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)
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.
Trend Analysis and Presentation

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.)?
Trend Analysis and Presentation

Visual methods for displaying trends

Average 7 day max by River Mile

10 12 14 16 18 20 22 24

0 5 10 15 20 25 30 35 40

River Mile

Average 7 day max for July 2000

20.9 20.6 20.2 18.9 21.5 15.9 18.6 18.9 18.2 20.6 20.6

Time/area series scatter plot

Summer 2000 E.coli Concentrations

Concentration (MPN/100mL)

Month

Site Number

Time series smoothed scatter plot*

LN OF SAND CONC

LN OF STREAMFLOW

12 14 16 18 20

7 8 9 10 11 12

Summer (June - Sept.) pH Summary 1995 to 2003

pH (S.U.)


Year

Bar Graphs

Time/area series box plot of statistics

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
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.
Trend Analysis and Presentation

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 range 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.
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.

Trend Analysis and Presentation

Statistical Methods for Determining Trends
Non-Parametric, distribution independent methods

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).

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)

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

<table>
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<tr>
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<td>2003</td>
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</tr>
<tr>
<td>2004</td>
<td>10</td>
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</table>

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

<table>
<thead>
<tr>
<th>Method</th>
<th>Minimizes:</th>
<th>Slope</th>
<th>Scale Change</th>
<th>Rotation</th>
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<tbody>
<tr>
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<td></td>
<td>( b_1 = \frac{s_x}{s_y} )</td>
<td>invariant</td>
<td>changes</td>
</tr>
<tr>
<td>OLS X on Y</td>
<td></td>
<td>( b_1' = \frac{1}{r s_x} )</td>
<td>invariant</td>
<td>changes</td>
</tr>
<tr>
<td>LOC</td>
<td></td>
<td>( b_1'' = \text{sign}(r) \frac{s_y}{s_x} )</td>
<td>invariant</td>
<td>changes</td>
</tr>
<tr>
<td>LNS</td>
<td></td>
<td>( b = -A + \frac{\sqrt{A^2 + r^2}}{r} )</td>
<td>changes</td>
<td>invariant</td>
</tr>
</tbody>
</table>

where \( A = \frac{s_x}{s_y} \)

\[ 0.5 \left( \frac{s_x}{s_y} - \frac{s_y}{s_x} \right) \]
Trend Monitoring...

*The devil is in the details*

Issues to consider when doing trend monitoring¹

- **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 Issue most applicable to statistical analysis
Issues to consider when doing trend monitoring

• **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).

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

* Issue most applicable to statistical analysis
References

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