An Exploration of Nutrient and Chlorophyll *a* Relationships in North Carolina Lakes and Reservoirs.
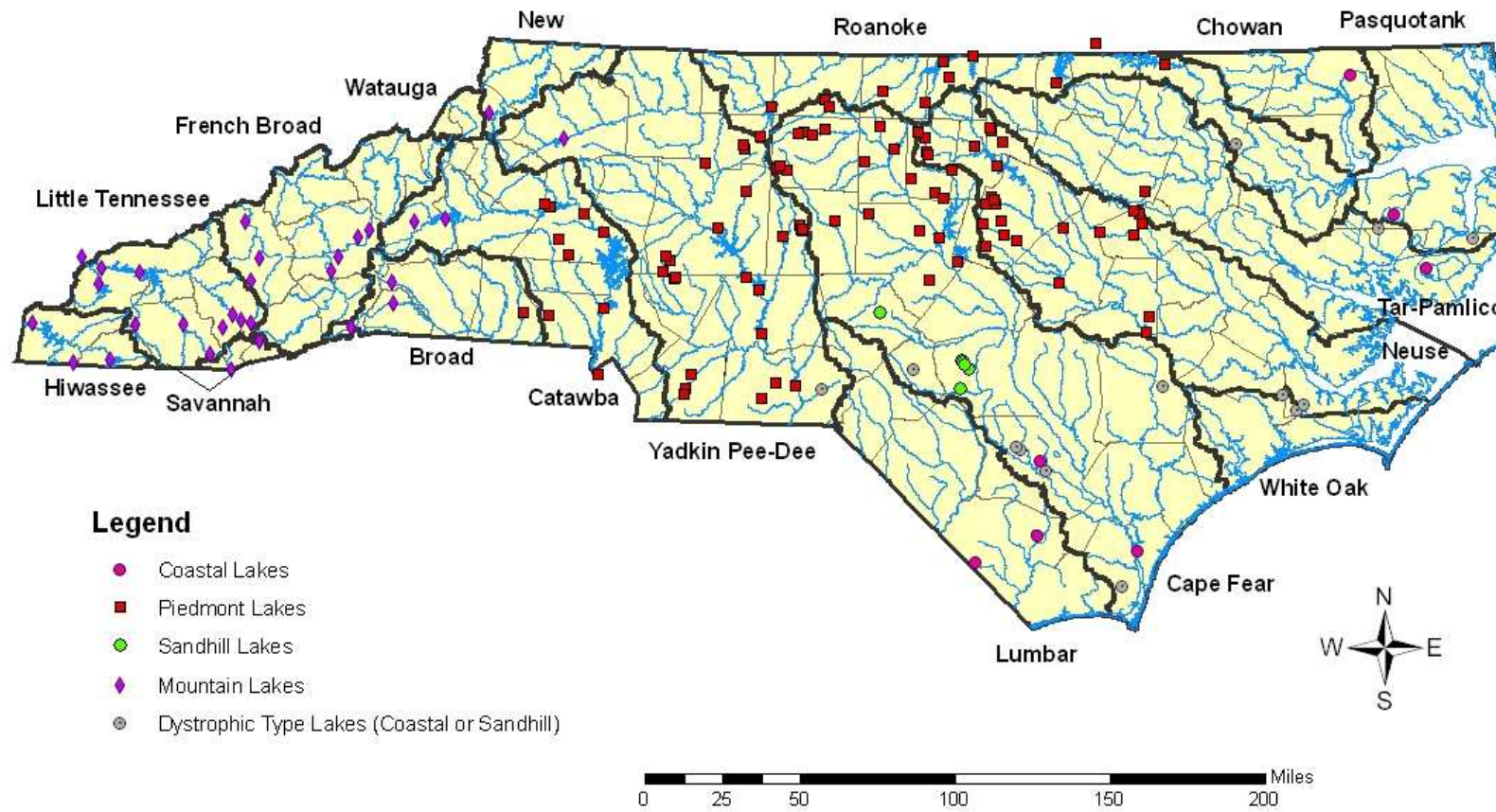
Introduction

North Carolina has many lakes and reservoirs across the state. Lakes are distinguished from reservoirs in that they are natural features and typically have a smaller watershed area, longer residence time and a simple shape, while reservoirs generally have larger drainage areas and are complex in size. Although natural lakes are found only in the Costal Plain of NC, this paper will refer to all lakes and reservoirs as "lakes". The NC Division of Water Quality (DWQ) monitors a portion of these lakes for various water quality parameters including nutrient and chlorophyll *a* concentrations on a rotating five year river basin schedule. Chlorophyll *a* is a measure of algal productivity within the waterbody and can be an indicator of nutrient enrichment. The purpose of this study is to determine whether linkages exist between nutrient and chlorophyll *a* concentrations that might allow for the development of regional nutrient criteria for North Carolina.

Methods

Through the Ambient Lake Monitoring Program (ALMP), DWQ monitors approximately 160 lakes statewide. Most lakes are sampled at least three times during May through September (growing season) of a single year in the ALMP for each five year river basin planning cycle. More intensive water quality studies have been performed on some lakes for TMDL development and other management strategies. In order to explore linkages between nutrient concentrations and chlorophyll *a* for possible nutrient criteria development, DWQ examined all lake data that included both chlorophyll *a* and nutrient concentrations from 1981-2007. Linear regressions were performed and the resulting coefficients of determination (r^2 values) were evaluated to assess the strength of the relationships between chlorophyll *a* and nutrient concentrations. These analyses were performed for several scenarios to assess the effects of region, seasonality, and severity of nutrient response. Nutrient species tested in the analysis included total phosphorus (TP), total nitrogen (TN), total organic nitrogen (TON) and total inorganic nitrogen (TIN).

Lakes considered in this analysis are shown below, organized by region and lake type. The regions shown (Mountain, Piedmont, Sandhills, and Coastal Plain) generally reflect the locations of those Level III ecoregions in NC, with the exception of some mountain lakes that do not lie in the mountain ecoregion but are considered mountain waters by the DWQ definition (15A NCAC 02B .0202 (45)). Dystrophic Lakes were separated as a lake type from other lakes in the Coastal Plain and Sandhills regions because nutrient response in these lakes is very different from other lakes in these regions due to the presence of various organic compounds and tannins in the water column.

Lakes Sampled by Division of Water Quality

Legend

- Coastal Lakes
- Piedmont Lakes
- Sandhill Lakes
- Mountain Lakes
- Dystrophic Type Lakes (Coastal or Sandhill)

Results

A summary of the DWQ lakes dataset used in this analysis is shown below.

Region / Lake Type	# Lakes	# Stations	# Samples
Coastal Plain	6	15	197
Piedmont	101	314	5108
Sandhills	12	15	115
Mountain	32	98	893
Dystrophic	16	44	215
Total	**167**	**486**	**6528**

As shown above, there are significantly more lake data for piedmont lakes than any of the other regions/lake types. In fact, the piedmont lakes comprise 78% of the total number of samples collected from 1981-2007. This is primarily due to intensive water quality studies performed on Falls Lake and Jordan Lake for TMDL model development. These studies included more frequent sampling at more stations over entire years (including the non-growing season). There are also a greater number of lakes sampled in the Piedmont than the other regions. Lakes in the other regions were typically sampled less frequently at fewer stations and only during the growing season.

Comparison of Mean Region/Type Chlorophyll a and Nutrient Concentrations

To gain a better understanding of how the regions/lake types differ in nutrient and Chla concentrations, box and whisker plots were created and grouped with "letters" representing the regions/types that were similar. Ambient monitoring lake samples are typically collected during the growing season (May – September); therefore, all non-growing season data were removed from the Piedmont region to make Piedmont data comparable to the other regions/types.

General distribution of chlorophyll *a* and nutrient concentrations for each lake region/type:
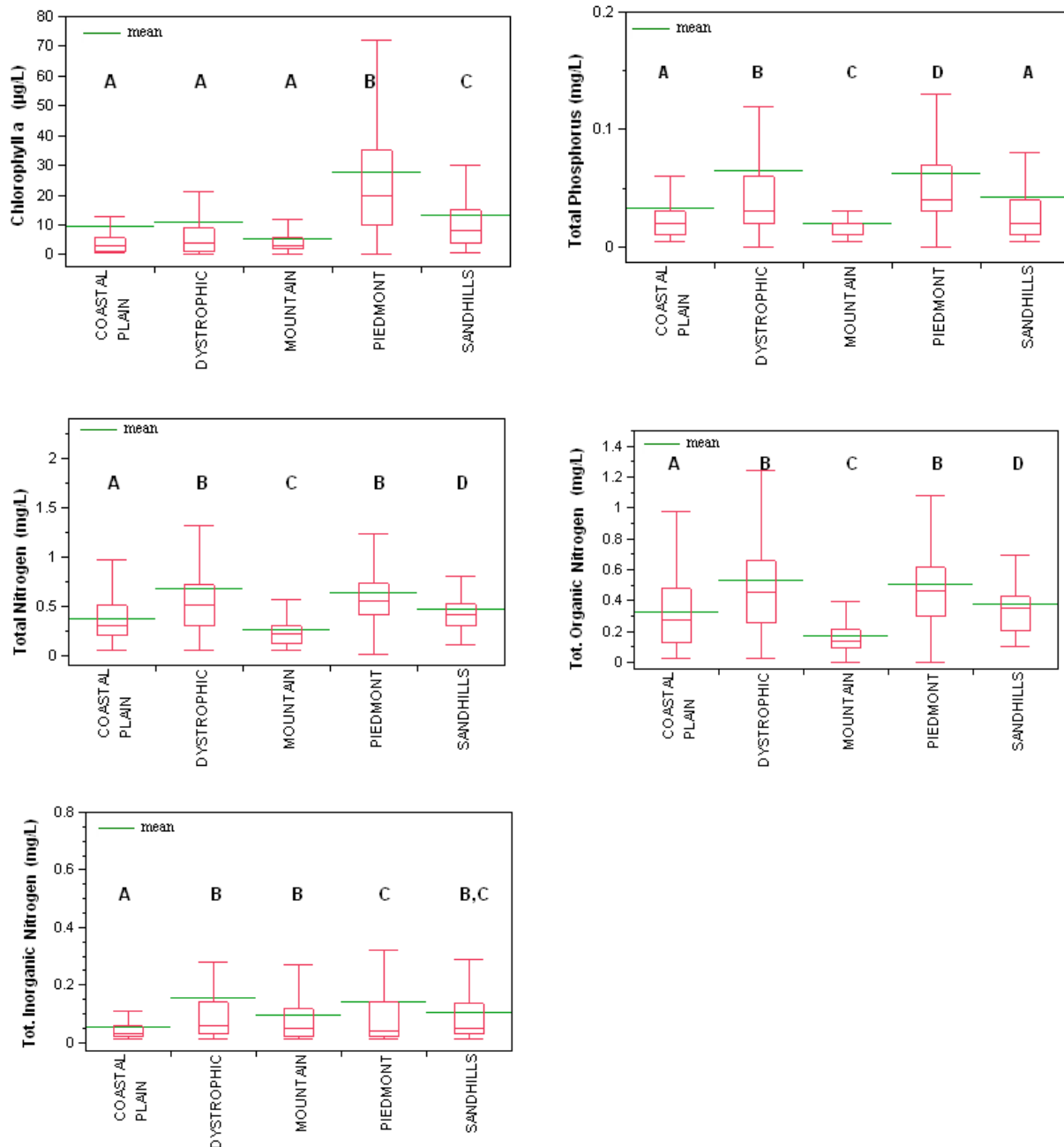
Notes: Columns with the same letter above the box plot are not significantly different at the 0.05 level. Piedmont data includes intensive studies such as: Jordan Lake, High Rock Lake and Falls of the Neuse Reservoir, representing nearly half of the piedmont dataset. All lake data that contained chlorophyll *a* collected during 1981-2007 were used. Coastal Plain (n = 197), Mountain (n = 215), Dystrophic (n = 891), Piedmont (n ~ 4009) and Sandhills lakes (n = 115).

All lake regions/types were compared using Mann-Whitney rank test, a nonparametric analysis that ranks medians, to determine significant effects of lake region/type and nutrient species. Nonparametric statistics methods were chosen due to the data not being normally distributed. Regions/types considered significantly different had p-values ≤ 0.05 and were given a specific letter.

4

The Piedmont lakes generally had the highest concentrations of Chla, while the Coastal Plain, Dystrophic, and Mountain lakes had the lowest. Results show no significant differences between Chla concentrations among the Coastal Plain, Dystrophic and Mountain lakes. TP concentrations in the Piedmont lakes had the greatest median concentration, while the mountain lakes had the lowest TP concentrations of all groups examined. Median TN and TON concentrations in the Piedmont lakes were similar to the Dystrophic type. TP, TN and TON concentrations were lowest in the mountain region. In general Coastal Plain lakes had lowest TIN concentrations. A list of p-values and Z-score results produced from the Mann-Whitney calculations are detailed in the Appendix.

Chlorophyll a / Nutrient Relationships

A summary of the coefficient of determinations values (r^2) for all analyses is shown below. Values shown in bold are significant at the 0.05 level. Detailed results of these analyses are shown in the Appendix.

Analysis	n	TP	TN	TON	TIN
All Lakes	6528	**0.15**	**0.12**	**0.27**	**0.00**
Mountain Lakes	891	**0.32**	**0.29**	**0.37**	**0.04**
Sandhills Lakes	113	**0.25**	**0.08**	**0.12**	0.01
Coastal Lakes	196	**0.32**	**0.20**	**0.19**	0.01
Dystrophic Lakes	215	**0.15**	**0.05**	**0.12**	0.00
Piedmont Lakes	5090	**0.11**	**0.09**	**0.23**	0.00
Falls & Jordan Lake	2321	**0.05**	**0.03**	**0.12**	0.00
Piedmont without Falls & Jordan	2771	**0.15**	**0.17**	**0.41**	**0.00**
Growing Season Piedmont	4002	**0.17**	**0.11**	**0.24**	**0.00**
Chlorophyll *a* exceeding 40 µg/L	1168	**0.06**	**0.02**	**0.06**	0.00

Discussion

All NC Lakes Combined

The first analyses performed were linear regressions between chlorophyll *a* (Chla) and nutrient concentrations for the entire lakes dataset. Results produced by linear regression indicate that there were weak, but statistically significant correlations ($p < 0.05$) between Chla concentrations and TP ($r^2 = 0.145$), TN ($r^2 = 0.124$), TON ($r^2 = 0.273$), and TIN ($r^2 = 0.0023$). It is likely that the large sample size considered in this analysis (n ~ 6528) contributes to the statistical significance of these relationships.

Mountain Lakes

Dividing by region/type slightly improved the correlations between Chla and nutrient concentrations within some regions, particularly for mountain lakes. Relationships between Chla and nutrient concentrations in the mountain region (n ~891) were slightly stronger than when the

all lakes were lumped together. Though statistically significant, these correlations were still rather weak with r^2 values for TP, TN and TON of 0.318, 0.291 and 0.372, respectively. Although TIN had p-value < 0.0001 showing a statistical significance, an r^2 of 0.036 indicates that there is not a linear relationship between TIN and Chla.

Sandhills Lakes

Lakes within the Sandhills region had the smallest sample size compared to all other ecoregions (n ~ 113), which may have contributed to the very weak correlation between Chla versus TN and TON   (r^2 = .084 and 0.116, respectively). The relationship between TP and Chla was greater within Sandhills lakes than the state average (r^2 = 0.252) and there was no significant correlation with between Chla and TIN.

Coastal Plain Lakes

Coastal Plain lakes also had a relatively small sample size (n ~ 196). This region had slightly stronger correlations between Chla and TP, TN and TON (r^2 = 0.321, 0.203 and 0.190, respectively) than did the Sandhills lakes. The majority of the TIN concentrations for this dataset were below laboratory detection limits, so the analysis for TIN and Chla was inconclusive.

Dystrophic Lakes

Dystrophic lakes data (n = 215) appears to have weaker correlations than the state average results. Very weak, but significant correlations between Chla versus TN and TON (r^2 = 0.046 and 0.116, respectively) were similar to what was found with Sandhills lakes. TP was comparable to the weak correlation found within the entire state (r^2 = 0.150) and no correlation was found between TIN and Chla.

All Piedmont Lakes, All Seasons

The Piedmont lakes had the greatest sample size (n ~ 5090) compared to all other types. This is primarily due to the large number of samples collected for Jordan Lake (n = 1214) and Falls of the Neuse Reservoir (n = 1110), which combined comprise 46% of the total Piedmont dataset from 1981 to 2007. There were significant but weak correlations found between Chla versus TP, TN and TON. TON had the strongest correlation compared to the other nutrients sampled ($r^{2=}$ 0.234). TP and TN exhibited weaker correlations with Chla (r^2 = 0.107 and 0.086, respectively), while TIN showed to be insignificant unlike the results from the entire state.

Piedmont Lakes without Falls Lake and Jordan Lake, All Seasons

Since nearly half of the Piedmont dataset was comprised of both Jordan Lake and Falls of the Neuse Reservoir, the piedmont data were also analyzed excluding these lakes. This approach slightly increased the relationship strength between Chla and TP (r^2 = 0.146), TN (r^2 = 0.173), and TON (r^2 = 0.41) when compared to using all the Piedmont lakes data during 1981-2007. The relationship between Chla and TIN was significant (p = 0.032) but very weak (r^2 = 0.0017).

Falls Lake and Jordan Lake Only, All Seasons

The relationship between Chla and TON for Falls and Jordan reservoirs alone ($r^2 = 0.119$) were weaker than the Piedmont without these reservoirs. Data obtained from Falls and Jordan Lake show statistically significant correlations with Chla versus TP and TN, but the low r^2 values (0.049 and 0.027, respectively) indicate that there is not a strong relationship. The relationship between Chla and TIN was not significant at the 0.05 level.

All Piedmont Lakes, Growing Season Only

Since much of the Piedmont data were collected outside of the growing season when the effects of nutrient concentrations on algal growth are reduced, further analysis was performed to determine if a correlation between Chla and nutrient concentrations exists in the Piedmont during growing season only (May through September). Using the growing season data within the Piedmont (n ~ 4009) region generally did not improve the overall strength of correlations between Chla and TP, TN, or TON ($r^2 = 0.170$, 0.0111 and 0.235, respectively). Although, TIN showed to be significantly correlated with Chla (p= 0.05), an r^2 value of 0.0017 indicates that this is a very weak relationship.

All NC Lakes, Chla > 40 µg/l

To determine if a correlation exists between Chla and a particular nutrient species when current chlorophyll *a* standards are exceeded ($\geq$ 40 µg/l); additional regressions were calculated using only data for which chlorophyll *a* was at or above 40 µg/l. Although there were statistical significance when analyzing data which had exceeded Chla ($\geq$ 40 µg/l), all r^2 values were less than 0.06 showing that the relationships were very weak.

Conclusions

There appears to be some weak relationships between Chla and TP, TN, and TON in NC lakes and reservoirs. However, these relationships should be evaluated with caution since laboratory analysis of these parameters includes the nitrogen and phosphorus already incorporated in the algal biomass. In general, there does not appear to be a significant relationship between TIN concentrations and Chla. TIN concentrations were generally low, often below detection levels, likely because this form of nitrogen is rapidly consumed by algae during the growing season.

The weak relationships between Chla and nutrient concentrations indicate that there are variables other than nutrient concentrations that affect chlorophyll *a* response. Site specific variables such as retention time, lake morphology, station location within the lake, watershed area and land use, etc. all play a role in the severity of chlorophyll *a* response to nutrient inputs.

APPENDIX:

Chlorophyll *a* vs. nutrient concentrations for all lakes & reservoirs (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus
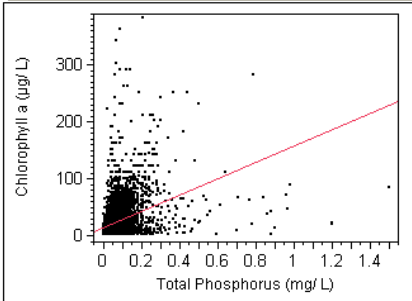
Summary of Fit

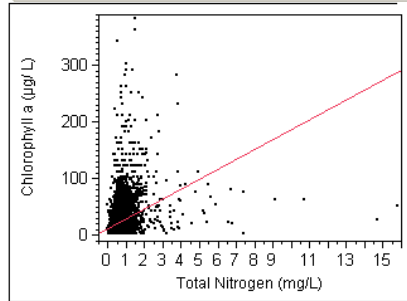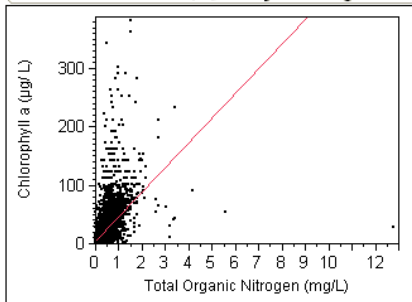|	
RSquare	0.145074
RSquare Adj	0.144942
Root Mean Square Error	26.18864
Mean of Response	23.93856
Observations (or Sum Wgts)	6504

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	756717.0	756717	1103.336
Error	6502	4459363.5	686	Prob > F
C. Total	6503	5216080.6		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	15.061176	0.420567	35.81	<.0001*
Total Phosphorus (mg/ L)	143.35712	4.315841	33.22	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

RSquare	0.123942
RSquare Adj	0.123808
Root Mean Square Error	26.55331
Mean of Response	23.9528
Observations (or Sum Wgts)	6496

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	647794.3	647794	918.7554
Error	6494	4578777.3	705	Prob > F
C. Total	6495	5226571.6		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.741383	0.49533	25.72	<.0001*
Total Nitrogen (mg/L)	17.417129	0.574615	30.31	<.0001*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

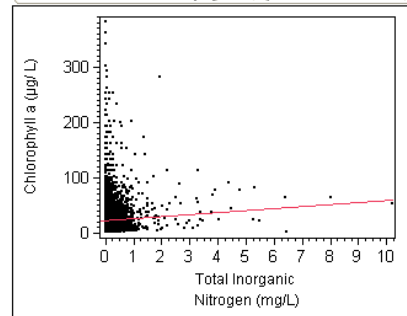|	
RSquare	0.272755
RSquare Adj	0.272643
Root Mean Square Error	24.20535
Mean of Response	23.98772
Observations (or Sum Wgts)	6484

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1424372.5	1424372	2431.089
Error	6482	3797797.7	586	Prob > F
C. Total	6483	5222170.1		0.0000*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.3419382	0.499119	8.70	<.0001*
Total Organic Nitrogen (mg/L)	42.316931	0.85825	49.31	0.0000*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen

Summary of Fit

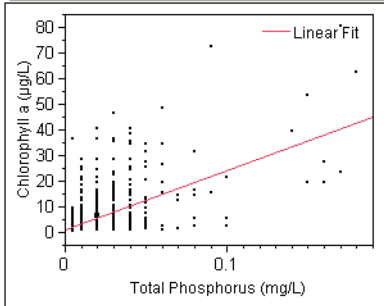|	
RSquare	0.002281
RSquare Adj	0.002127
Root Mean Square Error	28.33445
Mean of Response	23.96004
Observations (or Sum Wgts)	6497

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	11921.5	11921.5	14.8491
Error	6495	5214451.3	802.8	Prob > F
C. Total	6496	5226372.7		0.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	23.318534	0.388954	59.95	0.0000*
Total Inorganic Nitrogen (mg/L)	3.5376825	0.918054	3.85	0.0001*

8

Chlorophyll *a* vs. nutrient concentrations for Mountain lakes (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

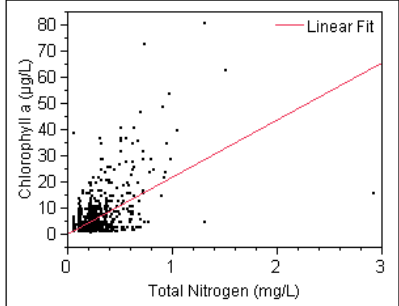|	
RSquare	0.318196
RSquare Adj	0.317429
Root Mean Square Error	6.45362
Mean of Response	5.558923
Observations (or Sum Wgts)	891

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	17280.011	17280.0	414.8941
Error	889	37026.146	41.6	**Prob > F**
C. Total	890	54306.157		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0460118	0.309568	3.38	0.0008*
Total Phosphorus	231.95867	11.38786	20.37	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

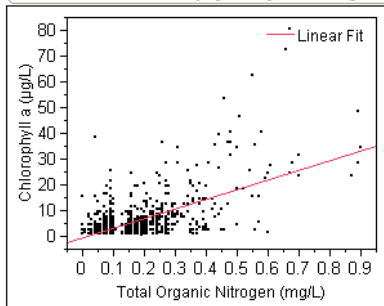|	
RSquare	0.291083
RSquare Adj	0.290285
Root Mean Square Error	6.578567
Mean of Response	5.548822
Observations (or Sum Wgts)	891

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	15797.394	15797.4	365.0252
Error	889	38473.733	43.3	**Prob > F**
C. Total	890	54271.126		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.149642	0.370852	-0.40	0.6867
Total Nitrogen (mg/L)	21.885991	1.145526	19.11	<.0001*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

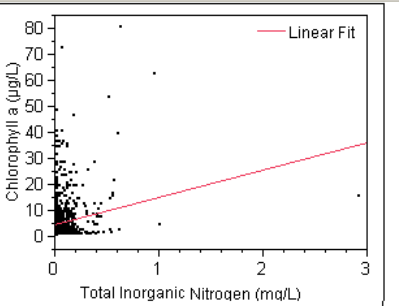|	
RSquare	0.371569
RSquare Adj	0.37086
Root Mean Square Error	6.203709
Mean of Response	5.572072
Observations (or Sum Wgts)	888

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	20161.288	20161.3	523.8603
Error	886	34098.600	38.5	**Prob > F**
C. Total	887	54259.887		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.762008	0.346304	-2.20	0.0280*
Total Organic Nitrogen (mg/L)	37.686183	1.646548	22.89	<.0001*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen

Summary of Fit

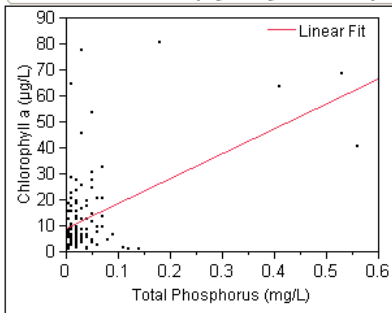|	
RSquare	0.035859
RSquare Adj	0.034774
Root Mean Square Error	7.671916
Mean of Response	5.548822
Observations (or Sum Wgts)	891

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1946.099	1946.10	33.0641
Error	889	52325.028	58.86	**Prob > F**
C. Total	890	54271.126		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.5573651	0.309497	14.73	<.0001*
Total Inorganic Nitrogen (mg/L)	10.522784	1.830004	5.75	<.0001*

Chlorophyll *a* vs. nutrient concentrations for Sandhills lakes (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

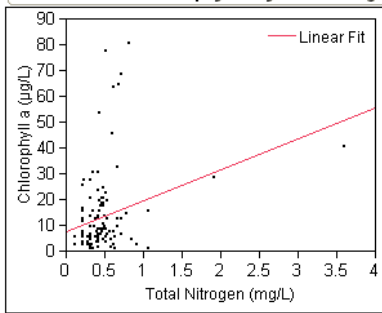|	
RSquare	0.251951
RSquare Adj	0.24515
Root Mean Square Error	13.64773
Mean of Response	13.17857
Observations (or Sum Wgts)	112

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	6900.781	6900.78	37.0491
Error	110	20488.648	186.26	Prob > F
C. Total	111	27389.429		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	9.0809653	1.454728	6.24	<.0001*
Total Phosphorus	96.111391	15.79014	6.09	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

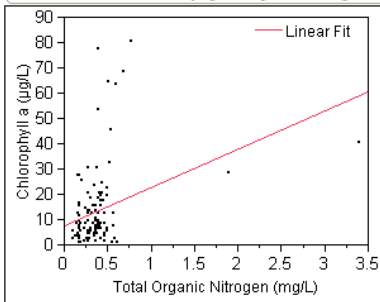|	
RSquare	0.083649
RSquare Adj	0.075393
Root Mean Square Error	15.07095
Mean of Response	13.07965
Observations (or Sum Wgts)	113

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2301.449	2301.45	10.1326
Error	111	25211.835	227.13	Prob > F
C. Total	112	27513.283		0.0019*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.3322121	2.295672	3.19	0.0018*
Total Nitrogen	12.076237	3.793776	3.18	0.0019*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

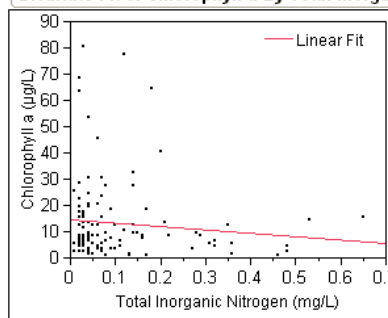|	
RSquare	0.115971
RSquare Adj	0.107934
Root Mean Square Error	14.8521
Mean of Response	13.15179
Observations (or Sum Wgts)	112

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3183.095	3183.09	14.4303
Error	110	24264.325	220.58	Prob > F
C. Total	111	27447.420		0.0002*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.4305445	2.058601	3.61	0.0005*
Total Organic Nitrogen	15.231258	4.009579	3.80	0.0002*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen

Summary of Fit

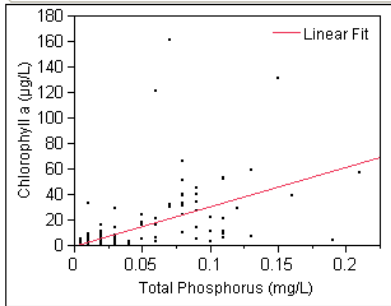|	
RSquare	0.010167
RSquare Adj	0.00125
Root Mean Square Error	15.66357
Mean of Response	13.07965
Observations (or Sum Wgts)	113

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	279.726	279.726	1.1401
Error	111	27233.557	245.347	Prob > F
C. Total	112	27513.283		0.2879

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	14.418729	1.934936	7.45	<.0001*
Total Inorganic Nitrogen	-12.75855	11.94883	-1.07	0.2879

10

Chlorophyll *a* vs. nutrient concentrations for Coastal lakes & reservoirs (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

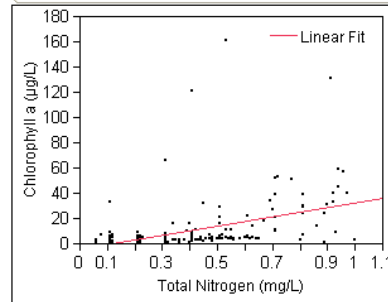|	
RSquare	0.320846
RSquare Adj	0.317345
Root Mean Square Error	16.72677
Mean of Response	9.640306
Observations (or Sum Wgts)	196

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	25642.109	25642.1	91.6493
Error	194	54278.283	279.8	Prob > F
C. Total	195	79920.392		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.586726	1.602715	-0.37	0.7147
Total Phosphorus	308.85953	32.26237	9.57	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

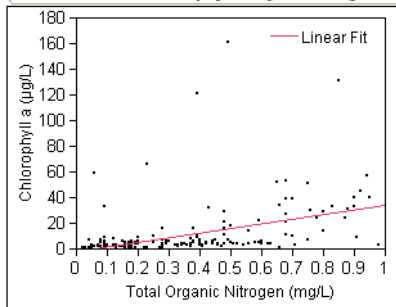|	
RSquare	0.20327
RSquare Adj	0.199142
Root Mean Square Error	18.10656
Mean of Response	9.525641
Observations (or Sum Wgts)	195

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	16143.287	16143.3	49.2402
Error	193	63274.585	327.8	Prob > F
C. Total	194	79417.872		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.420279	2.372986	-1.86	0.0640
Total Nitrogen	37.105394	5.287825	7.02	<.0001*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

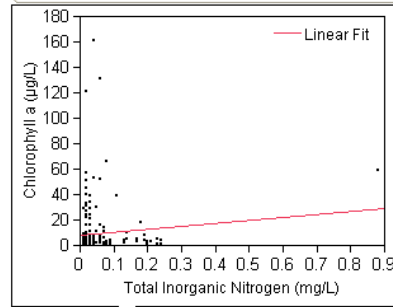|	
RSquare	0.188987
RSquare Adj	0.184807
Root Mean Square Error	18.27855
Mean of Response	9.640306
Observations (or Sum Wgts)	196

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	15103.920	15103.9	45.2070
Error	194	64816.472	334.1	Prob > F
C. Total	195	79920.392		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-2.059171	2.175412	-0.95	0.3450
Total Organic Nitrogen	35.947602	5.346467	6.72	<.0001*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen

Summary of Fit

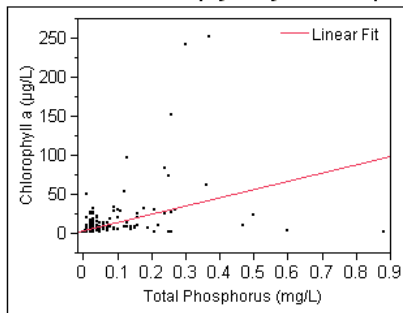|	
RSquare	0.007411
RSquare Adj	0.002268
Root Mean Square Error	20.20995
Mean of Response	9.525641
Observations (or Sum Wgts)	195

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	588.559	588.559	1.4410
Error	193	78829.313	408.442	Prob > F
C. Total	194	79417.872		0.2315

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.3114805	1.765677	4.71	<.0001*
Total Inorganic Nitrogen	22.721813	18.92837	1.20	0.2315

Chlorophyll *a* vs. nutrient concentrations for Dystrophic lakes (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

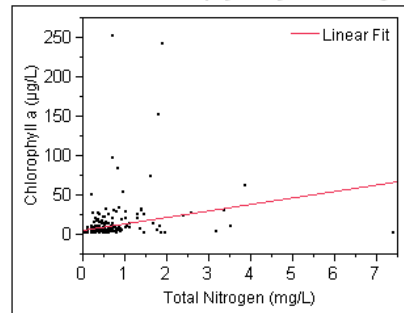|	
RSquare	0.149646
RSquare Adj	0.145654
Root Mean Square Error	25.72683
Mean of Response	10.95116
Observations (or Sum Wgts)	215

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	24809.52	24809.5	37.4840
Error	213	140978.22	661.9	Prob > F
C. Total	214	165787.74		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.1899263	2.07317	2.02	0.0445*
Total Phosphorus	103.7962	16.95347	6.12	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

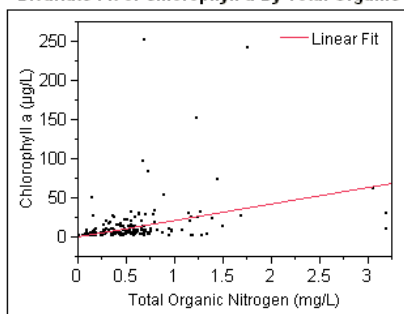|	
RSquare	0.045613
RSquare Adj	0.041132
Root Mean Square Error	27.25515
Mean of Response	10.95116
Observations (or Sum Wgts)	215

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	7562.09	7562.09	10.1799
Error	213	158225.64	742.84	Prob > F
C. Total	214	165787.74		0.0016*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5.3895819	2.548241	2.12	0.0356*
Total Nitrogen	8.1127613	2.542707	3.19	0.0016*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

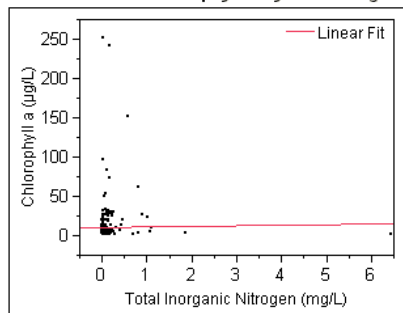|	
RSquare	0.116297
RSquare Adj	0.112148
Root Mean Square Error	26.22645
Mean of Response	10.95116
Observations (or Sum Wgts)	215

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	19280.65	19280.6	28.0313
Error	213	146507.09	687.8	Prob > F
C. Total	214	165787.74		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.337229	2.783004	-0.12	0.9037
Total Organic Nitrogen	21.274581	4.018275	5.29	<.0001*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen

Summary of Fit

RSquare	8.576e-5
RSquare Adj	-0.00461
Root Mean Square Error	27.89766
Mean of Response	10.95116
Observations (or Sum Wgts)	215

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	14.22	14.218	0.0183
Error	213	165773.52	778.279	Prob > F
C. Total	214	165787.74		0.8926

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	10.867732	2.000232	5.43	<.0001*
Total Inorganic Nitrogen	0.5368924	3.972271	0.14	0.8926

Chlorophyll *a* vs. nutrient concentrations for Piedmont lakes (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

RSquare	0.106978
RSquare Adj	0.106803
Root Mean Square Error	27.76714
Mean of Response	28.49183
Observations (or Sum Wgts)	5090

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	469939.4	469939	609.5083
Error	5088	3922918.8	771	Prob > F
C. Total	5089	4392858.2		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	19.775788	0.525468	37.63	<.0001*
Total Phosphorus	123.18207	4.989507	24.69	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

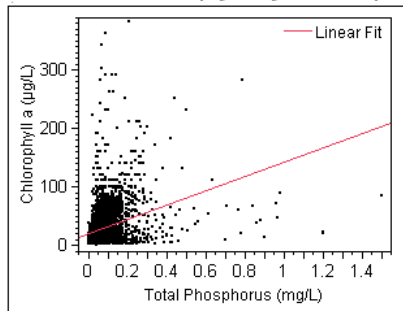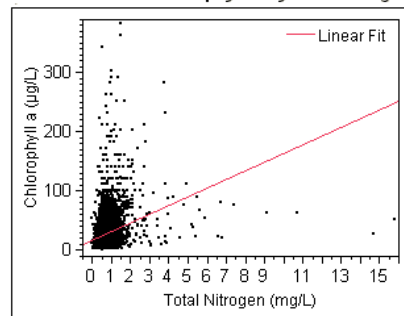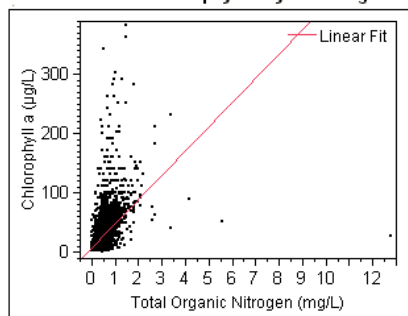|	
RSquare	0.085907
RSquare Adj	0.085727
Root Mean Square Error	28.14183
Mean of Response	28.52487
Observations (or Sum Wgts)	5082

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	378098.9	378099	477.4201
Error	5080	4023170.5	792	Prob > F
C. Total	5081	4401269.4		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.983895	0.623355	28.85	<.0001*
Total Nitrogen	14.576546	0.66712	21.85	<.0001*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

RSquare	0.233987
RSquare Adj	0.233836
Root Mean Square Error	25.77393
Mean of Response	28.55734
Observations (or Sum Wgts)	5073

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1028991.2	1028991	1548.996
Error	5071	3368642.4	664	Prob > F
C. Total	5072	4397633.6		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.2382015	0.651434	11.11	<.0001*
Total Organic Nitrogen	40.950691	1.040486	39.36	<.0001*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen

Summary of Fit

RSquare	0.000116
RSquare Adj	-8.12e-5
Root Mean Square Error	29.4279
Mean of Response	28.53323
Observations (or Sum Wgts)	5083

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	508.5	508.526	0.5872
Error	5081	4400152.6	866.001	Prob > F
C. Total	5082	4400661.2		0.4435

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	28.376971	0.460383	61.64	0.0000*
Total Inorganic Nitrogen	0.7648134	0.998063	0.77	0.4435

Growing season data for Piedmont lakes (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

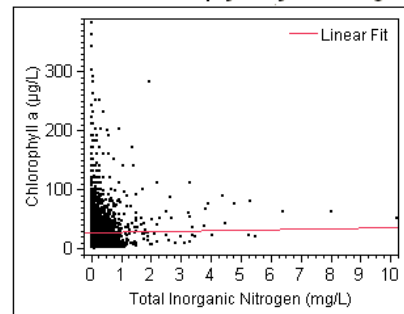|	
RSquare	0.169887
RSquare Adj	0.169679
Root Mean Square Error	26.67188
Mean of Response	27.78072
Observations (or Sum Wgts)	4009

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	583375.3	583375	820.0510
Error	4007	2850535.6	711	Prob > F
C. Total	4008	3433910.9		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.386092	0.556063	31.27	<.0001*
Total Phosphorus	165.79624	5.789676	28.64	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

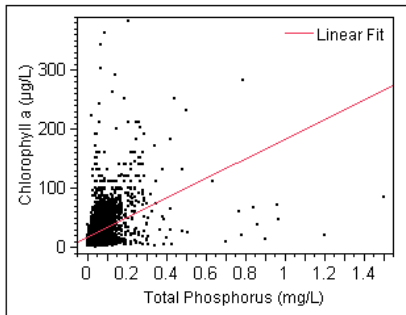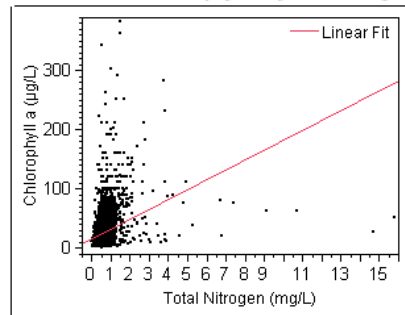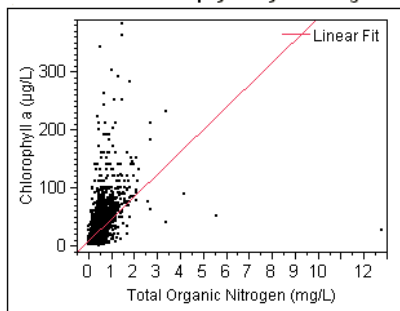|	
RSquare	0.111135
RSquare Adj	0.110913
Root Mean Square Error	27.65408
Mean of Response	27.79838
Observations (or Sum Wgts)	4003

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	382562.5	382562	500.2465
Error	4001	3059756.5	765	Prob > F
C. Total	4002	3442318.9		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	17.030358	0.650254	26.19	<.0001*
Total Nitrogen	16.712565	0.747224	22.37	<.0001*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen

Summary of Fit

RSquare	0.235005
RSquare Adj	0.234813
Root Mean Square Error	25.67113
Mean of Response	27.83798
Observations (or Sum Wgts)	3994

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	808161.2	808161	1226.332
Error	3992	2630755.7	659	Prob > F
C. Total	3993	3438916.8		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	8.3017402	0.69009	12.03	<.0001*
Total Organic Nitrogen	38.627216	1.103035	35.02	<.0001*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen
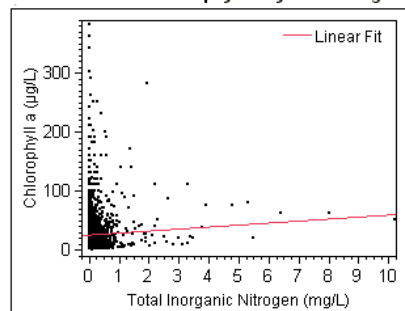
Summary of Fit

RSquare	0.0017
RSquare Adj	0.00145
Root Mean Square Error	29.30784
Mean of Response	27.80657
Observations (or Sum Wgts)	4002

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5849.2	5849.24	6.8098
Error	4000	3435797.7	858.95	Prob > F
C. Total	4001	3441646.9		0.0091*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	27.356132	0.494394	55.33	0.0000*
Total Inorganic Nitrogen	3.2058705	1.228514	2.61	0.0091*

14

Chlorophyll *a* vs. Nutrient concentrations for all NC lakes for all data that exceeded the chlorophyll *a* standard (≥ 40 µg/). (1981-2007)

Bivariate Fit of Chlorophyll a By Total Phosphorus

Summary of Fit

RSquare	0.061199
RSquare Adj	0.060392
Root Mean Square Error	38.37759
Mean of Response	68.03004
Observations (or Sum Wgts)	1165

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	111662.0	111662	75.8141
Error	1163	1712912.0	1473	Prob > F
C. Total	1164	1824573.9		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	57.62738	1.640615	35.13	<.0001*
Total Phosphorus	91.121069	10.46511	8.71	<.0001*

Bivariate Fit of Chlorophyll a By Total Nitrogen

Summary of Fit

RSquare	0.016202
RSquare Adj	0.015358
Root Mean Square Error	39.26884
Mean of Response	68.05223
Observations (or Sum Wgts)	1168

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	29611.5	29611.5	19.2028
Error	1166	1798020.4	1542.0	Prob > F
C. Total	1167	1827631.8		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	62.060683	1.78597	34.75	<.0001*
Total Nitrogen	5.8675114	1.338974	4.38	<.0001*

Bivariate Fit of Chlorophyll a By Total Organic Nitrogen
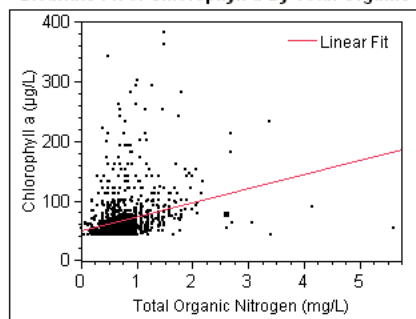
Summary of Fit

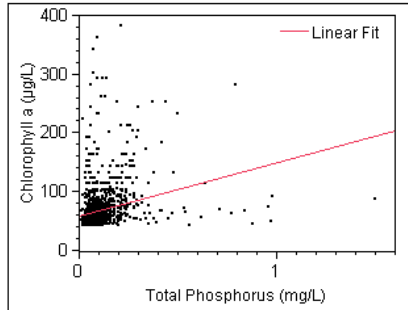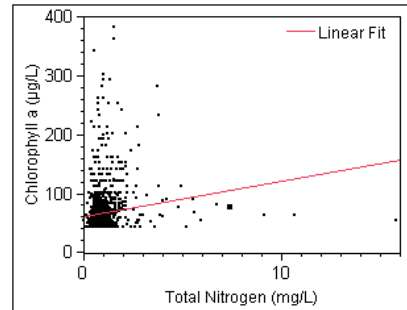|	
RSquare	0.064038
RSquare Adj	0.063236
Root Mean Square Error	38.30224
Mean of Response	68.05223
Observations (or Sum Wgts)	1168

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	117038.3	117038	79.7774
Error	1166	1710593.5	1467	Prob > F
C. Total	1167	1827631.8		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	49.325203	2.377403	20.75	<.0001*
Total Organic Nitrogen	23.562094	2.637996	8.93	<.0001*

Bivariate Fit of Chlorophyll a By Total Inorganic Nitrogen
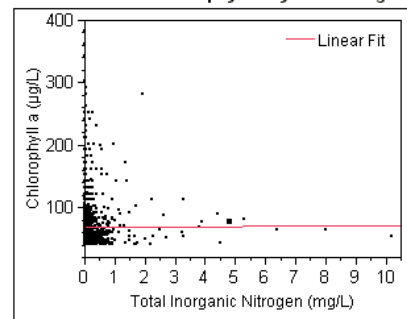
Summary of Fit

RSquare	7.623e-6
RSquare Adj	-0.00085
Root Mean Square Error	39.59072
Mean of Response	68.05223
Observations (or Sum Wgts)	1168

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	13.9	13.93	0.0089
Error	1166	1827617.9	1567.43	Prob > F
C. Total	1167	1827631.8		0.9249

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	68.012302	1.233407	55.14	0.0000*
Total Inorganic Nitrogen	0.1762058	1.868963	0.09	0.9249

15

Linear Regression Results Summarized.

	Entire State		Mountains		Sandhill		Coastal Plain		Dsytrophic		Piedmont	
	All data*	*5 years***	*All data**	*5 years***	*All data**	*5 years***	*All data**	*5 years***	*All data**	*5 years***	*All data**	*5 years***
TP												
R Sq.	0.145	0.224	0.318	0.183	0.252	0.009	0.321	0.421	0.150	0.31	0.107	0.174
Sig.	<.0001	<.0001	<.0001	<.0001	<.0001	0.6246	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
n	6504	2315	891	296	112	29	196	37	215	71	5090	1882
TN												
R Sq.	0.124	0.341	0.291	0.342	0.084	0.032	0.203	0.331	0.046	0.315	0.086	0.254
Sig.	<.0001	<.0001	<.0001	<.0001	0.0019	0.3496	<.0001	0.0002	0.0016	<.0001	<.0001	<.0001
n	6496	2306	891	296	113	29	195	36	215	71	5082	1874
TON												
R Sq.	0.273	0.612	0.372	0.544	0.116	0.451	0.190	0.33672	0.116	0.352	0.234	0.579
Sig.	<0.0001	0.0000	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0000
n	6484	2306	888	296	112	29	196	37	215	71	5073	1872
TIN												
R Sq.	0.002	0.0003	0.036	0.001	0.010	0.017	0.007	0.014	0.00008	0.081	0.0001	0.006
Sig.	0.0001	0.4138	<.0001	0.5691	0.2879	0.4959	0.2315	0.4885	0.8926	0.0164	0.44	0.0013
n	6497	2306	891	296	113	29	195	36	215	71	5083	1874

* All data with Chlorophyll *a* values

** Data collected from 2003-2007

Mann-Whitney Results: <u>Coastal Plan vs. Dystrophic Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	15207.500
U Prime	26932.500
Z-Value	-4.874
P-Value	<.0001
Tied Z-Value	-4.968
Tied P-Value	<.0001
# Ties	22

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	34513.500	176.089
DYSTROPHIC	215	50152.500	233.267

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	12967.500
U Prime	28957.500
Z-Value	-6.672
P-Value	<.0001
Tied Z-Value	-6.684
Tied P-Value	<.0001
# Ties	58

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	32077.500	164.500
DYSTROPHIC	215	52177.500	242.686

Mann-Whitney U for Tot. Organic Nitrogen
Grouping Variable: Region/Type

U	13752.000
U Prime	28388.000
Z-Value	-6.084
P-Value	<.0001
Tied Z-Value	-6.085
Tied P-Value	<.0001
# Ties	72

Mann-Whitney Rank Info for Tot. Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	33058.000	168.663
DYSTROPHIC	215	51608.000	240.037

Mann-Whitney U for Tot. Inorganic Nitrogen
Grouping Variable: Region/Type

U	13567.000
U Prime	28358.000
Z-Value	-6.172
P-Value	<.0001
Tied Z-Value	-6.228
Tied P-Value	<.0001
# Ties	25

Mann-Whitney Rank Info for Tot. Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	32677.000	167.574
DYSTROPHIC	215	51578.000	239.898

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	19471.000
U Prime	22884.000
Z-Value	-1.413
P-Value	.1575
Tied Z-Value	-1.420
Tied P-Value	.1555
# Ties	32

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	197	38974.000	197.838
DYSTROPHIC	215	46104.000	214.437

Mann-Whitney Results: <u>Coastal Plan vs. Mountain Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	71884.500
U Prime	102751.500
Z-Value	-3.879
P-Value	.0001
Tied Z-Value	-4.098
Tied P-Value	<.0001
# Ties	16

3 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	122057.500	622.742
MOUNTAIN	891	469270.500	526.678

3 cases w ere omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	64311.500
U Prime	109433.500
Z-Value	-5.687
P-Value	<.0001
Tied Z-Value	-5.713
Tied P-Value	<.0001
# Ties	72

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	128543.500	659.197
MOUNTAIN	891	461697.500	518.179

4 cases w ere omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	53469.000
U Prime	120579.000
Z-Value	-8.459
P-Value	<.0001
Tied Z-Value	-8.513
Tied P-Value	<.0001
# Ties	69

6 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	139885.000	713.699
MOUNTAIN	888	448185.000	504.713

6 cases w ere omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	61758.000
U Prime	111987.000
Z-Value	-6.331
P-Value	<.0001
Tied Z-Value	-6.388
Tied P-Value	<.0001
# Ties	37

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	80868.000	414.708
MOUNTAIN	891	509373.000	571.687

4 cases w ere omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	86544.000
U Prime	89377.000
Z-Value	-.354
P-Value	.7232
Tied Z-Value	-.357
Tied P-Value	.7214
# Ties	36

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	197	106047.000	538.310
MOUNTAIN	893	488548.000	547.086

Mann-Whitney Results: <u>Coastal Plan vs. Piedmont Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

U	208987.500
U Prime	576580.500
Z-Value	-11.078
P-Value	<.0001
Tied Z-Value	-11.138
Tied P-Value	<.0001
# Ties	39

16 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	228293.500	1164.763
PIEDMONT	4008	8610616.500	2148.357

16 cases were omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

U	207589.000
U Prime	572801.000
Z-Value	-11.052
P-Value	<.0001
Tied Z-Value	-11.057
Tied P-Value	<.0001
# Ties	148

23 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	226699.000	1162.559
PIEDMONT	4002	8582804.000	2144.629

23 cases were omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

U	235938.000
U Prime	546690.000
Z-Value	-9.399
P-Value	<.0001
Tied Z-Value	-9.401
Tied P-Value	<.0001
# Ties	126

31 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	255244.000	1302.265
PIEDMONT	3993	8520711.000	2133.912

31 cases were omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

U	317405.000
U Prime	462790.000
Z-Value	-4.401
P-Value	<.0001
Tied Z-Value	-4.465
Tied P-Value	<.0001
# Ties	90

24 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	336515.000	1725.718
PIEDMONT	4001	8468791.000	2116.669

24 cases were omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

U	131394.000
U Prime	661137.000
Z-Value	-15.864
P-Value	<.0001
Tied Z-Value	-15.867
Tied P-Value	<.0001
# Ties	111

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type
Row exclusion: Coastal_Piedmont-growing.svd

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	197	150897.000	765.975
PIEDMONT	4023	8755413.000	2176.339

Mann-Whitney Results: <u>Coastal Plan vs. Sandhills Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	10259.500
U Prime	11692.500
Z-Value	-.953
P-Value	.3406
Tied Z-Value	-.978
Tied P-Value	.3278
# Ties	14

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	29565.500	150.844
SANDHILLS	112	18020.500	160.897

4 cases w ere omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	8527.500
U Prime	13507.500
Z-Value	-3.306
P-Value	.0009
Tied Z-Value	-3.316
Tied P-Value	.0009
# Ties	42

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	27637.500	141.731
SANDHILLS	113	19948.500	176.535

4 cases w ere omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	9199.500
U Prime	12752.500
Z-Value	-2.363
P-Value	.0181
Tied Z-Value	-2.364
Tied P-Value	.0181
# Ties	57

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	196	28505.500	145.436
SANDHILLS	112	19080.500	170.362

4 cases w ere omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	7444.000
U Prime	14591.000
Z-Value	-4.744
P-Value	<.0001
Tied Z-Value	-4.798
Tied P-Value	<.0001
# Ties	25

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	195	26554.000	136.174
SANDHILLS	113	21032.000	186.124

4 cases w ere omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	6692.500
U Prime	15962.500
Z-Value	-6.030
P-Value	<.0001
Tied Z-Value	-6.050
Tied P-Value	<.0001
# Ties	26

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
COASTAL PLAIN	197	26195.500	132.972
SANDHILLS	115	22632.500	196.804

Mann-Whitney Results: <u>Dystrophic vs. Mountain Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	51038.000
U Prime	140527.000
Z-Value	-10.644
P-Value	<.0001
Tied Z-Value	-11.108
Tied P-Value	<.0001
# Ties	22

2 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	163747.000	761.614
MOUNTAIN	891	448424.000	503.282

2 cases w ere omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	33554.500
U Prime	158010.500
Z-Value	-14.803
P-Value	<.0001
Tied Z-Value	-14.848
Tied P-Value	<.0001
# Ties	76

2 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	181230.500	842.933
MOUNTAIN	891	430940.500	483.659

2 cases w ere omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	25791.000
U Prime	165129.000
Z-Value	-16.623
P-Value	<.0001
Tied Z-Value	-16.712
Tied P-Value	<.0001
# Ties	78

5 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	188349.000	876.042
MOUNTAIN	888	420507.000	473.544

5 cases w ere omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	88969.500
U Prime	102595.500
Z-Value	-1.621
P-Value	.1051
Tied Z-Value	-1.632
Tied P-Value	.1026
# Ties	42

2 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	125815.500	585.188
MOUNTAIN	891	486355.500	545.854

2 cases w ere omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	87995.000
U Prime	104000.000
Z-Value	-1.900
P-Value	.0575
Tied Z-Value	-1.911
Tied P-Value	.0560
# Ties	35

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	127220.000	591.721
MOUNTAIN	893	487166.000	545.539

Mann-Whitney Results: <u>Dystrophic vs. Piedmont Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	337431.000
U Prime	524504.000
Z-Value	-5.369
P-Value	<.0001
Tied Z-Value	-5.399
Tied P-Value	<.0001
# Ties	41

15 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	360651.000	1677.447
PIEDMONT	4009	8562549.000	2135.832

15 cases were omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	402390.000
U Prime	458255.000
Z-Value	-1.606
P-Value	.1083
Tied Z-Value	-1.606
Tied P-Value	.1082
# Ties	155

21 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	425610.000	1979.581
PIEDMONT	4003	8472261.000	2116.478

21 cases were omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	416305.000
U Prime	442405.000
Z-Value	-.752
P-Value	.4521
Tied Z-Value	-.752
Tied P-Value	.4521
# Ties	128

30 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	439525.000	2044.302
PIEDMONT	3994	8420420.000	2108.267

30 cases were omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	380344.000
U Prime	480086.000
Z-Value	-2.868
P-Value	.0041
Tied Z-Value	-2.907
Tied P-Value	.0036
# Ties	92

22 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	503306.000	2340.958
PIEDMONT	4002	8390347.000	2096.538

22 cases were omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	152808.500
U Prime	712351.500
Z-Value	-16.002
P-Value	<.0001
Tied Z-Value	-16.005
Tied P-Value	<.0001
# Ties	113

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	176028.500	818.737
PIEDMONT	4024	8810651.500	2189.526

Mann-Whitney Results: <u>Dystrophic vs. Sanhills Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	9595.000
U Prime	14485.000
Z-Value	-3.014
P-Value	.0026
Tied Z-Value	-3.054
Tied P-Value	.0023
# Ties	22

3 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	37705.000	175.372
SANDHILLS	112	15923.000	142.170

3 cases were omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	9350.500
U Prime	14944.500
Z-Value	-3.427
P-Value	.0006
Tied Z-Value	-3.430
Tied P-Value	.0006
# Ties	50

2 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	38164.500	177.509
SANDHILLS	113	15791.500	139.748

2 cases were omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	8696.500
U Prime	15383.500
Z-Value	-4.121
P-Value	<.0001
Tied Z-Value	-4.122
Tied P-Value	<.0001
# Ties	59

3 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	38603.500	179.551
SANDHILLS	112	15024.500	134.147

3 cases were omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	11618.000
U Prime	12677.000
Z-Value	-.649
P-Value	.5165
Tied Z-Value	-.652
Tied P-Value	.5146
# Ties	27

2 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	35897.000	166.963
SANDHILLS	113	18059.000	159.814

2 cases were omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	8304.500
U Prime	16420.500
Z-Value	-4.914
P-Value	<.0001
Tied Z-Value	-4.925
Tied P-Value	<.0001
# Ties	28

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
DYSTROPHIC	215	31524.500	146.626
SANDHILLS	115	23090.500	200.787

Mann-Whitney Results: <u>Mountain vs. Piedmont Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	544507.500
U Prime	3027511.500
Z-Value	-32.504
P-Value	<.0001
Tied Z-Value	-32.716
Tied P-Value	<.0001
# Ties	39

17 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	891	941893.500	1057.120
PIEDMONT	4009	11065556.500	2760.179

17 cases were omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	432882.500
U Prime	3133790.500
Z-Value	-35.405
P-Value	<.0001
Tied Z-Value	-35.418
Tied P-Value	<.0001
# Ties	151

23 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	891	830268.500	931.839
PIEDMONT	4003	11147796.500	2784.860

23 cases were omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	347713.000
U Prime	3198959.000
Z-Value	-37.527
P-Value	<.0001
Tied Z-Value	-37.535
Tied P-Value	<.0001
# Ties	127

35 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	888	742429.000	836.069
PIEDMONT	3994	11176974.000	2798.441

35 cases were omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	1683891.000
U Prime	1881891.000
Z-Value	-2.596
P-Value	.0094
Tied Z-Value	-2.630
Tied P-Value	.0085
# Ties	90

24 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	891	2279277.000	2558.111
PIEDMONT	4002	9693894.000	2422.262

24 cases were omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	423272.500
U Prime	3170159.500
Z-Value	-35.789
P-Value	<.0001
Tied Z-Value	-35.801
Tied P-Value	<.0001
# Ties	112

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	893	822443.500	920.989
PIEDMONT	4024	11268459.500	2800.313

Mann-Whitney Results: <u>Mountain vs. Sandhills Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	36872.500
U Prime	62919.500
Z-Value	-4.507
P-Value	<.0001
Tied Z-Value	-4.741
Tied P-Value	<.0001
# Ties	16

5 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	891	434258.500	487.383
SANDHILLS	112	69247.500	618.281

5 cases w ere omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	20494.000
U Prime	80189.000
Z-Value	-10.279
P-Value	<.0001
Tied Z-Value	-10.317
Tied P-Value	<.0001
# Ties	64

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	891	417880.000	469.001
SANDHILLS	113	86630.000	766.637

4 cases w ere omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	15790.000
U Prime	83666.000
Z-Value	-11.783
P-Value	<.0001
Tied Z-Value	-11.860
Tied P-Value	<.0001
# Ties	61

8 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	888	410506.000	462.282
SANDHILLS	112	89994.000	803.518

8 cases w ere omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	48780.000
U Prime	51903.000
Z-Value	-.538
P-Value	.5908
Tied Z-Value	-.542
Tied P-Value	.5880
# Ties	43

4 cases w ere omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	891	446166.000	500.747
SANDHILLS	113	58344.000	516.319

4 cases w ere omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	27874.500
U Prime	74820.500
Z-Value	-7.988
P-Value	<.0001
Tied Z-Value	-8.034
Tied P-Value	<.0001
# Ties	36

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
MOUNTAIN	893	427045.500	478.214
SANDHILLS	115	81490.500	708.613

Mann-Whitney Results: <u>Piedmont vs. Sandhills Lakes</u>

Mann-Whitney U for Total Phosphorus
Grouping Variable: Region/Type

U	127517.000
U Prime	321491.000
Z-Value	-7.809
P-Value	<.0001
Tied Z-Value	-7.853
Tied P-Value	<.0001
# Ties	39

18 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Phosphorus
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
PIEDMONT	4009	8359536.000	2085.192
SANDHILLS	112	133845.000	1195.045

18 cases were omitted due to missing values.

Mann-Whitney U for Total Nitrogen
Grouping Variable: Region/Type

U	149227.500
U Prime	303111.500
Z-Value	-6.176
P-Value	<.0001
Tied Z-Value	-6.179
Tied P-Value	<.0001
# Ties	149

23 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
PIEDMONT	4003	8317117.500	2077.721
SANDHILLS	113	155668.500	1377.597

23 cases were omitted due to missing values.

Mann-Whitney U for Total Organic Nitrogen
Grouping Variable: Region/Type

U	143543.000
U Prime	303785.000
Z-Value	-6.475
P-Value	<.0001
Tied Z-Value	-6.476
Tied P-Value	<.0001
# Ties	127

33 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Organic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
PIEDMONT	3994	8281800.000	2073.560
SANDHILLS	112	149871.000	1338.134

33 cases were omitted due to missing values.

Mann-Whitney U for Total Inorganic Nitrogen
Grouping Variable: Region/Type

U	204560.000
U Prime	247666.000
Z-Value	-1.731
P-Value	.0835
Tied Z-Value	-1.755
Tied P-Value	.0793
# Ties	90

24 cases were omitted due to missing values.

Mann-Whitney Rank Info for Total Inorganic Nitrogen
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
PIEDMONT	4002	8214563.000	2052.614
SANDHILLS	113	254107.000	2248.735

24 cases were omitted due to missing values.

Mann-Whitney U for Chlorophyll a
Grouping Variable: Region/Type

U	125025.500
U Prime	337734.500
Z-Value	-8.417
P-Value	<.0001
Tied Z-Value	-8.419
Tied P-Value	<.0001
# Ties	111

Mann-Whitney Rank Info for Chlorophyll a
Grouping Variable: Region/Type

	Count	Sum Ranks	Mean Rank
PIEDMONT	4024	8436034.500	2096.430
SANDHILLS	115	131695.500	1145.178