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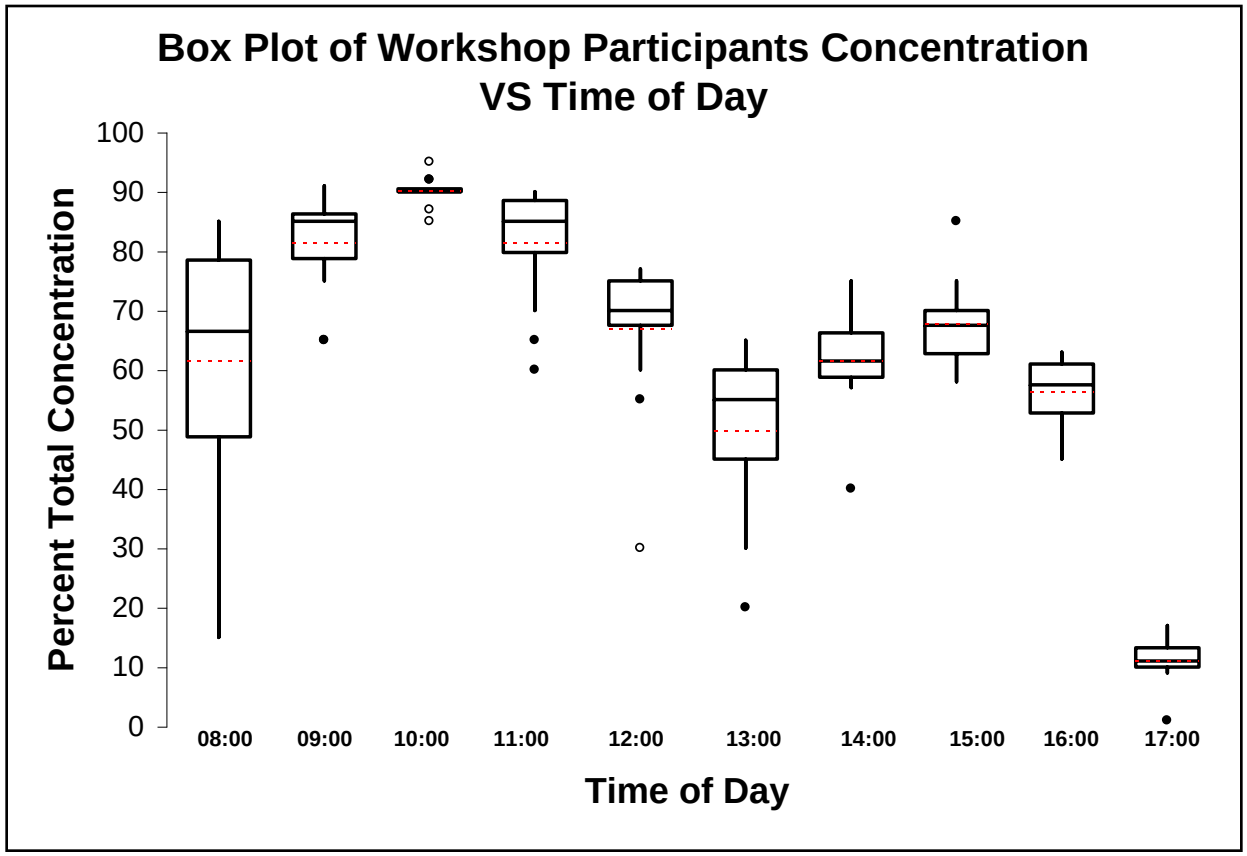
Trend Monitoring
What is it and why do we do it?

Trend monitoring looks for changes in environmental parameters over time periods (E.g. last 10 years) or in space (e.g. as you move downstream)



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*** Created with StatPlus™ Software

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How to find a trend

Visual-

*Good News...*Graphing or mapping data for people to see is the easiest way to communicate trends, especially to a non-technical crowd.

*Bad News…*No way of "measuring" that there is a trend or how big it is.

Statistical-

Good News…Can identify hard to see trends and gives a number that is defensible and repeatable.

Bad News…Easy to do wrong and hard to figure out.

http://www.barbneal.com/elmer.asp

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Selecting How to Analyze and Present a Trend

- Did your data meet your **data quality objectives**? Trend monitoring requires strict monitoring protocols.
- Who is your **audience** and what type of analysis or presentation is appropriate for them?
- If a statistical test is required, does the data satisfy all the **statistic's assumptions**?
- What is the trend telling you? Determining the **cause of the trend** is more difficult than determining the trend.
- Have you considered all the **exogenous parameters** that could influence your trends (flow, time of day, etc.)?

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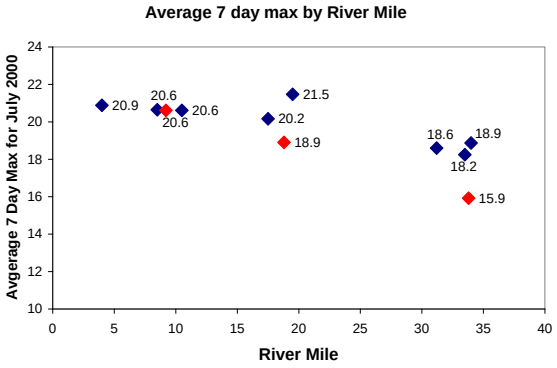
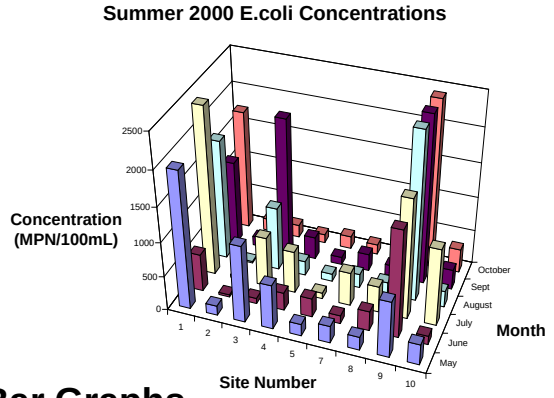
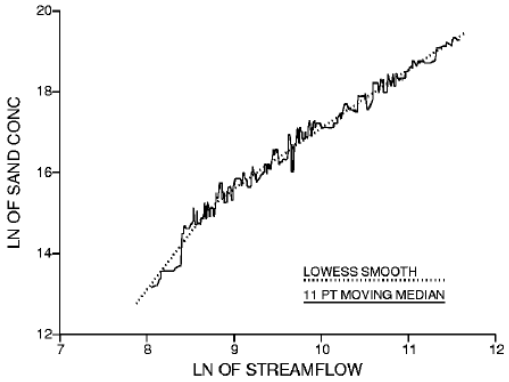
Visual methods for displaying trends



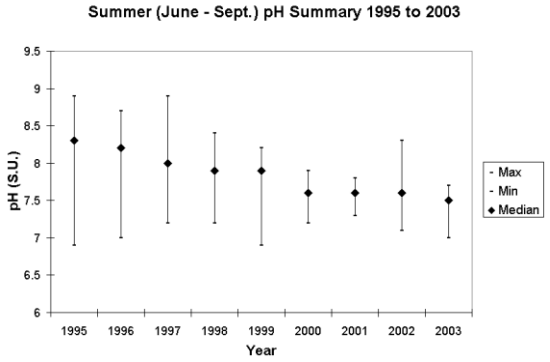
Time/area series scatter plot



Bar Graphs



Time series smoothed scatter plot*



Time/area series box plot of statistics

•From Helsel D.R. and R.M. Hirsch. 1991 Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the USGS Book 4. Chapter A3 p. 287

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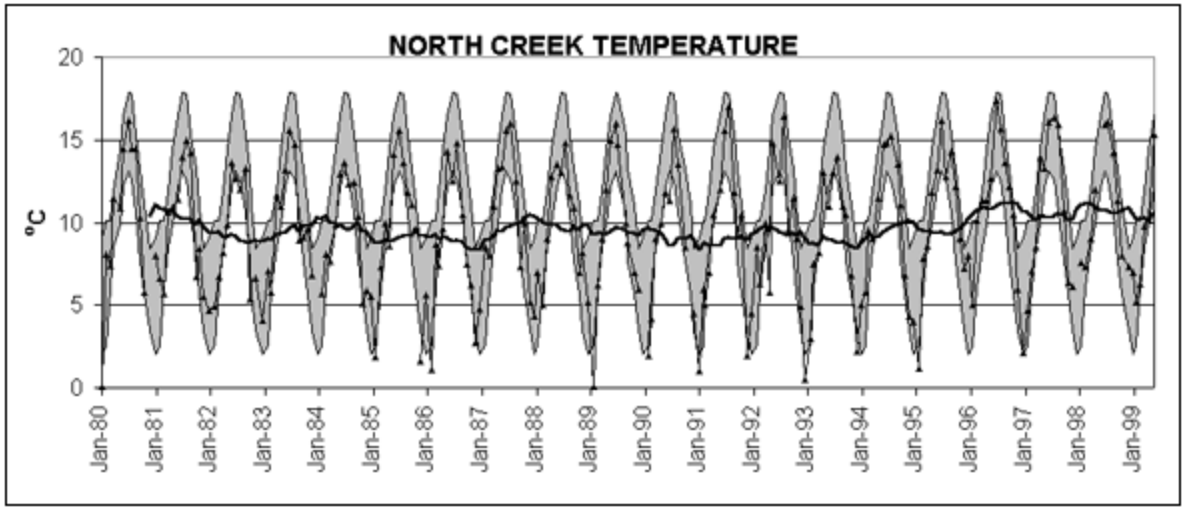
The Trouble with Graphs

- People tend to focus on the outliers and not on more subtle changes
- Gradual trends are hard to detect by eye
- Seasonal variation and exogenous variables can mask trends in a parameter.
- Viewers can “see what they want to see” sometimes



http://dnr.metrokc.gov/wlr/waterres/streams/northtrend.htm

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Statistical Trend Analysis Methods

Picking a statistic can be tricky- Review your data for the following characteristics:

- Normal Distribution
- Abrupt Changes
- Cycles
- Outliers
- Missing Values
- Censored Data
- Serial Correlation

Select a Statistic that is appropriate for the type of data set you have.

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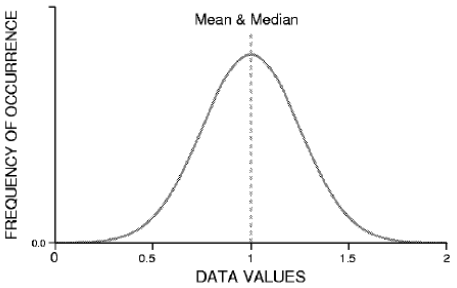
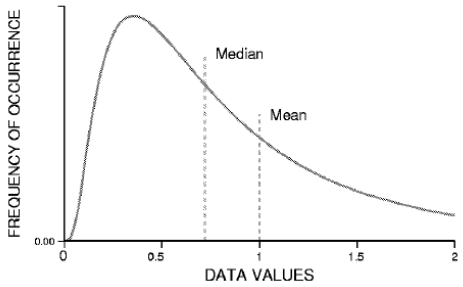
Statistical Trend Analysis Methods

Type of statistic depends on data characteristics- To test if an existing data set is "normally" distributed you may (a) plot a histogram of the results; or (b) conduct tests for normality like the Shapiro-Wilk W test, the Filliben's statistic, or the studentized rage test (EPA, 2000, p. 4-6).



Parametric- Statistics for **normally distributed** data. Includes regression of parameter against time or spatial measure, like river mile. Parametric statistics are rarely appropriate for environmental samples without massaging data. See the USGS guide by Helsel and Hirsch for descriptions of using regression.



Nonparametric- Statistics that are not as dependent on assumptions about data distribution. Generally the safer statistics to use, but are not as readily available. Test include the Kendall test for presence of consistent trend, Sen slope test for measure of magnitude of slope, and Wilcoxon-Mann-Whitney step trend analysis.

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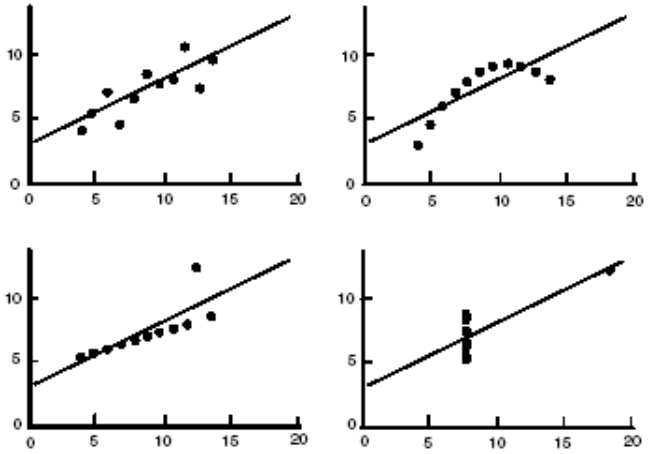
Things to watch out for with statistical analysis

- Verify and document that all assumptions have been tested and met. Failure to do so, may lead to misleading results
- The easiest test to do, OLS regression, is usually not appropriate.
- More robust, non-parametric tests like the seasonal Kendall test are not readily available and can be computationally demanding.
- Finding no trend may only mean your data was insufficient to find the trend.
- Infrequent use of statistical methods often requires relearning fairly complicated procedures every year. If you do use a statistical package, keep excellent notes of what you do and why.



Four OLS regression charts with the same R^2, slope, and intercept*

*** From Helsel D.R. and R.M. Hirsch. 1991 Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the USGS Book 4. Chapter A3 p.245**

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Statistical Methods for Determining Trends

Non-Parametric, distribution independent methods

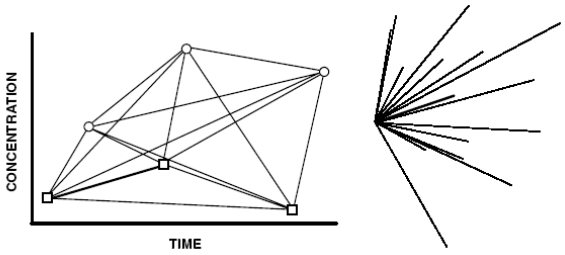


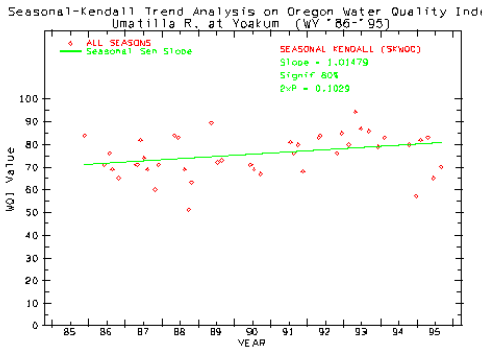
Figure 10.1 A. All possible pairwise slopes between six data points.
B. All possible slopes rearranged to meet at a common origin
The thick line is the median of the 15 slopes.

*

← **Sen Slope or Kendall –Theil:** Compares the change in value vs time (slope) for each point on the chart and takes the median slope as the a summary statistic describing the magnitude of the trend.

Seasonal Kendall Test: Compares the relationship between points at separate time periods or seasons and determines if there is a trend. Highly robust and relatively powerful, recommended method for most water quality trend monitoring (Aroner, 2001).

→



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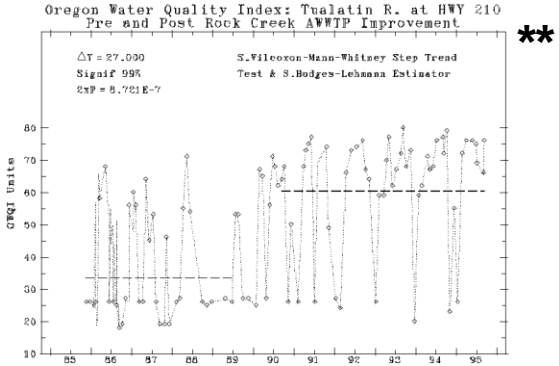

**

← **Wilcoxon-Mann-Whitney Step Trend:** Seasonal or non-seasonal test to identify changes that take place at a distinct time. Combine with Hodges-Lehmann estimator to determine magnitude of step (Aroner, 2001)

*** From Helsel D.R. and R.M. Hirsch. 1991 Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the USGS Book 4. Chapter A3. p. 266**

**** Created with WQHydro Water Quality/Hydrology Graphics/Analysis System Software**

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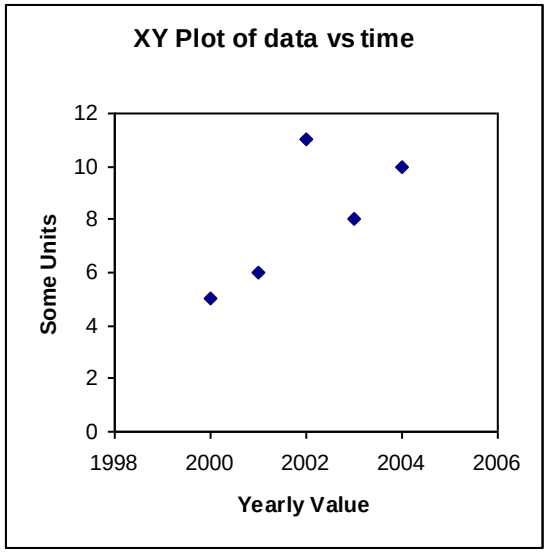
How to Calculate Non-Parametric Statistics

Kendall Test to determine if a significant trend exists see EPA guide QA/G-9 pages 4-16 to 4-20



Year	Units
2000	5
2001	6
2002	11
2003	8
2004	10

Sen Slope or Kendall-Theil line to measure the magnitude of the trend see USGS Statistical Methods for Water Resources pages 266 - 267

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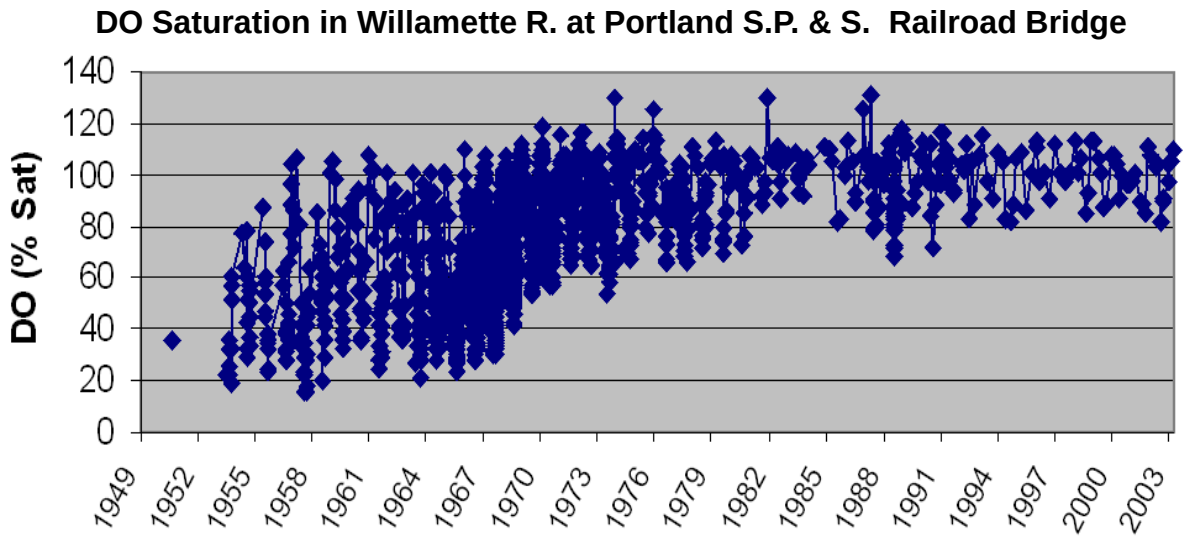
What type of trend analysis is right for you to use?

What would you need for temperature trend monitoring? Is there an exogenous variable?

What about changes in other water quality parameters?

How could changes in monitoring schedule impact trends?

Example Bob has been monitoring DO in the morning at a site for 3 years. He adds 4 new sites to his route and now visits his old site in the afternoon every visit. Now samples are collected in the pm. What impact will this have on your ability to track trends? What could you do to correct the problem?



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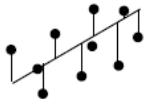
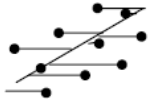
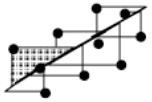
Statistical Methods for Determining Trends

Regressions

Regression methods draw a line as close to all the data as possible.

Use regressions only if you can satisfy the data requirements. Helsel and Hirsch (1991) give a good description of the steps needed to satisfy assumptions and data transformation tools to bring your data within the limits of the assumptions.

*

Method	Minimizes:	Slope	Scale Change	Rotation
OLS Y on X		$b_1 = r\frac{s_y}{s_x}$	invariant	changes
OLS X on Y		$b_1' = \frac{1}{r}\frac{s_y}{s_x}$	invariant	changes
LOC		$b_1'' = \text{sign}[r]\frac{s_y}{s_x}$	invariant	changes
LNS		$b = -A + \frac{\sqrt{r^2 + A^2}}{r}$ where $A = 0.5\left(\frac{s_x}{s_y} - \frac{s_y}{s_x}\right)$	changes	invariant

*** From Helsel D.R. and R.M. Hirsch. 1991 Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the USGS Book 4. Chapter A3. p. 279**

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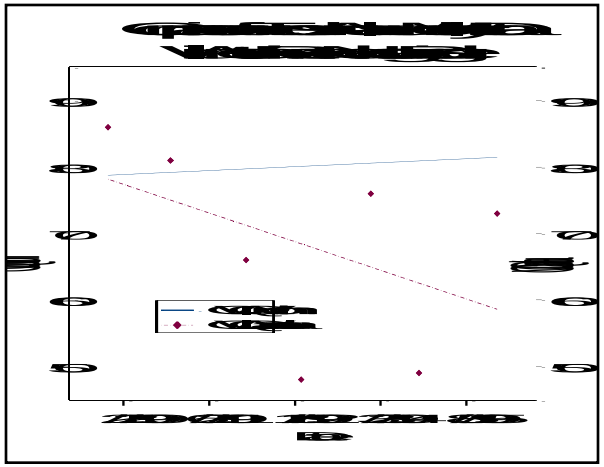
Trend Monitoring...

The devil is in the details

Issues to consider when doing trend monitoring[1]

- **Consistent data quality-** Trend monitoring assumes that the same or equivalent methods and protocols are used for all the monitoring.
- **Time frame & number of samples-** 5 years of monthly data for WQ monotonic trend analysis (Lettenmaier et.al., 1982); for step trends, at least 2 years of monthly data before and after management change (Hirsch, 1982). (Statistic should be pre-defined in QAPP to make sure you have everything you need.)
- **Seasonality-** Parameters that vary naturally in different seasons of the year require special statistics or "de-seasonalization".
- **Type of data distribution (Is your data Normal?)*-** If your data is not normally distributed, you need to use a non-parametric statistical test.



1. Based on Aroner, E.R. 2000 WQHYDRO Environmental Data Analysis Technical App. p. 146

* Issue most applicable to statistical analysis

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Issues to consider when doing trend monitoring[1]

- **Similar variance across data set*-** Statistical methods require consistent sampling frequency (i.e., constant number of samples per period, equally spaced across the period) to minimize variance.
- **Minimal missing observations*-** Missing observations may invalidate some tests by changing variance.
- **Outliers-** Statistical tests designed for normal distributions are very sensitive to outliers
- **Serial correlation*-** Each result must be independent of other samples (across time and space).
- **Exogenous variables-** Parameters like conductivity and pH can be greatly impacted by exogenous parameters, like stream discharge or time of day, respectively. Changes in these exogenous variables may impact trends you measure in the parameter of interest. To remove these impacts develop a regression between the two variables. Calculate the residuals (the difference between the measured value and value predicted by the regression) and then run the trend analysis on the residuals.
- **Differences in detection limits*-** Changing detection limits might fool the statistic into thinking concentrations are decreasing (make sure you have a way to statistically handle changing detection limits}.

1. Based on Aroner, E.R. 2000 WQHYDRO Environmental Data Analysis Technical Appendix p. 146

* Issue most applicable to statistical analysis

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References

Aroner, E.R., 2000. WQHYDRO Environmental Data Analysis Technical Appendix.

Berk K.N., and P. Carey, 2000. *Data Analysis with Microsoft® Excel.* Duxbury Press, Pacific Grove, CA. pp. 155-162.

EPA, 2000 (EPA/600/R-96/084). Guidance for Data Quality Assessment: Practical methods for Data Analysis, EPA QA/G-9, QA00 Update

Helsel D.R. and R.M. Hirsh. 1991 Statistical Methods in Water Resources. *Techniques of Water-Resources Investigations of the USGS* Book 4. Chapter A3

Hirsch R.M., J.R. Slack and R.A. Smith, 1982. Techniques of Trend Analysis for Monthly Water Quality Data. *Water Resources Research,* Vol. 18 (1) pp. 107-121 February.

Hirsch R.M., R.B. Alexander, and R.A. Smith 1991. Selection of Methods for the Detection and Estimation of Trends in Water Quality. *Water Resources Research,* Vol. 27(5), pp. 803-813 May.

Lettenmaier, D.P., L.L. Conquest and J.P. Hughes, 1982. Routine Streams and Rivers Water Quality Trend Monitoring Review. C.W. Harris Hydraulics Laboratory, Technical Report No. 75, Seattle, WA.