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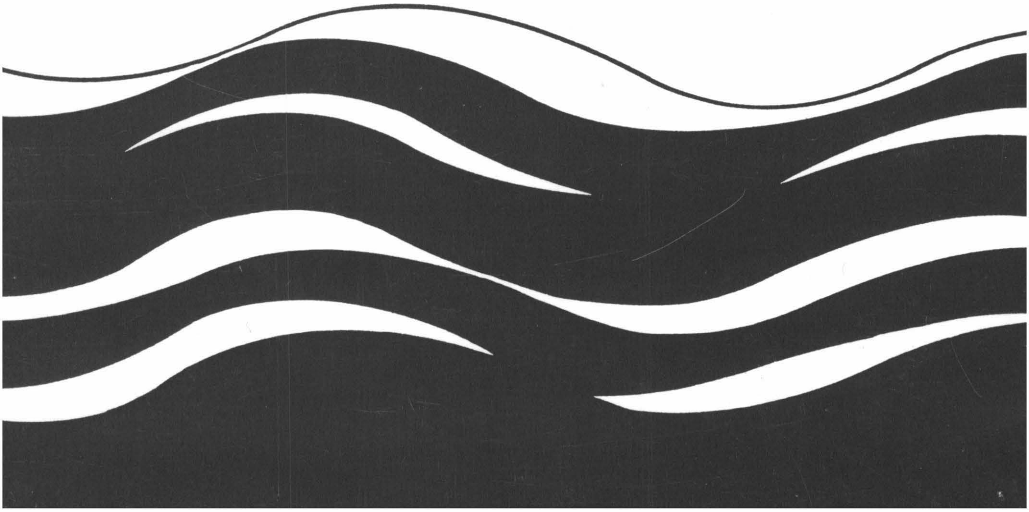

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Diana L. Weigmann
Assistant Director

Abstract

The major portion of far southwestern Virginia is drained by four major river systems: the Powell, the Clinch, the Holston, and the Big Sandy. The purpose of this study was to evaluate changes in water quality within these four river systems over a 20-year period extending from 1970 through 1989.

Data collected by the Virginia Water Control Board (VWCB) and the Tennessee Valley Authority (TVA) at 38 water quality monitoring stations were analyzed to identify long-term trends. Specific water quality variables analyzed were dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, filterable residue (FR), nonfilterable residue (NFR), total Kjeldahl nitrogen (TKN), total phosphorous (TP), and fecal coliforms (FC).

Statistical analyses to identify and characterize trends were conducted using the seasonal Kendall test for trend. To quantify trend, the rate of change (slope) of each water quality variable was estimated. Where flow data were available, the water quality data were adjusted for flow. The flow-adjusted data (with the effect of flow removed) then were analyzed for trend.

A comparison of median values to available VWCB standards indicate regional water quality to be good with respect to the majority of the variables studied. One exception is FR (an indicator of dissolved solids) concentrations in the Big Sandy basin, where medians approach VWCB standards for drinking water at some stations and increasing trends prevailed. Another exception is FC concentrations. Although declining trends were common and widespread, 10 stations with median FC concentrations exceeding the VWCB 200-per-100-ml standard failed to exhibit declining trends.

Marked water quality improvements were observed with respect to BOD and NFR (an indicator of suspended solids), both of which exhibited declining trends at a number of stations throughout the region. Numerous pH increases were detected in the Big Sandy and Powell basins, while high incidences of declining pH trends were detected in the Clinch and Holston basins.

TKN concentrations exhibited increasing trends at a high proportion of the Holston basin monitoring stations and at half the Clinch basin stations; rising TP trends were detected at 6 of 14 Holston basin stations. Median values for both TP and TKN concentrations were generally low. DO concentrations appeared to be generally stable throughout the region—six stations exhibited increases; eight stations exhibited declines.

Water quality trends occurred in association with land-use practices and other influences. Monitoring stations were classified according to four primary influences: land use in coal-mining areas, land use in agricultural areas, mixed land use (both agricultural and coal mining), and urban and point sources. Monitoring stations in agriculture-influenced locations showed high frequencies of pH and BOD declines, and TP and TKN increases. Stations influenced by coalfield land uses showed high frequencies of pH increases, BOD declines, NFR declines, and FR increases. Stations monitoring point-source and urban discharges showed high frequencies of BOD declines and DO increases.

Interpretation of these trends as general indicators of regional water quality must be made with caution, because monitoring station locations were not chosen for the specific purpose of establishing a network to monitor regional water quality.

Keywords: Surface water, land-use practices, monitoring station, statistical analysis, long-term trend.

1. Introduction

The quality of surface waters is of great concern to citizens, governments, and industries throughout Virginia and the U.S. The nation's rivers are essential natural resources. Surface-water quality affects the health and welfare of citizens and the economic vitality of communities.

Numerous legislative initiatives have been established for the purpose of maintaining or improving surface-water quality. Many funds and much effort have been spent to protect and monitor the quality of U.S. surface waters; however, little progress has been made in analyzing available water quality data and identifying the effects of public expenditures on long-term water quality trends (Smith et al., 1987).

Southwestern Virginia is drained by four major river systems: the Clinch, Powell, and Holston rivers, and tributaries of the Big Sandy. The Virginia Water Control Board (VWCB) has collected water quality data at monitoring stations on these river systems for many years. These data include information on the region's water quality that has never been analyzed for long-term trends.

In January 1990, we initiated a one-year research effort to evaluate long-term surface-water quality trends in southwestern Virginia. This report contains the results of those analyses.

1.1 The Southwestern Virginia Study Region

Four major river systems drain the major portions of nine counties, and a small portion of a tenth county, in the southwestern corner of Virginia (Figure 1). Three of these systems—the Powell, the Clinch, and the Holston—drain toward the state of Tennessee and the Tennessee River. These rivers drain major portions of Lee, Wise, Scott, Russell, Tazewell, Washington, and Smyth counties and a small portion of Bland County. Dickenson and Buchanan counties and a portion of Wise County drain toward Kentucky through tributaries of the Big Sandy River. The VWCB designated the region drained by these four river systems as the Tennessee and Big Sandy Planning Area.

The portion of Virginia drained by these four river systems is primarily rural, with an economy dependent on natural resource industries: agriculture (Holston, Powell, and Clinch river systems), mining (Big Sandy, Powell, and Clinch river systems), and forestry (throughout the region). Nonpoint pollution sources related to natural resource industries, primarily agriculture and mining, strongly affect water quality throughout the region (VDSWC 1989). Primary water quality problems in the region include metals, siltation, and pathogens (throughout the region), and nutrients (in agricultural areas) (VDSWC 1989). Point-source discharges, such as municipal water treatment systems and a few major industries, also influence water quality in the region (VWCB 1990).

The quality of these waters is important to southwestern Virginia for the following reasons.

- These rivers are essential components of the region's environment, which influences the quality of life experienced by residents.
- An abundance of clean water is vital to the region's economic development potential.
- A high-quality water resource is essential for the establishment and maintenance of a viable tourism industry in the region.
- Many municipalities depend on surface water for supplies provided to consumers through public systems.
- These river systems are unique biological resources.

1.2 Related Research

1.2.1 Water Quality in Southwestern Virginia

During the past 13 years, a variety of reports have been published that assess water quality and water quality effects within southwestern Virginia (Southwest Virginia 208 Planning Agency 1977; D'Appolonia 1980; Hufschmidt et al. 1981; Dyer 1982; Kiesler et al. 1983). Most of these studies focused on the mining industry, and were completed prior to 1983. The analyses tended to evaluate water quality at specific points in time; none examined long-term trends. In general, these studies determined that dissolved solids, sulfates, iron, manganese, and suspended sediment levels were high in Virginia's coal-mining areas.

In recent years, there has been renewed concern about the quality of surface water in southwestern Virginia. The Tennessee Valley Authority (TVA), U.S Fish and Wildlife Service, the Nature Conservancy (Dennis, 1989), the U.S. Geological Survey (USGS), and the Virginia Polytechnic Institute and State University (VPI&SU) Department of Fisheries and Wildlife all have initiated or proposed studies of water quality in this area. A major reason for this renewed emphasis is increased recognition of the ecological diversity of the region's aquatic resources.

The VWCB uses its water quality monitoring data to prepare biannual assessments of the commonwealth's surface water (VWCB, 1990). The primary purpose of these reports is to assess water quality in monitored streams with respect to the ability of those streams to serve designated uses as required by the Clean Water Act. If substantial changes in water quality occur at individual monitoring stations during the two-year period covered by the report, such changes are noted.

1.2.2 Statistical Methods for Identifying Trend

Linear regression is a commonly used statistical method for identifying time-series trends. However, application of linear regression to water quality trend assessment has been criticized for three major reasons:

- Most inferential methods, such as linear regression, are based on the assumption of a normal distribution, while most hydrologic variables are highly skewed and distinctly non-normally distributed.
- Water quality observations are often serially and cross-correlated, whereas traditional regression analysis is valid only when observations are uncorrelated and independent. When linear regression methods are applied, these violations of assumptions can mask existing trends or detect trends that, in reality, do not exist.
- The actual magnitudes of water quality monitoring observations that occur beyond technically feasible detection limits are unknown. In the context of classical linear regression, this amounts to incomplete information. Such observations cannot be used effectively in a conventional linear regression approach.

In spite of these limitations, linear regression is capable of detecting water quality trends where those trends are well defined. Reardon et al. (1982) identified definite trends in specific water quality variables in a Maryland watershed over a nine-year period using linear regression. Water quality data from four monitoring stations within the watershed, where the primary land use is agricultural, were retrieved from the STORET database. During the nine-year period covered by the study, farmers within the watershed increased use of conservation tillage row-crop production while upgrading animal-waste control facilities. Statistically significant improvements in phosphorous and fecal coliform concentrations were observed over the study period, presumably in response to the changes in land-use practices.

During the early 1980s, the USGS issued a series of reports identifying statistical techniques for water quality trend analysis that are major improvements over linear regression (Hirsch et al., 1982; Smith et al., 1982). The *Seasonal Kendall Test for Trend* is a statistical technique capable of analyzing time-series data for upward or downward trend, while accounting for the effect of seasonal variations. A related technique, the *Seasonal Kendall Slope Estimator,* estimates the magnitude of a trend so identified. Where accurate estimates of flow are available, a modified seasonal Kendall technique can eliminate the effects of flow on concentrations of water quality variables influenced by flow. In comparison with traditional linear regression, these techniques have the following advantages.

- They are distribution free.
- They account for seasonal hydrologic variations.

- They are not hampered by missing data values.
- They they are not hampered by observations that fall beyond detection limits.

Using these techniques, researchers analyzed and interpreted water quality trends in U.S. rivers over the 1974-1981 period (Smith et al. 1982, 1987a, 1987b). The water quality data sources included 294 NASQAN monitoring stations and 94 NWQSS stations. Variables studied included chloride, sulfates, nitrates, alkalinity and base cations, pH, suspended sediments, phosphorous, dissolved oxygen deficit, fecal coliforms, and the trace elements Pb, As, Cd, Cr, Fe, Mn, Hg, Se, and Zn. Definite patterns were observed for many of the variables analyzed. To interpret these trends, the researchers used a variety of data sources related to land use, and, in most cases, they were able to postulate causes for observed national and regional water quality trends. Factors such as levels of mining activity, regional investments in sewage treatment plants, changes in agricultural practices, and federal restrictions on leaded gasoline were identified as causes for observed trends.

Ryan et al. (1989) used Kendall's tau to identify long-term water quality trends in two catchment basins located in Shenandoah National Park, Virginia. They detected increasing trends in sulfates and acidity over an eight-year period, which they attributed to atmospheric deposition.

1.3 Research Objective

The objective of this study was to evaluate statistically long-term water quality trends at 36 water quality monitoring stations maintained by the VWCB in southwestern Virginia, and at 2 water quality monitoring stations maintained by the TVA on the Powell and Clinch rivers near the Virginia-Tennessee border.

2. Methods and Procedures

Water quality and surface-water flow data were obtained from three agencies that monitor surface-water flows in southwestern Virginia (Tables 1 and 2, Figure 2): the VWCB, the TVA, and the USGS. The data consisted of measurements of water quality variables at 38 monitoring stations in 4 watersheds: the Big Sandy, the Clinch, the Powell, and the Holston river basins. The water quality observations covered a period of 20 years (1970-1989). For some stations, data were not available for the full 20-year period—in most instances, because monitoring was not initiated until after 1970. For these stations, all available post-1970 data were analyzed. Waters were sampled at varying time periods but, generally, at three- to four-week intervals.

Analyses were conducted for eight water quality variables:

dissolved oxygen (DO)
biochemical oxygen demand (BOD)
pH
filterable residue (FR)—proxy for suspended solids
nonfilterable residue (NFR)—proxy for dissolved solids
total Kjeldahl nitrogen (TKN)
total phosphorous (TP)
fecal coliforms (FC)

The database contains numerous additional variables; however, sampling schedules for most of these variables were not sufficiently frequent to allow statistically valid analysis. The eight variables included in this study were chosen based upon the availability of more-or-less monthly observations over the time period of interest, as well as the utility of these variables as indicators of water quality.

The data were placed on magnetic tapes by VWCB and USGS personnel, and on diskettes by TVA personnel, and transferred electronically to the VPI&SU mainframe computer.

Rheem wrote a computer program (Rheem and Holtzman, 1991) to perform the long-term trend analysis on the data. The techniques are explained in detail in Appendix B, and summarized in section 2.1. The code for the program is given in Appendix C, and an example of program output is shown in Appendix D.

Each data set was screened for obvious errors in transcription and recording prior to statistical analysis using a combination of manual and computerized techniques. Because of the large volume of data, the data screening procedures were extremely time consuming.

For each monitoring station where sufficient data were available, statistical analyses were conducted to identify long-term trends in each of the variables under study. Not all analyses were performed at all stations. The two TVA stations lacked data for BOD, FR, TKN, and FC. The FR and NFR data for VWCB Station 29 were not collected at sufficient frequencies to allow statistical analyses to be performed. Thus, statistical analyses were performed on 294 separate data sets.

Seasonal Kendall analysis was performed on all data sets. Where flow data were available, two additional analyses were performed: regression of each water quality variable on a function of flow, and seasonal Kendall analysis on the flow-adjusted variable. For the purpose of analyzing the results of these analyses, each station was classified according to dominant influences on water quality, with the assistance of personnel at the VWCB Southwest Regional Office in Abingdon. Four primary water quality influence classes were established:

- Coalfield Land Uses (Coal): Nonpoint sources in coal mining areas.
- Agricultural Land Uses (Agricultural): Nonpoint sources in non-urban areas in the Ridge and Valley physiographic province, where agriculture is a major land use.
- Mixed Land Uses (Mixed): Nonpoint sources in both coal and agricultural areas.
- Point/Urban: Point-source discharges and urban runoff from Bristol.

2.1 Statistical Analyses

All data sets (i.e., observations for each water quality parameter, at each monitoring site) containing sufficient observations were analyzed using seasonal Kendall analysis. This technique analyzes monthly time series for trend by comparing all pairs of observations from the same month (but different years). The analysis determines whether the difference between the number of pairs demonstrating an increase with time, vs. the number of pairs demonstrating a decrease with time, is statistically significant, thus indicating an actual increasing (or decreasing) trend with time. In this report, statistically significant trends were reported to occur if the data allowed the null hypothesis—*there is no trend with time*—to be rejected at the 0.05 level of significance.

The rationale for the seasonal Kendall technique is that water quality parameter values typically change with the season of the year—they are cyclical. For example, by comparing January values only to other January values, the seasonal influence on water quality is removed from the analysis.

For all data sets containing sufficient observations, the seasonal Kendall slope estimator also was calculated. This is a value that estimates rate of change. Ninety-percent confidence intervals for slope also were estimated.

There were some data sets for which slope could not be estimated. Although the seasonal Kendall analysis indicated the existence of a statistically significant positive or negative trend, the slope of that trend was estimated to be zero. This occurred in situations where many observations were below the lower analytical detection limit (i.e., precise magnitudes were unknown) but higher levels were detected from time to time. A statistically significant trend with a magnitude of zero indicates that the frequency and/or magnitude of observations above the lower detection limit were increasing with time, but that the number of observations that did not exceed the lower detection limit was great enough to prevent estimation of the trend magnitude in a statistically valid fashion.

Because water quality variables often are influenced by flow, flow-adjusted analyses also were performed for monitoring stations where flow data were available. The purpose of flow-adjusted analysis is to determine whether a trend detected by non-flow-adjusted analysis is genuine or an artifact of flow. Flow-adjusted analysis eliminates the effect of flow on the water quality variable.

3. Results and Discussion

Statistical analyses conducted for the purpose of identifying regional water quality trends are summarized in Figures 4-11 and Tables 3-10. Detailed results of statistical analyses are summarized in the tables of Appendix E. For monitoring stations and parameters where we detected a statistically significant positive or negative relationship between a water quality variable and flow, Figures 4-11 and Tables 3-10 contain the results of flow-adjusted analyses. Results of non-flow-adjusted seasonal Kendall analyses are presented for all other variables.

Three primary indicators of water quality and water quality changes with time are reported. Tables 3-10 provide median values of each data set as indicators of overall water quality over the period for which data were available. For each water quality parameter, Tables 3-10 identify those stations where statistically significant trends were detected, and the signs of those trends. Median values are averaged, and positive and negative trends are totaled, by river basin and by primary water quality influence.

Figures 4-11 show the results of the statistical analyses. In these figures, NS indicates that no statistically significant trend was identified. For those stations that exhibited statistically significant trends, the trend magnitudes, or slope estimators, are listed as numerical values at the station locations. Parentheses indicate negative slopes. Trend magnitudes are represented as + for those stations where a statistically significant positive trend was identified, but where the magnitude of that trend could not be estimated due to the frequent occurrence of observations reported as below the analytical detection limits. (-) indicates a station where a statistically significant negative trend, the magnitude of which could not be estimated, was identified.

In the text that follows, a trend is said to exist only when the seasonal Kendall analysis identified a statistically significant trend ($P<0.05$). The results must be interpreted with caution because the VWCB selected its sampling locations to monitor the effects of specific point-source and nonpoint-source discharges, and not necessarily to evaluate regional water quality. TVA station locations, however, were chosen as indicators of regional water quality.

3.1 Interpretation of Medians

Median values of water quality variables are used to summarize conditions over the period of study (1970-1989). The median is preferable to the mean as an indicator of water quality because many observations were recorded as below analytical detection limits. The mean cannot be computed for such data, whereas the median can.

Medians are equivalent to means only for variables that are symmetrically (i.e., normally) distributed, and water quality variables seldom are.

The reader should be aware that median concentrations summarize conditions over a 20-year period. Thus, where trends are present, the median values represent conditions near the center of the time period studied, rather than current conditions.

3.2 Detailed Results

Detailed results of all analyses, including time-series graphs of each variable at each monitoring station, are maintained by the Department of Statistics and the Virginia Water Resources Research Center (VWRRC). Readers wishing to access detailed results for specific variables at specific stations should contact the VWRRC and be prepared to reference the station by the station number cited in this report and the specific water quality parameters of interest.

3.3 Medians and Trends

The following paragraphs discuss medians and trends (rates of change) for individual water quality variables. All trends are statistically significant at the $P<0.05$ level. In some cases, possible causes for observed trends are discussed. Such explanations are necessarily speculative, however, being based upon cursory analysis of available information. More powerful statistical tools are required to identify important factors with greater certainty. To assess the overall water quality, estimated medians are compared with standards adopted by the VWCB (1980).

3.3.1 Dissolved Oxygen

DO concentrations have a major influence on the biological systems of all surface waters. Median values for DO ranged from 8.6 mg/l to 10.9 mg/l (Table 3). Rising trends were identified at 8 sites, and falling trends at 6 sites; at 24 sites, no statistically significant trends were identified (Figure 4). Minimum surface-water DO standards for Virginia are 4 mg/l for a single sample and 5 mg/l as a daily average; therefore, DO does not appear to be a major problem at the locations monitored.

Two of the 10 Big Sandy stations exhibited rising DO trends. Both stations are located along the Levisa Fork tributaries. Establishment and expansion of municipal sewage treatment facilities by the Buchanan County Public Service Authority have occurred in this region in recent years. Of the remaining six stations showing DO rising trends, five are associated with point-source discharges or urban runoff. Thus, pollution control expenditures within the region appear to be paying dividends in terms of rising DO concentrations.

The only site influenced by point-source discharge that exhibited a declining DO trend is Station 7 at Holly Creek, the location of the Clintwood sewage treatment plant (STP). Although the median DO value at this station was 8.9 mg/l, the rate of DO decline was 0.07 mg/l/year, which is rapid relative to rates of decline at other stations. Four of the remaining five declining trends occurred at monitoring stations where water quality is influenced by agricultural land use, including both stations located on the Middle Fork of the Holston River.

3.3.2 Biochemical Oxygen Demand

BOD is a measure of the oxygen that would be required by bacteria to oxidize the organic materials present; thus, high levels of BOD indicate poor water quality. The BOD test used by VWCB uses a five-day bacterial incubation period.

No specific BOD standards have been adopted by Virginia for surface water; however, the BOD standards for effluent discharged into most surface water range from 3 to 6 mg/l. The two sites where median BOD concentrations exceeded 3.0 mg/l (Station 7 at Holly Creek near Clintwood, 10 mg/l; and Station 15 on Bear Creek near Wise, 3.7 mg/l) are influenced primarily by point-source discharges (Table 4). Of the three remaining sites where median BOD levels exceeded 2.0 mg/l, two stations (36 and 38) are influenced primarily by urban runoff from Bristol; the third is Station 11 on the Clinch River, directly below the Richlands STP. Thus, with the exception of five locations influenced by urban and point-source discharges, BOD levels generally appear to be low throughout the study region. Station 11 is the only one of those five stations with median BOD levels exceeding 1.00 mg/l that did not exhibit a declining trend. Station 7 at Clintwood, where the median BOD concentration was highest, also exhibited the most rapid rate of BOD decline (Figure 5).

BOD declined significantly at 25 sites, and exhibited no significant change at the remaining 11 stations where BOD data were available. Improvements in BOD levels were particularly apparent in the coalfield areas. Ten of 11 stations influenced by coal-mining land uses exhibited declining trends. Eight of 11 stations influenced by agricultural land use and 6 of 8 stations influenced primarily by urban and point sources also showed declining trends.

Median BOD values were high in the Big Sandy basin. The average Big Sandy BOD median was 2.34 mg/l, in comparison to 1.80 mg/l in the Clinch basin, 1.72 in the Holston, and 1.25 in the Powell. However, the 10.00 mg/l median value at Clintwood (Station 7) is extremely high, relative to all other monitoring stations. The average median of the remaining nine Big Sandy stations is 1.5 mg/l. While all 10 Big Sandy stations showed BOD improvements (i.e., declining trends), as did 11 of 14 Holston basin stations, only 2 of 8 Clinch basin stations showed BOD declines. These two declines occurred at stations having relatively high median values of 1.5 mg/l or greater. No trends were evident for the other three stations in the Clinch River basin where median BOD levels exceeded 1.5 mg/l.

In the Powell River basin, two of four stations exhibited declines. The median BOD concentrations at the sites showing declines were 1.5 mg/l, while the two non-declining stations had median BOD values below the analytical detection limit of 1.00 mg/l.

3.3.3 pH

pH is a measure of water's hydrogen ion activity, and an indicator of hydrogen ion concentrations. pH affects a water body's biological systems through its influence on the solubility of dissolved constituents. pH also affects water treatment methods and processes.

Median pH values were characteristic of surface water in regions of carbonate-dominant geologic formations, ranging from pH 7.2 to 8.5 (Table 5). Trends in pH showed a distinctive pattern: all instances of rising trends occurred at stations within, or close to, coalfield areas; no negative trends were detected within these areas. In contrast, negative trends were widespread at monitoring stations located outside of the coalfield areas. The only station exhibiting a positive trend located outside of the coalfield area was Station 19, on the North Fork of the Powell River near Pennington Gap. The watershed above this station contains the mining districts near St. Charles, as well as agricultural land-use areas.

Statistically significant increases in pH were observed at eight sites, six of which were locations where land use was dominated by mining or mixed mining and agricultural activities. The remaining two stations with rising trends were point-source influenced stations located within the coalfields, at Wise and Clintwood (Stations 7 and 15). No stations where water quality is primarily influenced by coal-mining land uses exhibited pH declines.

Increasing surface-water pH in the coalfields could be the result of environmental regulations imposed on the coal industry during the late 1970s and 1980s. Low pH is a common water quality problem that occurs as a consequence of coal mining in areas where acid mine drainage is present. Elevated iron and manganese concentrations often result. The problem is routinely treated by addition of alkaline reagents (e.g., $NaOH$, $NaCO_3$, CaO, and $CaCO_3$) to mine waters prior to discharge. Elevating the pH causes precipitation of iron and manganese compounds and, thus, a decline in iron and manganese concentrations in the discharge. There are numerous coal mines and associated operations producing discharges to surface waters throughout the Virginia coalfield region. The combined effect of water treatment practices may be a factor causing surface-water pH to increase throughout the area.

Declining pH trends were observed throughout the non-coalfield portion of the study area. Declines in pH were especially pronounced in the Holston River basin (13 of 14 stations) and at stations influenced by agricultural land uses (11 of 11 stations). Five of the six non-coalfield monitoring stations in the Clinch River basin also showed pH declines, with rates ranging from 0.02 to 0.07 pH units per year. Thus, over a 20-year period, overall declines could be expected to approach 0.5 pH units for stations showing low rates of decline, and to exceed a full pH unit for the stations showing rates of decline greater than 0.05 pH units per year.

Chemical weathering processes, facilitated by naturally acidic precipitation, are major contributors to soil and water pH reduction. However, additional factors may have played a role in southwest Virginia, including acid rain and/or nitrification of agricultural fertilizers and manures. During 1989, the mean value for field measurements of rainfall pH at Wise was 3.73, while the mean laboratory-measured value was 4.24 (Buikema et al. 1990). The concentration of declining pH trends in agricultural land-use areas suggests that agricultural practices may be a causative factor.

Station 13, on the Clinch River just above the Guest River junction at St. Paul, showed a pH decline of 0.07 units per year—a decline of greater magnitude than any other observed in the study. This monitoring station is close to areas identified by the Nature Conservancy as critical aquatic habitat on the Clinch. pH is an important ecological parameter, in part because of its influence on the solubility of numerous inorganic constituents. Water quality at Station 13 is influenced by coal-mining and agricultural land uses, and by the St. Paul STP located 3.5 miles upstream.

3.3.4 Nonfilterable Residue

NFR is a measure of suspended solids. It is determined by passing a water sample of known volume through a glass-fiber filter. The residue retained on the filter is dried to a constant weight at 103°-105°C. The ratio of dried residue weight to sample volume is the NFR value.

No surface-water quality standards exist for NFR, but an effluent standard of 30 mg/l was established by the VWCB for municipal sewage treatment plants with secondary treatment. None of the median values for NFR approach 30 mg/l (Table 6). In the Big Sandy, Powell, and Clinch river basins, the majority of stations with high median NFR values also show declining trends (Table 6, Figure 7). Twenty-two of 38 stations show declining NFR; no rising trends are evident.

At a number of monitoring stations, the slope of statistically significant declining NFR trends are estimated as 0.00 in Appendix E, and represented as (-) in Figure 7. For those stations, slope magnitudes could not be estimated because large numbers of observations were below the analytical detection limit.

Eight of 11 stations primarily influenced by coalfield land uses showed declining NFR trends. Generally, the coalfield stations with the highest median NFR values exhibited the sharpest declines. At four of the coalfield land use stations, NFR concentrations declined at rates of 0.7 mg/l/year or greater. The only additional station showing a decline of 0.6 mg/l/year or greater was Station 7, on Holly Creek, which monitors the Clintwood STP. Of the three coalfield stations that did not exhibit declines, two (Stations 3 and 5) have low median values; the third (Station 6) has been in operation only since 1982.

Two possible explanations for the large NFR declines in the coalfields are:

- The effect of environmental regulations on the coal industry—sediment control structures are now mandatory, while their use was not common practice in the early 1970s.
- The influence of time on the region's abandoned mined lands—natural revegetation processes during the past 10-20 years have greatly reduced sediment from many of these areas.

Declining NFR concentrations also were widespread throughout the Clinch and Powell basins. Each of five Powell basin stations, and seven of nine Clinch basin stations, showed declining NFR trends. Four of the five Clinch stations where median NFR values equaled or exceeded 10 mg/l exhibited statistically significant declines. The only Clinch basin station with a median concentration of 10 mg/l or higher that did not show a decline was Station 13, on the river itself, just below St. Paul.

Only 3 of 14 stations the Holston River basin exhibited declining NFR trends. Two of these (Stations 24 and 30) are primarily influenced by agriculture; the third (Station 35) is influenced by a point-source discharge. The Holston stations exhibiting declining NFR trends include two where median levels are 5 mg/l or lower, but the Holston stations with the highest median NFR levels do not show declines.

Five Holston River stations show median NFR concentrations equal to or greater than 10 mg/l. Two are associated with agricultural land uses, and three with urban and point-source influences. None of these high-median stations showed a declining trend.

Four of 10 stations primarily influenced by agricultural land uses, including 2 (Stations 18 and 24) where median NFR values are 5 mg/l or lower, showed declining trends. The two agriculture-influenced stations with the highest median values (Stations 31 and 37) did not show declining trends. Both agriculture-influenced stations in the Clinch River basin showed declining trends, but 7 of the 9 agriculture-influenced stations in the Holston basin showed no significant declines.

Six of eight stations where water quality is influenced by both agricultural and coalfield land uses showed declining NFR trends; however, it is difficult to attribute these water quality improvements to specific factors.

3.3.5 Filterable Residue

FR, determined by evaporating the filtrate from the NFR determination, is essentially a measure of total dissolved solids (TDS). The VWCB standard for TDS is 500 mg/l; this standard applies to groundwater and surface water used for water supplies.

Median values for FR ranged from 48 to 461 mg/l (Table 7). In general, the highest median values were found in the Big Sandy basin, where the average median FR concentration was 298 mg/l. The median FR concentrations at stations where water quality is influenced by coalfield land uses were relatively high (average = 298 mg/l), as were medians at the eight stations influenced primarily by point-source and urban discharges (average = 242 mg/l). Stations influenced by agricultural land uses, in general, had low median FR values (average = 163 mg/l).

At the median levels, FR concentrations pose little environmental risk; however, if FR levels continue to rise at the highest rates observed during the past 20 years, water quality will be affected negatively at stations currently exhibiting high median FR concentrations. The environmental effects of TDS are largely a result of the constituent compounds.

Overall, 16 of 35 stations showed increasing FR trends, while only 1 station showed a decline (Table 7, Figure 8). FR levels rose at 8 of 10 Big Sandy stations. Three of the larger increases in FR occurred at the Levisa Fork station at Big Rock (Station 10), at the Slate Creek junction with the Levisa Fork in Grundy (Station 9), and at the Cranesnest River station below Clintwood (Station 6). These stations also have high median FR concentrations (382 mg/l, 291 mg/l, and 461 mg/l, respectively).

All four stations in the Powell basin, and four of eight stations in the Clinch basin, also exhibited increasing FR concentrations. In general, increasing FR trends were associated with coalfield and mixed land uses—the mixed land-use stations located closer to the coalfield land-use areas tended to exhibit more rapid increases than those located farther from coalfield land-use areas. In the Powell basin, large increases in FR occurred at Station 22, on Straight Creek, which drains the St. Charles community and mining district, and at Station 20, in Big Stone Gap, which receives substantial discharge from mining areas above Appalachia and Norton. In the Clinch River watershed, a large increase in FR occurred along the Guest River, which drains the Coeburn-Wise mining district; however, the greatest increase was recorded at Station 15, which receives discharge from a point source at Wise.

The Holston River basin showed relatively modest median FR concentrations (average = 189 mg/l). Only one rising and one falling trend were evident, and these were of modest magnitudes. Only two of eight stations influenced primarily by point-source and urban discharges showed rising trends.

One possible cause for the rapidly rising FR values in the coalfields could be water treatment by the mining industry. Alkaline reagents, added to mine discharge waters to precipitate iron and manganese and raise pH, can increase surface-water TDS contents. Another possible cause could be the installation of numerous municipal water and sewage treatment facilities in the coalfields over the past 20 years.

3.3.6 Total Kjeldahl Nitrogen

The TKN measurement is defined as the sum of free-ammonia and easily hydrolyzed organic nitrogen forms. TKN includes the majority of surface N under most conditions. The effluent standard for N is 1.0 mg/l, and the drinking water standard for nitrates is 10 mg/l. With two major exceptions, N concentrations appear to be low throughout the region (Table 8). The two exceptions are Stations 7 and 15, which monitor the sewage treatment facilities at Wise and Clintwood, respectively. Except for Station 11, all stations having N concentrations of 0.3 mg/l or greater are at locations primarily influenced by point-source and urban discharges. Station 11 also is influenced by a point-source discharge (the Richlands STP), although that influence is not considered to be primary.

Nitrogen concentrations showed statistically significant increases at 15 of 36 stations (Table 8, Figure 9). The only statistically significant decline in TKN occurred at Station 32, which is influenced by a point-source discharge. Aside from Station 15 at Wise, all rises and declines were of relatively modest magnitude (0.01 mg/l/year or less). Six rising trends are reported as being of magnitude 0.00 in Table E-6, and indicated by a + in Figure 9. For these stations, large numbers of observations were below the analytical detection limit. None of the increasing TKN trends occurred in the Big Sandy basin. Only one statistically significant TKN increase was detected at a station where mining is a primary influence on water quality; however, this site (Station 14 on the Guest River below Coeburn), is located downstream from the sewage treatment facility at Wise and below the outfall of the Coeburn treatment plant. The Wise STP is monitored by Station 15, where TKN concentrations rose most rapidly (0.05 mg/l/year) over the study period.

Only one of four stations in the Powell basin and four of eight stations in the Clinch River basin (including two of six non-Guest River watershed stations) exhibited rising trends in TKN concentrations. In contrast, 10 of 14 stations in the Holston basin showed rising trends.

Eight of 11 stations where water quality is influenced primarily by agriculture showed rising trends. Thus, it appears that agricultural practices are a potential cause for rising TKN concentrations in the region. However, the two stations where median TKN concentrations were highest (Station 15, at Wise, and Station 7, at Clintwood) and the station where TKN rose most rapidly (Station 15) were primarily influenced by point sources.

3.3.7 Total Phosphorous

A surface-water TP standard exists for impounded water only, and is set at 0.05 mg/l. The effluent concentration limit is 0.2 mg/l. TP concentrations throughout the region are low (0.1 mg/l or less), with the only exceptions being those stations where water quality is primarily influenced by point-source discharges (Table 9).

Seven monitoring stations exhibited increasing TP trends; no declines were detected. Because of the prevalence of observations of concentrations below analytical detection limits, a slope magnitude could be estimated only for Station 33 in Washington County (Figure 10), located below the Abingdon STP on Wolf Creek and, therefore, influenced primarily by a point-source discharge. Five of the remaining 6 stations that exhibited increasing trends were primarily influenced by agriculture; the sixth (Station 36) monitors urban runoff from Bristol.

Six of the 7 increasing trends occurred at stations within the Holston River basin. Station 12, on the Little River near its confluence with the Clinch, also exhibited a statistically significant increase.

3.3.8 Fecal Coliforms

Fecal coliforms are a bacterial indicator of water contamination by warm-blooded animals. Humans, livestock, and wildlife are sources of fecal coliforms in surface waters. Virginia surface-water quality standards for FC are 1000 per 100 ml for any one sample, or 200 per 100 ml for 2 or more samples over any 30-day period.

Median FC concentrations were high at numerous locations throughout the region (Table 10), exceeding 1000 per 100 ml at 8 stations, and exceeding 200 per 100 ml at 27 of 38 stations. Although median FC levels are high, 21 of 36 stations show declining trends, and none show rising trends (Figure 11). Median FC levels exceeded 1000 per 100 ml at three of the four Powell River basin stations. The two stations with the highest FC levels (Station 22 on Straight Creek below St. Charles, and Station 19 on the North Fork of the Powell below Pennington Gap, farther downstream from the Straight Creek station) do not show declining trends. The other two Powell River basin stations exhibited declining trends; one, the Big Stone Gap station (20), had a high median FC concentration (1500 per 100 ml) and showed a rapid rate of decline.

Seven of eight stations in the Clinch River basin show declining FC concentrations. In general, median FC levels are low in the Clinch, relative to the other river basins. The Clinch basin station with the highest median value (Station 15, median = 900 per 100 ml) showed the most rapid rate of decline.

Seven of 14 stations in the Holston exhibited declining FC levels; however, the Holston station with the highest median FC concentration (Station 38) did not exhibit a statistically significant decline. Three additional Holston basin stations (33, 36, and 37) had median FC levels of 900 or 950, but at only one of these (Station 37) were FC concentrations declining.

Nine of the 11 stations where agricultural land use is the major water quality influence exhibited median FC concentrations exceeding 200 per 100 ml. However, none of the agricultural stations' median FC concentrations exceed 1000, and at only two (both in the Holston basin) do median FC concentrations exceed 300. Thus, although surface waters draining agricultural areas in the study region tend to exceed Virginia surface-water quality standards for FC, the highest FC levels in agricultural areas, in general, do not approach the higher median levels observed in the Big Sandy and the upper Powell basins, where agricultural land uses are not prevalent. Overall median values in agricultural areas are far less than in the Big Sandy and the upper Powell basins. Lack of adequate sewage treatment facilities remains a major concern in certain coalfield communities in the Big Sandy and upper Powell watershed areas.

Six of the 11 stations where agricultural land use is the major water quality influence show declining trends. These include five of the nine stations where median FC levels exceed 200 per 100 ml. However, of the remaining four agricultural stations where median FC levels exceeded 200 per 100 ml (Stations 24, 30, 31, 34, located in the Holston basin), none showed evidence of statistically significant decline.

Four of eight urban and point-source stations showed declining trends. Of the four remaining urban and point-source stations (those that did not show any improvement), two (Stations 36 and 38) are influenced by urban runoff from Bristol. Median values at both are relatively high.

4. Summary

This research analyzed monthly water quality monitoring data for 8 water quality parameters, gathered at 38 monitoring stations over a 20-year period. The monitoring stations were located throughout four river basins in southwest Virginia, and at two locations in Tennessee receiving waters from southwest Virginia. The locations of the southwest Virginia monitoring stations were not selected with the objective of establishing a network to monitor regional water quality.

Seasonal Kendall analytical procedures were used to identify long-term trends. The results were adjusted for the effects of flow at the eight stations where flow data were available. This study reports the occurrence of a trend only where the relationship between a water quality variable and time, at an individual monitoring station, is statistically significant at the $P<0.05$ level. Median values for water quality variables also are reported as indicators of average conditions over the periods for which data were available.

The results show widespread improvements (i.e., a prevalence of declining trends) with respect to FC, BOD, and NFR. Modest declines in water quality (i.e., a prevalence of rising trends) were observed with respect to TP, TKN, and FR. Results were mixed with respect to DO and pH, as the numbers of rising and declining trends were more evenly balanced for these two parameters.

Twenty-five of 36 monitoring stations showed declining BOD trends; no increasing trends were detected. BOD declines were most prevalent in the Big Sandy and Holston basins; only the Clinch River basin showed a low incidence of BOD declines. Monitoring stations primarily influenced by agricultural and coalfield land uses, and by point-source and urban discharges, all exhibited high incidences of declining BOD trends.

The widespread improvements in BOD were not reflected in DO concentration trends. Only six of 38 stations exhibited declining DO trends; 8 DO increases were detected. Five of the six DO increases occurred at stations monitoring point-source and urban discharges; four of the declines occurred at stations primarily influenced by agricultural land uses. Four DO increases and three declines occurred at monitoring stations in Holston basin; the remaining trends were distributed throughout the other three watershed areas.

Declining NFR trends were widespread: 22 of 37 monitoring stations showed declines; no rising trends were detected. The incidence of declining trends, as a proportion of all monitoring stations, was highest in the Powell basin, followed by the Clinch and Big Sandy basins. Only in the Holston basin did declines occur at less than half (3 of 13) of the monitoring stations. Monitoring stations primarily influenced by coalfield land uses showed a high incidence of declining trends; those stations primarily influenced by agricultural land uses showed a much lower incidence of declines, especially in the Holston basin.

In contrast to NFR, rising FR concentrations were prevalent throughout the study area. Seventeen of 35 stations exhibited increasing FR trends; only one decline was observed. Rising FR trends were most prevalent where median levels were highest—in the Big Sandy and Powell basins, where coalfield land uses are common. The stations with the highest median values exhibited the most rapidly rising trends. Rising trends were not prevalent in the Holston River basin, at monitoring stations influenced by agricultural land uses, or at monitoring stations influenced by point-source and urban discharges. At monitoring stations primarily influenced by both agricultural and coalfield land uses, rising trends appeared to be more prevalent, and of greater magnitude, closer to the coalfields.

Increasing trends were far more prevalent than declining trends for both TP and TKN. Fifteen TKN increases and one decline were observed; seven TP increases and no declines were observed. For both TP and TKN, increases were most heavily concentrated in agricultural areas; additional increases occurred at stations influenced by urban and point-source discharges. For both TP and TKN, rising trends were heavily concentrated in the Holston basin stations. Four of eight Clinch River monitoring stations showed TKN increases. The prevalence of TP and TKN observations listed as below analytical detection limits prevented estimation of the rate of increase at the majority of stations where rising trends were observed. Median TP and TKN levels at two monitoring stations (Station 7 on Holly Creek below the Clintwood STP, and Station 15 on Bear Creek below the Wise STP) were substantially higher than median levels elsewhere.

The pH monitoring data exhibited a mixture of trends and a distinctive geographical pattern. Increasing pH trends were detected at 8 of 38 monitoring stations; 18 stations exhibited declines. Seven of the eight increases occurred at stations in the Big Sandy and Powell basins; five of these stations were primarily influenced by coalfield land uses. No declining pH trends were observed in the Big Sandy or Powell basins, or at monitoring stations primarily influenced by coalfield land uses. In contrast, declining trends were prevalent in the Clinch basin, and especially prevalent in the Holston basin and at stations primarily influenced by agricultural land uses. No Holston or agriculture-influenced stations exhibited increasing pH trends.

Water quality improvements were also widespread with respect to fecal coliforms—21 of 36 stations showed declines; none showed increases. However, median FC levels were generally high, relative to the VWCB surface-water standard of 200 per 100 ml, and some of the stations with the highest FC levels (two in the Powell basin, and three in the Holston basin, primarily influenced by point sources and urban runoff) did not show statistically significant declines. Seven of eight Clinch basin stations showed FC declines, and the Big Sandy stations with the highest median FC values showed declining trends. One monitoring station in the Clinch River basin, two in the Powell, and seven in the Holston exhibited median FC values in excess of the VWCB 200-per-100-ml standard, but did not exhibit statistically significant declining trends.

Overall, a comparison of median values to VWCB standards, for parameters for which VWCB standards are available, indicate regional water quality to be good for the majority of the parameters observed. One exception is FR concentrations in the Big Sandy basin, where median values are approaching VWCB standards for drinking water sources at some stations and increasing trends prevail. The other exception is FC—although declining trends were common and widespread, 10 stations with median FC concentrations in excess of the VWCB 200-per-100-ml standard failed to exhibit declines. Marked water quality improvements were observed with respect to BOD outside of the Clinch River basin, and with respect to NFR outside of the Holston River basin. Numerous pH increases were detected in the Big Sandy and Powell basins; high incidences of declining pH trends were detected in the Clinch and Holston basins. TKN concentrations exhibited increasing trends at a high proportion of the Holston basin monitoring stations, and at half the Clinch basin stations; rising TP trends were detected at 6 of 14 Holston stations. DO concentrations appeared to be basically stable throughout the region—only six stations exhibited declines; eight stations exhibited increases.

References

Buikema, Arthur L., Boris Chevone, and Timothy Morgan. 1990. *Virginia Acid Precipitation Network 1989 Rain Water Analyses.* Report to Va. Dept. of Air Pollution Control by VPI&SU.

D'Appolonia Consulting Engineers, Inc. 1980. *Abandoned Coal Mined Land Survey.* Prepared for Va. Div. of Mined Land Reclamation, Big Stone Gap, VA.

Dennis, Sally D. 1989. Status of the Freshwater Mussell Fauna, Pendleton Island Mussell Preserve, Clinch River, Virginia. *Sterkiana,* 72(1):19-27. January

Dyer, Kenneth L. 1982. Stream Water Quality of the Virginia Coal Region. U.S. Forest Service. General Technical Report NE-78.

Gilbert, Richard O. 1987. *Statistical Methods for Environmental Pollution Monitoring.* Van Nostrand Reinhold Co., NY.

Gilliom, Robert J., Robert M. Hirsch, and Edward H. Gilroy. 1984. Effect of Censoring Trace-Level Water-Quality Data on Trend Detection. *Env. Sci. and Tech.,* 18(7):530-535.

Hirsch, R.M., and J.R. Slack. 1984. A Nonparametric Trend Test for Seasonal Data with Serial Dependence. *Water Resources Res.,* 20(6):727-732.

Hirsch, R.M., J.R. Slack, and R.A. Smith. 1982. Techniques of Trend Analysis for Monthly Water Quality Data. *Water Resources Res.,* 18(1):107-121.

Hufschmidt, P.W., and Others. 1981. Hydrology of Area 16, Eastern Coal Province, Virginia and Tennessee. *USGS Water Resources Investigations,* 81-204.

Kendall, Maurice G. 1970. *Rank Correlation Methods,* 4th ed. Griffin, London.

Kiesler, Jay, F. Quinones, D. Mull, and K. York. 1983. Hydrology of Area 13, Eastern Coal Province, Kentucky, Virginia, and West Virginia. USGS Water Resources Investigations Open File Report 82-505.

Lettenmaier, Dennis P. 1988. *Multivariate Nonparametric Tests for Trend in Water Quality.* Water Resources Bull., 21(3):505-512.

Reardon, John C., L.D. Hanson, and J. Randolph. 1982. Using EPA's computerized database (STORET) to analyze for agricultural water pollution. *J. Env. Quality,* 11(3):427-432.

Rheem, S., and G.I. Holtzman. 1991. A SAS program for seasonal Kendall trend analysis of monthly water quality data. *Proceedings, Sixteenth Annual SAS Users Group International (SUGI 16) Conference,* Feb. 17-20, 1991, New Orleans

Ryan, P.F., G.M. Hornsberger, B.J. Cosby, J.N. Galloway, J.R. Webb, and E.B. Rastetter. 1989. Changes in the chemical composition of stream water in two catchments in the Shenandoah National Park, Virginia, in response to atmospheric deposition of sulfur. *Water Resources Res.* 25(10):2091-2099.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987a. Analysis and Interpretation of Water Quality Trends in Major U.S. Rivers, 1974-1981. USGS Water Supply Paper 2307.

Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987b. Water Quality Trends in the Nation's Rivers. *Sci.*, 235:1607-1615.

Smith, R.A., R.M. Hirsch, and J.R. Slack. 1982. A Study of Trends in Total Phosphorous Measurements at NASQAN Stations. USGS Water Supply Paper 2190. U.S. Govt. Printing Off.

Southwest Virginia 208 Planning Agency. 1977. Southwest Virginia 208 Plan. LENOWISCO and Cumberland Plateau Planning District Commissions, Duffield and Lebanon, VA.

State Water Control Board. 1980. Water Quality Standards. Publ. No. RB-1-80, Commonwealth of Va., Richmond, VA.

Tukey, J.W. 1977. *Exploratory Data Analysis.* Addison-Wesley, Reading, MA.

Virginia Division of Soil and Water Conservation (VDSWC). 1989. Virginia Nonpoint Source Pollution Assessment Report.

Virginia Water Control Board (VWCB). 1990. Virginia Water Quality Assessment: 305(b) report to EPA and Congress. Info. Bull. 579. April, 1990. 3 volumes.

Tables and Figures

Notes for Tables 4 - 11:

Primary land use influence columns list water quality monitoring stations by number (Table 1; Figure 2) followed by the parameter median value. A + indicates a statistically-significant ($P<0.05$) rising trend, and a - represents a statistically-significant ($P<0.05$) declining trend. Lack of a + or - sign indicates lack of a statistically-significant trend.

Lack of a median value at a monitoring station indicates that data were not sufficient to allow the analysis to be performed. Where both flow-adjusted and non-flow-adjusted analyses were performed, the results of the flow-adjusted analyses are summarized.

Total numbers of statistically-significant + and - trends are listed as: (Number of statistically-signifcant trends) / (Number of stations where trend analysis was performed). Values listed as "Avg" represent means of all medians within a relevant category. Where medians expressed as "less than lower detection limit" are present, averages were calculated using the detection limit value.

Figure 1.
Nine Virginia counties in the Tennessee and
Big Sandy river basins.

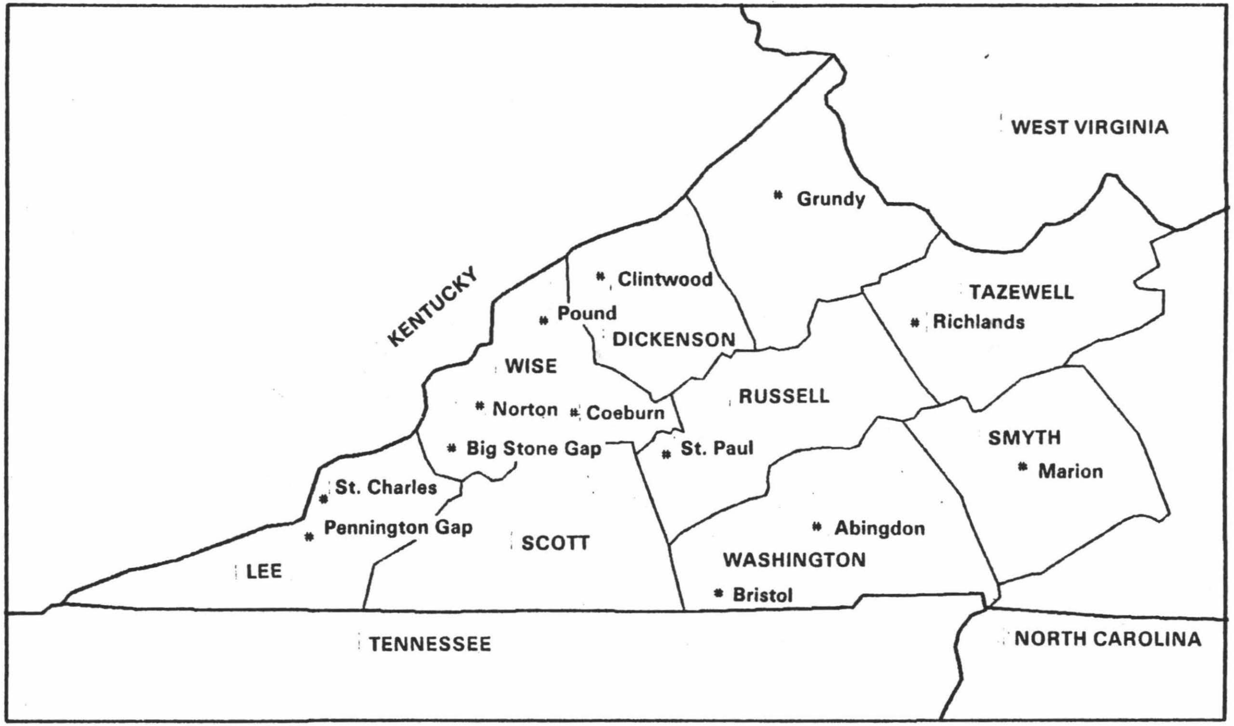


Table 1.
Water quality monitoring stations in the Tennessee and Big Sandy planning area.

Station Number	Stream	Location	Primary WQ Influence
		Big Sandy Basin	
1	Knox Creek	At Kentucky Line	C
2	McClure River	At Clinchco, Dickenson County	C
3	Pound River	Above Confluence of Cranesnest	C
4	Russell Fork	At Haysi, Dickenson County	C
5	Cranesnest River	At Confluence with Flannagan Reservoir	C
6	Cranesnest River	Off Rt. 83, Dickenson County	C
7	Holly Creek	Below Clintwood STP	P
8	Dismal Creek	Rt. 666 Bridge, Buchanan County	C
9	Slate Creek	In Grundy, Buchanan County	C
10	Levisa Fork	At Big Rock, Buchanan County	C
		Clinch River Watershed	
11	Clinch River	Rt. 723 Bridge, Tazewell County	M
12	Little River	Rt. 636, Russell County	A
13	Clinch River	End of Rt. 611, Wise County	M
14	Guest River	Rt. 82 Bridge, Wise County	C
15	Bear Creek	Off Rt. 681, Wise County	P
16	Stock Creek	Rt. 650 Bridge, Scott County	P
17	Clinch River	Rt. 58, Scott County	M
18	N.F. Clinch River	Rt. 621 Bridge, Scott County	A
TC	Clinch River	Tazewell, TN	M

Table 1, Cont'd.

Station Number	Stream	Location	Primary WQ Influence
		Powell River Watershed	
19	N.F. Powell River	Rt. 630 Bridge, Lee County	M
20	Powell River	Big Stone Gap, Wise County	M
21	Powell River	Rt. 70 Bridge, Lee County	M
22	Straight Creek	Rt. 352, Lee County	C
TP	Powell River	Arthur, TN	M
		Holston River Watershed	
23	N.F. Holston River	Rich Valley H.S., Smyth County	A
24	N.F. Holston River	Rt. 91 Bridge, Smyth County	A
25	N.F. Holston River	Rt. 613 Bridge, Smyth County	A
26i	N.F. Holston River	Olin Gaging Station, Smyth County	A
27i	N.F. Holston River	Rt. 19 Bridge, Washington County	A
28	N.F. Holston River	Rt. 615 Bridge, Washington County	A
29	N.F. Holston River	Rt. 23, Scott County	A
30	M.F. Holston River	Washington-Smyth County Line	A
31	M.F. Holston River	Rt. 58 Bridge, Washington County	A
32	Wolf Creek	Off Rt. 75, Washington County	P
33	Wolf Creek	At Green Springs, Washington County	P
34	S.F. Holston River	Rt. 710 Bridge, Washington County	A
35	Beaverdam Creek	Rt. 58 Bridge in Damascus, Washington County	P
36	Little Creek	State Street Bridge in Bristol	P
37	Beaver Creek	Off Rt. 11 above Bristol	A
38	Beaver Creek	State Street and 7th in Bristol	P

Figure 2a.
Locations of VWCB and TVA water quality monitoring stations.
Station locations denoted by symbols.

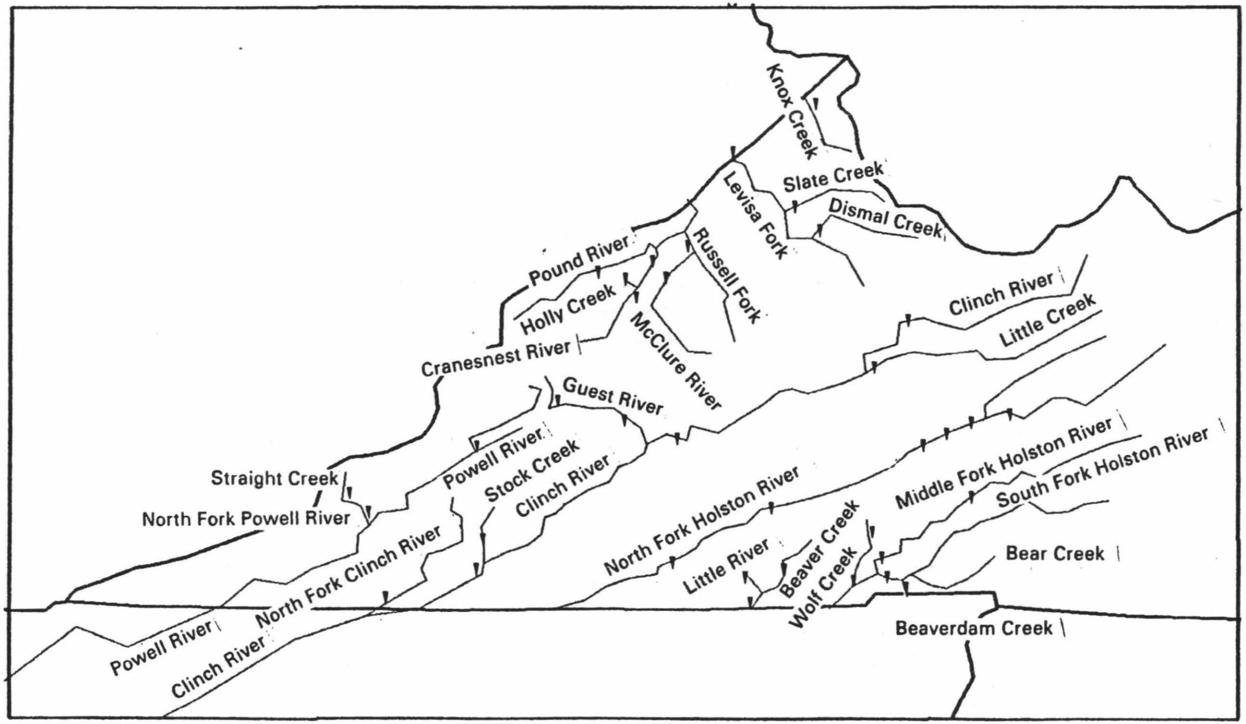


Figure 2b.
Locations of VWCB and TVA water quality monitoring stations.
Station locations denoted by station number; circled numbers indicate stations for which flow data were available.

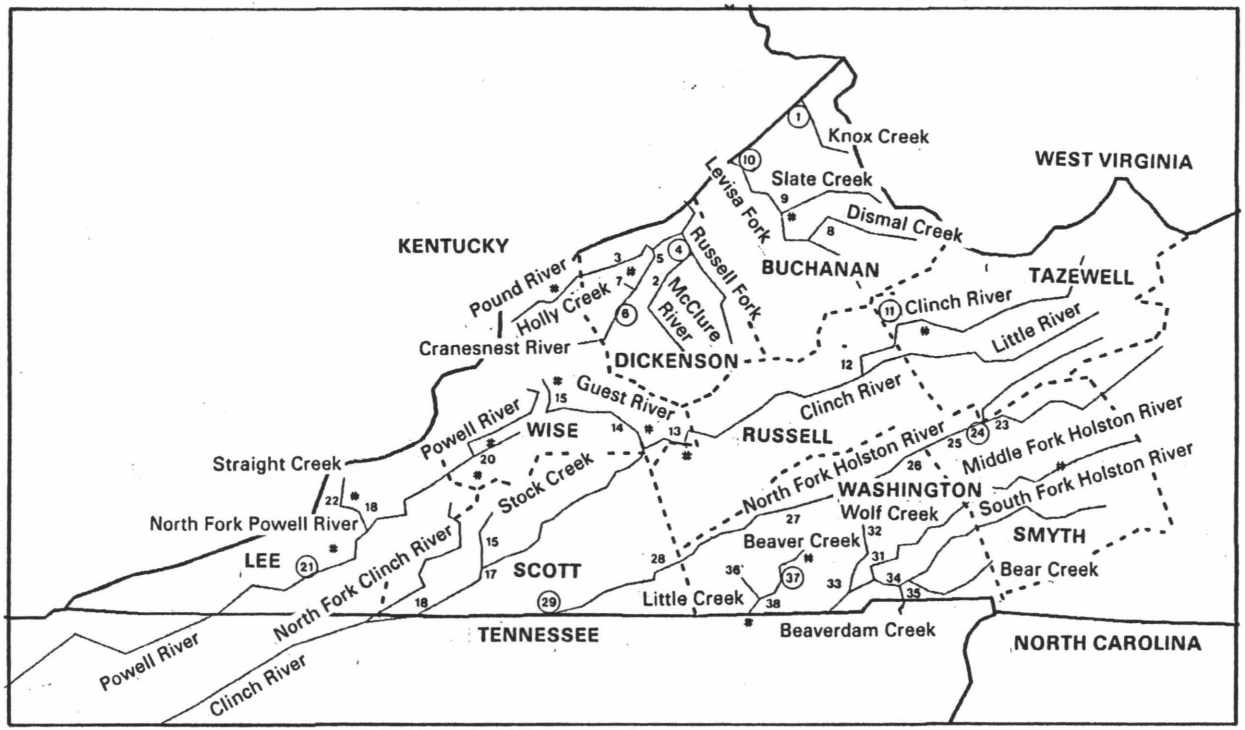


Table 2.
USGS flow gaging stations, period covered by data obtained, and comments regarding station location.

Station Number	Period	Comments
		Big Sandy Basin
03207800	10/69-2/90	Levisa Fork below Rt. 645 at Big Rock Just upstream from WQ Station 10
03208500	1/69-2/90	Russell Fork below Rt. 63 at Haysi Identical station to WQ Station 4
03208950	1/69-1/90	Cranesnest River below RR near Clintwood Just upstream from WQ Station 6
		Clinch River Watershed
03521500	1/69-9/89	Clinch River at Richlands, Rt. 707 Just downstream from WQ Station 11 Approx. 7 mi separates 2 points
		Powell River Watershed
03531500	10/69-11/89	Powell River near Jonesville, Identical to WQ Station 21
		Holston River Watershed
03478400	1/69-1/90	Beaver Creek near Bristol. Within 0.03 mi. of WQ Station 37
03488000	1/69-1/90	NF Holston River near Saltville Near identical location to WQ Station 24
03490000	1/69-12/81	NF Holston River at Hwy 23 near Gate City Identical location to WQ Station 29 Additional flow data (1/85 - 12/88) obtained from TVA

Figure 3.
Primary influences on water quality at VWCB and TVA monitoring stations.

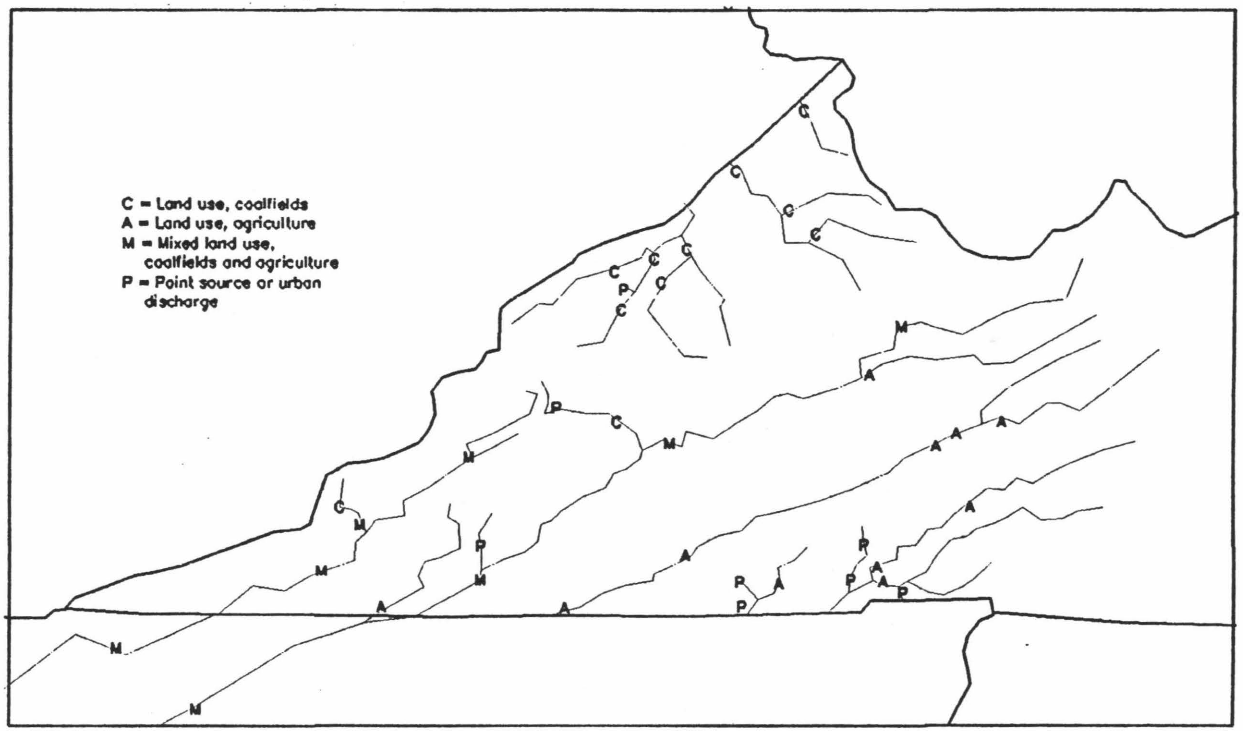
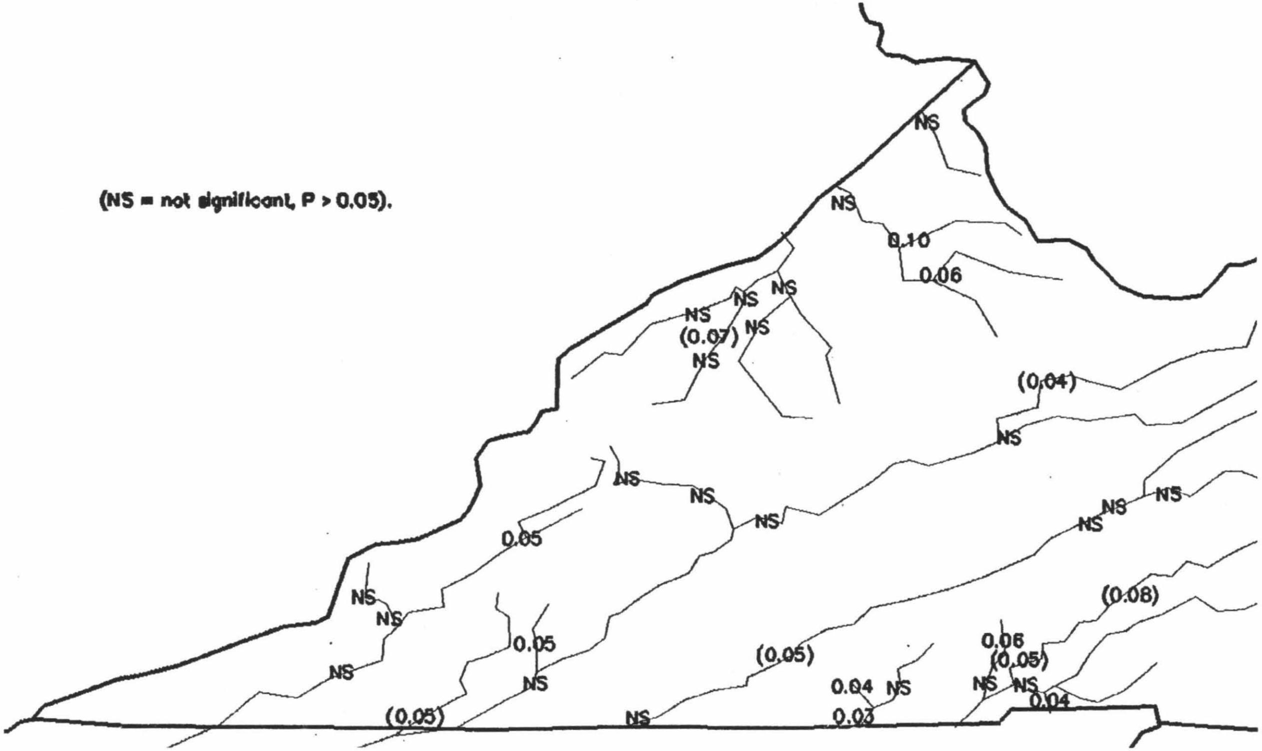


Table 3.
Median values (mg/l) and water quality trends for DO concentrations by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 10.40	no stations	no stations	7 8.90 -	2/10 +
2 10.39				1/10 -
3 9.00				Avg 9.76
4 10.39				
5 8.60	Clinch:	Clinch:	Clinch:	Clinch:
6 9.70	11 9.40 -	12 10.19	15 9.60	1/9 +
8 10.00 +	13 9.00	18 10.00 -	16 10.59 +	2/9 -
9 10.00 +	17 9.60	Avg 10.10	Avg 10.10	Avg 9.78
10 10.20	TC 9.80			
Avg 9.85	Avg 9.45			
		Powell:	Powell:	Powell:
		no stations	no stations	1/5 +
Clinch:	Powell:			0/5 -
14 9.80	19 9.80			Avg 10.08
	20 10.49 +	Holston:		
	21 9.80	23 10.95		
Powell:	TP 10.30	24 9.80	Holston:	Holston:
22 10.00	Avg 10.10	25 9.60	32 10.00 +	4/14 +
		28 9.60 -	33 10.00	3/14 -
		29 9.60	35 10.00 +	Avg 9.84
Holston:	Holston:	30 9.40 -	36 9.60 +	
no stations	no stations	31 9.60 -	38 9.60 +	
		34 10.00	Avg 9.84	
		37 10.00		
		Avg 9.84		
2/11 +	1/8 +	0/11 +	5/8 +	8/38 +
0/11 -	1/8 -	4/11 -	1/8 -	6/38 -
Avg 9.86	Avg 9.77	Avg 9.89	Avg 9.79	Avg 9.83

Figure 4.
Trends in DO, mg/l/year.

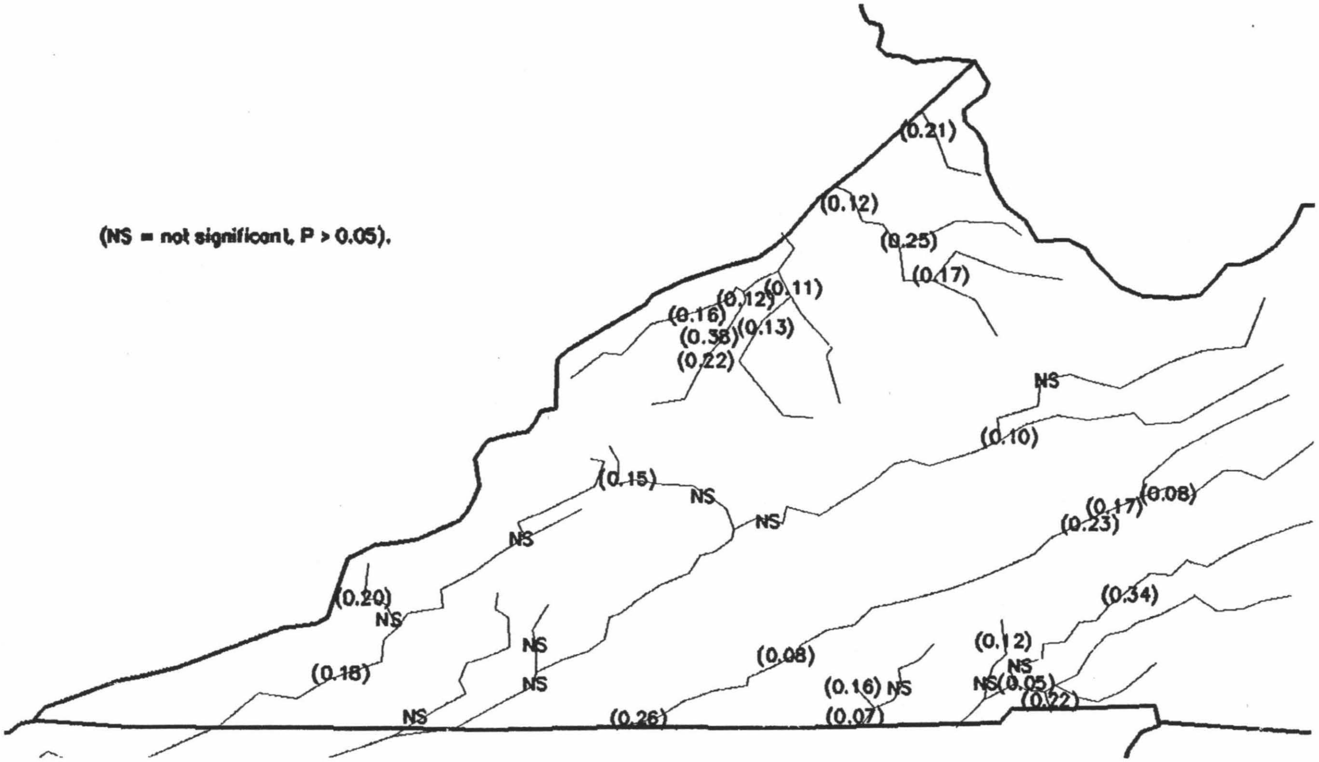


(NS = not significant, P > 0.05).

Table 4.
Median values (mg/l) and water quality trends for BOD by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 1.10 -	no stations	no stations	7 10.00 -	0/10 +
2 1.35 -				10/10 -
3 1.70 -				Avg 2.34
4 1.60 -				
5 1.50 -	Clinch:	Clinch:	Clinch:	Clinch:
6 1.40 -	11 2.30	12 1.50 -	15 3.70 -	0/8 +
8 1.50 -	13 1.60	18 <1.00	16 <1.00	2/8 -
9 1.50 -	17 1.30	Avg 1.25	Avg 2.35	Avg 1.80
10 1.75 -	TC			
Avg 1.50	Avg 1.73			
		Powell:	Powell:	Powell:
		no stations	no stations	0/4 +
Clinch:	Powell:			2/4 -
14 2.00	19 <1.00			Avg 1.25
	20 <1.00	Holston:		
	21 1.50 -	23 1.60 -		
Powell:	TP	24 1.00 -	Holston:	Holston:
22 1.50 -	Avg 1.17	25 1.30 -	32 2.00 -	0/14 +
		28 1.40 -	33 1.82	11/14 -
		29 1.45 -	35 1.40 -	Avg 1.72
Holston:	Holston:	30 2.00 -	36 2.70 -	
no stations	no stations	31 1.90	38 2.20 -	
		34 1.30 -	Avg 2.02	
		37 2.00		
		Avg 1.55		
0/11 +	0/6 +	0/11 +	0/8 +	0/36 +
10/11 -	1/6 -	8/11 -	6/8 -	25/36 -
Avg 1.54	Avg 1.45	Avg 1.50	Avg 3.10	Avg 1.86

Figure 5.
Trends in BOD, mg/l/year.

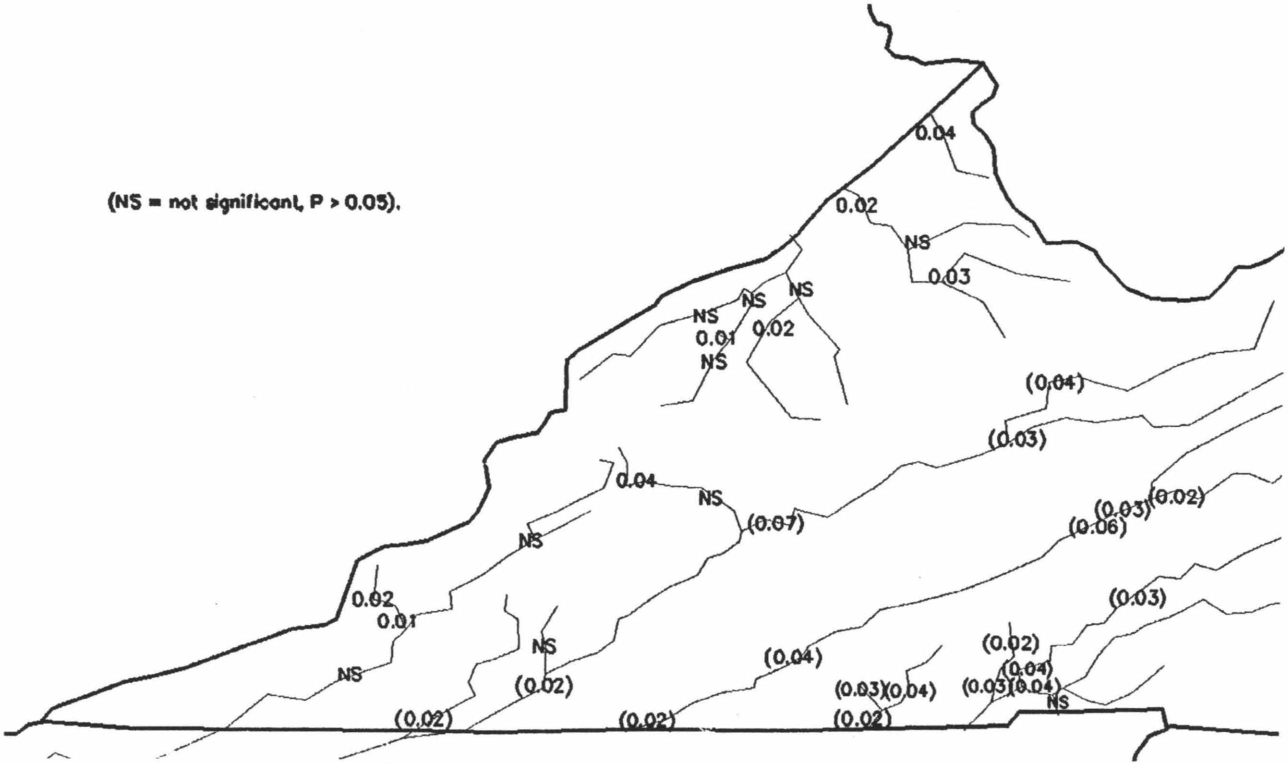


(NS = not significant, P > 0.05).

Table 5.
Median values and water quality trends for pH by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 7.70 +	no stations	no stations	7 7.40 +	5/10 +
2 8.00 +				0/10 -
3 7.68				Avg 7.74
4 8.00				
5 7.60	Clinch:	Clinch:	Clinch:	Clinch:
6 7.59	11 8.00 -	12 8.20 -	15 7.50 +	1/9 +
8 7.70 +	13 8.17 -	18 7.80 -	16 7.80	5/9 -
9 7.94	17 8.35 -	Avg 8.00	Avg 7.65	Avg 7.91
10 7.80 +	TC 7.80			
Avg 7.78	Avg 8.08			
		Powell:	Powell:	Powell:
		no stations	no stations	2/5 +
Clinch:	Powell:			0/5 -
14 7.60	19 7.50 +			Avg 7.80
	20 8.00	Holston:		
	21 7.88	23 8.47 -		
Powell:	TP 7.80	24 8.00 -	Holston:	Holston:
22 7.80 +	Avg 7.80	25 8.27 -	32 8.39 -	0/14 +
		28 8.16 -	33 8.32 -	13/14 -
		29 8.19 -	35 7.20	Avg 8.13
Holston:	Holston:	30 7.80 -	36 8.28 -	
no stations	no stations	31 8.10 -	38 8.50 -	
		34 7.80 -	Avg 8.14	
		37 8.35 -		
		Avg 8.13		
5/11 +	1/9 +	0/11 +	2/8 +	8/38 +
0/11 -	3/9 -	11/11 -	4/8 -	18/38 -
Avg 7.76	Avg 7.94	Avg 8.10	Avg 7.92	Avg 7.94

Figure 6.
Trends in pH, pH units/year.



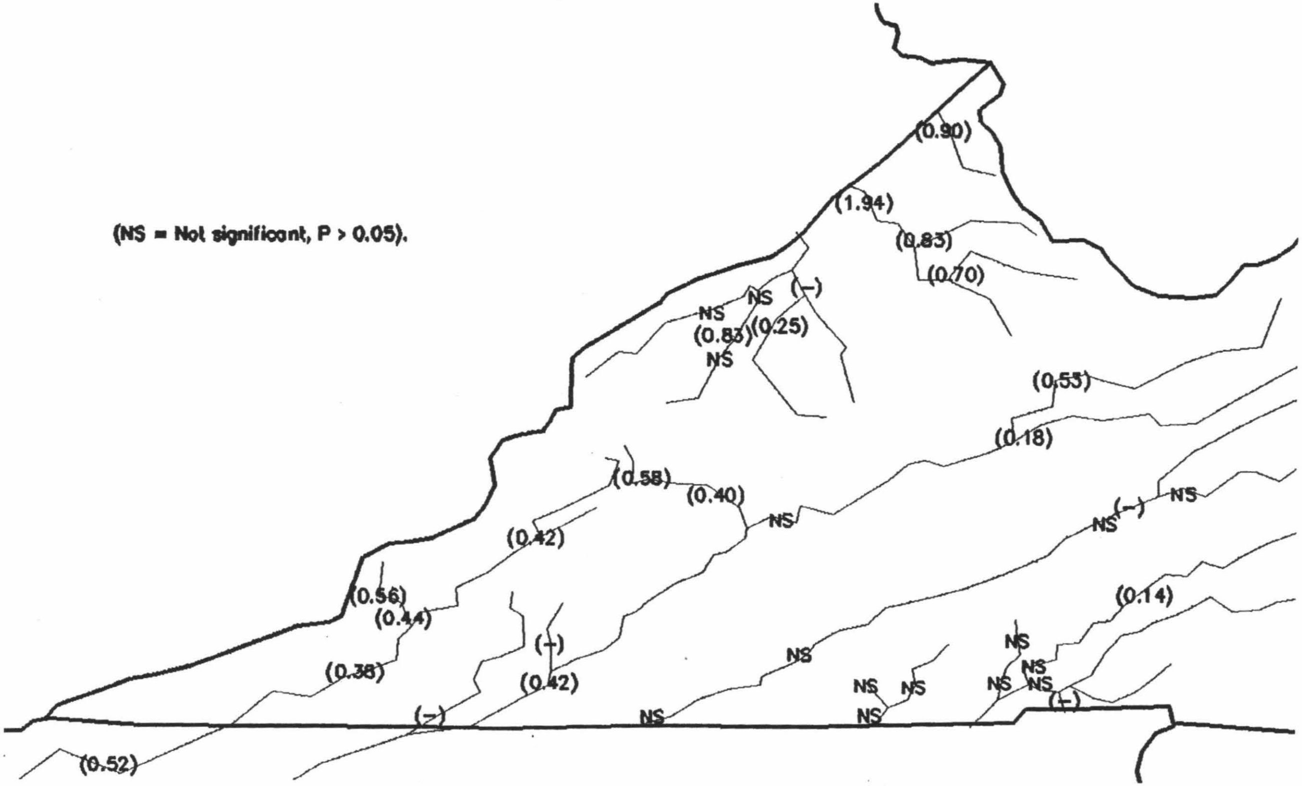
(NS = not significant, P > 0.05).

Table 6.

Median values (mg/l) and water quality trends for NFR concentrations by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by River Basin
Coal	Mixed	Agriculture	Point/Urban	
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 10.00 -	no stations	no stations	7 17.00 -	0/10 +
2 6.00 -				7/10 -
3 <5.00				Avg 8.83
4 5.00 -				
5 <5.00	Clinch:	Clinch:	Clinch:	Clinch:
6 8.75	11 11.00 -	12 7.00 -	15 11.00 -	0/9 +
8 7.00 -	13 10.00	18 <5.00 -	16 <5.00 -	7/9 -
9 7.00 -	17 6.00 -	Avg 6.00	Avg 8.00	Avg 8.22
10 17.50 -	TC 9.00			
Avg 7.92	Avg 9.00			
		Powell:	Powell:	Powell:
		no stations	no stations	0/5 +
Clinch:	Powell:			5/5 -
14 10.00 -	19 8.00 -			Avg 8.40
	20 7.00 -	Holston:		
	21 9.00 -	23 <5.00		
Powell:	TP 9.00 -	24 5.00 -	Holston:	Holston:
22 9.00 -	Avg 8.25	25 <5.00	32 12.00	0/13 +
		28 <5.00	33 13.00	3/13 -
		29	35 <5.00 -	Avg 8.50
Holston:	Holston:	30 9.00 -	36 7.00	
no stations	no stations	31 10.00	38 13.50	
		34 <5.00	Avg 10.10	
		37 16.00		
		Avg 7.50		
0/11 +	0/8 +	0/10 +	0/8 +	0/37 +
8/11 -	6/8 -	4/10 -	4/8 -	22/37 -
Avg 8.20	Avg 8.63	Avg 7.20	Avg 10.44	Avg 8.51

Figure 7.
Trends in NFR, mg/l/year.

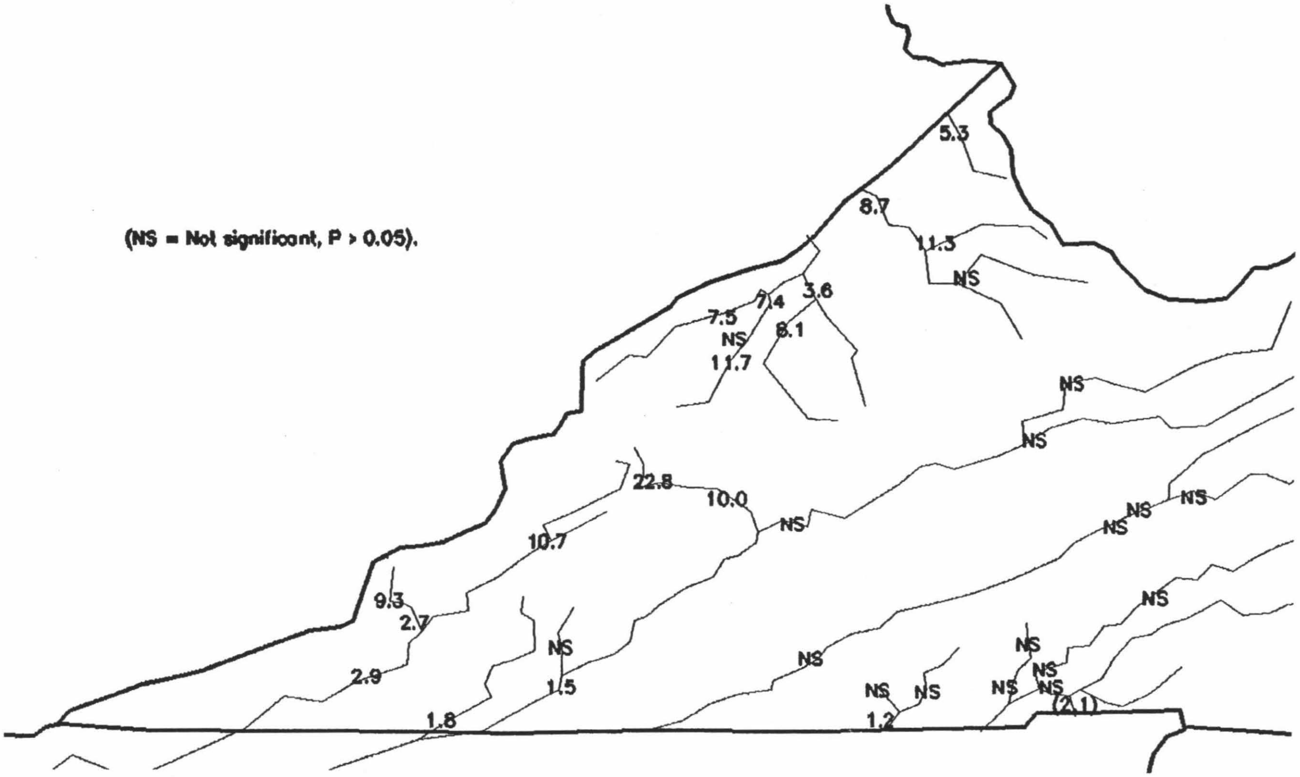


(NS = Not significant, P > 0.05).

Table 7.
Median values (mg/l) and water quality trends for FR concentrations by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 228 +	no stations	no stations	7 352	8/10 +
2 250 +				0/10 -
3 269 +				Avg 298
4 215 +				
5 230 +	Clinch:	Clinch:	Clinch:	Clinch:
6 461 +	11 174	12 155	15 374 +	4/8 +
8 307	13 190	18 143 +	16 91	0/8 -
9 292 +	17 179 +	Avg 149	Avg 232	Avg 191
10 382 +	TC			
Avg 292	Avg 181			
		Powell:	Powell:	Powell:
		no stations	no stations	4/4 +
Clinch:	Powell:			0/4 -
14 220 +	19 168 +			Avg 224
	20 256 +	Holston:		
	21 189 +	23 135		
Powell:	TP	24 119	Holston:	Holston:
22 283 +	Avg 204	25 127	32 262	1/13 +
		28 262	33 243	1/13 -
		29	35 49 -	Avg 189
Holston:	Holston:	30 177	36 299	
no stations	no stations	31 195	38 273 +	
		34 77	Avg 225	
		37 248		
		Avg 167		
10/11 +	4/6 +	1/10 +	2/8 +	17/35 +
0/11 -	0/6 -	0/10 -	1/8 -	1/35 -
Avg 285	Avg 193	Avg 164	Avg 243	Avg 225

Figure 8.
Trends in FR, mg/l/year.

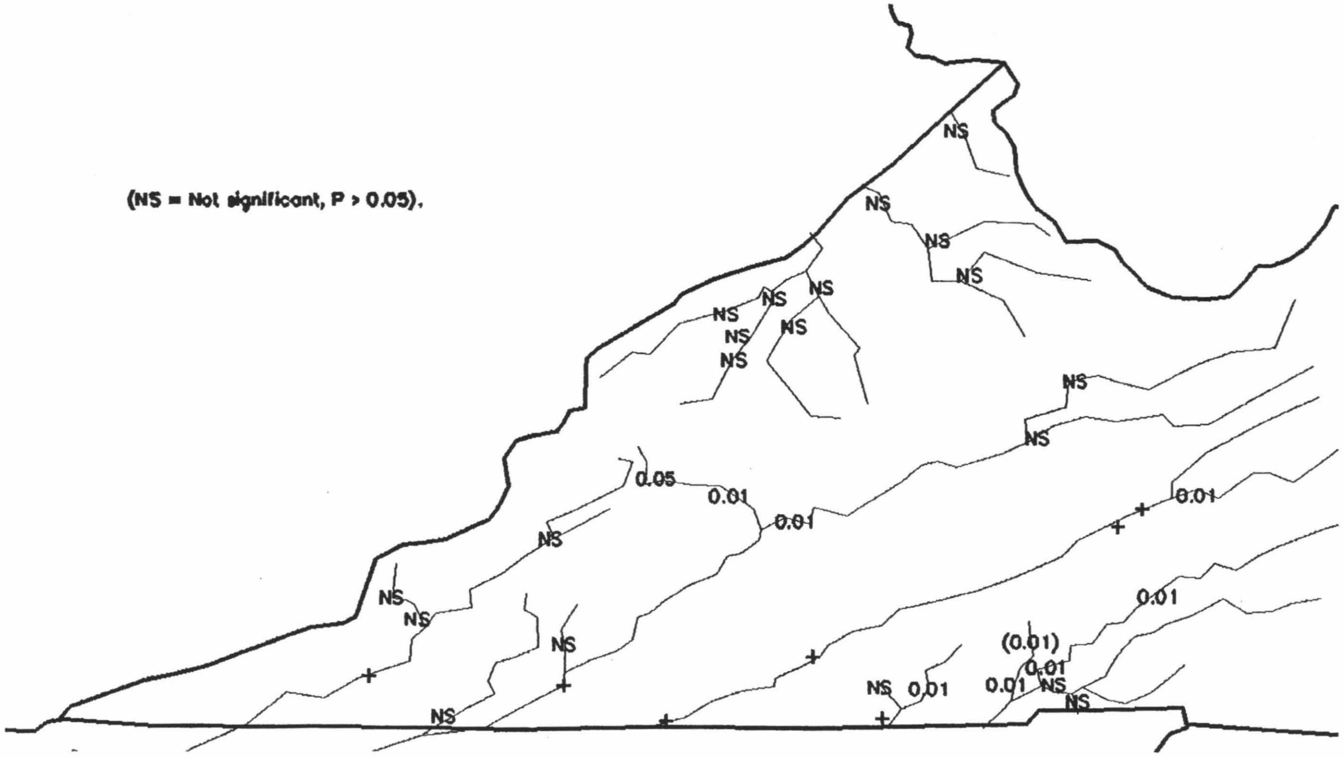


(NS = Not significant, P > 0.05).

Table 8.
Median values (mg/l) and water quality trends for TKN concentrations by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 .20	no stations	no stations	7 4.25	0/10 +
2 .20				0/10 -
3 .20				Avg .60
4 .20				
5 .20	Clinch:	Clinch:	Clinch:	Clinch:
6 .20	11 .30	12 .20	15 1.40 +	4/8 +
8 .10	13 .20 +	18 <.10	16 <.10	0/8 -
9 .20	17 .20 +	Avg .15	Avg .75	Avg .35
10 .20	TC			
Avg .19	Avg .23			
		Powell:	Powell:	Powell:
		no stations	no stations	1/4 +
Clinch:	Powell:			0/4 -
14 .30 +	19 <.10			Avg .18
	20 .20	Holston:		
	21 .20 +	23 .20 +		
Powell:	TP	24 .20 +	Holston:	Holston:
22 .20	Avg .17	25 .20 +	32 .40 -	10/14 +
		28 .20 +	33 .30 +	1/14 -
		29 .20 +	35 .10	Avg .23
Holston:	Holston:	30 .30 +	36 .30	
no stations	no stations	31 .20 +	38 .30 +	
		34 .10	Avg .28	
		37 .20 +		
		Avg .20		
1/11 +	3/6 +	8/11 +	3/8 +	15/36 +
0/11 -	0/6 -	0/11 -	1/8 -	1/36 -
Avg .20	Avg .20	Avg .19	Avg .89	Avg .35

Figure 9.
Trends in TKN, mg/l/year.

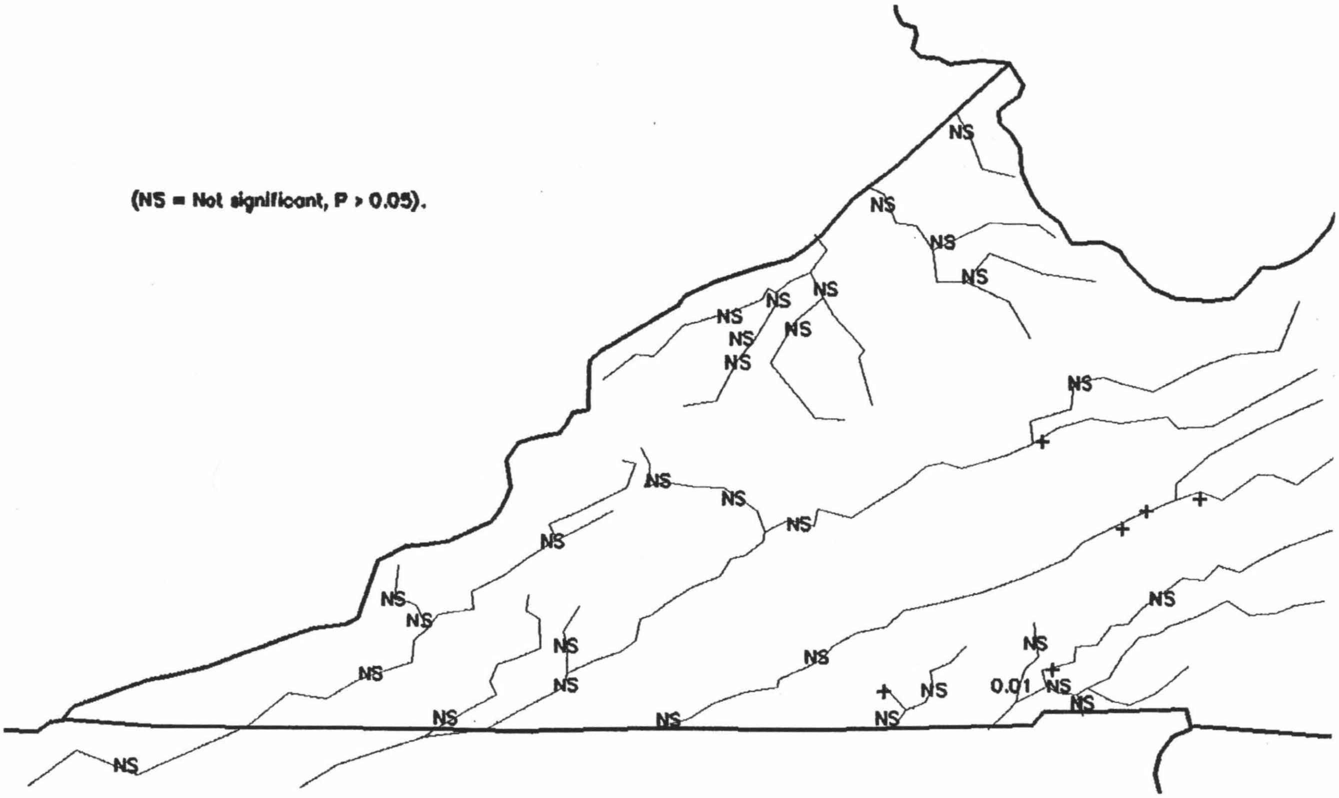


(NS = Not significant, P > 0.05).

Table 9.
Median values (mg/l) and water quality trends for TP concentrations by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 <.10	no stations	no stations	7 1.30	0/10 +
2 <.10				0/10 -
3 <.10				
4 <.10				
5 <.10	Clinch:	Clinch:	Clinch:	Clinch:
6 <.10	11 .10	12 <.10 +	15 .40	1/9 +
8 <.10	13 <.10	18 .10	16 .10	0/9 -
9 <.10	17 <.10			
10 <.10	TC .03			
		Powell:	Powell:	Powell:
		no stations	no stations	0/5 +
Clinch:	Powell:			0/5 -
14 .10	19 .10			
	20 <.10	Holston:		
	21 <.10	23 <.10 +		
Powell:	TP .03	24 <.10 +	Holston:	Holston:
22 <.10		25 <.10 +	32 .20	6/14 +
		28 <.10	33 .20 +	0/14 -
		29 <.10	35 <.10	
Holston:	Holston:	30 .10	36 .10 +	
no stations	no stations	31 .10 +	38 <.10	
		34 <.10		
		37 <.10		
0/11 +	0/8 +	5/11 +	2/8 +	7/38 +
0/11 -	0/8 -	0/11 -	0/8 -	0/38 -

Figure 10.
Trends in TP, mg/l/year.

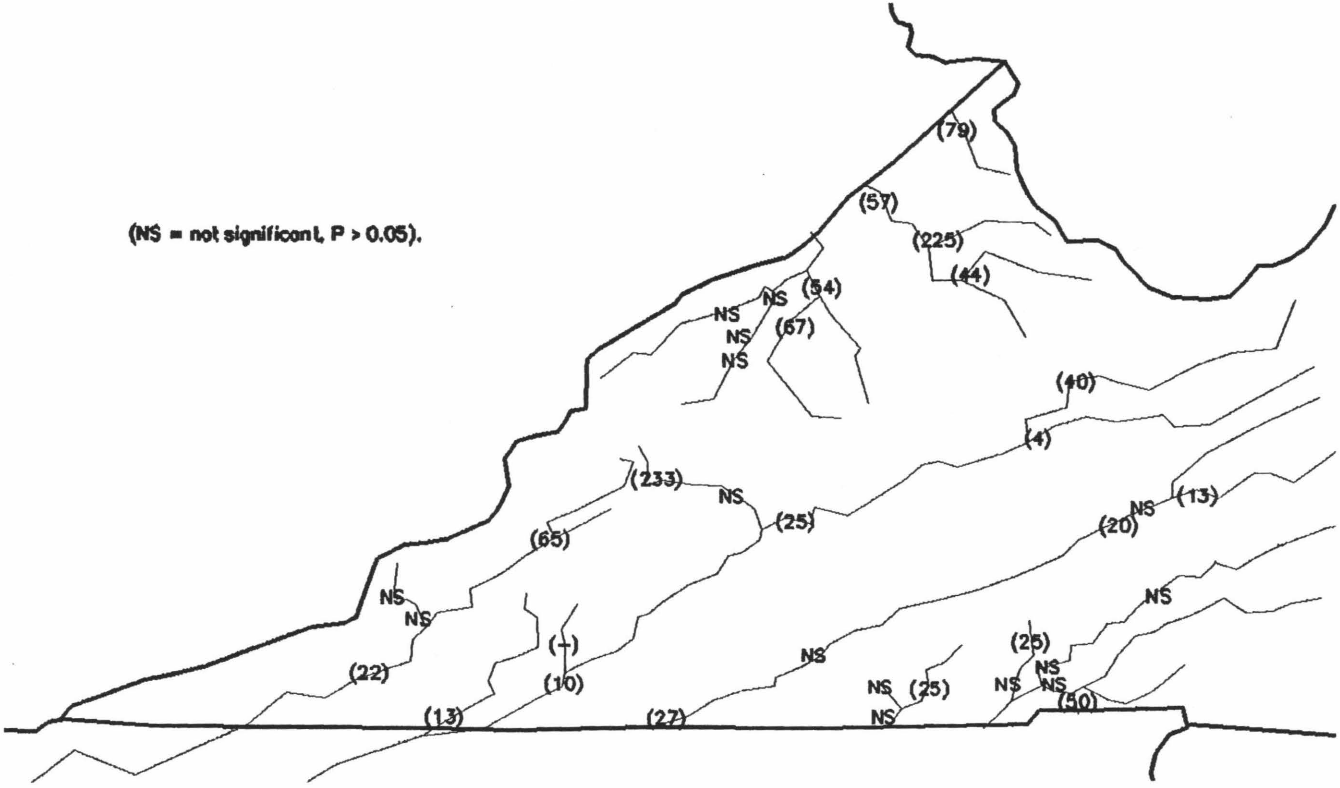


(NS = Not significant, P > 0.05).

Table 10.
Median values (number per 100 ml) and water quality trends for FC concentrations by primary water quality influence and by river basin.

Primary Water Quality Influence				Totals by
Coal	Mixed	Agriculture	Point/Urban	River Basin
Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:	Big Sandy:
1 1200 -	no stations	no stations	7 100	0/10 +
2 1200 -				6/10 -
3 <100				Avg 620
4 700 -				
5 <100	Clinch:	Clinch:	Clinch:	Clinch:
6 100	11 600 -	12 100 -	15 900 -	0/8 +
8 300 -	13 200 -	18 300 -	16 200 -	7/8 -
9 1400 -	17 100 -	Avg 200	Avg 550	Avg 388
10 1000 -	TC			
Avg 678	Avg 225			
		Powell:	Powell:	Powell:
		no stations	no stations	0/4 +
Clinch:	Powell:			2/4 -
14 700	19 2700			Avg 1650
	20 1500 -	Holston:		
	21 300 -	23 300 -		
Powell:	TP	24 300	Holston:	Holston:
22 2100	Avg 1125	25 300 -	32 400 -	0/14 +
		28 100	33 900	6/14 -
		29 300 -	35 300 -	Avg 600
Holston:	Holston:	30 700	36 950	
no stations	no stations	31 300	38 2350	
		34 300	Avg 980	
		37 900 -		
		Avg 389		
0/11 +	0/6 +	0/11 +	0/8 +	0/36 +
6/11 -	5/6 -	6/11 -	4/8 -	21/36 -
Avg 809	Avg 900	Avg 355	Avg 763	Avg 675

Figure 11.
Trends in FC, number/100 ml/year.



(NS = not significant, P > 0.05).

Appendix A:

Location and Purposes of VWCB Monitoring Stations

Station Number	Location and Purposes
1	*Stream Mile*: KOX 8.11; Knox Creek *Location*: 1.5 mi downstream of KY line, 7.5 mi downstream of Hurley *Primary Purpose*: WQ exiting VA *Secondary Purpose*: Coal mining effects, sewage
2	*Stream Mile*: MCR 7.46; McClure River *Location*: 1000 ft downstream of downtown Clinchco *Primary Purpose*: Sewage effects, Clinchco *Secondary Purpose*: Coal-mining effects
3	*Stream Mile*: PNR 8.15; Pound River *Location*: John Flannagan Reservoir, 2 mi WSW of Tandy *Primary Purpose*: WQ of Flannagan Reservoir *Secondary Purpose*: Coal-mining effects
4	*Stream Mile*: RSS 25.40; Russell Fork *Location*: Downtown Haysi, 200 ft upstream of USGS Gaging Station *Primary Purpose*: Coal-mining effects *Secondary Purpose*: Sewage effects of Haysi
5	*Stream Mile*: CNR 000.00; Cranesnest River *Location*: John Flannagan Reservoir, 0.5 mi E of Tandy *Primary Purpose*: WQ of Flannagan Reservoir *Secondary Purpose*: Coal-mining effects
6	*Stream Mile*: CNR 9.17; Cranesnest River *Location*: 3000 ft downstream of Holly Creek, 2.5 mi downstream of Clintwood STP *Primary Purpose*: STP effects, Clintwood *Secondary Purpose*: Coal-mining effects
7	*Stream Mile*: HLY 1.67; Holly Creek *Location*: 400 ft downstream of Clintwood STP *Primary Purpose*: STP recovery, Clintwood
8	*Stream Mile*: DIS 1.24; Dismal Creek *Location*: 1000 ft upstream of coke ovens, upstream of Vansant 4.5 mi *Secondary Purpose*: Coal-mining effects

9 *Stream Mile*: SAT 000.03; Slate Creek
Location: Downtown Grundy
Primary Purpose: Coal-mining effects
Secondary Purpose: Sewage effects of Grundy

10 *Stream Mile*: LEV 130.00; Levisa Fork
Location: 3000 ft downstream of KY line, 2.5 mi downstream of Big Rock
Primary Purpose: WQ exiting VA
Secondary Purpose: STP and coal-mining effects

11 *Stream Mile*: CLN 315.11; Clinch River
Location: 1.25 mi downstream of Richlands STP
Primary Purpose: STP effects, Richlands

12 *Stream Mile*: LTR 3.00; Little River
Location: 0.5 mi upstream of Clinch River, 3.0 mi ESE of Honaker
Primary Purpose: WQ of Little River

13 *Stream Mile*: CLN 249.62; Clinch River
Location: 3.5 mi downstream of St. Paul STP
Primary Purpose: STP effects, St. Paul

14 *Stream Mile*: GUE 6.50; Guest River
Location: 1.0 mi downstream of Coeburn STP, at USGS/GS
Primary Purpose: STP effects, Coeburn
Secondary Purpose: Coal-mining effects

15 *Stream Mile*: BER 1.14; Bear Creek
Location: 20 ft downstream of Wise STP, 1.5 mi SSW of downtown Wise
Primary Purpose: STP (lagoon) effects, Wise

16 *Stream Mile*: STO 4.56; Stock Creek
Location: 0.5 mi downstream of Foote Mineral Co. (acid feed)
Primary Purpose: Foote Mineral Co. effects

17 *Stream Mile*: CLN 211.00; Clinch River
Location: 2 mi downstream of Clinchport (Stock Creek—Foote Mineral)
Primary Purpose: Copper Creek effects
Secondary Purpose: Stock Creek (Foote Min.) effects

18 *Stream Mile*: NFC 3.80; N.F. Clinch River
Location: 1.5 mi upstream of Lee/Scott county line, VA/TN state line
Primary Purpose: WQ exiting Virginia

19 *Stream Mile*: PWL 1.49; N.F. Powell River
Location: 1.0 mi ESE of downtown Pennington Gap
Primary Purpose: STP effects, Pennington Gap
Secondary Purpose: Coal (AMD) effects

20 *Stream Mile*: POW 180.78; Powell River
Location: downtown Big Stone Gap at USGS/GS, 3 mi downstream of Appalachia STP
Primary Purpose: STP effects, Appalachia
Secondary Purpose: Coal-mining effects

21 *Stream Mile*: POW 143.53; Powell River
Location: 2.0 mi SSE of Jonesville at Sewell Bridge
Primary Purpose: WQ of Powell River
Secondary Purpose: Control, Jonesville, Town Branch

22 *Stream Mile*: SRA 1.11; Straight Creek
Primary Purpose: Downtown St. Charles, 1000 ft downstream of Big Branch
Primary Purpose: WQ of Powell River
Secondary Purpose: STP control, St. Charles

23 *Stream Mile*: NFH 97.67; N.F. Holston River
Location: 0.3 mi S of Rich Valley MS, 15 mi upstream of Olin Plant
Primary Purpose: WQ of N.F. Holston River
Secondary Purpose: Control for Saltville STP and Olin

24 *Stream Mile*: NFH 85.20; N.F. Holston River
Location: 1.7 mi upstream of Olin Chlorine Plant and Saltville STP
Primary Purpose: WQ of N.G. Holston River
Secondary Purpose: Control for Saltville STP and Olin

25 *Stream Mile*: NFH 83.32; N.F. Holston River
Location: 300 ft upstream of Saltville STP, 100 ft upstream of Olin Chlorine Plant
Primary Purpose: Control for Saltville STP and Olin
Secondary Purpose: Saltville effects

26 *Stream Mile*: NFH 80.43; N.F. Holston River
Location: 3.0 mi downstream of Saltville STP and Olin Chlorine Plant
Primary Purpose: STP effects, Saltville
Secondary Purpose: Olin Corp. effects (Hg)

27 *Stream Mile*: NFH 59.65; N.F. Holston River
Location: 7.0 mi NW of Abingdon, Rt US 19, 24 mi downstream of Olin
Primary Purpose: WQ of N.F. Holston River
Secondary Purpose: Olin Corp. effects (Hg)

28 *Stream Mile*: NFH 39.18; N.F. Holston River
Location: Mendota, Rt 615 bridge, 43.6 mi downstream of Olin
Primary Purpose: WQ of N.V. Holston River
Secondary Purpose: Olin Corp. effects (Hg)

29 *Stream Mile*: NFH 8.78; N.F. Holston River
Location: 1.0 mi S of Weber City, Rt US 23, at USGS/GS
Primary Purpose: WQ exiting VA
Secondary Purpose: STP effects, Gate City

30 *Stream Mile*: MFH 26.00; M.F. Holston River
Location: 0.9 mi downstream of Chilhowie Lagoon, at Smyth/Wash. county line
Primary Purpose: STP effects, Chilhowie Lagoon

31 *Stream Mile*: MFH 5.00; M.F. Holston River
Location: 5 mi ESE of downtown Abingdon, at Shallow Ford bridge
Primary Purpose: WQ of M.F. Holston River
Secondary Purpose: Edmondson Dam effects

32 *Stream Mile*: WLF 6.55; Wolf Creek
Location: 1.5 mi downstream of Abingdon STP, 5.0 mi upstream of S. Holston Lake
Primary Purpose: STP effects, Abingdon

33 *Stream Mile*: WLF 1.46; Wolf Creek
Location: 5.5 mi downstream of Abingdon STP, 1.0 mi upstream of S. Holston Lake
Primary Purpose: STP effects, Abingdon
Secondary Purpose: WQ of Wolf Creek entering lake

34 *Stream Mile*: SFH 73.62; S.F. Holston River
Location: 0.75 mi upstream of Alvarado, 2.0 mi upstream of S. Holston Lake at 712 Br
Primary Purpose: WP of S.F. Holston River upstream of lake
Secondary Purpose: Mobay Chemical recovery

35 *Stream Mile*: BVD 0.07; Beaverdam Creek
Location: downtown Damascus, 0.5 mi downstream of Mobay, 9 mi upstream of lake
Primary Purpose: Mobay Chemical recovery

36 *Stream Mile*: LTL 0.26; Little Creek
Location: Downtown Bristol, at State Street bridge
Primary Purpose: WQ exiting Virginia
Secondary Purpose: Bristol effects

37 *Stream Mile*: BEV 21.07; Beaver Creek
Location: Bristol (Kerns), at USGS/GS: 3 mi downstream of Bristol Indust. Park
Primary Purpose: Bristol Indust. Park effects
Secondary Purpose: Control for town of Bristol

38 *Stream Mile*: BEV 15.27; Beaver Creek
Location: Downtown Bristol, at 7th and State St.
Primary Purpose: WQ exiting Virginia
Secondary Purpose: Bristol effects

Appendix B:
Statistical Trend Analyses

The data consist of measurements of 8 water-quality variables at 38 monitoring stations in 4 watersheds. The data were collected on a more-or-less monthly basis over a 20-year period.

From the most general statistical perspective, the water quality variables at each site can be regarded as a multivariate time series, with flow as an explanatory covariate. For this initial study, however, the multivariate aspect was ignored. Thus, each (water quality) variable at each site is analyzed as a univariate time series with flow as a covariate. With a few embellishments that will be mentioned later, we have followed the methods of Hirsch et al. (1982) and Gilbert (1987, ch. 16 and 17).

B.1 Seasonal Kendall Analysis

Trend analysis consists of 1) statistical significance testing of the hypothesis that there is no time trend versus the alternative hypothesis of an overall increase or decrease with time, and 2) estimating the rate of change of the water quality variable with respect to time. As explained by Gilbert (1987, pp. 225-228), the seasonal Kendall test and slope estimator are used because of their robust statistical properties. They are well suited to data with missing values and to data that are censored, in the statistical sense, at upper and lower detection limits. They are valid, moreover, for data that are non-normal and cyclic. They are not robust, however, against serial correlation (Hirsch and Slack, 1984). In the presence of serial correlation, the probability of a Type I error, the erroneous conclusion that a trend is present, is larger than the nominal significance level of the test. In other words, in the presence of serial correlation, the true P-value of a result is larger (less significant) than computed by the method of Hirsch et al. (1982), which is used in the present study.

The problem of serial correlation is investigated in Hirsch and Slack (1984), which presents a modified version of the original 1982 method. The modified method has the favorable properties of the original method and is, in addition, robust against serial correlation. The cost of this improvement, as explained by Hirsch and Slack (1984, p.729) is a loss of power (to detect trend, i.e., a loss of sensitivity) in cases where serial correlation is not present.

> *Thus, choosing between the two tests involves a trade-off. The original test is more powerful, but the significance level can be seriously in error if there is serial correlation. The modified test requires some sacrifice of power but offers a more nearly exact statement of significance for a wide variety of cases (Hirsch and Slack, 1984, p.730).*

They conclude that "the original test is a useful screening device (and computationally much less demanding), but it is inexact. The modified test is a more exact (conservative) and expensive test..." (Hirsch and Slack, 1984, p.731). In consideration of the large quantity of data and the limited resources and time available, a screening device such as the original, less conservative, less exact, and less expensive method of Hirsch et al. (1982) is the better choice at this initial stage.

B.1.1 Seasonal Kendall Tau

Seasonal Kendall tau, a nonparametric correlation coefficient, is a measure of the strength of the consistency of the relationship between a water quality variable and time. Ranging from -1 to +1, its interpretation is analogous to that of the more familiar Pearson coefficient of correlation. A value of exactly -1 (+1) would be obtained only if there were, for each month of the year, a decrease (increase) from year to year for each year for which there are data. The analysis is *robust* because it takes into account only whether the yearly change is positive or negative, and completely ignores the magnitude of the change. The analysis is *seasonal* because month-to-month changes are not used to compute the test. Indeed, seasonal Kendall tau is a weighted average of 12 rank-correlation coefficients (Kendall 1970), one for each month of the year. Kendall's (1970) rank-correlation coefficient (Kendall's tau) is a coefficient of correlation between the rank of the water quality variable and time.

Let y_{ij} be the observed value of a water quality variable for month i and year j, $i = 1,2,\ldots, 12$; $j = 1,2,\ldots, n_i$. Kendall tau, τ, is based on the "signs" of the differences between the observed monthly values for all pairs of years, where sign is denoted by *sgn* and defined by

$$sgn(u) = \begin{cases} 1, \text{ if } u > 0 \\ 0, \text{ if } u = 0 \\ -1, \text{ if } u < 0 \end{cases}$$

Kendall tau for month i is then

$$\tau_i = \frac{\sum\limits_{j>k} \operatorname{sgn}(j-k)\operatorname{sgn}(y_{ij}-y_{ik})}{\sqrt{\sum\limits_{j>k}[\operatorname{sgn}(j-k)]^2 \sum\limits_{j>k}[\operatorname{sgn}(y_{ij}-y_{ik})]^2}}, \quad i = 1,2,\ldots,12$$

(Kendall and Gibbons 1990, pp.25 ff.). The formulation of this equation makes it clear that τ_i is indeed a correlation.

The definition of overall Kendall tau explicitly as a weighted average of the monthly τ_i is then

$$\tau = \frac{\sum\limits_{i} w_i \tau_i}{\sum\limits_{i} w_i}$$

with weights

$$w_i = \sqrt{\sum\limits_{j>k}[\operatorname{sgn}(j-k)]^2 \sum\limits_{j>k}[\operatorname{sgn}(y_{ij}-y_{ik})]^2}$$

For each variable and station, seasonal Kendall tau and the 12 monthly tau values were tabulated.[1]

The P-value accompanying each tau value is the result of a test of significance of the hypothesis $\tau = 0$ versus the alternative $\tau \neq 0$. The test of significance of seasonal Kendall tau is the test for trend. The seasonal test is much more sensitive (i.e., powerful) than the monthly tests because the seasonal test is based on a much larger sample (approximately 12 times larger). Thus, it is possible to have a seasonal Kendall tau that is significantly different from zero, while none of the monthly taus upon which it is based is significant.

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[1] The detailed output for each analysis is maintained by the VWRRC and the Department of Statistics.

B.1.2 Slope

The rate of change of each water quality variable is quantified by the seasonal Kendall slope estimator (Hirsch et al. 1982, and Gilbert, 1987, pp. 227-228). It is defined as the median of the

$$\frac{y_{ij} - y_{ik}}{j - k}$$

for all months *i*, and for all years $j > k$. The Kendall slope estimator has the same robust statistical properties as seasonal Kendall tau. Moreover, the test of significance of seasonal Kendall tau also can be interpreted as a test of significance of the hypothesis that the median change per year (slope) is different from zero, but there is one caveat, which is explained in the next paragraph. The seasonal Kendall slope estimate, along with 90% and 95% confidence limits of the change per year, is tabulated in Appendix E.

Caveat: The apparent paradox of a statistically significant estimated slope of zero. As explained in the preceding paragraph, it is generally reasonable to interpret the test of significance of tau as, equivalently, a test of significance of the slope. Under certain circumstances, however, an apparent paradox arises:

> *If a large number of the observations of a water quality variable are below the lower detection limit, then it is possible for seasonal Kendall tau to be significantly different from zero, and for the seasonal Kendall slope estimate to be zero.*

The detailed program output was inspected for all cases where this occurred. In most cases, many observations were below the detection limit, but higher levels were detected from time to time. A statistically significant tau indicates a statistically significant difference in the frequency with which these high levels have been observed in the two halves of the time series. In other words, it indicates that the instances of higher levels are not uniformly (not randomly) distributed in time. If the high levels occurred more often toward the beginning of the period of observation and less frequently toward the end, then tau will be negative. If the high levels occurred more frequently toward the end of the period of observation, then tau will be positive. Yet, in either case, because many observations were below the detection limit and higher levels are relatively rare, the estimate of the slope computed by the present method is zero.

In such cases, the estimated slope is invalid. The invalid estimate of zero should be disregarded (and the apparent paradox is resolved). Gilliom et al. (1984) showed by Monte Carlo experimentation that censoring data because they fall below a detection limit results in decreased power. Thus, when a significant trend is detected in spite of the diminished power, it must be a genuine trend, and an estimated slope of zero should, therefore, be regarded as an unreasonable artifact of the statistical procedure.

The technical explanation gets to the heart of this conceptually simple statistical method. The Kendall analysis of the time series is, in fact, an analysis of the differences between all pairs of observations for each month. All observations below the lower detection limit are considered tied, and the differences of all tied pairs are zero. The seasonal Kendall test of significance compares the number of positive differences with the number of negative differences. Seasonal Kendall tau is the ratio of the number of positive differences, minus the number of negative differences, to the number of pairs (discounted for ties).[2]

Thus, tau is zero only if the number of positive differences and the number of negative differences are exactly the same. If they are not exactly the same, then tau is nonzero, and, if the disparity is great enough, then tau is statistically significant, i.e., significantly different from zero, *regardless of the number of ties.* The seasonal Kendall slope estimator, on the other hand, is the median of all the differences (divided by the number of years involved), *including* the zero differences.

B.1.3 Comparisons among Stations

To compare the rate of change of a particular variable at one station to the rate of change of the same variable at another station, we suggest comparing the 90% confidence intervals in the original units of measure ("slope" in Appendix E). As an arbitrary, ad hoc, screening rule, if the 90% confidence intervals for the median change per year of the same variable at two different stations do not overlap, then one might choose to infer that the slopes are different.

This suggestion is, we emphasize, an arbitrary, ad hoc, screening rule. A rigorous comparison would require further statistical analyses that are beyond the objectives of the present study. Comparisons among monitoring stations of a single water quality variable could be accomplished by univariate techniques; however, multivariate analysis (see, e.g., Lettenmaier, 1988) is the most powerful and comprehensive way statistically to compare overall water quality at various locations.

B.2 Flow Adjustment

Detection of a statistically significant and, indeed, genuine trend in a water quality variable does not necessarily imply that there was a change in a process or processes bringing the substance to the river (Smith et al. 1982, p. 20). A genuine trend in concentration can be an artifact of a concurrent trend in a characteristic or characteristics of the river.

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[2] See Kendall (1970, pp. 34 ff.) for the exact formulation.

In particular, such artifactual changes can be caused by changes in the volume of flow. At those stations for which flow data has been obtained, artifactual changes in a water quality variable caused by concurrent changes in flow can be eliminated by adjusting for flow prior to applying the seasonal Kendall procedures.

Flow adjustment is accomplished by applying the seasonal Kendall analysis to the residuals of a regression of the water quality variable on a suitable function of flow.

B.2.1 Flow Model Selection

The suitable function of flow is the one with the highest coefficient of determination (R^2 value) among an extensive family of candidate models. The family of candidate regression models is defined as follows, where x represents flow, and y represents the water quality variable:

$$y = \beta_0 + \beta_1 x^i + \varepsilon, \quad i = -3.00, -2.75, \ldots, -0.25,$$

$$y = \beta_0 + \beta_1 \log(x) + \varepsilon,$$

$$y = \beta_0 + \beta x^i + \varepsilon, \quad i = +0.25, +0.50, \ldots, +2.00,$$

and the following hyperbolic models that were used by Smith, et al. (1982, p.8):

$$y = \beta_0 + \beta_1 \frac{1}{1 + 10^i x} + \varepsilon,$$

for $i = -2.5, -2.0, \ldots, -0.5, 0.0, 0.5$, if $10 \leqq \overline{X} < 100$, and for $i = -5.0, -4.5, \ldots, -0.5$ if $100 \leqq \overline{X} < 1{,}000$.

For the purpose of model selection, we chose to delete the points at which the variable was beyond its detection limits.

Empirical details of the model selection procedure are given in the computer output for those stations for which flow data were available. The most informative of these details is the scatter plot of the water quality variable versus flow, and the coefficient of determination (R^2) of the selected model. The coefficient of determination, as usual, may be interpreted as the proportion of the total variation in the water quality variable that is explained by regression on the selected function of flow.

For our purposes, the P-value is not nearly as important a statistic as the R^2 value. The P-value is the result of a test of the hypothesis $\beta_1 = 0$ versus the alternative $\beta_1 \neq 0$. A large P-value always will be accompanied by a small R^2 value and, indeed, indicates that the model is unsuitable. A small P-value, however, does not necessarily imply a large R^2, nor does it imply a strong relationship between the water quality variable and flow. This is, as usual, because the sample size is large, and, consequently, the significance test is very sensitive.

The slope (β_1), moreover, does not have the familiar properties it would have in a simple linear regression model. Specifically, the slope is not an estimate of the rate of change of the water quality with respect to flow. Indeed, a negative (positive) slope does not necessary indicate that the variable is a decreasing (increasing) function of flow, as it would in a simple linear regression. The best way to discern the nature of the relationship is to examine the scatterplot in the computer output, or to consult Tables E1 through E8, where the nature of the relationship is indicated in parentheses following the word *flow* and following the R^2 value.

B.2.2 Flow-Adjusted Seasonal Kendall Analysis

The flow-adjusted seasonal Kendall analysis, as mentioned earlier, is the same statistical procedure that was applied before adjusting for flow, except that the dependent variable is the residual (of the regression on the selected function of flow) rather than the observed value of the variable. While a time trend detected prior to flow adjustment may or may not be an artifact of flow, a time trend detected after flow adjustment cannot be an artifact of flow. If a significant time trend is detected in the flow-adjusted variable (which is the residual), then either it is an indication that changes occurred in processes that deliver the measured substance to the river (Smith et al. 1982), or it is an artifact of some river characteristic other than flow, or a combination of both.

B.3 Implementation

B.3.1 Automated Seasonal Kendall Anaysis

This statistical procedure—seasonal Kendall analysis, model selection and regression, followed by flow-adjusted seasonal Kendall analysis—has been automated by means of an original algorithm using SAS/IML[3] programming code (Rheem and Holtzman 1991). Code for the algorithm is listed in Appendix C.

B.3.2 Data Screening

Prior to implementation of this statistical analysis, the data were screened to detect obvious errors of transcription and recording. It was also necessary to reconcile cases where detection limits had changed during the course of the study. Finally, it was necessary to detect and modify the data for months during which there were multiple observations, because the seasonal Kendall procedure allows only one observation per month.

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[3] SAS/IML is a registered trademark of SAS Institute, Inc., Cary, NC.

Various exploratory techniques (Tukey 1977) were used to screen the data, including examination of histograms, boxplots, scatterplots, and summary statistics. Obvious errors were corrected, and inexplicable extreme outliers were discarded. For each variable at each station, we examined a stem-and-leaf display, a plot of the variable against time, and the successive differences of the observed water quality values sorted by magnitude. Observations that produced a successive difference that was an order of magnitude greater than those produced by the bulk of the data were deleted, or, when a typing error was the obvious reason for the departure, corrected.

B.3.3 Detection Limits

For the reconciliation of detection limits, a value less than the lower detection limit was replaced by a value half of that limit, and a value greater than the upper detection limit was replaced by a reasonable value greater than that limit. In cases where two or more different lower detection limits were used (i.e., where the detection limit changed over time), all values less than the greatest lower detection limit were replaced by values half of that limit, as recommended by Hirsch et al. (1982, p. 111). The lower detection limits are as follows.

Biological Oxygen Demand	1.00 mg/l
Nonfilterable Residue	5.00 mg/l
Total Kjeldahl Nitrogen	0.10 mg/l
Total Phosphorous, VA stations	0.10 mg/l
Total Phosphorous, TN stations (TC, TP)	0.01 mg/l
Fecal Coliforms	100 per 100 ml

Upper detection limits were found only in the fecal coliforms data. Raw data for fecal coliforms were particularly confusing because they had two or more upper detection limits, usually 6,000 and 8,000 per 100 ml. In such cases, observations reported to be greater than 6,000 per 100 ml were replaced by a suitable larger value. Observations greater that 8,000 per 100 ml were removed, because they were nearly always orders of magnitude greater than the bulk of the data, i.e., obvious extreme outliers.

B.3.4 Multiple Observations per Month

A few months, for a few years, had two (rather than one) observations per month. In each of those months, the median of the observations was chosen as a representative value for that month so that the data would consist of monthly observations. No months had more than two observations.

B.3.5 Screening Flow Data

Before the fitting of the flow model, a stem-and-leaf display of flow data, a plot of the variable against flow, and the successive differences from the sorted observations on flow were used to eliminate data points that were too far from the bulk of the two-dimensional variable-flow data. Otherwise, the regression model would be influenced unduly by outliers.

Data screening was the most time-consuming and tedious task of the project. It cannot be automated because judgement is required at each step.

Appendix C:
Computer Program for Seasonal Kendall Analysis and Flow Adjustment

```
* Allocating additional temporary disk space before
  running this program under CMS is recommended.;

* Data Screening -------------------------------------------------------;

     DATA ONE; SET SASDAT24.ST24;
               KEEP YY MM DATE PH FLOW;

               * PH is the variable name for pH.;
               * YY   is the variable name for Year.;
               * MM   is the variable name for Month.;
               * In the SAS program to create SASDAT24.ST24, INFORMAT
                 statement was used to make values of the variable DATE
                 represent dates in SAS. --- For details, see SAS
                 Informats and Formats in Sas User's Guide: Basics.;

     DATA TWO; SET ONE;
               IF FLOW > 1100 THEN X = . ; ELSE X=FLOW;
               Y=PH;
* ----------------------------------------------------------------------;


* Part 1: Unadjusted Seasonal Kendall Analysis -------------------------;

     OPTIONS NOOVP LS=90 NODATE;
     TITLE 'Station 24 (NFH085.20), pH, Seasonal Kendall Analysis';
     DATA A; SET ONE; VARIABLE=PH;
             IF PH NE 0 THEN Y=PH; ELSE Y=0.0001;

** Getting Summary Statistics ------------------------------------------;

     PROC MEANS DATA=A NOPRINT; VAR DATE YY;
          OUTPUT OUT=DATEOUT1 MIN=MINDATE MINYY MAX=MAXDATE MAXYY;
     DATA DATEOUT1; SET DATEOUT1; N_YRS=MAXYY-MINYY+1;
          LABEL MINDATE='STARTING DATE' MAXDATE='ENDING DATE'
          N_YRS='# OF YEARS';
     PROC UNIVARIATE DATA=A NOPRINT; VAR PH;
          OUTPUT OUT=SUMMARY0 N=N MEDIAN=MEDIAN MEAN=MEAN
                              STD=STD MIN=MIN MAX=MAX
                              SKEWNESS=SKEW KURTOSIS=KURT;
     PROC MEANS DATA=A NOPRINT; VAR PH;
          OUTPUT OUT=CV CV=CV;
     DATA SUMMARY0; MERGE DATEOUT1 SUMMARY0 CV;
          LABEL MEDIAN='MEDIAN' MEAN='MEAN' N='# OF OBS.'
                STD='STD. DEV.' MIN='MINIMUM' MAX='MAXIMUM'
                CV='C.V.(%)' SKEW='SKEWNESS' KURT='KURTOSIS';
     PROC PRINT LABEL;
          ID MINDATE; VAR MAXDATE N_YRS N MEDIAN MEAN STD MIN MAX;
          FORMAT MINDATE MAXDATE YYMMDD8.;
     RUN;

** Getting a plot of the water quality variable against time -----------;

     OPTIONS NOOVP LS=120 NODATE;
```

```
     PROC PLOT DATA=A; PLOT VARIABLE*DATE/ VPOS=36
          HAXIS='01JAN70'D TO '01JAN90'D BY YEAR;
          LABEL VARIABLE='pH' DATE='YEAR';
          FORMAT DATE DATE7.;
     RUN;

** Making Data Sets Needed for the Seasonal Kendall Trend Analysis -----;

     OPTIONS NOOVP LS=90 NODATE;
     DATA M01; SET A; IF MM= 1;  DATA M02; SET A; IF MM= 2;
     DATA M03; SET A; IF MM= 3;  DATA M04; SET A; IF MM= 4;
     DATA M05; SET A; IF MM= 5;  DATA M06; SET A; IF MM= 6;
     DATA M07; SET A; IF MM= 7;  DATA M08; SET A; IF MM= 8;
     DATA M09; SET A; IF MM= 9;  DATA M10; SET A; IF MM=10;
     DATA M11; SET A; IF MM=11;  DATA M12; SET A; IF MM=12;

     DATA M01DV; SET M01; KEEP Y;  DATA M01YR; SET M01; KEEP YY;
     DATA M02DV; SET M02; KEEP Y;  DATA M02YR; SET M02; KEEP YY;
     DATA M03DV; SET M03; KEEP Y;  DATA M03YR; SET M03; KEEP YY;
     DATA M04DV; SET M04; KEEP Y;  DATA M04YR; SET M04; KEEP YY;
     DATA M05DV; SET M05; KEEP Y;  DATA M05YR; SET M05; KEEP YY;
     DATA M06DV; SET M06; KEEP Y;  DATA M06YR; SET M06; KEEP YY;
     DATA M07DV; SET M07; KEEP Y;  DATA M07YR; SET M07; KEEP YY;
     DATA M08DV; SET M08; KEEP Y;  DATA M08YR; SET M08; KEEP YY;
     DATA M09DV; SET M09; KEEP Y;  DATA M09YR; SET M09; KEEP YY;
     DATA M10DV; SET M10; KEEP Y;  DATA M10YR; SET M10; KEEP YY;
     DATA M11DV; SET M11; KEEP Y;  DATA M11YR; SET M11; KEEP YY;
     DATA M12DV; SET M12; KEEP Y;  DATA M12YR; SET M12; KEEP YY;

** MACRO to calculate the necessary statistics at each month -----------;

     MACRO KENDALL

     PROC IML; USE DSNDV; READ ALL INTO PH;
               USE DSNYR; READ ALL INTO YEAR;
               N=NROW(PH);
               NCOMP=N*(N-1)/2;
               N_NCOMP=N||NCOMP;
               I=0;
               CONTRAST=J(NCOMP,N,0);
               PAIRSUM =J(NCOMP,N,0);
               DENINRD =J(NCOMP,N,0);
               START; DO J=1 TO N-1;
                         DO R=1 TO N-J;
                            K=J+R; I=I+1;
                            CONTRAST(|I,J|)=-1; CONTRAST(|I,K|)=1;
                            PAIRSUM(|I,J|) = 1; PAIRSUM(|I,K|) =1;
                            DENINRD(|I,J|) = 1;
                         END;
                      END;
               FINISH; RUN;

               * CONTRAST IS THE MATRIX REPRESENTING ALL POSSIBLE PAIRWISE
                 COMPARISONS.;
```

```
          DIFFINDV=CONTRAST*PH;
          DIFFINYR=CONTRAST*YEAR;
          SUMOFTWO=PAIRSUM*PH;
          DENFORRD=DENINRD*PH;

          SGN=SIGN(DIFFINDV);

          Q1=DIFFINDV/DIFFINYR;
          Q2=(DIFFINDV/DENFORRD) / DIFFINYR;
          Q=Q1||Q2;

          DIFF_SUM=DIFFINDV||SUMOFTWO;

          SI=SUM(SGN);
          VARSI1=N*(N-1)*(2*N+5)/18;
          IF SI>0 THEN SIADJ=(SI-1);
          IF SI=0 THEN SIADJ=0;
          IF SI<0 THEN SIADJ=(SI+1);
          SIADJ_V1=SI||SIADJ||VARSI1;

          CREATE N_NCOMP  FROM N_NCOMP;  APPEND FROM N_NCOMP;
          CREATE SIADJ_V1 FROM SIADJ_V1; APPEND FROM SIADJ_V1;
          CREATE DIFF_SUM FROM DIFF_SUM; APPEND FROM DIFF_SUM;
          CREATE Q        FROM Q;        APPEND FROM Q;

     DATA N_NCOMP;  SET N_NCOMP;  RENAME COL1=N COL2=NCOMP;
     DATA SIADJ_V1; SET SIADJ_V1; RENAME COL1=SI COL2=SIADJ COL3=VARSI1;
     DATA DIFF_SUM; SET DIFF_SUM; RENAME COL1=DIFFINDV COL2=SUMOFTWO;
     DATA Q_;       SET Q;        RENAME COL1=Q1 COL2=Q2;

*** Getting Statistics Needed for Adjusting for Ties ------------------;

     DATA ADJUST; SET DIFF_SUM;
                IF DIFFINDV NE 0 THEN SUMOFTWO=88888888; ONE=1;
     PROC SORT; BY SUMOFTWO;
     PROC MEANS NOPRINT; BY SUMOFTWO; VAR ONE;
          OUTPUT OUT=OUT1 N=NT;
     DATA OUT1; SET OUT1; VALUETIE=SUMOFTWO/2;
               IF VALUETIE=88888888/2 THEN T=0;
               ELSE T=INT(SQRT(2*NT))+1;
               VARADJ=T*(T-1)*(2*T+5)/18;
               TAUADJ=0.5*T*(T-1);
     PROC MEANS NOPRINT SUM; VAR VARADJ TAUADJ;
          OUTPUT OUT=OUT2 SUM=S_VARADJ S_TAUADJ;

*** Getting Monthly Tau Values with Corresponding P-values ------------;

     DATA ALL; MERGE N_NCOMP SIADJ_V1 OUT2;
               VARSI=VARSI1-S_VARADJ;
               IF VARSI NE 0 THEN Z_S=SIADJ/SQRT(VARSI);  ELSE Z_S=0;
               P_VALUE=2*(1-PROBNORM(ABS(Z_S)));
               DENTAUI=SQRT(NCOMP-S_TAUADJ)*SQRT(NCOMP);
               IF DENTAUI NE 0 THEN TAU=SI/DENTAUI; ELSE TAU=0;
     DATA SVARS; SET ALL; KEEP SI VARSI N DENTAUI;
     DATA TAU_;  SET ALL; KEEP TAU P_VALUE N;
```

```
     %

** Running the above MACRO at each of 12 months -----------------------;

     MACRO DSNDV M01DV    %    MACRO DSNYR M01YR %    MACRO DSN M01 %
     MACRO SVARS SVARS01 %    MACRO TAU_  TAU01 %    MACRO Q_  Q01 %
     KENDALL

     MACRO DSNDV M02DV    %    MACRO DSNYR M02YR %    MACRO DSN M02 %
     MACRO SVARS SVARS02 %    MACRO TAU_  TAU02 %    MACRO Q_  Q02 %
     KENDALL

     MACRO DSNDV M03DV    %    MACRO DSNYR M03YR %    MACRO DSN M03 %
     MACRO SVARS SVARS03 %    MACRO TAU_  TAU03 %    MACRO Q_  Q03 %
     KENDALL

     MACRO DSNDV M04DV    %    MACRO DSNYR M04YR %    MACRO DSN M04 %
     MACRO SVARS SVARS04 %    MACRO TAU_  TAU04 %    MACRO Q_  Q04 %
     KENDALL

     MACRO DSNDV M05DV    %    MACRO DSNYR M05YR %    MACRO DSN M05 %
     MACRO SVARS SVARS05 %    MACRO TAU_  TAU05 %    MACRO Q_  Q05 %
     KENDALL

     MACRO DSNDV M06DV    %    MACRO DSNYR M06YR %    MACRO DSN M06 %
     MACRO SVARS SVARS06 %    MACRO TAU_  TAU06 %    MACRO Q_  Q06 %
     KENDALL

     MACRO DSNDV M07DV    %    MACRO DSNYR M07YR %    MACRO DSN M07 %
     MACRO SVARS SVARS07 %    MACRO TAU_  TAU07 %    MACRO Q_  Q07 %
     KENDALL

     MACRO DSNDV M08DV    %    MACRO DSNYR M08YR %    MACRO DSN M08 %
     MACRO SVARS SVARS08 %    MACRO TAU_  TAU08 %    MACRO Q_  Q08 %
     KENDALL

     MACRO DSNDV M09DV    %    MACRO DSNYR M09YR %    MACRO DSN M09 %
     MACRO SVARS SVARS09 %    MACRO TAU_  TAU09 %    MACRO Q_  Q09 %
     KENDALL

     MACRO DSNDV M10DV    %    MACRO DSNYR M10YR %    MACRO DSN M10 %
     MACRO SVARS SVARS10 %    MACRO TAU_  TAU10 %    MACRO Q_  Q10 %
     KENDALL

     MACRO DSNDV M11DV    %    MACRO DSNYR M11YR %    MACRO DSN M11 %
     MACRO SVARS SVARS11 %    MACRO TAU_  TAU11 %    MACRO Q_  Q11 %
     KENDALL

     MACRO DSNDV M12DV    %    MACRO DSNYR M12YR %    MACRO DSN M12 %
     MACRO SVARS SVARS12 %    MACRO TAU_  TAU12 %    MACRO Q_  Q12 %
     KENDALL

** Combining the Statistics from 12 Months to Get the Value of
   Overall Tau and Corresponding P-value -----------------------------;
```

```
     DATA S_VARS; SET SVARS01 SVARS02 SVARS03 SVARS04 SVARS05 SVARS06
                      SVARS07 SVARS08 SVARS09 SVARS10 SVARS11 SVARS12;
     PROC MEANS DATA=S_VARS SUM NOPRINT; VAR SI VARSI N DENTAUI;
          OUTPUT OUT=OVERALL N=N_MONTH SUM=S VARS N_ALL DENTAU;
     DATA OVERALL; SET OVERALL;
          IF S>0 THEN Z=(S-1)/SQRT(VARS);
          IF S=0 THEN Z=0;
          IF S<0 THEN Z=(S+1)/SQRT(VARS);
          P_FOR_S=2*(1-PROBNORM(ABS(Z)));
          TAU_ALL=S/DENTAU;
          LABEL P_FOR_S='P-VALUE OF TEST FOR TREND'
                TAU_ALL='OVERALL TAU'
                VARS='VAR(S) UNDER HYPOTHESIS OF NO TREND'
                DENTAU='DENOMINATOR OF OVERALL TAU';
     PROC PRINT LABEL; ID S; VAR VARS Z TAU_ALL P_FOR_S;
     RUN;

** Printing the Monthly Tau Values ------------------------------------;

     DATA TAUS; SET TAU01 TAU02 TAU03 TAU04 TAU05 TAU06
                    TAU07 TAU08 TAU09 TAU10 TAU11 TAU12;
     DATA MONTHS; DO MONTH=1 TO 12; OUTPUT; END;
     DATA TAUS; MERGE MONTHS TAUS;
          LABEL P_VALUE='P-VALUE' N='# OF YEARS';
     PROC PRINT DATA=TAUS LABEL; ID MONTH; VAR TAU P_VALUE N;
          FORMAT P_VALUE 7.5;
     RUN;

** Getting Seasonal Kendall Estimates and Confidence Intervals ---------;

     DATA Q; SET Q01 Q02 Q03 Q04 Q05 Q06 Q07 Q08 Q09 Q10 Q11 Q12; Q2=100*Q2;

     PROC UNIVARIATE DATA=Q NOPRINT; VAR Q1;
          OUTPUT OUT=SUMMARY N=TNCOMP MEDIAN=Q1;

     DATA CI; MERGE SUMMARY OVERALL;
          C05=1.96*SQRT(VARS); C10=1.645*SQRT(VARS);
          RANK1_95=INT((TNCOMP-C05)/2+0.5);
          RANK2_95=INT((TNCOMP+C05)/2+0.5)+1;
          RANK1_90=INT((TNCOMP-C10)/2+0.5);
          RANK2_90=INT((TNCOMP+C10)/2+0.5)+1;
          LABEL TNCOMP='TOTAL # OF COMPARISONS';

     DATA C1; SET CI; DESCR='SEASONAL KENDALL ESTIMATE'; RANK=(1+TNCOMP)/2;
     DATA C2; SET CI; DESCR='LOWER LIMIT OF 95% C. I. '; RANK=RANK1_95;
     DATA C3; SET CI; DESCR='UPPER LIMIT OF 95% C. I. '; RANK=RANK2_95;
     DATA C4; SET CI; DESCR='LOWER LIMIT OF 90% C. I. '; RANK=RANK1_90;
     DATA C5; SET CI; DESCR='UPPER LIMIT OF 90% C. I. '; RANK=RANK2_90;
     DATA CCCCC; SET C1 C2 C3 C4 C5; PCT=RANK/(TNCOMP+1)*100;
          LABEL DESCR='ESTIMATE & CONFIDENCE INTERVALS'
                PCT='PERCENTILE';

     DATA CI2; SET CI; KEEP TNCOMP RANK1_90 RANK2_90 RANK1_95 RANK2_95;
```

```
     DATA INDEX; SET CI2; DO I=1 TO TNCOMP; OUTPUT; END;

     DATA SLOPE1; SET SUMMARY; DESCR='SEASONAL KENDALL ESTIMATE';
          KEEP DESCR Q1;

     PROC SORT DATA=Q OUT=Q1; BY Q1;
     DATA INDEXQ1; MERGE INDEX Q1;
     DATA L95; SET INDEXQ1; IF I=RANK1_95; DESCR='LOWER LIMIT OF 95% C. I. ';
     DATA U95; SET INDEXQ1; IF I=RANK2_95; DESCR='UPPER LIMIT OF 95% C. I. ';
     DATA L90; SET INDEXQ1; IF I=RANK1_90; DESCR='LOWER LIMIT OF 90% C. I. ';
     DATA U90; SET INDEXQ1; IF I=RANK2_90; DESCR='UPPER LIMIT OF 90% C. I. ';
     DATA CL1; SET L95 U95 L90 U90; IF I=. THEN DELETE; KEEP DESCR Q1;

     DATA SL_CL1; SET SLOPE1 CL1;

     PROC SORT DATA=Q OUT=Q2; BY Q2;
     PROC UNIVARIATE DATA=Q2 NOPRINT; VAR Q2;
          OUTPUT OUT=SUMMARY2 MEDIAN=Q2;
     DATA SLOPE2; SET SUMMARY2; DESCR='SEASONAL KENDALL ESTIMATE';

     DATA INDEXQ2; MERGE INDEX Q2;
     DATA L95; SET INDEXQ2; IF I=RANK1_95; DESCR='LOWER LIMIT OF 95% C. I. ';
     DATA U95; SET INDEXQ2; IF I=RANK2_95; DESCR='UPPER LIMIT OF 95% C. I. ';
     DATA L90; SET INDEXQ2; IF I=RANK1_90; DESCR='LOWER LIMIT OF 90% C. I. ';
     DATA U90; SET INDEXQ2; IF I=RANK2_90; DESCR='UPPER LIMIT OF 90% C. I. ';
     DATA CL2; SET L95 U95 L90 U90; IF I=. THEN DELETE; KEEP DESCR Q2;

     DATA SL_CL2; SET SLOPE2 CL2;
     DATA CHOVMDN; SET SUMMARY0; DO J=1 TO 5; OUTPUT; END; DROP J;

     DATA SL_CL12; MERGE CCCCC SL_CL1 CHOVMDN SL_CL2;
          Q12=100*(Q1/MEDIAN);
          LABEL  Q1='CHANGE PER YEAR (SLOPE)'
                 Q12='CHANGE PER YEAR (% OF MEDIAN)'
                 Q2='RELATIVE CHANGE PER YEAR (%)';

     PROC PRINT DATA=SL_CL12 LABEL;
          ID DESCR; VAR Q1 Q12 Q2; FORMAT Q1 10.4 Q12 Q2 8.2;
     RUN;

* ----------------------------------------------------------------------;


* Part 2:  Flow Model Selection ---------------------------------------;

     TITLE1 'Station 24 (NFH085.20), pH, Flow Model Selection';
     TITLE3 'Y = pH,  X = Flow';

** Listing the Candidate Models ---------------------------------------;

     TITLE5
'For i = -3 to 2 by 0.25 (except 0),  E(Y) = intercept + slope * X**i.      ';
     TITLE6
'For i = 0,                           E(Y) = intercept + slope * log(X).    ';
     TITLE7
```

```
'For i = 101 through 110,             E(Y) = intercept + slope * 1/(1+Bi*X),';
     TITLE8
"      where Bi's are:                                                        ";

     DATA A; SET TWO;

     PROC MEANS DATA=A NOPRINT; VAR X; OUTPUT OUT=BX MEAN=XMEAN;
     PROC MEANS DATA=A NOPRINT; VAR PH; OUTPUT OUT=BY N=NT;

     DATA B0; MERGE BX BY; LOG10XM=LOG10(XMEAN); BB=INT(LOG10XM);
          EF=-2.5*BB;  EL=1.5-BB; BF=10**EF; BL=10**EL; NN=(EL-EF)/0.5;

     DATA B1; SET B0; I=101; B=BF;
          KEEP I B;
     DATA B2; SET B0; DO I=1+101 TO NN+101;
                        B=10**0.5 * BF; BF=B; OUTPUT;
                      END;
          KEEP I B;
     DATA B12; SET B1 B2; RENAME B=B_I;
     DATA BBB1; SET B12(OBS=2);              RENAME I=I1 B_I=B_I1;
     DATA BBB2; SET B12(FIRSTOBS=3 OBS=4 ); RENAME I=I2 B_I=B_I2;
     DATA BBB3; SET B12(FIRSTOBS=5 OBS=6 ); RENAME I=I3 B_I=B_I3;
     DATA BBB4; SET B12(FIRSTOBS=7 OBS=8 ); RENAME I=I4 B_I=B_I4;
     DATA BBB5; SET B12(FIRSTOBS=9 OBS=10); RENAME I=I5 B_I=B_I5;

     DATA BBBB; MERGE BBB1 BBB2 BBB3 BBB4 BBB5;
          LABEL I1='i' B_I1='Bi' I2='i' B_I2='Bi'
                I3='i' B_I3='Bi' I4='i' B_I4='Bi'
                I5='i' B_I5='Bi';
     PROC PRINT LABEL; ID I1; VAR B_I1 I2 B_I2 I3 B_I3 I4 B_I4 I5 B_I5;
     RUN;

** Getting Summary Statistics -----------------------------------------;

     TITLE;
     TITLE1 'Station 24 (NFH085.20), pH, Flow Model Selection';
     TITLE3 'Y = pH,  X = Flow';
     DATA AA; SET A; IF X=. THEN DELETE; IF Y=. THEN DELETE;
     PROC MEANS DATA=AA NOPRINT; VAR DATE;
          OUTPUT OUT=DATESOUT MIN=MINDATE MAX=MAXDATE;
     DATA DATESOUT; SET DATESOUT;
          LABEL MINDATE='STARTING DATE' MAXDATE='ENDING DATE';

     PROC UNIVARIATE DATA=AA NOPRINT; VAR Y X;
          OUTPUT OUT=SUMMARY N=N MEDIAN=Y_MEDIAN X_MEDIAN
                                 MEAN=Y_MEAN X_MEAN STD=Y_STD X_STD;
     DATA SUMMARY; MERGE DATESOUT SUMMARY;
          LABEL Y_MEDIAN='MEDIAN OF Y' X_MEDIAN='MEDIAN OF X'
                Y_MEAN='MEAN OF Y' X_MEAN='MEAN OF X'
                N='# OF OBS.'
                Y_STD='STD. DEV. OF Y' X_STD='STD. DEV. OF X';
     PROC PRINT LABEL; ID MINDATE;
          VAR MAXDATE N Y_MEDIAN Y_MEAN Y_STD X_MEDIAN X_MEAN X_STD;
         FORMAT MINDATE MAXDATE YYMMDD8.;
```

```
** Selecting the Model with Maximum R-square --------------------------;

     DATA B; SET B0; DO J=1 TO NT; OUTPUT; END; DROP J;

     DATA C1; MERGE A B; I=101; B=BF; W=1/(1+B*X);

     DATA C2; MERGE A B; DO I=1+101 TO NN+101;
                            B=10**0.5 * BF; BF=B; W=1/(1+B*X); OUTPUT;
                         END;

     DATA D1; SET A; DO I=-3.00 TO -0.20 BY 0.25; W=X**I; OUTPUT; END;

     DATA D2; SET A; I=0; W=LOG(X);

     DATA D3; SET A; DO I=0.25 TO 2.05 BY 0.25; W=X**I; OUTPUT; END;

     DATA ALL; SET D1 D2 D3 C1 C2;
     PROC SORT; BY I;

     PROC RSQUARE DATA=ALL NOPRINT OUTEST=RSQ; MODEL Y=W; BY I;
     DATA RSQ; SET RSQ;
          F=_EDF_*_RSQ_/(1-_RSQ_); P_VALUE=1-PROBF(F,1,_EDF_);
     PROC SORT OUT=RSQ; BY DESCENDING _RSQ_;
     DATA RSQ; SET RSQ;
          LABEL I='i' INTERCEP='INTERCEPT' W='SLOPE' P_VALUE='P-VALUE'
                _EDF_='ERROR D.F.';
     DATA RSQ1; SET RSQ(OBS=1);
     DATA NNN; SET ALL; TAG=1; NNN+1;
     DATA NNNL; SET NNN; BY TAG; IF LAST.TAG;
     DATA NR; MERGE NNNL RSQ1; J=I; DO K=1 TO NNN; OUTPUT; END; KEEP J;
     DATA ALL_NR; MERGE ALL NR;
     DATA SELECTED; SET ALL_NR; IF I=J; SLOPE=W;

     PROC REG DATA=SELECTED NOPRINT; MODEL Y=SLOPE;
              OUTPUT OUT=REGOUT P=ESTIMATE;
     DATA A; SET REGOUT; RESIDUAL=PH-ESTIMATE;

** Getting a Plot of the Observed and Predicted Water-Quality Values
   Against Flow ---------------------------------------------------;

     OPTIONS NOOVP LS=120 NODATE;
     PROC PLOT DATA=A; PLOT ESTIMATE*X='+' Y*X/ VPOS=42 OVERLAY;
          LABEL ESTIMATE='pH' X='Flow';
     RUN;

** Getting a Statistical Description of the Selected Model ------------;

     OPTIONS NOOVP LS=90 NODATE;
     TITLE1 'Station 24 (NFH085.20), pH, Flow Model Selection';
     TITLE3 'Y = pH,  X = Flow';
     TITLE5 'REGRESSION MODEL WITH MAXIMUM R-SQUARED';
     PROC PRINT DATA=RSQ1 LABEL;
          ID I; VAR _RSQ_ F _EDF_ P_VALUE;
     RUN;
     PROC REG DATA=A; MODEL Y=SLOPE;
```

```
     RUN;

*-----------------------------------------------------------------------;


* Part 3: Flow-Adusted Analysis ---------------------------------------;

     TITLE;
     TITLE1
'Station 24 (NFH085.20), pH, Flow-Adjusted Analysis';
     TITLE3
'Here, the dependent variable is the residual from the regression';
     TITLE4
'with the model given on the bottom part of the preceding page.  ';
     TITLE5
'(Residual  =  Observed value on pH  minus';
     TITLE6
'Estimated value on pH as a function of Flow)';

** Getting a Plot of the Residual against Time -----------------------;

     OPTIONS NOOVP LS=120 NODATE;
     PROC PLOT DATA=A; PLOT RESIDUAL*DATE/ VPOS=34
          HAXIS='01JAN70'D TO '01JAN90'D BY YEAR;
          LABEL RESIDUAL='RESIDUAL' DATE='YEAR';
          FORMAT DATE DATE7.;
     RUN:

** Making Data Sets Needed for the Seasonal Kendall Trend Analysis -----;

     OPTIONS NOOVP LS=90 NODATE;
     DATA A; SET A; Y=RESIDUAL;
     DATA M01; SET A; IF MM= 1;  DATA M02; SET A; IF MM= 2;
     DATA M03; SET A; IF MM= 3;  DATA M04; SET A; IF MM= 4;
     DATA M05; SET A; IF MM= 5;  DATA M06; SET A; IF MM= 6;
     DATA M07; SET A; IF MM= 7;  DATA M08; SET A; IF MM= 8;
     DATA M09; SET A; IF MM= 9;  DATA M10; SET A; IF MM=10;
     DATA M11; SET A; IF MM=11;  DATA M12; SET A; IF MM=12;

     DATA M01DV; SET M01; KEEP Y;  DATA M01YR; SET M01; KEEP YY;
     DATA M02DV; SET M02; KEEP Y;  DATA M02YR; SET M02; KEEP YY;
     DATA M03DV; SET M03; KEEP Y;  DATA M03YR; SET M03; KEEP YY;
     DATA M04DV; SET M04; KEEP Y;  DATA M04YR; SET M04; KEEP YY;
     DATA M05DV; SET M05; KEEP Y;  DATA M05YR; SET M05; KEEP YY;
     DATA M06DV; SET M06; KEEP Y;  DATA M06YR; SET M06; KEEP YY;
     DATA M07DV; SET M07; KEEP Y;  DATA M07YR; SET M07; KEEP YY;
     DATA M08DV; SET M08; KEEP Y;  DATA M08YR; SET M08; KEEP YY;
     DATA M09DV; SET M09; KEEP Y;  DATA M09YR; SET M09; KEEP YY;
     DATA M10DV; SET M10; KEEP Y;  DATA M10YR; SET M10; KEEP YY;
     DATA M11DV; SET M11; KEEP Y;  DATA M11YR; SET M11; KEEP YY;
     DATA M12DV; SET M12; KEEP Y;  DATA M12YR; SET M12; KEEP YY;

** MACRO to calculate the necessary statistics at each month ----------;

     MACRO KENDALL
```

```
     PROC IML; USE DSNDV; READ ALL INTO PH;
               USE DSNYR; READ ALL INTO YEAR;
               N=NROW(PH);
               NCOMP=N*(N-1)/2;
               N_NCOMP=N||NCOMP;
               I=0;
               CONTRAST=J(NCOMP,N,0);
               PAIRSUM =J(NCOMP,N,0);
               DENINRD =J(NCOMP,N,0);
               START; DO J=1 TO N-1;
                         DO R=1 TO N-J;
                            K=J+R; I=I+1;
                            CONTRAST(|I,J|)=-1; CONTRAST(|I,K|)=1;
                            PAIRSUM(|I,J|) = 1; PAIRSUM(|I,K|) =1;
                            DENINRD(|I,J|) = 1;
                         END;
                      END;
               FINISH; RUN;

               * CONTRAST IS THE MATRIX REPRESENTING ALL POSSIBLE PAIRWISE
                 COMPARISONS.;

               DIFFINDV=CONTRAST*PH;
               DIFFINYR=CONTRAST*YEAR;
               SUMOFTWO=PAIRSUM*PH;
               DENFORRD=DENINRD*PH;

               SGN=SIGN(DIFFINDV);

               Q1=DIFFINDV/DIFFINYR;
               Q2=(DIFFINDV/DENFORRD) / DIFFINYR;
               Q=Q1||Q2;

               DIFF_SUM=DIFFINDV||SUMOFTWO;

               SI=SUM(SGN);
               VARSI1=N*(N-1)*(2*N+5)/18;
               IF SI>0 THEN SIADJ=(SI-1);
               IF SI=0 THEN SIADJ=0;
               IF SI<0 THEN SIADJ=(SI+1);
               SIADJ_V1=SI||SIADJ||VARSI1;

               CREATE N_NCOMP  FROM N_NCOMP;  APPEND FROM N_NCOMP;
               CREATE SIADJ_V1 FROM SIADJ_V1; APPEND FROM SIADJ_V1;
               CREATE DIFF_SUM FROM DIFF_SUM; APPEND FROM DIFF_SUM;
               CREATE Q        FROM Q;        APPEND FROM Q;

     DATA N_NCOMP;  SET N_NCOMP;  RENAME COL1=N COL2=NCOMP;
     DATA SIADJ_V1; SET SIADJ_V1; RENAME COL1=SI COL2=SIADJ COL3=VARSI1;
     DATA DIFF_SUM; SET DIFF_SUM; RENAME COL1=DIFFINDV COL2=SUMOFTWO;
     DATA Q_;       SET Q;        RENAME COL1=Q1 COL2=Q2;

*** Getting Statistics Needed for Adjusting for Ties ------------------;
```

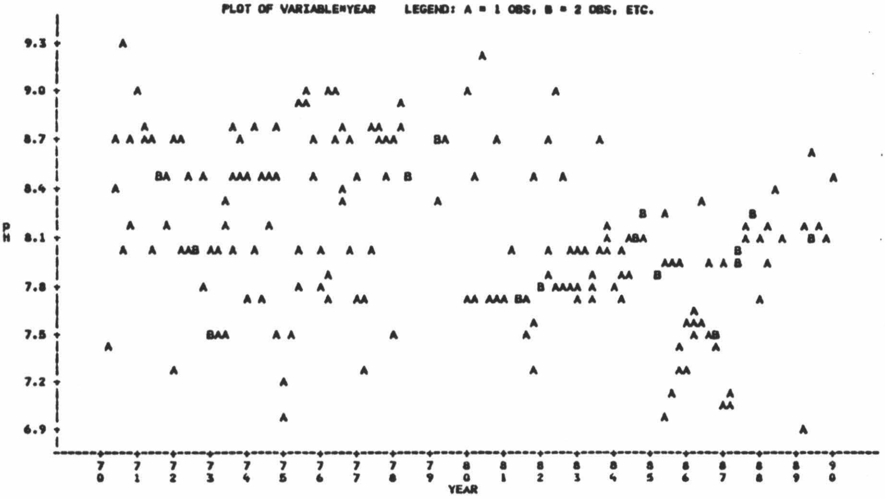
```
     DATA ADJUST; SET DIFF_SUM;
                  IF DIFFINDV NE 0 THEN SUMOFTWO=88888888; ONE=1;
     PROC SORT; BY SUMOFTWO;
     PROC MEANS NOPRINT; BY SUMOFTWO; VAR ONE;
          OUTPUT OUT=OUT1 N=NT;
     DATA OUT1; SET OUT1; VALUETIE=SUMOFTWO/2;
                IF VALUETIE=88888888/2 THEN T=0;
                ELSE T=INT(SQRT(2*NT))+1;
                VARADJ=T*(T-1)*(2*T+5)/18;
                TAUADJ=0.5*T*(T-1);
     PROC MEANS NOPRINT SUM; VAR VARADJ TAUADJ;
          OUTPUT OUT=OUT2 SUM=S_VARADJ S_TAUADJ;

*** Getting Monthly Tau Values with Corresponding P-values ------------;

     DATA ALL; MERGE N_NCOMP SIADJ_V1 OUT2;
               VARSI=VARSI1-S_VARADJ;
               IF VARSI NE 0 THEN Z_S=SIADJ/SQRT(VARSI);  ELSE Z_S=0;
               P_VALUE=2*(1-PROBNORM(ABS(Z_S)));
               DENTAUI=SQRT(NCOMP-S_TAUADJ)*SQRT(NCOMP);
               IF DENTAUI NE 0 THEN TAU=SI/DENTAUI; ELSE TAU=0;
     DATA SVARS; SET ALL; KEEP SI VARSI N DENTAUI;
     DATA TAU_;  SET ALL; KEEP TAU P_VALUE N;

     %

** Running the above MACRO at each of 12 months -----------------------;

     MACRO DSNDV M01DV    %   MACRO DSNYR M01YR %   MACRO DSN M01 %
     MACRO SVARS SVARS01 %   MACRO TAU_  TAU01 %   MACRO Q_  Q01 %
     KENDALL

     MACRO DSNDV M02DV    %   MACRO DSNYR M02YR %   MACRO DSN M02 %
     MACRO SVARS SVARS02 %   MACRO TAU_  TAU02 %   MACRO Q_  Q02 %
     KENDALL

     MACRO DSNDV M03DV    %   MACRO DSNYR M03YR %   MACRO DSN M03 %
     MACRO SVARS SVARS03 %   MACRO TAU_  TAU03 %   MACRO Q_  Q03 %
     KENDALL

     MACRO DSNDV M04DV    %   MACRO DSNYR M04YR %   MACRO DSN M04 %
     MACRO SVARS SVARS04 %   MACRO TAU_  TAU04 %   MACRO Q_  Q04 %
     KENDALL

     MACRO DSNDV M05DV    %   MACRO DSNYR M05YR %   MACRO DSN M05 %
     MACRO SVARS SVARS05 %   MACRO TAU_  TAU05 %   MACRO Q_  Q05 %
     KENDALL

     MACRO DSNDV M06DV    %   MACRO DSNYR M06YR %   MACRO DSN M06 %
     MACRO SVARS SVARS06 %   MACRO TAU_  TAU06 %   MACRO Q_  Q06 %
     KENDALL

     MACRO DSNDV M07DV    %   MACRO DSNYR M07YR %   MACRO DSN M07 %
     MACRO SVARS SVARS07 %   MACRO TAU_  TAU07 %   MACRO Q_  Q07 %
     KENDALL
```

```
     MACRO DSNDV M08DV   %   MACRO DSNYR M08YR %   MACRO DSN M08 %
     MACRO SVARS SVARS08 %   MACRO TAU_  TAU08 %   MACRO Q_  Q08 %
     KENDALL

     MACRO DSNDV M09DV   %   MACRO DSNYR M09YR %   MACRO DSN M09 %
     MACRO SVARS SVARS09 %   MACRO TAU_  TAU09 %   MACRO Q_  Q09 %
     KENDALL

     MACRO DSNDV M10DV   %   MACRO DSNYR M10YR %   MACRO DSN M10 %
     MACRO SVARS SVARS10 %   MACRO TAU_  TAU10 %   MACRO Q_  Q10 %
     KENDALL

     MACRO DSNDV M11DV   %   MACRO DSNYR M11YR %   MACRO DSN M11 %
     MACRO SVARS SVARS11 %   MACRO TAU_  TAU11 %   MACRO Q_  Q11 %
     KENDALL

     MACRO DSNDV M12DV   %   MACRO DSNYR M12YR %   MACRO DSN M12 %
     MACRO SVARS SVARS12 %   MACRO TAU_  TAU12 %   MACRO Q_  Q12 %
     KENDALL

** Combining the Statistics from 12 Months to Get the Value of
   Overall Tau and Corresponding P-value -----------------------------;

     DATA S_VARS; SET SVARS01 SVARS02 SVARS03 SVARS04 SVARS05 SVARS06
                      SVARS07 SVARS08 SVARS09 SVARS10 SVARS11 SVARS12;
     PROC MEANS DATA=S_VARS SUM NOPRINT; VAR SI VARSI N DENTAUI;
          OUTPUT OUT=OVERALL N=N_MONTH SUM=S VARS N_ALL DENTAU;
     DATA OVERALL; SET OVERALL;
          IF S>0 THEN Z=(S-1)/SQRT(VARS);
          IF S=0 THEN Z=0;
          IF S<0 THEN Z=(S+1)/SQRT(VARS);
          P_FOR_S=2*(1-PROBNORM(ABS(Z)));
          TAU_ALL=S/DENTAU;
          LABEL P_FOR_S='P-VALUE OF TEST FOR TREND'
                TAU_ALL='OVERALL TAU'
                VARS='VAR(S) UNDER HYPOTHESIS OF NO TREND'
                DENTAU='DENOMINATOR OF OVERALL TAU';
      PROC PRINT LABEL; ID S; VAR VARS Z TAU_ALL P_FOR_S;
      RUN;

** Printing the Monthly Tau Values ------------------------------------;

     DATA TAUS; SET TAU01 TAU02 TAU03 TAU04 TAU05 TAU06
                    TAU07 TAU08 TAU09 TAU10 TAU11 TAU12;
     DATA MONTHS; DO MONTH=1 TO 12; OUTPUT; END;
     DATA TAUS; MERGE MONTHS TAUS;
          LABEL P_VALUE='P-VALUE' N='# OF YEARS';
     PROC PRINT DATA=TAUS LABEL; ID MONTH; VAR TAU P_VALUE N;
          FORMAT P_VALUE 7.5;
     RUN;

** Getting Seasonal Kendall Estimates and Confidence Intervals ---------;

     DATA Q; SET Q01 Q02 Q03 Q04 Q05 Q06 Q07 Q08 Q09 Q10 Q11 Q12;
```

```
PROC UNIVARIATE DATA=Q,NOPRINT; VAR Q1;
     OUTPUT OUT=SUMMARY N=TNCOMP MEDIAN=Q1;

DATA CI; MERGE SUMMARY OVERALL;
     C05=1.96*SQRT(VARS); C10=1.645*SQRT(VARS);
     RANK1_95=INT((TNCOMP-C05)/2+0.5);
     RANK2_95=INT((TNCOMP+C05)/2+0.5)+1;
     RANK1_90=INT((TNCOMP-C10)/2+0.5);
     RANK2_90=INT((TNCOMP+C10)/2+0.5)+1;
     LABEL TNCOMP='TOTAL # OF COMPARISONS';

DATA C1; SET CI; DESCR='SEASONAL KENDALL ESTIMATE'; RANK=(1+TNCOMP)/2;
DATA C2; SET CI; DESCR='LOWER LIMIT OF 95% C. I. '; RANK=RANK1_95;
DATA C3; SET CI; DESCR='UPPER LIMIT OF 95% C. I. '; RANK=RANK2_95;
DATA C4; SET CI; DESCR='LOWER LIMIT OF 90% C. I. '; RANK=RANK1_90;
DATA C5; SET CI; DESCR='UPPER LIMIT OF 90% C. I. '; RANK=RANK2_90;
DATA CCCCC; SET C1 C2 C3 C4 C5; PCT=RANK/(TNCOMP+1)*100;
     LABEL DESCR='ESTIMATE & CONFIDENCE INTERVALS' PCT='PERCENTILE';

DATA CI2; SET CI; KEEP TNCOMP RANK1_90 RANK2_90 RANK1_95 RANK2_95;

DATA INDEX; SET CI2; DO I=1 TO TNCOMP; OUTPUT; END;

DATA SLOPE1; SET SUMMARY; DESCR='SEASONAL KENDALL ESTIMATE'; KEEP DESCR Q1;

PROC SORT DATA=Q OUT=Q1; BY Q1;
DATA INDEXQ1; MERGE INDEX Q1;
DATA L95; SET INDEXQ1; IF I=RANK1_95; DESCR='LOWER LIMIT OF 95% C. I. ';
DATA U95; SET INDEXQ1; IF I=RANK2_95; DESCR='UPPER LIMIT OF 95% C. I. ';
DATA L90; SET INDEXQ1; IF I=RANK1_90; DESCR='LOWER LIMIT OF 90% C. I. ';
DATA U90; SET INDEXQ1; IF I=RANK2_90; DESCR='UPPER LIMIT OF 90% C. I. ';
DATA CL1; SET L95 U95 L90 U90; IF I=. THEN DELETE; KEEP DESCR Q1;

DATA SL_CL1; SET SLOPE1 CL1;

DATA CHOVMDN; SET SUMMARY0; DO J=1 TO 5; OUTPUT; END; DROP J;

DATA SL_CL12; MERGE CCCCC SL_CL1 CHOVMDN;
         Q12=100*(Q1/MEDIAN);
         LABEL  Q1='CHANGE PER YEAR (SLOPE)'
                Q12='CHANGE PER YEAR (% OF MEDIAN)';
PROC PRINT DATA=SL_CL12 LABEL;
     ID DESCR; VAR Q1 Q12; FORMAT Q1 10.4 Q12 8.2;
RUN;
```

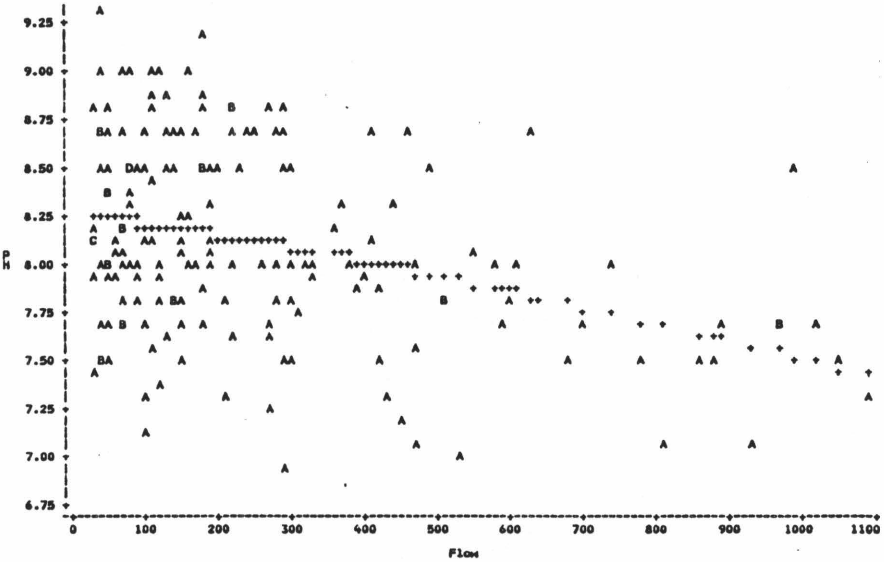
Appendix D:
Example of Program Output

```
Station 24 (NFH085.20), pH, Seasonal Kendall Analysis

STARTING   ENDING    # OF     # OF    MEDIAN    MEAN       STD.     MINIMUM   MAXIMUM
  DATE      DATE     YEARS    OBS.                         DEV.

70-04-15  89-12-05    20      191       8     8.09788   0.500802    6.91      9.299

                          PLOT OF VARIABLE*YEAR    LEGEND: A = 1 OBS, B = 2 OBS, ETC.
```



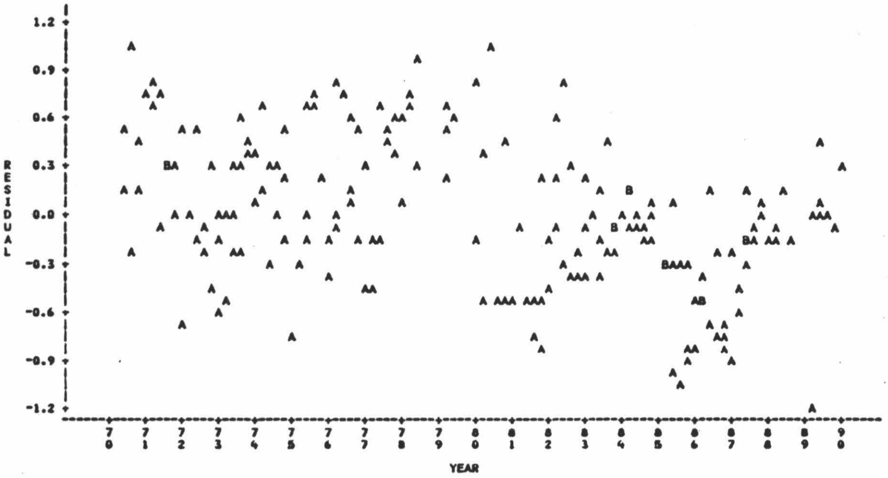
```
        S        VAR(S) UNDER          Z          OVERALL      P-VALUE OF
                 HYPOTHESIS OF                      TAU         TEST FOR
                    NO TREND                                       TREND

      -258          6076            -3.297      -0.18026     0.000977095

                 MONTH            TAU     P-VALUE      # OF
                                                      YEARS

                   1          0.04495    0.92844        10
                   2          0.00744    1.00000        17
                   3         -0.40014    0.03098        17
                   4          0.03540    0.86088        19
                   5         -0.27724    0.11963        18
                   6         -0.10449    0.59083        17
                   7         -0.25963    0.19711        15
                   8         -0.25373    0.21282        15
                   9         -0.28708    0.15075        15
                  10         -0.32854    0.10119        15
                  11         -0.11325    0.56159        17
                  12         -0.22037    0.25841        16

ESTIMATE &                        CHANGE PER      CHANGE PER       RELATIVE CHANGE
CONFIDENCE                              YEAR      YEAR (X OF        PER YEAR (X)
INTERVALS                            (SLOPE)         MEDIAN)

SEASONAL KENDALL ESTIMATE            -0.0249         -0.31              -0.29
LOWER LIMIT OF 95X C. I.             -0.0371         -0.46              -0.45
UPPER LIMIT OF 95X C. I.             -0.0075         -0.09              -0.09
LOWER LIMIT OF 90X C. I.             -0.0349         -0.44              -0.42
UPPER LIMIT OF 90X C. I.             -0.0111         -0.14              -0.14
```

```
Station 24 (NFH085.20), pH, Flow Model Selection
                              Y = pH,  X = Flow

     For i = -3 to 2 by 0.25 (except 0),  E(Y) = intercept + slope * X**i.
     For i = 0,                           E(Y) = intercept + slope * log(X).
     For i below,                         E(Y) = intercept + slope * 1/(1+Bi*X),
          where Bi's are:

   i        Bi         i        Bi          i        Bi         i       Bi        i      Bi

  101  0.0000100000  103  0.000100000  105  0.00100000  107  0.0100000  109  0.100000
  102  0.0000316228  104  0.000316228  106  0.00316228  108  0.0316228  110  0.316228

 STARTING    ENDING     # OF    MEDIAN     MEAN      STD.     MEDIAN    MEAN      STD.
   DATE       DATE      OBS.     OF Y      OF Y      DEV.      OF X     OF X      DEV.
                                                     OF Y                         OF X

 70-05-18   89-12-05    184       8      8.10168   0.49397   173.5    258.435   243.678

                                PLOT OF ESTIMATE*X    SYMBOL USED IS +
                                PLOT OF Y*X           LEGEND: A = 1 OBS, B = 2 OBS, ETC.
```



```
NOTE:     14 OBS HAD MISSING VALUES     128 OBS HIDDEN

                        REGRESSION MODEL WITH MAXIMUM R-SQUARED

                    i       R-SQUARED       F        ERROR      P-VALUE
                                                      D.F.

                  1.25      0.13462      28.3122      182     3.00977E-07

                             PARAMETER        STANDARD      T FOR H0:
                   DF         ESTIMATE           ERROR    PARAMETER=0      PROB > |T|

        INTERCEPT  1        8.25598097      0.04466407        184.846          0.0001
        SLOPE      1      -0.000133064     0.000025008         -5.321          0.0001
```

```
Station 24 (NFH085.20), pH, Flow-Adjusted Analysis

          Here, the dependent variable is the residual from the regression
          with the model given on the bottom part of the preceding page.
                   (Residual  =  Observed value on pH  minus
                  Estimated value on pH as a function of Flow)

                    PLOT OF RESIDUAL*YEAR    LEGEND: A = 1 OBS, B = 2 OBS, ETC.
```



```
NOTE:     7 OBS HAD MISSING VALUES OR WERE OUT OF RANGE

       S       VAR(S) UNDER         Z         OVERALL      P-VALUE OF
               HYPOTHESIS OF                    TAU          TEST FOR
                  NO TREND                                      TREND

     -350         6122          -4.4605    -0.24096     .00000817874

                 MONTH       TAU         P-VALUE      # OF
                                                      YEARS

                   1      -0.15556      0.59151        10
                   2      -0.14706      0.43383        17
                   3      -0.42647      0.01888        17
                   4      -0.03519      0.86105        19
                   5      -0.29412      0.09559        18
                   6      -0.14706      0.43383        17
                   7      -0.27619      0.16586        15
                   8      -0.31429      0.11329        15
                   9      -0.27619      0.16586        15
                  10      -0.33333      0.09246        15
                  11      -0.22059      0.23225        17
                  12      -0.31667      0.09575        16

         ESTIMATE &                          CHANGE PER     CHANGE PER
         CONFIDENCE                                YEAR     YEAR (% OF
         INTERVALS                              (SLOPE)        MEDIAN)

         SEASONAL KENDALL ESTIMATE            -0.0270          -0.34
         LOWER LIMIT OF 95% C. I.             -0.0403          -0.50
         UPPER LIMIT OF 95% C. I.             -0.0152          -0.19
         LOWER LIMIT OF 90% C. I.             -0.0387          -0.48
         UPPER LIMIT OF 90% C. I.             -0.0166          -0.21
```

Appendix E: Detailed Results

The following pages contain detailed results of statistical analyses conducted to determine long-term water quality trends. The table headings are explained as follows.

Stations: Water quality monitoring stations, as described in Table 1 and Appendix A.

Period: Time span for which data were available, analyses were performed.

Median: The median water quality parameter value.

Tau: The Kendall's tau statistic, as described in Appendix B. A negative tau indicates a negative association of the water quality parameter with time, which may or may not be statistically significant, while an unsigned tau indicates a positive association, which may or may not be statistically significant.

Significance: Indicator of the statistical significance of an association of the the water quality parameter with time. NS means $P > 0.05$, which is not statistically significant; * means $0.01 < P \leqq 0.05$; ** means $0.001 < P \leqq 0.1$; *** means $0.0001 < P \leqq 0.001$; **** means $P \leqq 0.0001$.

Slope: The seasonal Kendall slope estimate of change per year; an indicator of trend magnitude.

Lower and Upper Limits: A 90% confidence interval for change per year.

Where flow-adjusted analyses were performed, the results are displayed on the line immediately below the non-flow-adjusted analysis results. R_2 represents the strength of association between the water quality parameter value and flow. Where this association was not statistically significant, NS follows the R_2 figure, and flow-adjusted analysis for trend was not performed. Otherwise, a + or a value indicates the sign of the flow association for the model with the highest R_2 value, and the flow-adjusted analysis values for Kendall's tau, and associated parameters, follow. The flow-adjusted analysis procedure is described in detail in Appendix B.

Table E-1.
Dissolved Oxygen (DO), Seasonal Kendall and Flow Analyses

Station number	Period	Median (mg/l)	Tau	Statistical Significance	P-value	Slope (change /year)	90% Lower Limit	90% Upper Limit
						------	mg/l	-------
Big Sandy Basin								
1	3/70-12/89	10.40	0.07	NS	0.18	0.02	0.00	0.05
2	3/70-12/89	10.39	0.08	NS	0.13	0.02	0.00	0.04
3	5/73-12/89	9.00	0.12	NS	0.10	0.03	0.00	0.06
4	3/70-12/89	10.39	0.05	NS	0.36	0.00	-0.01	0.03
	flow (Rι = 0.10, +):		0.08	NS	0.16	0.02	-0.00	0.04
5	6/74-12/89	8.60	0.03	NS	0.70	0.00	-0.02	0.04
6	4/82-12/89	9.70	0.11	NS	0.26	0.10	-0.02	0.20
	flow (Rι = 0.17, +):		0.11	NS	0.28	0.05	-0.04	0.17
7	3/70-12/89	8.90	-0.16	**	0.00619	-0.07	-0.10	-0.03
8	7/76-12/89	10.00	0.16	*	0.02755	0.06	0.00	0.12
9	7/76-12/89	10.00	0.19	**	0.00698	0.10	0.03	0.14
10	3/70-12/89	10.20	0.12	*	0.02294	0.03	0.00	0.05
	flow (Rι = 0.06, +):		0.10	NS	0.06	0.03	0.00	0.06
Clinch River Watershed								
11	3/70-12/89	9.40	-0.15	**	0.00727	-0.05	-0.09	-0.03
	flow (Rι = 0.36, +):		-0.13	*	0.01908	-0.04	-0.07	-0.01
12	1/73-12/89	10.19	-0.12	NS	0.07	-0.05	-0.08	0.00
13	5/74-12/89	9.00	-0.06	NS	0.34	-0.03	-0.06	0.00
14	3/70-12/89	9.80	-0.01	NS	0.85	0.00	-0.03	0.01
15	1/73-12/89	9.60	0.06	NS	0.35	0.00	-0.01	0.05
16	1/73-12/89	10.59	0.18	**	0.00261	0.05	0.02	0.08
17	3/70-12/89	9.60	-0.04	NS	0.47	-0.01	-0.04	0.00
18	3/70-12/89	10.00	-0.15	**	0.00917	-0.05	-0.08	-0.02
TC	10/73- 3/90	9.80	0.11	NS	0.24	0.04	-0.02	0.10
Powell River Watershed								
19	3/70-12/89	9.80	0.00	NS	0.95	0.00	-0.03	0.02
20	3/70-12/89	10.49	0.17	**	0.00253	0.05	0.02	0.07
21	3/70-12/89	9.80	-0.08	NS	0.17	-0.02	-0.04	0.00
	flow (Rι = 0.24, +):		-0.02	NS	0.66	-0.00	-0.03	0.02
22	3/70-12/89	10.00	0.06	NS	0.26	0.01	-0.01	0.04
TP	8/73- 3/90	10.30	-0.06	NS	0.59	-0.02	-0.07	0.05
Holston River Watershed								
23	3/73-12/89	10.95	0.00	NS	1.00	0.00	-0.03	0.02
24	4/70-12/89	9.80	-0.04	NS	0.44	-0.01	-0.04	0.00
	flow (Rι = 0.14, +):		0.01	NS	0.81	0.00	-0.02	0.04
25	4/70-12/89	9.60	-0.01	NS	0.89	0.00	-0.03	0.02
28	4/70- 9/89	9.60	-0.17	**	0.00143	-0.05	-0.08	-0.02
29	3/70-12/89	9.60	0.01	NS	0.82	0.00	-0.02	0.02
	flow (Rι = 0.10, +):		0.07	NS	0.19	0.02	-0.00	0.05
30	4/70-12/89	9.40	-0.23	****	0.00004	-0.08	-0.10	-0.05
31	4/70-12/89	9.60	-0.17	**	0.00162	-0.05	-0.08	-0.03
32	4/70-12/89	10.00	0.24	****	0.00001	0.06	0.03	0.08
33	4/70-12/89	10.00	0.04	NS	0.49	0.00	-0.02	0.03
34	8/71-12/89	10.00	-0.09	NS	0.17	-0.03	-0.07	0.00
35	4/70-12/89	10.00	0.14	**	0.00969	0.04	0.01	0.07
36	4/70-12/89	9.60	0.12	*	0.02892	0.04	0.00	0.07
37	12/72-12/89	10.00	-0.01	NS	0.92	0.00	-0.03	0.03
	flow (Rι = 0.02, +):		0.04	NS	0.46	0.02	-0.02	0.04
38	4/70-12/89	9.60	0.14	**	0.00911	0.03	0.00	0.06

Table E-2.
Biological Oxygen Demand (BOD), Seasonal Kendall and Flow Analyses

Station number	Period	Median (mg/l)	Tau	Significance	P-value	Slope (change /year) --------mg/l	90% Lower Limit	90% Upper Limit ------
			Big Sandy Basin					
1	8/82-10/89	1.10	-0.34	**	0.00181	-0.21	-0.33	-0.03
2	7/79-12/89	1.35	-0.32	***	0.00010	-0.13	-0.20	-0.06
3	8/79-10/89	1.70	-0.36	****	0.00001	-0.16	-0.21	-0.10
4	7/79-10/89	1.60	-0.27	**	0.00123	-0.11	-0.17	-0.06
	flow (R_ι = 0.01, NS):		.	.	.	.	.	.
5	7/79- 9/89	1.50	-0.25	**	0.00302	-0.12	-0.18	-0.04
6	4/82-10/89	1.40	-0.54	****	0.00000	-0.22	-0.30	-0.13
	flow (R_ι = 0.01, NS):		.	.	.	.	.	.
7	3/75-10/89	10.00	-0.17	*	0.01497	-0.38	-0.64	-0.14
8	7/82-10/89	1.50	-0.44	****	0.00002	-0.17	-0.25	-0.10
9	7/82-10/89	1.50	-0.33	**	0.00153	-0.25	-0.33	-0.12
10	7/79- 8/89	1.75	-0.24	**	0.00502	-0.12	-0.18	-0.02
	flow (R_ι = 0.02, NS):		.	.	.	.	.	.
			Clinch River Watershed					
11	3/75- 8/89	2.30	-0.05	NS	0.45	-0.02	-0.05	0.02
	flow (R_ι = 0.09, -):		-0.11	NS	0.10	-0.03	-0.07	0.00
12	7/79- 8/89	1.50	-0.26	**	0.00149	-0.10	-0.20	-0.03
13	3/75- 8/89	1.60	-0.01	NS	0.90	0.00	-0.03	0.03
14	3/75- 9/89	2.00	-0.04	NS	0.56	-0.02	-0.04	0.02
15	3/75- 9/89	3.70	-0.20	**	0.00308	-0.15	-0.22	-0.07
16	6/82- 9/89	<1.00	0.00	NS	1.00	0.00	0.00	0.00
17	10/76- 9/89	1.30	-0.14	NS	0.06	-0.04	-0.10	0.00
18	3/70- 9/89	<1.00	0.00	NS	1.00	0.00	0.00	0.00
TC	insufficient data							
			Powell River Watershed					
19	3/70- 9/89	<1.00	0.00	NS	1.00	0.00	0.00	0.00
20	3/70- 9/89	<1.00	0.00	NS	1.00	0.00	0.00	0.00
21	6/82- 9/89	1.50	-0.40	***	0.00022	-0.18	-0.28	-0.12
	flow (R_ι = 0.00, NS):		.	.	.	.	.	.
22	6/82- 9/89	1.50	-0.40	***	0.00015	-0.20	-0.30	-0.10
TP	insufficient data							
			Holston River Watershed					
23	7/79-10/89	1.60	-0.19	*	0.02488	-0.08	-0.12	0.00
24	7/82-10/89	1.00	-0.51	****	0.00000	-0.18	-0.23	-0.13
	flow (R_ι = 0.12, +):		-0.40	****	0.00010	-0.17	-0.22	-0.10
25	7/82-10/89	1.30	-0.50	****	0.00000	-0.23	-0.30	-0.16
28	7/79- 9/89	1.40	-0.23	**	0.00439	-0.08	-0.13	0.00
29	6/82- 9/89	1.45	-0.59	****	0.00000	-0.26	-0.32	-0.23
	flow (R_ι = 0.01, NS):		.	.	.	.	.	.
30	7/82-10/89	2.00	-0.58	****	0.00000	-0.34	-0.40	-0.27
31	7/79- 9/89	1.90	-0.14	NS	0.08	-0.06	-0.12	0.00
32	3/75- 9/89	2.00	-0.31	****	0.00000	-0.12	-0.17	-0.08
33	6/82- 9/89	1.82	-0.13	NS	0.22	-0.08	-0.19	0.00
34	7/79- 9/89	1.30	-0.17	*	0.03897	-0.05	-0.08	0.00
35	6/82- 9/89	1.40	-0.43	****	0.00002	-0.22	-0.30	-0.15
36	4/75- 9/89	2.70	-0.28	****	0.00002	-0.16	-0.24	-0.10
37	4/75- 9/89	2.00	-0.01	NS	0.95	0.00	-0.04	0.03
	flow (R_ι = 0.03, NS):		.	.	.	.	.	.
38	4/75- 9/89	2.20	-0.20	**	0.00255	-0.07	-0.12	-0.03

Table E-3.
pH, Seasonal Kendall and Flow Analyses

Station number	Period	Median pH	Tau	Signif- icance	P-value	Slope (Change /year)	90% Lower Limit	90% Upper Limit
						---- pH	units	-----
Big Sandy Basin								
1	3/70-12/89	7.70	0.28	****	0.00000	0.04	0.03	0.05
2	3/70-12/89	8.00	0.12	*	0.02272	0.02	0.00	0.03
3	5/73-12/89	7.68	0.13	NS	0.09	0.02	0.00	0.04
4	3/70-10/89	8.00	0.10	NS	0.07	0.01	0.00	0.03
	flow (Rι = 0.38,	-):	0.09	NS	0.09	0.01	0.00	0.02
5	6/74-12/89	7.60	0.14	NS	0.08	0.01	0.00	0.03
6	4/82-12/89	7.59	0.16	NS	0.10	0.03	0.00	0.07
6	flow (Rι = 0.07,	-):	0.11	NS	0.30	0.02	-0.01	0.05
7	3/70-12/89	7.40	0.15	*	0.01064	0.01	0.00	0.02
8	7/76-12/89	7.70	0.18	*	0.01169	0.03	0.01	0.05
9	7/76-12/89	7.94	0.11	NS	0.12	0.03	0.00	0.06
10	3/70-12/89	7.80	0.26	****	0.00000	0.03	0.02	0.05
	flow (Rι = 0.33,	-):	0.21	****	0.00009	0.02	0.01	0.03
Clinch River Watershed								
11	3/70-12/89	8.00	-0.32	****	0.00000	-0.04	-0.05	-0.03
	flow (Rι = 0.02,	+):	-0.32	****	0.00000	-0.04	-0.05	-0.03
12	1/73-12/89	8.20	-0.19	**	0.00351	-0.03	-0.04	-0.01
13	5/74-12/89	8.17	-0.39	****	0.00000	-0.07	-0.08	-0.05
14	3/70-12/89	7.60	0.02	NS	0.76	0.00	-0.01	0.01
15	1/73-12/89	7.50	0.44	****	0.00000	0.04	0.03	0.05
16	1/73-12/89	7.80	0.08	NS	0.16	0.01	0.00	0.03
17	3/70-12/89	8.35	-0.18	***	0.00068	-0.02	-0.03	-0.01
18	3/70-12/89	7.80	-0.14	*	0.01647	-0.02	-0.03	-0.00
TC	10/73- 3/90	7.80	0.15	NS	0.13	0.02	0.00	0.04
Powell River Watershed								
19	5/70-12/89	7.50	0.17	**	0.00188	0.01	0.00	0.02
20	3/70-12/89	8.00	0.07	NS	0.19	0.01	0.00	0.02
21	3/70-12/89	7.88	-0.05	NS	0.38	-0.00	-0.01	0.00
	flow (Rι = 0.19,	-):	-0.10	NS	0.09	-0.01	-0.02	0.00
22	3/70-12/89	7.80	0.13	*	0.01373	0.02	0.00	0.03
TP	8/73- 3/90	7.80	0.09	NS	0.39	0.01	-0.01	0.04
Holston River Watershed								
23	1/73-12/89	8.47	-0.19	**	0.00144	-0.02	-0.03	-0.01
24	4/70-12/89	8.00	-0.18	***	0.00098	-0.02	-0.04	-0.01
	flow (Rι = 0.13,	-):	-0.24	****	0.00001	-0.03	-0.04	-0.02
25	4/70-12/89	8.27	-0.36	****	0.00000	-0.06	-0.07	-0.04
28	4/70- 9/89	8.16	-0.29	****	0.00000	-0.04	-0.05	-0.02
29	3/70-12/89	8.19	-0.16	**	0.00202	-0.02	-0.03	-0.01
	flow (Rι = 0.01,	NS):	.	.	.	.	.	.
30	4/70-12/89	7.80	-0.26	****	0.00000	-0.03	-0.04	-0.02
31	4/70-12/89	8.10	-0.25	****	0.00000	-0.04	-0.05	-0.03
32	4/70-12/89	8.39	-0.17	**	0.00131	-0.02	-0.03	-0.01
33	4/70-12/89	8.32	-0.24	****	0.00001	-0.03	-0.04	-0.02
34	8/71-12/89	7.80	-0.18	**	0.00759	-0.04	-0.06	-0.01
35	4/70-12/89	7.20	0.10	NS	0.06	0.01	0.00	0.02
36	4/70-12/89	8.28	-0.27	****	0.00000	-0.03	-0.04	-0.02
37	12/72-12/89	8.35	-0.33	****	0.00000	-0.04	-0.05	-0.03
	flow (Rι = 0.02,	+):	-0.32	****	0.00000	-0.04	-0.05	-0.02
38	4/70-12/89	8.50	-0.22	****	0.00005	-0.02	-0.03	-0.01

Table E-4.
Non-Filterable Residue (NFR), Seasonal Kendall and Flow Analyses

Station number	Period	Median (mg/l)	Tau	Signif- icance	P-value	Slope (change /year) ------	90% Lower Limit mg/l	90% Upper Limit -------
			Big Sandy Basin					
1	5/73-10/89	10.00	-0.26	****	0.00005	-0.90	-1.39	-0.50
2	5/73-12/89	6.00	-0.26	****	0.00006	-0.25	-0.47	0.00
3	5/73-10/89	<5.00	-0.07	NS	0.40	0.00	0.00	0.00
4	3/70-10/89	5.00	-0.16	*	0.03141	0.00	-0.31	0.00
	flow (Rι = 0.11,	+):	-0.04	NS	0.60	-0.01	-0.22	0.03
5	6/74- 9/89	<5.00	-0.09	NS	0.32	0.00	0.00	0.00
6	4/82-10/89	8.75	-0.08	NS	0.47	0.00	0.00	0.00
	flow (Rι = 0.03,	NS):	.	.	.	.	.	.
7	1/74-10/89	17.00	-0.21	**	0.00122	-0.83	-1.13	-0.50
8	7/76-10/89	7.00	-0.34	****	0.00001	-0.70	-1.00	-0.39
9	7/76-10/89	7.00	-0.28	***	0.00025	-0.83	-1.42	-0.27
10	3/70- 8/89	17.50	-0.30	****	0.00000	-1.68	-2.50	-0.93
	flow (Rι = 0.07,	+):	-0.30	****	0.00000	-1.94	-2.62	-1.21
			Clinch River Watershed					
11	3/70- 8/89	11.00	-0.27	****	0.00002	-0.57	-0.90	-0.31
	flow (Rι = 0.04,	+):	-0.22	***	0.00029	-0.53	-0.79	-0.29
12	1/73- 8/89	7.00	-0.24	***	0.00073	-0.18	-0.41	0.00
13	5/74- 9/89	10.00	-0.12	NS	0.08	-0.12	-0.50	0.00
14	3/70- 9/89	10.00	-0.17	**	0.00939	-0.40	-0.75	0.00
15	1/73- 9/89	11.00	-0.26	****	0.00003	-0.58	-0.90	-0.28
16	1/73- 9/89	<5.00	-0.19	**	0.00971	0.00	0.00	0.00
17	3/70- 9/89	6.00	-0.28	****	0.00001	-0.42	-0.67	-0.11
18	3/70- 9/89	<5.00	-0.16	*	0.02218	0.00	0.00	0.00
TC	10/73- 1/90	9.00	-0.16	NS	0.11	-0.23	-0.46	0.00
			Powell River Watershed					
19	3/70- 9/89	8.00	-0.28	****	0.00002	-0.44	-0.71	-0.08
20	3/70- 9/89	7.00	-0.25	***	0.00016	-0.42	-0.77	-0.08
21	3/70- 9/89	9.00	-0.15	*	0.02631	0.00	-0.43	0.00
	flow (Rι = 0.12,	+):	-0.14	*	0.02840	-0.38	-0.75	-0.11
22	3/70- 9/89	9.00	-0.29	****	0.00002	-0.56	-0.88	-0.38
TP	8/73- 1/90	9.00	-0.30	**	0.00582	-0.52	-1.07	0.00
			Holston River Watershed					
23	7/79-10/89	<5.00	-0.09	NS	0.35	0.00	0.00	0.00
24	5/79-10/89	5.00	-0.21	*	0.03589	0.00	-0.50	0.00
	flow (insufficient data)							
25	5/80-10/89	<5.00	-0.17	NS	0.10	0.00	0.00	0.00
28	5/70- 9/89	<5.00	-0.16	NS	0.07	0.00	0.00	0.00
29	insufficient data							
	flow (insufficient data)							
30	4/70-10/89	9.00	-0.14	*	0.01299	-0.14	-0.33	0.00
31	1/71- 9/89	10.00	0.06	NS	0.33	0.00	0.00	0.29
32	8/76- 9/89	12.00	-0.13	NS	0.07	-0.41	-0.83	0.00
33	8/76- 9/89	13.00	0.02	NS	0.80	0.00	-0.20	0.33
34	6/76- 9/89	<5.00	-0.07	NS	0.41	0.00	0.00	0.00
35	4/70- 9/89	<5.00	-0.34	****	0.00000	0.00	0.00	0.00
36	8/76- 9/89	7.00	-0.11	NS	0.15	0.00	-0.33	0.00
37	1/73- 9/89	16.00	0.00	NS	0.99	0.00	-0.31	0.33
	flow (Rι = 0.09,	+):	0.11	NS	0.055	0.44	0.09	0.88
38	5/73- 9/89	13.50	-0.08	NS	0.20	-0.18	-0.58	0.00

Table E-5.
Filterable Residue (FR), Seasonal Kendall and Flow Analyses

Station number	Period	Median (mg/l)	Tau	Signif- icance	P-value	Slope (change /year)	90% Lower Limit	90% Upper Limit
						------	mg/l	-------
Big Sandy Basin								
1	5/73-10/89	227.5	0.24	***	0.00015	5.32	3.16	7.46
2	5/73-12/89	249.5	0.30	****	0.00000	8.08	5.19	10.65
3	5/73-10/89	268.5	0.37	****	0.00000	7.46	5.18	10.26
4	3/76-10/89	214.5	0.13	NS	0.07	4.12	0.45	7.89
	flow (Rι = 0.70, -):		0.20	**	0.00730	3.58	1.33	5.79
5	6/74- 9/89	230.3	0.47	****	0.00000	7.37	5.57	8.50
6	4/82-10/89	461.0	0.14	NS	0.19	14.06	-7.01	22.87
	flow (Rι = 0.54, -):		0.23	*	0.02434	11.71	5.99	18.99
7	1/74-10/89	352.0	-0.03	NS	0.60	-0.99	-4.08	3.56
8	7/76-10/89	307.3	0.13	NS	0.07	4.24	0.34	8.17
9	7/76-10/89	291.8	0.31	****	0.00004	11.35	6.74	16.92
10	5/73- 8/89	382.0	0.27	****	0.00002	11.15	7.41	14.36
	flow (Rι = 0.73, -):		0.38	****	0.00000	8.71	6.69	11.38
Clinch River Watershed								
11	5/73- 8/89	174.0	0.10	NS	0.10	1.20	0.00	2.00
	flow (Rι = 0.43, -):		0.03	NS	0.59	0.28	-0.56	0.89
12	1/73- 8/89	154.5	-0.07	NS	0.33	-0.32	-0.85	0.28
13	5/74- 9/89	190.3	0.02	NS	0.72	0.21	-1.01	1.01
14	3/70- 9/89	219.5	0.41	****	0.00000	10.01	7.51	12.99
15	1/73- 9/89	374.0	0.62	****	0.00000	22.78	20.05	25.32
16	1/73- 9/89	90.5	-0.06	NS	0.32	-0.50	-1.38	0.37
17	3/70- 9/89	179.0	0.21	***	0.00069	1.52	0.89	2.20
18	3/70- 9/89	142.5	0.22	***	0.00080	1.80	1.00	2.71
TC	insufficient data							
Powell River Watershed								
19	3/70- 9/89	167.5	0.18	**	0.00451	2.71	0.84	4.51
20	3/70- 9/89	255.8	0.47	****	0.00000	10.69	8.44	13.28
21	3/70- 9/89	188.5	0.30	****	0.00000	4.07	2.24	5.50
	flow (Rι = 0.68, -):		0.38	****	0.00000	2.87	2.13	4.17
22	3/70- 9/89	282.5	0.38	****	0.00000	9.35	6.78	10.90
TP	insufficient data							
Holston River Watershed								
23	7/79-10/89	134.5	-0.01	NS	0.89	-0.40	-2.00	1.13
24	5/79-10/89	119.0	-0.01	NS	0.90	-0.29	-2.75	1.67
	flow (Rι = 0.68, -):		-0.05	NS	0.60	-0.81	-3.12	1.01
25	11/81-10/89	127.0	0.12	NS	0.23	1.99	-0.66	5.91
28	9/78- 9/89	261.5	-0.01	NS	0.95	-0.55	-5.99	7.24
29	insufficient data							
30	4/70-10/89	177.0	0.04	NS	0.46	0.28	-0.37	0.99
31	1/71- 9/89	195.0	0.06	NS	0.30	0.58	-0.41	1.50
32	8/76- 9/89	261.5	0.07	NS	0.36	0.63	-0.65	1.49
33	8/76- 9/89	242.5	0.08	NS	0.26	0.87	-0.34	1.99
34	6/76- 9/89	76.5	0.14	NS	0.09	1.20	0.00	2.67
35	4/70- 9/89	48.5	-0.34	****	0.00000	-2.10	-2.59	-1.55
36	8/76- 9/89	299.0	0.13	NS	0.07	2.00	0.09	3.56
37	1/73- 9/89	248.3	0.15	*	0.01036	0.99	0.40	1.74
	flow (Rι = 0.10, -):		0.08	NS	0.21	0.47	-0.22	1.27
38	5/73- 9/89	273.0	0.14	*	0.02521	1.17	0.25	1.99

Table E-6.
Total Kjeldahl Nitrogen (TKN), Seasonal Kendall and Flow Analyses

Station number	Period	Median (mg/l)	Tau	Signif-icance	P-value	Slope (change /year)	90% Lower Limit	90% Upper Limit
						------	mg/l	-------
Big Sandy Basin								
1	3/70-11/89	0.20	0.05	NS	0.46	0.00	0.00	0.00
2	3/70-11/89	0.20	0.00	NS	0.95	0.00	0.00	0.00
3	5/73-11/89	0.20	0.15	NS	0.06	0.00	0.00	0.01
4	5/73-11/89	0.20	0.08	NS	0.19	0.00	0.00	0.00
	flow (Rι = 0.01,	NS):	.	.	.	.	.	.
5	6/74-11/89	0.20	0.03	NS	0.73	0.00	0.00	0.00
6	4/82-11/89	0.20	-0.18	NS	0.09	0.00	-0.02	0.00
	flow (Rι = 0.02,	NS):	.	.	.	.	.	.
7	3/70-11/89	4.25	0.05	NS	0.46	0.05	-0.06	0.18
8	7/76-11/89	0.10	0.05	NS	0.51	0.00	0.00	0.00
9	7/76-11/89	0.20	-0.06	NS	0.46	0.00	0.00	0.00
10	5/73-11/89	0.20	0.06	NS	0.39	0.00	0.00	0.00
	flow (Rι = 0.01,	NS):	.	.	.	.	.	.
Clinch River Watershed								
11	3/70-11/89	0.30	0.07	NS	0.27	0.00	0.00	0.00
	flow (Rι = 0.45,	-):	-0.00	NS	0.99	0.00	-0.00	0.00
12	5/73-11/89	0.20	-0.06	NS	0.39	0.00	0.00	0.00
13	5/74-11/89	0.20	0.29	****	0.00003	0.01	0.00	0.02
14	3/70-11/89	0.30	0.26	****	0.00003	0.01	0.01	0.02
15	5/73-11/89	1.40	0.20	***	0.00078	0.05	0.03	0.08
16	5/73-11/89	<0.10	0.00	NS	1.00	0.00	0.00	0.00
17	3/70-11/89	0.20	0.27	****	0.00002	0.00	0.00	0.01
18	3/70-11/89	<0.10	0.00	NS	1.00	0.00	0.00	0.00
TC	insufficient data							
Powell River Watershed								
19	3/70-11/89	<0.10	0.00	NS	1.00	0.00	0.00	0.00
20	3/70-11/89	0.20	0.12	NS	0.051	0.00	0.00	0.01
21	5/73-11/89	0.20	0.21	***	0.00086	0.00	0.00	0.01
	flow (Rι = 0.02,	NS):	.	.	.	.	.	.
22	3/70-11/89	0.20	0.02	NS	0.70	0.00	0.00	0.00
TP	insufficient data							
Holston River Watershed								
23	5/73-11/89	0.20	0.28	****	0.00001	0.01	0.00	0.01
24	5/73-11/89	0.20	0.18	**	0.00281	0.00	0.00	0.00
	flow (Rι = 0.03,	-):	0.12	*	0.03736	0.00	0.00	0.01
25	4/70-11/89	0.20	0.24	***	0.00012	0.00	0.00	0.01
28	4/70-11/89	0.20	0.26	****	0.00004	0.00	0.00	0.01
29	5/73-11/89	0.20	0.26	****	0.00003	0.01	0.00	0.01
	flow (Rι = 0.04,	-):	0.14	*	0.01725	0.00	0.00	0.01
30	4/70-11/89	0.30	0.30	****	0.00000	0.01	0.01	0.01
31	4/70-11/89	0.20	0.30	****	0.00000	0.01	0.00	0.01
32	4/70-11/89	0.40	-0.22	***	0.00016	-0.01	-0.02	0.00
33	4/70-11/89	0.30	0.31	****	0.00000	0.01	0.01	0.02
34	8/71-11/89	0.10	-0.02	NS	0.79	0.00	0.00	0.00
35	4/70-11/89	0.10	-0.10	NS	0.11	0.00	0.00	0.00
36	4/70-11/89	0.30	0.07	NS	0.22	0.00	0.00	0.01
37	5/73-11/89	0.20	0.24	****	0.00005	0.01	0.00	0.01
	flow (Rι = 0.01,	NS):	.	.	.	.	.	.
38	4/70-11/89	0.30	0.18	**	0.00343	0.00	0.00	0.01

Table E-7.
Total Phosphorus (TP), Seasonal Kendall and Flow Analyses

Station number	Period	Median (mg/l)	Tau	Signif- icance	P-value	Slope (change /year)	90% Lower Limit	90% Upper Limit
						------	mg/l	-------
Big Sandy Basin								
1	7/79-11/89	<0.10	0.09	NS	0.37	0.00	0.00	0.00
2	8/79-11/89	<0.10	0.06	NS	0.59	0.00	0.00	0.00
3	8/79-11/89	<0.10	0.10	NS	0.32	0.00	0.00	0.00
4	8/79-11/89	<0.10	0.13	NS	0.20	0.00	0.00	0.00
	flow (insufficient data)							
5	8/79-11/89	<0.10	0.11	NS	0.32	0.00	0.00	0.00
6	4/82-11/89	<0.10	0.05	NS	0.70	0.00	0.00	0.00
	flow (insufficient data)							
7	8/79-11/89	1.30	-0.04	NS	0.60	-0.01	-0.07	0.03
8	7/79-11/89	<0.10	0.05	NS	0.66	0.00	0.00	0.00
9	7/79-11/89	<0.10	0.14	NS	0.13	0.00	0.00	0.00
10	1/79-11/89	<0.10	0.17	NS	0.09	0.00	0.00	0.00
	flow (insufficient data)							
Clinch River Watershed								
11	7/79-11/89	0.10	0.02	NS	0.80	0.00	0.00	0.00
	flow (insufficient data)							
12	7/79-11/89	<0.10	0.20	*	0.03419	0.00	0.00	0.00
13	7/79-11/89	<0.10	0.06	NS	0.55	0.00	0.00	0.00
14	7/79-10/89	0.10	0.05	NS	0.60	0.00	0.00	0.00
15	7/79-11/89	0.40	0.02	NS	0.85	0.00	-0.01	0.02
16	7/79-11/89	0.10	-0.10	NS	0.68	0.00	0.00	0.00
17	12/79-11/89	<0.10	0.04	NS	0.71	0.00	0.00	0.00
18	7/79-11/89	0.10	0.00	NS	1.00	0.00	0.00	0.00
TC	10/73- 1/90	0.03	-0.02	NS	0.84	0.00	-0.00	0.00
Powell River Watershed								
19	7/79-11/89	0.10	0.12	NS	0.21	0.00	0.00	0.00
20	7/79-11/89	<0.10	0.00	NS	1.00	0.00	0.00	0.00
21	8/79-11/89	<0.10	-0.01	NS	0.90	0.00	0.00	0.00
	flow (insufficient data)							
22	7/79-11/89	<0.10	0.06	NS	0.57	0.00	0.00	0.00
TP	8/73- 1/90	0.03	-0.06	NS	0.57	0.00	-0.00	0.00
Holston River Watershed								
23	12/78-11/89	<0.10	0.24	**	0.00962	0.00	0.00	0.00
24	1/79-11/89	<0.10	0.24	*	0.02241	0.00	0.00	0.00
	flow (insufficient data)							
25	11/80-11/89	<0.10	0.30	**	0.00291	0.00	0.00	0.00
28	7/79-11/89	<0.10	0.06	NS	0.54	0.00	0.00	0.00
29	7/79-11/89	<0.10	0.00	NS	1.00	0.00	0.00	0.00
	flow (insufficient data)							
30	5/79-11/89	0.10	0.15	NS	0.09	0.00	0.00	0.00
31	7/79-11/89	0.10	0.34	***	0.00011	0.00	0.00	0.00
32	7/79-11/89	0.20	0.14	NS	0.11	0.00	0.00	0.01
33	7/79-11/89	0.20	0.23	**	0.00532	0.01	0.00	0.02
34	12/78-11/89	<0.10	0.12	NS	0.20	0.00	0.00	0.00
35	7 79-11/89	<0.10	0.01	NS	0.96	0.00	0.00	0.00
36	7 79-11/89	0.10	0.19	*	0.03097	0.00	0.00	0.00
37	7 79-11/89	<0.10	0.03	NS	0.77	0.00	0.00	0.00
	flow (insufficient data)							
38	7 79-11/89	<0.10	0.13	NS	0.14	0.00	0.00	0.00

Table E-8.
Fecal Coliforms (FC) Seasonal Kendall and Flow Analyses

Station number	Period	Median (/100 ml)	Tau	Signif- icance	P-value	Slope (change /year)	90% Lower Limit	90% Upper Limit
						--- per	100 ml	----
			Big Sandy Basin					
1	12/70-12/89	1200	-0.24	***	0.00033	-78.60	-125	-39.96
2	2/71-12/89	1200	-0.25	***	0.00048	-66.72	-106.7	-33.36
3	5/73-12/89	<100	-0.06	NS	0.45	0.00	0.00	0.00
4	2/71-12/89	700	-0.33	****	0.00000	-53.55	-88.90	-39.97
	flow (Rι = 0.01, NS):		.	.	.	.	.	.
5	6/74-12/89	<100	-0.05	NS	0.58	0.00	0.00	0.00
6	4/82-12/89	100	-0.04	NS	0.75	0.00	-12.50	0.00
	flow (Rι = 0.03, NS):		.	.	.	.	.	.
7	2/71-12/89	100	0.11	NS	0.17	0.00	0.00	4.55
8	8/76-12/89	300	-0.31	****	0.00003	-44.43	-62.49	-21.42
9	7/76-10/89	1400	-0.40	***	0.00027	-225	-371.4	-125
10	12/70-12/89	1000	-0.22	***	0.00038	-54.50	-84.40	-28.60
	flow (Rι = 0.09, +):		-0.21	***	0.00045	-57.40	-86.70	-23.40
			Clinch River Watershed					
11	3/71-12/89	600	-0.24	***	0.00040	-40.02	-66.66	-19.98
	flow (Rι = 0.03, -):		-0.19	**	0.00426	-39.84	-60.30	-18.84
12	1/73-12/89	100	-0.21	**	0.00308	-4.17	-11.54	0.00
13	5/74-12/89	200	-0.30	****	0.00002	-25.00	-37.50	-9.10
14	12/70-12/89	700	-0.10	NS	0.11	-16.66	-39.97	0.00
15	12/73-12/89	900	-0.35	***	0.00083	-233.4	-350	-74.97
16	1/73-12/89	200	-0.20	**	0.00115	0.00	-11.12	0.00
17	3/71-12/89	100	-0.29	****	0.00000	-10.00	-17.86	-4.17
18	3/71-12/89	300	-0.29	****	0.00000	-12.51	-24.99	-2.94
TP	insufficient data							
			Powell River Watershed					
19	2/71-12/89	2700	-0.07	NS	0.25	0.00	0.00	0.00
20	4/71-12/89	1500	-0.19	**	0.00669	-65.10	-123.1	-25.05
21	1/71-12/89	300	-0.27	****	0.00001	-21.54	-35.01	-8.34
	flow (Rι = 0.21, +):		-0.25	****	0.00004	-22.59	-35.19	-12.45
22	4/71-12/89	2100	-0.03	NS	0.73	-17.85	-116.8	45.78
TP	insufficient data							
			Holston River Watershed					
23	1/73-12/89	300	-0.18	**	0.00608	-12.51	-26.91	0.00
24	12/70-12/89	300	-0.11	NS	0.08	-2.94	-13.65	0.00
	flow (Rι = 0.03, NS):		.	.	.	.	.	.
25	12/70-12/89	300	-0.28	****	0.00000	-20.43	-33.33	-12.51
28	12/70-11/89	100	-0.04	NS	0.55	0.00	0.00	0.00
29	3/71-12/89	300	-0.33	****	0.00000	-27.27	-40.92	-16.68
	flow (Rι = 0.06, +):		-0.14	*	0.01552	-16.59	-32.40	-5.58
30	12/70-12/89	700	-0.04	NS	0.49	-6.65	-23.10	8.33
31	3/71-12/89	300	-0.01	NS	0.92	0.00	-8.34	3.84
32	4/71-12/89	400	-0.19	**	0.00517	-25.00	-60.72	-3.32
33	4/71-12/89	900	-0.07	NS	0.26	-15.39	-39.96	0.00
34	8/71-12/89	300	-0.03	NS	0.67	0.00	-16.68	0.00
35	3/71-12/89	300	-0.37	****	0.00000	-50.01	-60.72	-30.78
36	3/71-12/89	950	0.05	NS	0.63	6.27	-21.47	46.83
37	12/72-12/89	900	-0.20	**	0.00174	-42.30	-62.46	-18.72
	flow (Rι = 0.04, +):		-0.12	NS	0.06	-24.57	-52.47	-3.51
38	3/71-12/89	2350	0.01	NS	0.89	10.10	-50.05	86.71

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