Groundwater Statistics for the Statistically Challenged

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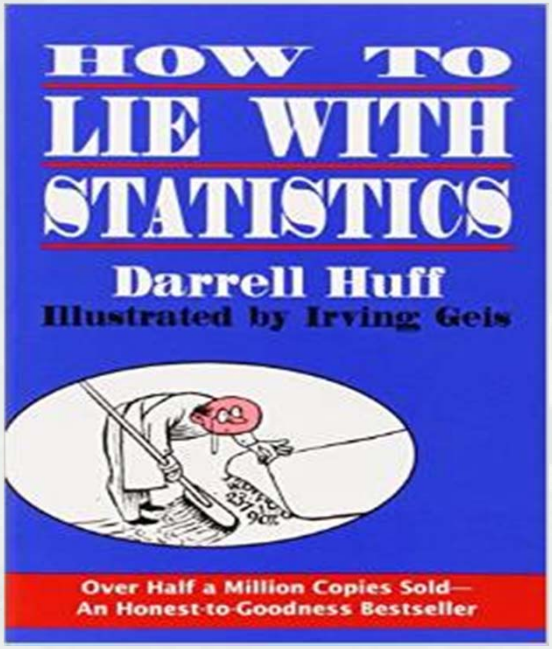
Why do we need statistics?

- "There are three degrees of falsehood: the first is a fib, the second is a lie, and then come statistics" – Anonymous, 1891



"Stats.con: How we've been fooled by statistics-based research in medicine"

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Example of Judgmental Decision Criteria

- Source Water Monitoring [rule] for Total Arsenic
  - *A system with a sampling point result above the MCL must collect quarterly samples…until the system is reliably and consistently below the MCL. At a minimum two consecutive groundwater samples…will need to be collected to demonstrate the system is below the MCL.*

RECLAMATION
Managing Water in the West
U.S. Department of the Interior
Bureau of Reclamation

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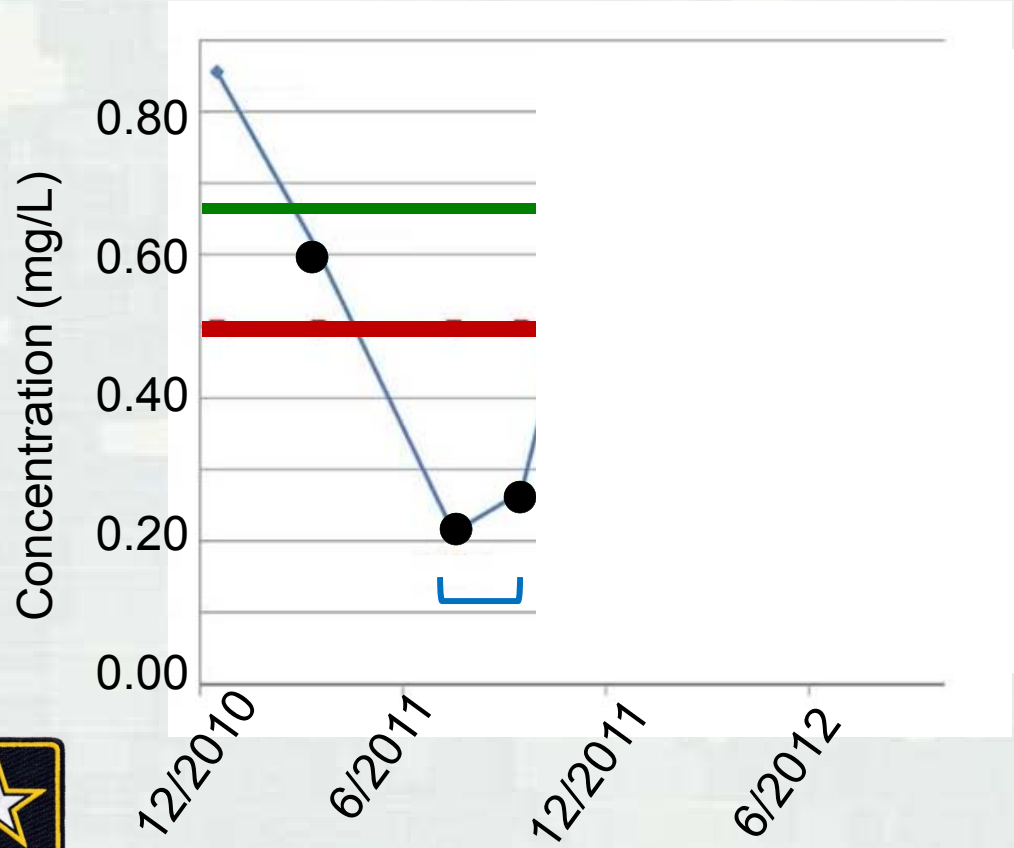
Application of Judgmental Criteria

- Decision rule: Two consecutive values < 0.5 mg/L



Compliance not confidently demonstrated.

UCL ≈ 0.7 mg/ L > 0.5 mg/kg.

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Example of Judgmental Methodology

- Replace non-detects with multiples of reporting limits.
  - *If there is reason to believe that the chemical is present in a sample at a concentration below the SQL* [Sample Quantitation Limit] *use one-half of the SQL as a proxy concentration…*
    - Risk Assessment Guidance for Superfund, December 1989.

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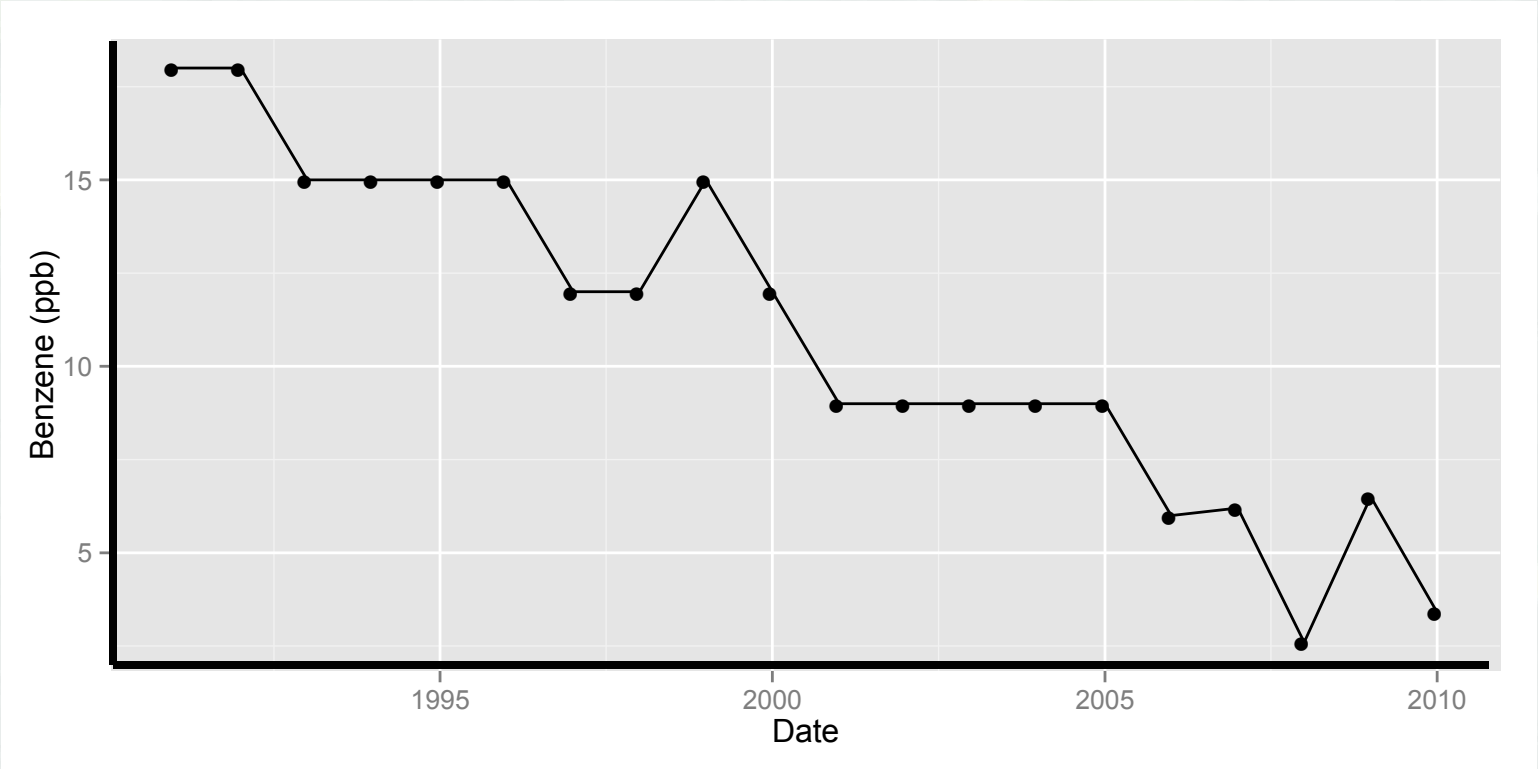
Times series plot with non-detects replaced with reporting limits*



* GMSC-1 web-based training, 2013

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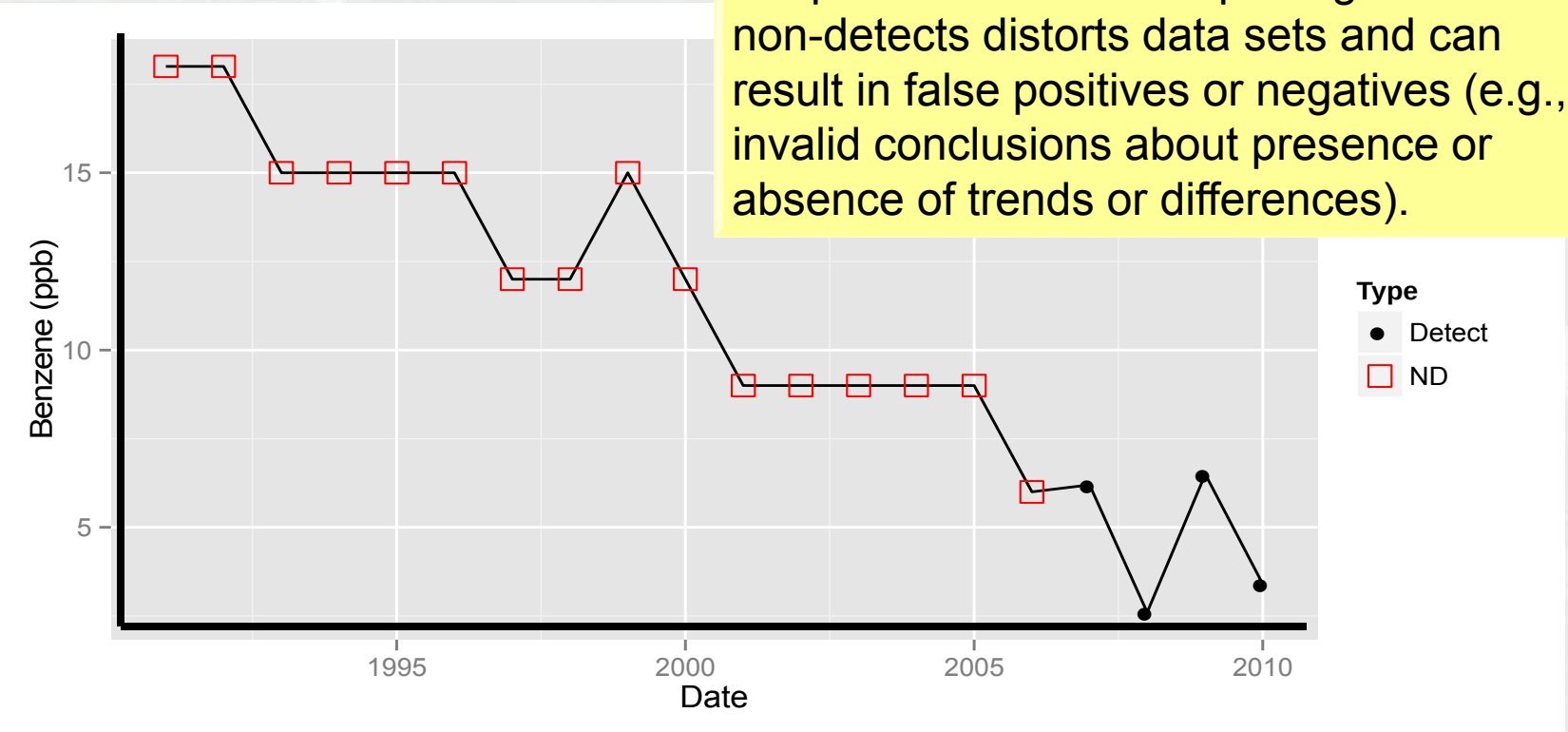
Time series plot with detects distinguished from non-detects*

Simple substitution of reporting limits for non-detects distorts data sets and can result in false positives or negatives (e.g., invalid conclusions about presence or absence of trends or differences).



* GMSC-1 web-based training, 2013

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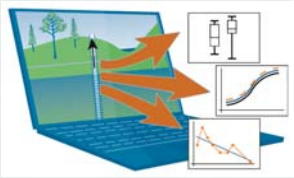
Groundwater Statistics and Monitoring Compliance (GSMC)

- Web-based guidance by ITRC (Interstate Technology & Regulatory Council) on statistical methods for groundwater for all project life cycle stages for "users without deep statistical expertise" [aka the "statistically challenged"]

http://www.itrcweb.org/gsmc-1/



  - Based on "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities: Unified Guidance"– 884-page EPA document (March 2009).

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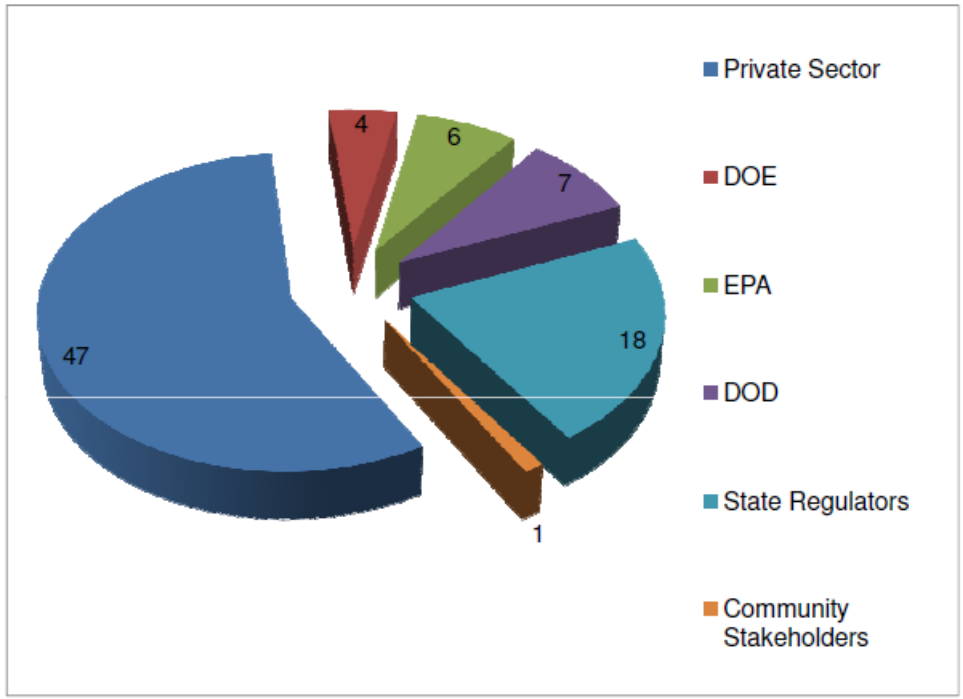
Composition of GMSC Team*



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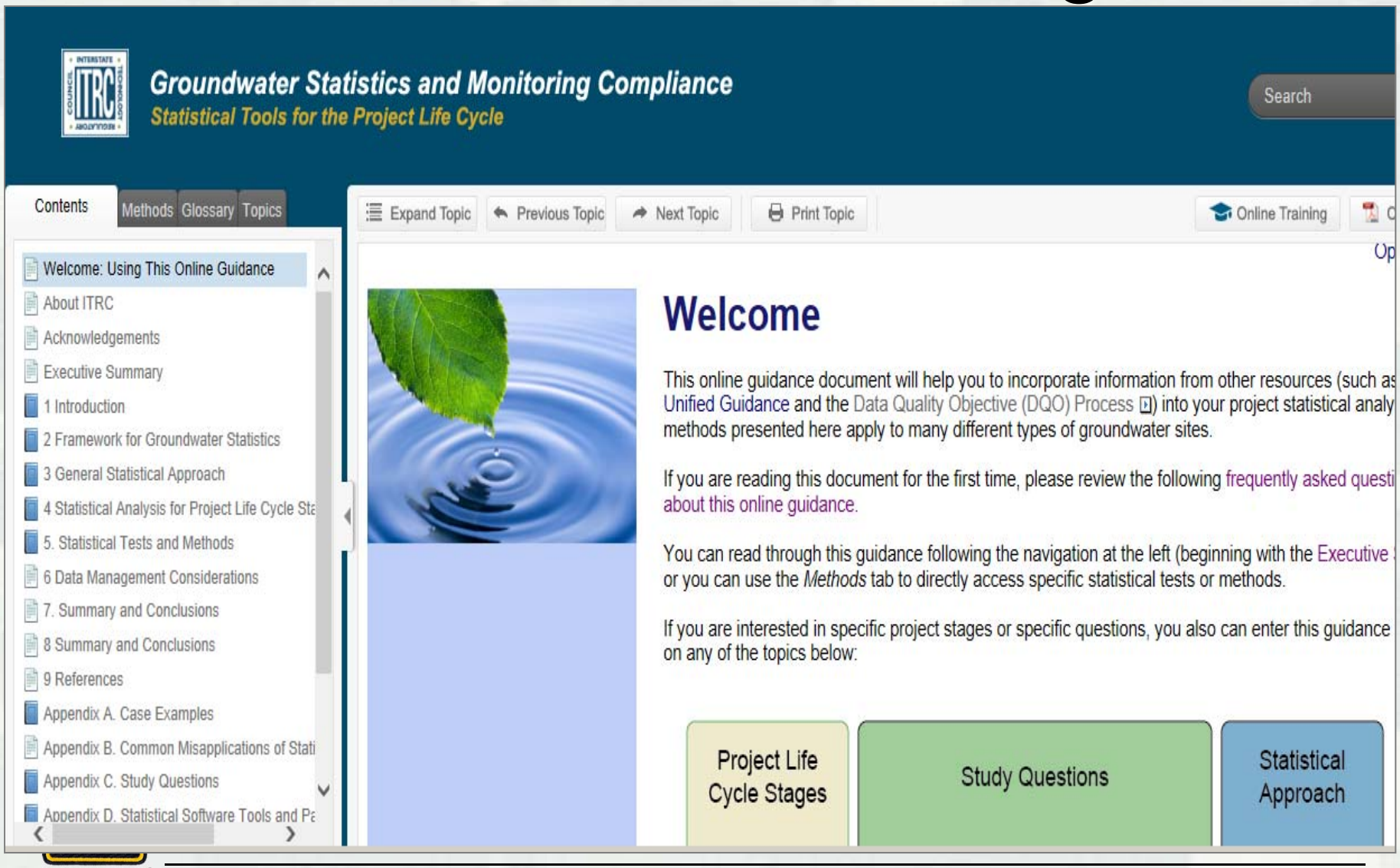
GSMC Welcome Page



Welcome Page - Central User's Table

Project Life Cycle Stages

- Release Detection
- Site Characterization
- Remediation
- Monitoring
- Closure

Study Questions

1	Background concentrations?
2	Above background?
3	Above or below a criterion?
4	When will criterion be met?
5	Is there a trend?
6	Is there seasonality?
7	Attenuation rates in well?
8	Changes with distance?
9	Sampling frequency?
10	Spatial coverage?

Statistical Approach

- Exploratory Data Analysis
- Methods
- Software

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Objective: Determine compliance with MCL

Project Life Cycle Stages

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Above or below a criterion?

- **Study Question 3**
  - *…if the criterion being used is a health-based concentration, and the mean exposure should not exceed the criterion, then select a predetermined confidence that the upper confidence limit of the mean (UCL) is below the standard.*

UCL < L	– Mean is confidently below criterion (L)
LCL > L	– Mean is confidently above criterion (L)
LCL < L < UCL	– Inconclusive result

LCL = lower confidence limit, UCL = upper confidence limit

Appendix B. Common Misapplications of Statistics

- *Error (Planning/Implementation): Using arbitrary decision rules; for example, concluding that groundwater is clean when three consecutive rounds of results are less than a criterion.*
  - *Recommendation: Use a systematic planning process, such as the seven-step DQO process, to develop a statistical approach that controls decision errors to an acceptable degree. Then use one-sample hypothesis tests.* [General approach for determining above or below a criterion.]

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Hypothesis Tests

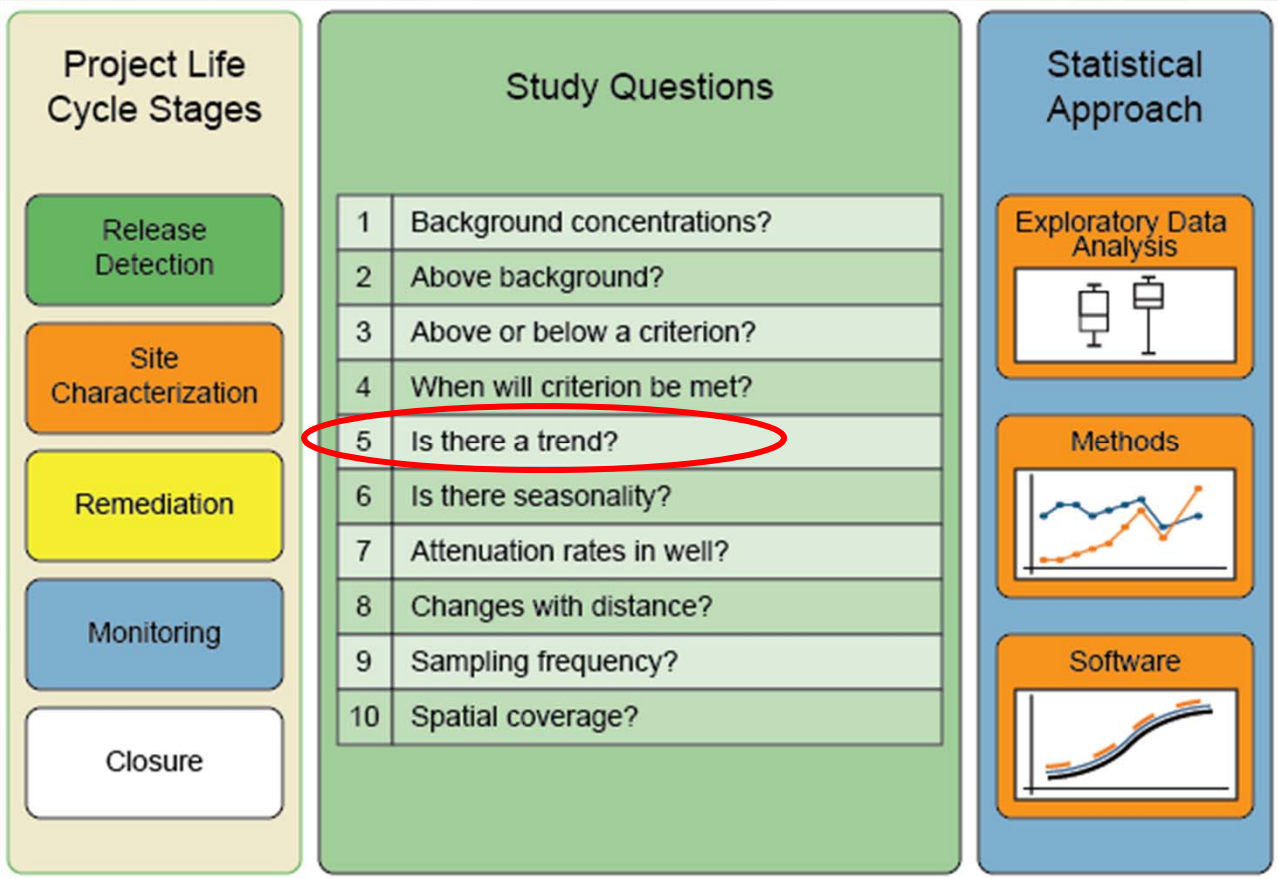
- Null Hypothesis (H_0): Opposite of what to prove.
- Alternative Hypothesis (H_1): What to prove.
- <u>Example</u> (one-sample hypothesis test):

  H_0: $\mu \geq L$, H_1: $\mu < L$, $L = MCL^*$, μ = "true" mean

  - ► Reject H_0 (accept H_1) when probability H_0 is true (p) is small such as when 95% UCL < MCL (p < 5%).
  - ► Generally, failure to reject H_0 is an inconclusive result.

* MCL = Maximum Contaminant Level (drinking water)

Objective: Determine if contamination is decreasing



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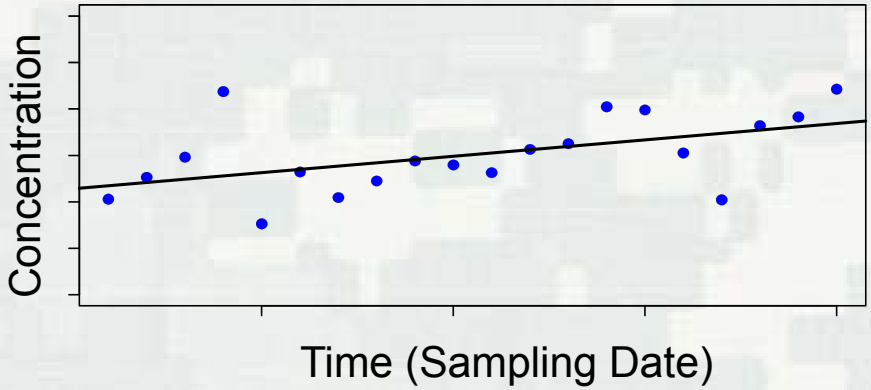
Study Question 5. Is there a trend in contaminant concentrations?

- Time Series Plots
  - *These plots show concentration on the y-axis versus time on the x-axis.*
  - *You must assign values to nondetects for these plots.*



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Nondetects

http://www.itrcweb.org/gsmc-1/#GW%20Stats/5 Methods in indiv Topics/5 7 Nondetect

Groundwater Statistics for Monitoring and Compliance

Statistical Tools for the Project Life Cycle

Contents | Questions | Glossary | Topics

- 5.6 Distributional Tests
- 5.7 Managing Nondetects in Statistical Ana
- 5.8 Temporal Analysis
- 5.9 Time Series Forecasting
- 5.10 Identification of Outliers
- 5.11 One Sample and Two Sample Tests
- 5.12 Correlation Tests
- 5.13 Control Charts
- 5.14 Spatial Statistics
- 6. Data Management Considerations
- 7. Public and Tribal Stakeholders Perspective
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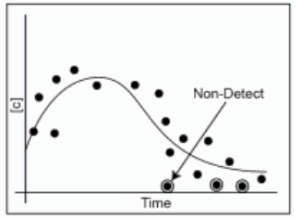
  - Study Question 2. Are concentrations great
  - Study Question 3. Are concentrations abov
  - Study Question 4. When will contaminant c
  - Study Question 5. Is there a trend in contan

Expand Topic | Previous Topic | Next Topic | Print Topic | Online Training | Open Full Document | Feedback

5.7 Managing Nondetects in Statistical Analyses



Environmental statistics is constrained by a practical reality of laboratory analysis: it is technically impossible for a laboratory analysis to confirm the complete absence of a chemical or compound of interest. Instead, a chemical may be present at some unknown concentration below the low end of the concentration range that the analysis is able to detect. Since the true level is unknown, laboratories report the nonzero value representing the lowest concentration that can be reliably detected for the given analytical method. This alternate value is often used in environmental statistical applications, even though the true value can only be narrowed to a range of possible concentrations (for example, from zero up to the reporting limit).

5.7.1 Definition of Detection Limits

In environmental testing, a detection limit is the concentration that is statistically greater than the concentration of a method blank with a high level of confidence (typically, 99%), or the lowest level of a given chemical that can be positively identified when using a particular analytical method. Signal intensity below the detection limit cannot be reliably distinguished from a method blank or "baseline noise." Therefore, an analyte is confidently reported as present in an environmental sample only when the measured concentration is greater than the detection limit.

Statisticians refer to any threshold at which a nondetect is reported as a "censoring limit." Nondetects are sometimes referred to as censored values. Censoring limits affect how one should manage data. For instance, reporting nondetects to larger censoring limits (higher detection limits) than needed tends to adversely impact data quality and increase data uncertainty. Unfortunately, different environmental testing laboratories

Appendix B. Common Misapplications of Statistics

- *Problem/Error (Implementation): Comparing sequential measurements in time with one another on a sample-by-sample basis to determine if there are increasing or decreasing trends.*
  - *Recommendation: Present time series plots with the results of statistical trend analyses (for example, p-values from Mann-Kendall tests).*

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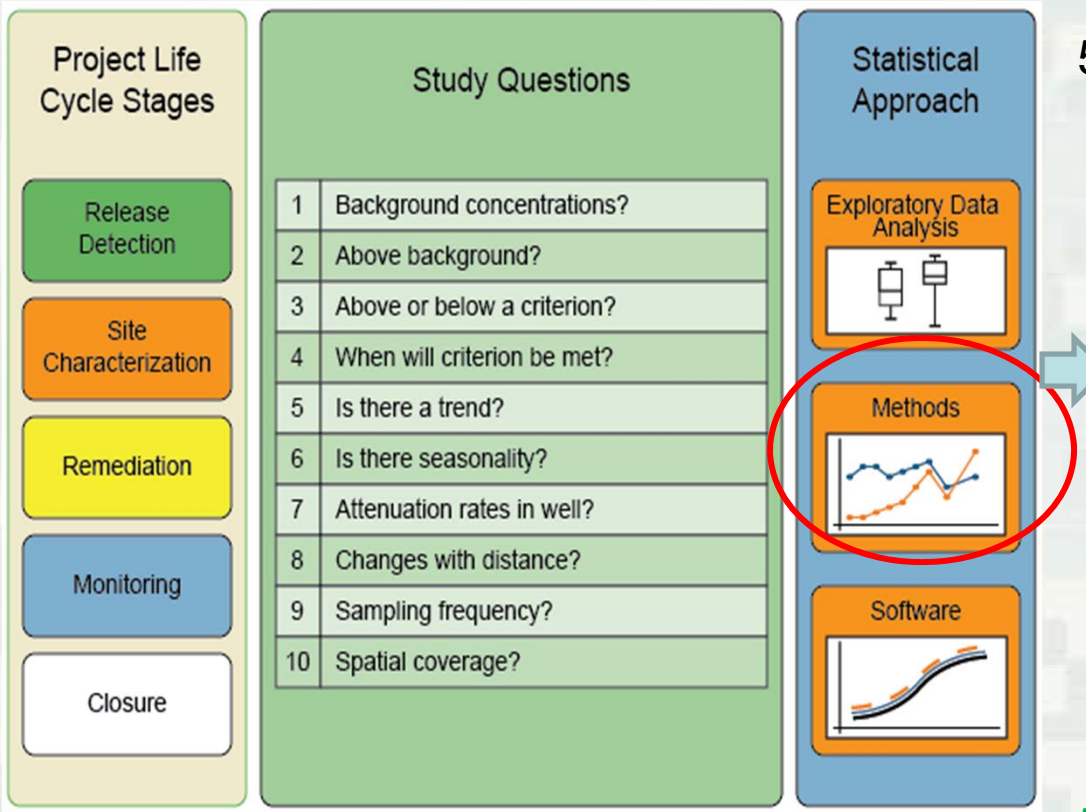
- 5.5.2 Mann-Kendall Test

…*nonparametric test for monotonic trends* (concentrations consistently increasing or decreasing).

- *Applications and Relevant Study Questions*
- *Assumptions*
- *Requirements and Tips:*
  - *Trend tests should be accompanied by time series plots.*
  - *A minimum of 8 to 10 measurements…*
- *Strengths and Weakness*
  - *...can be used when data sets contain non-detects*
  - *Results are not impacted by…extreme values*

Welcome Page



5. Statistical Tests and Methods

5.1 Graphical Methods
5.2 Confidence Limits
5.3 Tolerance Limits
5.4 Prediction Limits
5.5 Trend Tests
5.6 Distribution Tests
5.7 Managing Nondetects
…
5.14 Spatial Statistics

5.5.2 Mann-Kendall Test

H_0: No trend
H_1: Trend is present

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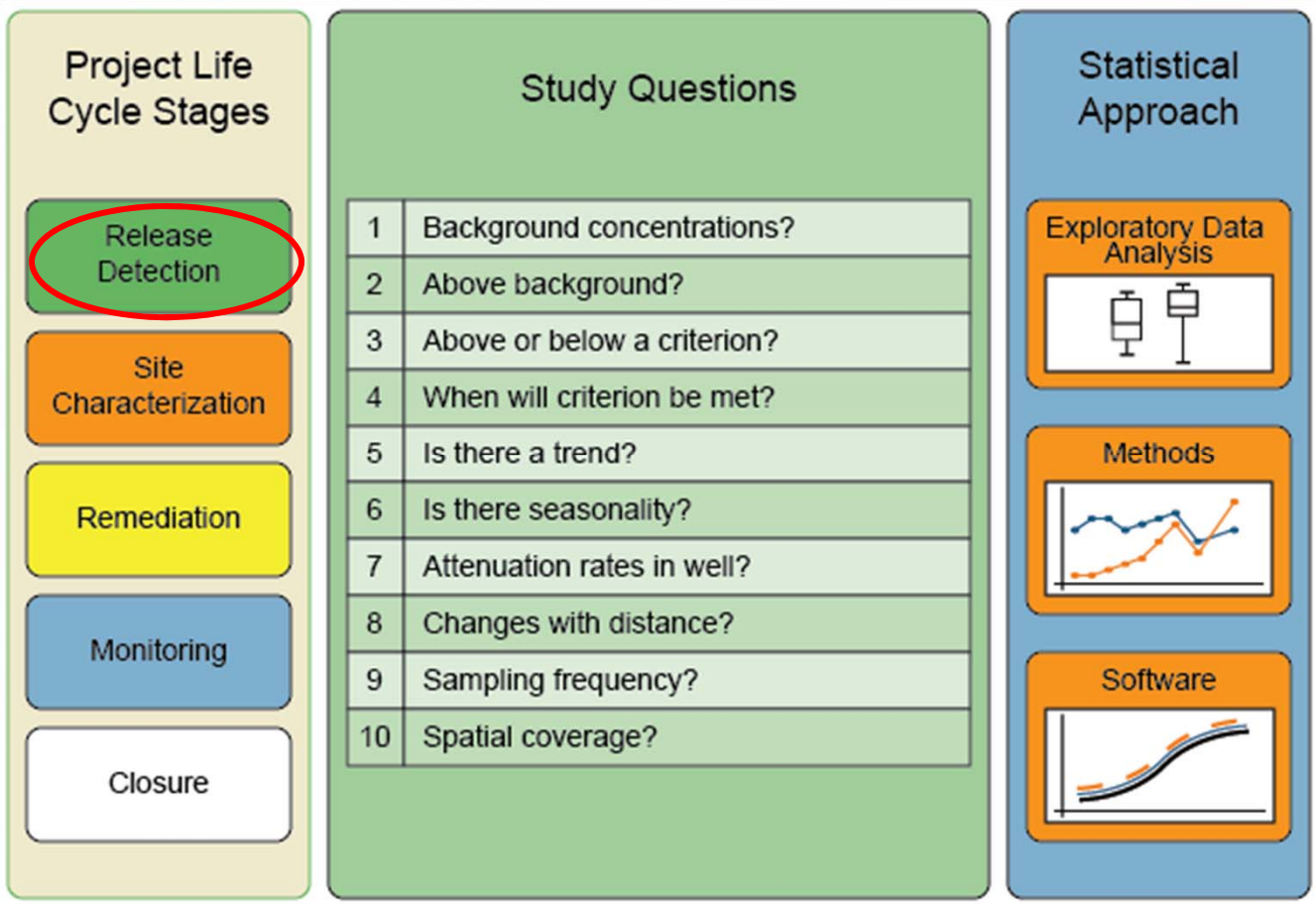
Objective: Determine if a release occurred.



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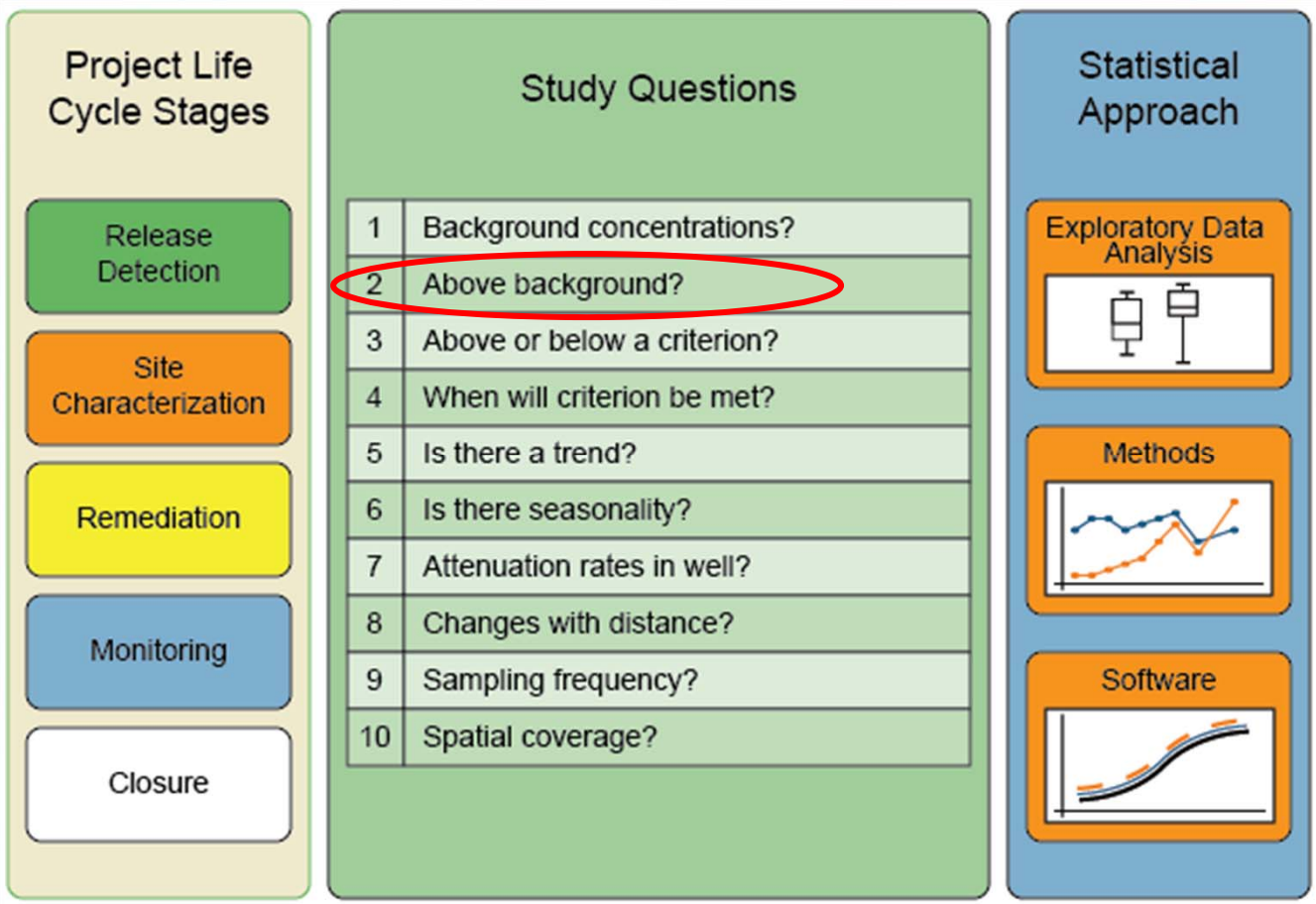
Release Detection

Release Detection Study Questions
1. What are the background concentrations?
2. Are concentrations greater than background concentrations?
3. Are concentrations above or below a criterion?
9. Is the sampling frequency appropriate (temporal optimization)?
10. Is the spatial coverage of the monitoring network appropriate (spatial optimization)?

Objective: Determine if a release occurred.



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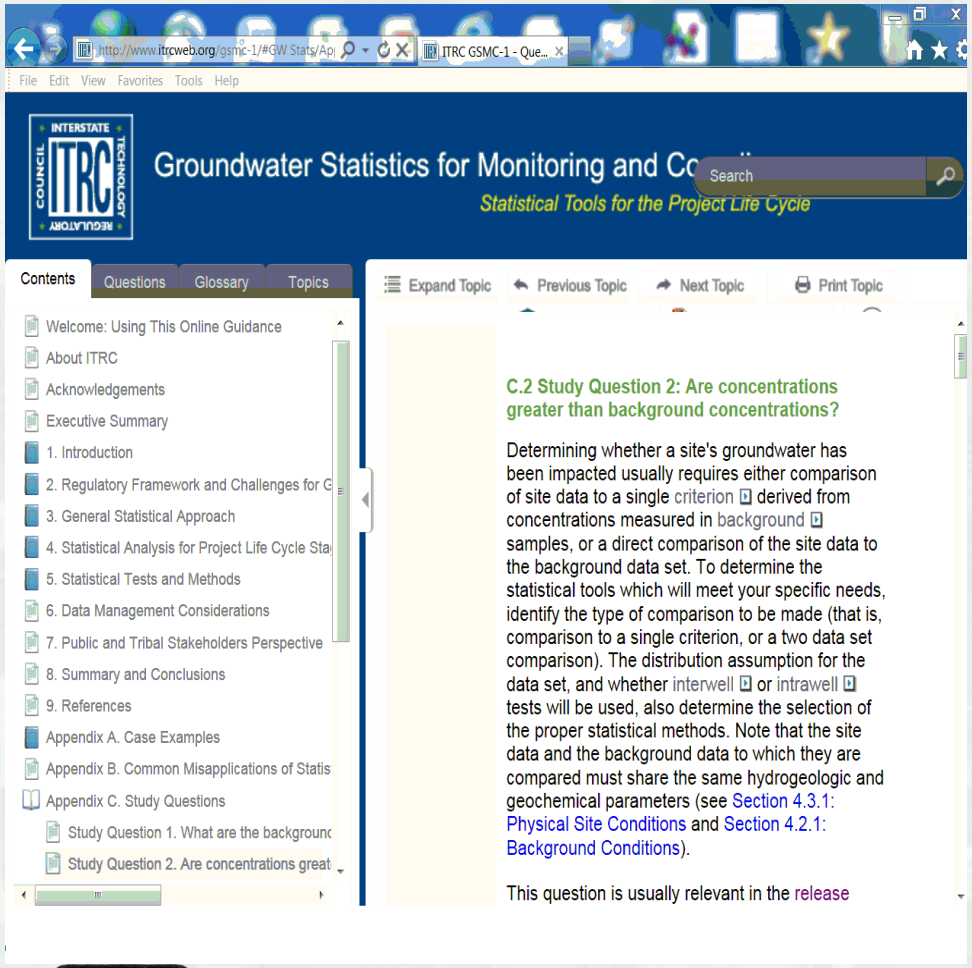
Study Question 2: Above Background?



- *Statistical Methods*
  - Prediction limits
  - Tolerance limits
  - Parametric hypothesis tests (e.g., t-test)
  - Nonparametric hypothesis tests (e.g., Wilcoxon rank sum test)

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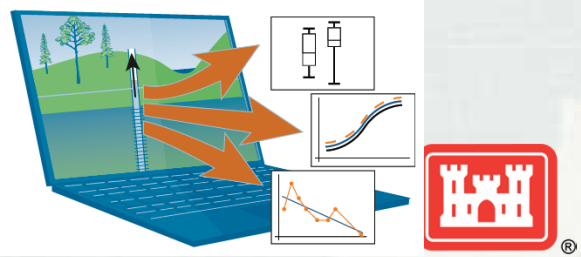
Conclusions – ITRC GSMC Guidance

- Useful web-based guidance for the statistically challenged.
  - ► Explains basic statistical methods for groundwater.
  - ► Helps select appropriate methods by project study question or life-cycle.
  - ► Presents techniques that can avoid common problems resulting in erroneous conclusions.