THE QUEST FOR AVERAGE WATER

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WORK IN PROGRESS

Presentation outline

INTRODUCTION

Objectives

Data space

Definition of representative concentration

METHODS

Methods for calculating representative concentrations

RESULTS

Influence of values incorporated in representative concentration on risk decision

Learning objectives

1. What is a representative concentration? How can it inform a chemical risk decision?

2. How may a representative concentration be calculated when some values censored?

3. How does incorporation of different types of censored values influence risk decisions?

Background

- With thousands of chemicals in commerce and the environment, efficient tools are needed to support risk prioritization and evaluation.

- The U.S. Environmental Protection Agency's ExpoCast project developed the SEEM (Systematic Evaluation of Empirical Models) approach to "integrate, evaluate, and calibrate exposure predictor [tools]."

- The National Science & Technology Council identified *exposure characterization of contaminants of emerging concern in water* as a critical research gap in 2018.
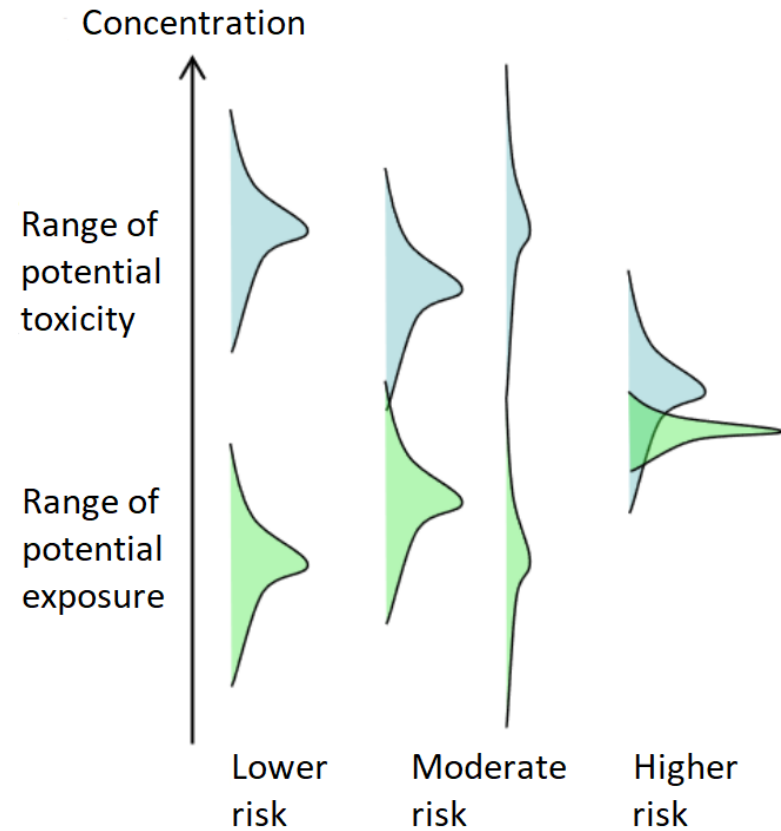
Even a highly uncertain estimate can provide enough information to rank chemicals for risk prioritization.

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# SEEM approach, applied to water exposure
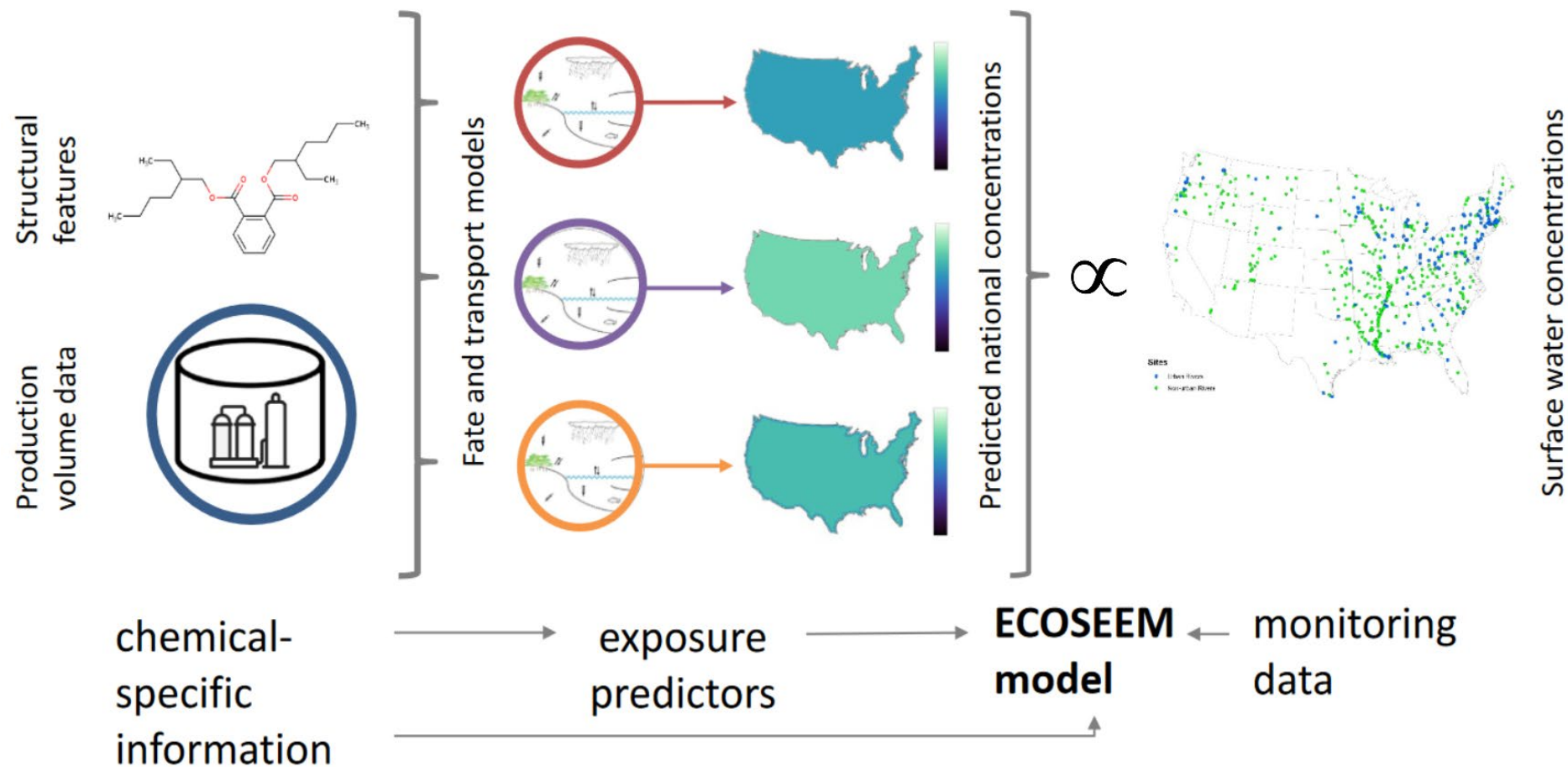
Data availability

Water Quality Portal

https://www.waterqualitydata.us/portal

- Data collected by over 400 state, federal, tribal, and local agencies
- Searched for any organic chemical samples in water for the contiguous United States from 2008 to 2018

Chemical samples are available across the US but are not collected for our purpose.
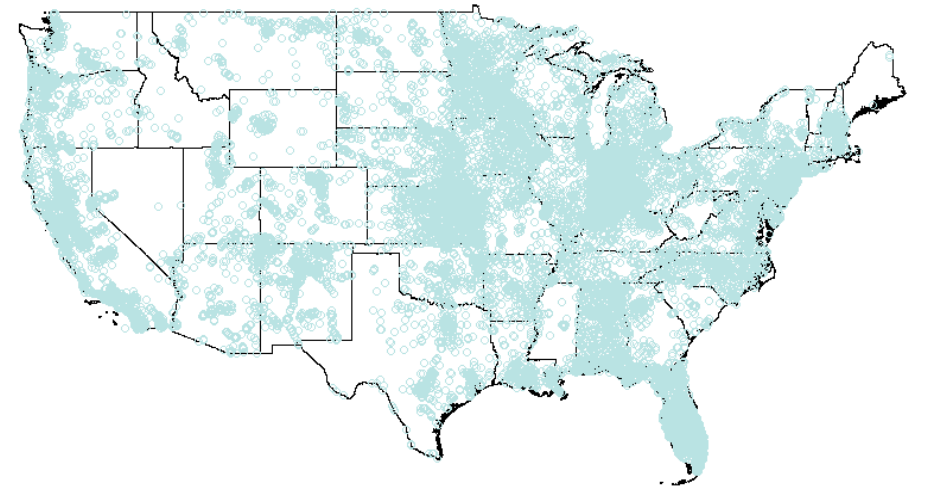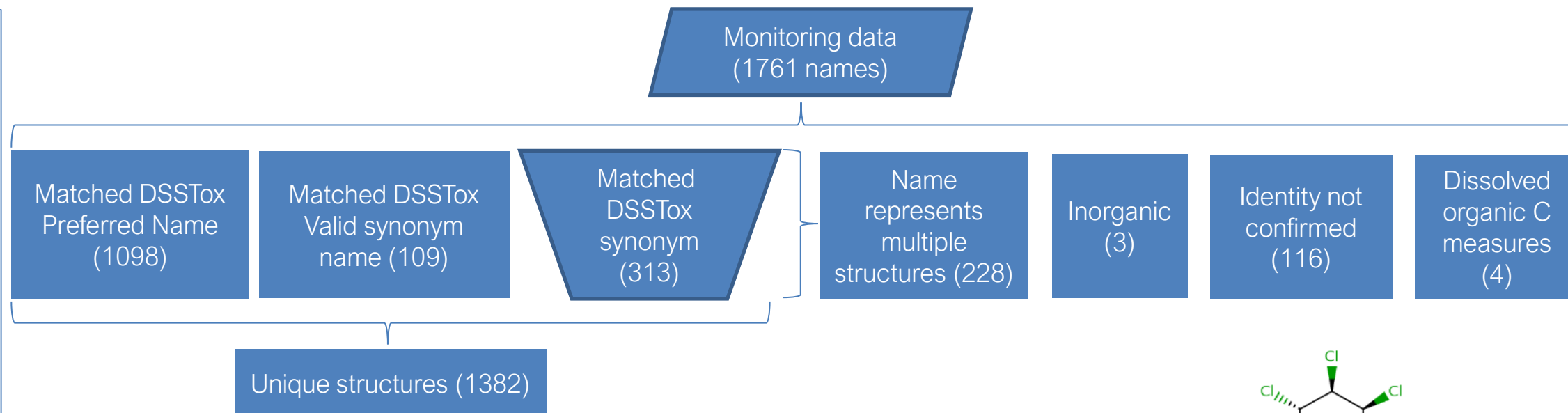

Map of surface water monitoring locations in the continental United States included in the Water Quality Portal
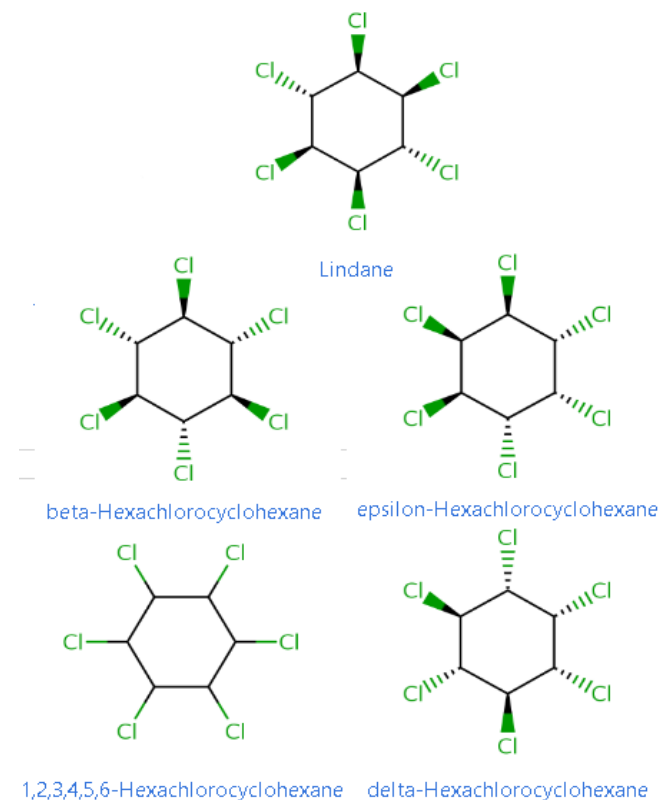

National Water Quality Monitoring Council
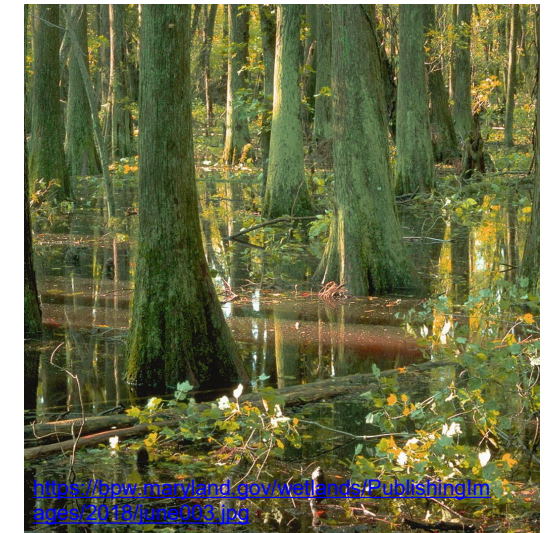Working together for clean water

Chemicals

Monitoring data
(1761 names)

| Matched DSSTox Preferred Name (1098) | Matched DSSTox Valid synonym name (109) | Matched DSSTox synonym (313) | Name represents multiple structures (228) | Inorganic (3) | Identity not confirmed (116) | Dissolved organic C measures (4) |

Unique structures (1382)

Lindane and several of its isomers

Lindane

beta-Hexachlorocyclohexane

epsilon-Hexachlorocyclohexane

1,2,3,4,5,6-Hexachlorocyclohexane

delta-Hexachlorocyclohexane

Data curation workflow 1)

Chemicals

Monitoring data
(1761 names)

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Name represents multiple structures (228)

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Unique structures (1382)

Sites

Inside continental U.S.

Fresh water (i.e. not estuary, ocean)

Surface water (i.e. not borehole, mine pit)

Ambient sites (i.e. not initial dilution zone, drinking water)

https://bpw.maryland.gov/wetlands/PublishingImages2016/sas923.jpg

A palustrine wetland: one type of place where surface water may be monitored

Data curation workflow 2)

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Data curation workflow 3)

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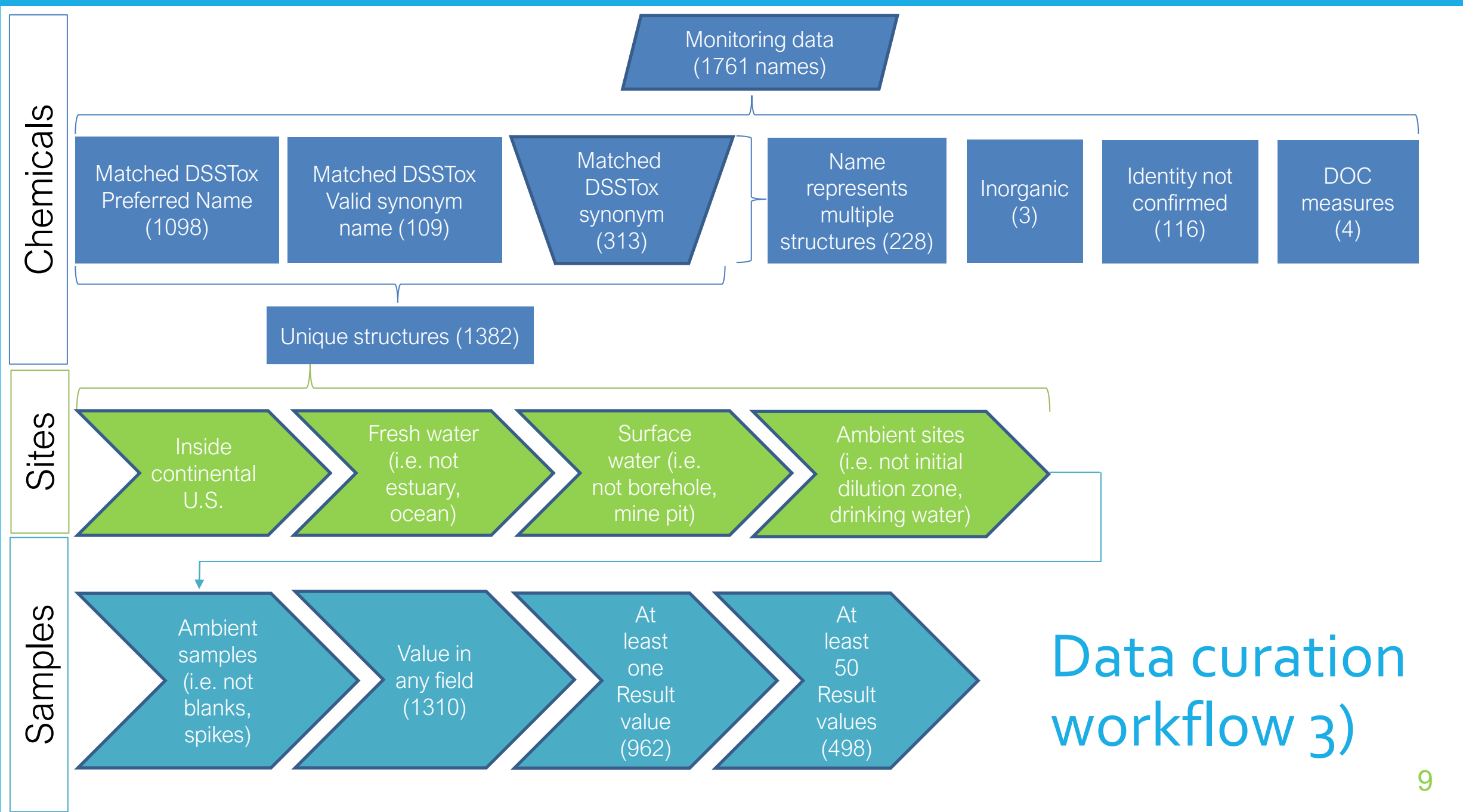
Characteristics of distributions of chemical concentrations in water

- Lower bound of zero
- Non-normal (Positive skewness)
- **Censored data**
- *Seasonal patterns*
- *Autocorrelation*
- *Dependence on environmental variables*

A. Probability density function
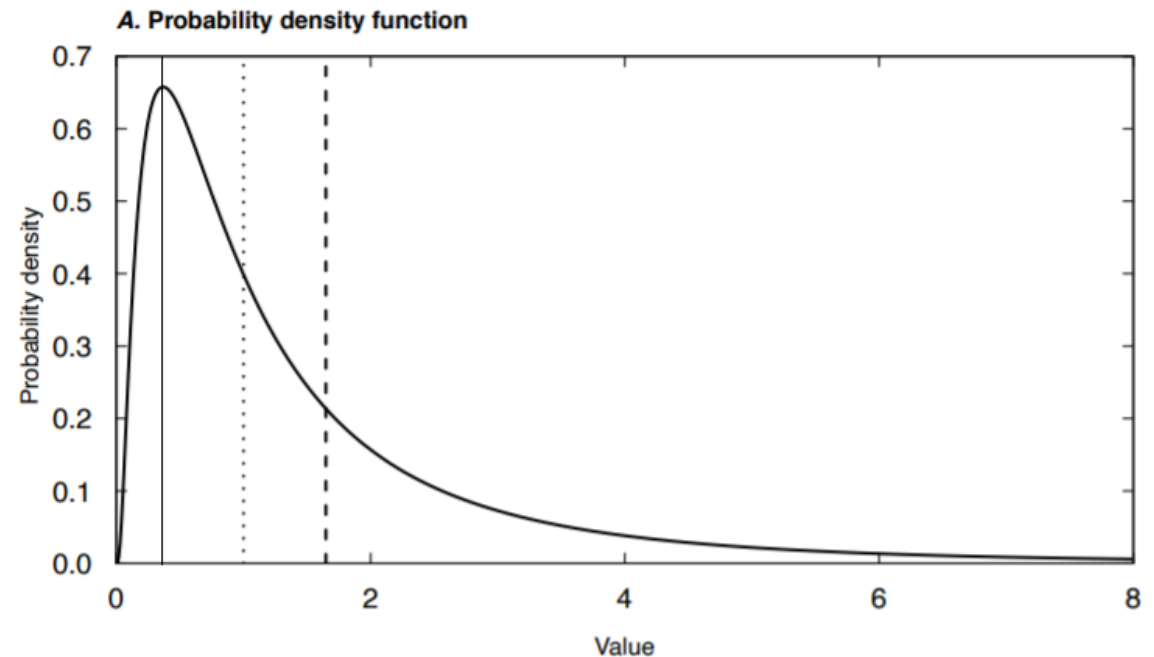
Probability density function (PDF) of a lognormal distribution

From USGS book, Statistical Methods in Water Resources:
Section A, Statistical Analysis Book 4, Hydrologic Analysis and Interpretation

Types of representative values

Summary value	Definition	On figure	Calculation
Mode	Most commonly occurring value	Solid line	$\exp(\mu - \sigma^2)$
Median	Value between higher and lower half	Dotted line	$\exp(\mu)$
Mean	Expected value	Dashed line	$\exp\left(\mu + \dfrac{\sigma^2}{2}\right)$

A. Probability density function
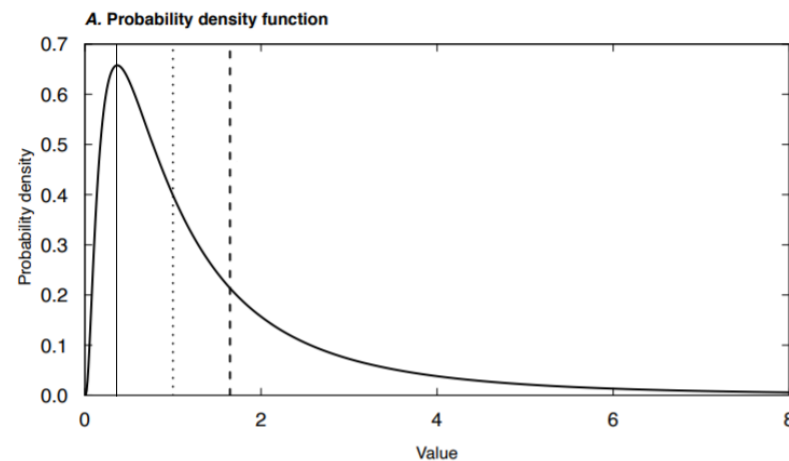
QUESTION 1.

What is a representative concentration, and how may it be used?

A high proportion of censored results
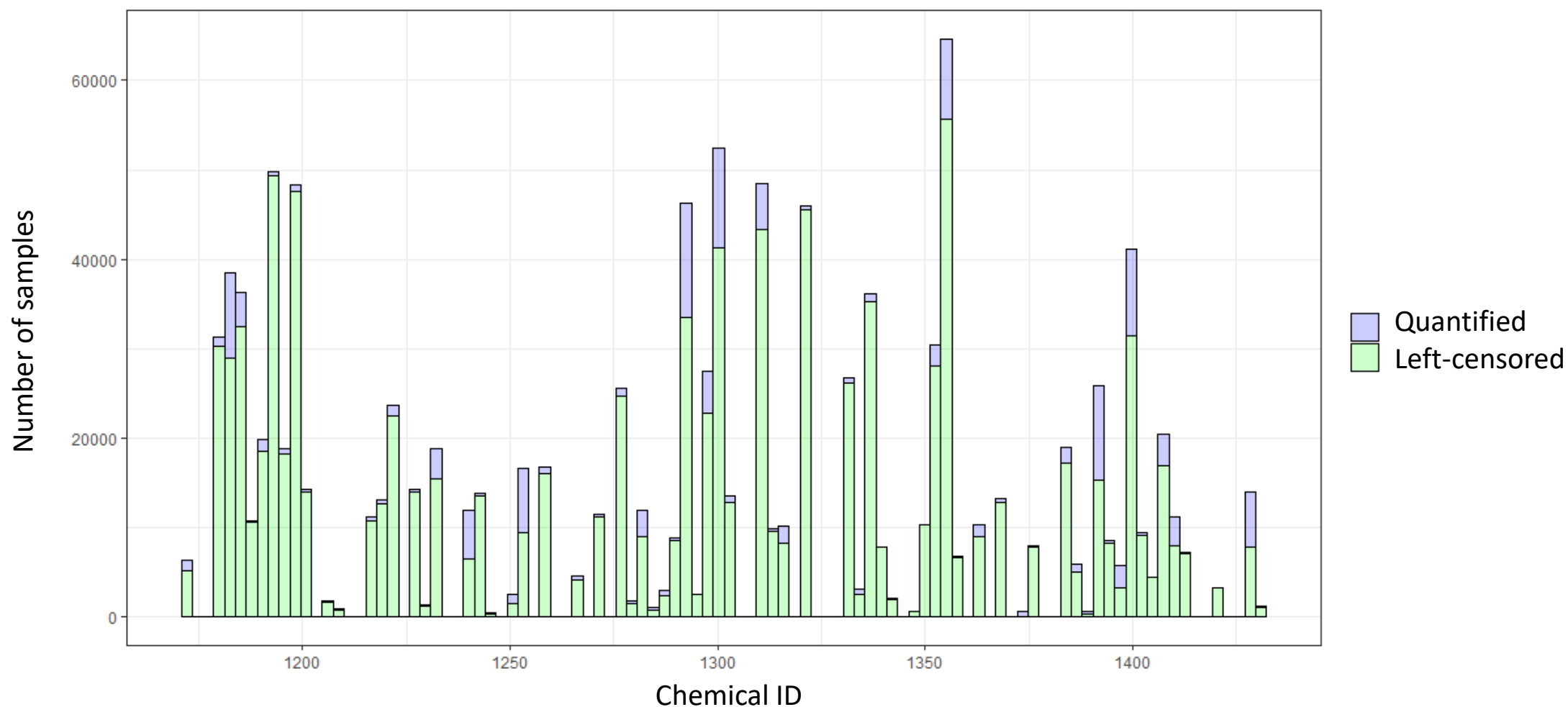
Histogram of 100 randomly-selected chemicals. All have more left-censored results than discrete result values.

Using knowledge from left-censored results

- Blue values are quantified result values
- Green values are generally *limits*: the result value is below a certain limit

Single high limit value

Number of samples

Concentration (ln-ug/L)

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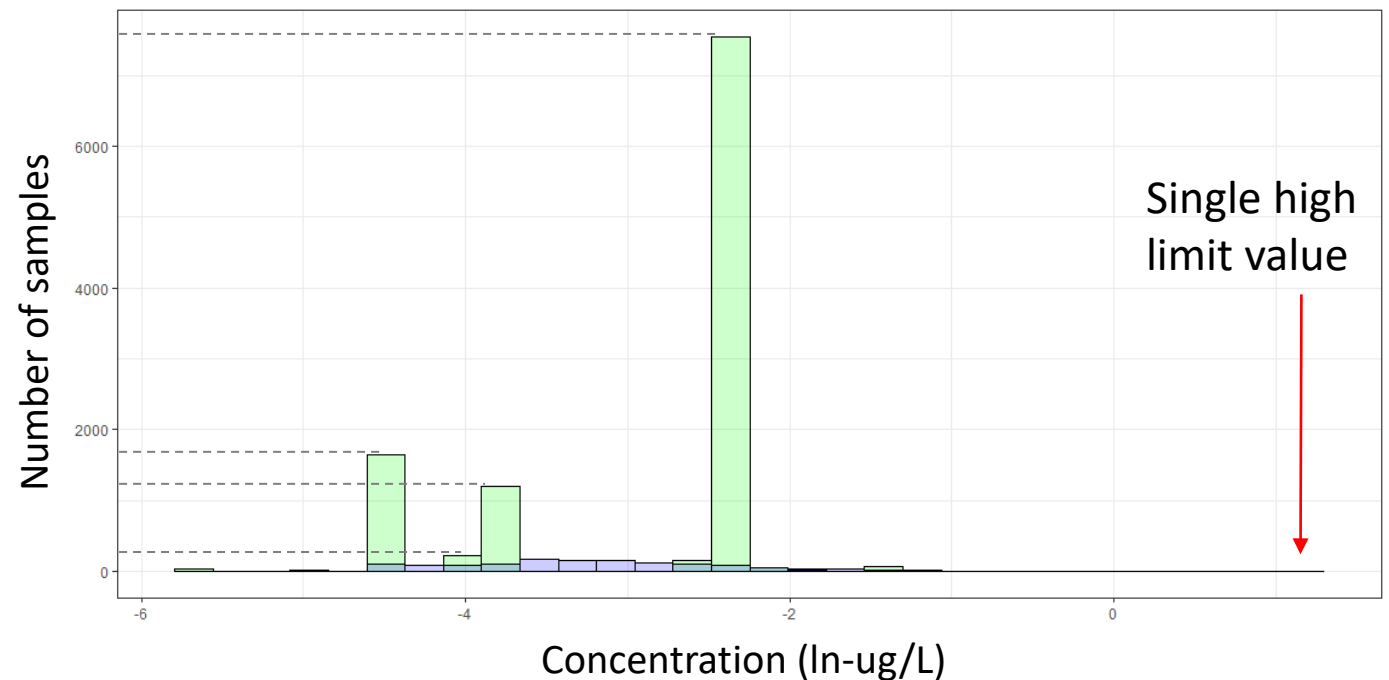
Method 1) *Maximum likelihood estimation (lMLE)*

Assuming the values are lognormally distributed, what curve is most likely to contain the values that have been observed?

- The probability density at a single observed value x in a lognormal distribution is:

$$\frac{1}{x\sigma\sqrt{2\pi}} \exp\left(-\frac{(\ln x - \mu)^2}{2\sigma^2}\right)$$

- In lMLE, we find the *joint likelihood* of mu and sigma using all x
- To incorporate censored data, we use the Cumulative Distribution Function (CDF) instead of the PDF

**Log-Normal Distribution**
— PDF — CDF
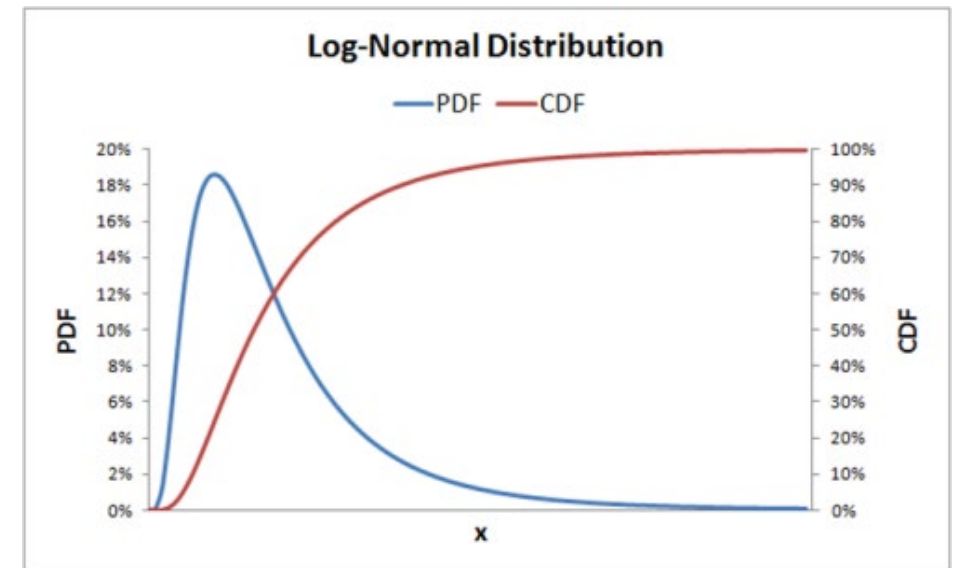
http://fekete.com/SAN/TheoryAndEquations/HarmonyTheoryEquations/Content/HTML_Files/Reference_Material/Analysis_Method_Theory/Risk_Theory.htm

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Method 2) *Kaplan-Meier (K-M)*

K-M is non-parametric – no underlying distribution is assumed

Originally designed for right-censored data (survival analysis)

Empirical distribution, which makes it step-wise rather than continuous
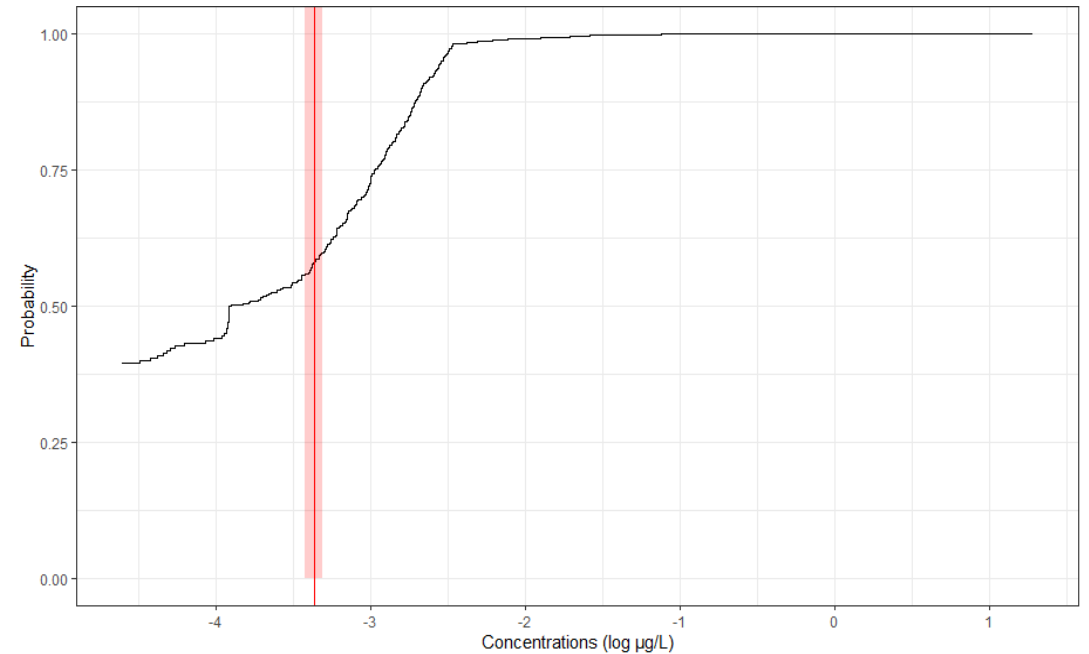
$$\hat{\mu} = \sum_{i=1}^{n} y_i [\hat{F}(y_i) - \hat{F}(y_{i-1})]$$

Where y is the list of ordered uncensored observations, F_hat is the estimated cumulative probability at y (including the censored observations), and n is the count of y.

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Comparison of means generated with different methods
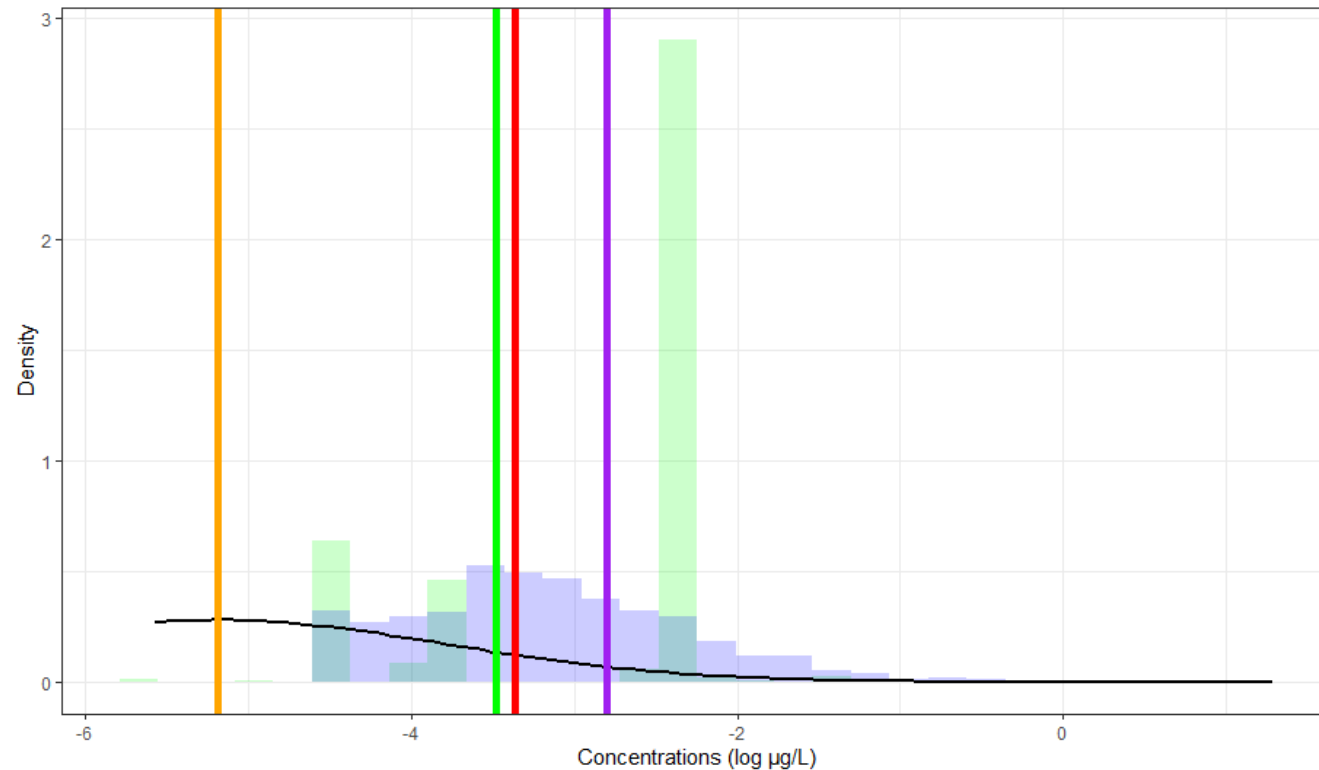
Histogram of quantified (blue) and non-quantified (green) results, along with the mean of the lMLE estimate in orange, mean of the quantified values and *half* of each limit value in green, mean of the K-M estimate in red, and mean of the quantified untransformed values only in purple.
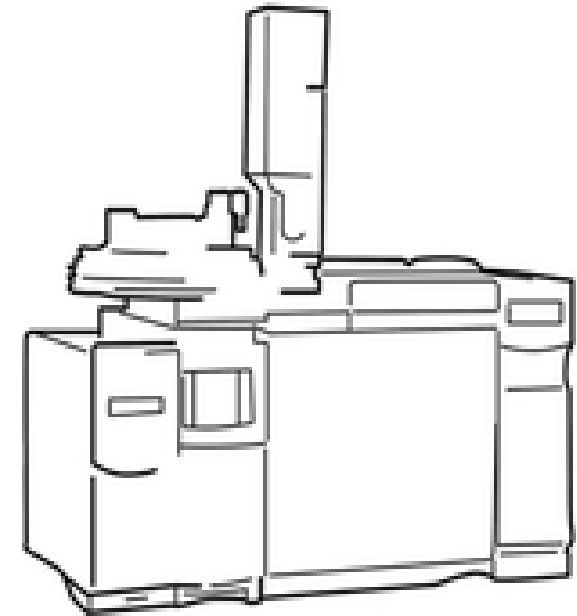
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QUESTION 2.

How may you calculate a representative concentration when some measurements are censored (non-quantified, below a limit value)?
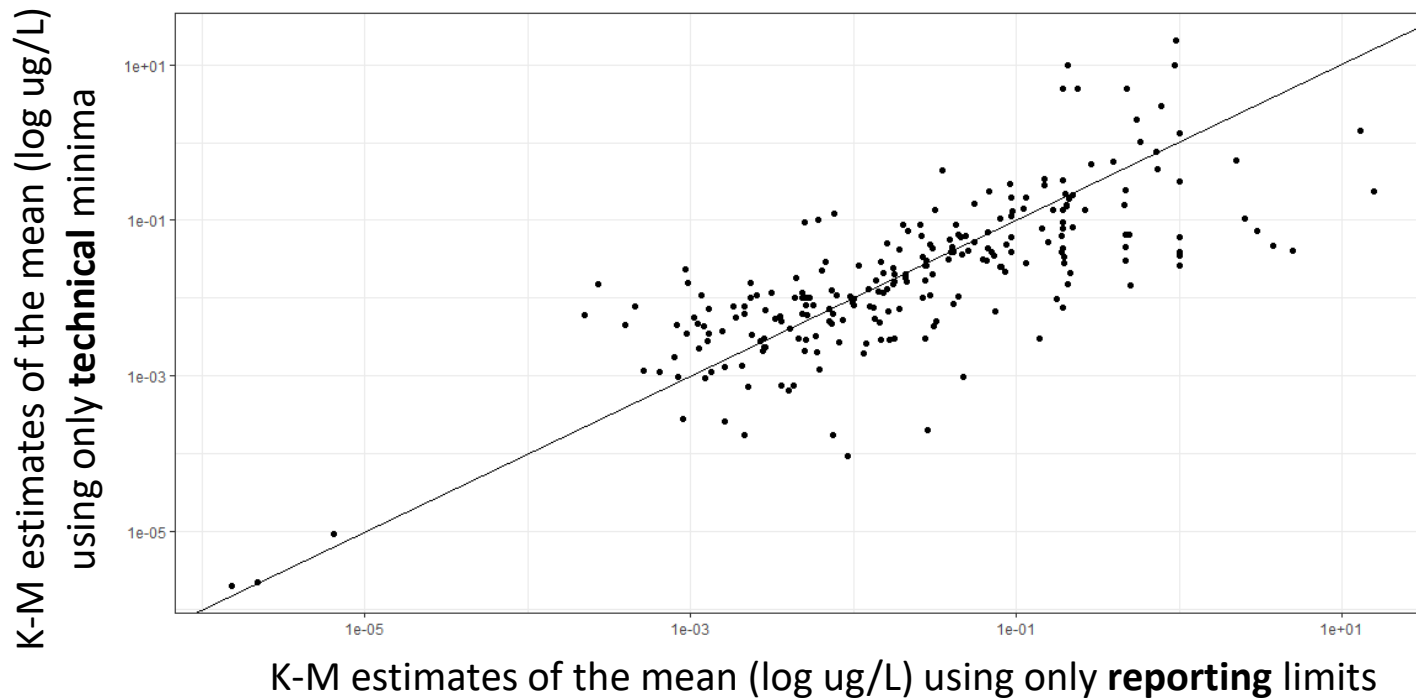
Why are there censored results?

Based on text analysis of the sample metadata, we identified three categories of censored results:

1. **Technical minimum** (*the minimum concentration detectable using the given machine or analytical method*): 50% of samples
2. **Technical quantitation limit** (*the minimum concentration measurable using the given machine or analytical method*): 15% of samples
3. **Reporting limit** (*the minimum concentration a lab is required to report, or the precision level a lab may report*): 35% of samples

A gas chromatography-mass spectrometry system.

Comparison of mean by limit type

K-M estimates of the mean (log ug/L) using only **technical** minima

K-M estimates of the mean (log ug/L) using only **reporting** limits

Is this rough estimate good enough?

Is the same prioritization decision made using technical minima as a limit versus reporting minima?

To test the effect of this uncertainty, characterize the exposure in the context of the toxicity using the **bioactivity:exposure ratio** (BER), where the bioactivity value is the **predicted no-effect concentration** (PNEC) for *Daphnia magna*


https://www.amazon.com/Generic-1000-Live-Daphnia-Magna/dp/B07YX9396K

Daphnia serve a sentinel indicator species, since they are ecologically ubiquitous and sensitive to changes in water quality

Comparison of prioritization by limit type

The black dots are the PNEC (predicted no-effect concentration in *Daphnia*) for each chemical; the vertical lines span from the K-M estimate of the mean to the mean + sd. For the purple lines, the mean exceeds the PNEC (higher risk), for the magenta lines, the mean + sd exceeds the PNEC (moderate risk), and for the orange lines the span is below the PNEC (lower risk).

The upper plot shows estimates using only the technical minima, and the lower plot shows estimates using only the reporting minima.

Chemicals (sorted by most to least toxic to *Daphnia*)
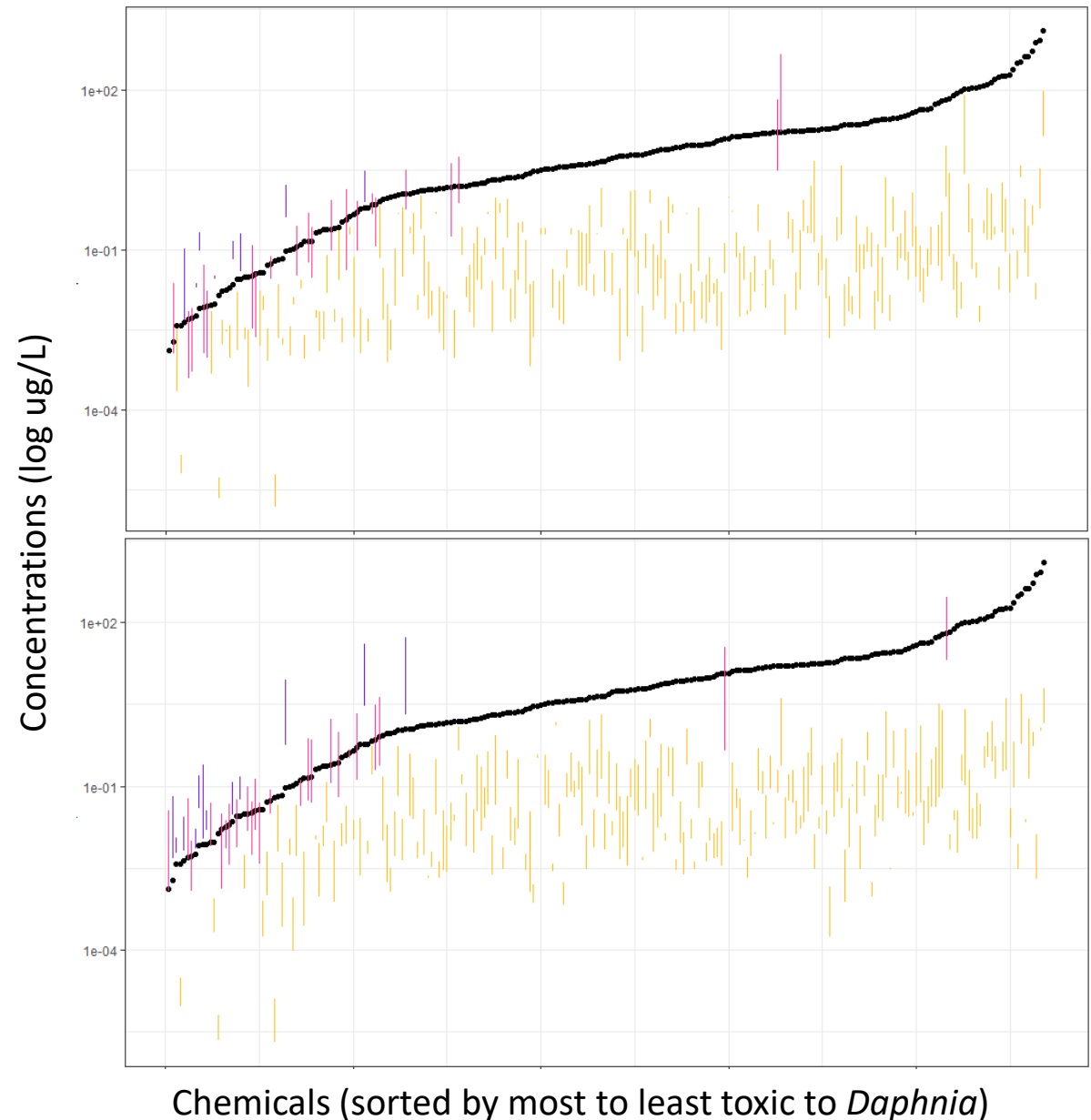
Result of estimating means incorporating different limit types on prioritization

For 87% of evaluated chemicals, the prioritization category was the same when switching from the technical minima to the reporting minima. For 9% of chemicals, the priority increased; for 3% chemicals, the priority decreased.

Concentrations (log ug/L)

Chemicals (sorted by most to least toxic to *Daphnia*)
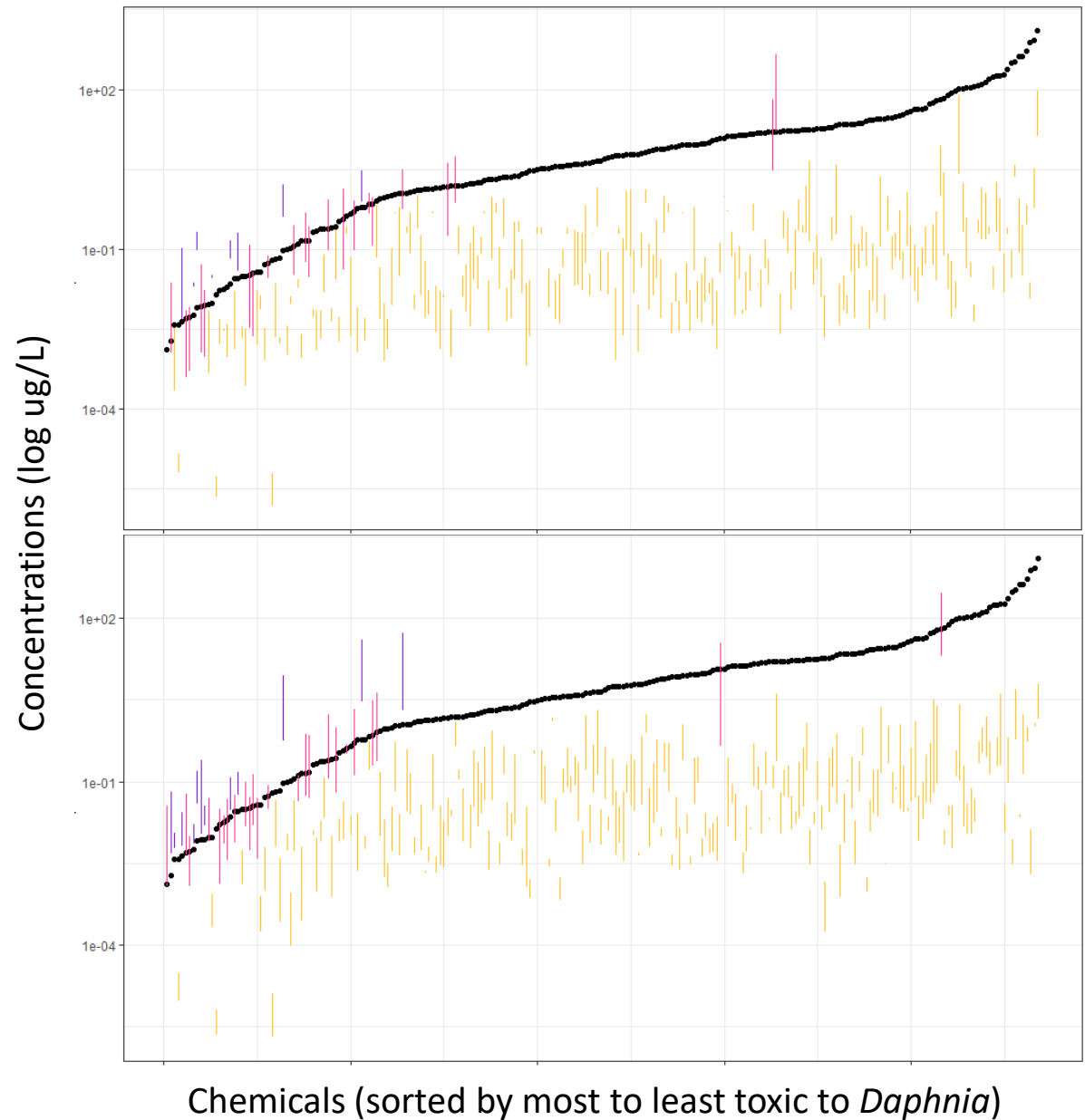
QUESTION 3.

Are representative concentrations incorporating different types of below-limit values different enough to influence risk decisions?

Thank you!

For comments, suggestions, or questions please email
sayre.risa@epa.gov

Loading sources (*j*)

- NPV: Chemical Data Reporting under the Toxic Substances Control Act (data reported to the EPA about the <u>total mass</u> of chemicals imported into or produced in the U.S. by year) + Pesticides Industry Sales and Usage, 2008 – 2012 Market Estimates (EPA report)

- SHEDS-DTD (Stochastic Human Exposure and Dose Simulation): model simulating the amount of a chemical that goes down the drain based on <u>household usage</u>, reduced by the percentage removed by wastewater treatment

- Toxic Release Inventory (TRI): data reported to the EPA about <u>industrial releases</u>

$$\ln y_i = m_0 + \sum_{j=1}^{n_j} \sum_{k=1}^{n_{kj}} m_{jk} \ln\left(l_{ji} p_{ki}\right)$$

Where *i* is a given chemical, *y* is the representative concentration, *j* is a loading source, *l* is the value of that loading given the source and chemical (amount/time) , *k* is an exposure model, *p* is the value of an exposure model (amount/amount/time), and *m* is a model weight

Metamodel loading weights (m_j)
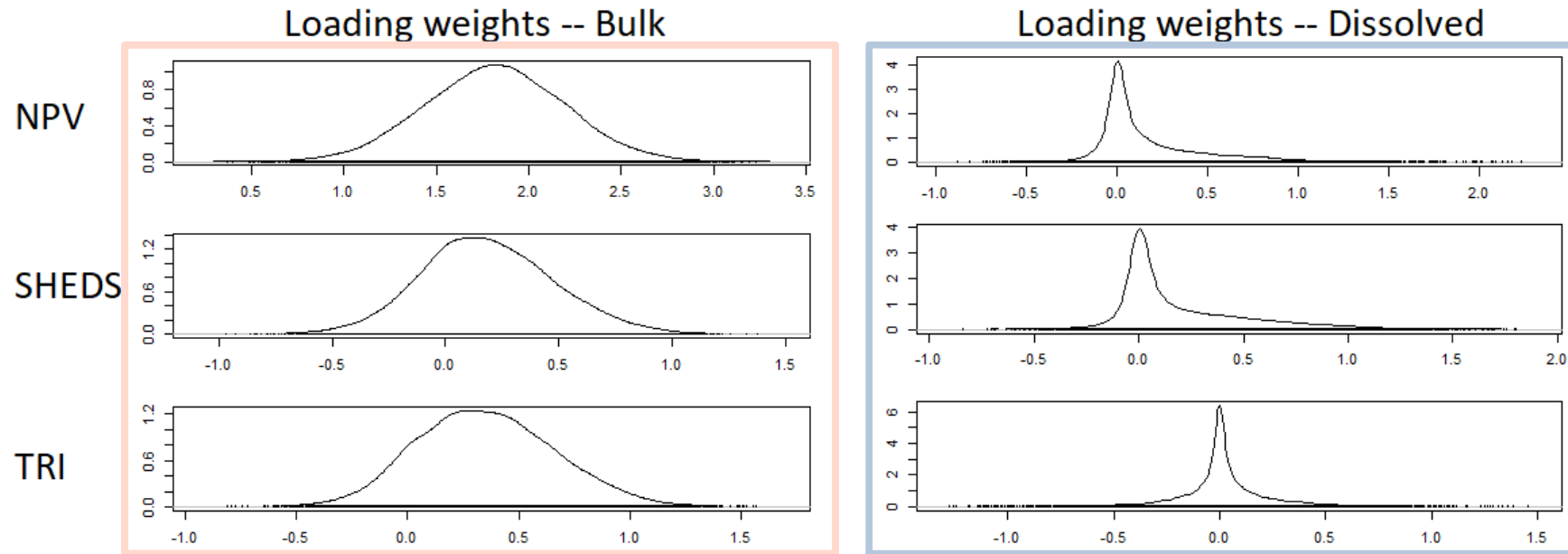
The predictive density for thousands of possible comparisons of the loadings with the lMLE representative values. The *prior probabilities* are set to zero. When a model explains the observations for the chemicals, the metamodel is updated to increase (or decrease) the weight of the model.

Metamodel loading*fate weights (m_{jk})

Loading*fate weights - Bulk
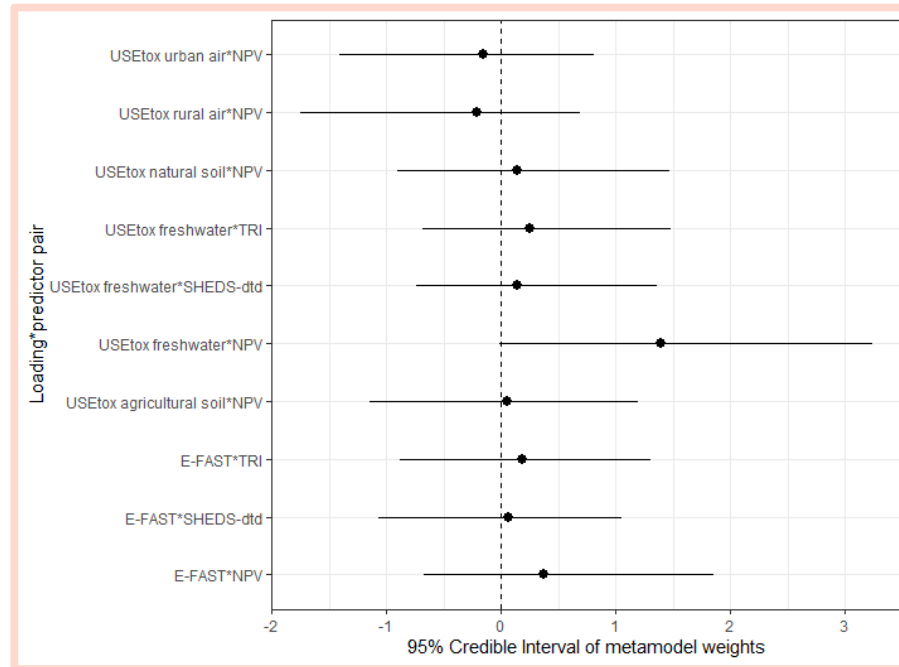
Loading*fate weights - Dissolved
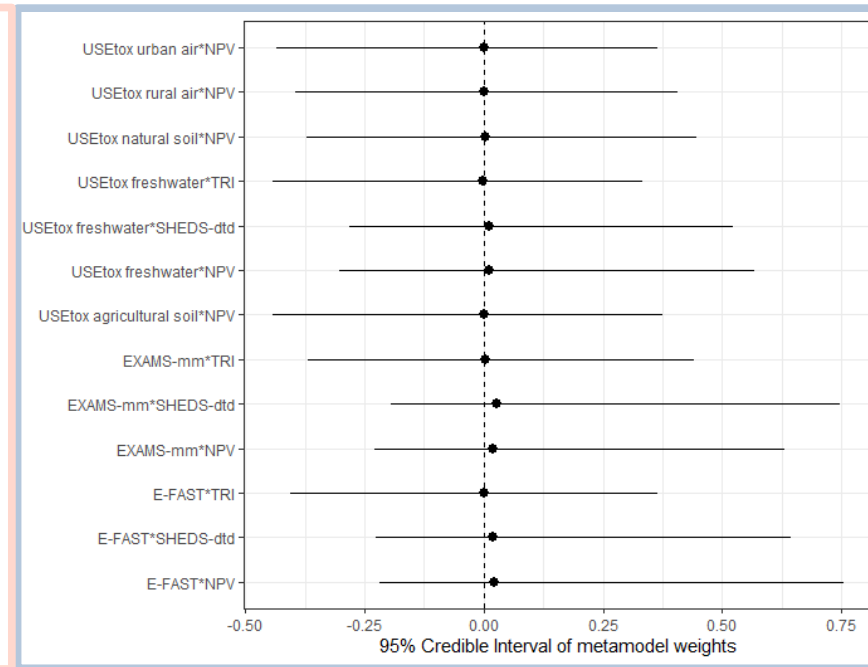
The most informative pair for bulk concentrations (left) was USEtox freshwater model using loadings from NPV. No tested pair explained observed dissolved concentrations (right).