



Arkansas Water Resources Center

BEAVER LAKE WATER QUALITY ENHANCEMENT PROJECT DATA ANALYSIS

MSC-201

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Executive Summary

This study consists of analyses of the water quality data generated during the 4 years of sampling for the Beaver Lake Water Quality Enhancement Project along with limited data on best management practices (BMPs) implemented by farmers in the studied subwatersheds. The water quality data were collected from 12 stream sites, 3 overland flow sites, and 5 lake sites. The water quality data were collected by Environmental and GIS Consulting, Inc. (EGIS) and compiled in a report to the U.S. Army Corps of Engineers, Little Rock District (Corps) and the Arkansas Soil and Water Conservation Commission (ASWCC) in June 1996. The study described in the attached report analyzed the stream and lake data for trends and parameter relationships, examined the effects of statistically regenerated data in the original study, assessed the eutrophic state of Beaver Lake, and evaluated the impacts of BMP implementation on water quality.

Trend analysis on the data indicated decreasing trends for ortho phosphate and total phosphate at all stream and lake sites, although most of these trends were not statistically significant and there was uncertainty in the quality of the phosphorus data. Trends in the other water quality parameters were non-uniform (not all positive or all negative) and showed few significant trends for individual sites.

Calculation of the correlation between BMP implementation and parameter trends suggested that a relationship may exist between greater extent of BMP implementation and decreases in total P; however, this relationship is not seen with ortho P. The BMPs may contribute to the apparent downward trend in phosphorus values during the study period, however, a cause and effect relationship cannot be established. Other parameters are not significantly correlated to the relative extent of BMP implementation.

The trophic status of Beaver Lake is predominantly eutrophic based on primary productivity measured as chlorophyll *a* in this study and total P levels obtained from a USDA/ARS study by Haggard.

Correlation coefficients for the relationships between different parameters were calculated. Although some relationships were statistically significant, there was only a weak association between the parameters in that the correlations were far from ± 1 , meaning that one parameter could only explain a small amount of variation in the other parameter.

The effect of regenerated flow data in the original study was examined and it was determined that the flow data regeneration is unlikely to be a major source of inaccuracy.

Acknowledgments

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Dr. Philip Moore of USDA/ARS, gave permission for unpublished data from Brian Haggard's thesis (collected under a USDA/ARS project directed by Dr. Moore) to be used for comparison in this study. Parts of the MathCAD documents for trend analysis by the Seasonal Kendall test were adapted from MathCAD documents written by Jan Zwaenepoel.

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1. Observations on Loads and Flows

The stream loads were recalculated and examined. The loads were calculated by integration of the concentrations on cumulative flow. This differs somewhat from the method used by EGIS. Loads calculated in this study are compared to those of the EGIS study in Figures 1.1 and 1.2. Figure 1.1 shows the “total nitrogen” (which we refer to as Total Kjeldahl Nitrogen, TKN) loads while Figure 1.2 shows the Ortho Phosphate (also called Soluble Reactive Phosphate, SRP) loads. The stream nitrogen loads calculated in this study are similar to those reported by EGIS. In the EGIS study, SRP data below the detection limit was reported as the detection limit and calculations were based on the detection limit values. The SRP loads calculated in this study used data values below the detection limit for calculation and thus the calculated loads in this study are consistently smaller.

More than 70% of the SRP data in the original study was “censored”, i.e., reported at the detection limit which is set based on confidence in the data values. Based on Monte-Carlo studies, Gilliom et al. (1984) recommended reporting and using the actual measured concentrations in trend analysis even if they are below the detection limit. Censoring the data is a loss of information. Davis et al. (1995) suggest that “when dealing with censored values, the objective is to maximize information without losing statistical integrity.” Even though the data below the detection level are not accurate enough to be reported, calculations using the uncensored data are likely to be more representative of actual conditions than calculations using the detection limit. Specifically, mean values and loads will be overestimated if the detection limit is used rather than the actual value which is known to be less. Loads and trends were calculated

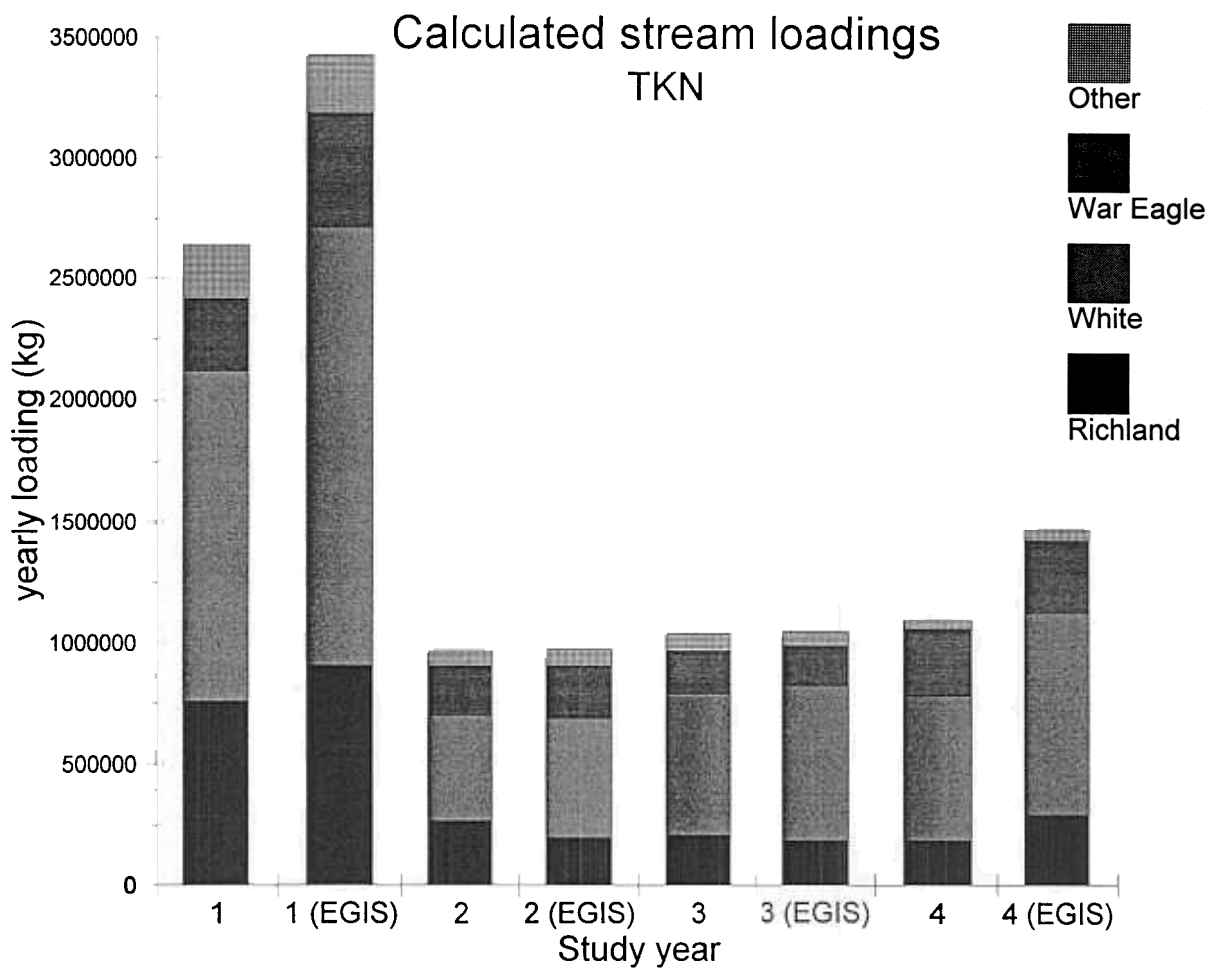


Figure 1.1 Nitrogen loads calculated in the present study and by EGIS

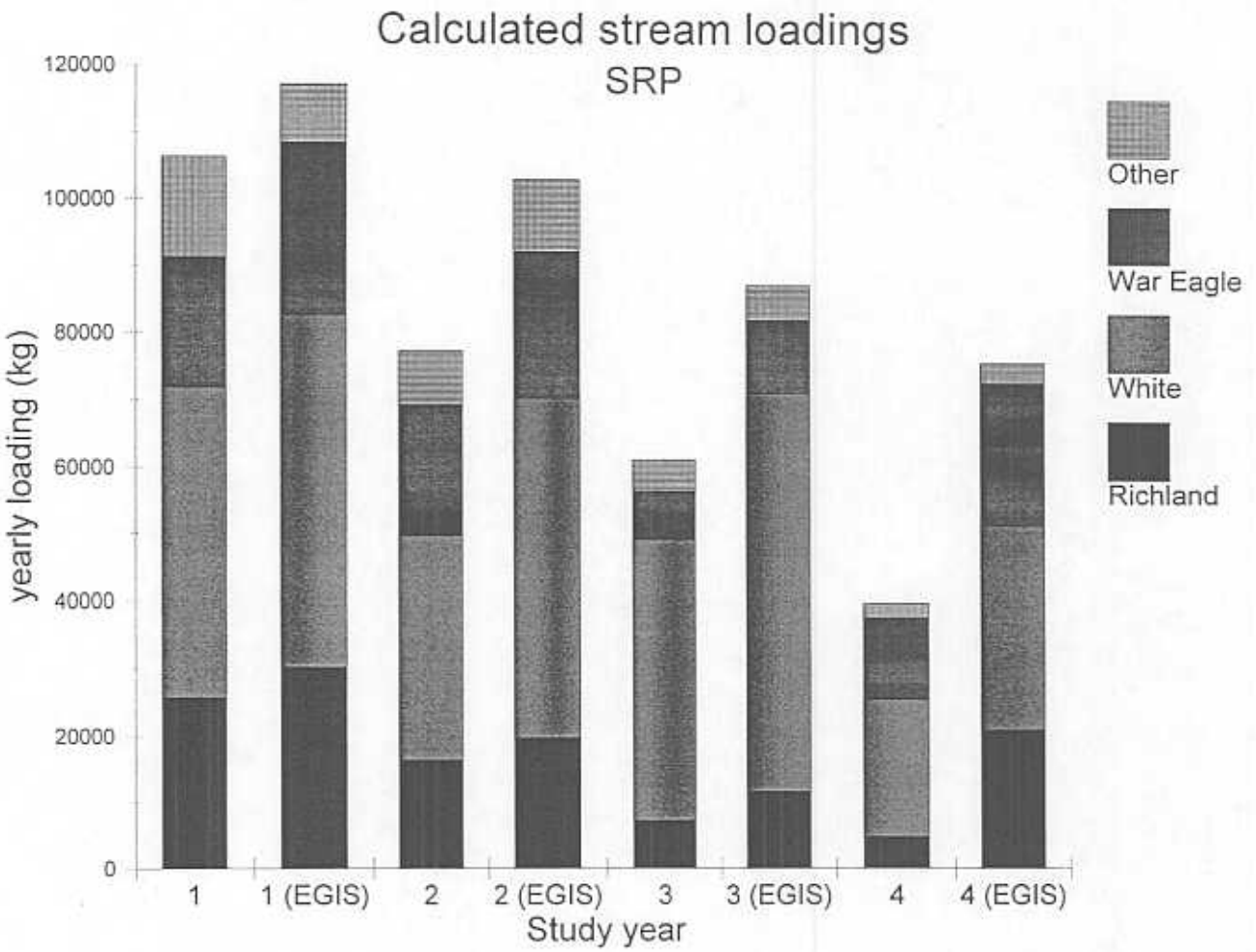


Figure 1.2 Phosphorus loads calculated in the present study and by EGIS

with both the censored and uncensored data. The results calculated using the uncensored data are reported here.

The discharge at stream site 3 appeared anomalously high during the fourth year of the study. This is apparent in the charts of seasonal discharge and load in the EGIS report (Figures 3.2 and following in the EGIS report). In fact, the reported discharge was higher at site 3 than at site 4 during the final year. This is questionable because site 3, Clifty Creek, is a tributary to site 4, War Eagle Creek. Figure 1.3 shows the discharge at sites 3 and 4. It is possible that the storm beginning May 1, 1995 altered the stream and changed the stage-discharge relationship. By comparing the discharge in the year before and after this date at site 3 and site 4, it was determined that the discharge data could be adjusted by dividing the reported value by 20. The adjusted discharge is also shown in Figure 2. The adjusted discharge values were used to calculate loads.

stream site 3 and 4 flow data

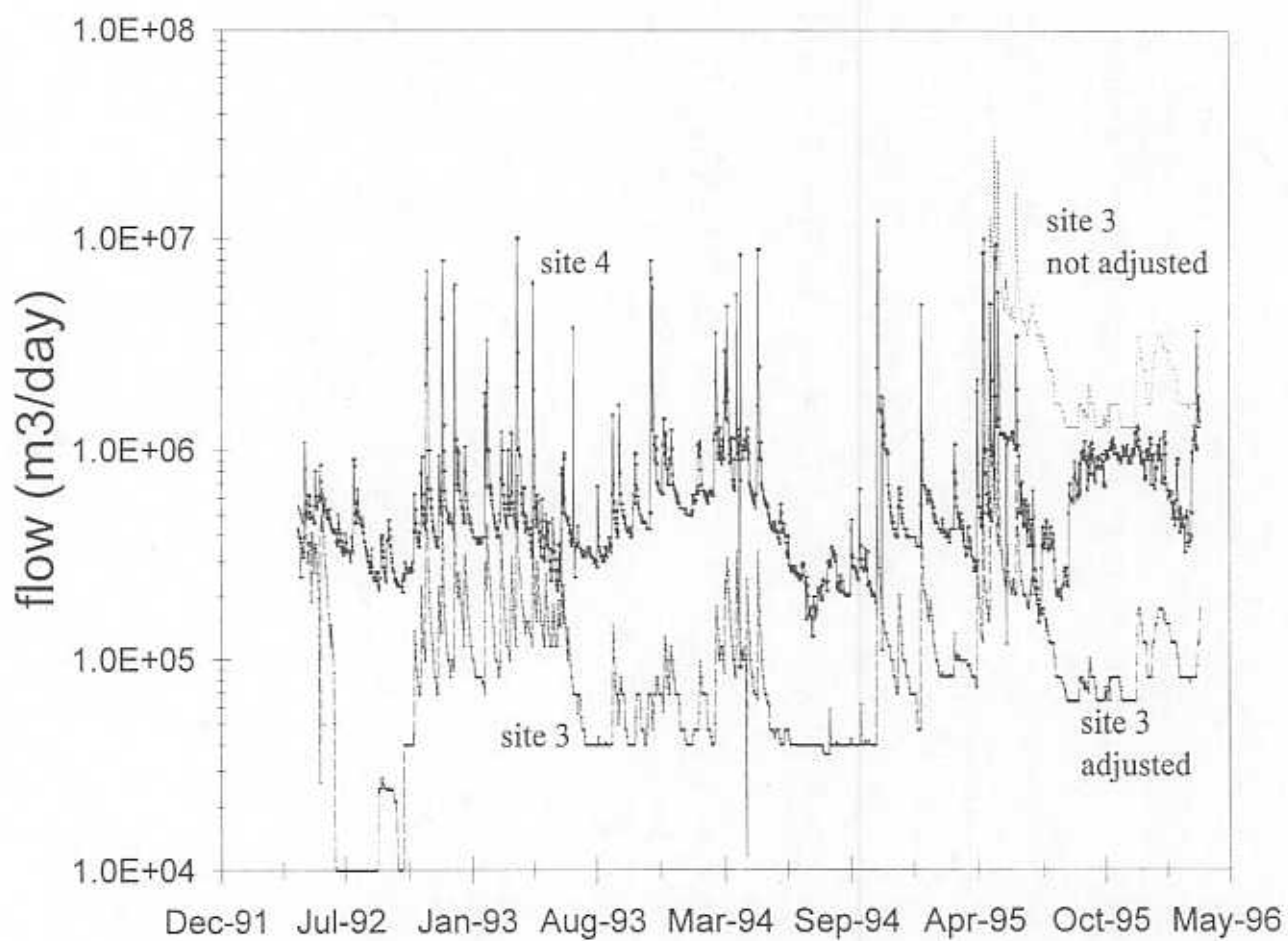


Figure 1.3 Flow at stream sites 3 and 4

2. Statistically regenerated data

Due to equipment malfunctions, a portion of the flow data in the original study had to be statistically regenerated. Also, the flow data at sites 4 and 7 were calculated from the measured flow at sites 2 and 9 respectively because of difficulties in measuring

The data were examined with and without the statistically regenerated flow data at several sites. The mean and variance of the data sets with and without the regenerated data were not significantly different. Without the regenerated data, concentrations of samples taken during the period of equipment malfunction cannot be used to calculate

Loads calculated for stream site 2 with and without the statistically regenerated flow data are shown in Figure 2.1. The values are similar. Years 1 and 2 of the TSS loads show a difference between the two data sets; however, the sum of the two years is similar.

The regeneration of flow data, which according to EGIS was performed by a professional statistician, allowed the use of all sample concentrations in the loading calculations. In comparison to the uncertainties in stage-discharge relationships and loading calculations (as demonstrated previously), the flow data regeneration is unlikely to be a major source of inaccuracy. Although having the actual data would be more accurate than and preferable to using the regenerated data, the use of the regenerated data is likely to be more accurate than omitting the regenerated data. The accuracy of using other sites to calculate discharge at site 4 and site 7 cannot be determined without actual data from those sites. However, the approach to calculating the discharges at site 4 and 7 seems logical and the loading results are within a reasonable range.

loadings with/without recreated data stream site 2

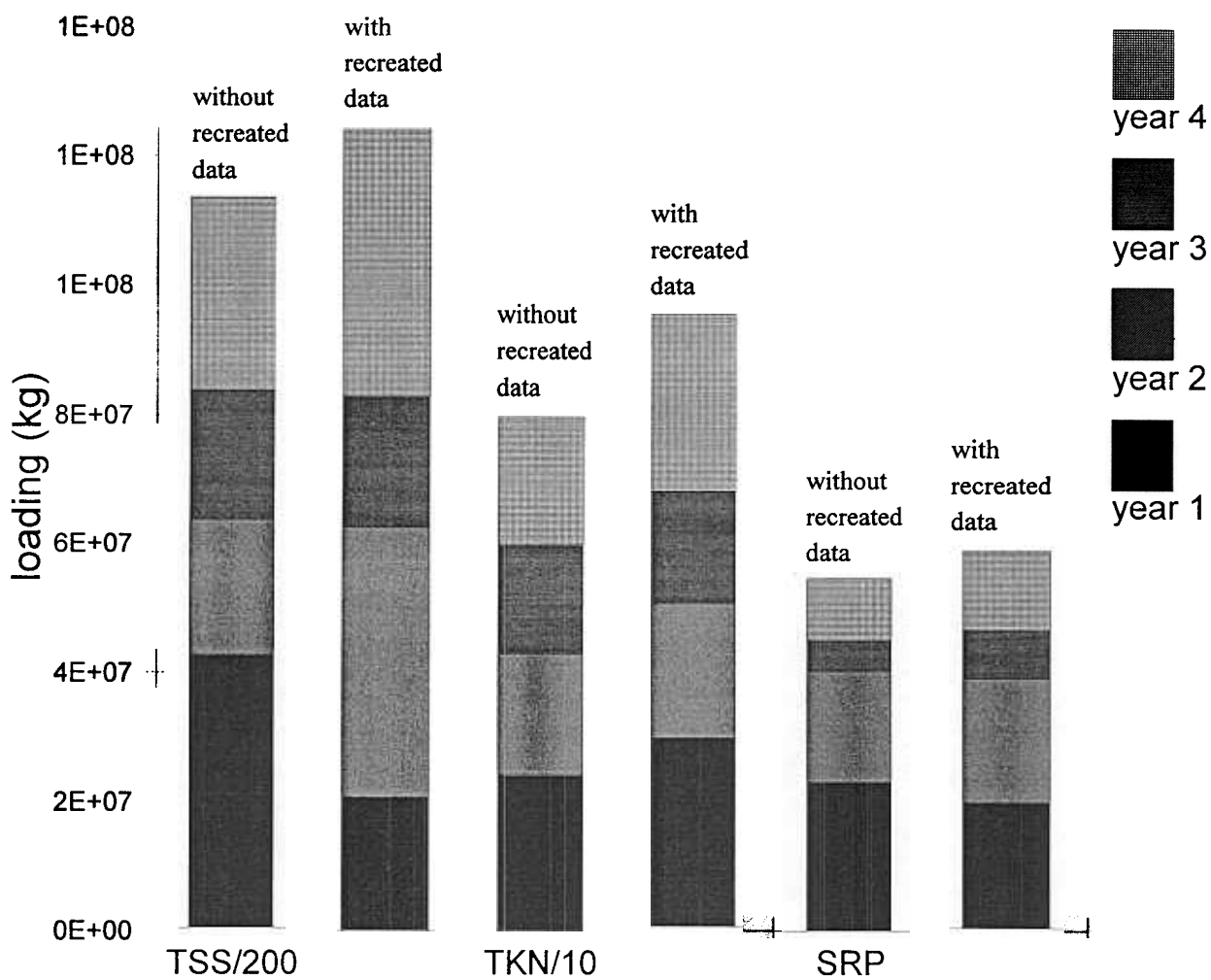


Figure 2.1 Site 2 loads calculated with and without statistically regenerated data (TSS and TKN are scaled to show on the same scale as SRP)

3. Trends

The stream and lake data were examined for trends using the modified Seasonal Kendall test for trend (Hirsch and Slack, 1984). The Seasonal Kendall test is a nonparametric test which compares a data value to data values taken during the same “season” in subsequent years. In this way, seasonal effects are reduced. If the later value in time is larger, a plus is assigned to the comparison. If the later value is smaller, a minus is scored. A season can be defined in any appropriate way. The test statistic, S , is the sum of plusses and minuses for all comparisons. For the statistical tests, S was normalized to the normal distribution statistic z ($z = S/\text{variance}$).

The Seasonal Kendall test has been used in a number of water-quality trend studies including Petersen (1992) and Baldys et al. (1995). Although Petersen (personal communication, 1996) suggested that as “a rule of thumb” a minimum of five years of data is needed to make inferences about trends, the Seasonal Kendall test was chosen as the method used to examine trends in the four years of data in this study. The method was programmed into MathCAD software. Examples of MathCAD worksheets used are provided in the appendix. The USGS uses the computer program ESTREND (Schertz et al., 1991) to perform trend analysis including the Seasonal Kendall test; however, at this time the program can only be run on a PRIME series 50 minicomputer (Ohe, personal communication, 1996).

Trend analysis on the stream site concentrations was performed using flow-adjusted residuals. Values of water-quality parameters are often related to streamflow. To reduce flow effects, the log of the concentration values were regressed on the log of the flow values using a locally weighted regression procedure built into MathCAD. The

residual is the actual concentration minus the concentration predicted by the regression. This reduction of flow-related variability is a fairly well-established technique (Helsel and Hirsch, 1992). Figure 3.1 shows a plot of residuals versus date for Ortho P (SRP) at stream site 7.

Trend analysis on the lake data was performed on the residual of the actual value minus the geometric mean. Because the test only measures the sign of the difference in data pairs (higher or lower), the use of residuals for the lake data trends is a visual and numerical convenience and not crucial to the method.

The base concentration data for both the stream and lake sites were divided into 9 seasons determined by the 9 sampling events each year. For example, the third sampling event in year 1 was compared to the third sampling event in subsequent years. Although the sampling date was not the same every year, this way of determining “seasons” provided the best combination of data pairs. Missing values were not used in the comparisons. Although there were only 8 sampling events the first year for most sites, using 9 seasons allows 9 comparisons to be made between years 2-3, 2-4, 3-4. Storm sampling events were not used in trend analysis because the dates of the storm sampling were too irregular and there were not enough sampling events to collate into seasons.

For the lake data, the seasons were further divided by depth so that there were 27 “seasons” per year (9 dates x 3 depths). This way, comparisons were made between concentrations at the same depth - near surface, mid, and supra-bottom. In addition, the data from all lake sites were combined to calculate a trend statistic for all the lake data together. Comparisons were made only between samples at the same site, but the

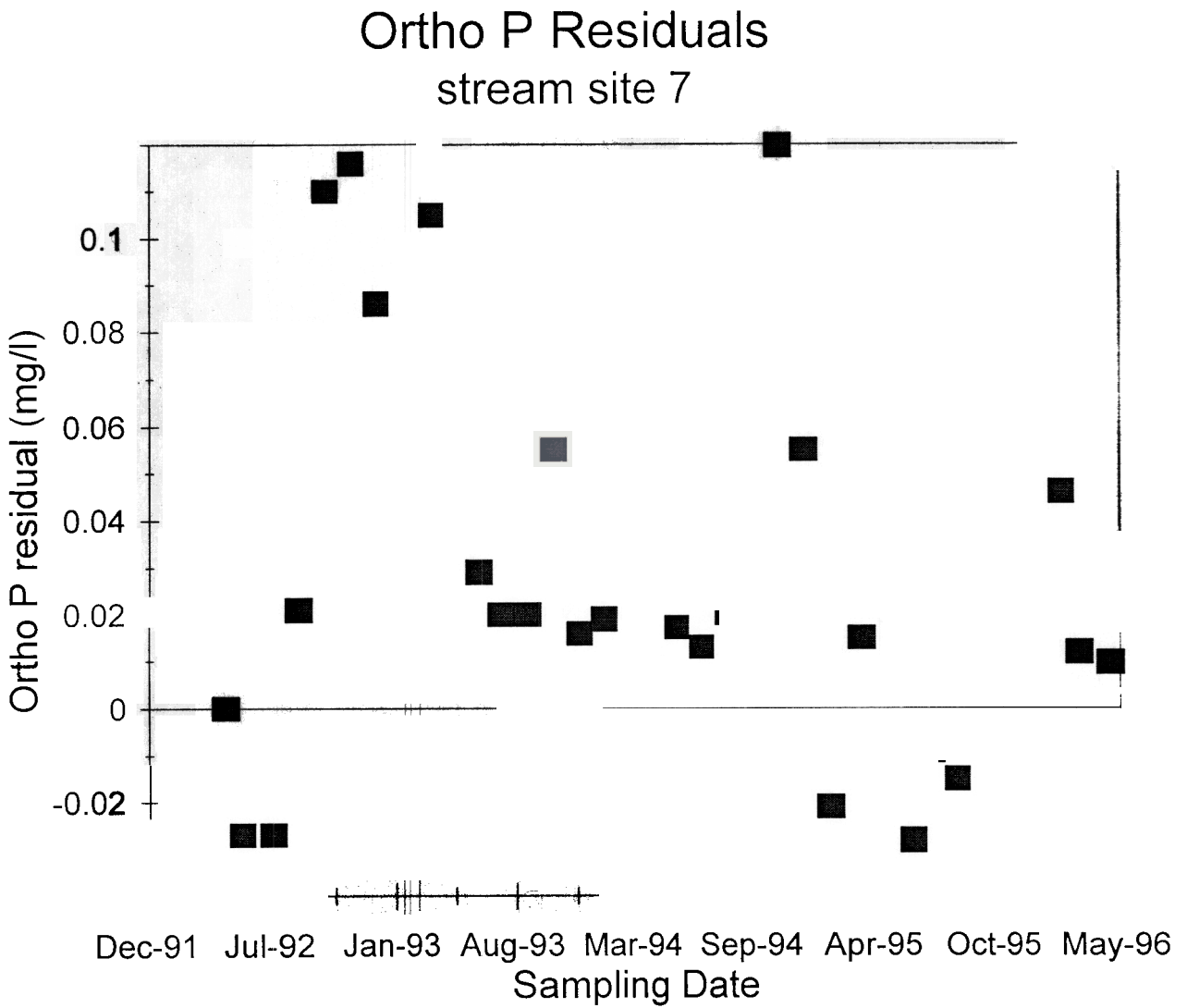


Figure 3.1 Residuals plot for Ortho P at stream site 7

combined statistic is calculated based on the sum of all comparisons for all sites for each parameter.

Table 3.1 shows the z values for trend for the stream sites (sites 1 and 5 were excluded due to insufficient data). A trend is significant at the $\alpha = 0.05$ significance level if $z < -1.960$ (decreasing trend) or if $z > 1.960$ (increasing trend). The critical value for $\alpha = 0.10$ is ± 1.645 . Figures 3.2 through 3.6 show the trends for the stream sites. Figures 3.7 through 3.11 show the trends for the lake sites.

The phosphorus trends, shown in Figure 3.2 for the stream sites and figure 3.7 for the lake sites, are all decreasing. Although none of the phosphorus trends are significant at the $\alpha = 0.05$ level, a number of the Ortho P (SRP) trends, including the combined lake trend, are significant at the $\alpha = 0.10$ level. The fact that phosphorus trends at all sites are decreasing and that some of the trends are significant at the $\alpha = 0.10$ tends to support the observation that phosphorus concentrations and loads, especially Ortho P, decreased during the four year study period. Figure 3.1 shows the Ortho P residuals versus time for stream site 7 for which a decreasing trend was calculated. As noted elsewhere in this report, because of data uncertainty due to high detection and reporting levels of the P analyses, caution should be used in discerning trends in the P data. Haggard (1997) found that SRP and TP concentrations increased from 1993-94 to 1994-95.

No clear trends can be seen in the nitrogen data (Figures 3.3 and 3.8). Nitrate shows positive trends at eight out of the ten stream sites with one negative trend and one having no trend ($z = 0$ at site 10). The lake sites show downward trends in nitrate with the exception of site E. Ammonia trends are mixed at the stream and lake sites. TKN is

decreasing at most stream sites and all lake sites although most trends are far from being significant.

Chlorophyll trend results are also mixed (Figures 3.4 and 3.9). None of the chlorophyll trends are significant. Most of the dissolved oxygen (DO) trends at the stream (Figure 3.5) and lake sites are positive but not significant. Figure 3.10 shows the combined lake trends for nutrients and DO. Temperature trends are mostly negative but not significant (Figures 3.6 and 3.11). Trends in the other parameters are mixed.

Table 3.1 Beaver Lake Trend Analysis

z values for trend

stream site	TSS	Ammonia	Nitrate	TKN	uncensored Ortho P	Total P	censored Ortho P	Total P	TOC	Chor-a	Chlor-b	Chlor-c	Temp	pH	DO	Cond	Turb
avg	-0.7918	-0.4193	0.9169	-0.5941	-1.4005	-1.0661	-1.1569	-0.7567	-0.636	0.3951	-0.4523	-0.7609	-0.5764	-1.0103	0.7871	0.7303	-0.4972
2	-1.06	-1.044	1.036	-0.836	-1.661	-1.096	-1.908	-0.767	-0.418	1.089	0	-1.429	-0.667	-1.141	0.871	0.234	-1.085
3	-0.643	0	1.12	0	-1.377	-0.764	-1.377	-0.815	-0.703	0.916	0	-0.772	0	-0.417	1.243	1.249	0.914
4	-1.661	-1.103	1.488	-1.116	-1.459	-0.455	-1.736	-0.321	-0.881	0.086	-0.31	-0.606	0	-1.33	0.618	1.356	-1.249
6	-0.571	-0.862	0.757	-0.178	-1.176	-1.036	-1.066	-0.611	0	0.646	-1.093	-1.091	-0.895	-0.746	1.455	-0.543	-0.486
7	-0.864	1.057	1.834	0.169	-1.779	-1.143	-1.743	-0.956	-1.349	1.163	0.697	0.294	-1.036	-0.588	0	1.495	-1.38
8	-0.593	-1.664	-0.987	-0.76	-1.413	-1.196	0	-0.587	-1.253	1.357	-0.528	-1.569	-1.455	-1.357	-0.53	0.954	-0.93
9	-1.674	1.057	1.706	-0.835	-1.542	-1.032	-1.214	-1.368	0	0.578	-0.584	-0.303	1.741	-0.937	1.816	1.407	-0.744
10	-0.729	-0.16	0	-0.384	-1.703	-1.091	-1.495	-0.928	-1.203	-0.234	-0.435	-1.459	-1.556	-0.97	1.393	0.67	-1.531
11	-0.486	-0.332	0.62	-1.6	-1.122	-1.643	0.323	-0.784	0	-1.468	-0.992	-1.202	-0.647	-1.629	0	0.715	1.171
12	0.363	-1.142	1.595	-0.401	-0.773	-1.205	-1.353	-0.43	-0.553	-0.182	-1.278	0.528	-1.249	-0.988	1.005	-0.234	0.348

Nutrient trends - stream sites Phosphorus

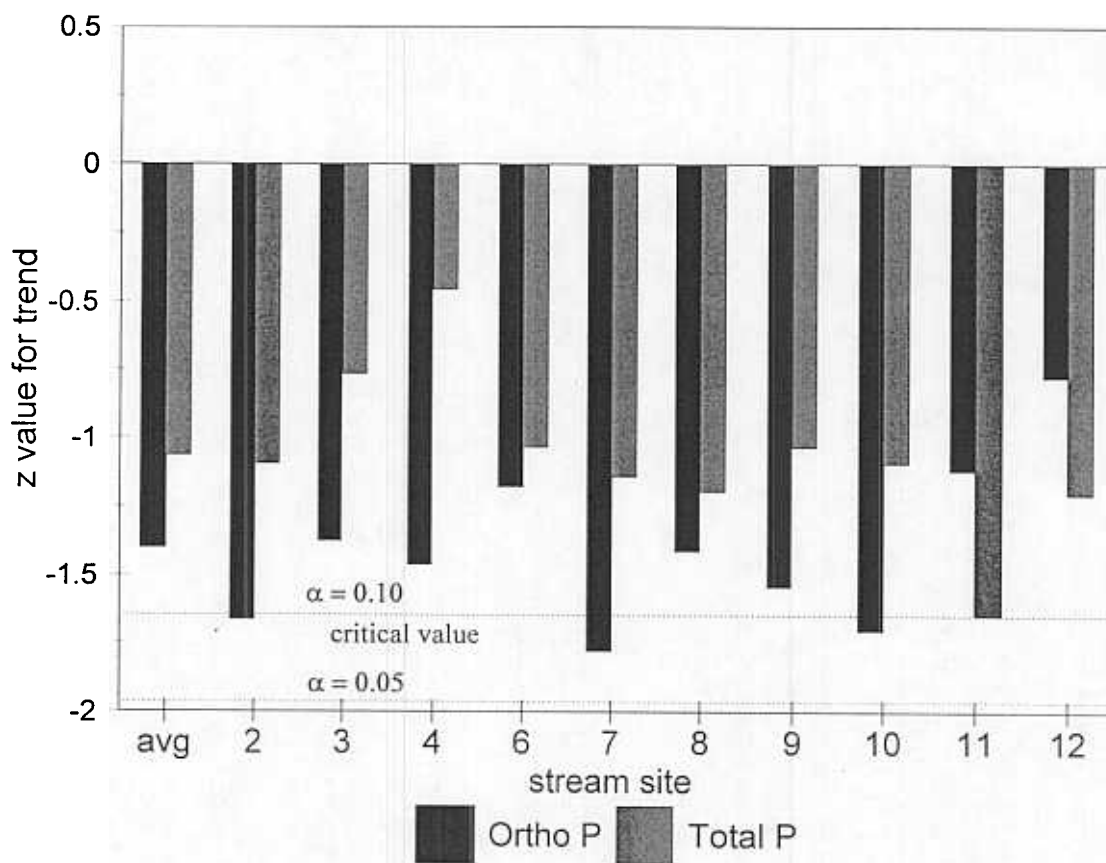


Figure 3.2 Stream site trends for phosphorus

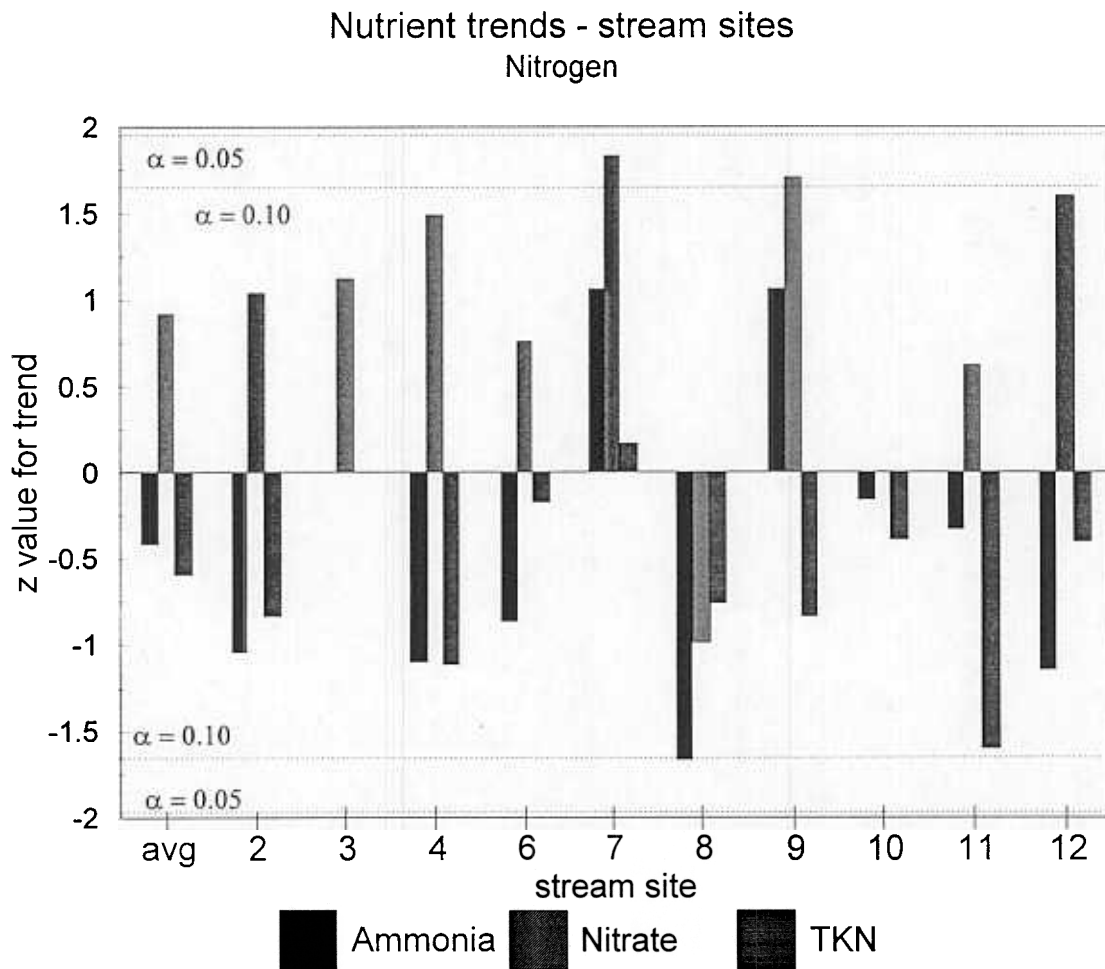


Figure 3.3 Stream site trends for nitrogen

Parameter trends - stream sites
Chlorophyll

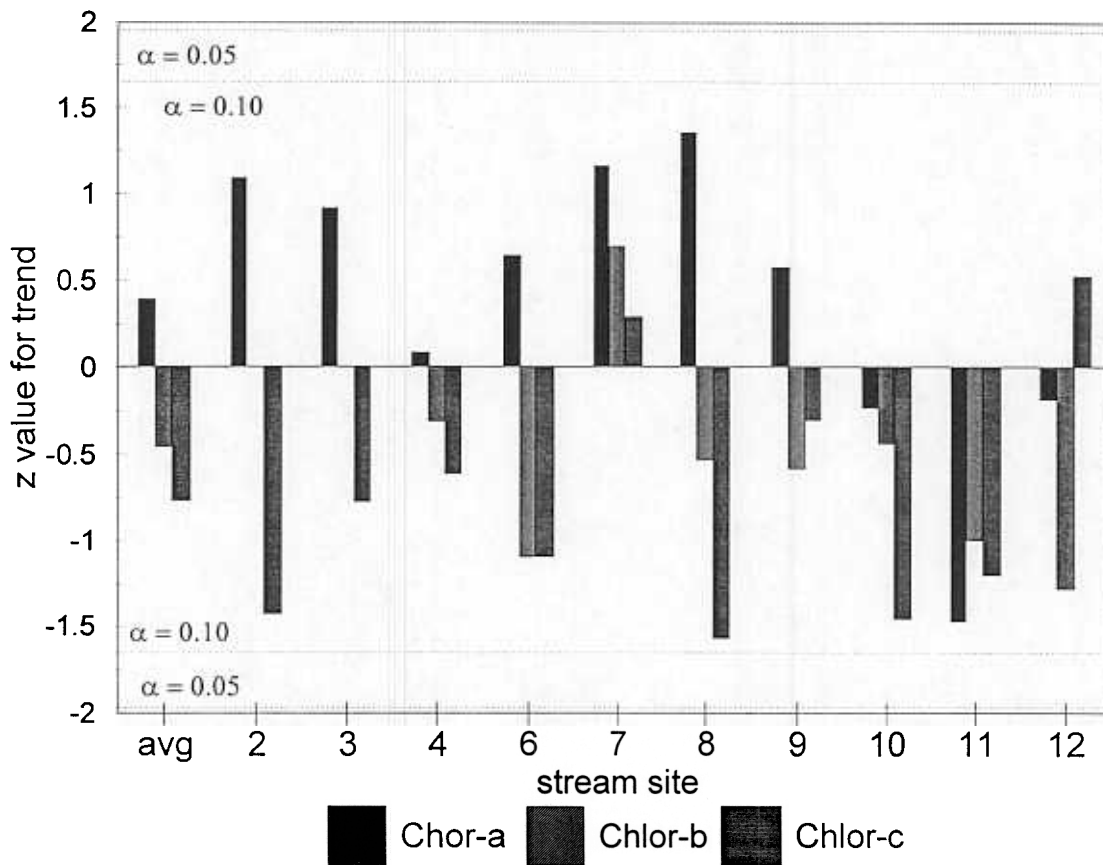


Figure 3.4 Stream site trends for chlorophyll

Parameter trends - stream sites
TSS, TOC, DO

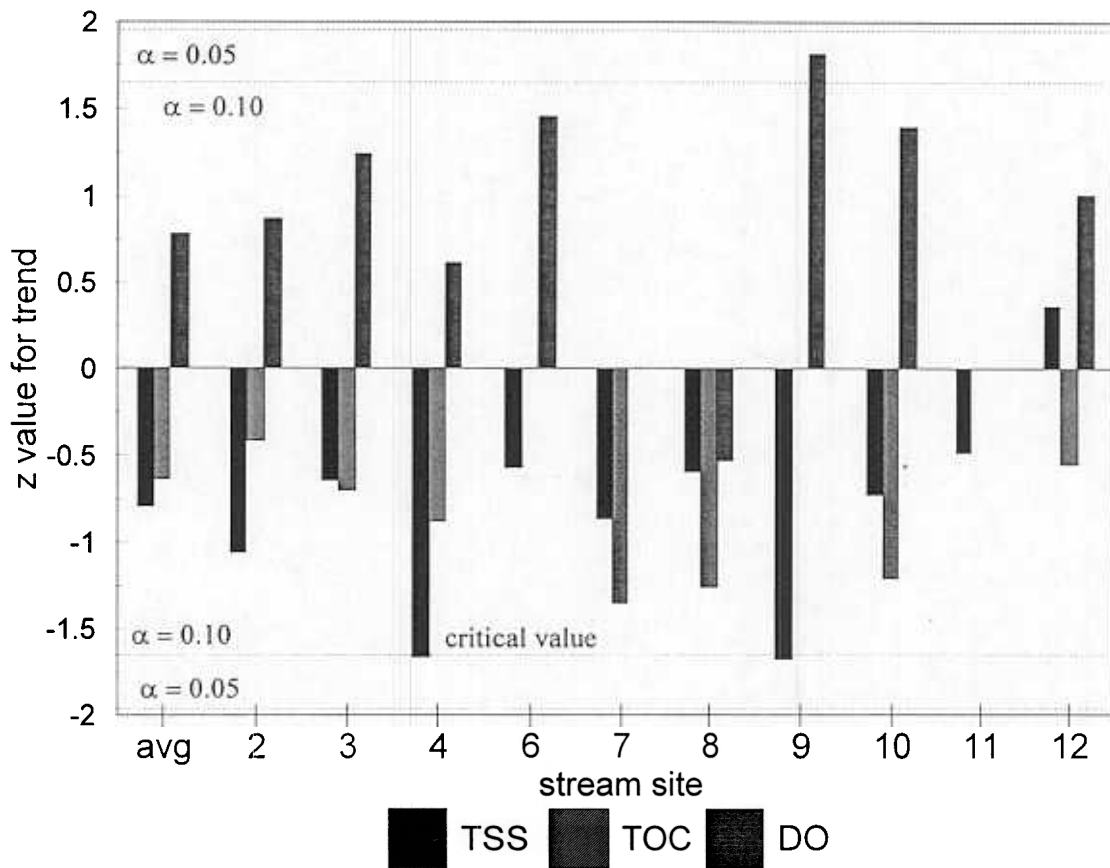


Figure 3.5 Stream site trends for TSS, TOC, DO

Parameter trends - stream sites
Temp, pH, Cond, Turb

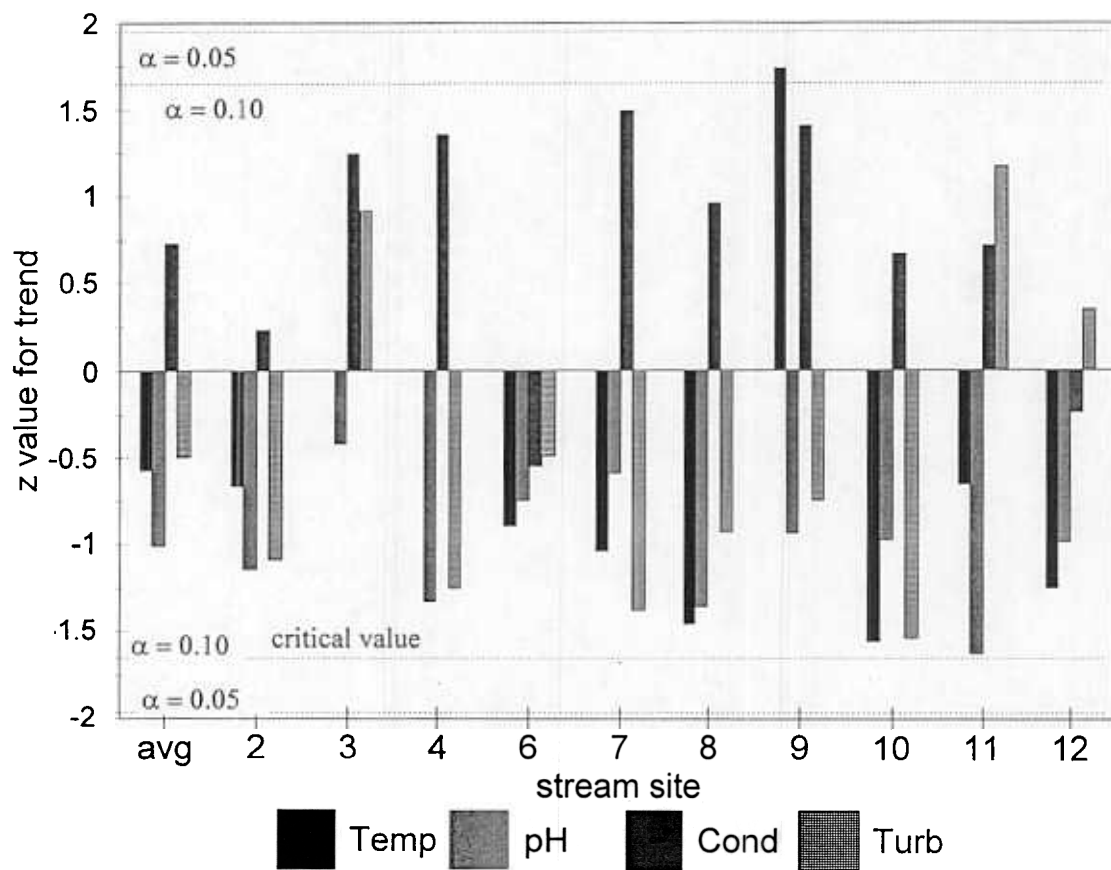


Figure 3.6 Stream site trends for temperature, pH, conductivity, and turbidity

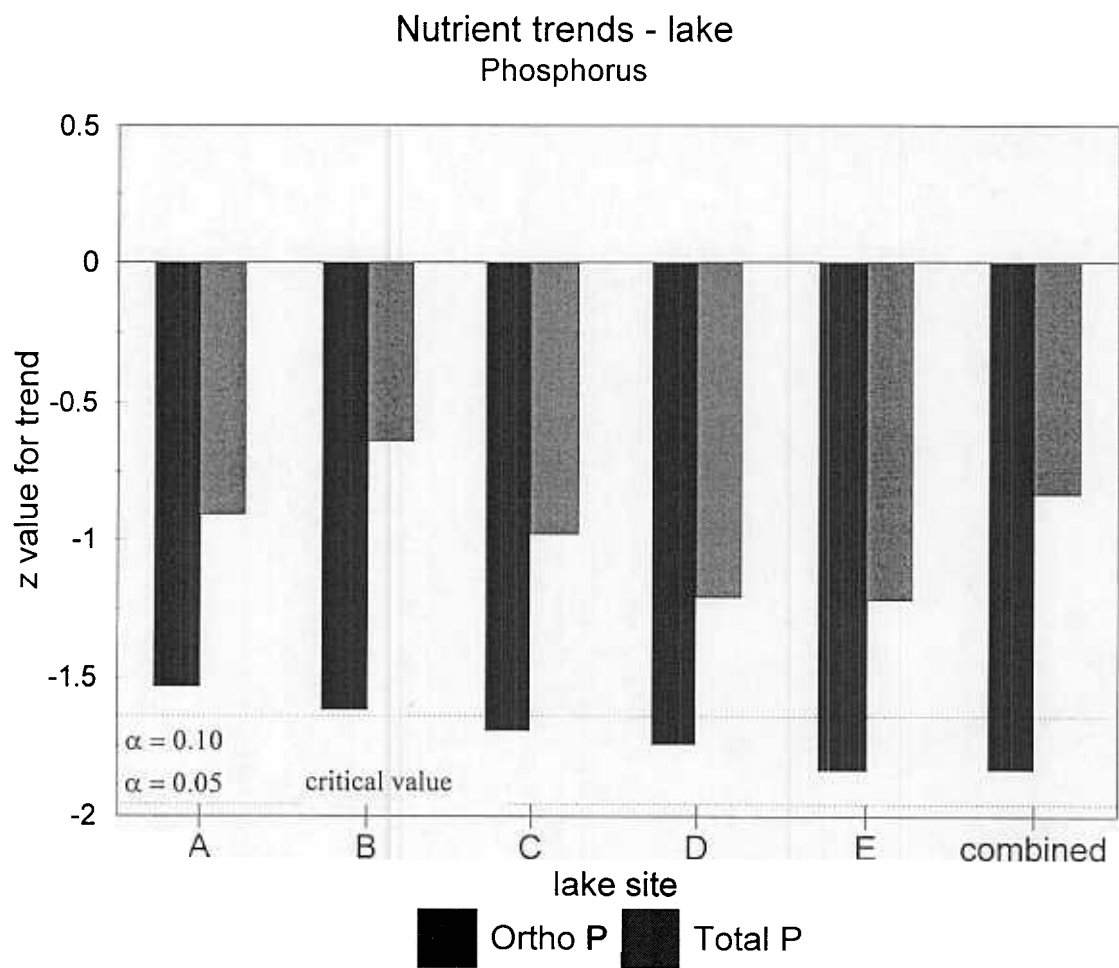


Figure 3.7 Lake site trends for phosphorus

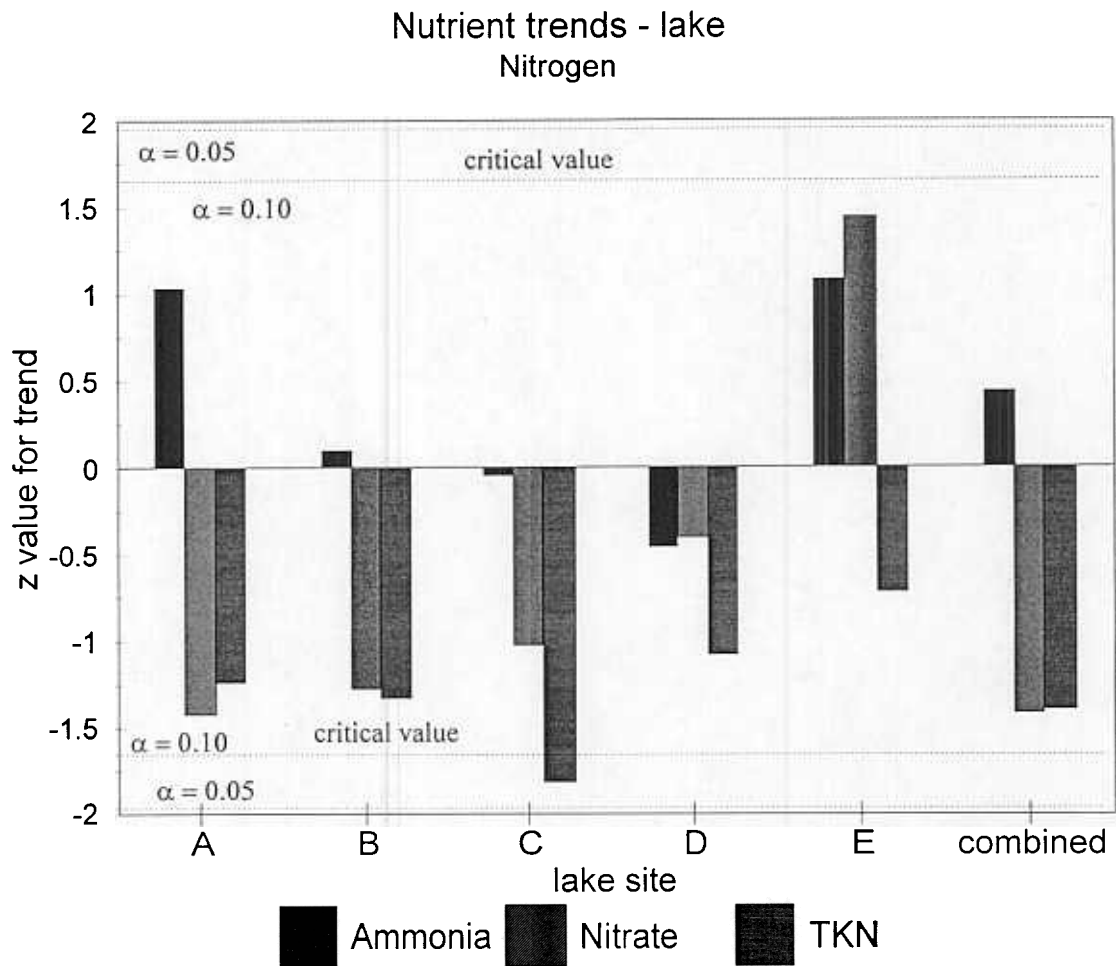


Figure 3.8 Lake site trends for nitrogen

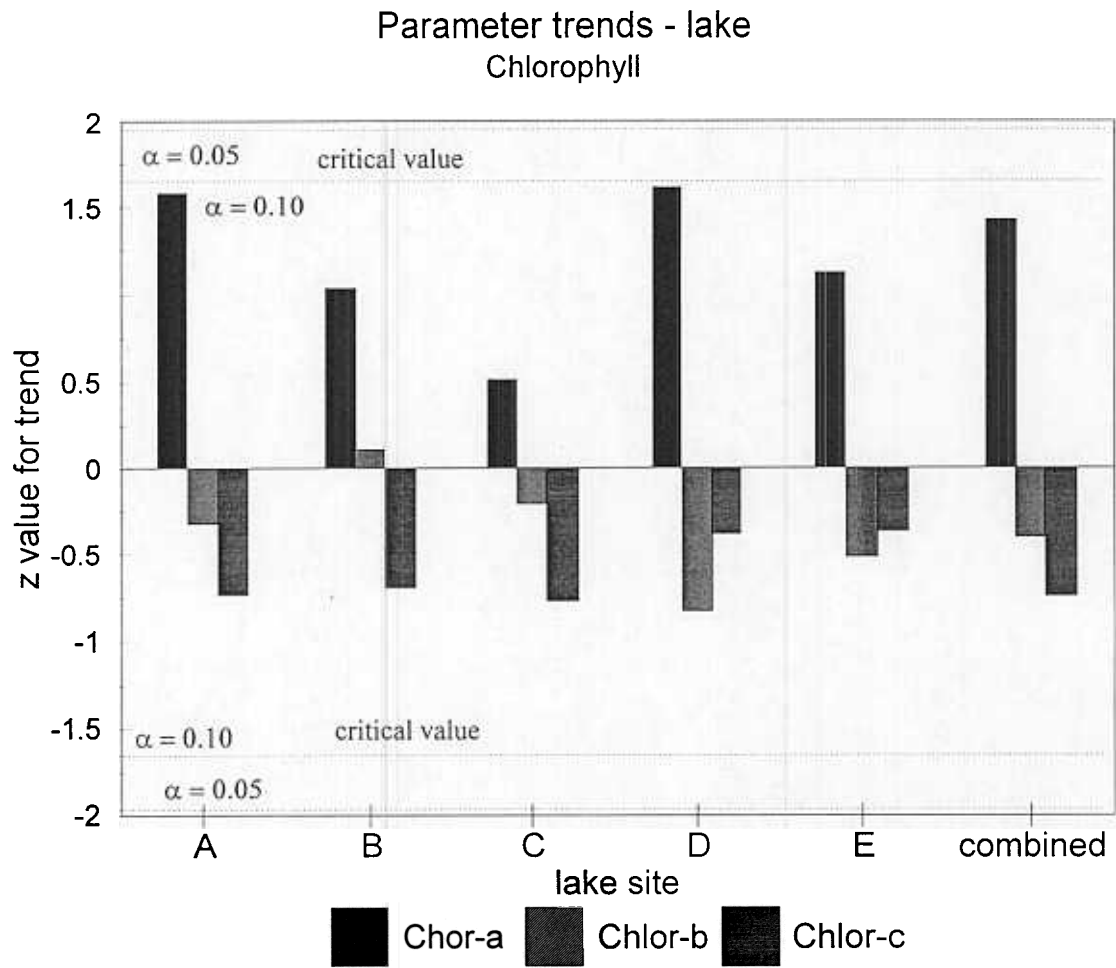


Figure 3.9 Lake site trends for chlorophyll

Trends - combined lake data
Nitrogen, Phosphorus, DO

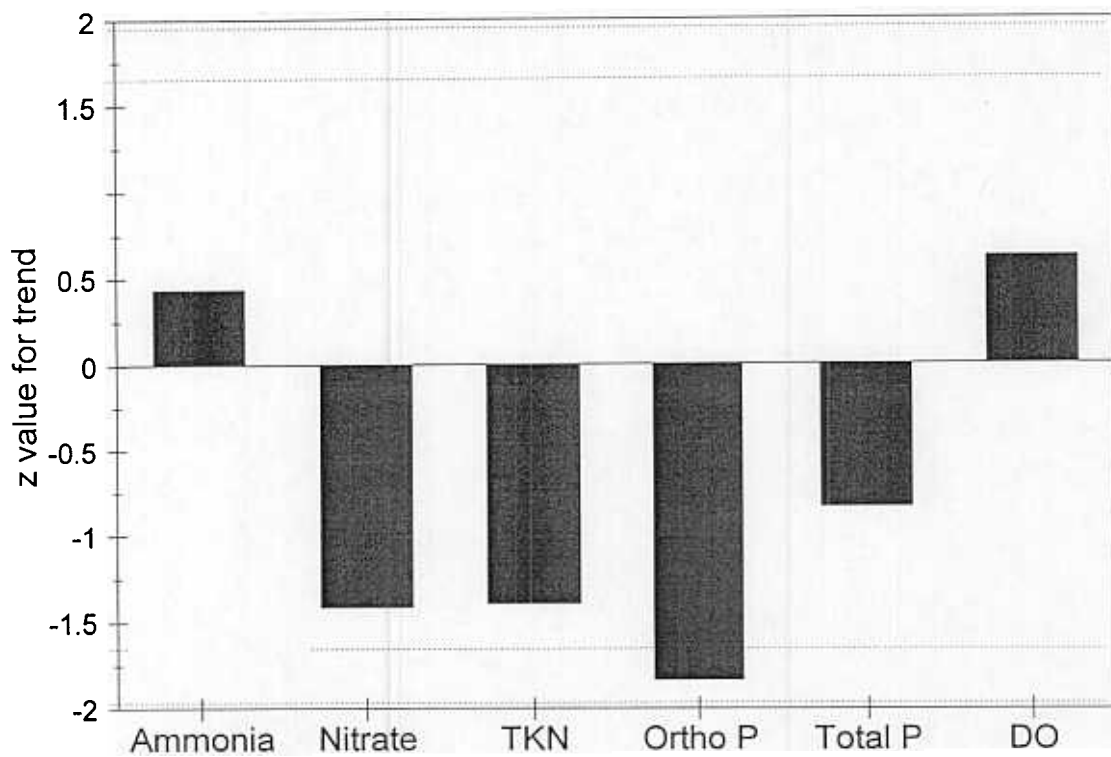


Figure 3.10 Combined lake data trends for nitrogen, phosphorus, and DO

Trends - combined lake data
various parameters

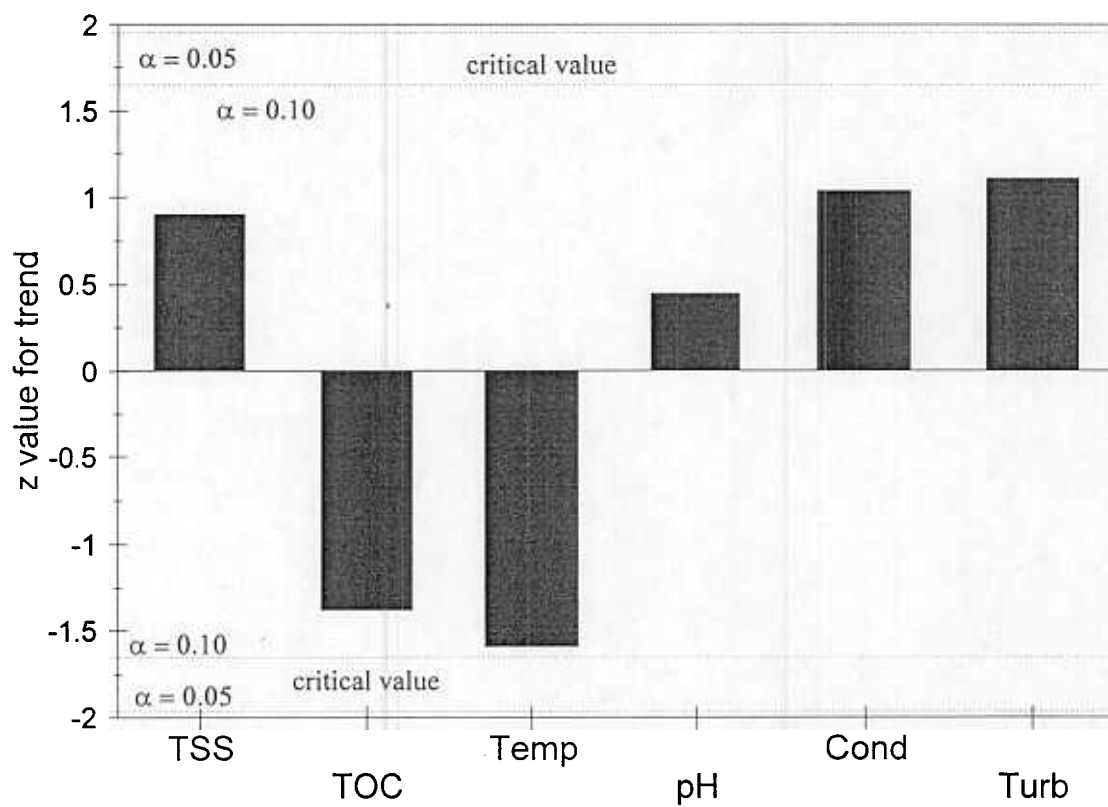


Figure 3.11 Combined lake data trends for various parameters

4. Correlation of BMPs and Trends

To examine the relationship between BMP implementation and water quality trends, the correlation between measured BMP implementation and water quality parameter trends were calculated. Measurements of six BMPs (e.g., acres of pasture and hayland establishment) for each site subwatershed were divided by the acres of grassland in that subwatershed. These fractions were then normalized by dividing by the maximum value among the site subwatersheds. In this way, for each site subwatershed and each of the six evaluated BMPs, there is a number between 0 and 1 which is a relative measure of the extent of that BMP implementation in that subwatershed. These measures are shown in Figure 4.1. Figure 4.2 shows the relative average of the six BMPs for each site subwatershed. The relative average varies between 0.33 and 1. Thus, some site subwatersheds have had three times as much relative BMP implementation than others by these measures.

The correlation coefficient between the trends at the sites and the six BMP measures and the average for the sites was calculated. In addition, the correlation between parameter trends and fraction of grassland, woodland, and other was calculated. Table 4.1 shows the calculated correlation coefficients. Figure 4.3 shows the correlation coefficients for the relationship between phosphorus trends and BMP implementation. Four of the six BMPs and the overall average had an inverse correlation with total P which was significant at the $\alpha = 0.05$. In other words, more BMP implementation corresponds with a more significant decreasing trend in total P. This is contradicted somewhat, however, by the fact that BMPs and Ortho P (SRP) have slightly positive correlation.

BMP implementation in subwatershed

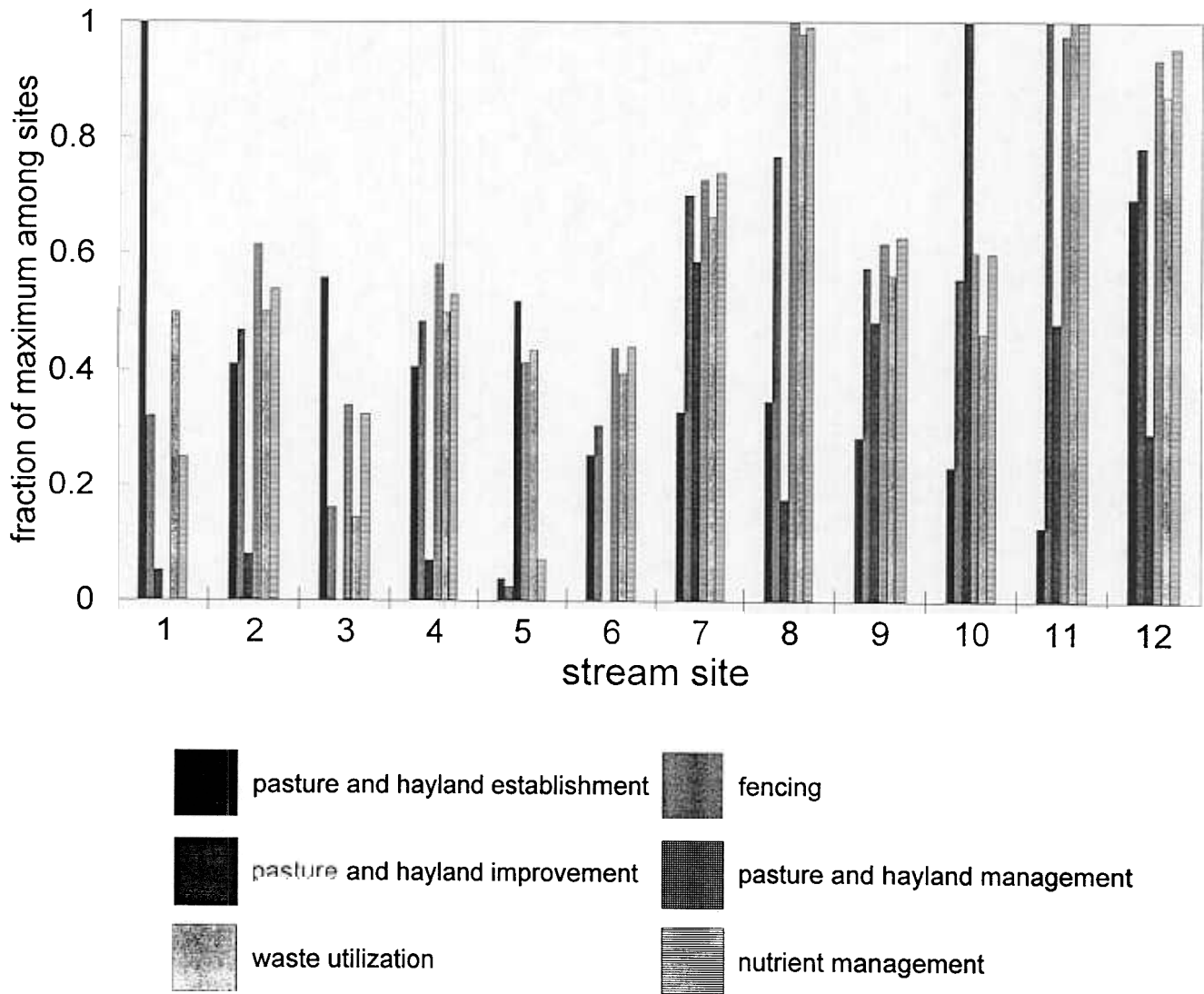


Figure 4.1 Relative measures of BMPs in stream subwatersheds

BMP implementation in subwatershed average of BMPs

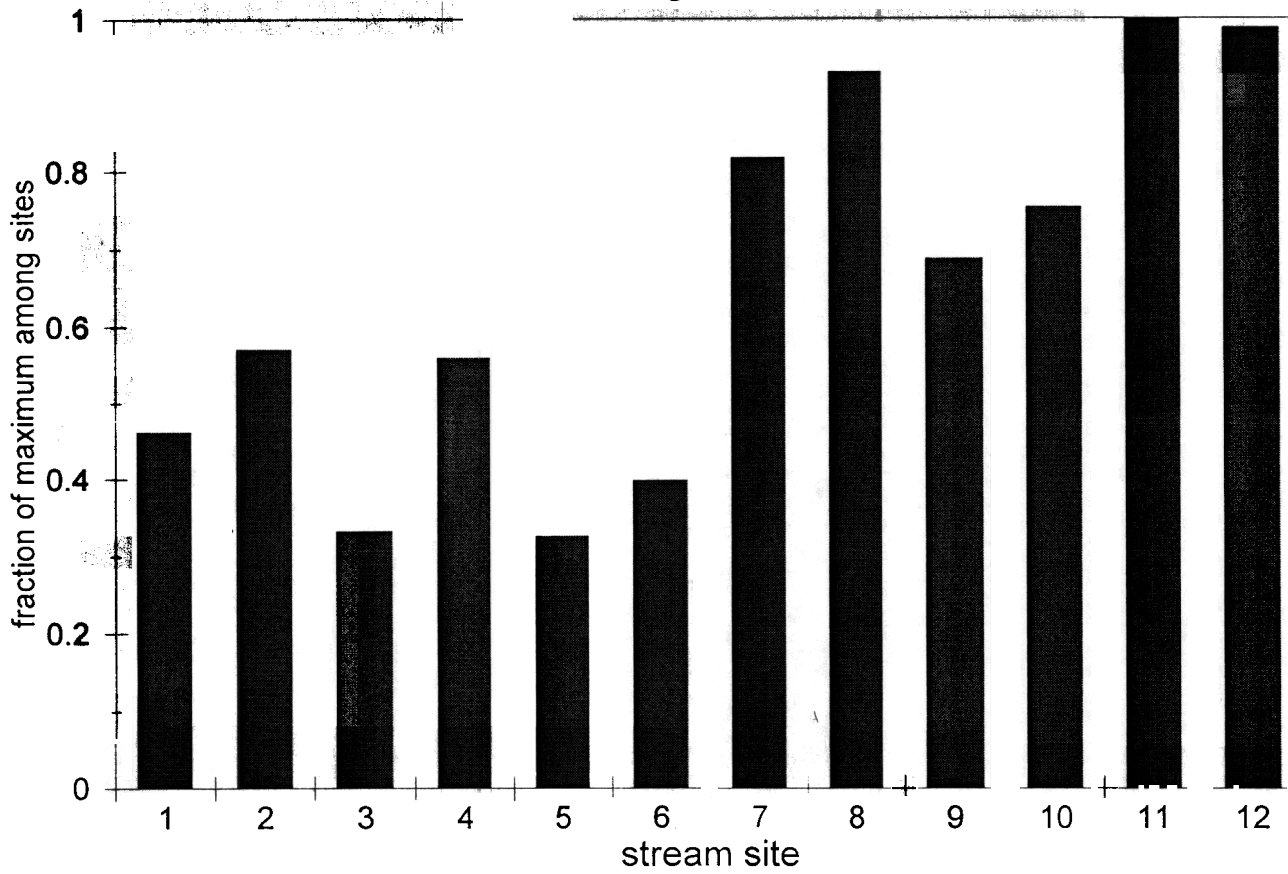


Figure 4.2 Average BMP implementation in stream site subwatershed

Correlation of BMPs and parameter trends

Pearson's correlation coefficient, r

BMP	TSS	Ammonia	Nitrate	TKN	uncensored Ortho P	Total P	censored Ortho P	Total P	TOC	Chor-a	Chlor-b	Chlor-c	Temp	pH	DO	Cond	Turb
Grassland	-0.244	-0.174	-0.205	0.194	-0.114	0.473	-0.043	0.103	0.19	0.359	0.089	-0.508	0.165	0.324	0.261	-0.072	0.107
Wooded	0.279	0.128	0.22	-0.239	0.203	-0.5	0.113	-0.052	-0.131	-0.361	-0.131	0.535	-0.141	-0.362	-0.32	0.057	-0.015
Other	-0.268	0.291	-0.129	0.338	-0.627	0.248	-0.487	-0.339	-0.386	0.057	0.301	-0.242	-0.146	0.301	0.435	0.093	-0.62
Drainage	-0.566	0.414	0.541	-0.039	-0.495	0.173	-0.489	-0.332	-0.167	0.298	0.49	0.468	0.386	-0.00469	-0.037	0.445	-0.582
establish	0.374	-0.271	0.338	0.381	0.378	0.385	-0.432	0.411	-0.185	0.287	0.009119	0.522	-0.046	0.364	0.141	-0.142	0.204
fencing	0.295	-0.047	-0.168	-0.514	0.246	-0.732	0.575	0.019	-0.047	-0.499	-0.264	0.136	-0.267	-0.67	-0.61	0.038	0.119
improve	0.018	0.503	-0.09	0.02	-0.341	-0.398	0.02	-0.513	-0.297	-0.381	0.094	0.057	-0.171	-0.056	0.042	0.227	-0.285
manage	0.411	-0.28	-0.312	-0.46	0.341	-0.678	0.61	0.188	-0.129	-0.324	-0.311	0.085	-0.371	-0.67	-0.689	-0.053	0.128
waste	0.366	-0.264	-0.293	-0.502	0.365	-0.696	0.659	0.178	-0.033	-0.349	-0.363	0.075	-0.322	-0.698	-0.68	-0.081	0.134
nutrient	0.452	-0.21	-0.292	-0.413	0.378	-0.714	0.64	0.139	-0.103	-0.36	-0.346	0.133	-0.359	-0.616	-0.653	-0.057	0.176
overall	0.406	-0.073	-0.217	-0.365	0.258	-0.698	0.504	0.029	-0.185	-0.417	-0.263	0.193	-0.355	-0.564	-0.562	0.011	0.073

Correlation of BMPs and nutrient trend Phosphorus

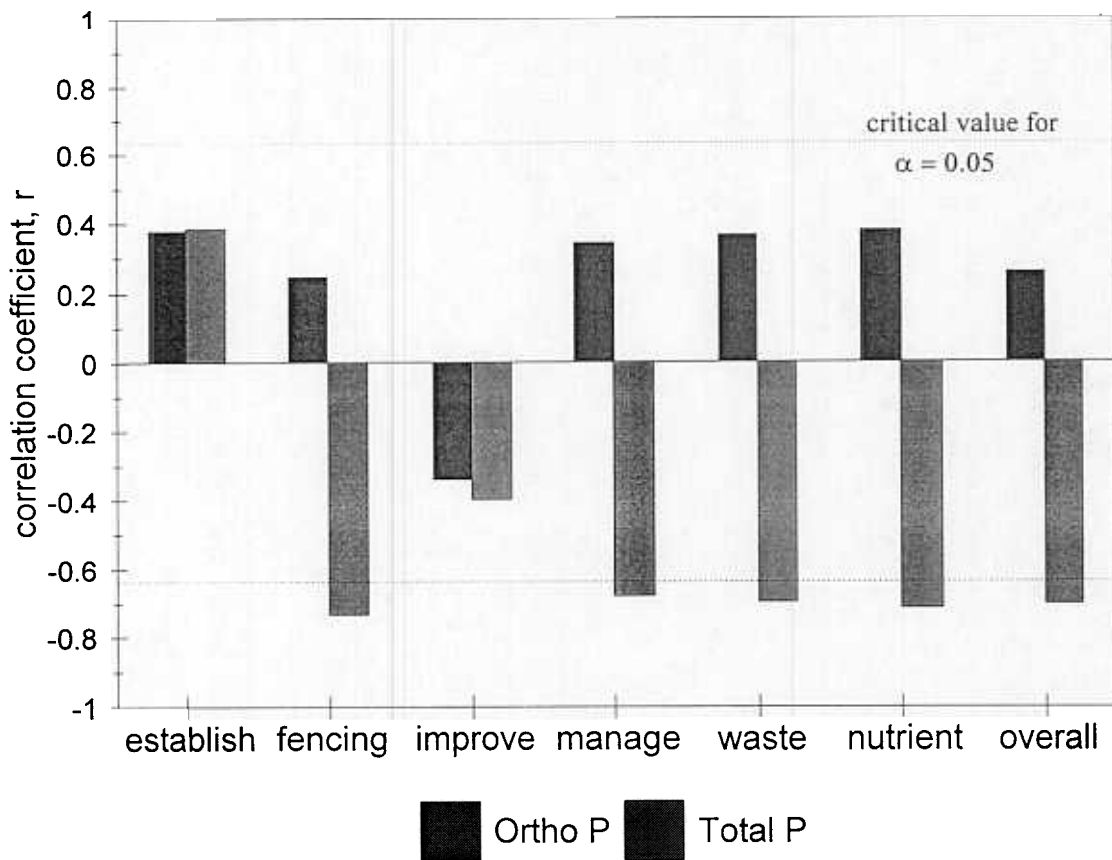


Figure 4.3 Correlation of BMP implementation and phosphorus trends

The use of correlation to infer that BMP implementation causes decreasing total P should be used with caution. Mendenhall and Sincich (1988) warn

“High correlation does not imply causality. If a large positive or negative value of the sample correlation coefficient r is observed, it is incorrect to conclude that a change in x causes a change in y . The only valid conclusion is that a linear trend *may* exist between x and y .”

Figure 4.4 shows the correlation between BMPs and nitrogen trends. Although most correlations are negative, all the correlations are far from being significant. Correlation between BMPs and chlorophyll, shown in Figure 4.5, are not significant. Correlation coefficients for the relationship between BMPs and other parameters, shown in Figure 4.6, are not significant with the exception of pH. The correlation between three of the BMPs and pH is significantly negative at the $\alpha = 0.05$ level, but the correlation between the overall BMP average and pH is not significant.

In summary, a relationship may exist between greater extent of BMP implementation and decreases in total P; however, this relationship is not seen with ortho P (SRP). Other parameters are not significantly correlated to BMP implementation. It is possible that there was not enough difference between subwatersheds in their BMP implementation to clearly delineate the effects of BMP implementation.

Because all the subwatersheds in the study have had some BMP implementation, and because phosphorus data did seem to show a downward trend at all sites, it is logical to suggest that BMP implementation may be causing the decreases in P. However, many other factors could be involved. Green (1996) examined the oxygen deficit in Beaver

Lake and found that the level of eutrophication decreased. He suggested that it is possible that the aging and evolutionary process in the lake was dominant in controlling eutrophication in the lake. The implementation of BMPs in the Beaver Lake watershed may be helping decrease eutrophication in the lake, but causality cannot be established.

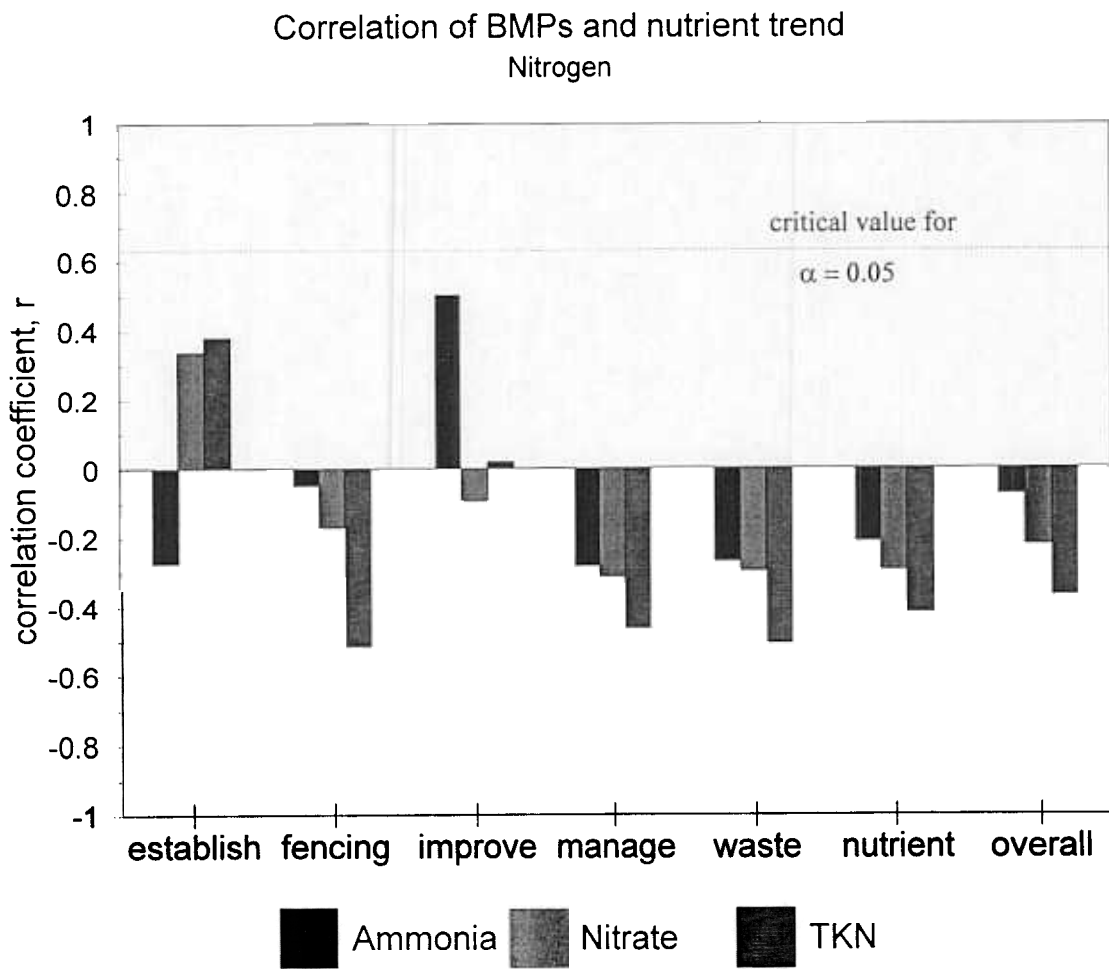


Figure 4.4 Correlation of BMP implementation and nitrogen trends

Correlation of BMPs to parameter trend Chlorophyll

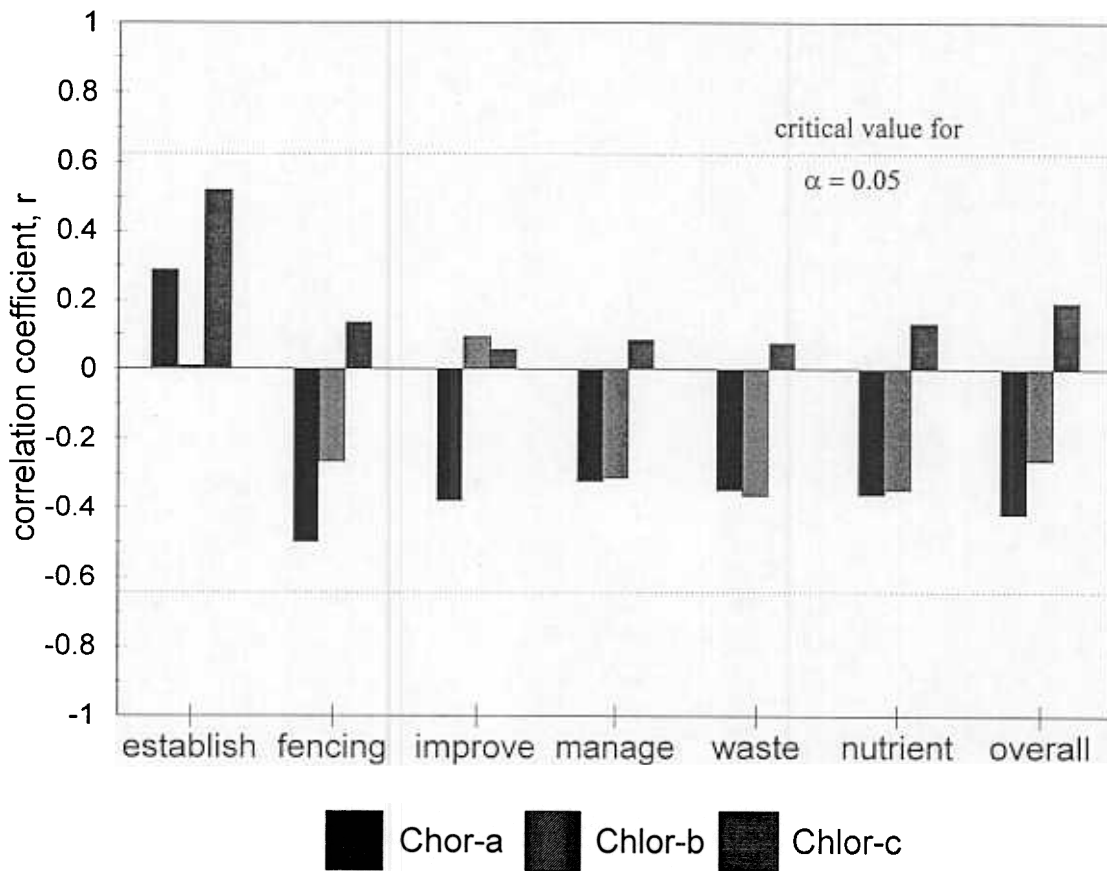


Figure 4.5 Correlation of BMP implementation and chlorophyll trends

Correlation of BMPs to parameter trend
Various Parameters

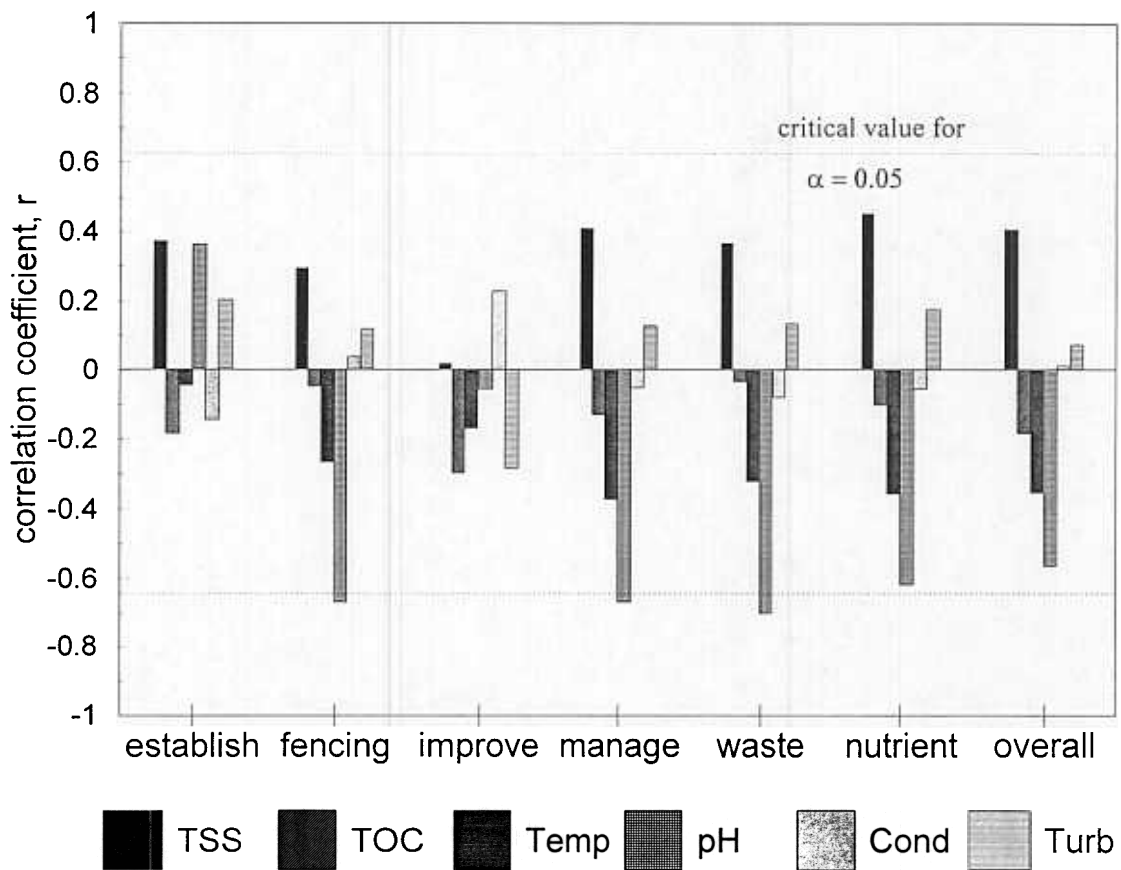


Figure 4.6 Correlation of BMP implementation and parameter trends

5. Parameter Relationships

Pearson's correlation coefficients were used to determine significant relationships between all parameters measured for all sites, depths and sampling dates using SAS software (SAS, Inst. 1995). The statistical analysis was limited to the lake sites. A low α value, $\alpha = 0.001$, was selected in respect to the large number of observations. With $\alpha = 0.001$ and approximately 900 samples, a correlation is significant if the correlation coefficient, r , is greater than 0.11 or less than -0.11. Although all the relationships to be mentioned are statistically significant, there is only a weak association between the parameters in that the correlation coefficient is far from ± 1 , meaning that one parameter can only explain a small amount of the variation in the other parameter. Table 5.1 shows the statistically significant calculated correlation coefficients.

The parameter relationships of greatest concern are the correlations with primary productivity. Meyer and Green (1984) reported that chlorophyll a is the best measure of primary productivity. Previous research has found a linearly increasing relationship between chlorophyll a and total P (TP) (Carlson, 1977; Palmer, 1978; Weisse, 1969), while Smith (1982) has shown a stronger association between chlorophyll a and PP (TP-soluble reactive P) when factors other than P are limiting the fresh water system. Research conducted by Walker (1985) suggested TP has a tendency to overestimate phytoplankton productivity. Haggard (1997) produced results from Beaver Lake, Arkansas, that supported the conclusions of Smith (1982) and Walker (1985). A factor other than P such as light is limiting growth in this reservoir due to the suspended sediments. Total P levels were at greatest concentration when light was limited and PP produced a stronger relationship with chlorophyll a than TP (Haggard, 1997).

Table 5.1. Relationship of lake parameters through all sites, depths and sampling dates. Significance of Pearson's correlation coefficient (r value) is $\alpha = 0.001$ due to the large number of observations (approximately 900).

	<u>Chl b</u>	<u>Chl c</u>	<u>Depth</u>	<u>NH₃</u>	<u>NO₃⁻</u>	<u>S.C.</u>	<u>Temp</u>	<u>TKN</u>	<u>TOC</u>	<u>TSS</u>
Chl a	0.47	0.11	-0.13	*	*	0.17	0.16	*	*	*
Chl b	*	0.20	*	*	*	*	*	0.16	*	*
D.O.	*	*	-0.40	-0.31	*	-0.48	-0.35	-0.15	-0.31	*
NH ₃	*	*	*	*	*	0.33	*	0.20	0.18	*
Temp	*	*	-0.31	*	*	0.49	*	*	0.29	*
TKN	0.16	*	*	0.20	*	*	*	*	0.18	*
TN	*	*	*	*	0.95	*	*	*	0.30	*
Turbidity	*	*	*	*	*	-0.16	*	*	*	0.73

Chl = chlorophyll, D.O. = dissolved oxygen, S.C. = specific conductivity, Temp = temperature, TKN = total Kjeldahl nitrogen, TN = total nitrogen, TOC = total organic carbon, TSS = total suspended solids. (* - correlation insignificant).

This study produced no significant correlation between chlorophyll *a* and any form of P possibly due to the detection limit of the method and apparatus used in the P determinations (censored data). The detection limit of 0.05 mg P l⁻¹ established using a Hach DR2000 was not low enough to compare the P data to the other parameters and the values below detection limit were reported as 0.05 mg P l⁻¹ not allowing for any statistical analysis. Despite the incomplete P data there was a positive relationship established between soluble reactive P (SRP) and TP.

However, some significant relationships between chlorophyll *a* and the other physico-chemical parameters did exist. Depth and chlorophyll *a* displayed a negative relationship. This would be expected since primary productivity should decrease with increasing depth in the water column due to limitation by light. Temperature and specific conductivity produced an increasing relationship with chlorophyll *a*. Primary productivity typically increases during the warmer, summer months. The relationship with specific conductivity could possibly be related to the respective increases in primary productivity and specific conductivity up the transitional and riverine zone of Beaver Lake.

Chlorophyll *a* also displayed a strong correlation to chlorophyll *b* and *c*. This is expected since both, chlorophyll *b* and *c*, are accessory pigments to chlorophyll *a* in certain taxa of algae. Chlorophyceae contain the accessory pigment chlorophyll *b*, while chlorophyll *c* is contained in dinoflagellates, diatoms, golden-brown algae and cryptomonads. The green algae tend to dominate in late spring and early fall, while the chlorophyll *c* containing algae dominate the winter. Cyanophyta (blue green) only contain chlorophyll *a* and tend to dominate the summer months. Chlorophyll *b* and *c* were positively correlated with one another.

Dissolved O₂ was negatively associated to depth. Since primary productivity is the major producer of O₂ in fresh water systems, the amount of dissolved O₂ is related to the presence and amount of algae photosynthesizing. Respiration overcomes photosynthesis at depths below the photic zone explaining the decrease in dissolved O₂ through the depth profile.

Temperature displayed a decreasing relationship with dissolved O₂ and depth. Temperature tends to decrease down the water column. The fact that gases are more soluble in lower temperatures could possibly explain the negative correlation expressed by temperature and dissolved O₂.

Total organic C (TOC) displayed significant relationships with temperature and dissolved O₂. Total organic C increased with increasing temperature possibly due to increased productivity, while TOC decreased with increasing dissolved O₂ suggesting that algae do not make up the greatest portion of TOC. Total organic C and chlorophyll *b* displayed positive relationships with total Kjeldahl N (TKN). Total Kjeldahl N is a measure of inorganic NH₃-N and organically bound N, explaining the association between TOC and TKN. Chlorophyll *b* may possibly have some organically bound N which would could rationalize the relationship.

Because TKN is a measure of NH₃-N and organic N, TKN and NH₃-N displayed a positive relationship. Both, TKN and NH₃-N, produced negative correlations with dissolved O₂. Ammonia-N and specific conductivity demonstrated a positive relationship throughout Beaver Lake.

Total N (TN) is the combination of $\text{NO}_3\text{-N}$ and TKN. Nitrate-N exhibited the strongest positive relationship to TN, while TKN was also positively correlated but displayed a weaker association. This suggests that $\text{NO}_3\text{-N}$ controls increases in TN more than TKN does in the water samples.

Turbidity and total suspended solids (TSS) produced a good positive relationship. This would be expected since turbidity is a measure of inhibition of light transmission due to suspended solids in the water while TSS is a weight measurement of the suspended solids. Specific conductivity and turbidity displayed a negative association possibly due to the cation exchange capacity of the suspended sediments in the waters of Beaver Lake.

Parameters relationships were similar at each site through the sampling years. These relationships were also consistent between individual sampling years and individual sampling sites.

6. Trophic State of Beaver Lake

The trophic state index concept is based on the relationship between nutrient concentrations, primary productivity and eutrophication (Carlson, 1977). Eutrophication is a Greek word meaning 'well-nourished'. Eutrophication is a natural process which can be enhanced by human activities such as agricultural runoff, septic system effluent, waste water treatment effluent, and in many other ways. Beaver Lake contains anthropogenic activities in the forms previously mentioned. Beaver Lake receives approximately half of Fayetteville's waste water treatment effluent and its watershed contains extensive agricultural operations and numerous septic systems.

Past research has shown Beaver Lake to be P limited (Meyer and Green, 1985) and P should be the nutrient of concern for eutrophication. However, the soluble reactive P (SRP) and total P (TP) data for this study was not able to be reported to the desired detection limits in order to determine the state of eutrophy. The methods and equipment used had a detection limit of 0.05 mg l^{-1} and lakes by Carlson's trophic state index are considered eutrophic above 0.025 mg l^{-1} .

Traditional trophic state indices have determined that fresh waters with chlorophyll *a* concentrations greater than 7 ug l^{-1} are considered eutrophic. Mean chlorophyll *a* concentrations for all sites, depths and sampling dates for all four sampling years were greater than the level indicating eutrophic classification. Based on chlorophyll *a* concentrations Beaver Lake should be considered eutrophic throughout the sampling years of this study. Table 6.1 summarizes the average chlorophyll *a* values and the trophic states inferred.

Table 6.1. Mean chlorophyll *a* concentrations for all sites, depths and sampling dates within the sampling years and trophic status of Beaver Lake for each sampling year.

Sampling Year	Chl <i>a</i> ($\mu\text{g l}^{-1}$)	Trophic Status
1992-93	14.34	Eutrophic
1993-94	7.17	Eutrophic
1994-95	11.08	Eutrophic
1995-96	9.45	Eutrophic

Chl = chlorophyll, Trophic status based on Carlson trophic state index.

Limiting the analysis to mean chlorophyll *a* concentrations for all depths and sampling dates at individual sampling locations produced similar results (Figure 6.1). Beaver Lake should be considered eutrophic through the sampling years except at Site A during year 1992-93, 1993-94 and 1994-95, and site B, C and D during year 1993-94 when the particular lake stations were determined to be mesotrophic.

Table 6.2. Trophic status of Beaver Lake by sampling location according to mean chlorophyll *a* concentrations for all sampling depths and dates within sampling years.

Sampling Site	Sampling Year			
	1992-93	1993-94	1994-95	1995-96
A	Meso	Meso	Meso	Eu
B	Eu	Meso	Eu	Eu
C	Eu	Meso	Eu	Eu
D	Eu	Meso	Eu	Eu
E	Eu	Eu	Eu	Eu

Eu = eutrophic, Meso = mesotrophic.

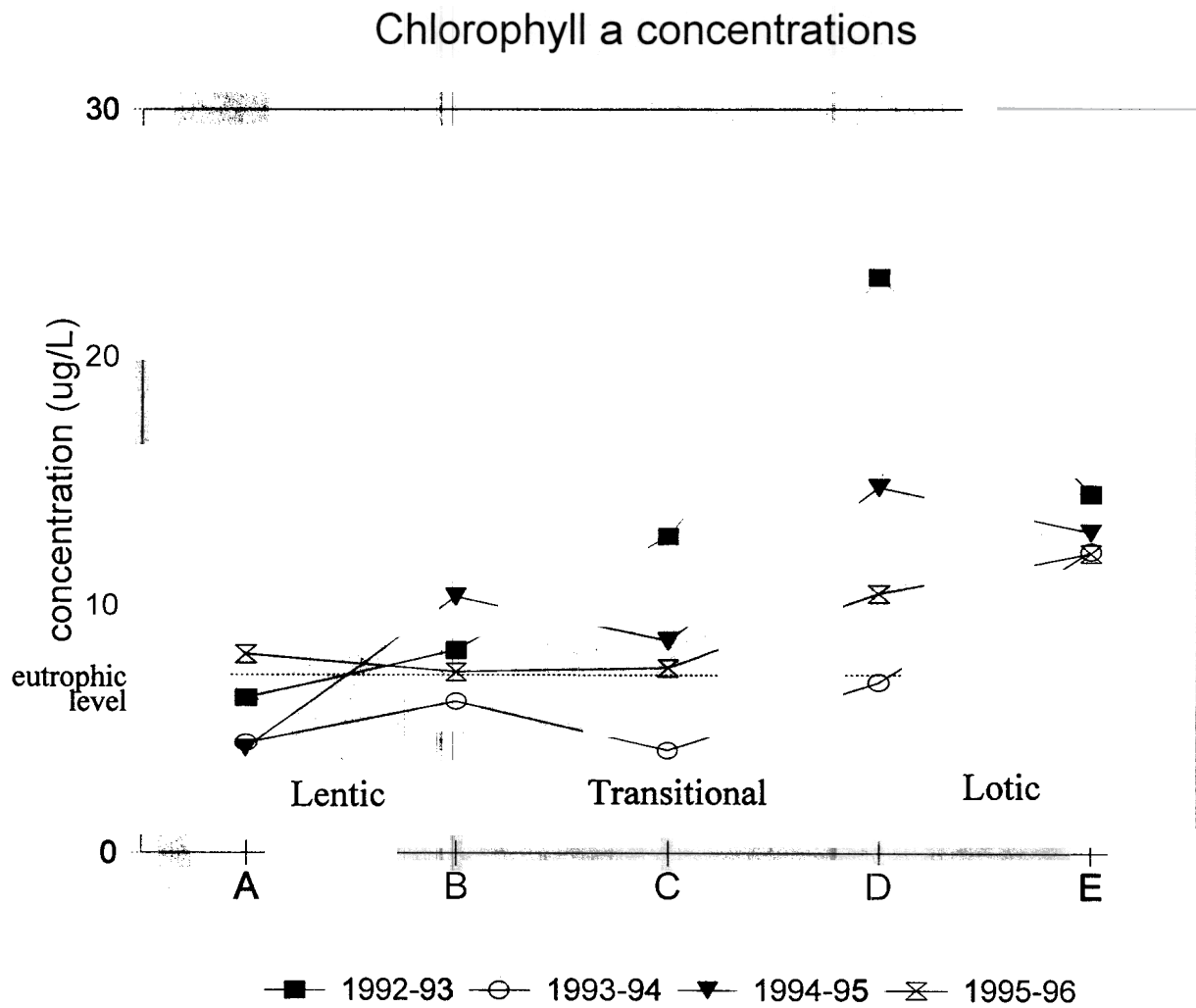


Figure 6.1 Chlorophyll a concentrations in Beaver Lake

These results differ from the chlorophyll *a* data presented in Haggard (1997). Their chlorophyll *a* concentrations indicated Beaver Lake to be mesotrophic during 1993-94 and oligotrophic for 1994-5 of this study. The results also indicated a change in the trophic status through the different zones in the reservoir. Reservoirs are dynamic systems since they contain a true lake zone, a transitional zone and a riverine zone. The transitional zone is the location of change in flow from lotic to lentic. The discrepancy in trophic state between the three reservoir zones were not as defined in this study, but increases in primary productivity are seen in the transitional and lotic zones of Beaver Lake. This was similar to the increases reported by Haggard (1997).

So not to confine determining the trophic status to primary productivity, permission was obtained from USDA for this study to use SRP and TP data collected by the USDA/ARS in Fayetteville, Arkansas during 1993-1995. The TP levels attained in the data collected by the USDA/ARS (Haggard, 1997) concluded that Beaver Lake is eutrophic by TP standards in traditional trophic state indices at most locations (Haggard, 1997). The overall annual mean TP concentrations were 0.045 mg l⁻¹ in 1993-94 and 0.054 mg l⁻¹ in 1994-95. The Prairie Creek site, the only true lake site in the study, had TP values less than 0.025 mg l⁻¹ during 1993-94. The trophic status of this data corresponds well to the trophic status determined by chlorophyll *a* concentrations in this study. However, Walker (1985) reported TP levels in reservoirs tend to overestimate chlorophyll *a* concentrations due to their dynamic nature. This was further supported by the chlorophyll *a* and TP levels attained by Haggard (1997). Table 6.3 and Figure 6.2 show the censored (data below the detection limit reported as the detection limit) and uncensored (actual value reported) average P values for this study and for the Haggard

(1997) study. The uncensored P values in this study are higher than those of the Haggard (1997) study, likely because of the higher detection limit of the analysis method itself.

Table 6.3. Average phosphorus concentrations in Beaver Lake

<u>site</u>	<u>SRP</u>	<u>TP</u>	<u>SRP (cens)</u>	<u>TP (cens)</u>
A	0.066	0.092	0.083	0.185
B	0.062	0.111	0.075	0.114
C	0.056	0.122	0.069	0.125
D	0.054	0.109	0.067	0.112
E	0.063	0.141	0.073	0.144
avg	0.060	0.115	0.073	0.136
Haggard	0.016	0.050		

SRP = soluble reactive P; TP = total P; (cens) = censored data

In summary, the trophic status of most of Beaver Lake is eutrophic based on primary productivity measured as chlorophyll *a* in this study and TP levels attained from the USDA/ARS in Haggard (1997).

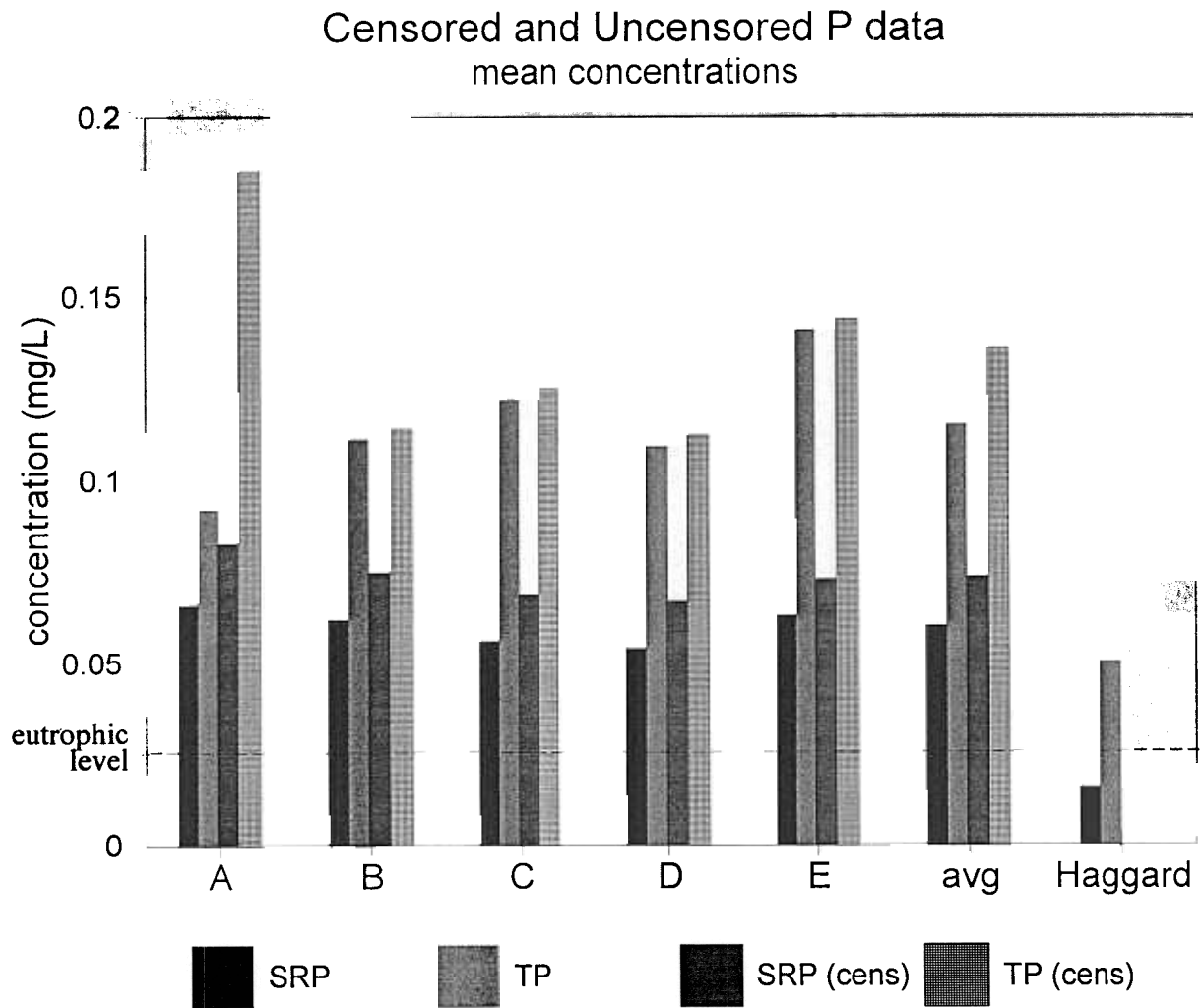


Figure 6.2 Average phosphorus concentration in Beaver Lake

7. Conclusions

This study analyzed the stream and lake data for trends and parameter relationships, examined the effects of statistically regenerated data in the original study, assessed the eutrophic state of Beaver Lake, and evaluated the impacts of BMP implementation on water quality.

Trend analysis calculated decreasing trends for ortho phosphate and total phosphate at all stream and lake sites, although most of these trends were not statistically significant and there was uncertainty in the phosphorus data. Three stream sites, three lake sites, and the combined lake data showed decreasing ortho P trends which were significant at the $\alpha = 0.10$ level but not significant at the $\alpha = 0.05$ level. No total P trends were statistically significant. Trends in the other water quality parameters were non-uniform (not all positive or all negative) and showed few significant trends for individual sites.

Calculation of the correlation between BMP implementation and parameter trends suggested that a relationship may exist between greater extent of BMP implementation and decreases in total P; however, this relationship is not seen with ortho P. The BMPs may contribute to the apparent downward trend in phosphorus values during the study period, however, a cause and effect relationship cannot be established. Other parameters are not significantly correlated to the relative extent of BMP implementation.

The trophic status of Beaver Lake is mostly eutrophic based on primary productivity measured as chlorophyll *a* in this study and total P levels obtained from a USDA/ARS study by Haggard.

Correlation coefficients for the relationships between different parameters were calculated. Although some relationships were statistically significant, there was only a weak association between the parameters in that the correlations were far from ± 1 , meaning that one parameter could only explain a small amount of variation in the other parameter.

The effect of the regenerated flow data was examined and it was determined that the flow data regeneration is unlikely to be a major source of inaccuracy.

8. References

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Appendix: Example MathCAD Documents

Trend analysis for individual stream sites

Conc = matrix of concentrations : 17 parameters

4 years x 9 sampling events per year = 36 values

$$L = \text{length}(\text{Flow}_{\text{inst}}) \quad M = \text{cols}(\text{Conc})$$

$$L = 36 \quad M = 17$$

$$i = 1..L \quad j = 1..M$$

Flow adjustment

regressing C vs flow

$$\text{Flow}_{\text{inst}_i} = \ln(\text{Flow}_{\text{inst}_i})$$

use logarithm of flow

$$\text{Cnomax}_{i,j} = \left(\text{if}(\text{Conc}_{i,j} = 999999, \text{median}(\text{Conc}^{\langle j \rangle}), \text{if}(\text{Conc}_{i,j} = 0, \text{median}(\text{Conc}^{\langle j \rangle}), \text{Conc}_{i,j})) \right)$$

replace missing values with median
(missing values are set = 999999)

$$\text{Creg}_{i,j} = \text{if} \left(\frac{|\text{Cnomax}_{i,j} - \text{median}(\text{Cnomax}^{\langle j \rangle})|}{\text{stdev}(\text{Cnomax}^{\langle j \rangle})} > 2, \text{median}(\text{Cnomax}^{\langle j \rangle}), \text{Cnomax}_{i,j} \right)$$

replace outliers with median

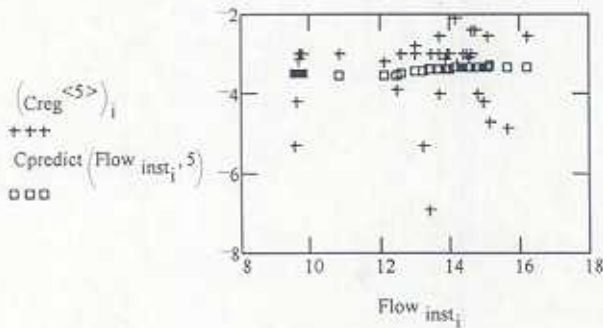
$$\text{Creg}_{i,j} = \ln(\text{Creg}_{i,j})$$

use logarithm of concentration

$$\text{adj}^{\langle j \rangle} = \text{loess} \left[(\text{Flow}_{\text{inst}}, \text{Creg}^{\langle j \rangle}, 1) \right]$$

regression

$$\text{Cpredict}(x,j) = \text{interp}(\text{adj}^{\langle j \rangle}, \text{Flow}_{\text{inst}}, \text{Creg}^{\langle j \rangle}, \text{Flow}_{\text{inst}_i})$$

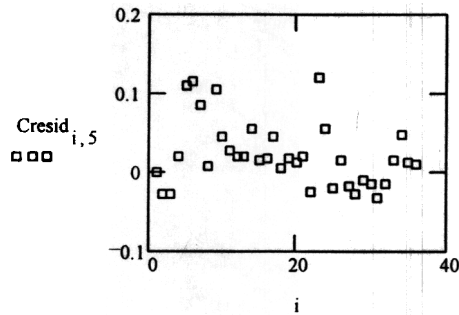


$$\text{stdev}(\text{Cnomax}^{\langle 5 \rangle}) = 0.041$$

$$\text{median}(\text{Cnomax}^{\langle 5 \rangle}) = 0.05$$

$$\text{Cpred}_{i,j} = \exp(\text{Cpredict}(\text{Flow}_{\text{inst}_i}, j))$$

$$\text{Cresid}_{i,j} := \text{if}(\text{Conc}_{i,j} = 999999, 0, \text{Cnmax}_{i,j} - \text{Cpred}_{i,j})$$



Residual is the sample value - regression prediction
(residual for missing data is zero)

Cresid

The Modified Seasonal Kendall test for trend

col := 5

$$\text{data}_i := (\text{Cresid}^{\langle \text{col} \rangle})_i$$

Perform analysis on each parameter (column)

$$N := 4 \quad j := 1..N$$

N = number of years

$$b := 9 \quad k := 1..b$$

b = number of seasons per year

$$Y_{1,k} := \text{data}_k \quad Y_{2,k} := \text{data}_{k+9}$$

Divide the data into seasons

$$Y_{3,k} := \text{data}_{k+18} \quad Y_{4,k} := \text{data}_{k+27}$$

$$n_k := \left[\sum_{i=1}^N Y_{i,k} \neq 0 \right]$$

number of nonzero data per season

$$\text{sgn}(x) := \text{if}(x \neq 0, \frac{x}{|x|}, 0)$$

$$\sum_{i=1}^{N-1} \sum_{j=i+1}^N (Y_{j,k} \cdot Y_{i,k} \neq 0) \cdot \text{sgn}(Y_{j,k} - Y_{i,k})$$

$$S := \sum_{k=1}^b S_k \quad \text{Seasonal Kendall test statistic}$$

$$n_k + \frac{\sum_{j=1}^N (Y_{i,k} \cdot Y_{j,k} \neq 0) \cdot \text{sgn}(Y_{i,k} - Y_{j,k})}{2}$$

ranking

$$K_{k,l} = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \operatorname{sgn}(Y_{j,k} - Y_{i,k}) \cdot (Y_j - Y_{i,l}) \quad \sigma_k = \frac{K_{k,l} + 4 \cdot \sum_{i=1}^N R_{i,k} \cdot R_{i,l} - N \cdot (n_k + 1) \cdot (n_l + 1)}{3}$$

$$\operatorname{var}(S) := \sum_{k=1}^b \frac{n_k \cdot (n_k - 1) \cdot (2 \cdot n_k + 5)}{18} + 2 \sum_{k=2}^b \sum_{l=1}^{k-1} \sigma_k \quad \text{variance}$$

N = 4

S = -19

var(S) = 102.333

col = 5

$$Z = \operatorname{if}(N < 10, \frac{S - \operatorname{sgn}(S)}{\sqrt{\operatorname{var}(S)}}, \frac{S}{\sqrt{\operatorname{var}(S)}})$$

Z = -1.779 standard normal distribution statistic

cnorm(Z) = 0.0376

cumulative normal distribution with Z

qnorm(0.095, 0, 1) = -1.311

Trend analysis for individual Lake sites

Conc = matrix of concentrations : 17 parameters

4 years x 9 sampling events per year x 3 depths per sampling event = 108 values

$L := \text{rows}(\text{Conc})$

$M := \text{cols}(\text{Conc})$

$L = 108$

$M = 17$

$i := L$

$j := M$

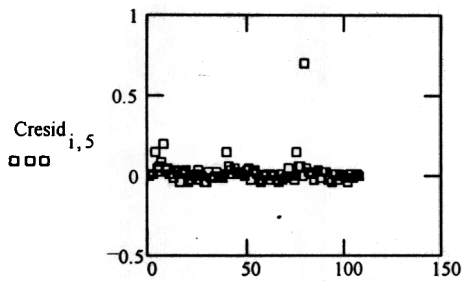
missing values are set = 999999

$$\text{avrg}(X) := \left[\prod_{i=1}^L \left(\text{if}(X_i=999999, 1, \text{if}(X_i=0, 1, X_i)) \right) \right]^{\frac{1}{\sum_{i=1}^L \left(\text{if}(X_i=999999, 0, \text{if}(X_i=0, 0, 1)) \right)}}$$

Residual is the sample value - geometric mean for that parameter

(residual for missing data is zero)

$$\text{Cresid}_{i,j} = \text{if}(\text{Conc}_{i,j}=999999, 0, \text{Conc}_{i,j} - \text{avrg}(\text{Conc}^{<j>}))$$



$$\text{avrg}(\text{Conc}^{<5>}) = 0.043$$

Cresid

The Modified Seasonal Kendall test for trend

col := 5

$$= (\text{Cresid}^{\langle \text{col} \rangle})$$

Perform analysis on each parameter (column)

N := 4

N j N

N = number of years

b := 27

kn := 9 b

b = number of seasons per year

km := 10..18

Divide the data into seasons

$$Y_{1, kn} := \text{data}_{kn} \quad Y_{2, kn} := \text{data}_{kn+1}$$

$$Y_{3, kn} := \text{data}_{kn+18} \quad Y_{4, kn} := \text{data}_{kn+27}$$

$$Y_{1, km} := \text{data}_{km+27} \quad Y_{2, km} := \text{data}_{km+36}$$

$$Y_{3, km} := \text{data}_{km+45} \quad Y_{4, km} := \text{data}_{km+54}$$

different depths
are different
"seasons"

ks := 19..27

$$Y_{1, ks} := \text{data}_{ks+54} \quad Y_{2, ks} := \text{data}_{ks+63}$$

$$Y_{3, ks} := \text{data}_{ks+72} \quad Y_{4, ks} := \text{data}_{ks+81}$$

k := 1..b

total of 27 "seasons"

$$n_k := \left[\sum_{i=1}^N Y_{i,k} \neq 0 \right]$$

number of nonzero data per season

n

$$\text{sgn}(x) := \text{if}(x \neq 0, \frac{x}{|x|}, 0)$$

$$S_k := \sum_{i=1}^{N-1} \sum_{j=i+1}^N (Y_{j,k} \cdot Y_{i,k} \neq 0) \cdot \text{sgn}(Y_{j,k} - Y_{i,k})$$

$$S := \sum_{k=1}^b S_k$$

Seasonal Kendall test statistic

$$R_{i,k} := \frac{n_k + 1 + \sum_{j=1}^N (Y_{i,k} \cdot Y_{j,k} \neq 0) \cdot \text{sgn}(Y_{i,k} - Y_{j,k})}{2}$$

ranking

$$K_{k,l} = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}[(Y_{j,k} - Y_{i,k}) \cdot (Y_{j,l} - Y_{i,l})]$$

$$\sigma_k = \frac{K_k + 4 \cdot \sum_{i=1}^N R_{i,k} \cdot R_{i,l} \cdot N \cdot (n_k + (n_l + 1))}{3}$$

$$\text{var}(S) := \sum_{k=1}^b \frac{n_k \cdot (n_k - 1) \cdot (2 \cdot n_k + 5)}{18} + 2 \sum_{k=2}^b \sum_{l=1}^{k-1} \sigma_{k,l} \quad \text{variance}$$

$$\text{var}(S) = 2.796 \cdot 10^3$$

$$S = -98$$

$$\text{col} = 5$$

$$Z := \text{if}(N < 10, \frac{S - \text{sgn}(S)}{\sqrt{\text{var}(S)}} - \frac{S}{\sqrt{\text{var}(S)}})$$

$$Z = -1.834 \quad \text{standard normal distribution statistic}$$

$$\text{cnorm}(Z) = 0.0333$$

cumulative normal distribution with Z

$$\text{qnorm}(0.025, 0, 1) = -1.96$$

Calculate stream loadings

$L := \text{length}(\text{Flow})$

$M = \text{cols}(\text{Conc})$

$L = 51$

$M = 17$

$\text{rows}(\text{Conc}) = 51$

L

$j := 1..M$

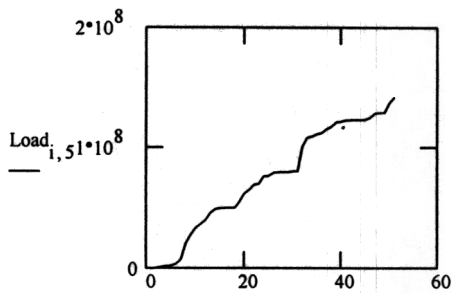
$b4(C,i) := \begin{cases} n \leftarrow i - 1 \\ \text{while } C_n \neq 999999 \\ n \leftarrow n - 1 \end{cases}$

Load calculated by integration of concentration on cumulative flow

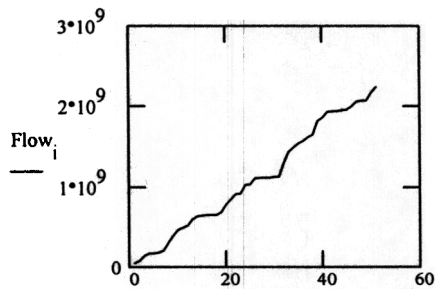
$= 2..L$

$$\text{Load}_{k,j} = \sum_{i=2}^k \left[(\text{Conc}^{<j>})_{i=999999} \cdot \left[0.5 \cdot \left[(\text{Conc}^{<j>})_{i=999999} + (\text{Conc}^{<j>})_{i=b4[(\text{Conc}^{<j>}),i]} \right] \cdot \left[\text{Flow}_{i=999999} - \text{Flow}_{i=b4[(\text{Conc}^{<j>}),i]} \right] \right]$$

$$\text{Load}_{L,5} = 1.416 \cdot 10^8$$



Load



yearly loads

$i = 1..L$

$j = 1..M$

$ip = 1..5$ $ipair_1 = 1$

$ipair_2 = \left[\begin{array}{l} n \leftarrow L \\ \text{while } |365 - (\text{Date}_{n-1} - \text{Date}_1)| < |365 - (\text{Date}_n - \text{Date}_1)| \\ \quad n \leftarrow n - 1 \end{array} \right]$

$ipair_3 = \left[\begin{array}{l} n \leftarrow L \\ \text{while } |2 \cdot 365 - (\text{Date}_{n-1} - \text{Date}_1)| < |2 \cdot 365 - (\text{Date}_n - \text{Date}_1)| \\ \quad n \leftarrow n - 1 \end{array} \right]$

$ipair_4 = \left[\begin{array}{l} n \leftarrow L \\ \text{while } |3 \cdot 365 - (\text{Date}_{n-1} - \text{Date}_1)| < |3 \cdot 365 - (\text{Date}_n - \text{Date}_1)| \\ \quad n \leftarrow n - 1 \end{array} \right]$

$ipair_5 = \left[\begin{array}{l} n \leftarrow L \\ \text{while } |4 \cdot 365 - (\text{Date}_{n-1} - \text{Date}_1)| < |4 \cdot 365 - (\text{Date}_n - \text{Date}_1)| \\ \quad n \leftarrow n - 1 \end{array} \right]$

$ipair = \begin{bmatrix} 1 \\ 13 \\ 26 \\ 39 \\ 51 \end{bmatrix}$

$\text{length}(\text{Flow}) = 51$

$i = 1..4$

$\text{YearLoad}_{i,j} = \text{Load}_{(ipair_{i+1}),j} - \text{Load}_{(ipair_i),j}$

$\text{rows}(\text{Load}) = 51$

YearLoad

$\text{YearFlow}_i = \text{Flow}_{(ipair_{i+1})} - \text{Flow}_{(ipair_i)}$

$\text{YearConc}_{i,j} = \frac{\text{YearLoad}_{i,j}}{\text{YearFlow}_i}$

YearConc