Day 5: Statistical Analyses of Stormwater Data

Mostly excerpted from:
Burton, G.A. Jr., and R. Pitt. *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers*. CRC Press, Inc., Boca Raton, FL . 2002. 911 pages
Freely available at:
http://unix.eng.ua.edu/~rpitt/Publications/BooksandReports/Stormwater%20Effects%20Handbook%20by%20%20Burton%20and%20Pitt%20book/MainEDFS_Book.html

Plus excerpts from various research projects

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Selection of Statistical Tests Based on Probability Distribution and Other Characteristics

Comparing Paired Observations of Data

Parametric tests (data require normality and equal variance)
- Paired Student's *t*-test (more power than non-parametric tests but only if data requirements are met)

Non-parametric tests
- Sign test (no data distribution requirements, some missing data accommodated)
- Friedman's test (can accommodate a moderate number of "non-detectable" values, but no missing values are allowed
- Wilcoxon signed rank test (more power than sign test, but requires symmetrical data distributions)

Comparing Two Independent Groups of Data

Parametric tests (data require normality and equal variance)
- Independent Student's *t*-test (more power than non-parametric tests, but only if data distribution requirements are met)

Non-parametric tests
- Mann-Whitney rank sum test (probability distributions of the two data sets must be the same and have the same variances, but do not have to be symmetrical; a moderate number of "non-detectable" values can be accommodated)

Comparing many groups (use multiple comparison tests, such as the Bonferroni *t*-test, to identify which groups are different from the others if the group test results are significant)

Parametric tests (data require normality and equal variance)
- One-way ANOVA for single factor, but for >2 "locations" (if 2 "locations, use Student's *t*-test)
- Two-way ANOVA for two factors simultaneously at multiple "locations"
- Three-way ANOVA for three factors simultaneously at multiple "locations"
- One factor repeated measures ANOVA (same as paired *t* test, except that there can be multiple treatments on the same group)
- Two factor repeated measures ANOVA (can be multiple treatments on two groups)

Many Groups (cont.)

Non-parametric tests:

- Kurskal-Wallis ANOVA on ranks (use when samples are from non-normal populations or the samples do not have equal variances).

- Friedman repeated measures ANOVA on ranks (use when paired observations are available in many groups).

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Many Groups (cont.)

Nominal observations of frequencies (used when counts are recorded in contingency tables)

- Chi-square (X^2) test (use if more than two groups or categories, or if the number of observations per cell in a 2X2 table are > 5).

- Fisher Exact test (use when the expected number of observations is <5 in any cell of a 2X2 table).

- McNamar's test (use for a "paired" contingency table, such as when the same individual or site is examined both before and after treatment)

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Example 1-way ANOVA

- Is at least one member of a group significantly different from the other members?
- Complement analysis with group box-whisker plot
- This doesn't identify which one(s) is(are) different.
- If a significant member, should be able to recognize from box-whisker plot and with Bonferroni T-test (multiple pair-wise comparisons).

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1-way ANOVA

Site A	Site B	Site C	Site D	Site E
78	43	153	14	12
45	79	87	53	9
63	54	245	42	34
54		432	64	14
24		43	23	
		164		

Are any of these sites different from the others?

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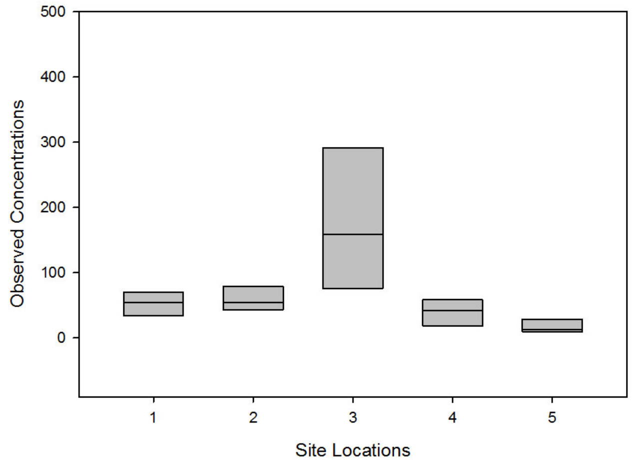
One-Way ANOVA Example Box and Whisker Plot



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ANOVA Single Factor (using Excel)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	5	264	52.8	407.7
Column 2	3	176	58.66667	340.3333
Column 3	6	1124	187.3333	19161.87
Column 4	5	196	39.2	427.7
Column 5	4	69	17.25	128.9167

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ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	98255	4	24564	4.41	0.0116	2.9277
Within Groups	100218	18	5567			
Total	198473	22				

With a p = 0.012, at least one site is significantly different from the others. Observing the box and whisker plot, it is likely that sites A, B, and D form one group, while C and E are likely two other groups.

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Example 2-way ANOVA

- Want to investigate the differences between different data strata. In this example, both rain depth and season are being investigated together.
- Are the variations between groups more important than the variations within the groups?
- What about interactions between different variables?
- ANOVA requires normally distributed data. In most stormwater cases, log-transformed values need to be used.

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The rain group factor and the season factor are both highly significant. The prior 2-way ANOVA found that the interaction term was not significant; the ANOVA was therefore re-run without that term.

262 total cases

ANOVA

Analysis of Variance For **LTSS**
No Selector

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	631.103	631.103	3993.4	≤ 0.0001
Pgp	3	6.29608	2.09869	13.28	≤ 0.0001
Ssn	3	4.63302	1.54434	9.772	≤ 0.0001
Error	255	40.2994	0.158037		
Total	261	50.5397			

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Coefficients

Coefficients of: LTSS on Pgp

Level of Pgp	Coefficient	std. err.	t Ratio	prob
1	-0.3302	0.06357	-5.195	≤ 0.0001
2	-0.003782	0.04182	-0.09044	0.9280
3	0.1966	0.04005	4.91	≤ 0.0001
4	0.1374	0.05064	2.712	0.0071

Expected Cell Means

Expected Cell Means of: LTSS on Pgp

Level of Pgp	Expected Cell Mean	Cell Count
1	1.165	25
2	1.491	86
3	1.692	104
4	1.632	47

Scheffe Post Hoc Tests

The first, third, and fourth rain categories are significant.

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Coefficients

Coefficients of: LTSS on Ssn

Level of Ssn	Coefficient	std. err.	t Ratio	prob
FA	-0.1701	0.04282	-3.974	≤ 0.0001
SP	0.07531	0.04581	1.644	0.1015
SU	0.178	0.04421	4.026	≤ 0.0001
WI	-0.08311	0.0405	-2.052	0.0412

Expected Cell Means

Expected Cell Means of: LTSS on Ssn

Level of Ssn	Expected Cell Mean	Cell Count
FA	1.325	67
SP	1.57	54
SU	1.673	60
WI	1.412	81

Scheffe Post Hoc Tests

Only Fall and Summer are significant (maybe winter also). Therefore, lots of potential subgroups.

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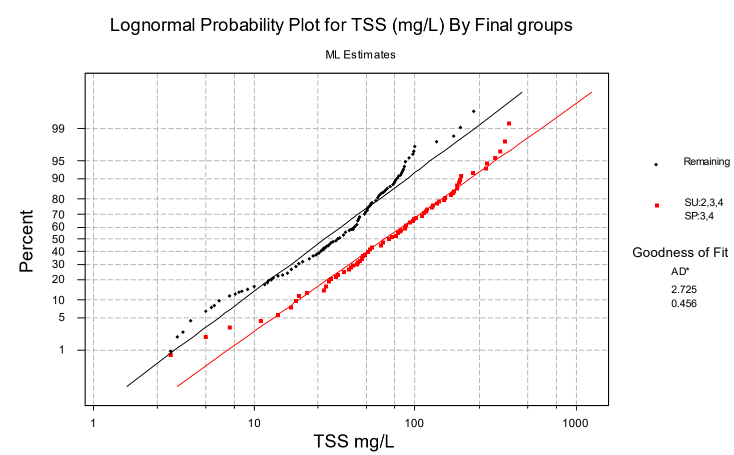
Further analyses resulted in only two main groups of the data, as show on this probability plot:



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Model Building

- If you can't see it, it is likely not there…. (or certainly not very important, even if you have lots of data that make statistically significant results more likely than the usual handful of available data)

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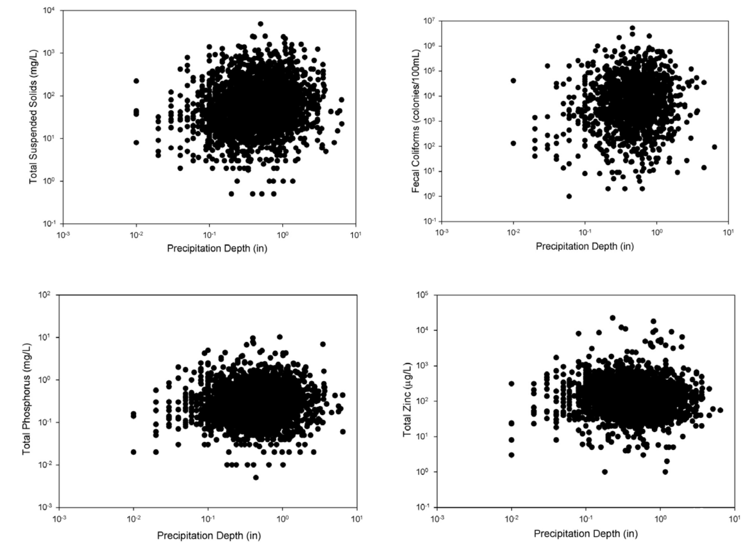
Plots of concentrations vs. rain depth typically show random patterns.



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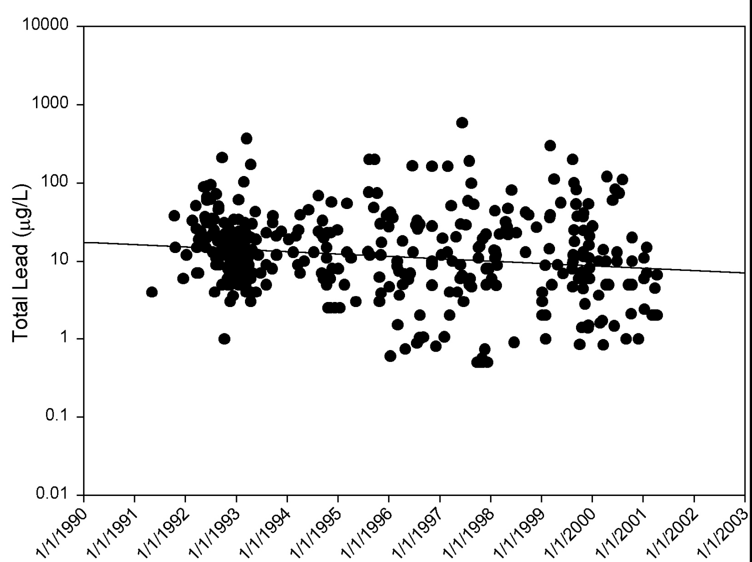

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Model building/equation fitting (these are parametric tests and the data must satisfy various assumptions regarding behavior of the residuals)

Linear equation fitting (statistically-based models)

- Simple linear regression (y=b0+b1x, with a single independent variable, the slope term, and an intercept. It is possible to simplify even further if the intercept term is not significant).

- Multiple linear regression The equation is a multi-dimensional plane describing the data).

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- Stepwise regression (a method generally used with multiple linear regression to assist in identifying the significant terms to use in the model.)

- Polynomial regression ($y=b0+b1x^1+b2x^2+b3x^3+\ldots+bkx^k$, having one independent variable describing a curve through the data).

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Non-linear equation fitting (generally developed from theoretical considerations, usually through the solution of a partial differential equation)

- Nonlinear regression (a nonlinear equation in the form: $y=b^x$, where x is the independent variable. Solved by iteration to minimize the residual sum of squares: Newton-Rast).

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Model Building Steps

1) Re-examine the hypothesis of cause and effect (an original component of the experimental design previously conducted and was the basis for the selected sampling activities).

2) Prepare preliminary examinations of the data, as described previously (most significantly, prepare scatter plots and grouped box/whisker plots).

3) Conduct comparison tests to identify significant groupings of data. As an example, if seasonal factors are significant, then cause and effect may vary for different times of the year.

4) Conduct correlation matrix analyses to identify simple relationships between parameters. Again, if significant groupings were identified, the data should be separated into these groupings for separate analyses, in addition to an overall analysis.

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Modeling Building (cont.)

5) Further examine complex inter-relationships between parameters by possibly using combinations of hierarchical cluster analyses, principal component analyses (PCA), and factor analyses.

6) Compare the apparent relationships observed with the hypothesized relationships and with information from the literature. Potential theoretical relationships should be emphasized.

7) Develop initial models containing the significant factors affecting the parameter outcomes. Simple apparent relationships between dependent and independent parameters should lead to reasonably simple models, while complex relationships will likely require further work and more complex models.

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Initial Analyses and Plots to Assist in Model Building

- Simple Correlation Matrices
- Hierarchical Cluster Analyses
- Principal Component Analyses (PCA) and Factor Analyses

Simple Data Associations

- Pearson Correlation (residuals, the distances of the data points from the regression line, must be normally distributed. Calculates correlation coefficients between all possible data variables. Must be supplemented with scatterplots, or scatter plot matrix, to illustrate these correlations. Also identifies redundant independent variables for simplifying models).

- Spearman Rank Order Correlation (a non-parametric equivalent to the Pearson test).

Pearson Correlations

Emery (Industrial)

	RAINTOT	RAINDUR	AVEINT	PEAKINT	DRYPER	RUNTOT	RUNDUR	AVEDIS	PEAKDIS	LAG
RAINTOT	1.000									
RAINDUR	0.533	1.000								
AVEINT	0.138	-0.387	1.000							
PEAKINT	0.512	-0.039	0.675	1.000						
DRYPER	0.169	0.273	-0.096	-0.132	1.000					
RUNTOT	<u>0.906</u>	0.562	0.007	0.405	0.075	1.000				
RUNDUR	0.501	<u>0.965</u>	-0.348	0.035	0.184	0.556	1.000			
AVEDIS	0.709	-0.013	0.480	0.654	-0.095	0.680	-0.026	1.000		
PEAKDIS	0.729	0.129	0.372	<u>0.748</u>	0.041	0.699	0.150	<u>0.849</u>	1.000	
LAG	0.135	0.220	-0.292	-0.217	0.052	0.205	0.134	0.098	0.107	1.000

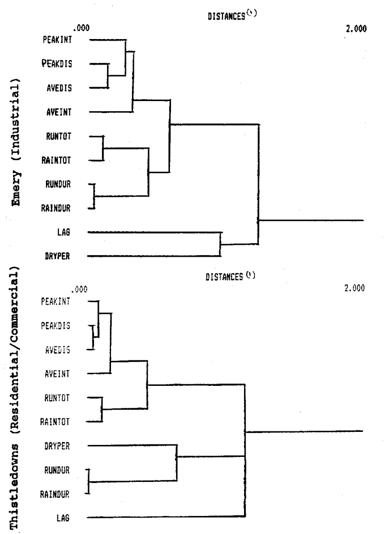
Thistledowns (Residential/Commercial)

	RAINTOT	RAINDUR	AVEINT	PEAKINT	DRYPER	RUNTOT	RUNDUR	AVEDIS	PEAKDIS	LAG
RAINTOT	1.000									
RAINDUR	0.553	1.000								
AVEINT	0.321	-0.295	1.000							
PEAKINT	0.564	-0.104	<u>0.827</u>	1.000						
DRYPER	0.281	0.308	-0.190	-0.122	1.000					
RUNTOT	<u>0.903</u>	0.448	0.187	0.551	0.283	1.000				
RUNDUR	0.508	<u>0.989</u>	-0.322	-0.148	0.337	0.402	1.000			
AVEDIS	0.398	-0.178	0.593	0.817	-0.037	0.585	-0.227	1.000		
PEAKDIS	0.600	-0.051	0.659	<u>0.917</u>	0.009	0.702	-0.106	<u>0.946</u>	1.00	
LAG	-0.192	-0.037	-0.114	-0.202	-0.122	-0.184	-0.094	-0.138	-0.173	1.000

Complex Data Associations (typically only available in advanced software packages; also in MiniTab)

- Hierarchical Cluster Analyses (graphical presentation of simple and complex inter-relationships. Data should be standardized to reduce scaling influence. Supplements simple correlation analyses).

- Principal Component Analyses (identifies groupings of parameters by factors so that variables within each factor are more highly correlated with variables in that factor than with variables in other factors. Useful to identify similar sites or parameters).



(1) Distance metric is 1-Pearson correlation coefficient (normalized) and the linkage method is nearest neighbor

Dendogram (tree) from a cluster analysis of data previously shown on Pearson Correlation matrix. Shows similar urban hydrology "data structure" for these two very different sites.

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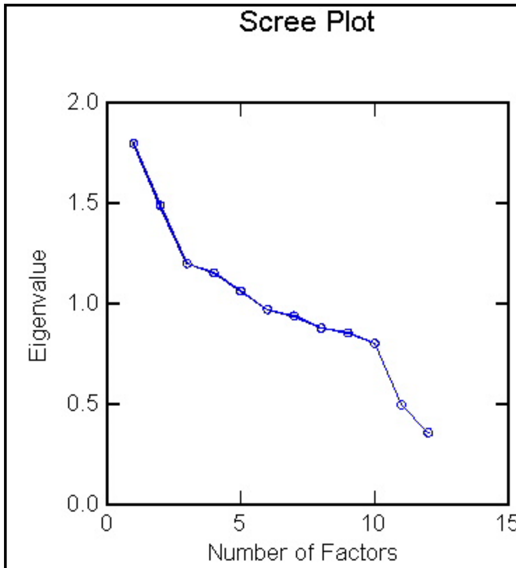

Principal Component Analysis (PCA) is a sophisticated procedure where information is sorted to determine the constituents needed to explain the variance of the data. This plot indicates how much of the data variability occurs in each combination of principal components.

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Regression Analyses

1) Formulate the objectives of the curve-fitting exercise (a subset of the experimental design previously conducted).

2) Prepare preliminary examinations of the data, as described previously (most significantly, prepare scatterplots and probability plots of the data, plus correlation evaluations to examine independence between multiple parameters that may be included in the models)

3) Identify candidate and alternative models from the literature that have been successfully applied for similar problems (part of the previously conducted experimental design activities in order to identify which parameters to measure, or to modify or control).

4) Evaluate the data to ensure that regression is applicable and make suitable data transformations.

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Regression (cont.)

5) Apply regression procedures to the selected alternative models.

6) Evaluate the regression results by examining the coefficient of determination (R^2) and the results of the analysis of variance of the model (standard error analyses and p values for individual equation parameters and overall model).

7) Conduct an analysis of the residuals (as described below).

8) Evaluate the results and select the most appropriate model(s).

9) If not satisfied, it may be necessary to examine alternative models, especially based on data patterns (through cluster analyses and principal component analyses) and re-examinations and modification of the theoretical basis of existing models. Statistical based models can be developed using step-wise regression routines.

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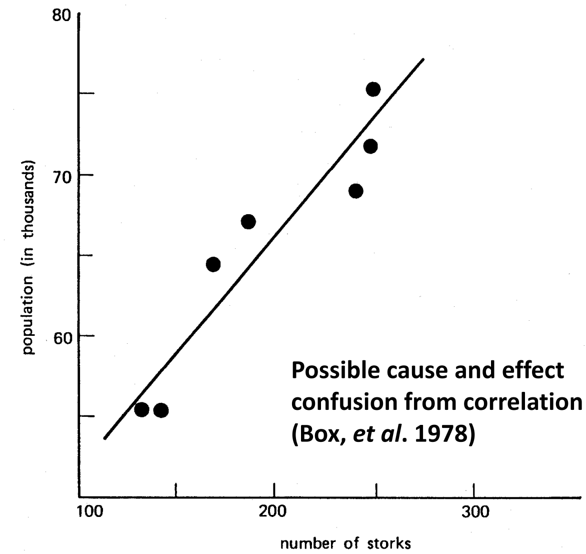

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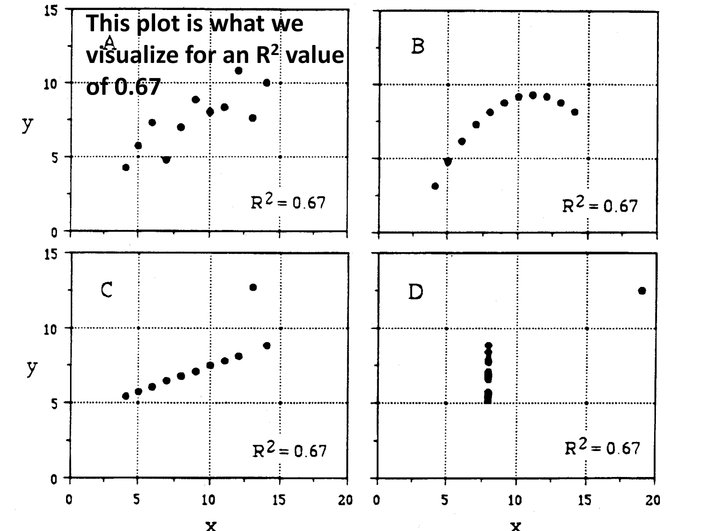

The use of the index of determination (R^2) alone can be misleading (data from Anscombe, in Draper and Smith 1981)

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Regression Example with ANOVA

- Performance of TSS control of the Multi-Chamber Treatment Train (MCTT)
- Examining overall treatment effects with regression and associated plots with ANOVA

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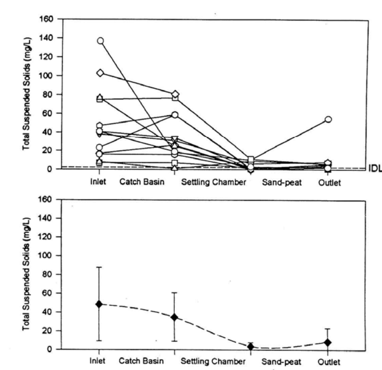
MCTT PERFORMANCE DATA - UNFILTERED SAMPLES
Total Suspended Solids



	Catch Basin Chamber	Settling Chamber	Sand-peat Chamber	MCTT Overall
Concentration Difference				
1-sided P Value	0.1543	0.0010	-0.1191	0.0002
Min. Percent Reduction	-157	-800	-500	25
Max. Percent Reduction	88	100	45	100
Median Percent Reduction	17	91	-400	83
Std. Dev. of Percent Reduction	65	257	240	22
COV of Percent Reduction	7.4	19	-1.5	0.28

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Total Suspended Solids mg/L

STORM	INLET	OUTLET
1	137	55
2	7	3
3	8	6
4	38	8
5	17	6
6	16	4
7	23	<2.5
8	75	6
9	77	<2.5
10	41	5
11	103	8
12	41	<2.5

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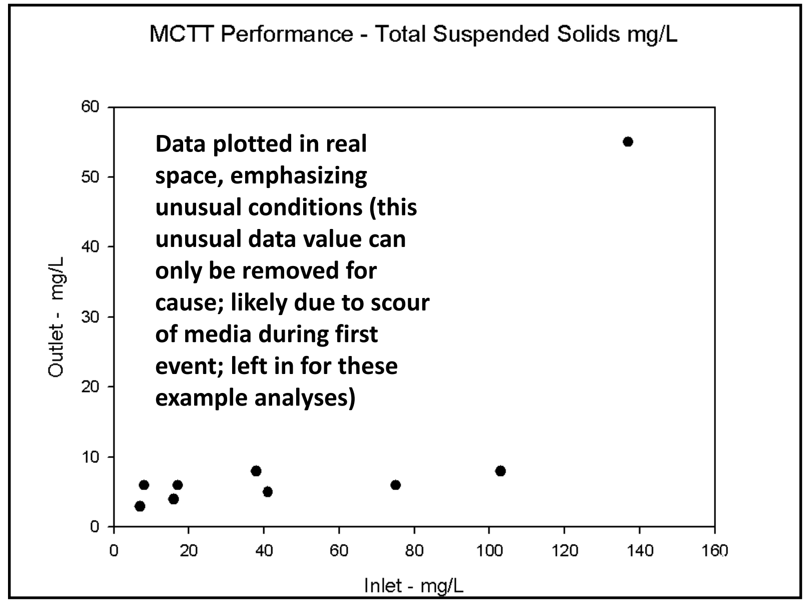

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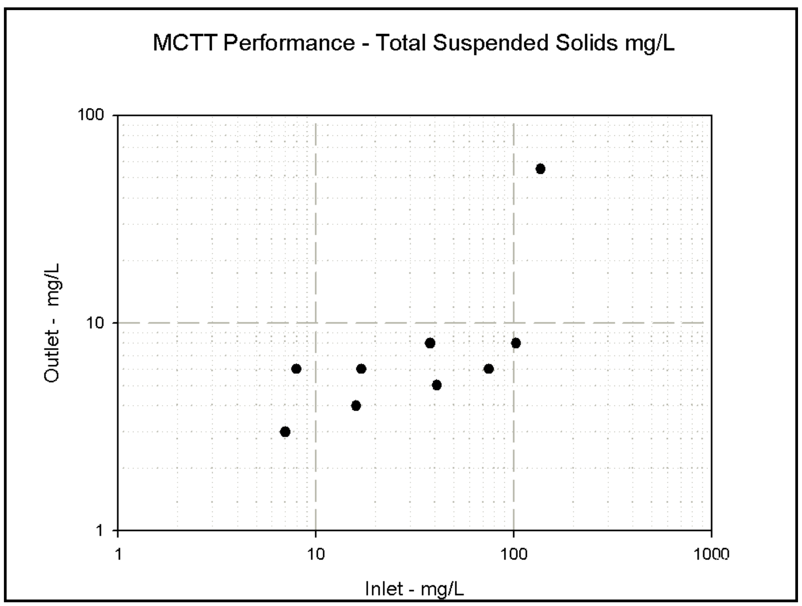

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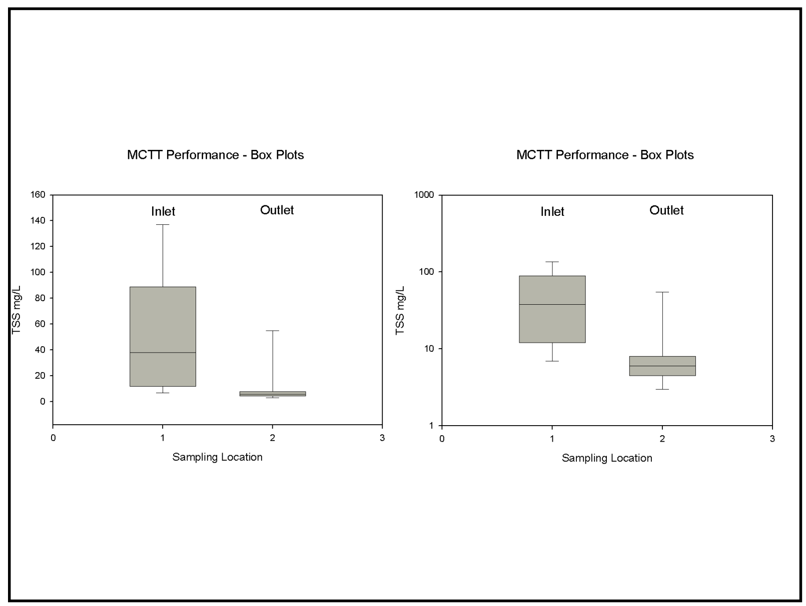

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	Influent	Effluent
N	12	12
Detected Observations	12	9
Mean	48.6	11.22
Median	39.5	5.5
StDev	41.1	16.5
SE Mean	11.9	5.5
Minimum	7	3
Maximum	137	55
Q1	16.3	2.7
Q3	76.5	7

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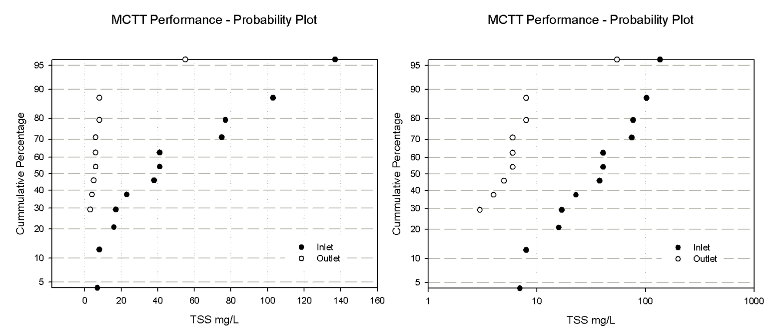

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```
Dependent variable is:   LOGOUTLET
No Selector
R squared = 15.6%     R squared (adjusted) = 7.2%
s =  0.4332  with  12 - 2 = 10  degrees of freedom

Source      Sum of Squares   df    Mean Square    F-ratio
Regression  0.347854          1       0.347854     1.85
Residual    1.87625          10       0.187625

Variable    Coefficient    s.e. of Coeff    t-ratio    prob
Constant    0.0333252      0.4876           0.0683     0.9469
LOGINLET    0.421692       0.3097           1.36       0.2032
```

Lousy overall R^2 and insignificant P values for both constant and slope terms. Re-ran without intercept term (forcing the regression through the zero), but slope term was still not significant. Therefore, no regression relationship and the effluent is a constant value (with some uncertainty) [and with one unusual value].

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Residual Analyses of Regression Models

- the residuals must be independent
- the residuals have zero mean
- the residuals have a constant variance (S^2)
- the residuals have a normal distribution (required for making F-tests)

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Plots to Check Residuals

- Check for normality of the residuals (preferably by constructing a probability plot and having the residuals form a straight line,
- plot the residuals against the predicted values,
- plot the residuals against the predictor variables, and
- plot the residuals against time in the order the measurements were made.

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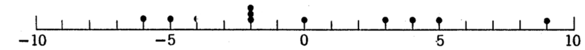
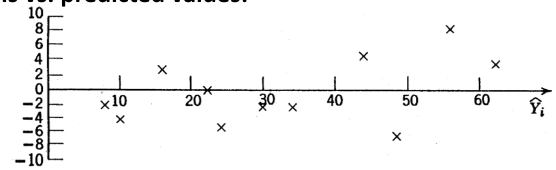
Histogram of residuals (and/or probability plot):

(a)



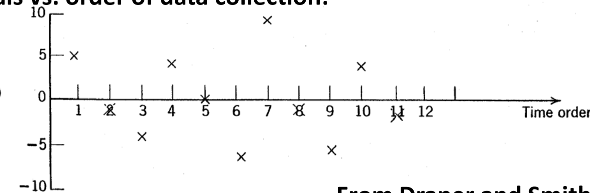
Residuals vs. predicted values:

(b)



Residuals vs. order of data collection:

(c)



From Draper and Smith, 1981

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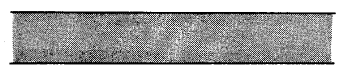
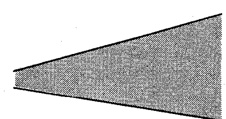
Desired pattern (random band of residuals):

(a)



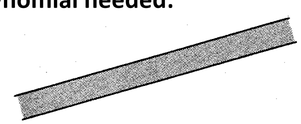
Fanning out of residuals indicated need for log transformation:

(b)



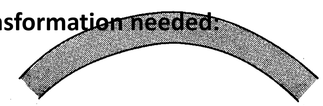
Slope implies a higher level of polynomial needed:

(c)



Curve indicates a data squared transformation needed:

(d)



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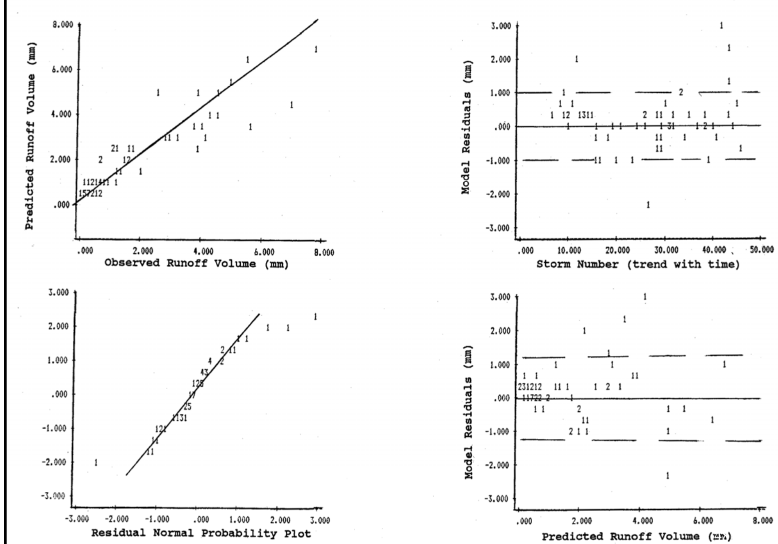

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Analyses for Data Trends

- Graphical methods (simple plots of concentrations versus time of data collection).

- Regression methods (perform a least-squares linear regression on the data plot and examine ANOVA for the regression to determine if the slope term is significant. Can be misleading due to cyclic data, correlated data, and data that are not normally distributed).

- Mann-Kendall test (a nonparametric test that can handle missing data and trends at multiple stations. Short-term cycles and other data relationships affect this test and must be corrected).

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Data Trends (cont.)

- Sen's estimator of slope (a nonparametric test based on ranks closely related to the Mann- Kendall test. It is not sensitive to extreme values and can tolerate missing data).

- Seasonal Kendall test (preferred over regression methods if the data are skewed, serially correlated, or cyclic. Can be used for data sets having missing values, tied values, censored values, or single or multiple data observations in each time period. Data correlations and dependence also affect this test and must be considered in the analysis).

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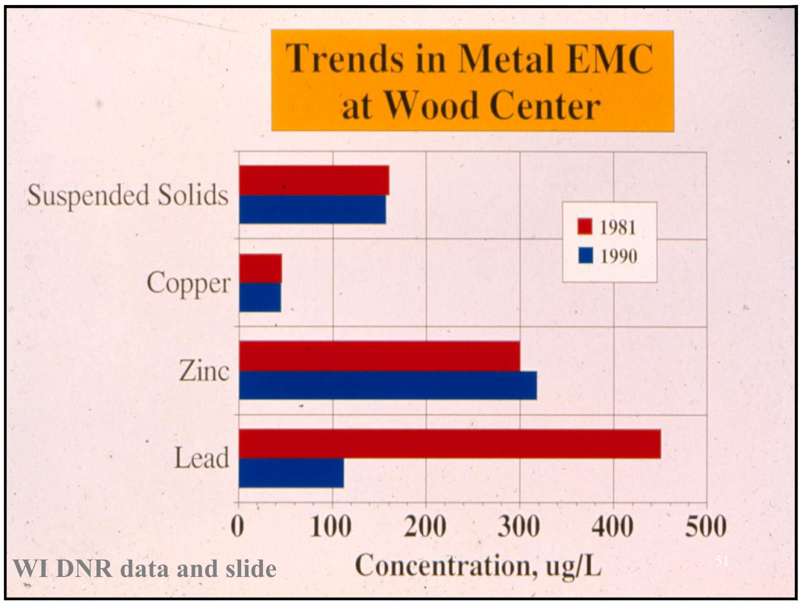

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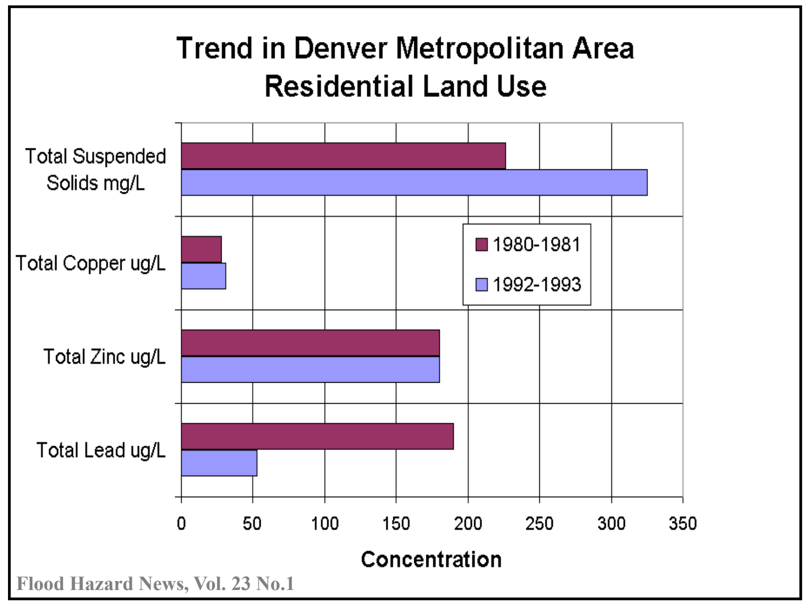

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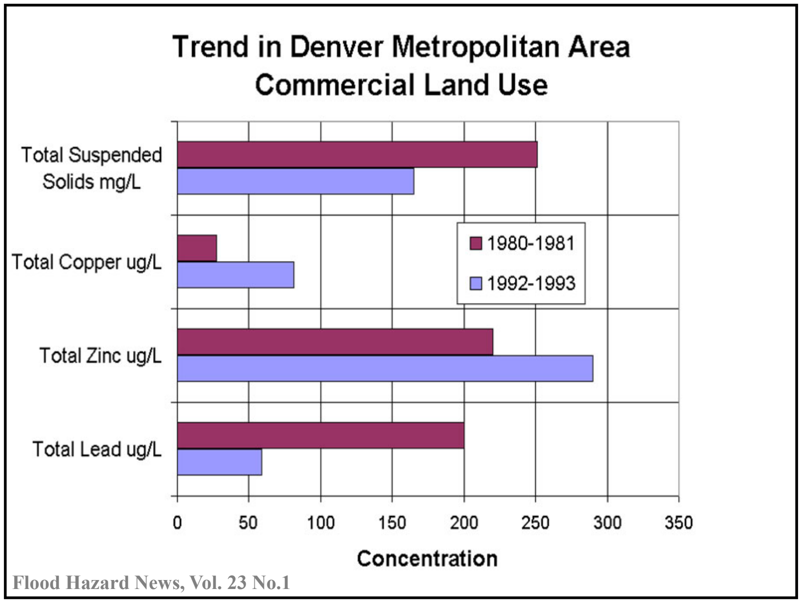

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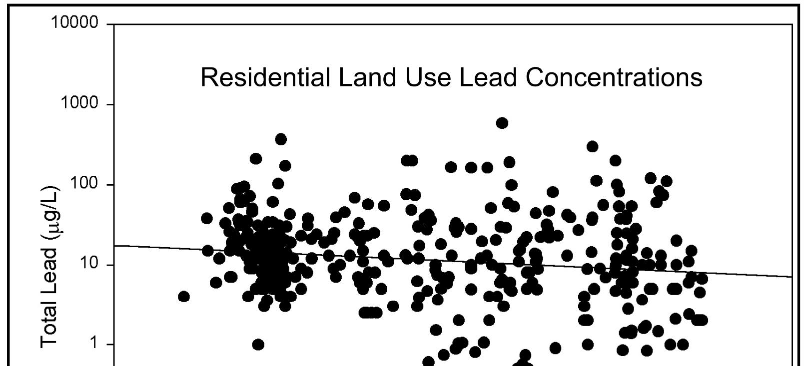

Concentration plots vs. time indicate possible trends. Lead has historically dropped significantly from the earliest stormwater studies to the present due to increased use of unleaded gasoline (simple regression trend line shown).

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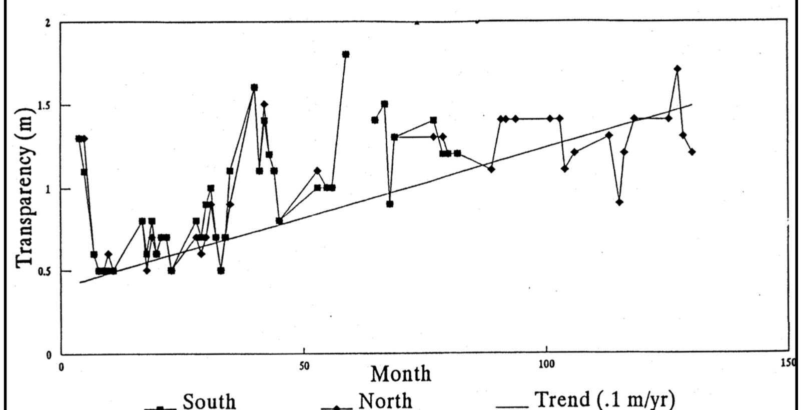

Secchi disk trends by season and year in Lake Rönningesjön, Sweden (m), showing initial steep improvement then leveling off (Pitt 1995)

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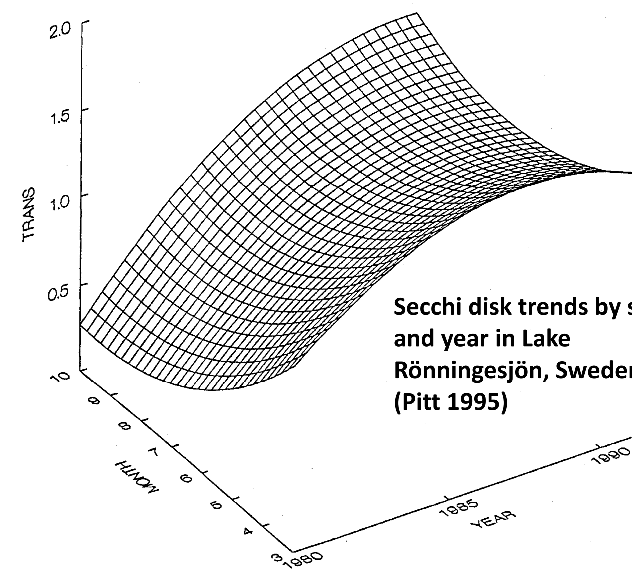

Secchi disk trends by season and year in Lake Rönningesjön, Sweden (m) (Pitt 1995)

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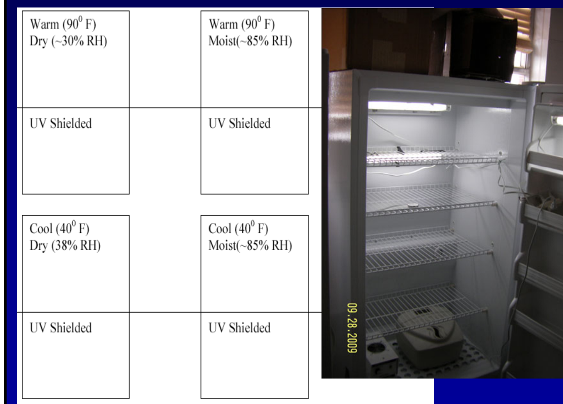
Model Building Example: Complex Modeling of Bacteria Survival Data

- Factorial experiments
- Multi-point trend analyses

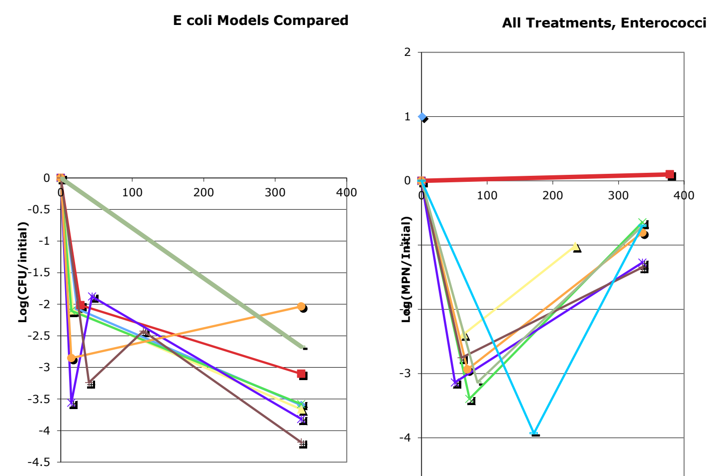
2^3 Factorial Experiment (temperature, UV light, and humidity)



Used 4 large incubators separated into compartments for test conditions. Used dog feces slurry on concrete blocks. Later experiments added nutrients to experimental design for survival in soil.

Individual Treatments Modeled by Segmented Regression with Unknown Breakpoints

- MLE=Min SSE [Hudson'66]
- Unstationarity of MLE at T(obs) [Feder, 75]
- Grid-search method for edited and identified models [Lerman,'80)
- Sequential Search - sup(Ft) test [Bai and Perron,'98]
- Multiple linear regression (each segment) of environmental factors on rate constant k

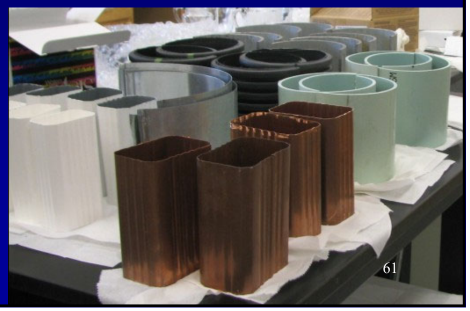


Warm, moist, and dark conditions resulted in slowest decrease in populations (and no initial breakpoint). Significant re-growth observed for all other conditions after several days.

Material Exposure Metal Release Rate Modeling Example

- Many clustered laboratory analyses, data analyses tools, and chemical modeling evaluations.

Many pipe and gutter materials (several plastics, concrete, aluminum, copper, and galvanized steel) examined over several month exposure periods in different pH and ionic strength water.



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Analysis Components for Model Development

1.
   - Time Series plots
     - To illustrate metal release with the exposure time.
2.
   - Spearman Correlation
     - To identify simple relationships between water quality parameters and contaminants
3.
   - Principal Component and Cluster Analysis
     - To evaluate complex associations between water quality parameters and contaminant releases and to identify groupings of samples with similar characteristics
4.
   - Full Factorial Analyses
     - To determine significant factors and their interactions on pollutant releases
5.
   - Empirical models were developed
     - to predict pollutant releases for different materials and uses, water types and exposure times.
6.
   - Chemical Modeling
     - To identify different chemical speciation and associations under different conditions and exposure periods

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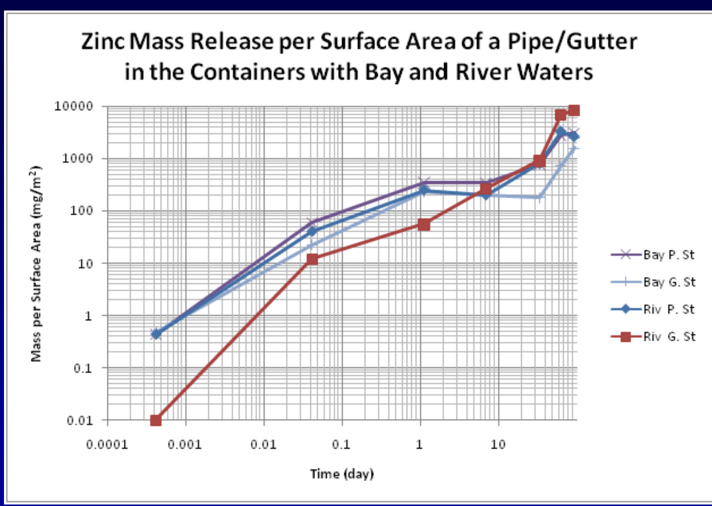

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Spearman Correlation Matrices

Performed:

- On the samples collected during controlled and natural pH tests.
- To determine the association between
  - Pb, Cu, and Zn concentrations
  - pH
  - Conductivity
  - Toxicity of the samples at 5, 15, 25, and 45 min of bacteria exposure
  - Time of material exposure to the experimental water
  - For each pipe and gutter material.

Example: Galvanized steel pipe during the natural pH tests

	Zn	pH	Cond.	Tox. 5min	Tox. 15min	Tox. 25min	Tox. 45min	Time
Pb	-0.175	0.413	-0.406	-0.508	-0.462	-0.462	-0.427	-0.496
Zn		-0.0699	0.000	0.853	0.846	0.846	0.860	0.905
pH			-0.902	-0.399	-0.399	-0.399	-0.413	-0.0283
Cond.				0.392	0.399	0.399	0.399	0.000
Tox. 5min					0.986	0.986	0.972	0.862
Tox. 15min						1.000	0.986	0.820
Tox. 25min							0.986	0.820
Tox. 45min								0.806

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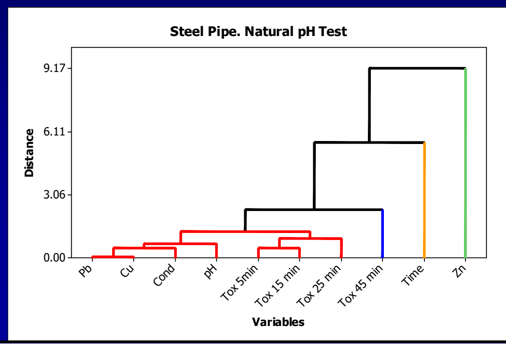
Cluster Analyses

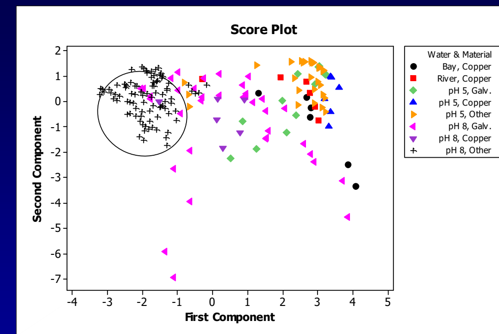
- For each pipe and gutter material using the data for buffered and natural pH tests.
- For the same data that were used to compute the correlation matrices
- To identify more complex relationships between the parameters.



Principal Components Analyses

- PCA was performed for all samples
- Score plot of the first two Principal Components shows groupings of samples having similar water quality characteristics.

- **1st PC (toxicity) accounts for 57% of the total variance in the data.**
- **2nd PC (Pb, Zn, and time) accounts for the next 12% of the total variance.**



Circled group:

- **Mostly concrete, PVC, HDPE, vinyl, and aluminum materials under controlled pH 8 conditions**
- **Low loadings of toxicity and metals**

Detailed Analyses Flow Chart

1
- Kruskal-Wallis Test
  - To combine data into similar populations before the following analyses

2
- Full Factorial Analyses
  - To identify significant effects of pH, salinity, and exposure time

3
- Based on Factorial Analyses results
  - Combine into groups

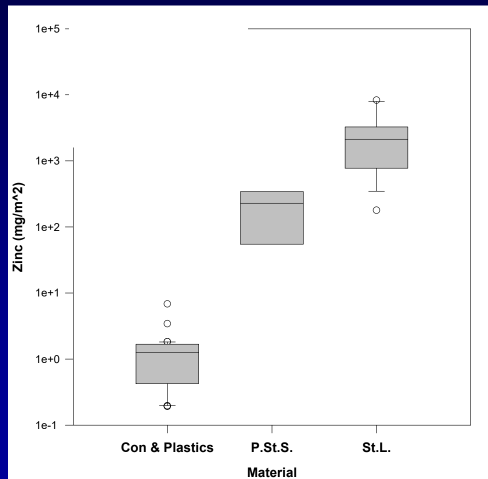
4
- Mann-Whitney Test
  - To compare the groups

Factorial Analyses for Material Exposures

- During the first testing stage to estimate the effects of
  - Exposure time (short and long)
  - pH value (5 and 8)
- During the second testing stage to evaluate the effects of
  - Exposure time (short and long)
  - Salinity (high and low)
- The factorial analyses were used to identify the significant factors and their interactions.
- Conducted several series of 2^2 and 2^3 Factorial Analyses to isolate missing conditions that were impossible to obtain (such as low pH and low conductivity).

Group Box Plot for zinc releases in mg/m² for various gutter and pipe materials immersed in bay and river waters.

- **Zinc releases were the largest from galvanized steel materials.**
- **As the exposure time increased, the zinc releases also increased.**
- **During long exposure times, there was no difference between galvanized pipe and gutter samples.**
- **The box plot for other materials represents all the data combined (for bay and river waters and for short and long exposure times).**



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Model Building with Linear Regression

Objective:

- To predict metal releases from the exposure times for all test conditions.
- The regression requirements (normally distributed, zero mean, constant variance, independent) revealed that first order polynomials can be fitted to the log of metal releases vs. log of time.

Conducted on:

- For different pipe and gutter materials under controlled and natural pH conditions.
- Metals: Cu, Zn, Pb

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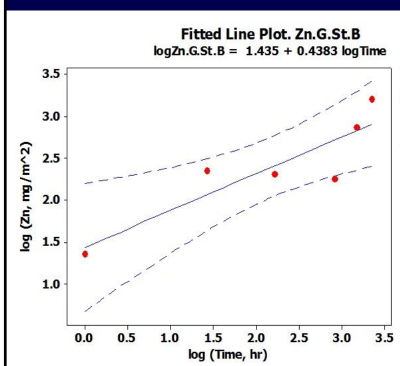
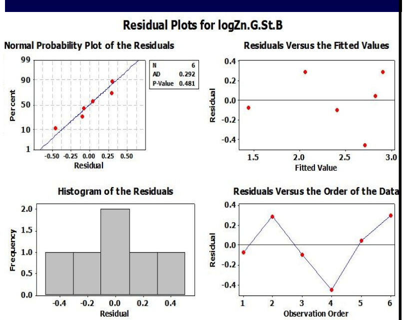
Zinc releases from galv. steel gutter immersed in bay water.





- ANOVA analyses tested the significance of the slope and intercept terms and the overall model. Residual analyses were all acceptable (considering the few data).

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Model for Galv. Steel Pipe under Natural pH Conditions

- **Quantifying the expected contaminant releases**

Constituent	Galvanized Steel Pipe. Natural pH Conditions				p-value
Pb, mg/m²	S.B.: Avg.= 0.4 (COV = 0.22)	S.R.: Avg.= 0.1 (COV = 0.02)	L.B.: Avg.= 0.1 (COV = 0.02)	L.R.: Avg.= 0.42 (COV = 0.79)	0.014 (for Cond.*Time)
Cu, mg/m²	ND in bay and river waters				
Zn, mg/m²	S.: Avg.= 208 (COV = 0.65)		L.: Avg.= 2230 (COV = 0.51)		0.002 (for Time)

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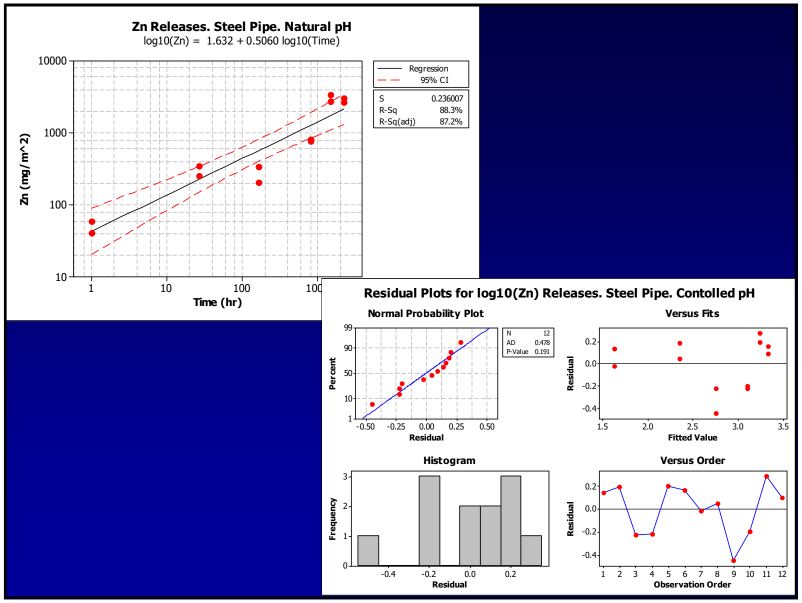

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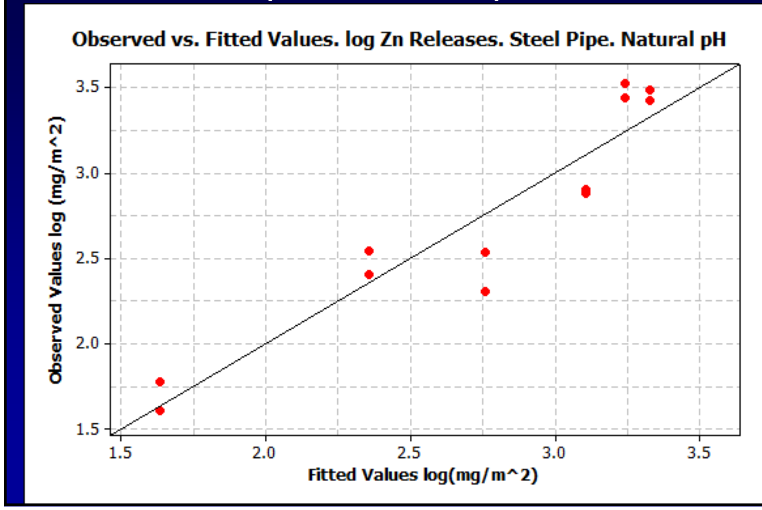
Final Plot of Fitted vs. Observed Values for Zinc Releases from Steel Pipe under Natural pH Conditions



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Subarea Ranking Methodology

- **Statistical methodology** (using binomial distribution) developed to rank the sites based on threshold comparisons while accounting for the number of usable data available at each site
- **"Weighting factors"** were calculated for each site for metals (cadmium, copper, and lead), dioxins (TCDD TEQ and 2,3,7,8-TCDD), and TSS.
  - **Multi-constituent "score"** was produced from metals and dioxin weighting factors to allow for relative ranking amongst potential stormwater control sites.

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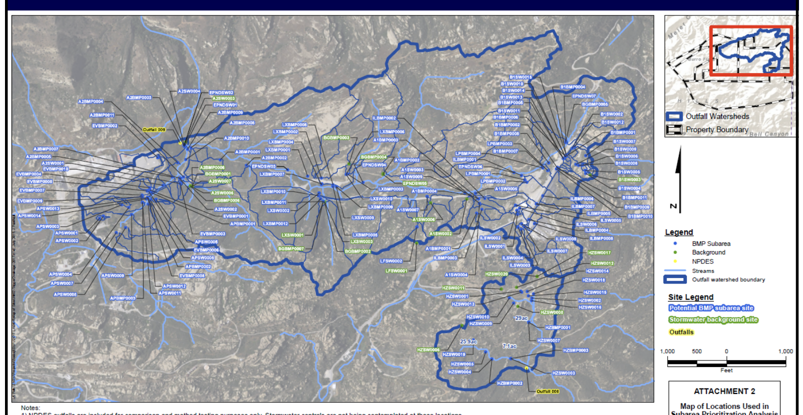
Locations of Sub-Area Sampling for Ranking for Stormwater Controls



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Example:

Site A: n = 10, m = 7 Weight$_A$ = 0.83

Site B: n = 14, m = 2 Weight$_B$ = 0.01

Based on weight alone, Site A would be prioritized over Site B.

Total Number of Observations (n)	Total Number of Critical Values in Data Set (m)													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	50													
2	50	[illegible]												
3	50	[illegible]	87											
4	31	[illegible]	69	94										
5	19	[illegible]	50	81	97									
6	11	[illegible]	50	66	89	98								
7	6	[illegible]	50	50	77	94	[illegible]							
8	4	[illegible]	36	50	64	86	[illegible]	99						
9	2	[illegible]	25	50	50	75	[illegible]	98	99					
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	83	95	99	99				
11	1	[illegible]	11	27	50	50	73	89	97	99	99			
12	0	[illegible]	7	19	39	50	63	81	93	98	99	99		
13	0	[illegible]	5	13	29	50	50	71	87	95	99	99	99	
14	[illegible]	1	3	9	21	40	50	61	79	91	97	99	99	99
15	0	0	2	6	15	30	50	50	70	85	94	98	99	99

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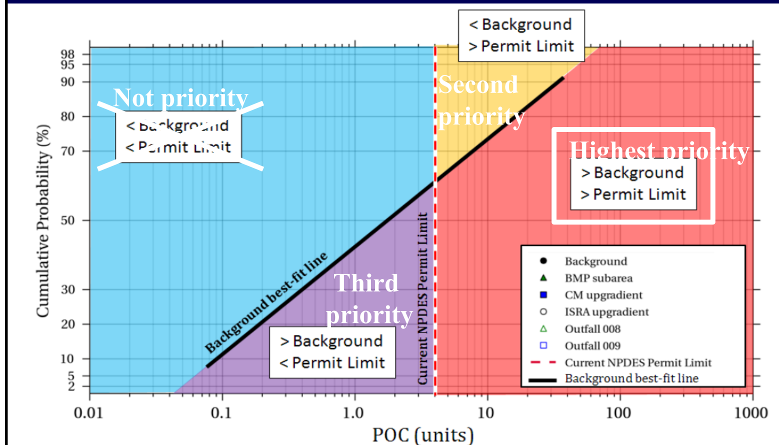
Basic Approach (example)



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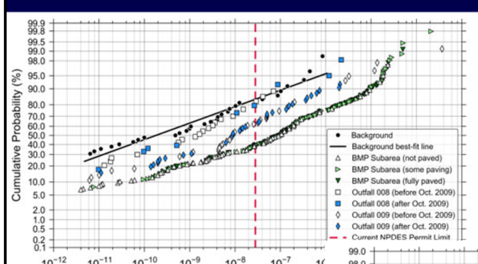
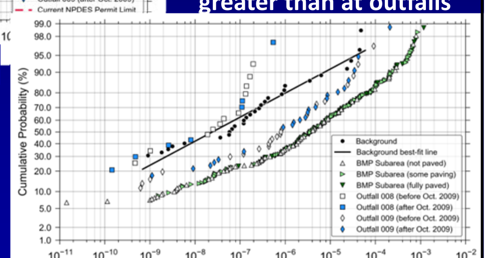
Example: Dioxin (TCDD TEQ)

- Background subareas occasionally exceed NPDES permit limit
- Water concentrations and particulate strengths at potential treatment subareas generally greater than at outfalls





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2012/2013 Ranking Results

Rank	Potential BMP Subarea (Co-locations)	Description	BMP Status	Approximate Upgradient Drainage Area (ac)	Multi-Constituent Score	Rank from Maximum Metal Weighting	Rank from Maximum Dioxin Weighting	Total Number of Events Sampled
1	**ILBMP0002**[a]	Road runoff to CM-9	Addressed by current BMP; Influent site	2.5	0.95	1[c]	6	9
2	**EVBMP0003** (A2SW0001)[a]	CM-1 upstream west	Addressed by current BMP; Influent site	11.8	0.94	3[c]	1	17
3	EVBMP0001-A[b]	ELV culvert inlet (helipad road and ELV ditch, composite)	Will be addressed by BMP; discontinued	2.5	0.67	17.5	7	5
4	**EVBMP0002**[a b]	Helipad (pre-sandbag berms)	Addressed by current BMP	4.1	0.66	15.5	10	10
5.5	**EVBMP0005**[b]	2012/13 ELV drainage ditch (pre-ELV-1C ISRA)	Will be addressed by BMP	11	0.63	21	9	2
5.5	**A1SW0009-A**	CM-9 downstream-underdrain outlet (post-A1LF asphalt removal, pre-filter fabric over weir boards)	BMP site has since been improved (old site)	16.4	0.63	4	21	1
7	**EVBMP0004**[b]	2012/13 Lower Helipad Road	Will be addressed by BMP	1.8	0.62	2	31.5	3
8	**APBMP0001**[b]	Ashpile culvert inlet/ road runoff	NA	34	0.60	5	21	2
9	**ILBMP0001**[b]	Lower lot 24" stormdrain outlet	Addressed by current BMP and planned building demolition	23	0.57	23	8	16
10	B1BMP0004 (B1SW0015, B1BMP0004-5)	B-1 media filter north	Addressed by current BMP; Influent site	3.7	0.53	29	2	6
14.5	LPBMP0001-A	Lower lot sheetflow (post-gravel bag berms)	Addressed by current BMP; discontinued	5.1	0.50	37.5	3	6
14.5	B1SW0002[a]	Woolsey Canyon Road runoff	Addressed by current BMP; Influent site; discontinued	1.3	0.50	10	21	2

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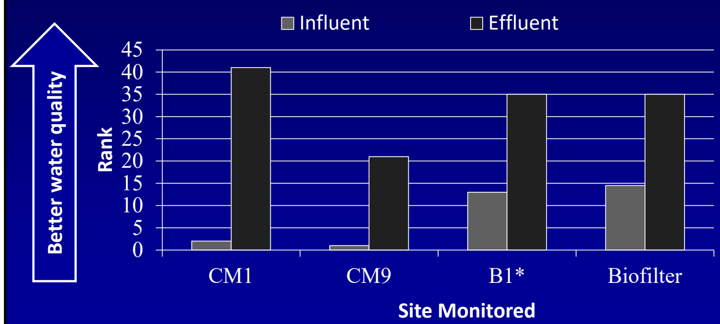
Water Quality Improvements

- Demonstrated by ranks, comparing influent and effluent.
- Limited to sites with at least 2 samples.



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South Detention Bioswale

	Total Suspended Solids inf mg/L	Total Suspended Solids efl mg/L	Total Suspended Solids % reduc
9/15/15	21.89	8.6	61
12/22/15	220	3.2	99
1/5/16	34.89	15	57
3/7/16	50.02	17	66
3/11/16	179.02	24	87
4/9/16	140.46	7	95
5/6/16	16.54	23	-39
12/16/16	46.72	5.8	88
12/30/16	20.05	5	75
1/7/17	18.42	2.1	89
1/12/17	27.68	3.3	88
1/20/17	29.98	4.4	85
2/3/17	14.25	5.4	62
2/17/17	104.06	1.8	98
1/9/18	27.13	17	37
3/2/18	20.07	9.3	54
count	16	16	16
minimum	14.25	1.8	-39
maximum	220	24	99
average	61	9.5	69
median	29	6.4	80
stdev	64	7.3	34
COV	1.1	0.77	0.49

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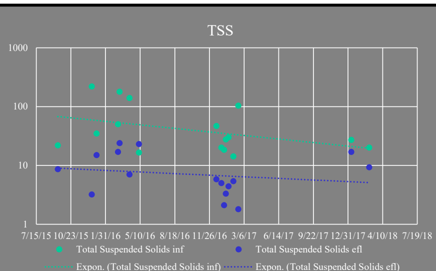
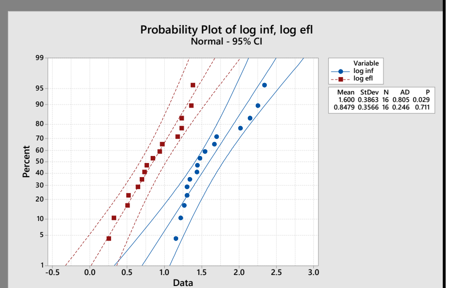


Sign Test: 1 of 16; p = 0.0003



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Regression Analysis: log efl versus log inf					
Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	0.00556	0.005559	0.04	0.843
log inf	1	0.00556	0.005559	0.04	0.843
Error	14	1.90224	0.135874		
Total	15	1.90779			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.36861	0.29%	0.00%	0.00%

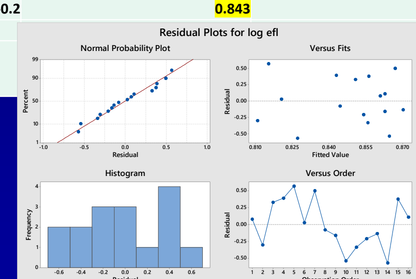
Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.928	0.405	2.29	0.038	
log inf	-0.05	0.246	-0.2	0.843	1

Regression Equation

log efl = 0.928 - 0.050 log inf

Regression not significant; effluent a constant value



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Conclusions

- Statistical tools need to be selected based on data characteristics (presence of non-detected values, data distributions, redundancy, objectives, etc.)
- A stepped approach is needed, from exploratory data analyses, to multivariate analyses, and to model building
- Residual analyses are required to confirm correct tool selection and utility of results