The Sky’s the Limit

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Nice to meet you.

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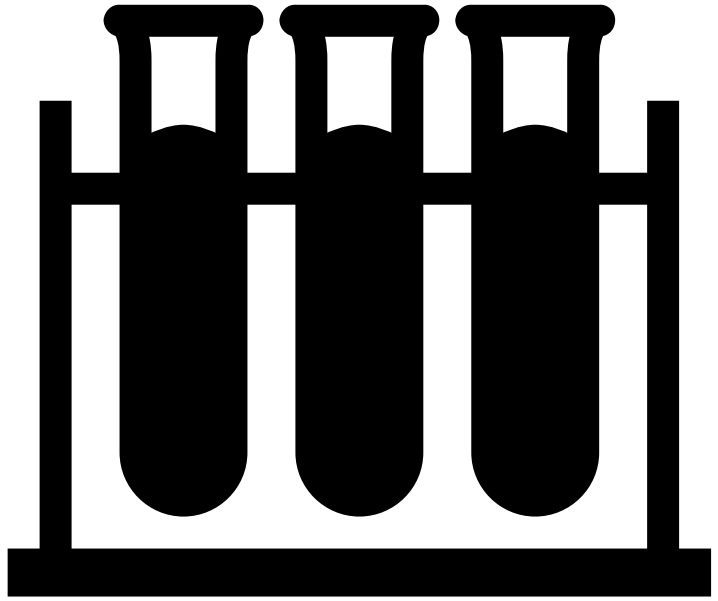


Review of laboratory limits of detection and implications in the statistical analysis of groundwater samples

What are laboratory limits of detection?

Not an exhaustive list

Can you fill in the blanks?

- The lowest concentration of an analyte in a sample that can be consistently detected with a stated probability (typically at 95% or 99% certainty)
  - Good definition if there were only one type of limit of detection
- IDL - Instrument Detection Limit
  - _____
- MDL – Method Detection Limit
  - _____
- LOQ – Limit of Quantitation
  - _____
- RL – Reporting Limit, DLR – Detection Limit for Purposes of Reporting
  - _____ etc.

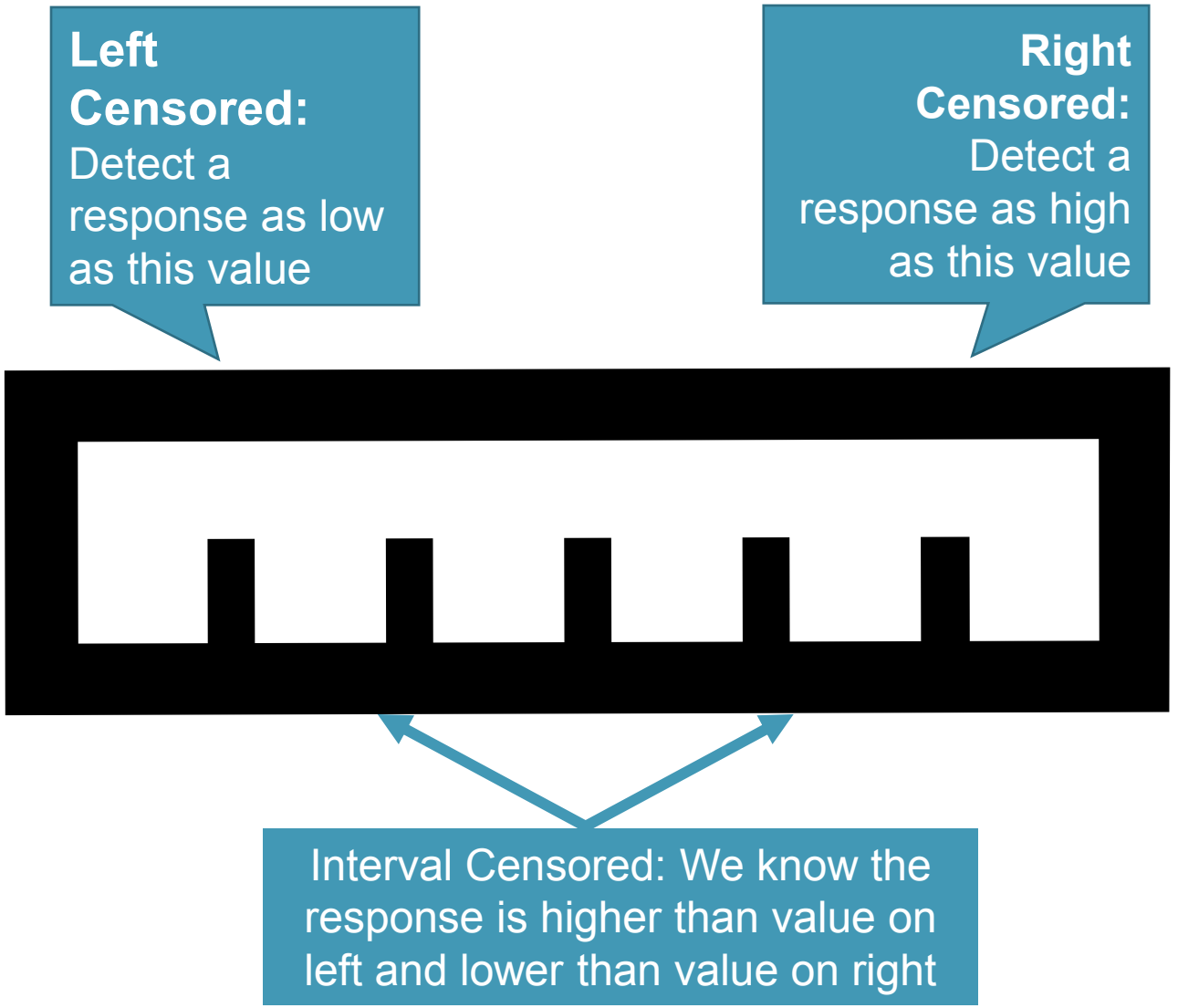
Let’s Talk About Censoring

- Dictionary
  - to remove anything offensive from books, films, etc.
  - to ban or cut portions of (a publication, film, letter, etc.)
- Can also mean to remain unknown due to time or technical limitations
  - lab equipment has minimum levels of performance below which it can not operate reliably

Scientific Applications of Censoring

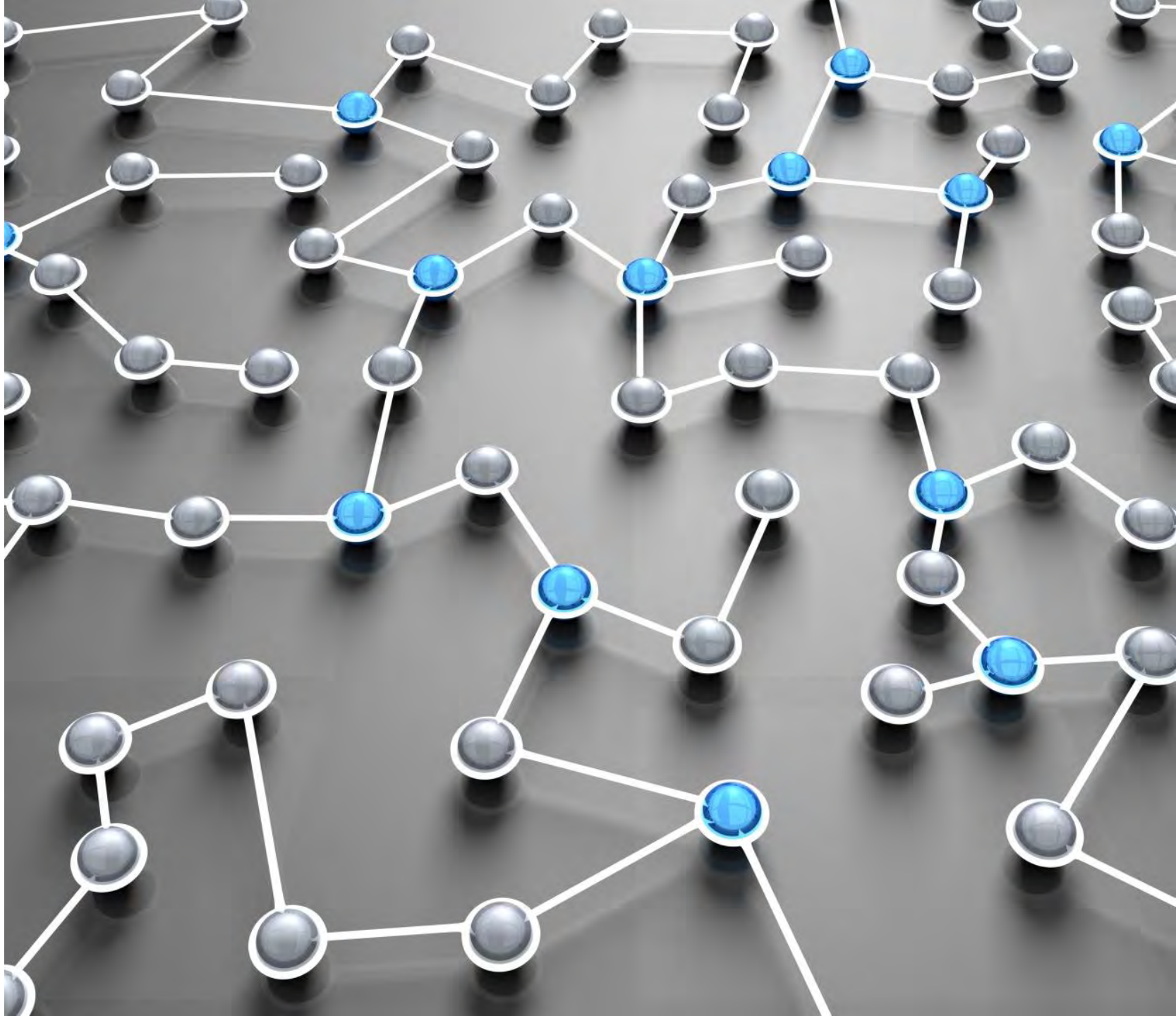
- **Medical Statistics**
  - Study survival times of diseases
  - End of study, outcome is either survival (censored) or death
  - Right censored data
- **Transportation Planning**
  - Present mode choices as sets of experiments as a function of cost, travel time, and mode attributes
  - Cost choices people are willing to pay (or not) are the cost limits
  - Left, interval, right censored data
- **Groundwater Statistics**
  - Censored values are the limits of detection
  - Samples with lower concentrations may exist but cannot be reliably measured
  - Left censored data

Types of Censoring



Questions

1. Do all limits of detection mean the same thing?
2. If a lab provides more than one type of limit of detection, which one should be used?
3. What if there is only one type of limit of detection but its value changes?



Answer 1

Do all limits of detection mean the same thing?

- No industry standard exists for establishing censoring limits
- EDL – Starting point for MDL established during method development process or calibration
- MDL – About one to five times the EDL, based on replicate samples
- PQL or RL – multiples of the IDL, EDL or MDL
- A hierarchy is evident
- EDL < MDL < PQL < RL<SQL, ….. the sky's the limit
- Work by ASTM Committee D22 on Air Quality
  - Goal to standardize the practice of detection limits with statistical rigor that will produce consistent results

Answer 2

If a lab provides more than one limit of detection, which one should be used?

- Use the one based on statistically derived principles in conjunction with qualifiers
  - MDL is the most defensible and preserves information on analyte concentration
- Challenge: Each sampling event is unique
  - Limits of detection will change
  - Function of analytical method, equipment, operator, sample quality
  - Availability of each type of limit of detection not consistent across samples

Answer 3

What if there is only one type of limit of detection but its value changes?

- This is a type of censoring: multiply censoring
  - Censoring limits occur at multiple measurements
- Statistical imputation techniques can be used
  - Regression on Order Statistics (semi-parametric)
  - Kaplan-Meier (nonparametric)
  - Maximum Likelihood Estimation (parametric)
  - Avoid simple substitution or deletion

Considerations for Multiply Left-Censored Data

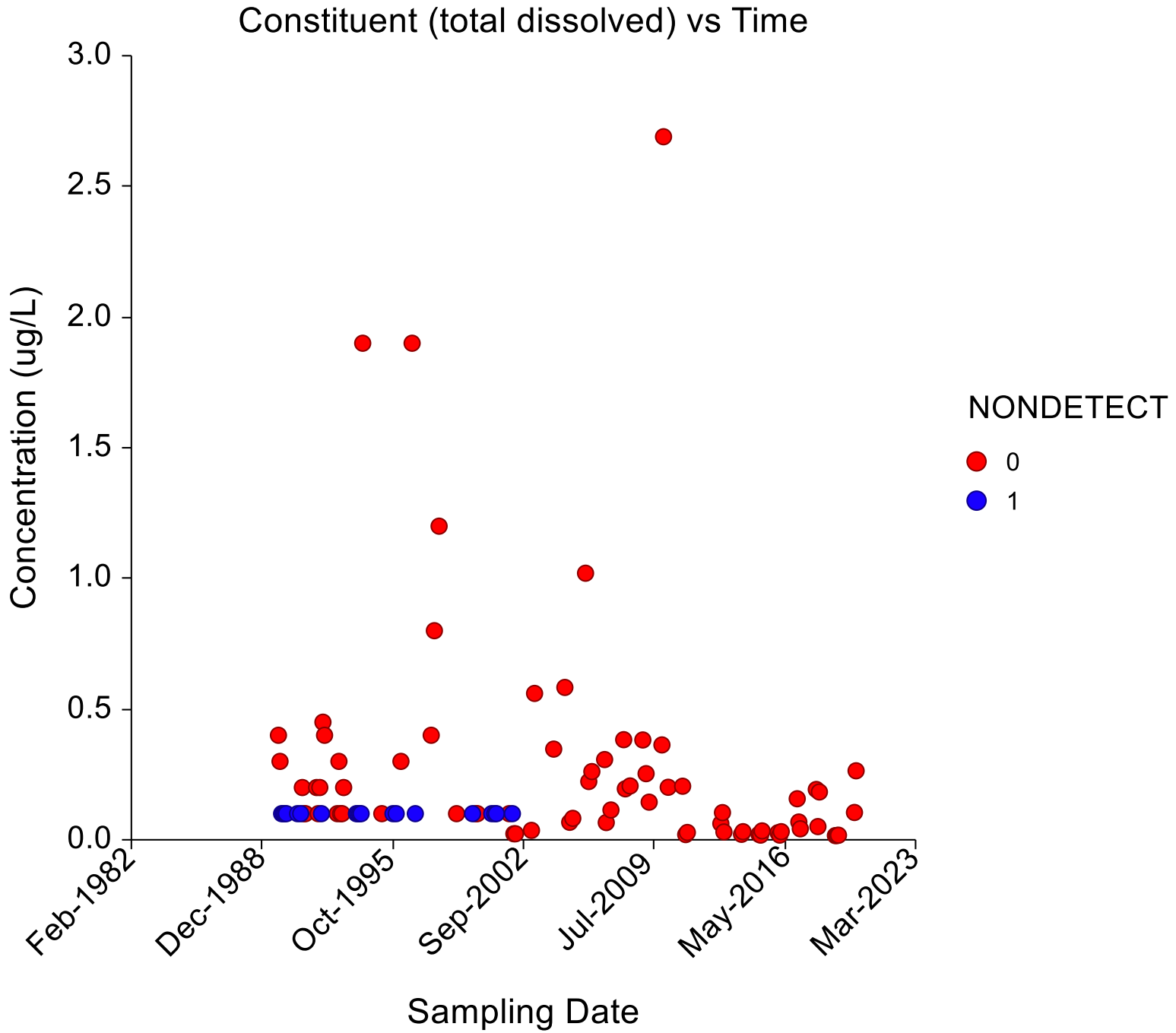
All can be used provided samples are good quality and within calibration range

- Watch out for very high dilutions
  - Difficult to find EPA recommendation specifically for metals in groundwater
  - Better to dilute than to provide measurement outside calibration range
- Investigate censored values higher than highest detect

Examples

Impact of Imputation Method

- 93 observations
- ~lognormal
- 20% Non-detects
- 1 distinct value for censored observations : 0.1 ug/L
- What method would you use?

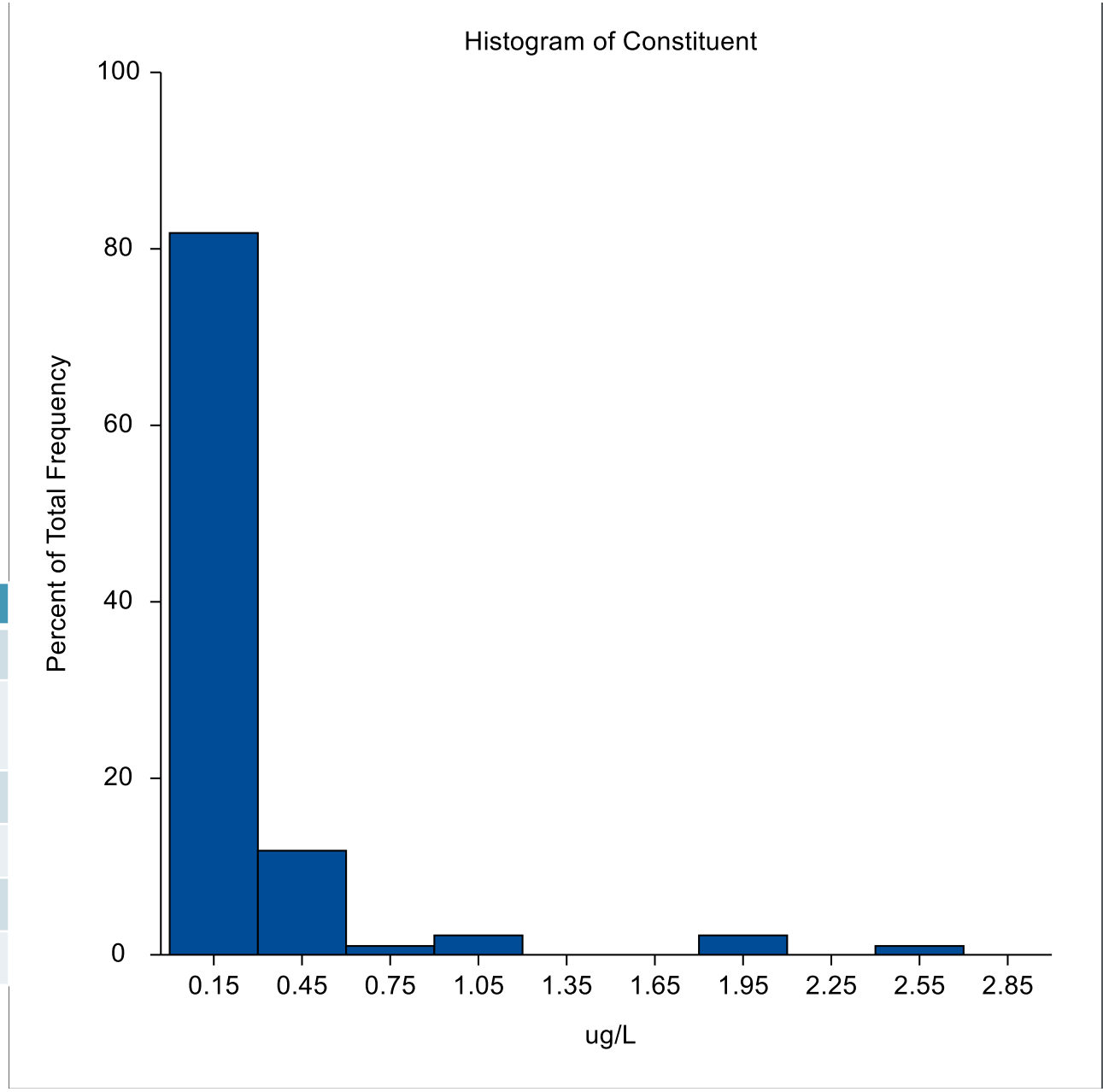


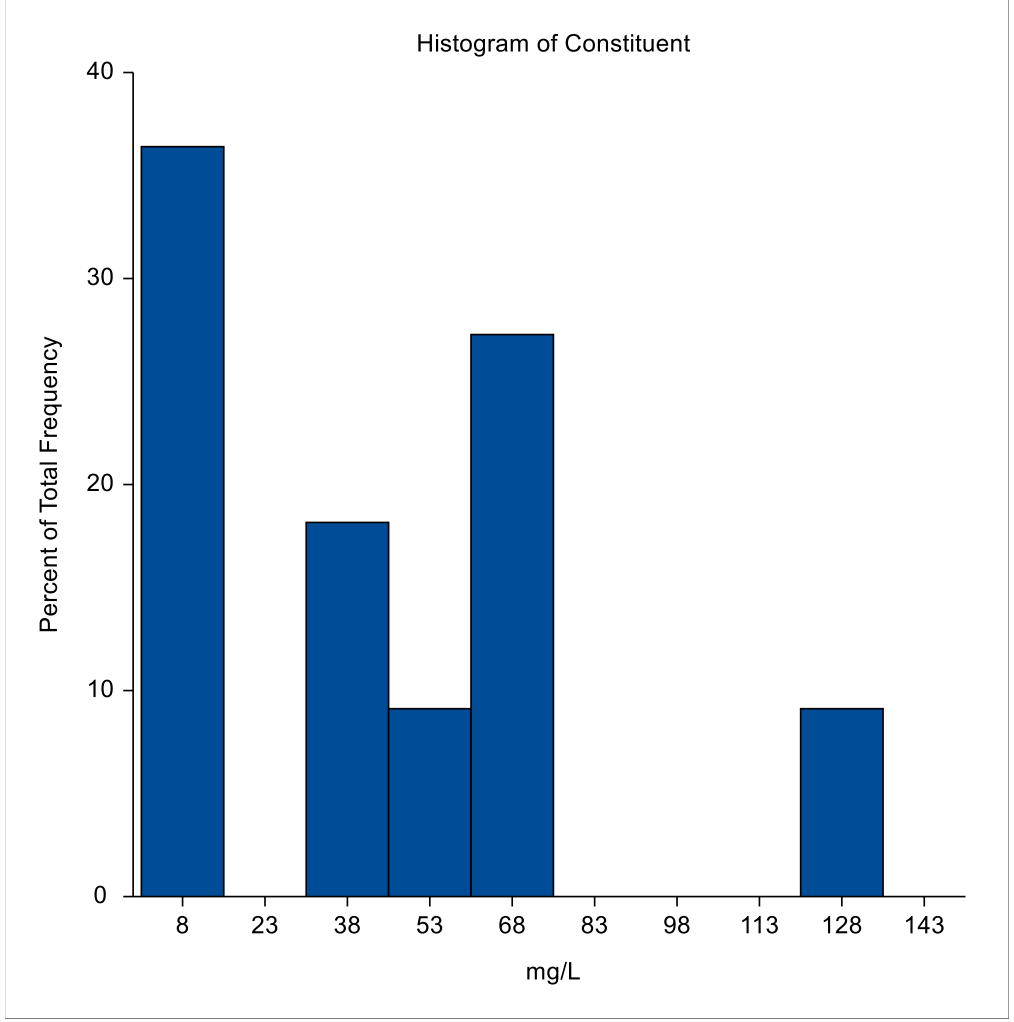
Impact of Imputation Method

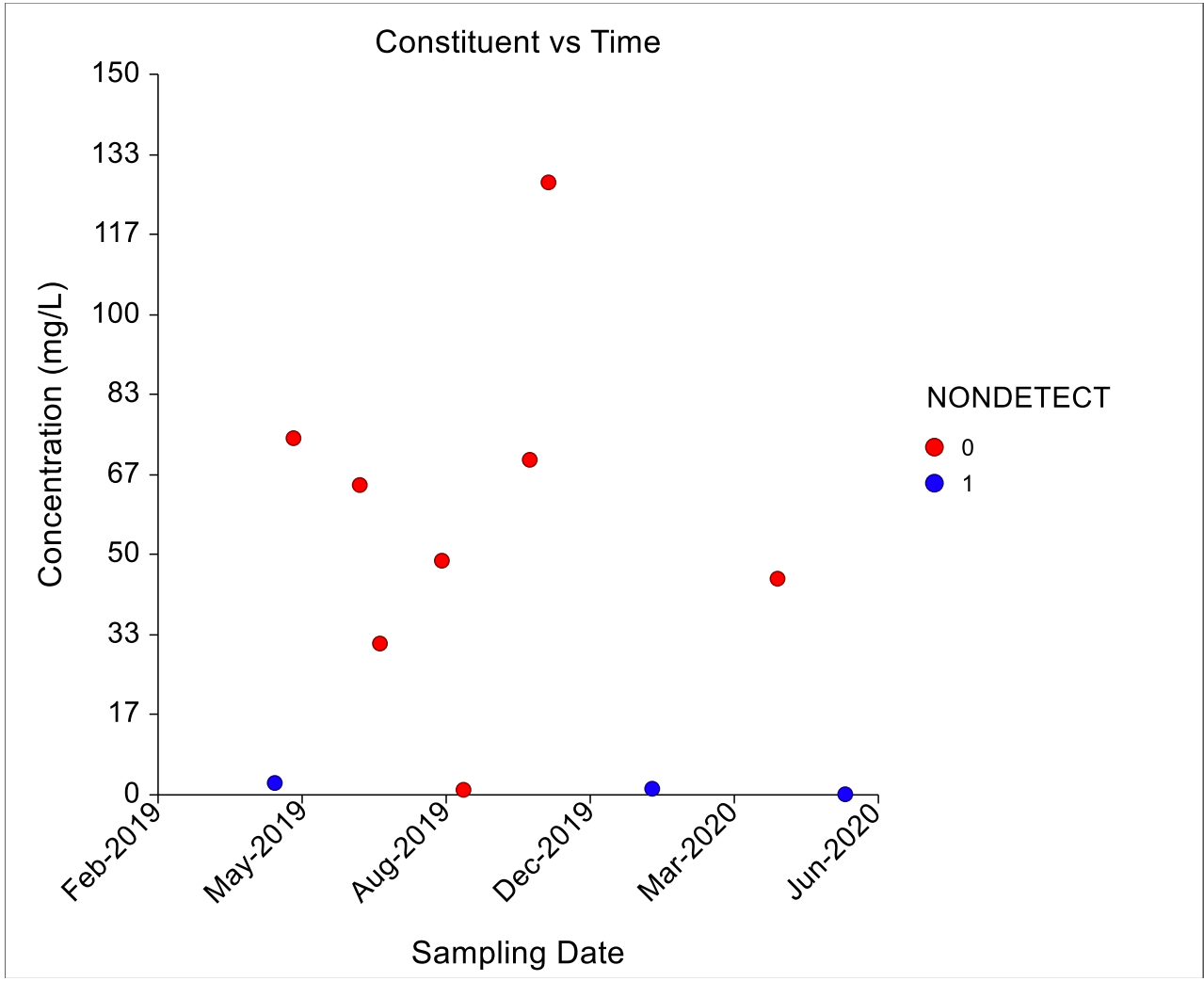
- Simple substitution and statistical imputation produce similar values
- Deleting censored values moves distribution tail furthest to the right

Method	Mean*	SD*	UPL	UTL
Censored Value	-2.11	1.11	0.779	1.05
1/2 Censored Value	-2.25	1.17	0.747	1.02
Deletion	-2.06	1.24	1.03	1.49
KM	-2.35	1.26	0.816	1.14
ROS	-2.34	1.28	0.788	1.10
MLE	-2.11	1.04	0.688	0.91

*mean and standard deviation are on log scales







Impact of Multiply Left-Censored Data

- 11 observations, 3 non-detects
- ~Normal
- MDLs: 128, 2.48, 0.1.28, 0.128 mg/L

Multiply Limits of Detection

- All limits are on the left tail of the distribution
- Minimal impact between the two methods
- KM provides less biased results
- Radium isotopes often have multiply left-censored data

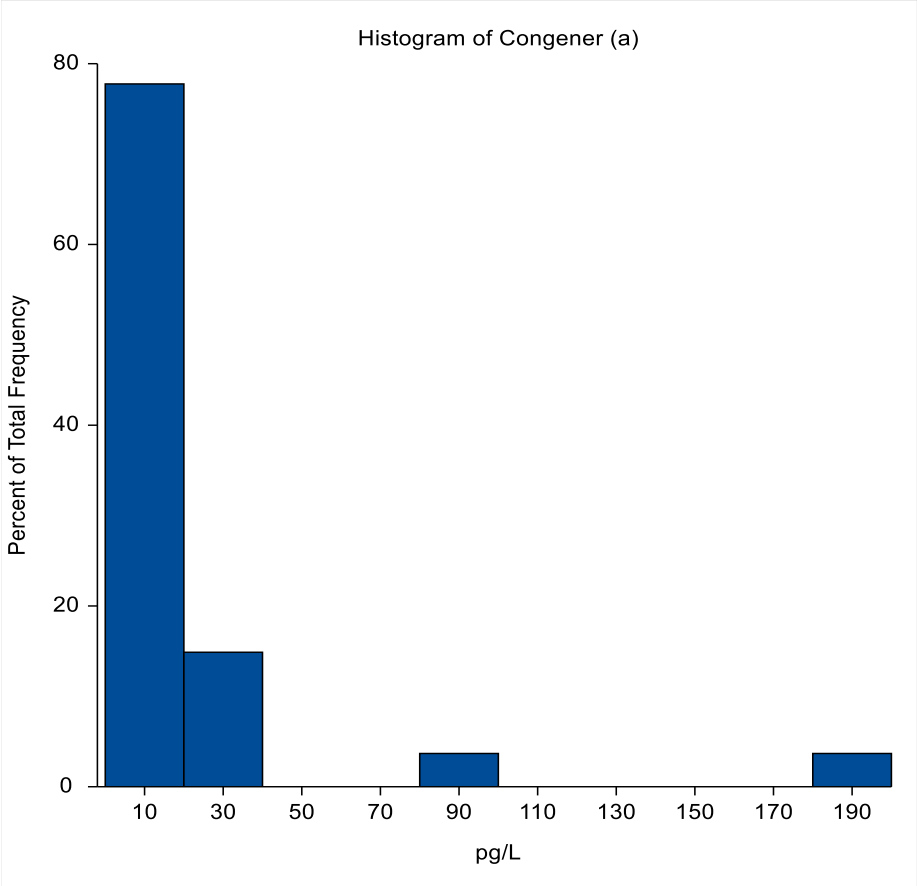
Method	Mean	SD	UPL	UTL
1/2 Censored Value	42.2	40.7	119	157
KM	42.2	38.9	116	152

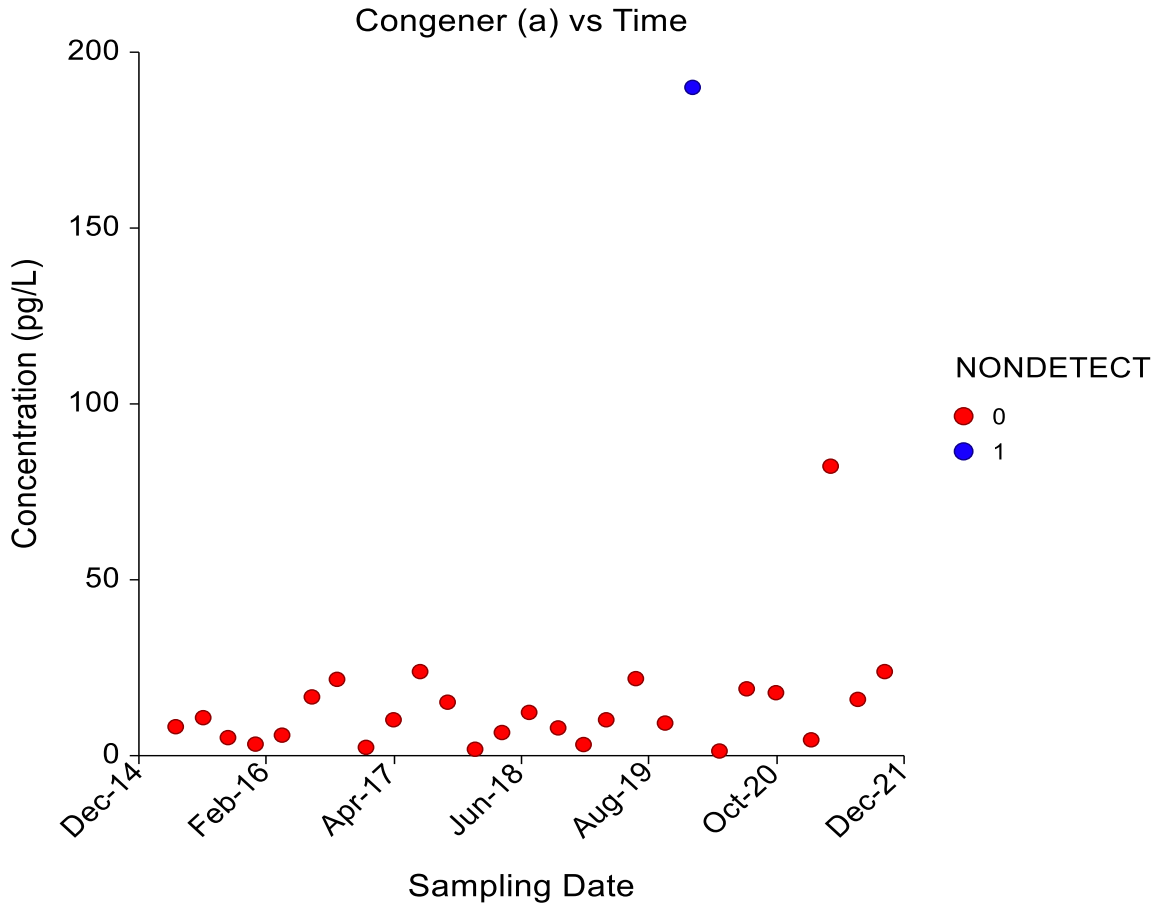
Impact of Different Limits of Detection

- Sometimes labs only provide the RL (or equivalent) and use that to represent the non-detect
- As an illustration, use RLs provided in previous dataset as the limit of detection
  - 6 non-detects
  - RLs: 375, 7.50, 3.75, 1.88, 0.375 mg/L
  - ~Lognormal
- Methods provide results notably different than using MDLs
- However, non-detects > 50% of sample: Use nonparametric methods to estimate upper limits
  - UPL and UTL estimated at 375 mg/L

Method	Mean	SD	UPL	UTL
1/2 Censored Value	41.8	55.7	717	5,650
KM*	1.47	2.46	460	4,450
ROS	35.3	20.1	86.4	143

*mean and standard deviation are in log scale





Impact of High Limit of Detection

- 27 observations, 1 non-detect
- ~Lognormal
- RL: 190 pg/L
- Use of substitution method yields higher upper limits

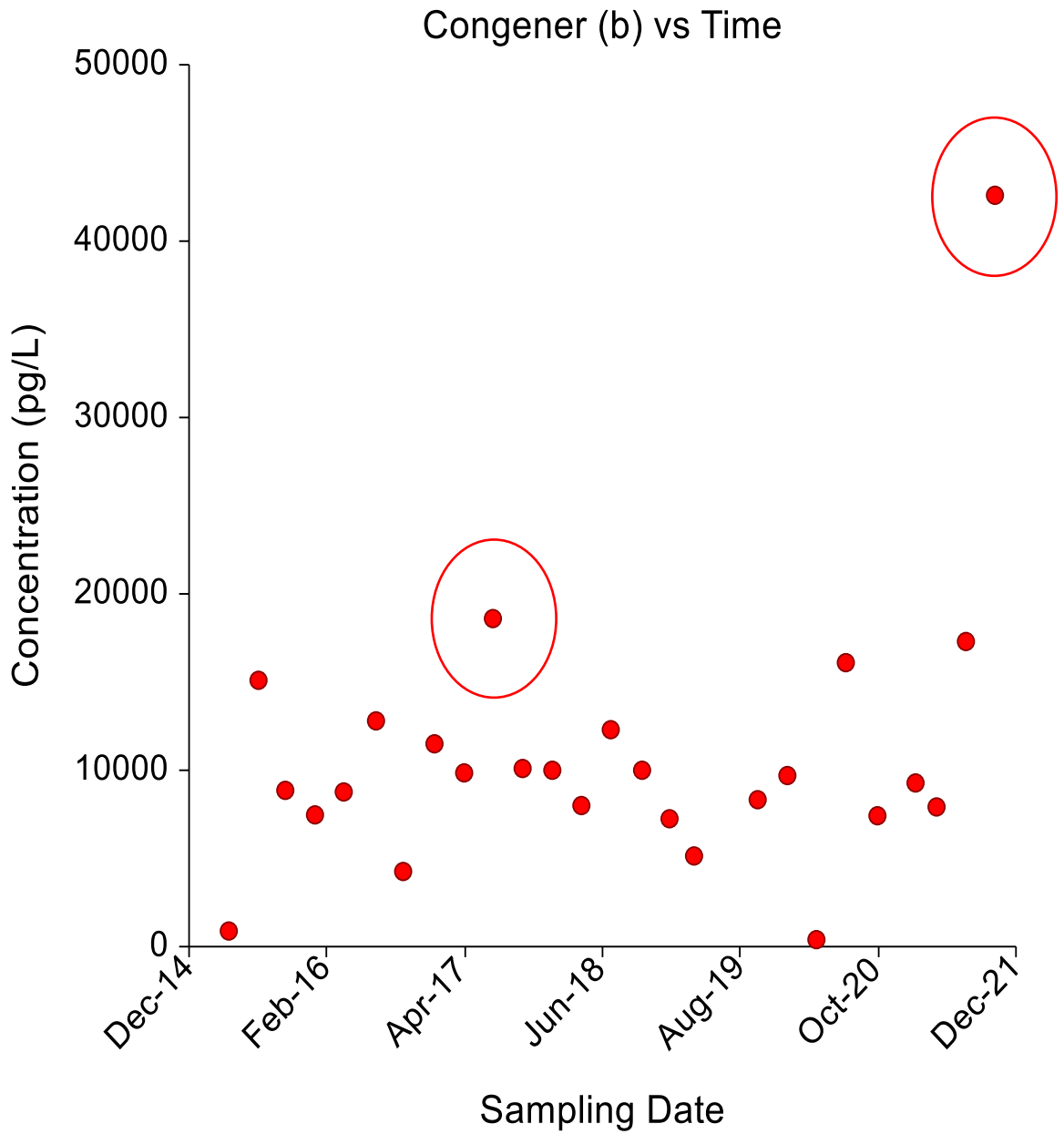
Method	Mean	SD	UPL	UTL
1/2 Censored Value	2.31	1.02	59.2	101
KM/ROS	2.23	0.915	45.4	73.2

*mean and standard deviation are on log scales

J Estimates Higher than Detects

- 26 observations, all detects
- Nonparametric
- RL: 190,192,199,275 pg/L
- J estimates of 43,000 and 17,000 higher than confirmed detects
- Lab notes indicated samples were outside calibration range

Method	Mean	SD	UPL	UTL
Nonparametric	10,767	7,799	34,200	42,600



Best Practices

Partner with Laboratories

Request laboratory to provide:

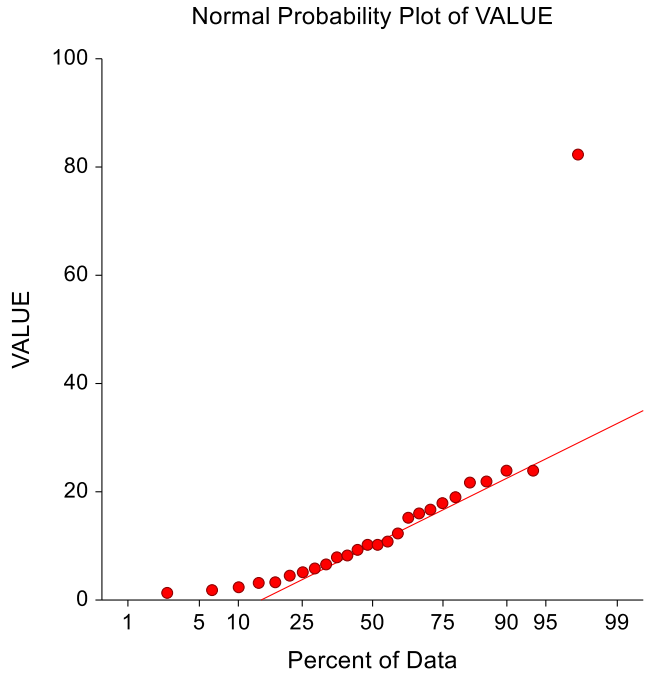
- Results from screening and dilution
- MDL
  - Limits with higher values may introduce bias into results and impact data quality
- Notes on calibration
- Notes on qualifiers: J-, J, J+, U, UJ, etc.
  - Investigate J estimates higher than confirmed detects
- Notes on dilution factors
- Keep dilution factors low

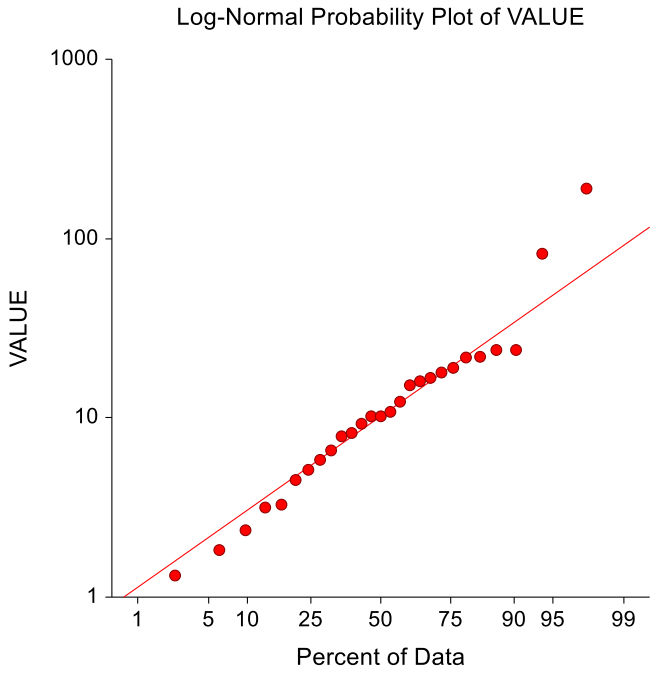
EPA Opinion

EPA NPDES/Remediation FAQ:

- “Q22 There are one or two VOCs in our influent samples at very high levels and we have to dilute our samples. This results in detection levels in the 100's or 1000's. Is this acceptable?

- A22 This is a common problem. EPA’s recommendation is to **run the sample twice**, at different dilutions. I would look at the final concentration of the high compound and look at your initial calibration. The EPA would recommend rerunning the sample at a lower dilution. 5,000/1,000 or **1:5 dilution** to get the other compounds at a lower reporting level. (Unless the 5 ppm is a NPDES violation).”





Practice Good Statistics

- Preliminary Data Analysis
  - Descriptive statistics per well-constituent pair
  - Graphical analysis
  - % non-detects, multiply left-censored data
    - Non-detects higher than detects?
  - Determine distribution
    - Goodness of fit tests
    - Probability plots
  - Apply appropriate imputation method

Questions