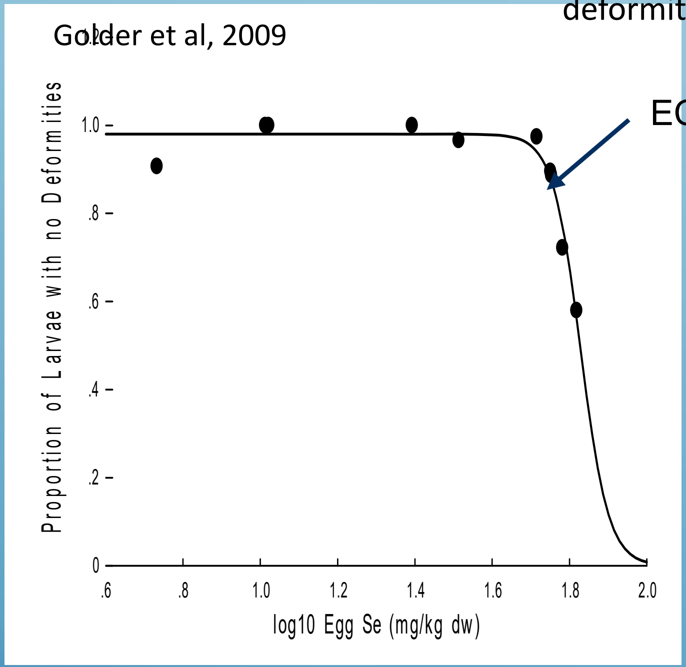
Effect of aluminum exposure on growth of brook trout



EC20 = 162 ug/L

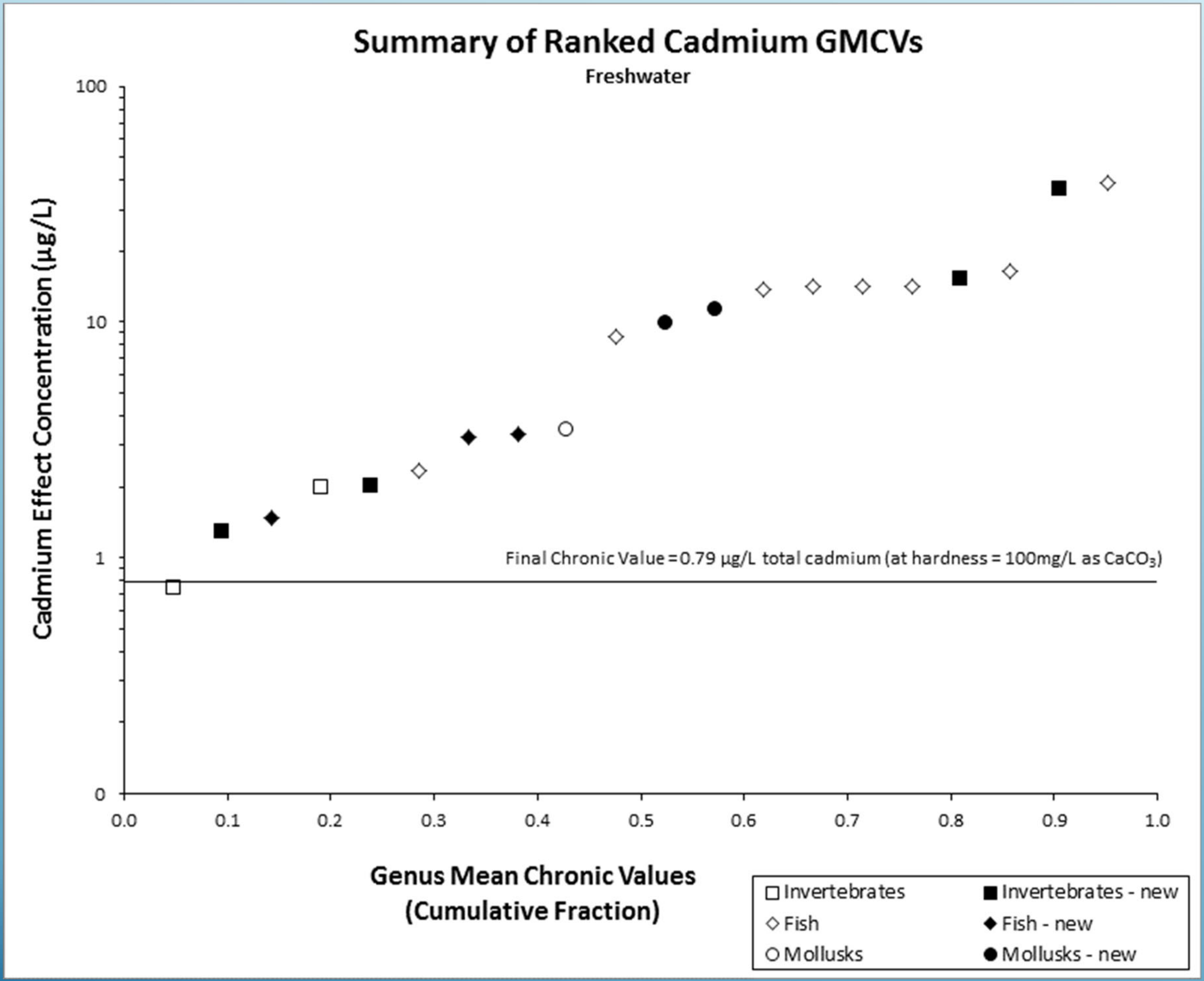
EC20 (or ECx) uses regression analysis to determine a certain level (10%, 20%, 50%) of toxic effect.

Effect of maternal dietary selenium on larval deformities in Dolly Varden alevins

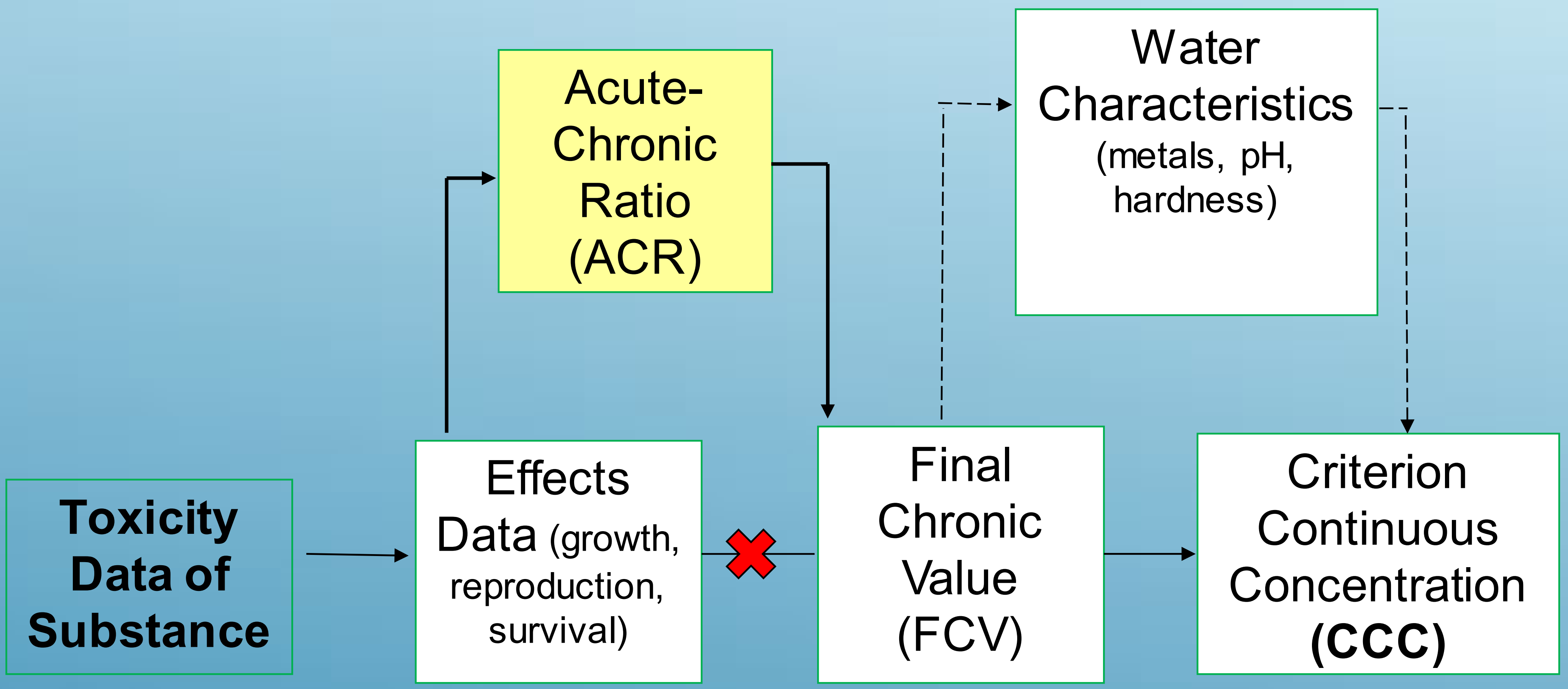


EC10 = 56.22 mg Se/kg dw

EXAMPLE: CHRONIC CRITERIA FRESHWATER CADMIUM SENSITIVITY DISTRIBUTION



DERIVATION OF CHRONIC VALUE WHEN DATA ARE INSUFFICIENT TO FULFILL DISTRIBUTION



ACUTE-CHRONIC RATIO (ACR)

Calculating and applying the ACR:

1. Acute & chronic tests using same species

↓

2. Use results of tests to calculate Acute-Chronic Ratios (ACR)

$$ACR = \frac{\text{Acute Value}}{\text{Chronic Value}}$$

↓

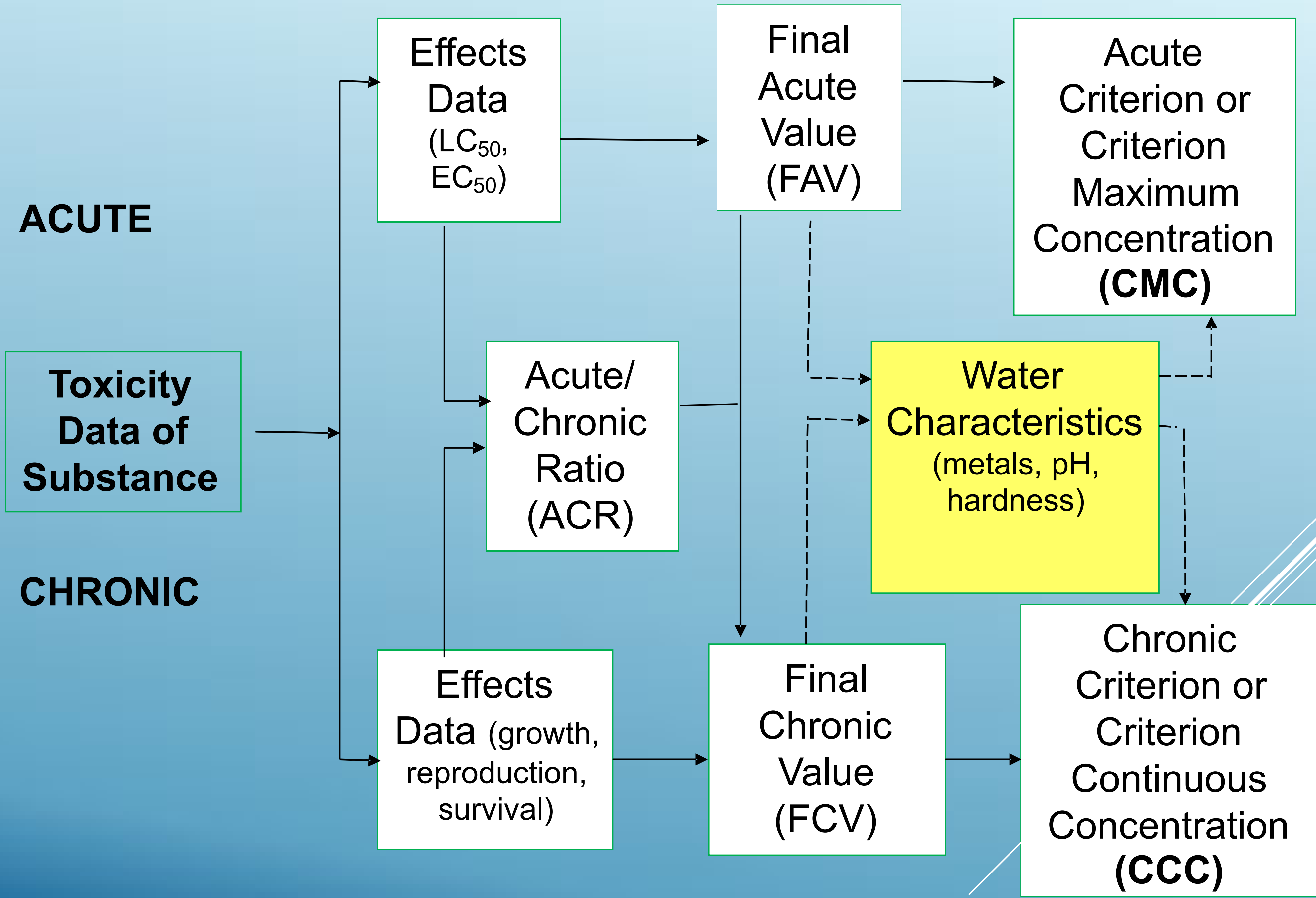
3. Develop a Final Acute-Chronic Ratio (FACR) by taking a geometric mean of the appropriate ACRs *(3 minimum)*

↓

4. Calculate the Final Chronic Value (FCV) using the FACR

$$FCV = \frac{\text{Final Acute Value}}{\text{FACR}}$$

CRITERIA DERIVATION OVERVIEW



ACCOUNTING FOR EFFECTS OF WATER CHEMISTRY ON METAL BIOAVAILABILITY AND TOXICITY

- Water quality criteria can be modified quantitatively when enough data are available to demonstrate that water chemistry conditions affect metal toxicity considering the results with a variety of species
- For example, aluminum chronic toxicity data collected across a range of DOC, pH and hardness demonstrated the effects of water chemistry on metal toxicity

ACCOUNTING FOR EFFECTS OF WATER CHEMISTRY ON METAL BIOAVAILABILITY AND TOXICITY

Example: Cadmium Criteria Equation*

$= e^{(0.9789 \times (\ln \text{Hardness}) - 3.866)} \times CF,$

where CF (conversion factor from Total to Dissolved)
= 1.136672 – [(ln hardness) x (0.041838)]

Hardness (mg/L)	Criteria Value (µg/L dissolved)
25	0.49
50	0.94
100	1.8
200	3.4

** Based on dissolved concentration, 2016 Final Cd criteria document*

BLMS, MLRS, & WERS

- Historically, the Water Effect Ratio (WER) approach was used to adjust hardness-based criteria for metals
- In 2007, the biotic ligand model (BLM) was developed for copper
  - The BLM models the bioavailability of copper based on 10 water chemistry parameters (pH, DOC, temperature, alkalinity and 6 geochemical ions)
  - Implementation issues have slowed its widespread adoption and use
- Recently, a multiple linear regression method (MLR) was developed for aluminum, that simplifies the modeling necessary based on 3-4 water chemistry parameters
  - EPA published a Final Revised Aluminum ALC (December 2018) based on 3 water chemistry parameters (pH, DOC, and hardness)

DERIVING AQUATIC LIFE CRITERIA: TISSUE-BASED CRITERIA

June 2024

WATER COLUMN VS. TISSUE BASED CRITERIA

Need for a specific type of criteria is dependent on MAIN route of exposure and potential for bioaccumulation/biomagnification

Water-Column Based Criteria

- Exposure from water is predominant route
- Examples: Ammonia, Cadmium

Tissue-Based Criteria

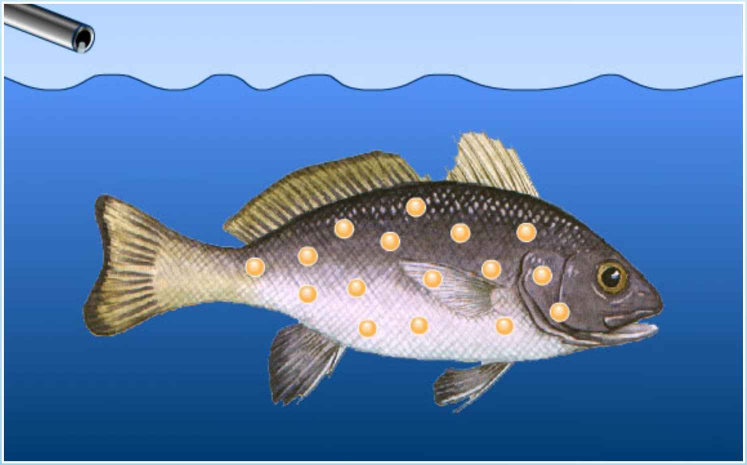
- Exposure from food is predominant route
- Examples: Selenium, mercury

EPA'S CURRENT TISSUE-BASED CRITERIA

- 2016 Selenium AWQC
- Draft PFOA and PFOS Chronic AWQC
  - In revision after the public comment period
- Draft (state) Mercury Chronic AWQC
  - In progress

BIOCONCENTRATION

Bioconcentration refers to the net accumulation of a toxic chemical in the tissue of organisms from water only



https://www.deviantart.com/amadeublasco/art/Bioconcentration-454672375

A Bioconcentration Factor (BCF) is determined from laboratory measurements of concentrations in biota and water, and is calculated using the equation:

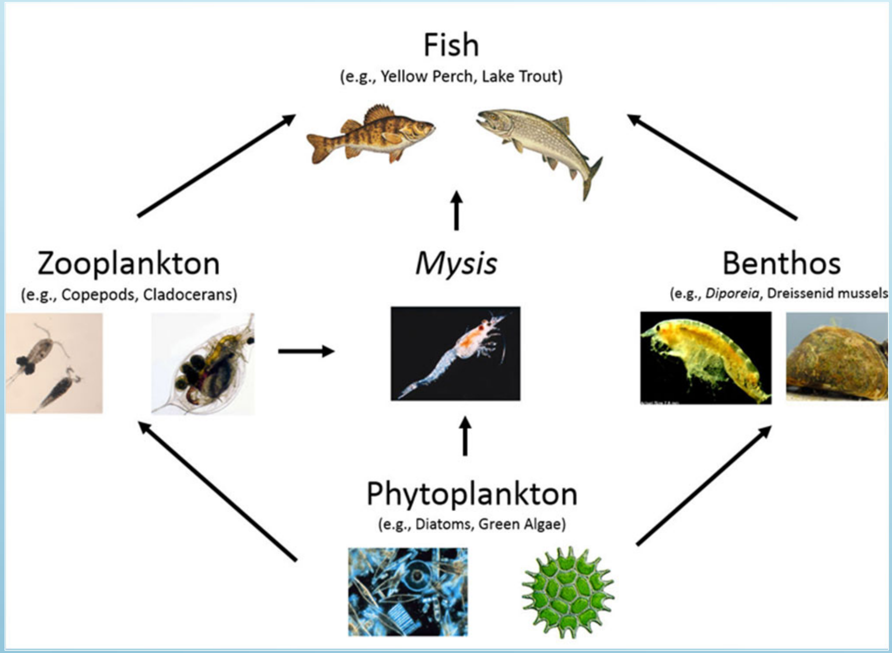
$$BCF = \frac{C_{biota}}{C_{water}}$$

Where:

- **C_{biota} = concentration in organismal tissue(s)**
- **C_{water} = concentration in water**

BIOACCUMULATION

Bioaccumulation refers to net accumulation of a toxic chemical in the tissue of organisms from all exposure sources (e.g., water, food, sediment)



Simplified Great Lakes Food Web (NOAA GLERL Images)

A Bioaccumulation Factor (BAF) is determined from field measurements of concentrations in biota and water at the same site, and is calculated using the equation:

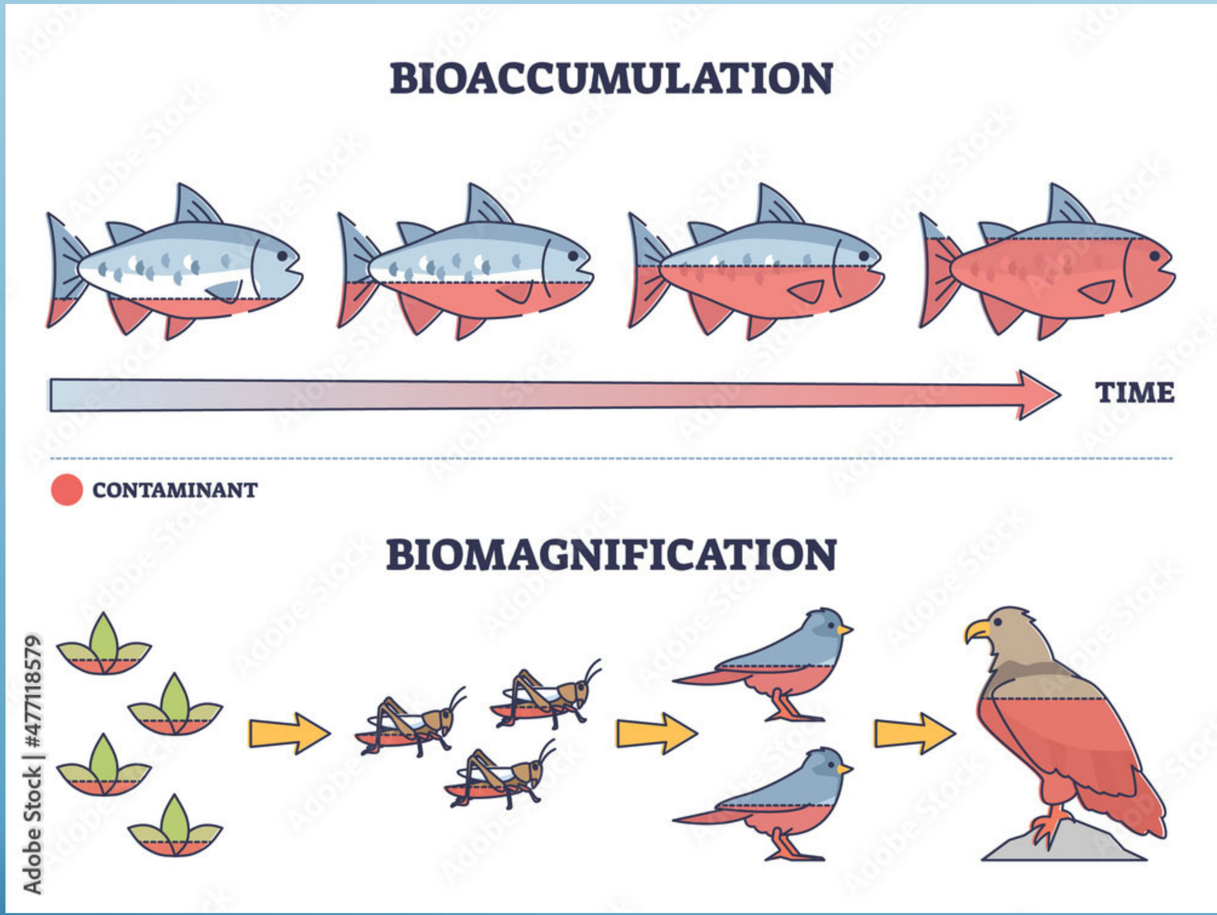
$$BAF = \frac{C_{biota}}{C_{water}}$$

Where:

- **C_{biota} = concentration in organismal tissue(s)**
- **C_{water} = concentration in water where organism collected**

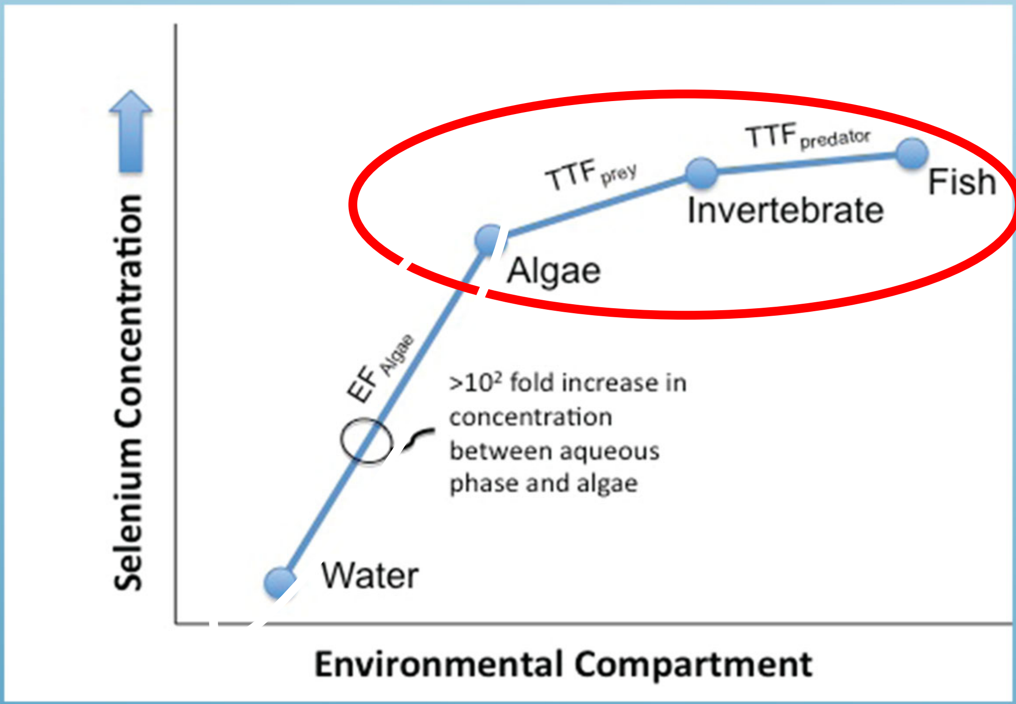
BIOMAGNIFICATION

Biomagnification refers to increased concentrations of a toxic chemical as you move from one trophic level to the next attributable to the accumulation from food



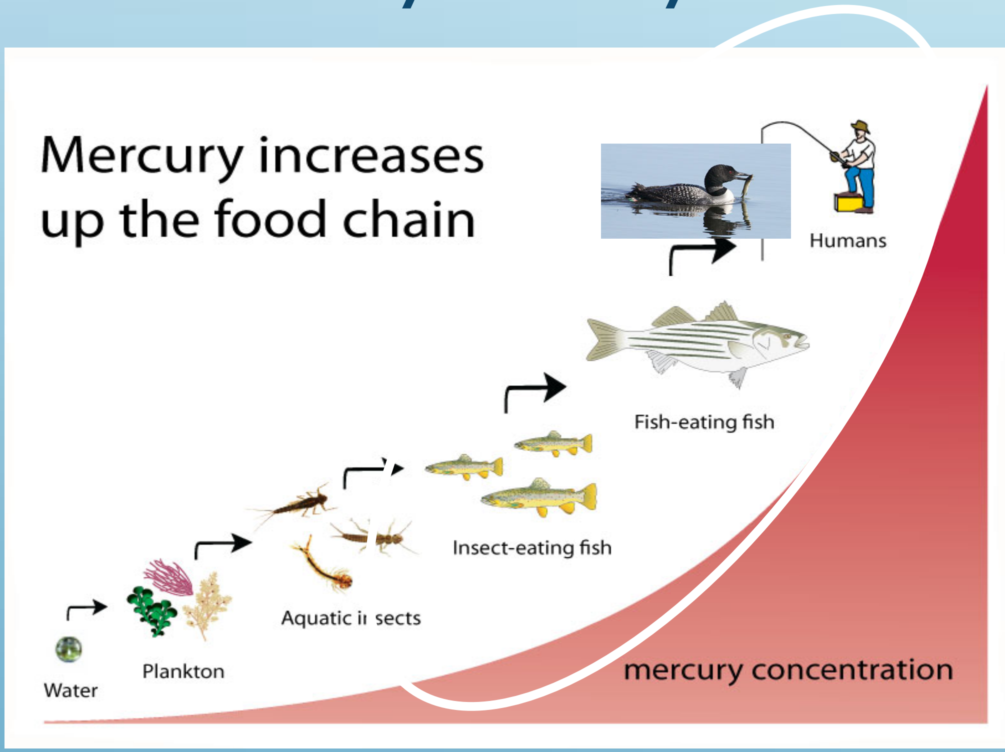
EXAMPLES OF BIOACCUMULATION AND BIOMAGNIFICATION

Selenium



SETAC, 2010

Methylmercury

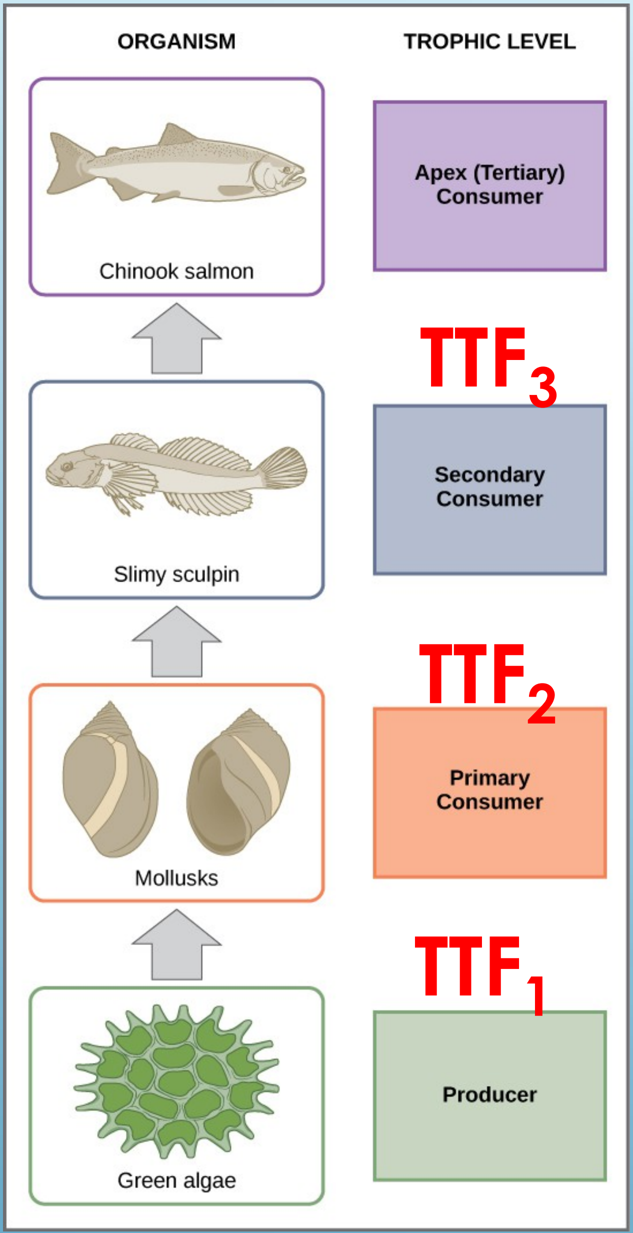


https://www.nps.gov/subjects/air/humanhealth-toxics.htm
https://www.nwf.org/Educational-Resources/Wildlife-Guide/Birds/Common-Loon

TROPHIC TRANSFER FACTORS

Trophic Transfer Factors (TTFs) refer to the concentration in a consumer species divided by the concentration in food (prey)

Composite TTFs take into consideration the individual TTFs from all levels on the food web, from the base of the food chain to the tissues of the target species



https://opentextbc.ca/conceptsofbiologyopenstax/chapter/energy-flow-through-ecosystems/

BIOACCUMULATION AND MAGNIFICATION IN AQUATIC FOOD WEBS

Selenium

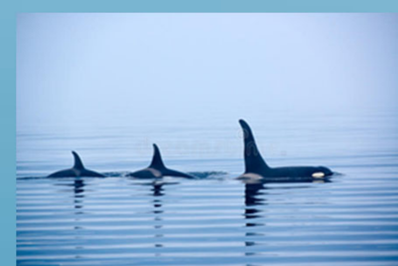
- Trophic transfer at base of food web most influential
- Highest bioaccumulation potential in benthic-associated fish (molluscivores, invertivores)

Methylmercury, PFOA and PFOS

- Trophic transfer at all trophic levels have similar influence on bioaccumulation
- Highest bioaccumulation and biomagnification potential in top level predators

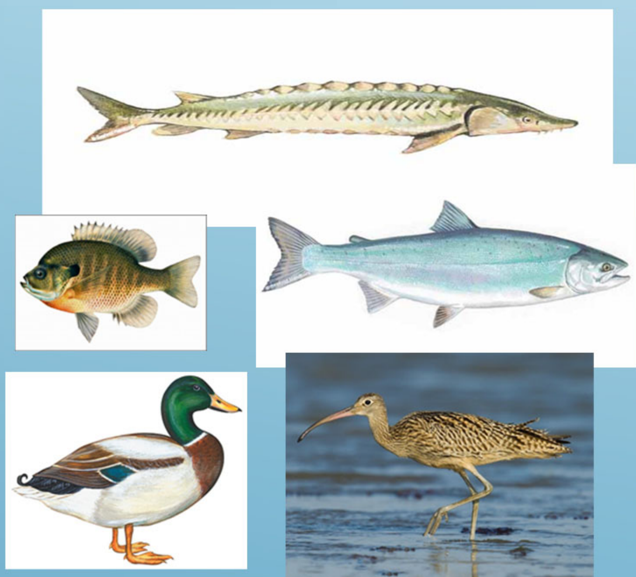




SENSITIVE RECEPTORS

Selenium



Oviparous (egg-laying) vertebrates
- fish
- aquatic-dependent birds

Methylmercury

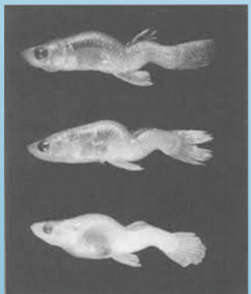
Although fish are sensitive to methylmercury, main focus on:
- aquatic-dependent wildlife (birds and mammals)

PFOA & PFOS

Effects data available for a variety of aquatic life and to a lesser extent, aquatic-dependent wildlife

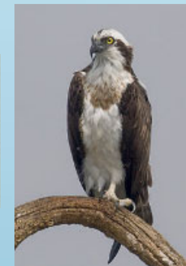
EFFECTS ENDPOINTS

Selenium



Reproductive Effects
- Larval mortality
- Malformations
- Impaired swimming, feeding and predator avoidance
- Impaired recruitment results in population level effects

Methylmercury



Reproductive Effects –
- Decreased spawning
- Increased larval mortality
- Neurological, developmental & behavioral impacts (e.g., difficulty schooling - fish); tremors and difficulty flying (birds); impaired sensory and motor skills (mammals)

PFOA & PFOS

Impacts on several organ systems
- Negative effects on growth, reproduction, and mortality

TRANSLATION OF CRITERIA ELEMENTS

SELENIUM
(EPA 2016)

Chronic tissue criteria were translated into water-column criteria for lentic and lotic waters

Water Column Criterion = Tissue Criterion/ (TTFs x EF x CF)

PFOA & PFOS
(Final expected in spring 2023)

Chronic water column criteria were translated into corresponding tissue-based criteria through BAFs

Tissue Criteria= Water Column Criterion × BAF

MERCURY
(Draft state criteria in progress 2023/2024)

EPA is currently developing state fish tissue criteria and water column criteria translated through BAFs

Water Column Criterion = Tissue Criterion/BAFs

QUESTIONS?