TREND ANALYSIS OF TEMPORAL NUTRIENT CONCENTRATIONS IN THE ILLINOIS RIVER BASIN IN OKLAHOMA AND ARKANSAS

By

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CHAPTER I

INTRODUCTION

This study is an attempt to analyze the available nutrient data at selected water quality monitoring stations in the Illinois River Basin for temporal trends using two nonparametric trend analysis techniques, Kendall's Tau and the Seasonal Kendall test. The results of these tests should help to determine if there has been a real deterioration of water quality in the Illinois River Basin in terms of nutrient concentrations over the past five to 15 years.

The null hypothesis for both of these tests will be that no temporal trend exists. The alternative hypothesis will be that a temporal trend does exist, either increasing or decreasing. The sign, positive or negative, of the test statistic can be used to determine the direction of the temporal trend.

As is the case with many water quality constituents in streams, the concentration of a particular water quality parameter may be correlated, either positively or negatively, with discharge. Variable discharge over the period of record at a monitoring station can mask and/or influence results of trend tests. Techniques have been described which attempt to remove this correlation effect so the true temporal nutrient trends might be discovered.

Ever since a portion of the Illinois River, and portions of two of its major tributaries, were designated as state scenic rivers by the Oklahoma legislature, there has been a written commitment to ensure that these segments remain as pristine as possible. However, it is not necessarily an easy task to balance economic development and growth with environmental concerns. Population growth, expanded recreational and leisure opportunities, agricultural diversification, and changing land uses can and have put additional stress on the Illinois River system.

Lake Tenkiller, which acts as the ultimate recipient of all nutrients carried by the upper Illinois River system, has been reported to be suffering from accelerated eutrophication. This body of water is a treasure when the benefits derived from recreational and aesthetic qualities are considered. If the lake suffers from premature aging, economic losses to the region and the state could be significant.

Point source nutrient inputs into the system, attributed to municipalities, industries, and farming operations with identifiable discharge points, can certainly be related to water quality in the river and Lake Tenkiller. Once identified, these sources can be controlled to some extent, although such controls involve time and expense.

Perhaps greater significance, however, could be placed on the contribution of nonpoint source contributions. A cursory review of raw data and previous studies leads to the conclusion that nonpoint sources are providing the majority of nutrients to the system. Unfortunately, these sources are difficult to identify with a great deal of accuracy, and once identified, they are the most difficult and expensive to control given current technologies.

A relatively large number of surveys and studies have been performed to determine if water quality in this system has changed over time. Difficulties have often arisen in attempting to analyze the results.

An attempt to identify and quantify temporal trends in nutrient concentrations in this system should provide valuable information which can be used to determine if, and which, management strategies could be used to control any observed problem trends. The Illinois River system is the "crown jewel" of Oklahoma's scenic river system and it would seem appropriate for us to do our utmost to see that it retains that distinction.

Nonparametric statistical methods for detecting temporal trends in nutrient concentrations have not been commonly used to evaluate water quality in the Illinois River Basin. Nonparametric statistical techniques can be particularly useful in detecting trends in water quality time series. Environmental time series often have many missing observations, follow nonnormal distributions, and possess censored observations that are listed as being below a detection limit. All of these factors occur in the nutrient data sets available for the Illinois River Basin.

A nonparametric test is a method for testing a hypothesis whereby the test does not depend upon the form of the underlying distribution of the null hypothesis. Nonparametric tests tend to ignore the magnitude of the observations for the relative values or ranks of the data. The output from nonparametric trend tests may or may not give an indication of the type or magnitude of the trend (Hipel, 1988). Methods exist which can elucidate temporal trend direction and magnitude.

A Seasonal Kendall Sen Slope Estimate for each parameter at each station will allow for a determination of the magnitude and direction of the trend, if one exists. This is also a nonparametric method.

Chapter II provides a description of the Illinois River Basin. Chapter III is a literature review discussing previous studies done in the Illinois River Basin, eutrophication, and the nonparametric statistical techniques used in this study. Chapter IV discusses the methodology and procedures involved in implementing the temporal trend tests on nutrient data sets at the 14 sampling stations selected for analysis. Chapter V reports the results of the study and Chapter VI concludes the study recapping the results, pointing out some weaknesses of the study, and presenting some suggestions for future research.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Scenic River Status

The Illinois River above 650 feet mean sea level, was designated as a state "scenic river" in 1969 by an act of the Oklahoma Legislature in an attempt to preserve and protect the qualities of the river that make it unique and attractive. The Oklahoma Scenic Rivers Act of 1969 states "... some of the free-flowing streams and rivers of Oklahoma possess such unique natural scenic beauty, water conservation, fish, wildlife and outdoor recreational values of present and future benefit to the people of the state that it is the policy of the Legislature to preserve these areas for the benefit of the people of Oklahoma" (OK Statute, Title 82 O.S. Supp. 1981, Sec. 1451).

A supplement to the Scenic Rivers Act in 1981 designated portions of two major tributaries of the Illinois River, Flint Creek and Baron Fork Creek, as state scenic rivers as well. The act provides that designated scenic river areas be preserved in their free-flowing forms, and directs and authorizes the Director of the Oklahoma Water Resources Board and other state water pollution control agencies to assist in preventing and eliminating pollution of waters within a scenic river area (OK Statutes, Title 82 O. S. Supp. 1981, Sec. 1451).

An Act of the Oklahoma Legislature in 1977 provided for the formation of the Oklahoma Scenic Rivers Commission with responsibility to carry out the intended purpose of the Oklahoma Scenic Rivers Act. The Illinois River has been, and continues to be, a premier tourist attraction of the state, drawing thousands of people annually to northeastern Oklahoma. The region offers abundant camping, hunting and fishing, and canoeing opportunities in a setting that most people would not expect to find in Oklahoma.

The Oklahoma Water Quality Standards of 1988 (1989) list beneficial uses of the scenic river portions of the Illinois River, Flint Creek, and Baron Fork Creek as: 1) public and private water supply, 2) smallmouth bass fishery, 3) primary recreation, 4) agriculture (non-irrigation), and 5) aesthetics. These standards list no numerical standards for nutrient concentrations. However, an Anti-Degradation Policy in section 200.4, which applies to designated scenic river segments, states "no degradation shall be allowed in waters which constitute an outstanding resource or have exceptional recreational value and/or ecological significance".

The listed beneficial use as aesthetics does have a stipulation regarding nutrients. It states, "nutrients from point source discharges or other sources shall not cause excessive growth of periphyton, phytoplankton, or aquatic macrophyte communities which impairs any existing or designated beneficial use". These same scenic river segments are also classified as "Outstanding Resource Waters" and as such, non-point source discharges are to be controlled using best management practices in the watersheds.

Illinois River Basin

The headwaters of the Illinois River are in the Boston Mountains of northwestern Arkansas in Washington County, about 15 miles southwest of Fayetteville. The stream flows in a northerly and westerly direction through this Ozark region, crossing the Oklahoma/Arkansas state line near Siloam Springs, Arkansas. The river continues in a westerly direction until it is joined by Flint Creek. It then flows in a southerly direction to its confluence with the Arkansas River in Sequoyah County near Gore, Oklahoma. The river flows approximately 160 miles from its headwaters to its confluence with the Arkansas River (Figure 1).

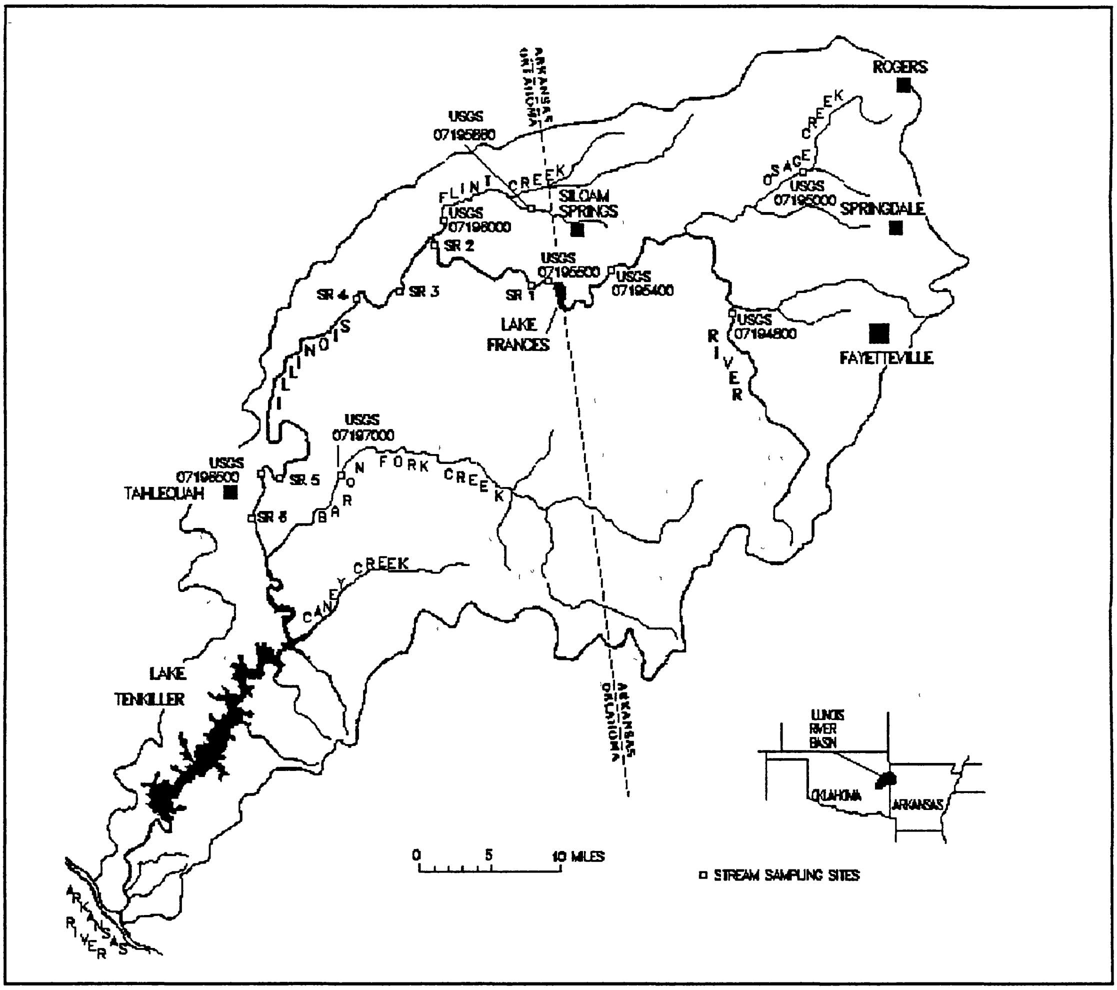

Figure 1. Map of the Illinois River Basin Indicating Locations of Water Quality Monitoring Stations Used in the Study.

Two of the major tributaries of the Illinois River also have their origins in the Ozark region of Arkansas. Flint Creek, originating in Benton County, Arkansas, flows in a westerly direction out of Arkansas through Delaware County, Oklahoma and joins the Illinois River from the north just south of Kansas, Oklahoma. Baron Fork Creek originates in Washington County, Arkansas and flows in a southwesterly direction to its confluence with the Illinois River just south of Tahlequah, Oklahoma. Both of these tributary basins are largely forested. Osage Creek, a smaller tributary of the Illinois River, flows southwesterly from Rogers, Arkansas to its confluence with the Illinois River about ten miles east of Siloam Springs, Arkansas. Sager Creek is a tributary of Flint Creek which originates just east of Siloam Springs, Arkansas and flows northwesterly joining Flint Creek in Delaware County, Oklahoma about three miles west of the Oklahoma/Arkansas state line.

The Illinois River Basin, including about 1660 square miles, lies within the southwestern portions of the physiographic province called the Ozark Uplift which covers nearly 40,000 square miles in Missouri, Arkansas, and Oklahoma. Approximately 53% of the Illinois River Basin is in Oklahoma while the remaining 47% is in Arkansas (Lyhane, 1987). The Illinois River and its tributaries are included in a part of the Ozark Uplift called the Springfield Plateau. This plateau is generally deeply dissected with rolling upland areas separated by V-shaped stream valleys that range from 200 to 300 feet in depth. Geologic processes have created cliffs of erosion resistant rock along much of the Illinois River and to a lesser extent on the Flint Creek and Baron Fork Creek basins (U.S. Dept. of Interior, 1979).

Soil types in the basin range from soils derived from sandstones, shale, clay, and some limestones. These soils support vegetation ranging from tall grasses to oak, hickory and pine forests (Lyhane, 1987). Estimated land use percentages calculated by the U.S. Dept. of Agriculture - Soil

Conservation Service of Arkansas and Oklahoma (USDA-SCS AR/OK) in a 1989 report show that about 42% of the basin is forested, 48% is grassland, 3% is urban, 2% is cropland, and the remaining 5% is a mixture of water, feedlots, and other minor land use types.

The significant economic benefits of recreation on the Illinois River can be explained in part by the extensive use of the Illinois River by canoeists. The Oklahoma Scenic Rivers Commission has tallied the $1.00 per canoe user fee paid at the numerous canoe rental operations on the river. Results show 52,000 to 67,000 canoes were rented each year from 1984 to 1988 (USDA-SCS AR/OK, 1989).

Lake Frances

Lake Frances, one of two impoundments on the mainstem of the Illinois River, a 570 surface acre lake located in Adair County in Oklahoma and Benton County, Arkansas, was first impounded in 1931. In 1954, the City of Siloam Springs, Arkansas purchased the dam and most of the adjacent land with the intentions to rebuild the dam and use the reservoir as a water supply source. The dam is considered the upper limit of the scenic river portion of the Illinois River.

Water supply is the major commercial use of Lake Frances. It serves as a water supply source for Siloam Springs and other small communities in the area both in Arkansas and Oklahoma. The lake provides some recreational uses as a fishery but the lake is generally too shallow to be used for recreational boating other than fishing.

Concerns have been raised about the dam impounding Lake Frances. The U. S. Army Corps of Engineers and the Oklahoma Water Resources Board have declared the dam a safety hazard. The Oklahoma Water Resources Board has ordered the City of Siloam Springs to repair the aging dam. The City of Siloam Springs has since offered to sell the dam and the lake for a nominal fee. There are currently alternatives being discussed which include removing the dam and draining the lake, or repairing the dam and dredging the lake. A portion of the top of the dam broke off during flooding in May, 1990.

Lake Frances is relatively shallow with a mean depth of 1.2 meters. The lake has a short hydraulic retention time of about 2 days (Threlkeld, 1981). The lake suffers substantial seasonal algal blooms which deter from its attractiveness as a recreational area. These blooms have been cited as a possible cause for decreased water quality in the Illinois River several miles below the dam.

Lake Tenkiller

The Lake Tenkiller dam is located on the Illinois River about 7 miles northeast of Gore, Oklahoma. The lake extends more than 25 miles up the Illinois River in Cherokee and Sequoyah counties and at normal power pool of 632 feet mean sea level has a surface area of approximately 12,900 acres, 130 miles of shoreline, and a volume of 654,100 acre-feet

(U. S. Army Corps of Engineers, 1988). The lake was completed by the U.S. Army Corps of Engineers in 1952 with authorized project purposes being flood control and hydropower generation. The lake also serves as a water supply source for numerous municipalities in the immediate vicinity and is valued as a prime recreational facility (Nolen et al., 1987).

The lake is primarily fed by the Illinois River with the main tributaries being Flint Creek, Baron Fork Creek, and Caney Creek which enters the lake directly.

Several studies have been performed on the lake to estimate its current and future trophic status because concerns have been raised about water quality deterioration in the Illinois River Basin. Because flow velocities along the mainstem of the Illinois River are relatively high even during low flow periods, and because Lake Frances has a low mean hydraulic retention time, nutrient discharges from the upper Illinois River watershed are likely to end up in Lake Tenkiller (Walker, 1987).

CHAPTER III

LITERATURE REVIEW

Water Quality Studies

Several water quality studies have been performed on various segments of the Illinois River Basin over the past 15 years. The Oklahoma State Department of Health (1977) conducted studies in the Illinois River Basin during the period from June 1975 to October 1977 which included assessments of Lake Frances and Lake Tenkiller, the Illinois River from Lake Frances to Lake Tenkiller, and portions of Flint Creek and Baron Fork Creek. Lake Frances was described as being in the late stages of eutrophication. The impact of the outflow from Lake Frances was determined to extend downstream to the Illinois River's confluence with Flint Creek. Flint Creek was shown to be carrying elevated loads of nutrients. Baron Fork Creek was judged to have superior water quality. Water quality in the Illinois River generally improved going downstream from Lake Frances to Lake Tenkiller. Lake Tenkiller was described as having high water quality and was classified as being mesotrophic.

Threlkeld (1983) conducted a diagnostic feasibility study for the potential restoration of Lake Frances from October 1981 to October 1982. The study included regular sampling of sites in Lake Frances, inflows from the Illinois River and Ballard Creek, and the outflow from Lake Frances. The lake was described as very eutrophic and the primary cause was attributed to phosphorus entering the system from discharges from Springdale and Rogers' wastewater treatment plants (WWTPs). It was concluded that Lake Frances was heavily loaded with both nitrogen and phosphorus but that the lake retained negligible amounts of these nutrients partially due to the short hydraulic retention time of about 2.4 days.

The study concluded that dredging of the upper end of Lake Frances was necessary to increase the residence time of waters in the lake to allow for greater retention of nutrients by the lake. Also, the treatment of phosphorus in the WWTPs at Springdale and Rogers would greatly reduce the amount of phosphorus entering the lake. Nutrient loading from the Lake Frances watershed was determined to contribute to water quality degradation in the Illinois River downstream of Lake Frances.

The U.S. Geological Survey (Terry et al., 1984) conducted an extensive water quality study on the Illinois River Basin above Lake Frances from September 1978 to September 1981. The purposes of that study were to determine existing water quality conditions and to calibrate and verify a water quality model that would be used to simulate changes in water quality caused by changes in nutrient loadings. The study concluded that existing water quality in the Illinois River, and several major tributaries, did not meet the Arkansas State Guideline of 100 ug/l total phosphorus (as P) in streams.

Roberts/Schornick and Associates (1984) reviewed studies of the Illinois River Basin for the Office of the Attorney General of Oklahoma in response to the City of Fayetteville's plan to upgrade their existing wastewater treatment plant and divert a portion of the effluent into a subtributary of the Illinois River. They concluded that the quality of water in the Illinois River apparently improved going downstream from Lake Frances, but indicated that the river was probably assimilating as much waste as possible and that increased loads of nutrients would generate increasing water quality problems.

Oklahoma's 305(b) Report (Oklahoma Department of Pollution Control, 1984) included an assessment of trends of certain water quality parameters at USGS gaging stations 07195500, 07196000, 07196500, and 07197000 for the period from 1975 to 1983 done by the Oklahoma Department of Pollution Control (ODPC). It was concluded there was an apparent increasing trend in concentrations of total phosphorus at all four stations. Nitrite + nitrate trend tests showed no apparent trend at USGS stations 07195500 and 07197000. USGS 07196000 showed an apparent decreasing trend and 07196500 showed a possible decreasing trend. The ODPC used an U. S. Environmental Protection Agency (EPA) software package to analyze the data which applied Spearman's Rho and

Sen test statistics. These are nonparametric tests for trend based on rank correlated with time. An apparent trend was defined as being statistically significant at the 90% level. A possible trend was statistically significant at the 80 - 90% level.

Gakstatter and Katko (1986) performed an intensive study of the Illinois River Basin in both Arkansas and Oklahoma in August 1985. This study was performed in response to concerns that water clarity had decreased in the reach of the Illinois River between Lake Frances and Lake Tenkiller, the designated scenic river portion. The survey included water sample collection and analysis of 24 mainstem and tributary sites throughout the basin. The study concluded that background phosphorus concentrations in the basin were generally very low. However, Osage Creek, which receives wastewater effluent from the cities of Rogers and Springdale, Arkansas, typically had much higher phosphorus concentration levels which substantially affected concentration levels in the Illinois River above Lake Frances and in Lake Frances. It was also concluded that the effects of water flowing through Lake Frances, sustaining substantial algal growth, adversely affected water clarity for some 20 miles below the Lake Frances dam.

Walker (1987) also prepared a report for the Office of the Attorney General of Oklahoma in response to the proposed discharge of a portion of Fayetteville's effluent into the Illinois River Basin. Reviewing data entered into EPA's

STORET data base as well as Gakstatter and Katko's data, Walker concluded that phosphorus concentrations have increased by a factor of roughly two to three over the past decade. The increased levels of stream phosphorus have been accompanied by substantial increases in chlorophyll a concentrations in both Lake Frances and Lake Tenkiller. Chlorophyll a is a pigment produced by algae and is an indicator of algal density. Walker used flow-weighted annual mean total phosphorus concentrations to develop conclusions about trends. He suggested that it would only be proper to compare years of comparable flow to determine if total phosphorus concentrations had indeed increased.

Walker also concluded the most probable cause for accelerated eutrophication in Lake Tenkiller is increased point source nutrient loadings. Generally, non-point sources tend to be rich in nitrogen while point sources tend to be rich in phosphorus.

A study done by the U. S. Army Corps of Engineers (1988) on Lake Tenkiller in 1985 and 1986 showed relatively high concentrations of nutrients in the upper portion of the lake which gradually decreased going downstream toward the dam. Using a trophic state index proposed by Carlson (1977), which provides a numeric measure of trophic status using total phosphorus data, the lake was classified as eutrophic throughout the lake. Carlson's index can also use chlorophyll a and Secchi disk data to determine trophic status. Using these data the lake was shown to be borderline eutrophic at the upper end decreasing to mesotrophic near the dam. It was concluded "immediate and intense" efforts by federal and state agencies, municipalities, industries, and private landowners would be required to control point and non-point sources of nutrients to protect Lake Tenkiller from further deterioration.

Burks and Kimball (1988) performed a study evaluating existing concentrations of nutrients transported by the Illinois River to make an assessment of the potential effects on water quality in Lake Tenkiller. They found the highest levels of nutrient concentrations (nitrogen and phosphorus) just below Lake Frances with a steady decline downstream to Tahlequah where that city's WWTP effluent caused an apparent increase. A steady state computer model (QUAL2E) of the lower reaches of the Illinois River above Lake Tenkiller and the upper segment of Lake Tenkiller was developed. They found that a projected decrease in phosphorus concentration input from Tahlequah's WWTP, after construction and implementation of a phosphorus removal system, would be adequate in reducing the rate of eutrophication of Lake Tenkiller. However, they concluded that other point and non-point sources within the basin would still contribute to the further deterioration of water quality in Lake Tenkiller. They recommended concerted efforts by public and private agencies to reduce phosphorus input into Lake Tenkiller to prevent further deterioration.

Harton (1989) performed a modeling study of the Illinois River in an attempt to analyze contributions of point and non-point source phosphorus loading on Lake Tenkiller. Included in the objectives of the study was an attempt to determine the effects of the discharge of half of Fayetteville, Arkansas' treated effluent into a tributary of the Illinois River and the subsequent effects on eutrophication in Lake Tenkiller. The Fayetteville wastewater treatment plant effluent was determined to have no observable effect on eutrophication in Lake Tenkiller. The substantial distance from the point of entry of the effluent into the Illinois River to Lake Tenkiller was sufficient to allow for nearly total removal due to sedimentation and biological activity.

Non-point source total phosphorus loadings from Oklahoma and Arkansas were found to be the main loading sources to the lake. Harton concluded that removal of 70 to 90% of the total phosphorus loading from point and non-point sources would be necessary to bring eutrophication under control at Lake Tenkiller.

Eutrophication

Nutrient parameters are of special interest. Historically, attention has been given to phosphorus and nitrogen because they are often limiting nutrients which are necessary for algal growth. Typical plant organic matter of aquatic algae and macrophytes contains phosphorus, nitrogen, and carbon in approximately the ratios 1 P: 7 N: 40 C per

500 units wet weight. If one of these three elements is limiting and all other elements are present in excess of physical needs, phosphorus can theoretically generate 500 times its weight in living algae, nitrogen 71 times, and carbon 12 times (Wetzel, 1983). Carbon is often found to be particularly abundant and thus attempts to limit excessive algal growth have focused on phosphorus and nitrogen.

Eutrophication is a natural process of lake aging whereby a lake matures from a relatively unproductive oligotrophic status to a highly productive eutrophic state. Unfortunately, anthropogenic wastes have greatly accelerated this process in many lakes in developed areas. The nutrients nitrogen and phosphorus, abundant in anthropogenic wastes, are not often found in abundance in natural conditions. If anthropogenic activities produce significant quantities of these nutrients, and if they are allowed to enter stream and lake systems, they provide ample nutrients for accelerated growth. As a lake becomes increasingly productive certain species are no longer able to compete and diversity decreases. Accelerated rates of eutrophication of lakes have been attributed to increased amounts of nutrients discharged into waters flowing into the lakes (Warren, 1971). If nutrient levels are left unchecked, their abundance may lead to undesirable water quality problems. The water quality problems can include reduced diversity of organisms and conditions which are aesthetically undesirable such as extensive algal blooms, reduced water clarity, and offensive odors. If the water body is used as a water supply source, increased cost for water treatment may be required.

Streams can also be adversely affected by increased levels of nutrients. It is certain that enrichment causes changes in the flora and encourages the growth of periphyton and macrophytes. In some areas of the United States there has been a documented decrease in clear-water fish species as a result of nutrient enrichment. These species are often replaced by warm-water species. Additionally, turbidity levels may increase due to increased suspended algae (Hynes, 1970).

Nonparametric Trend Analysis Techniques

Mann (1945) described a nonparametric test for randomness against trend. The test he described is a particular application of Kendall's test for correlation commonly known as Kendall's Tau. Kendall's Tau is a test of correlation after paired observations, a x and y measurement on each of n units (eg. date and concentration), are ranked by arranging the n units in increasing order on the x-variable (eg. date), and the resulting order of the y-variable (eg. concentration) is tested for randomness. If the two variables are correlated, the observations should form an increasing or decreasing sequence (Bradley, 1968). In this test assumptions include random sampling, and tied values cannot occur within the n observations upon the x-variate nor among the n observations upon the y-variate.

Kendall (1975) suggested improvements to this test which would allow for ties in the data as well as missing data values. In the Kendall Tau test, paired observations are ranked earliest to latest by date. The sign of all possible differences, $y_i - y_j$, where $i > j$, are then determined. If the difference is positive a plus one is tallied. If the difference is negative a minus one is tallied. If the observations are equal and the difference is zero then a zero is scored. An S statistic is then calculated which equals the number of positive differences minus the number of negative differences. The variance of the S statistic is calculated accounting for ties and the number of tied groups. Finally, a Z statistic, which has or approximates a normal distribution, is calculated from S and the square root of the variance of S. The Z value is then found in the appropriate statistical table and the significance is found at the desired alpha level (Gilbert, 1987).

Hirsch et al. (1982) suggested a procedure in which Kendall's Tau, computed for each month of a year, and a weighted average of the 12 statistics is formed to provide a single over-all test for trend that is distribution-free and not affected by seasonality. This Seasonal Kendall test is essentially Kendall's Tau test restricted to those pairs of data which are multiples of twelve months apart thus making comparisons only between data from the same month of the year. The method can be applied to quarterly observations as well. In this way the problem of seasonality is avoided.

Seasonality can be described as regular fluctuations in concentration of a particular water quality measure within a season or year. The data collected in the Illinois River indicate that nitrite + nitrate (NO_2 + NO_3) concentrations cycle over a regular pattern in a year with higher concentrations measured in the colder months of the year dropping to lower concentrations in the warmer months. This cycle is evident for all stations and nearly all years. Figure 2 shows mean seasonal average concentrations of NO_2 + NO_3 (as N) at SR 3. The seasonal variation is evident and regular throughout the period of record. This seasonal variation can mask attempts to determine temporal trends. Figure 3 shows total phosphorus (as P) mean seasonal averages for the same time period at the same sampling station. Seasonality seems evident for total phosphorus but the variation in concentration over time is not as regular as NO_2 + NO_3 concentration. SR 3 is the scenic river station located at river mile 86.7 below the confluence of Flint Creek and the Illinois River.

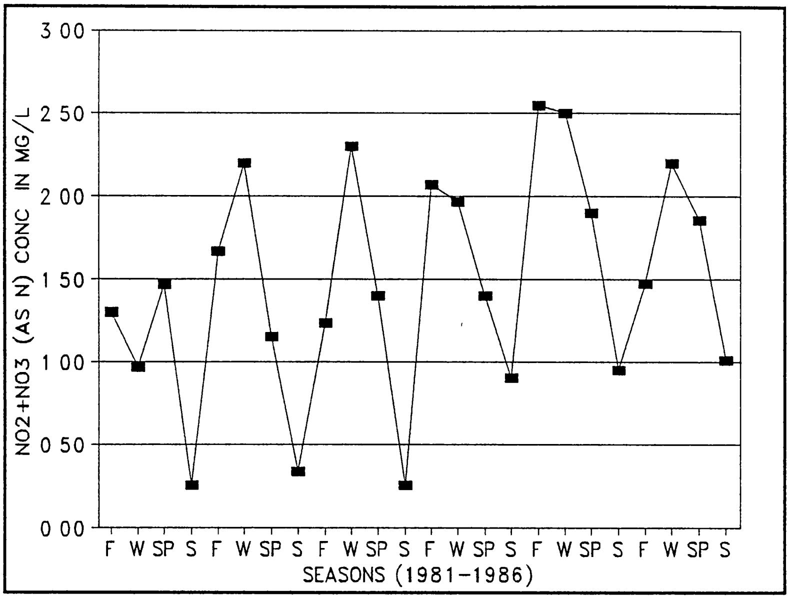

Figure 2. $NO_2 + NO_3$ (as N) Mean Seasonal Concentrations at SR 3.

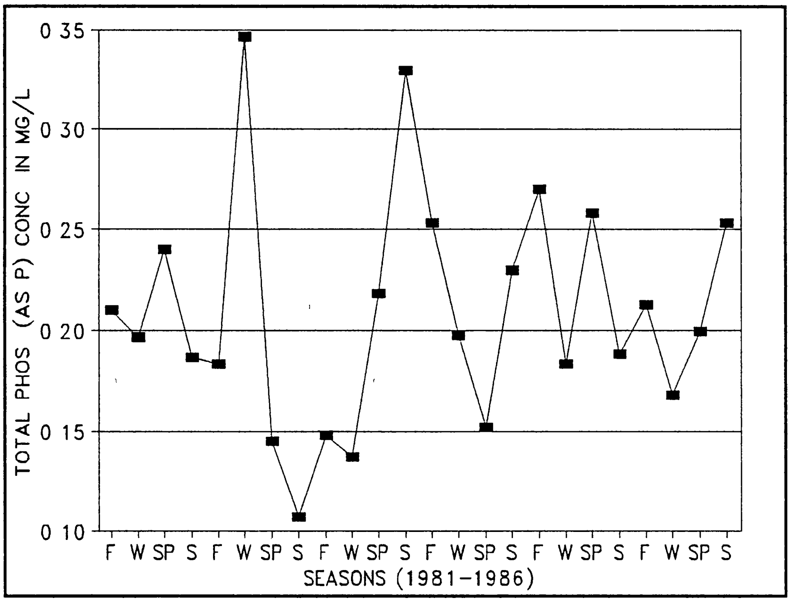

Figure 3. Total Phos. (as P) Mean Seasonal Concentrations at SR 3.

The Kruskall-Wallis test, used in this study to determine if seasonality is significant, is a distribution-free test which tests for equal medians among three or more groups of data. In this application, median nutrient concentration values of each of the 12 months of the year, at a station for the entire period of record, are compared. The null hypothesis is that all months have the same median (no seasonal variation), and the alternative hypothesis is that at least one month has a median larger or smaller than at least one other month (Gilbert, 1987).

The Seasonal Kendall Sen slope estimate is a calculation where the slope between any two observations of the same month of different years, x_i and x_j, is calculated by $x_i - x_j$, where x_i and x_j are data values at times i and j respectively and $i > j$. The resulting individual slope estimates for each month (season) are then ranked and the median of these individual slope estimates is then found (Gilbert, 1987).

Smith et al. (1982) applied the Seasonal Kendall test to total phosphorus time series data collected at National Stream Accounting Network stations in an attempt to determine long-term trends. They were confronted with the problem that increasing stream flow is often positively correlated with increasing total phosphorus measurements. A method was developed using a time series of flow-adjusted concentrations (FAC) and testing this series of residuals for trend. The method is fairly straightforward. The relationship between discharge and phosphorus concentration is estimated and used to provide a conditional expected value of concentration for every flow value. The FAC value is defined as the actual concentration minus the estimated conditional expected concentration. The relationship between flow and concentration is expressed as a flow-adjustment equation of the form:

$$\hat{C} = a + b * f(Q)$$

where $\hat{C}$ is the estimated concentration, Q is the discharge, and $f(Q)$ may have one of the following forms:

Functional Form	Name
$f(Q)=Q$	*linear*
$f(Q)=\ln Q$	*log*
$f(Q)=1/(1+BQ)$	*hyperbolic**
$f(Q)=1/Q$	*inverse*

* where B is a positive constant.

If all of these relationships are very poor then the flow adjustment is simply $\hat{C} = \bar{C}$ where $\bar{C}$ is the average or observed concentration.

Harned et al. (1981) also described two methods of discharge compensation. One is a discharge normalization technique which includes four parts. Daily discharges are shifted on an annual basis toward a central period-of-record discharge value. Daily concentration values of the parameter of interest are adjusted to compensate for the shift in discharges. Daily constituent concentrations are estimated using the normalized constituent concentration values. Finally, annual concentrations or annual loads are calculated from normalized daily concentrations and normalized discharges. A trend analysis can then be performed on the resulting annual values. The second method is discharge-frequency weighting which involves weighting constituent concentrations relative to the discharge frequency distribution for the entire period of record.

CHAPTER IV

METHODOLOGY

Using the software package WQSTAT II developed by Colorado State University (Phillips et al., 1989) it is possible to analyze temporal trends in nutrient concentrations using the Kendall Tau and the Seasonal Kendall tests which test the null hypothesis of no temporal trend in the selected data against a two-sided alternative of either increasing or decreasing trend. Both of these tests are nonparametric and compute results at the 95, 90, and 80% confidence levels. Temporal trends in nutrient concentrations were classified as highly significant at the 95% confidence level, significant at the 90% confidence level, and weakly significant at the 80% confidence level. WQSTAT II will also compute a trend line using the Seasonal Kendall Sen Slope Estimator. Testing for trend using these methods can be viewed as a comparison of early observations in the series with later observations. The Kendall Tau test checks for a correlation between ranks of data and time. The Seasonal Kendall test computes Kendall Tau test statistics for each season (month or quarter) and combines them into an overall statistic (Loftis et al., 1989).

A key assumption in the Kendall Tau test described above is independence of observations. When seasonality occurs in the data set this assumption is violated. This assumption is met using a technique which subtracts the seasonal (eg. monthly) mean from the respective original observations thus smoothing the distribution. This method is called deseasonalization. This method reduces the artificially increased variance of seasonality and thus increases the power of the statistical analysis.

Data were collected from EPA's STORET data base and the USGS WATSTORE database for 14 stations in the Illinois River Basin. The water quality monitoring stations used in this study, include the four USGS gaging stations (USGS 07194800, 07195400, 07195500, and 07196500) and six Scenic River Commission monitoring stations (SR 1, SR 2, SR 3, SR 4, SR 5, and SR 6) on the mainstem of the Illinois River, and four tributary USGS stations (USGS 07195000 on Osage Creek, 07195860 on Sager Creek, 07196000 on Flint Creek, and 07197000 on Baron Fork Creek). These stations were chosen because they represent nearly all of the free flowing reaches of the river and they all have a period of record of at least five years for the nutrient measures of interest. Table I describes the locations of the stations to be used in the study. The Illinois River Basin, with the locations of the monitoring stations as well as municipalities, are depicted in Figure 1.

TABLE I

ILLINOIS RIVER BASIN WATER QUALITY MONITORING STATIONS

Station ID	Verbal Description	Legal Location	Longitude & Latitude	River Mile
USGS 07194800	W of Savoy, Hwy 16 bridge	SEC36,T17N, R32W Wash. Co., AR	36 06 11.0 94 20 39.0	133.1
USGS 07195400	S of Siloam Springs, Hwy 16 bridge	SEC15,T17N, R33W Benton Co., AR	36 08 41.0 94 29 41.0	115.5
USGS 07195500	Hwy 54 bridge N of Watts	SEC18,T19N, R26E Adair Co., OK	36 07 48.0 94 34 12.0	106.2
SR 1	Below USGS 07195500	SEC14,T19N, R25E Del. Co., OK	36 07 47.0 94 34 31.0	104.2
SR 2	100 yds above confl. with Flint Creek	SEC35,T20N, R24E Del. Co., OK	36 10 31.0 94 43 13.0	93.8
SR 3	Chewey bridge W of Chewey	SEC19,T19N, R24E Del. Co., OK	36 06 16.0 94 46 59.0	86.7
SR 4	Round Hollow State Park	SEC26,T19N, R23E Cher. Co., OK	36 05 30.0 94 49 55.0	82.3
SR 5	2 mi above USGS 07196500	SEC24,T17N, R22E Cher. Co., OK	35 56 25.0 94 54 58.0	57.8
USGS 07196500	At bridge on Hwy G2 2.2 mi NE of Tahl.	SEC26,T17N, R22E Cher. Co., OK	35 55 17.0 94 55 15.0	55.8
SR 6	Just below Tahl. STP	SEC11,T16N, R22E Cher. Co., OK	35 52 55.0 94 56 33.0	51.9
USGS 07195000	Osage Creek NR Elm Springs, AR	SEC21,R31W, T18N Benton Co., AR	36 13 19.0 94 17 18.0	10.0
USGS 07195860	Sager Creek 0.8 mi W of state line	SEC24,T20N, R25E Del. Co., OK	36 11 50.0 94 35 00.0	3.0
USGS 07196000	Flint Creek at Hwy 33 bridge	SEC24,T20N, R24E Del. Co., OK	36 11 54.0 94 42 30.0	2.8

TABLE I (Continued)

Station ID	Verbal Description	Legal Location	Longitude & Latitude	River Mile
USGS 07197000	Baron Fork Creek at Hwy 51 bridge at Eldon	SEC27,T17N, R23E Cher. Co., OK	35 55 16.0 94 50 18.0	8.8

The parameters chosen for analysis in this study are total phosphorus (as P) and NO_2 + NO_3 (as N). These parameters have a relatively complete record, measured at monthly intervals with relatively few missing months, at all stations for the available period of record. This provides a data set sufficient for trend calculation. The period of record (POR) at each station for each parameter is shown in Table II.

After the data were retrieved from the STORET and WATSTORE databases, the data were entered chronologically into separate spreadsheets for each monitoring station. The spreadsheets included rows of parameter concentration measured on a particular date. Instantaneous and/or daily average discharge values were only available at the USGS gaging stations. Observations which were recorded as being below a particular concentration level in the either dataset (nondetects) were recorded as one-half of the detection limit. The resulting spreadsheets were then used as input files in the WQSTAT II program which created a separate file for each parameter at each station. The WQSTAT II software package read both the dates and the corresponding parameter

TABLE II

PERIOD OF RECORD, BY WATER YEAR, OF SELECTED WATER QUALITY PARAMETERS AT MONITORING STATIONS IN THE ILLINOIS RIVER BASIN

Station	NO_2+NO_3 (as N)	Total P (as P)
USGS 07194800	77*-88	75-88
USGS 07195400	81*-87	81*-87
USGS 07195500	75,77*-86	70-72,73*-86
SR 1	81-86	81-86
SR 2	81-86	81-86
SR 3	81-86	81-86
SR 4	81-86	81-86
SR 5	81-86	81-86
USGS 07196500	78-86	76-86
SR 6	81-86	81-86
USGS 07195000	77*-87	74*-87
USGS 07195860	77*-83,85*-86	74*-83,85*-86
USGS 07196000	78-84,85*-86	76-86
USGS 07197000	78-84,85*-86	76-86

* indicates only partial data for that water year.

concentration (or discharge) values. There were some dates where one parameter was measured and another was not. To get the software package to throw out those dates where a parameter was not measured, read as zero concentration by the WQSTAT II program, some editing of the files was necessary. The data analyzed was manipulated into monthly means within the software package by arithmetic averaging of multiple observations in any one month of a particular year.

The distribution of each of the monitoring station data sets for each parameter was then tested for normality based on skew and kurtosis values. If either the skew or kurtosis value was significant the data distribution was probably not normal, thus supporting the use of nonparametric techniques for analysis.

A Kruskal-Wallis test to check for significant seasonal variation, a predictable change in water quality with time of year, was performed on each of the monitoring station data sets for each parameter. The Kruskal-Wallis test is a nonparametric test which checks for equal medians among three or more groups of data (Phillips et al., 1989). In this study this test was used to determine if long-term median values of each of the months of the year were significantly different from each other. Results from this test were used to determine whether or not deseasonalization of the data would later be required for the Kendall Tau trend test.

Temporal trend analysis was then performed on each of the monitoring station data sets for each parameter after the results of the seasonality test were accounted for. This analysis included the Kendall Tau test, the Seasonal Kendall test, and a Seasonal Kendall Sen Slope Estimate.

Refined data sets accounting for correlation between nutrient concentrations and discharge were created at those stations where both nutrient concentration and discharge data was available. The method used to compensate for variable is the FAC method described by Hirsch et al. (1982). Linear regression was used to estimate the coefficients a and b of $C = a + bQ$ for each of the functional forms of $f(Q)$ and an R^2 value was calculated for each. The linear regressions on linear, log, and inverse functional forms were straightforward. The linear regression equations for the hyperbolic relationships were set up as follows. First the average discharge value, Q, was determined at each of the stations with consistent discharge data. The integer part of $logQ$ was found and called $B*$. B in the hyperbolic functional form was then set as $B = 10^{-2.5B*}$. Linear regressions were performed on this equation and additional hyperbolic equations which were developed by incrementing the value of B by $10^{0.5}$ until $B = 10^{1.5-B*}$. This resulted in 12 hyperbolic equations. The relationship with the highest R^2 was then used to perform the flow adjustment. The flow adjusted data sets were then tested for temporal trend using the same methods and software package. The results of trend tests on the refined data set were then compared to results of trend tests on the original data sets to determine differences attributable to trends in discharge.

CHAPTER V

RESULTS

Distributions of the Data

The total phosphorus and NO_2 + NO_3 data set distributions, at each of the monitoring stations, were tested with skew and kurtosis tests to determine if the data sets were in fact not normally distributed. If either the skew or kurtosis value was significant the data distribution was determined to be nonnormal. As shown in Table III, all of the total phosphorus data sets indicated positive skewness at the 98% confidence level. Kurtosis test results on total phosphorus data indicated that 12 of the 14 monitoring stations had distribution shapes which were significantly nonnormal at the 98% confidence level. Thus it could be concluded that nonparametric statistical analysis techniques would be appropriate, and probably the best choice, for temporal trend analysis of total phosphorus data.

Also shown in Table III are results of skew and kurtosis tests for NO_2 + NO_3 data sets. Skew tests showed six of the 14 data sets with positive skewness significant at the 98% confidence level, two data sets with positive skewness significant at the 80% confidence level, one data set with negative skewness significant at the 90% confidence level, and five data sets with nonsignificant skew values. Kurtosis tests on these same data sets showed nine of the 14 having distribution shapes significantly nonnormal at the 98% confidence level, two at the 90% confidence level, and one at the 80% confidence level. Only two data sets, USGS 07195400 and USGS 07195860, indicated nonsignificant kurtosis values. While the results for $NO_2 + NO_3$ were not as uniform as those for total phosphorus, it was determined that nonparametric analysis techniques would be most appropriate for analysis.

Seasonality

As discussed above, regular variation of water quality measures over the period of a year or season, defined as seasonality, could affect the results of the Kendall's Tau test for temporal trend. The Kruskall-Wallis test was used to determine if the total phosphorus and $NO_2 + NO_3$ data sets at each of the monitoring stations displayed seasonality. Results of these tests are shown in Table IV. One of the 14 total phosphorus data sets, USGS 07195000, indicated significant seasonality at the 98% confidence level. None of the other total phosphorus data sets showed significant seasonality. While this would indicate little predictable change in total phosphorus concentration with month of the year, as was shown in Figure 3, total phosphorus average monthly concentrations are highly variable. It was determined that deseasonalization would still be effective in reducing this

TABLE III

RESULTS OF TESTS FOR NORMALITY OF DISTRIBUTIONS OF TOTAL PHOSPHORUS (TP) AND NITRITE + NITRATE (NO) DATA SETS AT SAMPLING STATIONS IN THE ILLINOIS RIVER BASIN

Station ID	Skew Test Statistic (TP)	Kurtosis Test Statistic (TP)	Skew Test Statistic (NO)	Kurtosis Test Statistic (NO)
USGS 07194800	7.306***	66.09***	1.578***	9.35***
USGS 07195400	0.998***	3.56	0.156	2.85
USGS 07195500	5.413***	40.51***	0.174	2.10***
SR 1	2.218***	12.43***	0.470*	3.75*
SR 2	5.692***	40.76***	4.942***	34.77***
SR 3	2.237***	10.42***	-0.079	1.98***
SR 4	1.636***	7.37***	0.089	2.00***
SR 5	6.860***	52.80***	1.549***	8.05***
USGS 07196500	4.958***	40.22***	0.585***	2.29**
SR 6	1.769***	5.50***	1.243***	5.14***
USGS 07195000	3.874***	24.65***	-0.432**	5.16***
USGS 07195860	0.806***	2.73	0.004	3.00
USGS 07196000	1.755***	8.70***	0.357*	2.05***
USGS 07197000	3.172***	17.47***	0.990***	3.81**

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 98% confidence level

variability and thus improve the power of the Kendall Tau test.

$NO_2 + NO_3$ data sets showed significant seasonality at the 98% confidence level at nine of the 14 stations. This is evidence that $NO_2 + NO_3$ concentrations do change predictably with month of the year thus requiring deseasonalization to get accurate results from Kendall's Tau test. Reasons for the observed seasonality of $NO_2 + NO_3$ concentrations could include temperature, biological activity, and discharge variation over the period of a year.

Total Phosphorus Trend

The time series of average monthly total phosphorus concentrations at each of the 14 stations were tested for significant temporal trends using Kendall's Tau test and the Seasonal Kendall test. Shown in Table V are the results of these tests where variable flow was not considered. Using the Kendall Tau test, seven of the 14 stations showed positive trends in total phosphorus concentration highly significant at the 95% confidence level. One station showed a positive trend weakly significant at the 80% confidence level, and one station showed a negative trend weakly significant at the 80% confidence level. The remaining five stations showed no apparent significant trend in total phosphorus concentration over the period of record.

Results of the Seasonal Kendall test on total phosphorus concentrations, which restricts comparisons to the same

TABLE IV

RESULTS OF KRUSKALL-WALLIS TEST FOR SEASONALITY, BASED ON MONTHLY AVERAGES, ON TOTAL PHOSPHORUS (TP) AND NITRITE + NITRATE (NO) DATA SETS AT SAMPLING STATIONS IN THE ILLINOIS RIVER BASIN

Station ID	Test Statistic (TP)	Test Statistic (NO)
USGS 07194800	13.66	84.52***
USGS 07195400	5.17	17.17*
USGS 07195500	5.98	62.04***
SR 1	1.44	2.30
SR 2	5.42	29.63***
SR 3	7.50	31.63***
SR 4	9.46	33.19***
SR 5	11.70	24.45***
USGS 07196500	6.52	48.50***
SR 6	10.73	8.90
USGS 07195000	19.72***	12.86
USGS 07195860	15.40*	14.65*
USGS 07196000	2.14	74.08***
USGS 07197000	3.82	92.01***

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 98% confidence level

months of the year, were roughly the same but there were some interesting differences. USGS 07194800, which showed no apparent significant trend using the Kendall Tau test, showed a highly significant positive trend (95% confidence level) using the Seasonal Kendall test. The negative trend at USGS 07195400, which tested weakly significant using Kendall's Tau, was highly significant using the Seasonal Kendall test. The highly significant positive trend at SR 5 using Kendall's Tau was only weakly significant using the Seasonal Kendall test.

Seasonal Kendall Sen Slope Estimates for total phosphorus concentration trends indicate direction and magnitude of the observed trends. All but three stations showed positive slopes indicating increasing total phosphorus concentrations over the period of record. Positive slopes ranged from a minimum of 0.0025 mg/l/yr at USGS 07194800, near the headwaters of the Illinois River, to a maximum of 0.104 mg/l/yr at SR 6 below Tahlequah and Tahlequah's WWTP effluent discharge. Three negative slopes were observed. USGS 07195400 was the only station where a negative slope (-0.0133 mg/l/yr) corresponded with a highly significant downward trend using the Seasonal Kendall test. Other stations having nonsignificant downward trend slopes in total phosphorus concentration over the period of record were SR 1 (-0.008 mg/l/yr) and SR 2 (-0.0043 mg/l/yr). Graphic representations of the time series concentration with the slope estimate are included in Appendix A, Figures

TABLE V

TEMPORAL TREND TEST RESULTS FOR TOTAL PHOSPHORUS DATA SETS AT SAMPLING STATIONS IN THE ILLINOIS RIVER BASIN

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (mg/l/yr)
USGS 07194800	1.010	1.982***	0.00250
USGS 07195400	-1.343*	-2.024***	-0.01333
USGS 07195500	5.223***	5.955***	0.01000
SR 1	-1.089	-0.950	-0.00800
SR 2	-0.509	-0.794	-0.00432
SR 3	0.836	0.976	0.00850
SR 4	0.614	0.612	0.00409
SR 5	2.048***	1.405*	0.00940
USGS 07196500	5.677***	5.589***	0.01257
SR 6	3.013***	2.389***	0.10400
USGS 07195000	1.639*	1.810**	0.02250
USGS 07195860	3.216***	3.112***	0.07889
USGS 07196000	6.025***	5.810***	0.01143
USGS 07197000	3.919***	2.936***	0.00540

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

4 through 17.

Nitrite + Nitrate Trend

Temporal trend test results on NO_2 + NO_3 concentrations unadjusted for variable discharge are shown in Table VI. Kendall Tau tests on deseasonalized data sets indicated highly significant upward trends in nine of the 14 stations. Of the remaining five stations, two showed weakly significant upward trends, and three showed no apparent trend in NO_2 + NO_3 concentrations over the period of record. It is interesting to note that only one of the four tributary monitoring stations (USGS 07195860) tested as having a significant upward trend.

Seasonal Kendall tests on NO_2 + NO_3 concentrations over the period of record gave essentially the same results as the Kendall Tau test. Seven of the 14 stations tested as having highly significant upward trends. Of the remaining seven stations, one tested as having an upward trend significant at the 90% confidence level, one had an upward trend weakly significant at the 80% confidence level, and five showed no apparent trend. The Seasonal Kendall test indicated no apparent trend at USGS 07195400 which tested as having a highly significant upward trend in concentration using the Kendall Tau test. The only other difference between the results of the two trend tests on NO_2 + NO_3 concentrations was at USGS 07195860 which had upward trend significant at the 90% confidence level using the Seasonal

Kendall test (95% confidence level with the Kendall Tau).

Seasonal Kendall Slope Estimates showed positive upward trends at 11 of the 14 stations. Only USGS 07195000 showed a downward trend (-0.025 mg/l/yr). Two stations, USGS 07196000 and 07197000, had flat slope results indicating no observable upward or downward trend in concentration over the period of record. Increasing slopes ranged from a minimum of 0.0125 mg/l/yr at USGS 07196500 just above Tahlequah to a maximum of 0.32 mg/l/yr ar SR 6 just below Tahlequah. Graphic representations of the time series at each station with the slope estimate are included in Appendix A, Figures 18 through 31.

Flow Adjustment

Correlation between discharge of water flowing past a sampling station at the time a sample is taken and either total phosphorus or $NO_2 + NO_3$ concentrations can mask temporal trends. Long-term changes in discharge can cause long-term changes of water quality and produce apparent temporal trends in nutrient concentration. Trend analysis of discharge, measured at the same time samples are taken for nutrient analysis, should indicate whether there exist long-term trends in discharge. Only two of the Illinois River mainstem USGS gaging stations, 07194800 and 07195400, both in Arkansas, recorded instantaneous discharge relatively regularly at the time samples were taken. The two mainstem USGS gaging stations on the Illinois River in Oklahoma

TABLE VI

TEMPORAL TREND TEST RESULTS FOR NITRITE + NITRATE DATA SETS AT SAMPLING STATIONS IN THE ILLINOIS RIVER BASIN

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (mg/l/yr)
USGS 07194800	3.054***	2.981***	0.05000
USGS 07195400	2.005***	0.998	0.05000
USGS 07195500	3.175***	2.400***	0.03333
SR 1	2.943***	2.803***	0.15000
SR 2	1.611*	1.603*	0.07500
SR 3	3.764***	3.507***	0.15000
SR 4	3.232***	2.425***	0.10250
SR 5	2.519***	2.447***	0.10917
USGS 07196500	1.377*	1.082	0.01250
SR 6	3.116***	2.545***	0.32000
USGS 07195000	-0.199	-0.994	-0.02500
USGS 07195860	2.356***	1.845**	0.08542
USGS 07196000	0.510	0.177	0.00000
USGS 07197000	0.854	-0.287	0.00000

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

(USGS 07195500 and 07196500) recorded instantaneous discharge infrequently and generally for periods much shorter than the period of record for nutrient concentration data. The same is true for the tributary monitoring stations. However, those stations which did not have regular instantaneous discharge recorded did have mean daily discharges recorded by USGS and reported in USGS Water Resources Data publications. One tributary station, USGS 07195860 on Sager Creek, did not have any discharge data. USGS 07195000 had intermittent discharge data which proved to be insufficient for FAC calculations. It was decided to use whatever discharge data was available, on the days when samples were taken, to test for temporal trends in discharge.

The results of trend tests and slope estimates of discharge at USGS gaging stations where sufficient discharge data was available are shown in Table VII. Of these six stations, five tested as having highly significant upward trends (95% confidence level) in discharge over the period of record using Kendall's Tau test. Seasonal Kendall test results were similar with four stations showing highly significant upward trends and one station, USGS 07196500, having a weakly significant upward trend.

These trend results indicate that the significant increases in discharge over the period of record should at least be considered in attempting to determine true temporal trends of nutrient concentrations. The flow adjusted concentration method described by Hirsch et al. (1982) was used

TABLE VII

TEMPORAL TREND TEST RESULTS FOR DISCHARGE AT USGS GAGING STATIONS IN THE ILLINOIS RIVER BASIN

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (cfs/yr)
USGS 07194800	3.174***	3.243***	2.54167
USGS 07195400	2.047***	2.882***	27.66667
USGS 07195500	0.249	-0.735	-1.54545
USGS 07196500	3.057***	1.515*	17.03333
USGS 07196000	3.386***	3.000***	4.00000
USGS 07197000	2.808***	2.270***	5.25926

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

to determine correlations between discharge and concentrations of both total phosphorus and NO_2 + NO_3.

The FAC method described by Hirsch et al. (1982), applied to the Illinois River Basin USGS monitoring stations with discharge and nutrient concentration data, showed generally weak relationships between nutrient concentration and discharge (Table VIII). Graphic representations of the relationships are shown in Appendix B Figures 32 through 43.

The relationships with the highest R^2 were used to develop revised data sets of flow adjusted concentrations for both nutrient parameters at each of these USGS stations. It should be noted that the number of FAC values was in some cases less than the total number of concentration values since some discharge values were missing (eg. USGS 07194800 and 07195400). In Tables IX and X are shown the results of temporal trend tests on these adjusted data sets.

Comparing total phosphorus trends of unadjusted and FAC data sets, it is evident that there are some differences. USGS 07194800, which had a highly significant upward trend using the Seasonal Kendall test in the unadjusted data set, showed no significant upward trend in the FAC data set. The slope estimate is still positive but nearly three times less in magnitude. The highly significant downward trend at USGS 07195400 in the original data set was found to be nonsignificant in the FAC data set even though the slope estimate is approximately the same. USGS 07197000 showed a weakly significant upward trend with the FAC data compared to a

TABLE VIII

CORRELATIONS BETWEEN NUTRIENT CONCENTRATION AND DISCHARGE AT USGS GAGING STATIONS IN THE ILLINOIS RIVER BASIN

Station ID	Nutrient Measure	Highest R^2 Value	Functional Form
USGS 07194800	Total Phosphorus	0.16	linear
	$NO_2 + NO_3$	0.27	hyperbolic
USGS 07195400	Total Phosphorus	0.23	hyperbolic
	$NO_2 + NO_3$	0.07	hyperbolic
USGS 07195500	Total Phosphorus	0.22	hyperbolic
	$NO_2 + NO_3$	0.30	hyperbolic
USGS 07196500	Total Phosphorus	0.13	hyperbolic
	$NO_2 + NO_3$	0.40	hyperbolic
USGS 07196000	Total Phosphorus	0.11	linear
	$NO_2 + NO_3$	0.47	hyperbolic
USGS 07197000	Total Phosphorus	0.16	hyperbolic
	$NO_2 + NO_3$	0.45	hyperbolic

TABLE IX

TEMPORAL TREND TEST RESULTS FOR FLOW ADJUSTED TOTAL PHOSPHORUS CONCENTRATIONS AT USGS GAGING STATIONS IN THE ILLINOIS RIVER BASIN

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (mg/l/yr)
USGS 07194800	0.183	0.942	0.00086
USGS 07195400	-0.997	-1.218	-0.01227
USGS 07195500	4.545***	4.818***	0.01009
USGS 07196500	4.835***	4.731***	0.00953
USGS 07196000	4.381***	3.962***	0.00941
USGS 07197000	2.493***	1.622*	0.00235

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

TABLE X

TEMPORAL TREND TEST RESULTS ON FLOW ADJUSTED NO_2 + NO_3 CONCENTRATIONS AT USGS GAGING STATIONS IN THE ILLINOIS RIVER BASIN

Station	Kendall Tau Test Statistic	Seasonal Kendall Test Statistic	Seasonal Kendall Sen Slope Estimate (mg/l/yr)
USGS 07194800	2.373***	1.808**	0.04343
USGS 07195400	-1.591*	-1.345*	-0.13975
USGS 07195500	3.534***	3.324***	0.05506
USGS 07196500	0.336	0.601	0.01264
USGS 07196000	-1.237	-1.985***	-0.03411
USGS 07197000	-0.599	-0.999	-0.01002

* = significant at the 80% confidence level
** = significant at the 90% confidence level
*** = significant at the 95% confidence level

highly significant trend using the original data set. The other USGS gaging stations (USGS 07195500, 07196500, and 07196000) retained highly significant upward temporal trends with the FAC data sets with slope estimates generally lower.

Comparing NO_2 + NO_3 trends of unadjusted and FAC data sets also showed some differences. The most obvious difference was at USGS 07195400. The Kendall Tau test on the original data set resulted in highly significant upward trend where the FAC data set resulted in weakly significant downward trends for both the Kendall Tau and the Seasonal Kendall tests. USGS 07195500 results again showed highly significant upward trend for both tests in the FAC data set. The slope estimate, however, was of slightly greater magnitude. USGS 07196000 FAC trend tests resulted in a highly significant downward trend using the Seasonal Kendall test compared to a nonsignificant trend in the original data set. The results for USGS 07196500 and 07197000 were essentially the same as the original data set.

Graphic time series representations of the FAC data sets with slope estimates are shown in Appendix B, Figures 44 through 55.

In most cases total phosphorus and discharge were only very weakly correlated implying that increasing discharge had minimal effects on concentration. Additionally, the greatest R^2 values were recorded using a hyperbolic functional form. This would indicate a rather complex relation ship where concentrations might increase with the first flush of a runoff event but would shortly thereafter be diluted to a lower concentration, or the concentration may decrease immediately with increasing discharge and gradually return to pre-runoff event levels.

NO_2 + NO_3 and discharge showed generally higher correlations. As suggested by Walker (1987), non-point source loading is generally higher in nitrogen, and thus a more evident relationship between concentration and discharge would be expected.

CHAPTER VI

CONCLUSIONS

Nonparametric methods for analyzing temporal nutrient trends in the Illinois River Basin have not been fully utilized up to this time. A review of literature published on the Illinois River indicates that most past efforts to analyze trends in nutrient concentrations in the basin have been limited to an analysis of average annual concentrations. Parametric trend analysis techniques include assumptions which are difficult to meet with environmental time series data. Irregular sampling times, nonnormal distributions, missing data, and censored data are all common characteristics of environmental time series. Nonparametric trend analysis techniques can accommodate these problems.

An analysis of the distributions of the nutrient data sets at the sampling stations in the Illinois River Basin indicated that they were generally nonnormal. This, along with the fact that there did exist missing and censored data in the nutrient data sets created for the Illinois River Basin sampling stations, supported the use of nonparametric analysis techniques.

The results of the trend tests performed in this study indicate that, at many of the water quality sampling stations included in this study, nutrient levels have been increasing over time. The results of this study would indicate that it may be a basin-wide trend.

Results of temporal trend tests on total phosphorus concentrations indicated that 50% of the sampling stations included in this study had highly significant upward trends using either the Kendall Tau or the Seasonal Kendall tests. Only one station had a significant decreasing trend.

Kendall Tau tests on NO_2 + NO_3 concentration data indicated that 64% of the stations had highly significant upward trends. Seasonal Kendall tests on NO_2 + NO_3 data indicated that 50% of the stations had highly significant upward trends in concentration. No significant downward trends were indicated.

Discharge trend tests, performed at those six USGS gaging stations where adequate discharge data was available, indicated a general upward trend during the period in which samples were collected for nutrient analysis. Because of possible correlation between discharge and nutrient concentration, this increasing trend in discharge could have masked or enhanced temporal trends in nutrient concentrations.

A flow adjustment method was applied to remove this possible correlation. Correlations between discharge and nutrient concentrations were identified. Linear regression equations which best described the correlation were used to create an adjusted data set which was then tested for temporal trend using the same nonparametric techniques.

Total phosphorus concentrations and discharge were found to have weak positive correlations. Trend analysis on the total phosphorus adjusted data sets indicated results similar to those of the unadjusted data sets. 66% of the stations had highly significant upward temporal trends using the Kendall Tau test. 50% of the stations had highly significant upward trends using the Seasonal Kendall test.

Correlations between NO_2 + NO_3 concentrations and discharge were somewhat greater. Differences between temporal trend analysis on NO_2 + NO_3 adjusted data sets and unadjusted data sets were identified. Kendall Tau trend tests on adjusted data sets showed two of the six stations having highly significant upward trends. Kendall Tau trend tests on unadjusted data sets indicated that three of the six stations had highly significant upward trends. Seasonal Kendall tests on adjusted data sets showed only one station with a highly significant upward trend in concentration. The same test on unadjusted data sets indicated that two of these six stations had highly significant upward trends. The Seasonal Kendall test on adjusted data sets also indicated one highly significant downward trend in NO_2 + NO_3 concentration at a station which recorded no significant trend in the unadjusted data set.

This study concentrated on the nutrients total phosphorus and NO_2 + NO_3. Total phosphorus may not be the best indicator of phosphorus available for algal and aquatic plant growth since it includes phosphorus which is bound to suspended sediments and therefore not readily available. Unfortunately, orthophosphate, the inorganic form of phosphorus which would more accurately indicate available phosphorus for growth, was not measured for a period of record long enough for temporal trend analysis. Another indicator of available nitrogen is ammonia. Again, this water quality measure was not available for a period of record long enough for temporal trend analysis.

The preferred measure of discharge to be used in the flow adjustment procedure is instantaneous discharge. Instantaneous discharge was not regularly measured at sampling times at all USGS gaging stations.

Tenkiller Lake is essentially the receptacle for all nutrients discharged into the Illinois River watershed. Since studies have already determined that the upper reaches of Tenkiller Lake is already considered eutrophic, it would follow that increases of nutrient loading of any magnitude would accentuate the problem.

Harton (1989) concluded that Lake Tenkiller currently appears to suffer from significant eutrophication problems primarily due to non-point phosphorus loading. Oklahoma and Arkansas appear to contribute equal amounts of phosphorus load to the Illinois River and Lake Tenkiller. Individual state removal of phosphorus load would have beneficial impacts on reducing load levels. However, the removal of large percentages of the total phosphorus load appears necessary to bring the eutrophication of Lake Tenkiller under control. Thus the need for cooperation between the states of Oklahoma and Arkansas is necessary to develop techniques and practices which will improve water quality in the Illinois River Basin.

Further research on nutrient problems within the Illinois River Basin should begin to identify the specific sources of nutrient input into the system. When specific sources of nutrient input are identified, the task of reducing that input will become more manageable.

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APPENDIX A

TOTAL PHOSPHORUS TREND ANALYSIS FIGURES AND NITRITE + NITRATE TREND ANALYSIS FIGURES

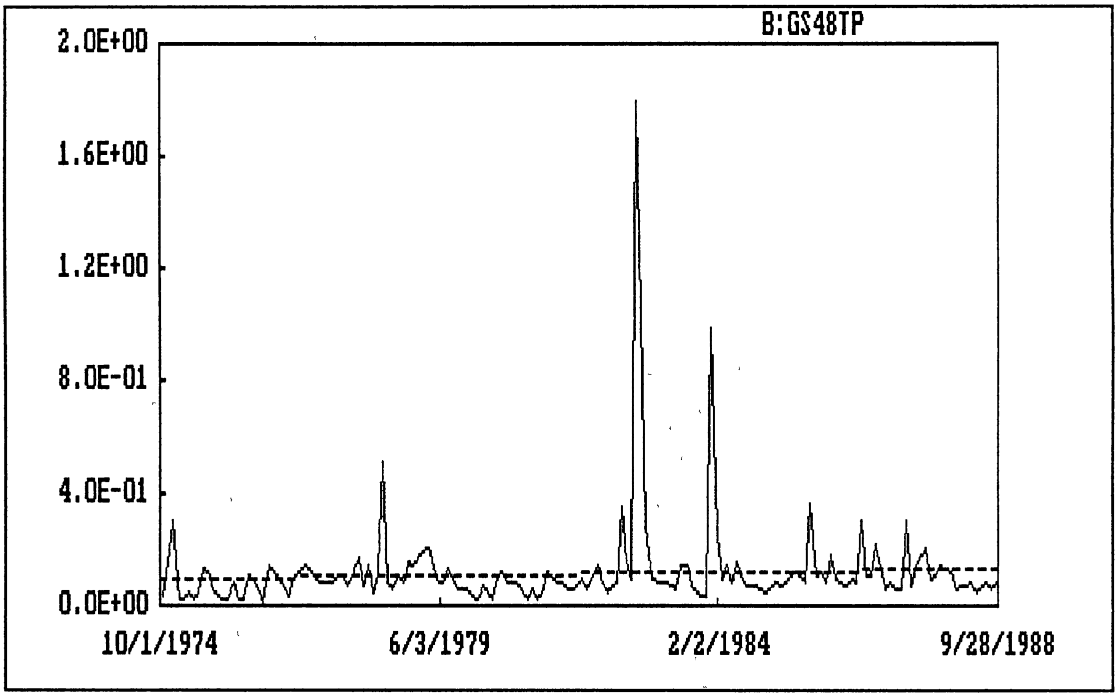

Figure 4. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07194800. Slope Estimate = 0.00250 mg/l/yr.

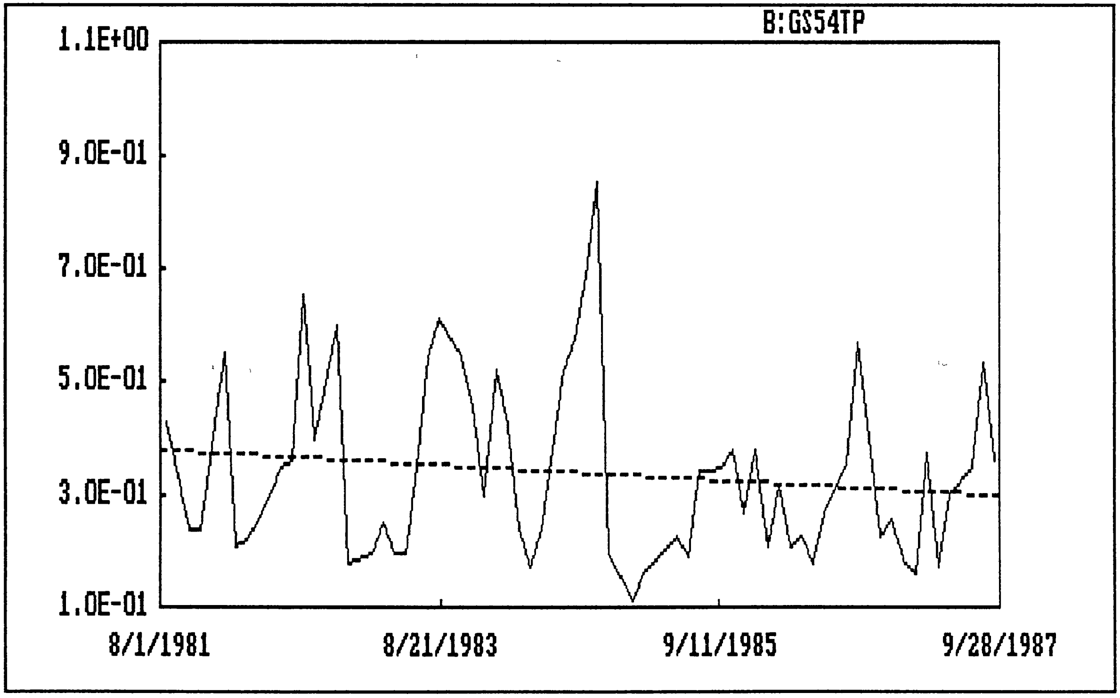

Figure 5. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07195400. Slope Estimate = -0.01333 mg/l/yr.

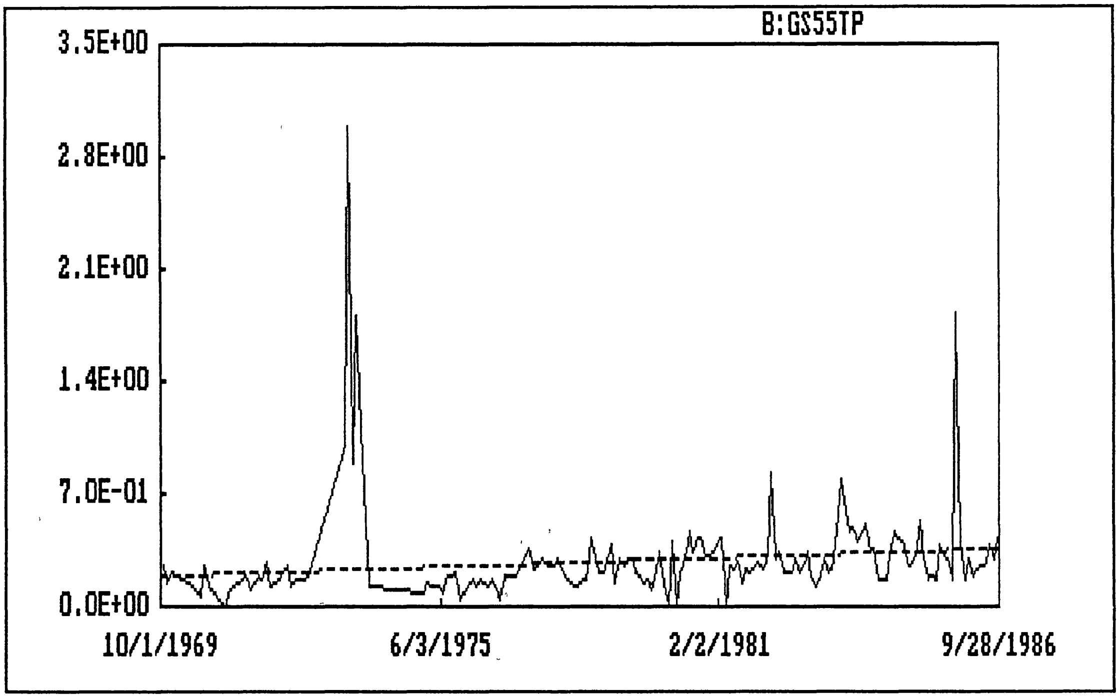

Figure 6. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07195500. Slope Estimate = 0.01000 mg/l/yr.

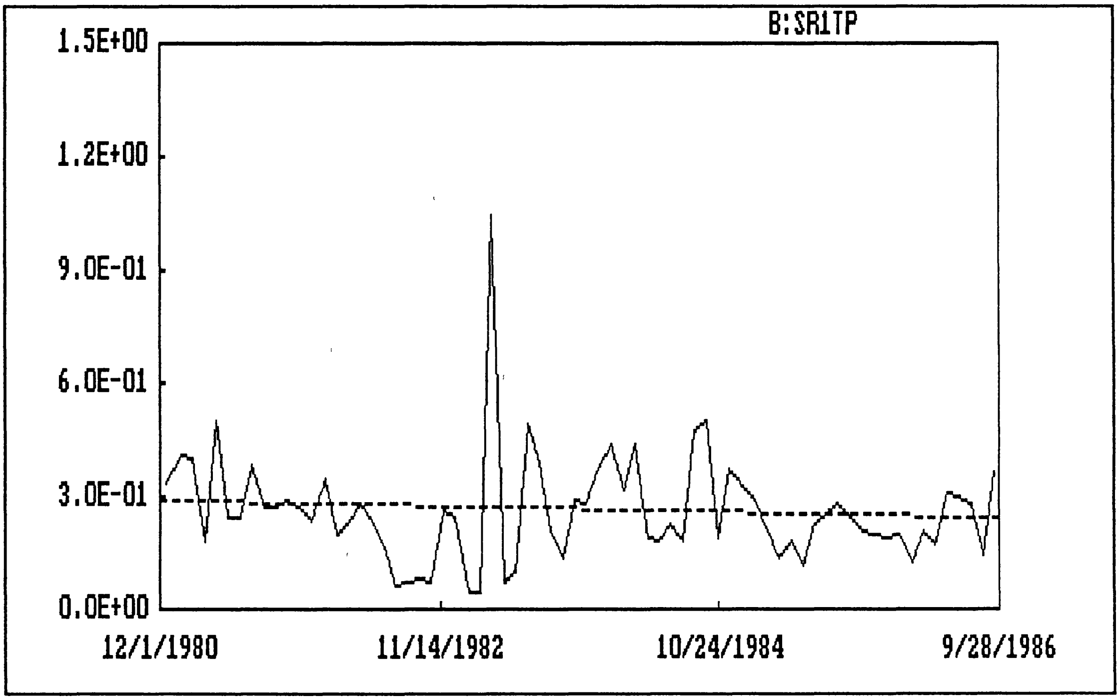

Figure 7. Times Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at SR 1. Slope Estimate = -0.00800 mg/l/yr.

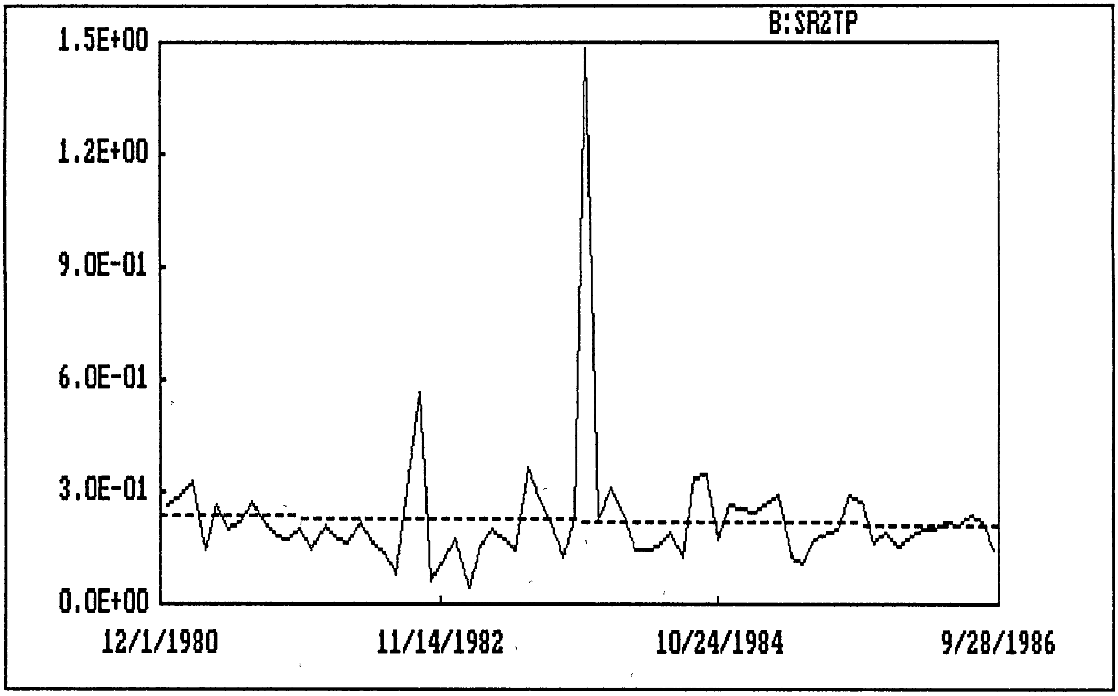

Figure 8. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at SR 2. Slope Estimate = -0.00432 mg/l per year.

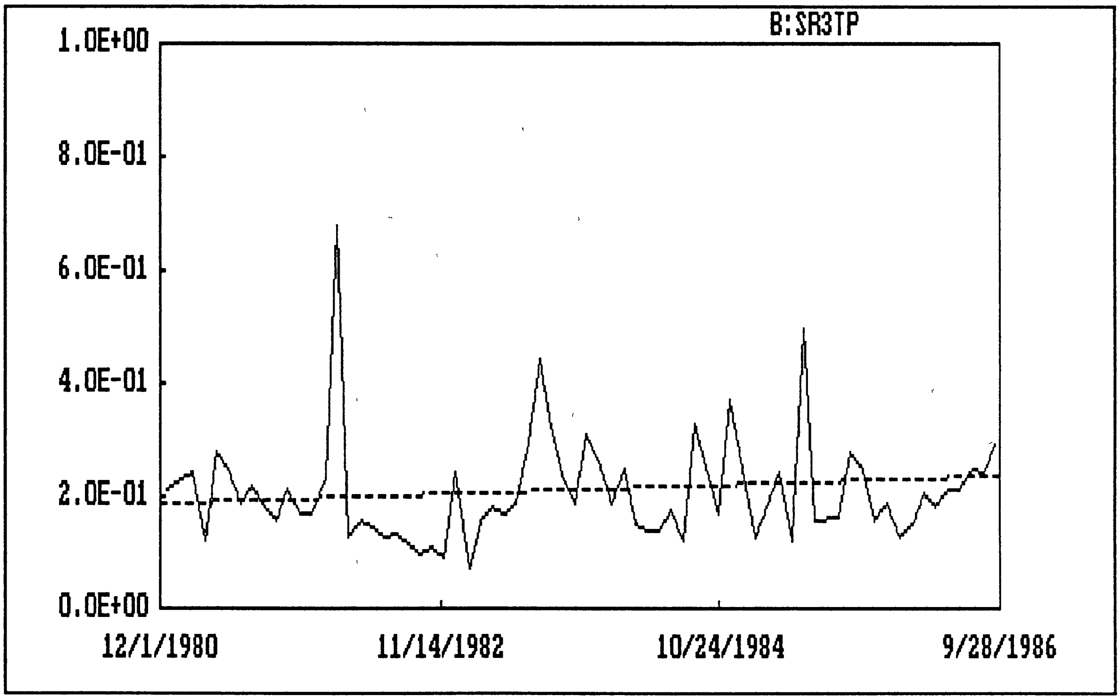

Figure 9. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at SR 3. Slope Estimate = 0.00850 mg/l per year.

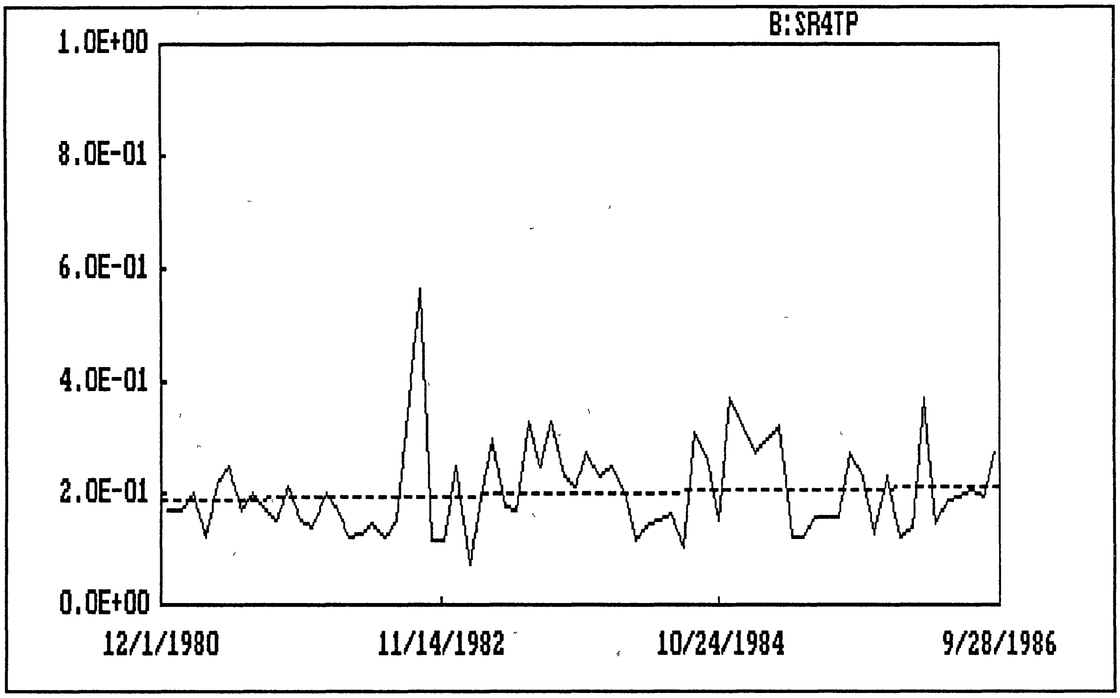

Figure 10. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at SR 4. Slope Estimate = 0.00409 mg/l/yr.

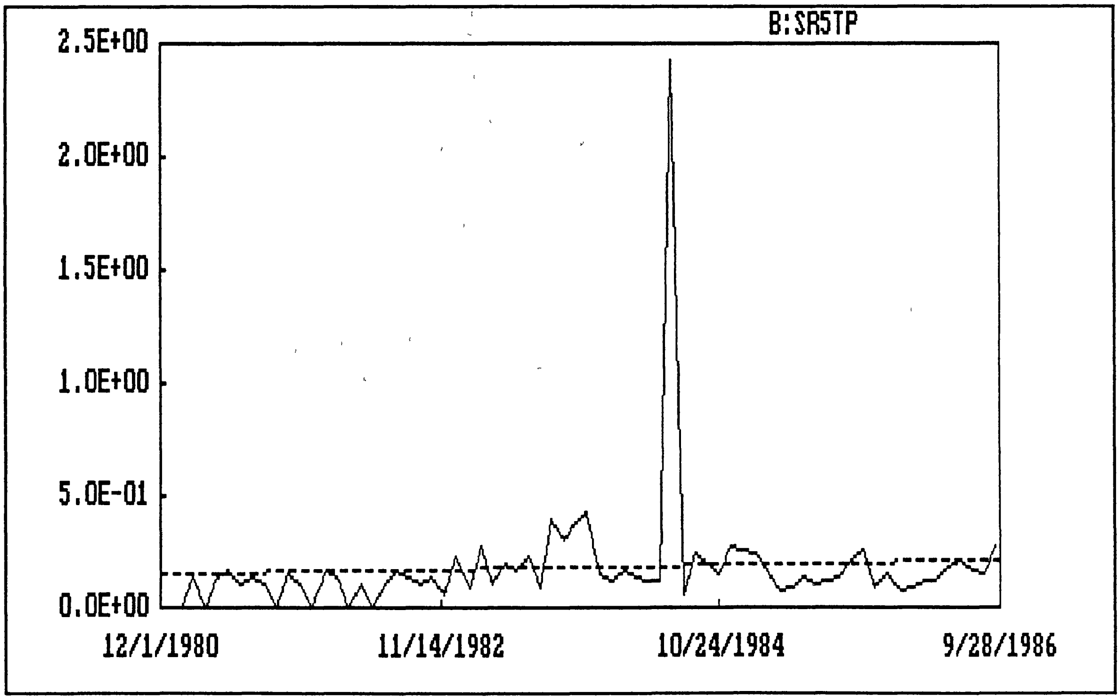

Figure 11. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at SR 5. Slope Estimate = 0.00940 mg/l/yr.

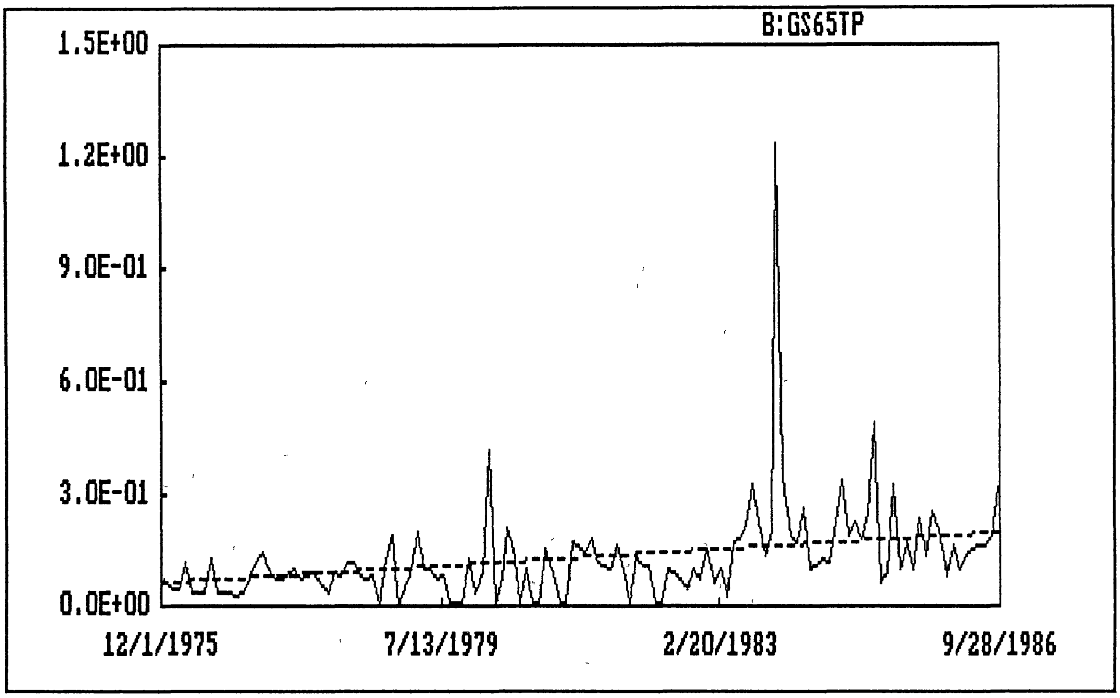

Figure 12. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07196500. Slope Estimate = 0.01257 mg/l/yr.

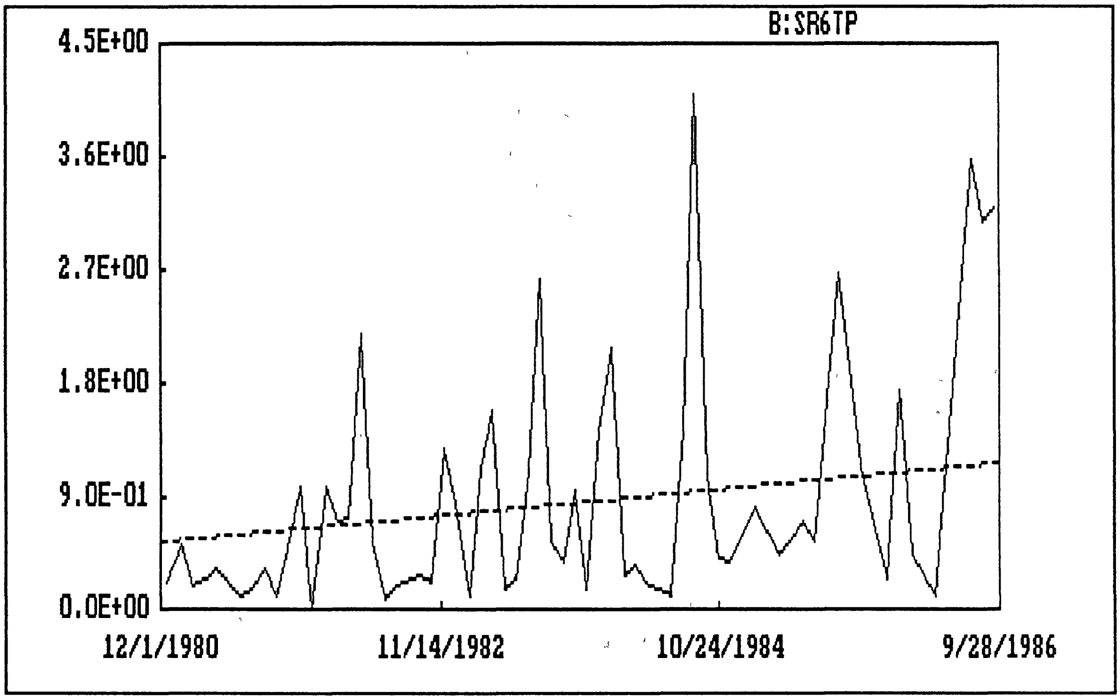

Figure 13. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at SR 6. Slope Estimate = 0.10400 mg/l/yr.

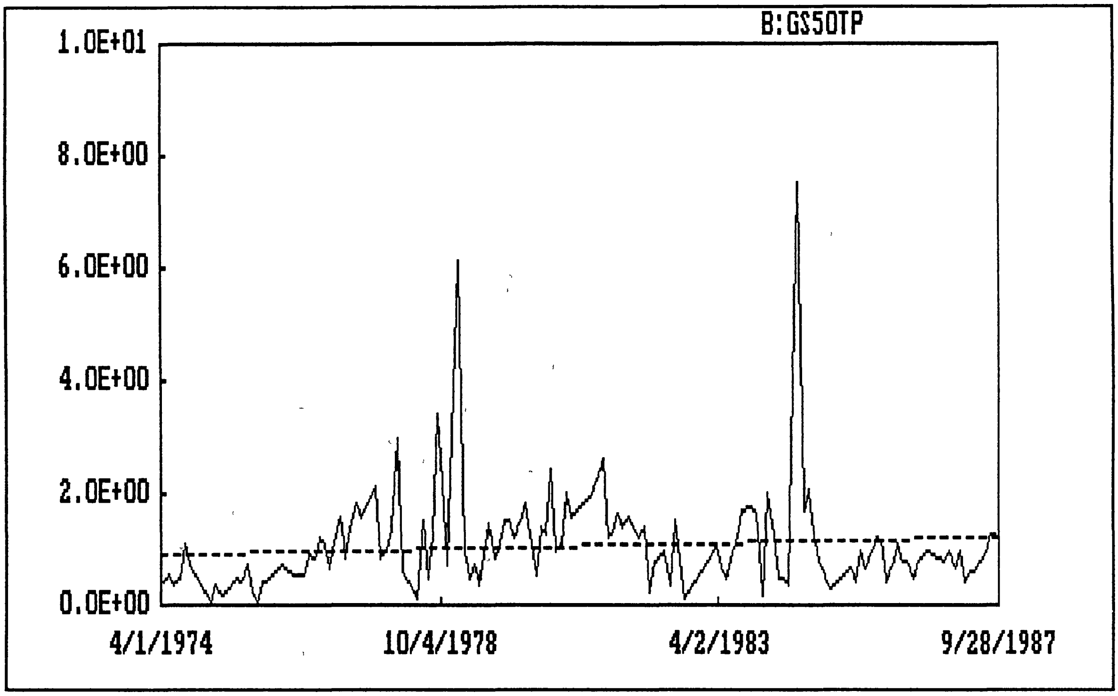

Figure 14. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07195000. Slope Estimate = 0.02250 mg/l/yr.

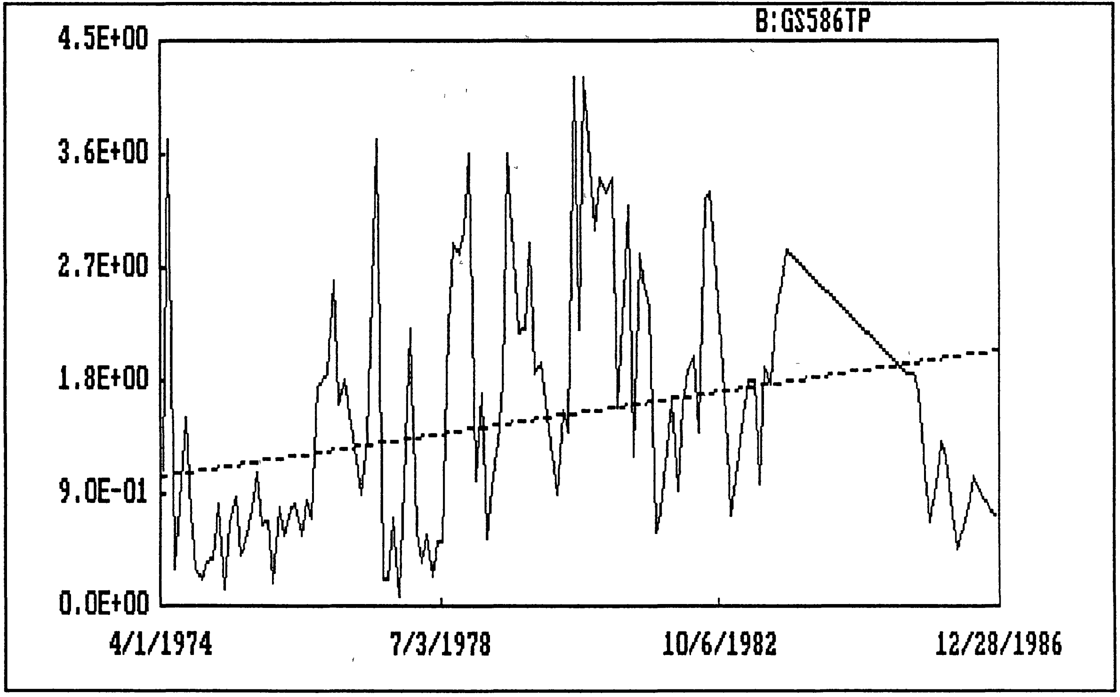

Figure 15. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07195860. Slope Estimate = 0.07889 mg/l/yr.

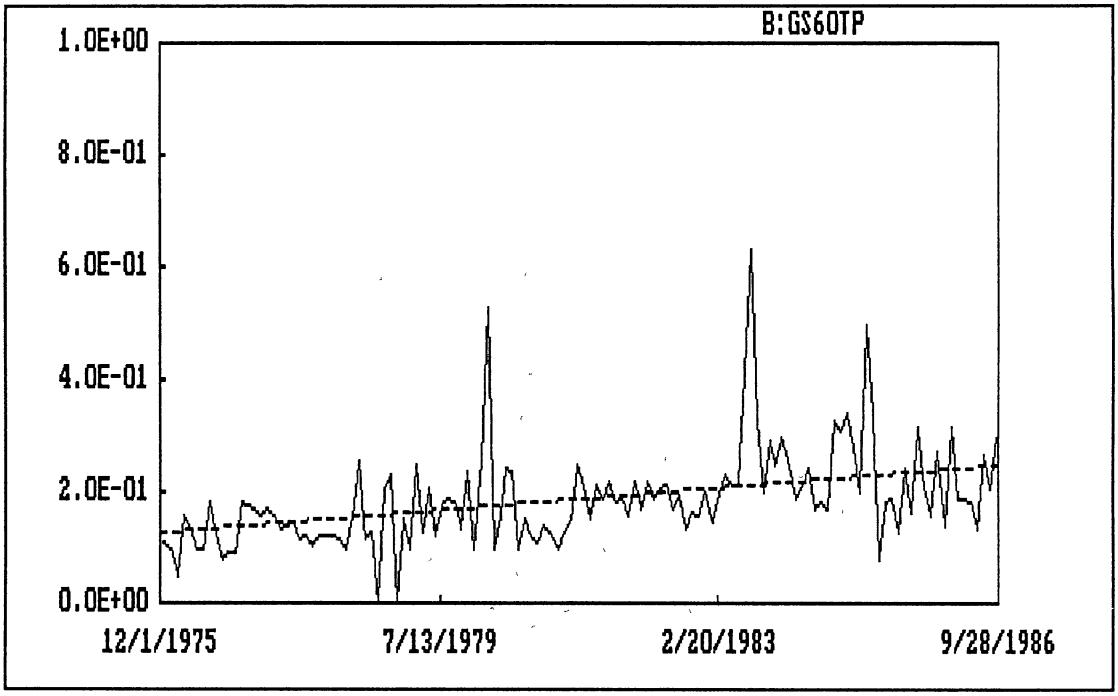

Figure 16. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07196000. Slope Estimate = 0.01143 mg/l/yr.

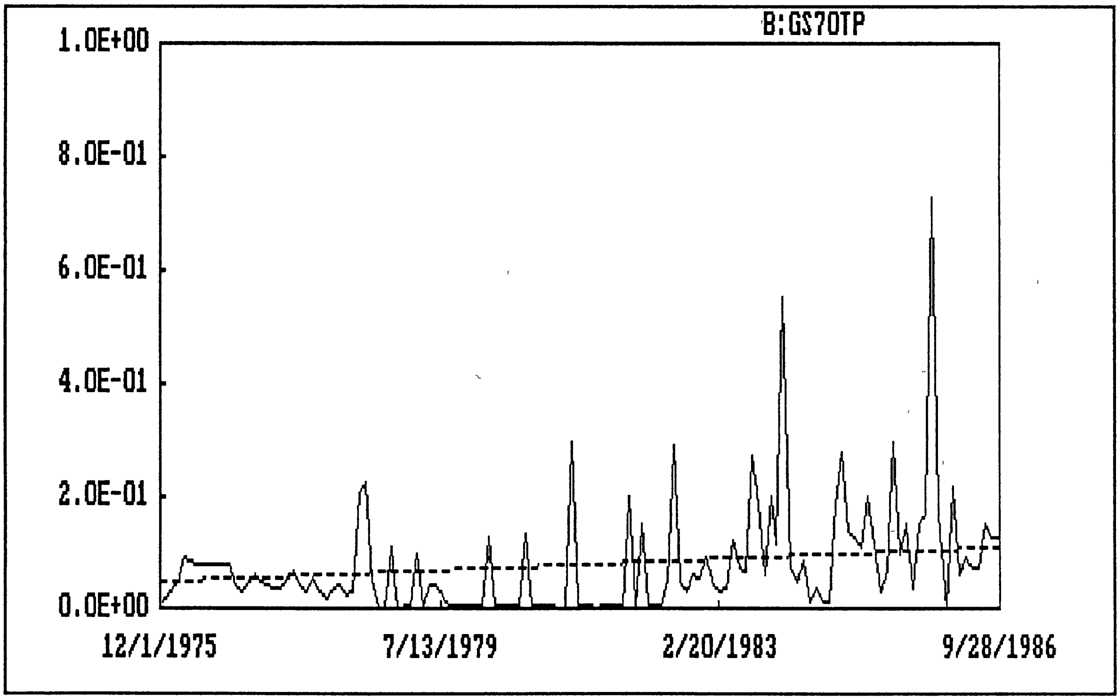

Figure 17. Time Series of Monthly Average Total Phosphorus Concentration (as mg/l P) at USGS 07197000. Slope Estimate = 0.00540 mg/l/yr.

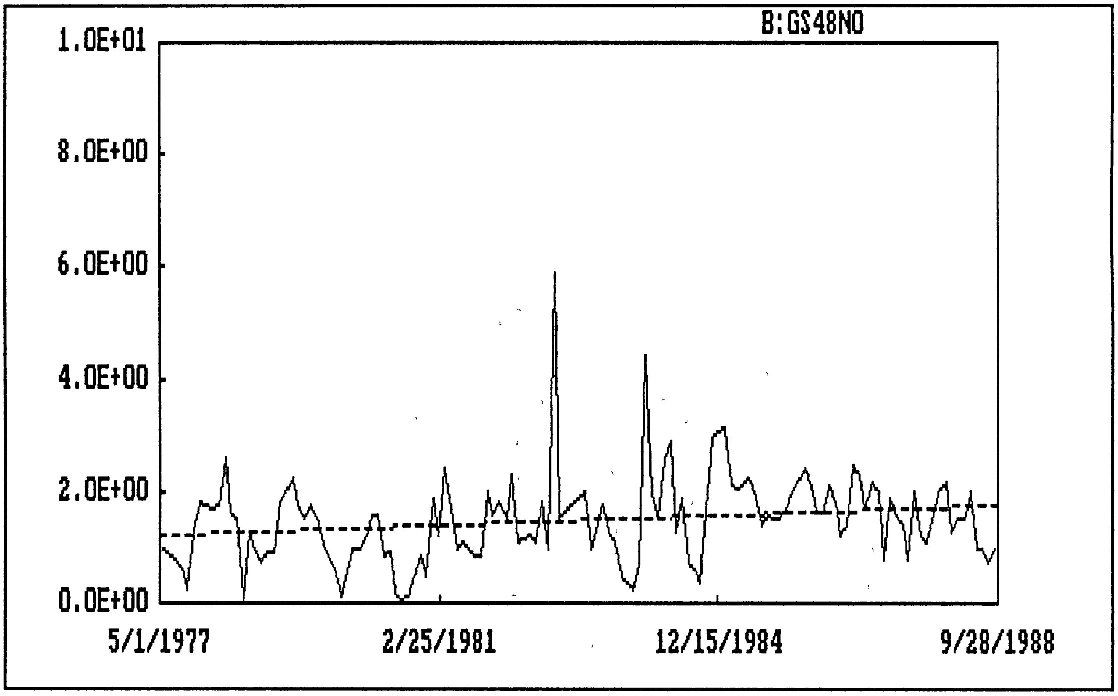

Figure 18. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07194800. Slope Estimate = 0.05000 mg/l/yr.

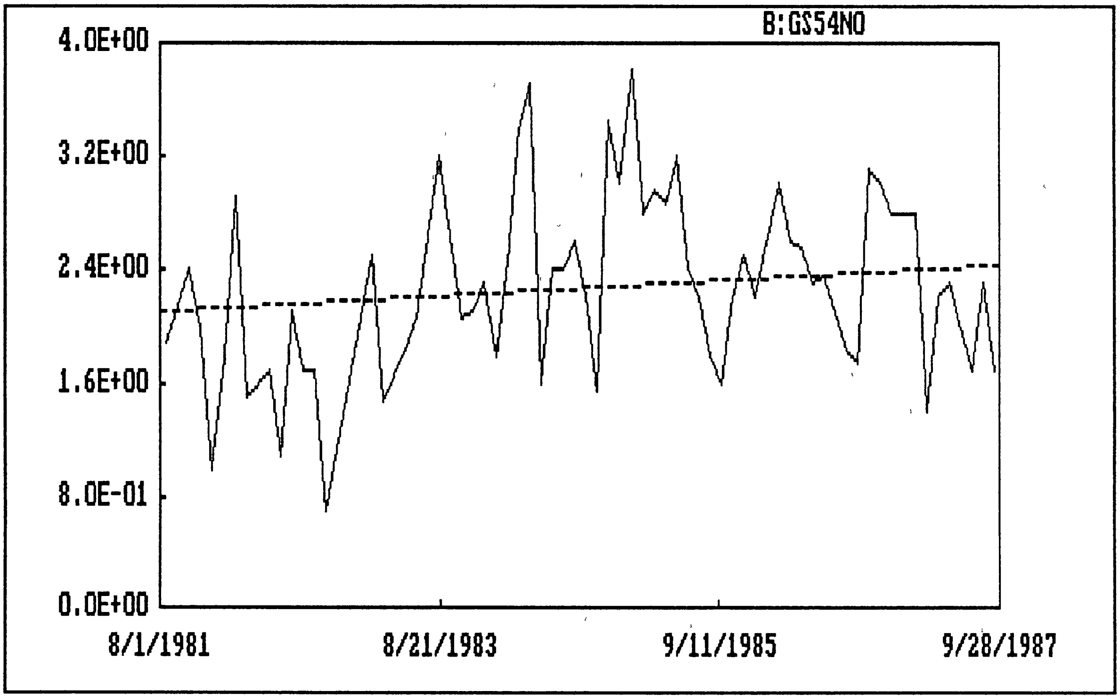

Figure 19. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07195400. Slope Estimate = 0.05000 mg/l/yr.

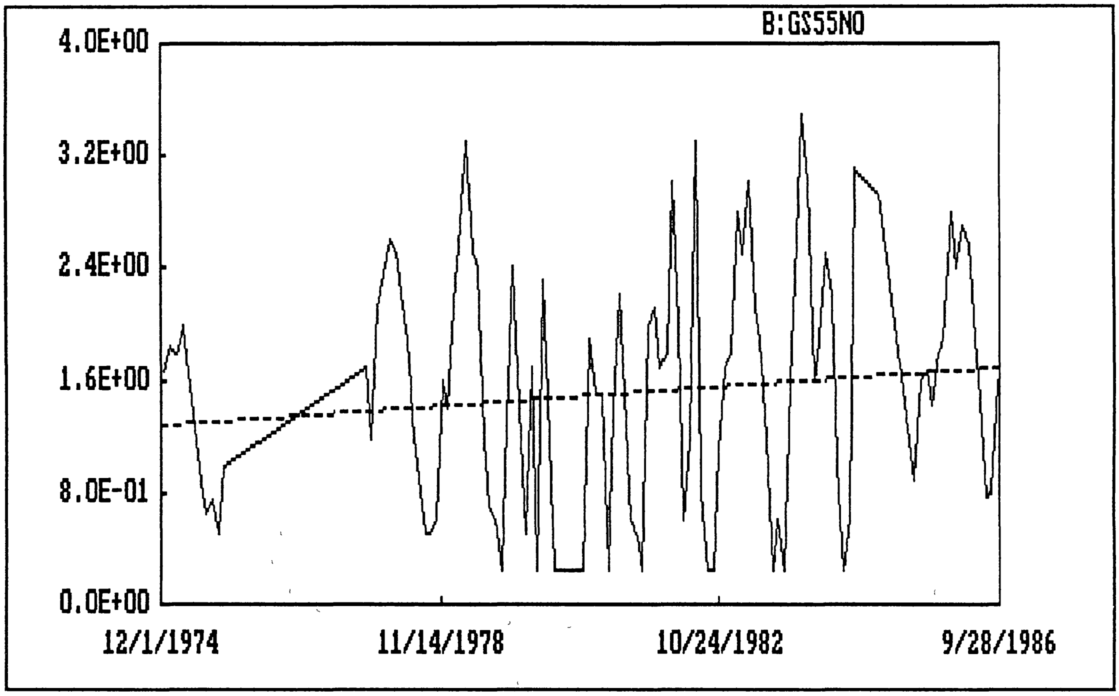

Figure 20. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07195500. Slope Estimate = 0.03333 mg/l/yr.

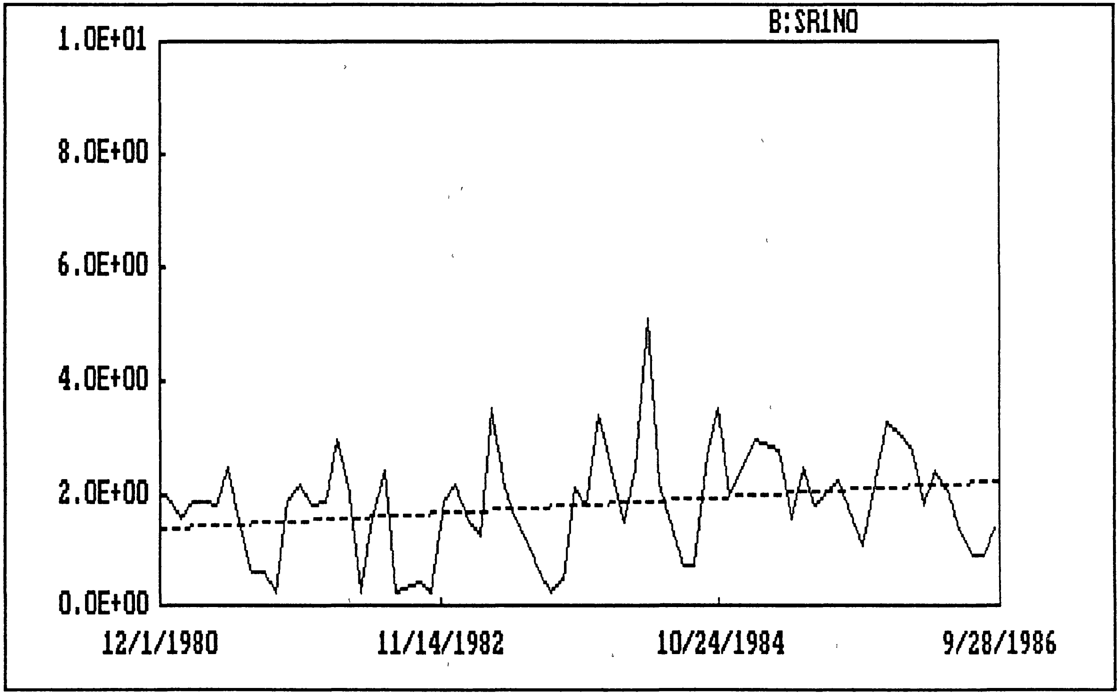

Figure 21. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at SR 1. Slope Estimate = 0.15000 mg/l/yr.

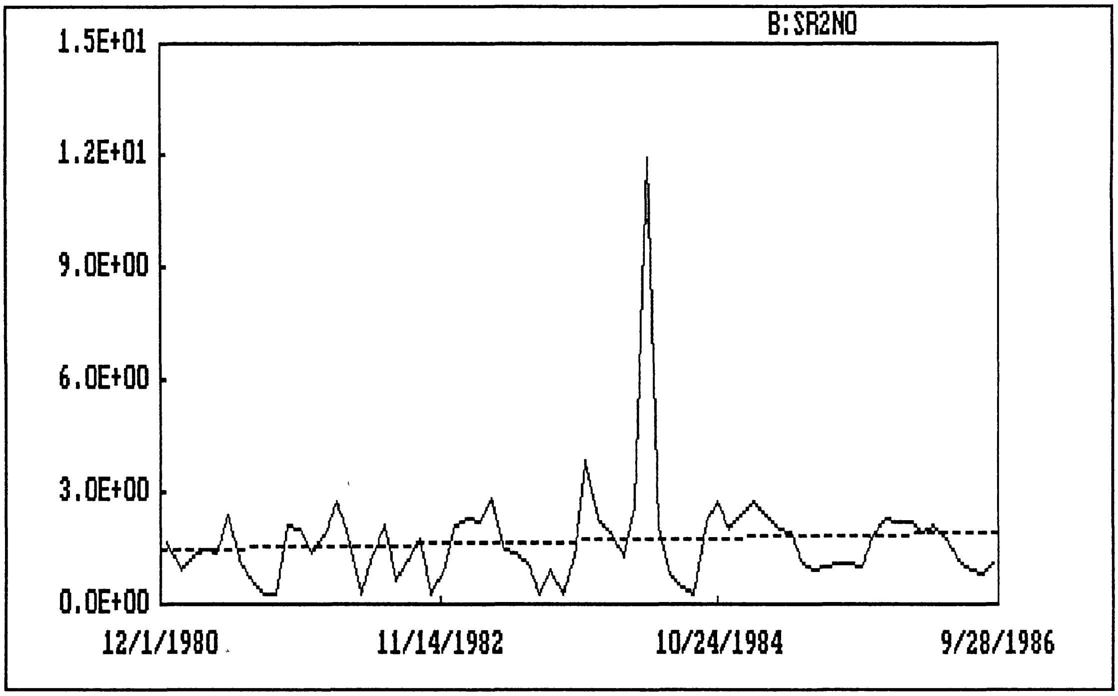

Figure 22. Time Series of Monthly Average $NO_2 + NO_3$ Concentration (as mg/l N) at SR 2. Slope Estimate = 0.07500 mg/l/yr.

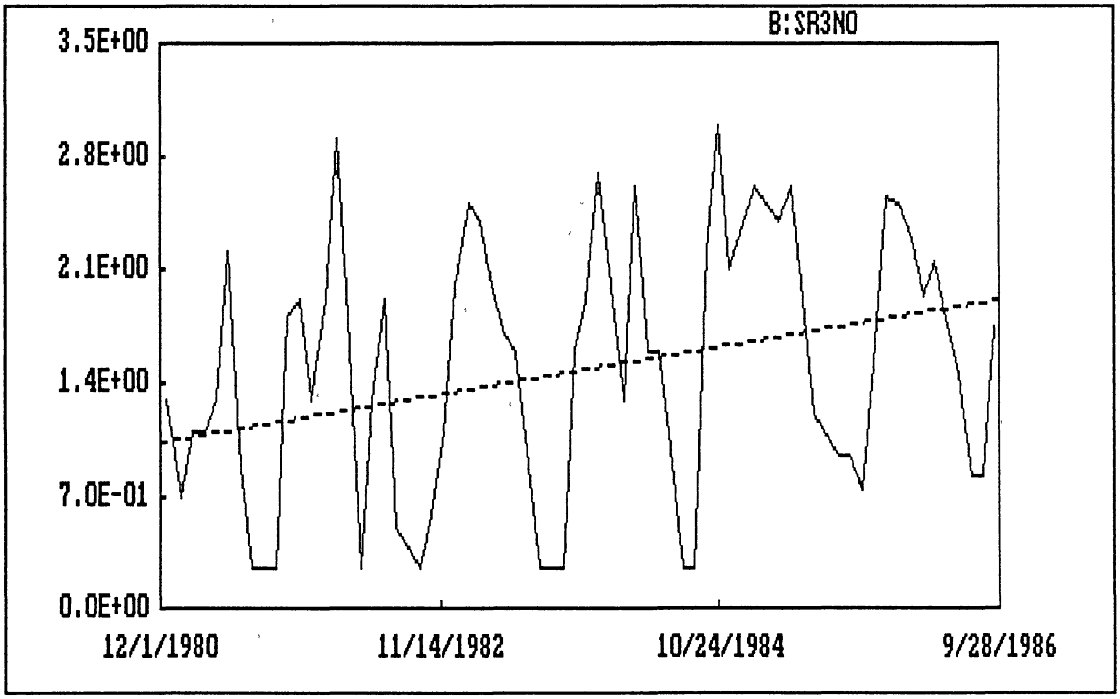

Figure 23. Time Series of Monthly Average $NO_2 + NO_3$ Concentration (as mg/l N) at SR 3. Slope Estimate = 0.15000 mg/l/yr.

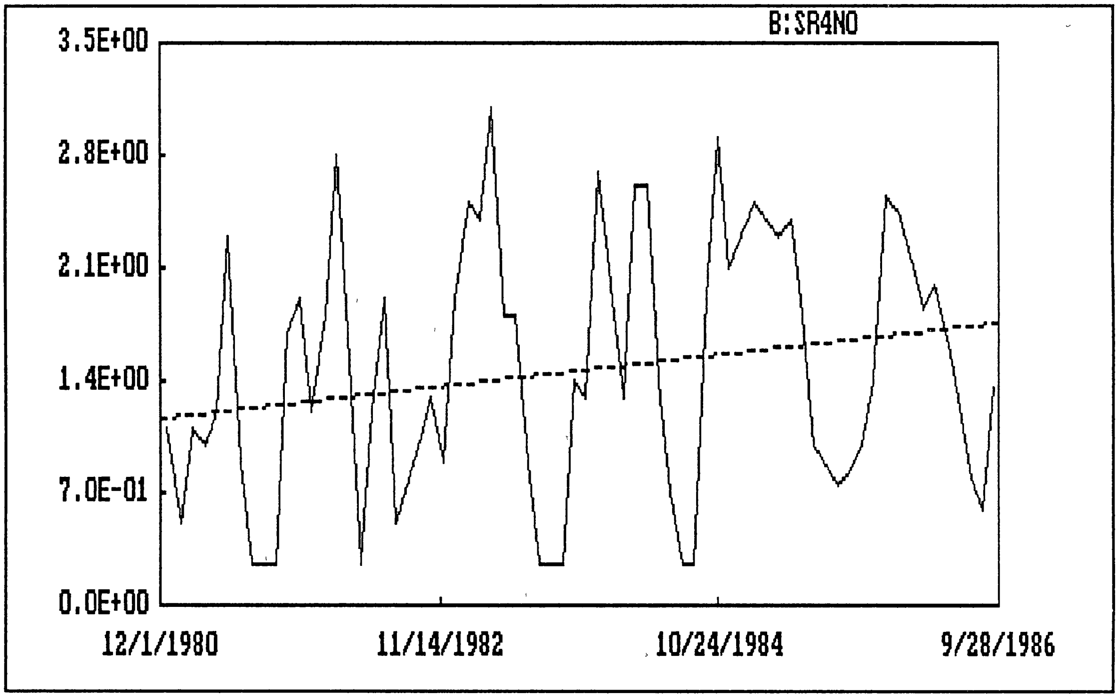

Figure 24. Time Series of Monthly Average $NO_2 + NO_3$ Concentration (as mg/l N) at SR 4. Slope Estimate = 0.10250 mg/l/yr.

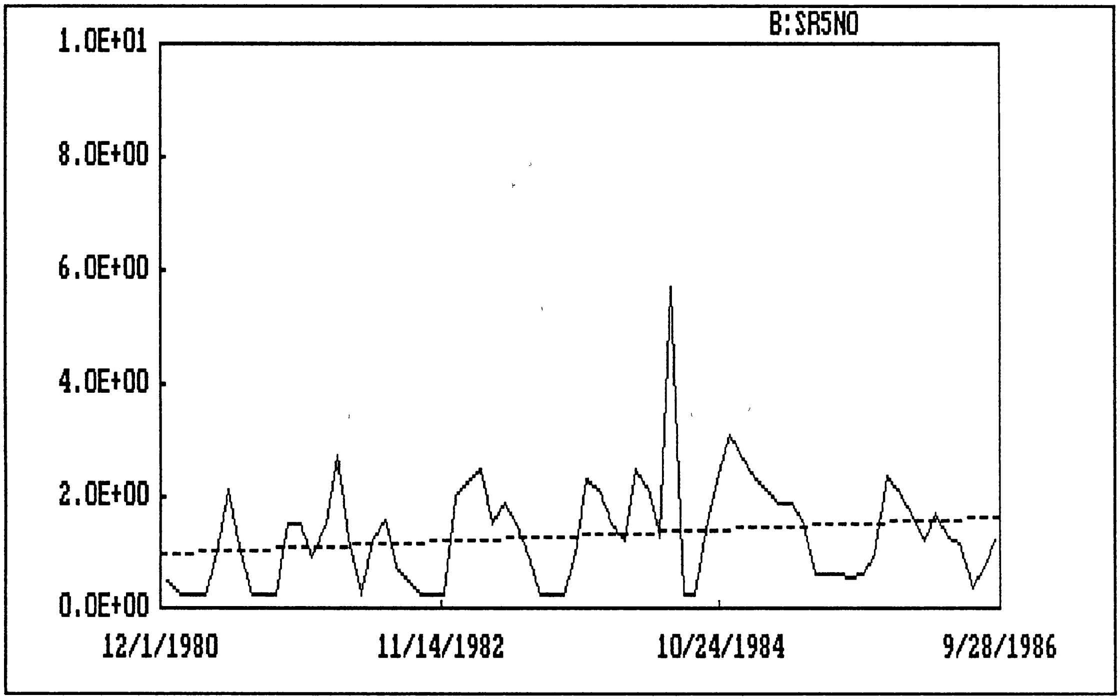

Figure 25. Time Series of Monthly Average $NO_2 + NO_3$ Concentration (as mg/l N) at SR 5. Slope Estimate = 0.10917 mg/l/yr.

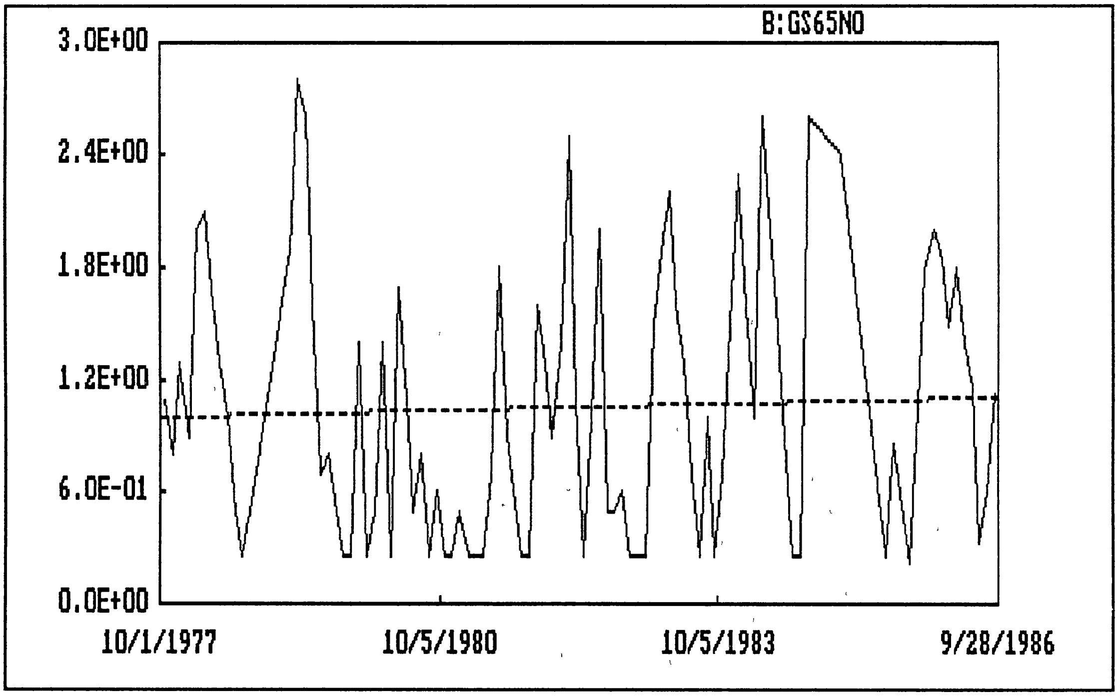

Figure 26. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07196500. Slope Estimate = 0.01250 mg/l/yr.

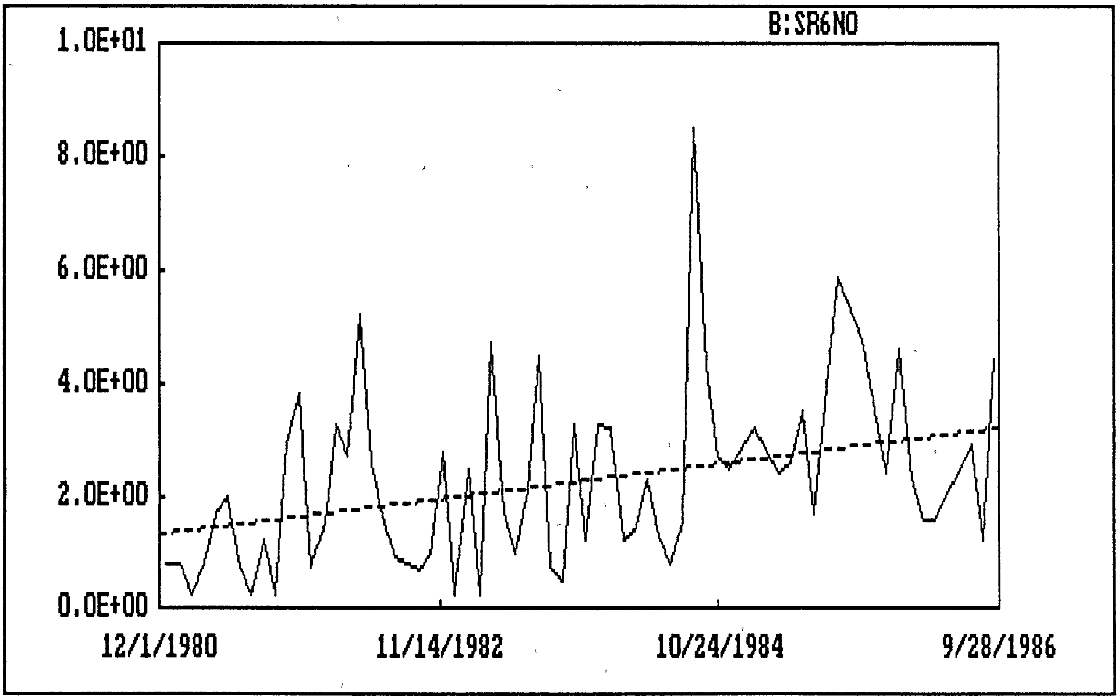

Figure 27. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at SR 6. Slope Estimate = 0.32000 mg/l/yr.

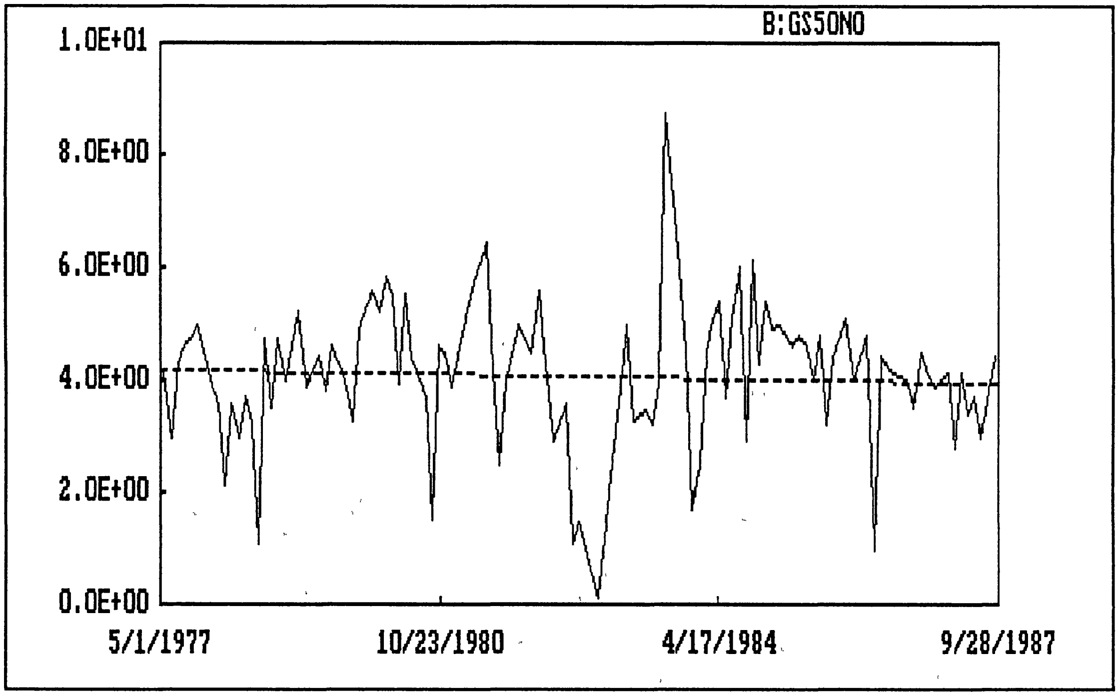

Figure 28. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07195000. Slope Estimate = -0.02500 mg/l/yr.

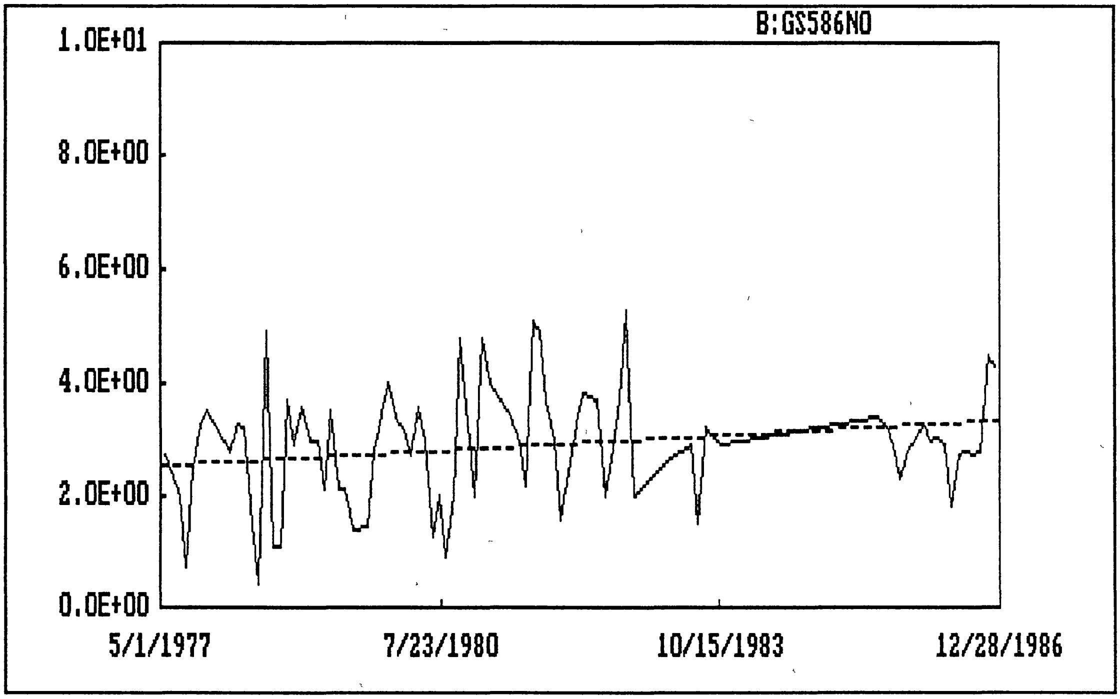

Figure 29. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07195860. Slope Estimate = 0.08542 mg/l/yr.

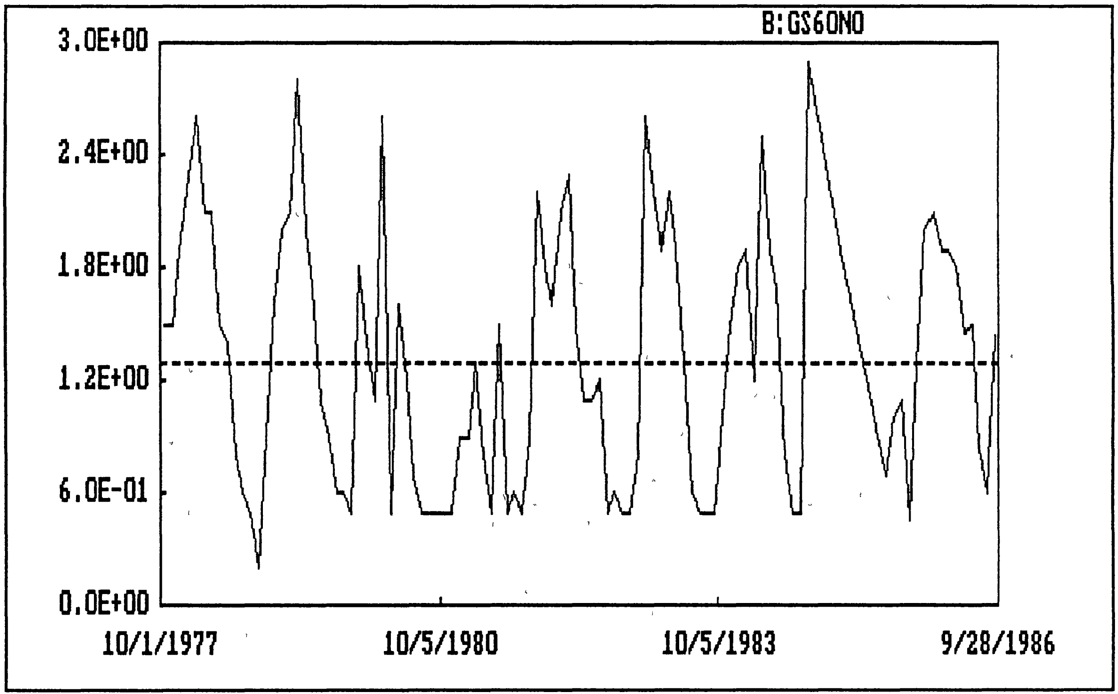

Figure 30. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07196000. Slope Estimate = 0.00000 mg/l/yr.

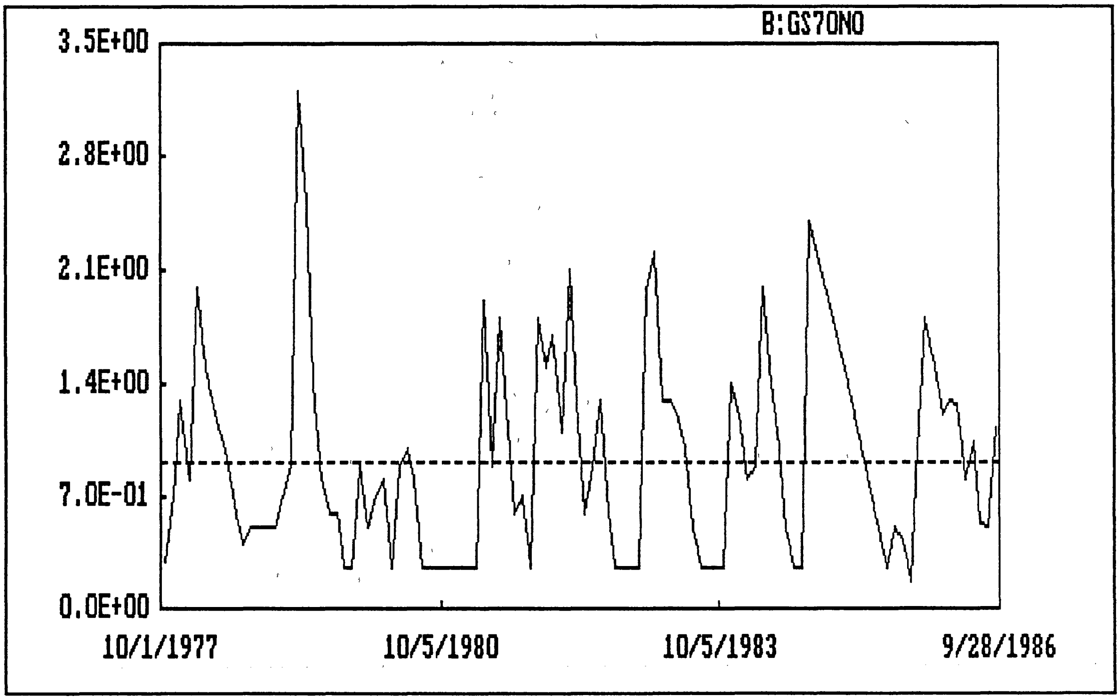

Figure 31. Time Series of Monthly Average NO_2 + NO_3 Concentration (as mg/l N) at USGS 07197000. Slope Estimate = 0.00000 mg/l/yr.

APPENDIX B

PLOTS OF RELATIONSHIPS BETWEEN NUTRIENT CONCENTRATION AND DISCHARGE AND TIME SERIES PLOTS OF FAC FAC NUTRIENT CONCENTRATIONS AT USGS STATIONS

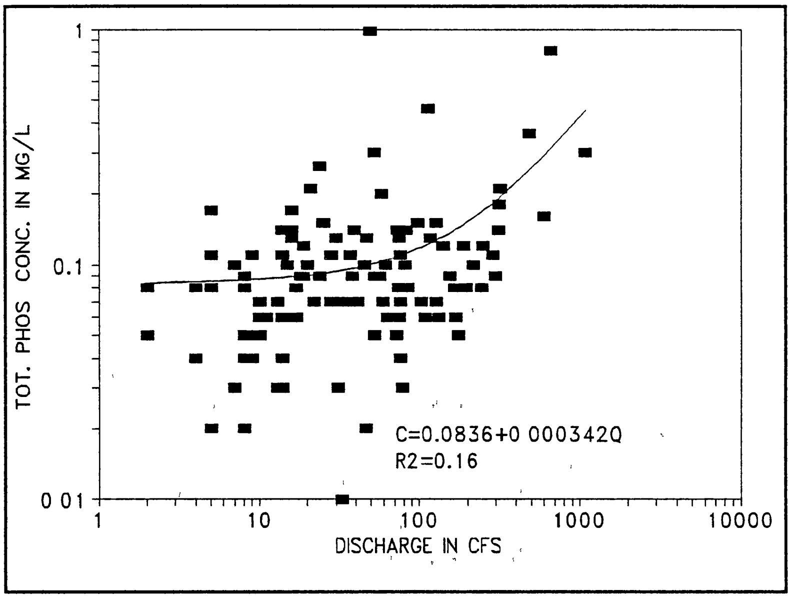

Figure 32. Relationship Between Total Phosphorus Concentration and Discharge at USGS 07194800.

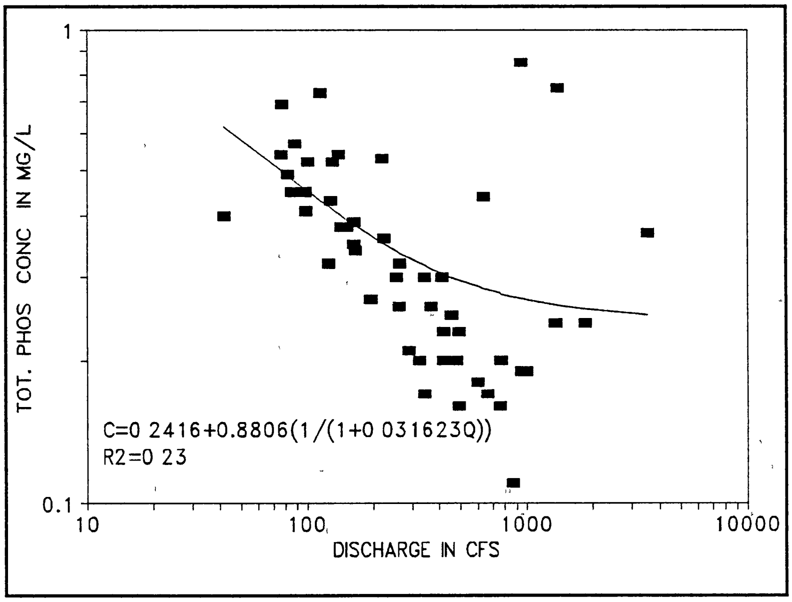

Figure 33. Relationship Between Total Phosphorus Concentration and Discharge at USGS 07195400.

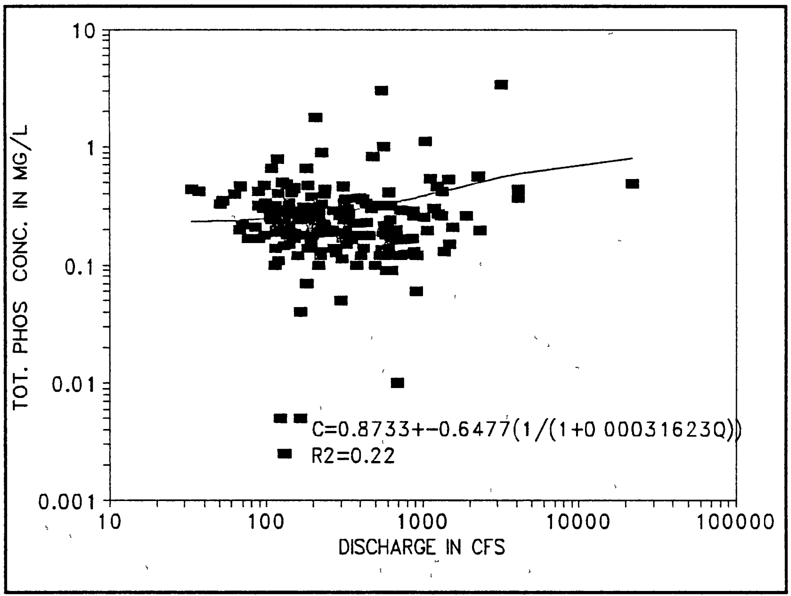

Figure 34. Relationship Between Total Phosphorus Concentration and Discharge at USGS 07195500.

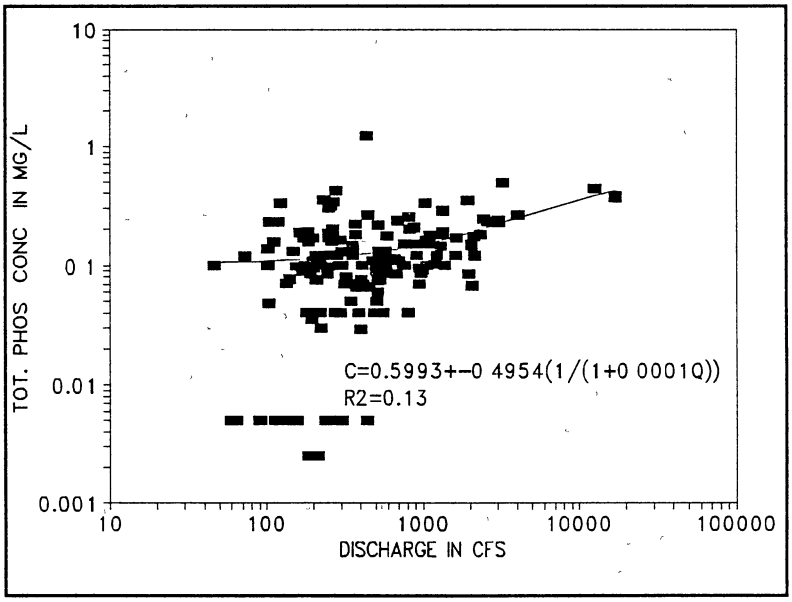

Figure 35. Relationship Between Total Phosphorus Concentration and Discharge at USGS 07196500.

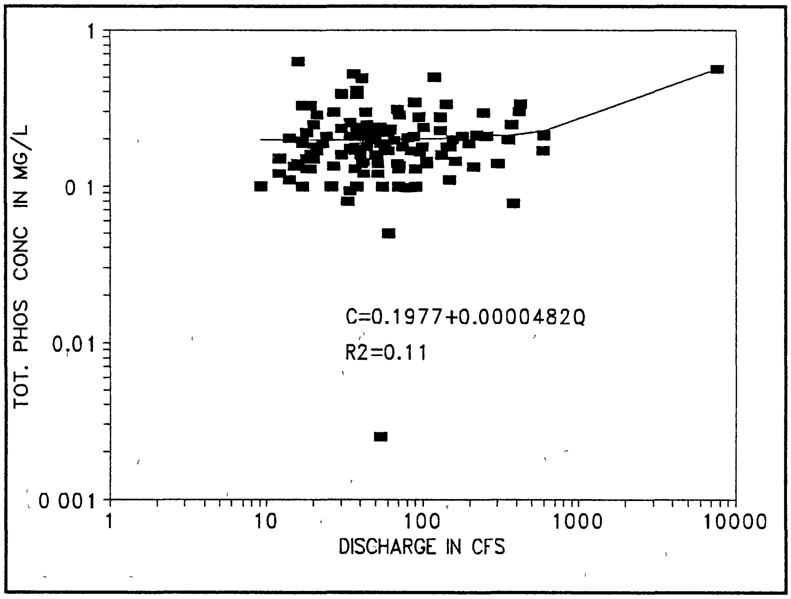

Figure 36. Relationship Between Total Phosphorus Concentration and Discharge at USGS 07196000.

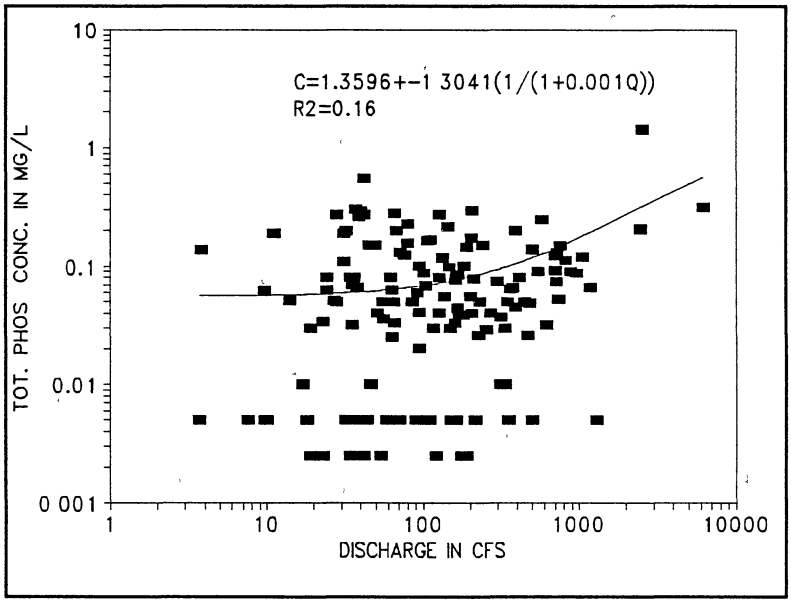

Figure 37. Relationship Between Total Phosphorus Concentration and Discharge at USGS 07197000.

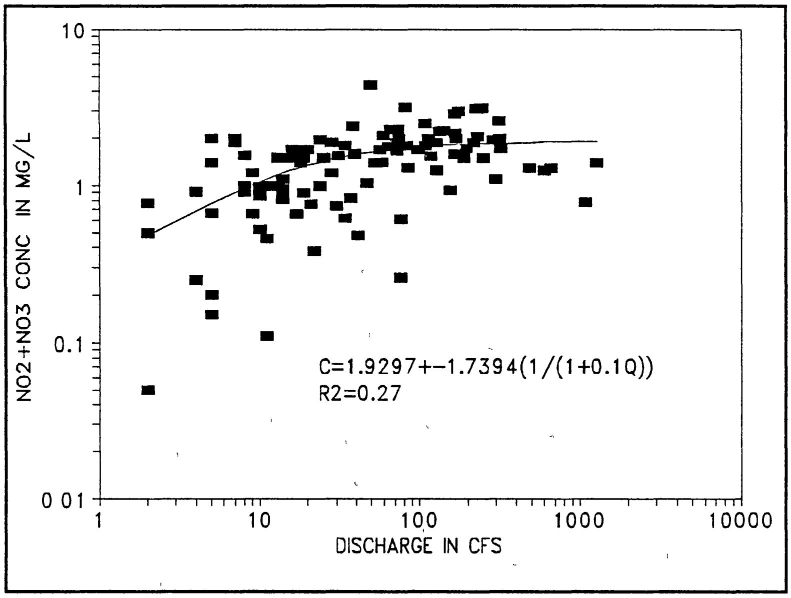

Figure 38. Relationship Between NO_2 + NO_3 Concentration and Discharge at USGS 07194800.

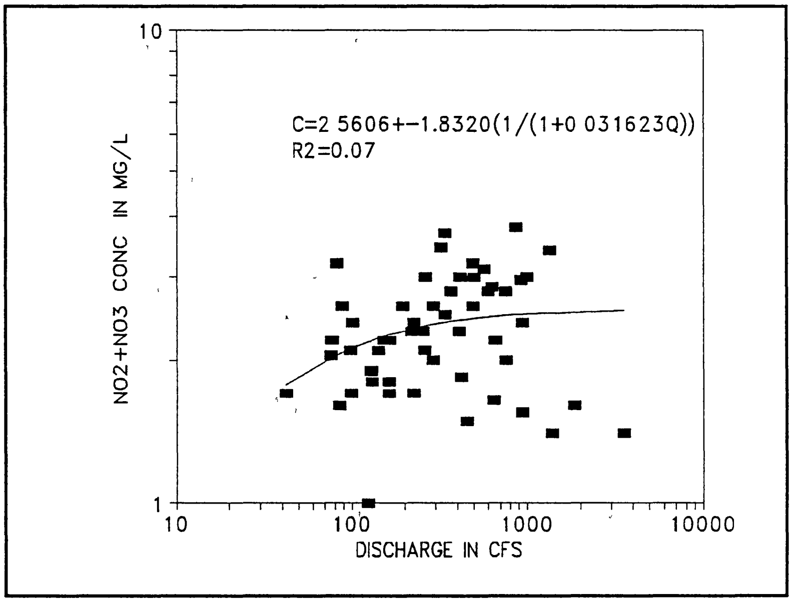

Figure 39. Relationship Between NO_2 + NO_3 Concentration and Discharge at USGS 07195400.

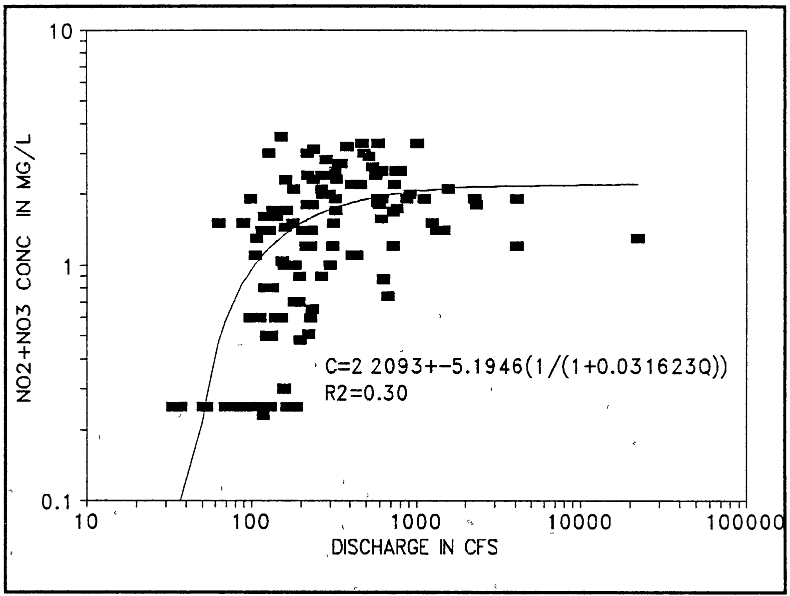

Figure 40. Relationship Between NO_2 + NO_3 Concentration and Discharge at USGS 07195500.

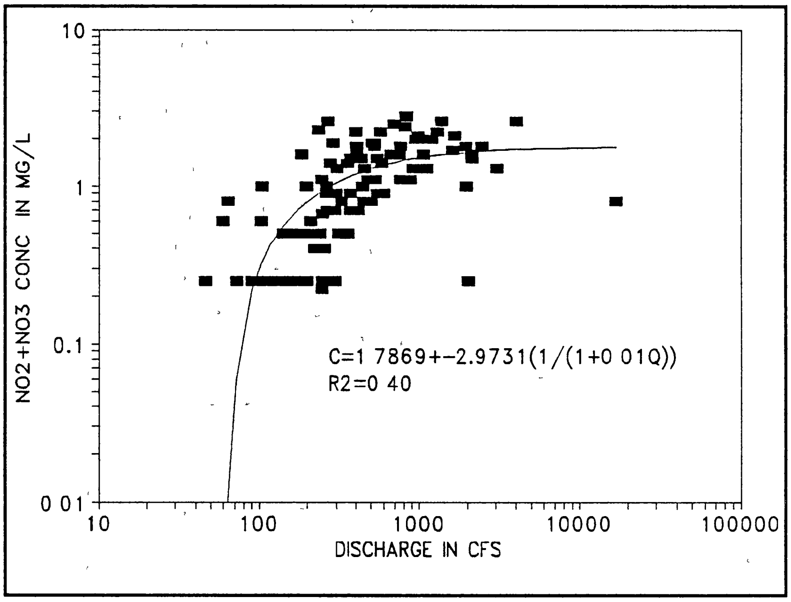

Figure 41. Relationship Between NO_2 + NO_3 Concentration and Discharge at USGS 07196500.

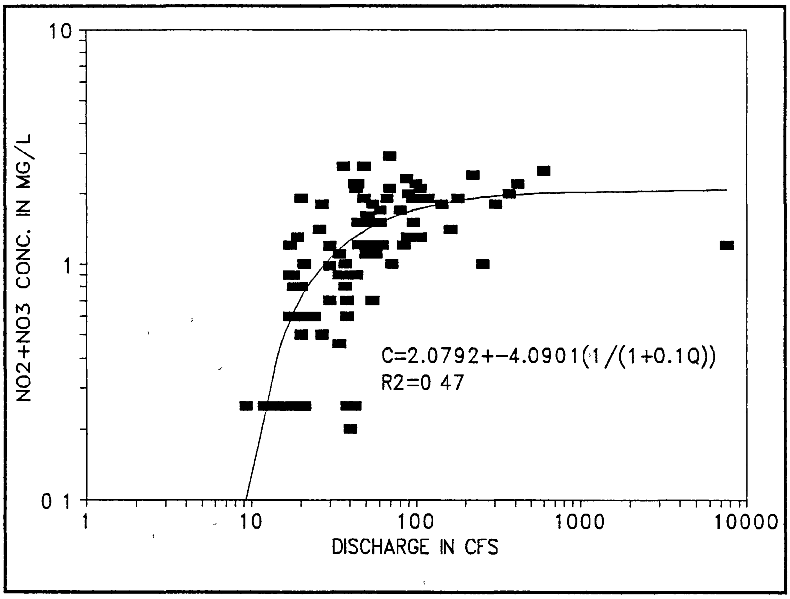

Figure 42. Relationship Between NO_2 + NO_3 Concentration and Discharge at USGS 07196000.

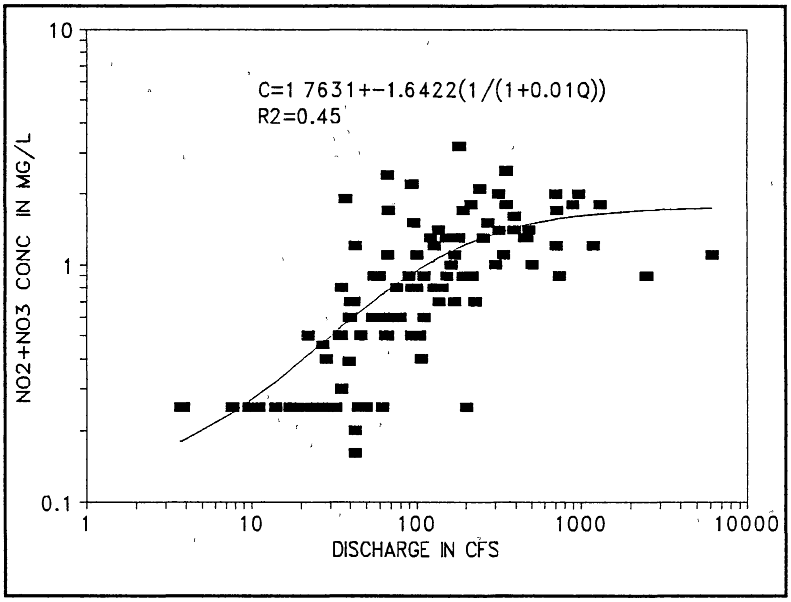

Figure 43. Relationship Between NO_2 + NO_3 Concentration and Discharge at USGS 07197000.

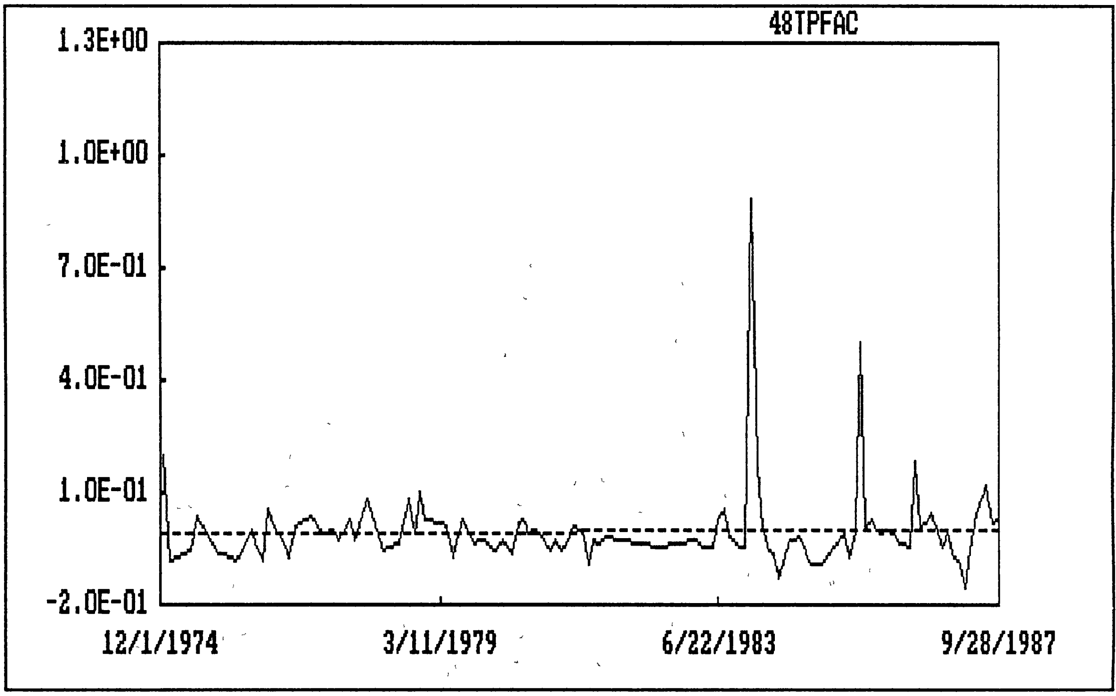

Figure 44. Time Series of Residual Total Phosphorus Concentration (as mg/l P) at USGS 07194800. Slope Estimate = 0.00086 mg/l/yr.

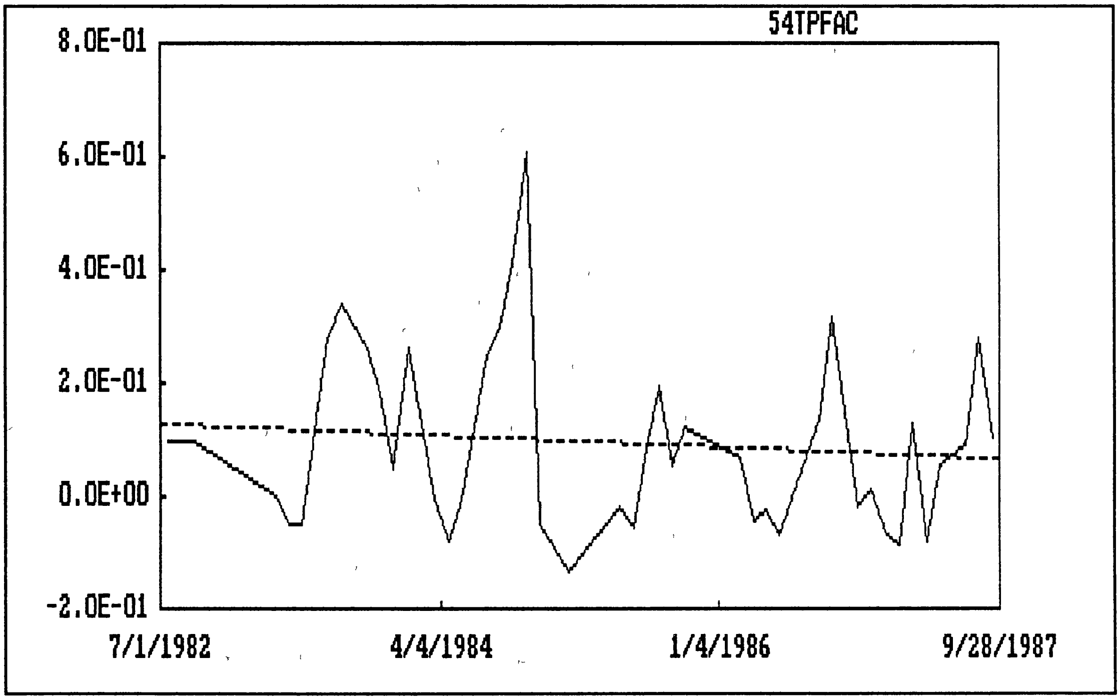

Figure 45. Time Series of Residual Total Phosphorus Concentration (as mg/l P) at USGS 07195400. Slope Estimate = -0.01227 mg/l/yr.

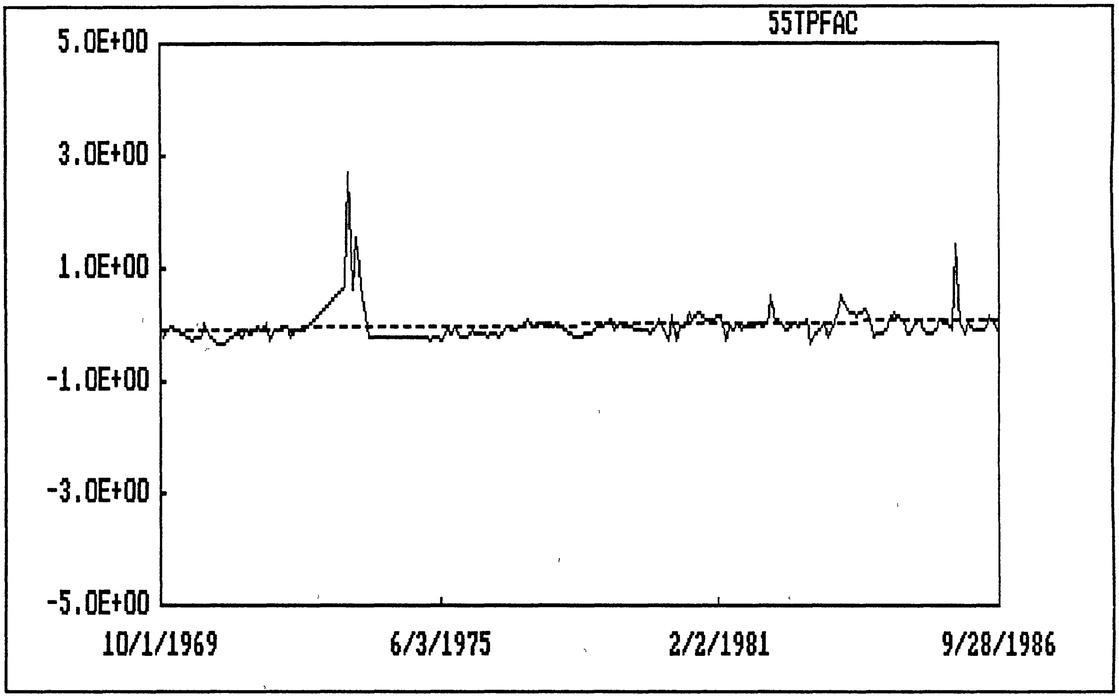

Figure 46. Time Series of Residual Total Phosphorus Concentration (as mg/l P) at USGS 07195500. Slope Estimate = 0.01009 mg/l/yr.

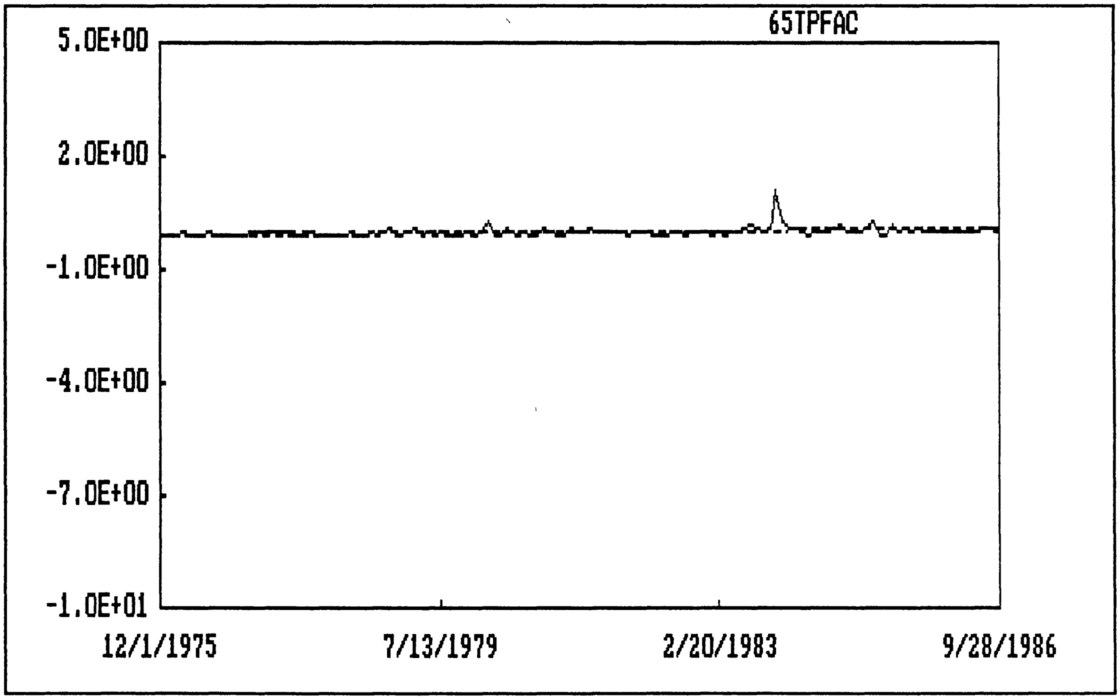

Figure 47. Time Series of Residual Total Phosphorus Concentration (as mg/l P) at USGS 07196500. Slope Estimate = 0.00953 mg/l/yr.

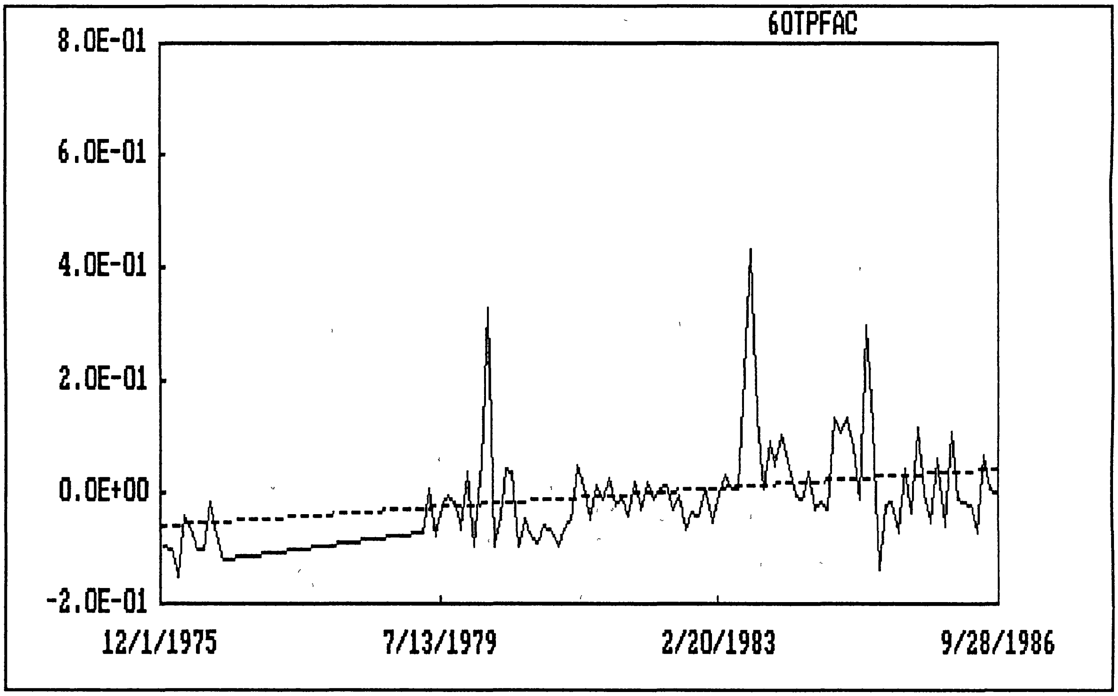

Figure 48. Time Series of Residual Total Phosphorus Concentration (as mg/l P) at USGS 07196000. Slope Estimate = 0.00941 mg/l/yr.

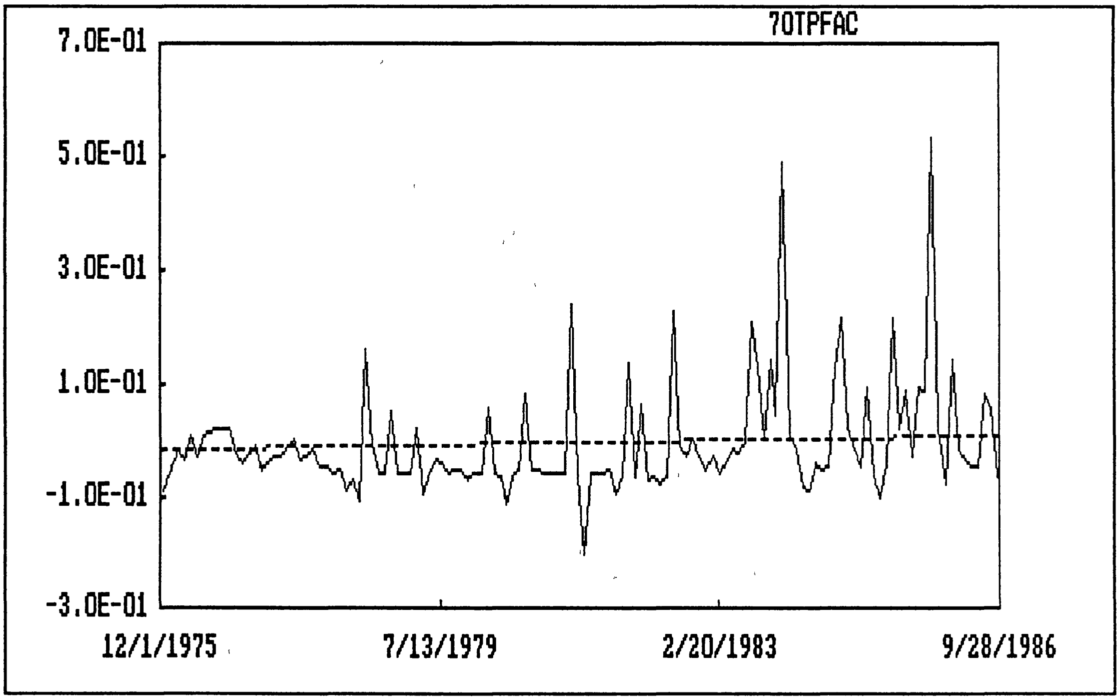

Figure 49. Time Series of Residual Total Phosphorus Concentration (as mg/l P) at USGS 07197000. Slope Estimate = 0.00235 mg/l/yr.

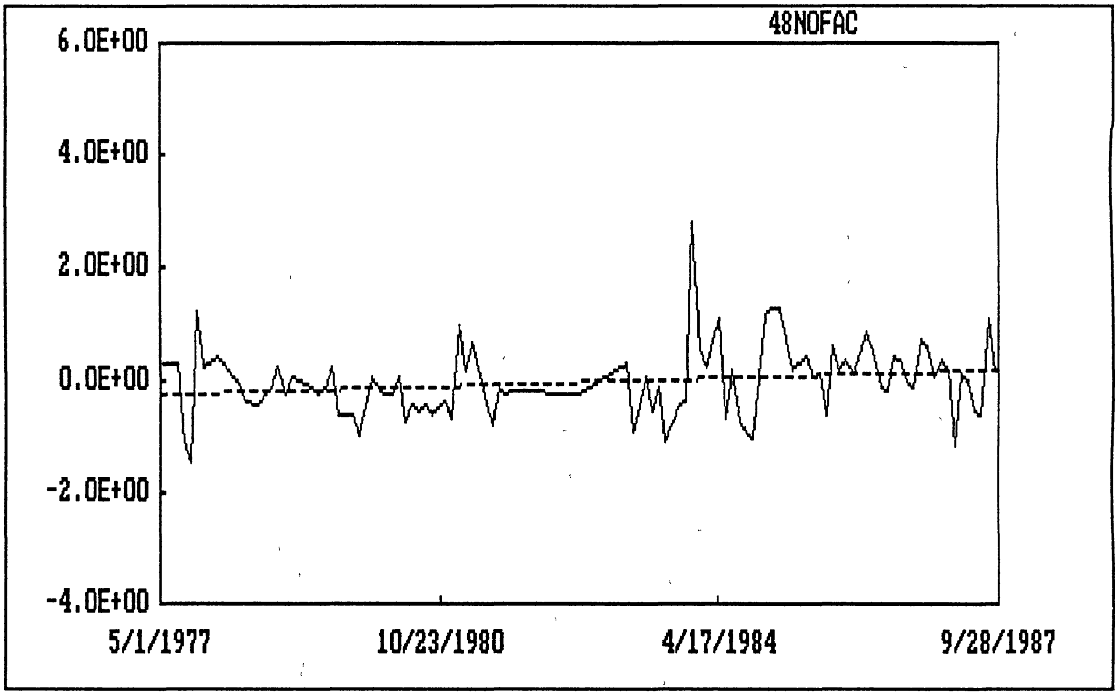

Figure 50. Time Series of Residual NO_2 + NO_3 Concentration (as mg/l N) at USGS 07194800. Slope Estimate = 0.04343 mg/l/yr.

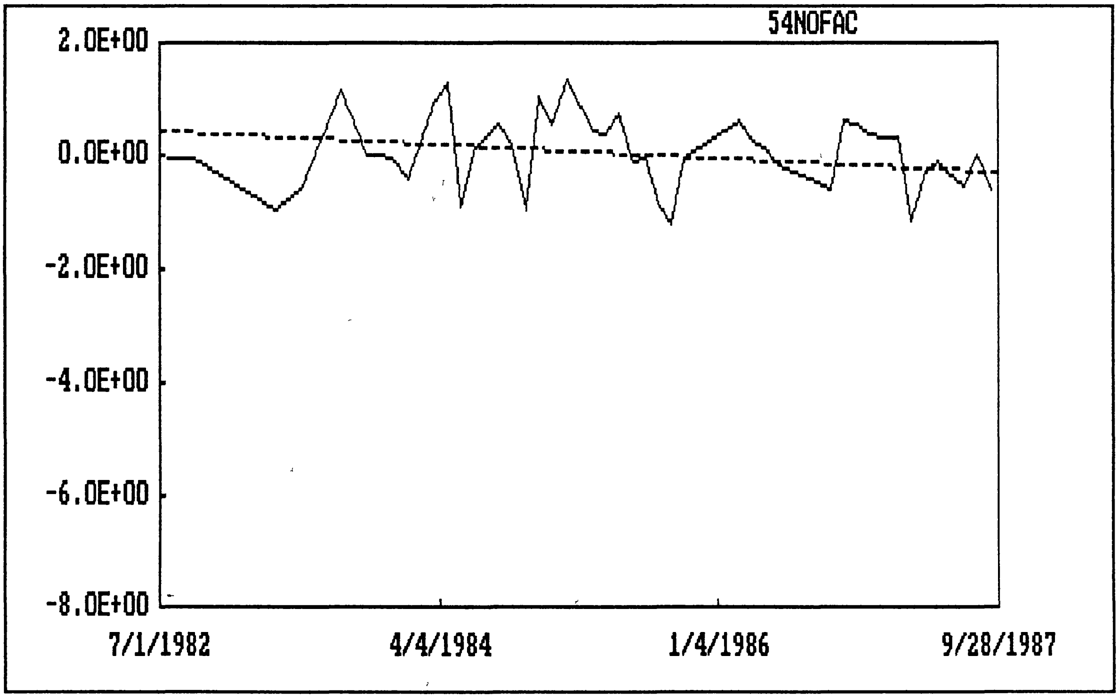

Figure 51. Time Series of Residual NO_2 + NO_3 Concentration (as mg/l N) at USGS 07195400. Slope Estimate = -0.13975 mg/l/yr.

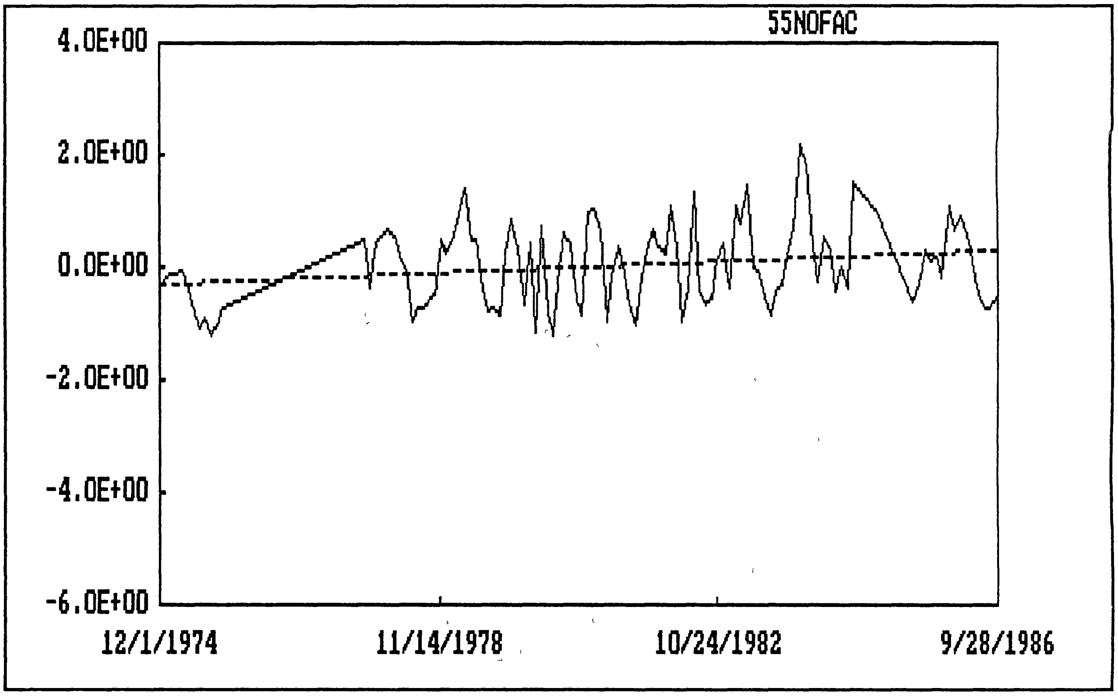

Figure 52. Time Series of Residual $NO_2 + NO_3$ Concentration (as mg/l N) at USGS 07195500. Slope Estimate = 0.05506 mg/l/yr.

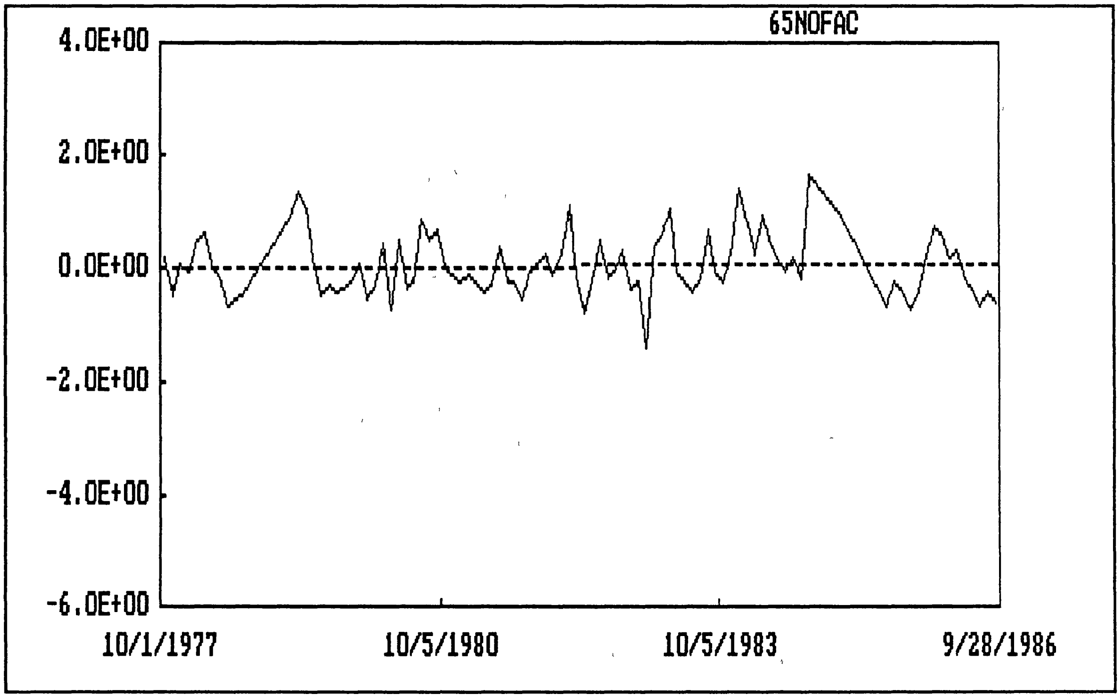

Figure 53. Time Series of Residual $NO_2 + NO_3$ Concentration (as mg/l N) at USGS 07196500. Slope Estimate = 0.01264 mg/l/yr.

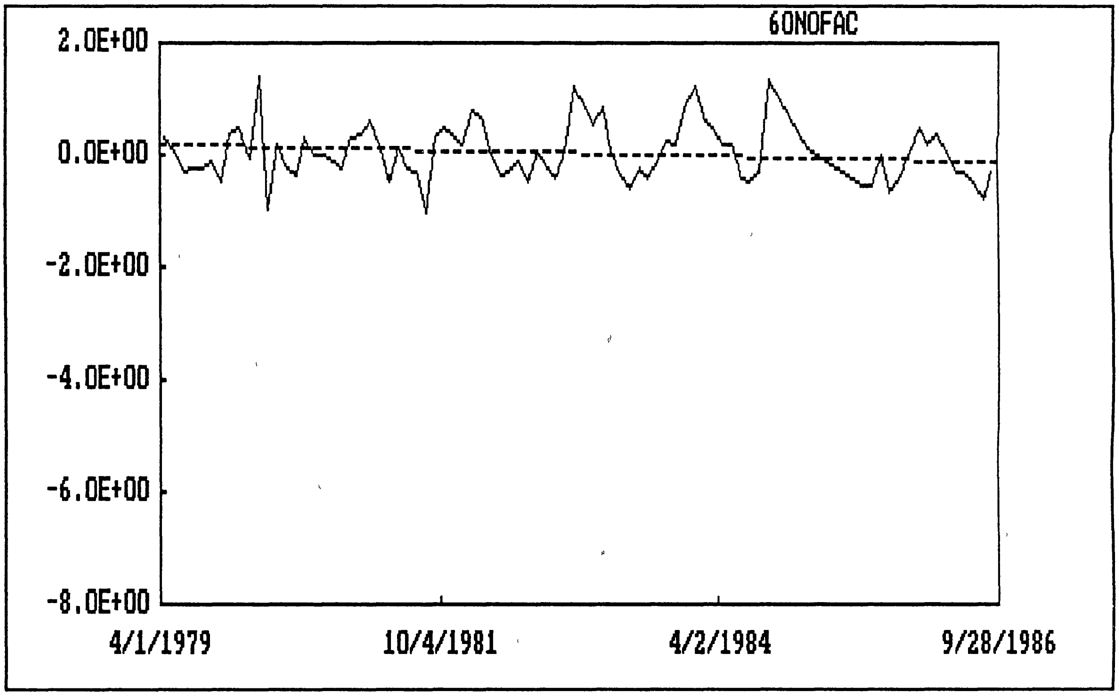

Figure 54. Time Series of Residual NO_2 + NO_3 Concentration (as mg/l N) at USGS 07196000. Slope Estimate = -0.03411 mg/l/yr.

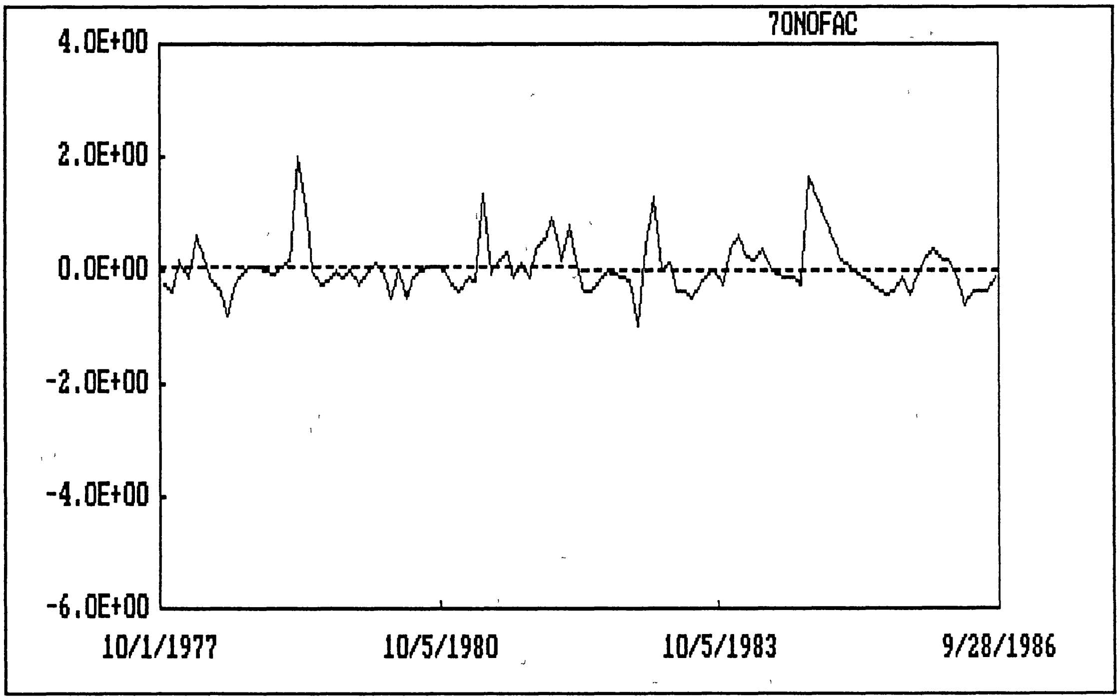

Figure 55. Time Series of Residual NO_2 + NO_3 Concentration (as mg/l N) at USGS 07197000. Slope Estimate = -0.01002 mg/l/yr.

VITA

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Master of Science

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