

**NC Division of Water Quality
Planning Branch
Modeling and TMDL Unit**

MEMORANDUM

Date: 11/02/2009
To: Kathy Stecker
From: Pam Behm
CC: Alan Clark, Dianne Reid, Heather Patt, John Huisman, and Jennie Atkins
Subject: Trend Analyses in the Tar-Pam River Basin in North Carolina

Introduction

In 2003, the Modeling and TMDL Unit (MTU) performed trend analysis of nutrient concentrations in the Tar-Pam River Basin at the Basinwide Planning Unit's request (Kennedy, 2003 attached as an appendix to this memorandum). The 2003 trend analysis focused on data from the ambient monitoring station O6500000 for the 1991 – 2002 timeframe. This station is located at Grimesland, which is approximately 7-miles upstream of Washington, shown below in Figure 1. Results of the 2003 trend analysis indicated that both total nitrogen (TN) and total phosphorus (TP) concentrations were decreasing.

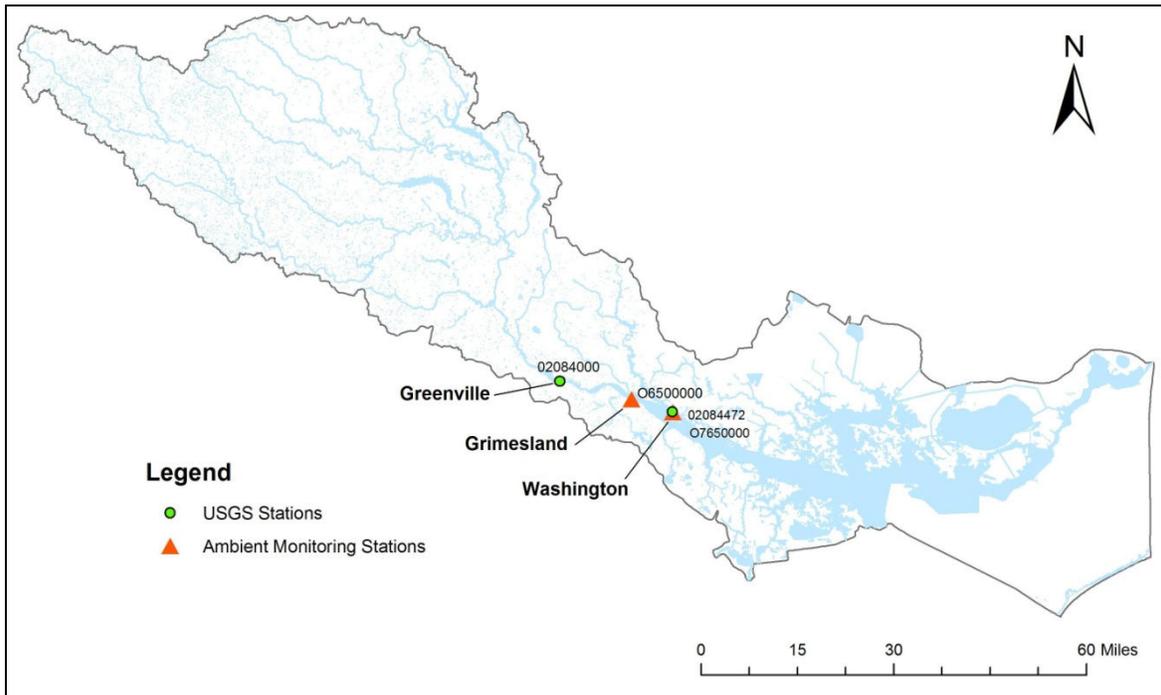


Figure 1. Tar-Pamlico River Basin

The Basinwide Planning Unit requested the MTU perform trend analysis of annual nutrient loads and concentrations for the 1991 – 2008 timeframe for the same station used for the 2003 trend analysis to evaluate progress towards meeting TMDL reduction goals. MTU does not recommend performing trend analysis on load because the effects of flow could lead to misleading results. At this point in time, there are not enough years of data to perform statistical testing on annual load; however there are enough data to perform statistical analysis of daily load. In addition to concentration, trend analysis results for daily load are presented in this report, but must be interpreted carefully.

Daily load was calculated as measured concentration multiplied by average daily flow and converted to units of kilograms per day. For the 1991-2008 timeframe, there are 186 data points, with an average of 10.3 sampling events per year. Trend analysis was performed for TN, TP, Total Kjeldahl Nitrogen (TKN), ammonia, and nitrate/nitrite. TN is not directly measured and was calculated as nitrate/nitrite plus TKN.

This analysis was designed to replicate the methods and location of the 2003 analysis for the 1991-2008 timeframe. This analysis used the same data for 1991-2002 as used in the 2003 trend analysis. As described in Kennedy, 2003, due to the lack of a stream gage at Grimesland, flow data for 2003-2008 was generated by multiplying flow from the closest upstream gage, which is approximately 13 miles upstream at Greenville (USGS 02084000), by a drainage area (DA) ratio of 1.07 (Grimesland DA divided by Greenville DA).

Methods

The purpose of any statistical trend testing is to determine whether a set of data that arise from a particular probability distribution represent a detectable increase or decrease over time (or space). There are a wide variety of trend testing techniques, all of which have certain assumptions that must be met for the analysis to be valid. The result of false assumptions may be that interpretations are incorrect or unnecessarily inconclusive.

Detecting trends in a water quality data series is not as simple as drawing a line of best fit and measuring the slope. There are likely to be multiple factors contributing to variation in water quality over time, many of which can hide or exaggerate trend components in the data. Changes in water quality brought about by human activity will usually be superimposed on natural sources of variation such as flow and season. Identification and separation of these components is one of the most important tasks in trend testing.

The WQStat Plus model was used to evaluate trends in TP, TN, TKN, ammonia, and nitrate/nitrite in the Tar River. The model is a multi-faceted computer program, which is capable of computing flow-adjusted concentration and the nonparametric Seasonal Kendall test.

For water quality constituents that are closely related to flow, an apparent trend in quality could be caused by a change in flow. By flow adjusting concentrations before trend analysis, one is able to determine the magnitude and statistical significance of trends that are not explained by

flow. The WQStat Plus model removes the concentration variation related to stream flow with flow-adjusted data by assuming a log-log relationship between water quality and flow:

$$\log \text{ concentration} = b(\log \text{ flow}) + a$$

WQStat Plus uses linear regression to estimate the slope (b) and intercept (a) of the line above. The resulting equation is used to predict concentration at each sampling point. Then, from each water quality observation, the corresponding prediction is subtracted, producing a series of residuals. To each residual, the mean of the original log concentration series is added, producing a flow-adjusted series of log concentrations.

Many water quality constituents are also influenced by season. The Seasonal Kendall test accounts for seasonality by computing the Mann-Kendall test on each of the user-specified seasons separately, and then combining the results (Helsel and Hirsch, 2002). For this analysis, seasons are defined as monthly. So, for monthly “seasons,” January data are compared only with January, February only with February, etc.

The Seasonal Kendall test was applied to test a null hypothesis that there was no trend in measured nutrient concentrations or daily load. The alternative hypothesis is that there is a trend. For this analysis, upward trend (positive slope) indicates degradation of water quality, whereas downward trend (negative slope) indicates improvement of water quality. The hypothesis was tested at 95% confidence level.

Trend Analysis Results

Flow-Adjusted Concentration

The results of the Seasonal Kendall test for flow-adjusted concentrations of TP, TN, TKN, ammonia, and nitrate/nitrite are provided in Table 1. The results indicate that there were statistically significant trends for ammonia, nitrate/nitrite, and TKN. There was no statistically significant trend for TN or TP. TKN showed an increasing trend in concentration, while both ammonia and nitrate/nitrite showed decreasing trends.

Trend slope (seasonal sen trend slope) represents the median rate of change in flow-adjusted concentrations and is shown in Table 1 for each statistically significant parameter. For example, the statistically significant upward slope of TKN suggests that the average increase in median TKN concentration per year was 0.01 mg/L during the study period, representing a 32% increase in median TKN concentration over the 18 years of the study period. Conversely, there was a 28% decrease in nitrate/nitrite concentrations.

Table 1. Results of Seasonal Kendall Trend Analysis for flow-adjusted constituents.

Parameters	Seasonal Sen Trend Slope (mg/L per year)	Significant Trend at 95%	1991 Median	Avg. % Change in Median from 1991 - 2008
TP (mg/L)	x	No	0.16	x
TN (mg/L)	x	No	1.27	x
TKN (mg/L)	0.01	Yes	0.50	32%
Ammonia (mg/L)	-0.002	Yes	0.07	-45%
NO ₂ + NO ₃ (mg/L)	-0.01	Yes	0.77	-28%

Daily Load

The results of the Seasonal Kendall test for daily loads of TP, TN, TKN, ammonia, and nitrate/nitrite are provided in Table 2. Daily average flow was also tested for trend to check for bias. The results indicate that there were statistically significant decreasing trends in ammonia and nitrate/nitrite daily loads. There was no statistically significant trend for TKN, TN, or TP. As shown in Table 2, there was a statistically significant decreasing trend for flow. Therefore, even though there is a statistically significant decreasing trend for ammonia and nitrate/nitrite flow adjusted concentrations (Table 1), it is possible that the decreasing trends for ammonia and nitrate/nitrate loads are also partially explained by the decreasing trend in flow. Trend slope (seasonal sen trend slope) represents the median rate of change in daily load and is shown in Table 2 for each statistically significant parameter.

Table 2. Results of Seasonal Kendall Load Trend Analysis.

Parameters	Seasonal Sen Trend Slope (kg/d per year)	Significant Trend at 95%
TP (kg/day)	x	No
TN (kg/day)	x	No
TKN (kg/day)	x	No
Ammonia (kg/day)	-8.84	Yes
NO ₂ + NO ₃ (kg/day)	-44.37	Yes
	(cfs per year)	
Flow (cfs)	-20	Yes

Annual Load

As mentioned above, there are not enough years to do statistical trend analysis of annual load. As an alternative, the U.S. Army Corps of Engineers' FLUX program was used to estimate annual loads of TP and TN for 1991-2008 and plotted as a time series.

The TP annual load time series is provided below in Figure 2. Annual total precipitation is also provided for comparison. As shown in Figure 2, 2007 and 2008 are the only years with total TP loads less than the 1991 baseline load. It should be noted that both years were impacted by drought conditions. The annual load of TP is closely related to the amount of precipitation. This implies that the total load is being driven more by the amount of precipitation, which drives flow, than by nutrient concentrations.

The TN annual load time series is provided below in Figure 3. As with TP, the only years with estimated total TN loads less than the 1991 baseline load are 2007 and 2008. This is more likely due to the drought conditions than due to decreases in nutrient concentrations.

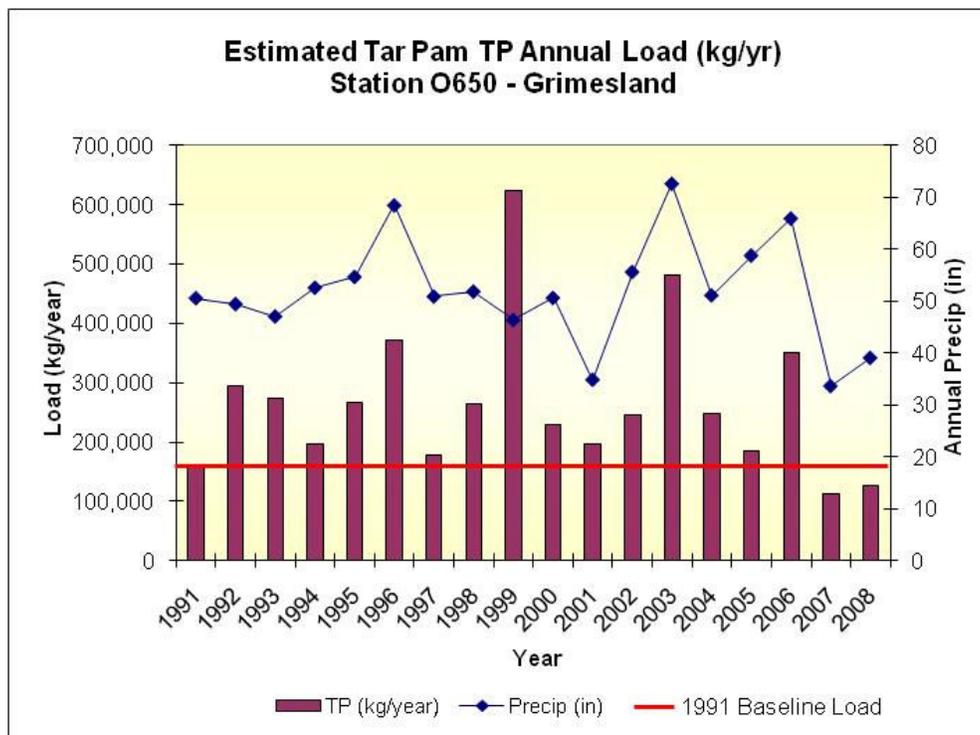


Figure 2. Time series of annual load of TP (kg/year) with total annual precipitation provided for comparison.

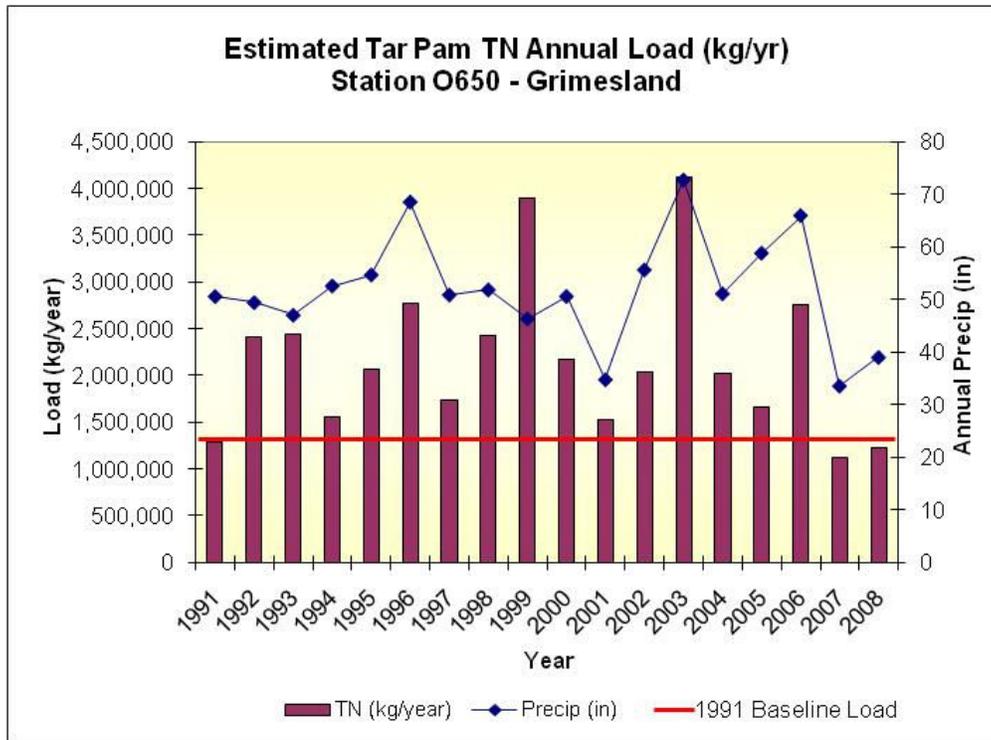


Figure 3. Time series of annual load of TN (kg/year) with total annual precipitation provided for comparison.

Conclusion

Trend analyses of TP, TN, TKN, Ammonia, and Nitrate/Nitrite concentrations and estimated daily loads were performed for the Tar River at Station O650000. The WQStat Plus model was used to test a null hypothesis that no trends in nutrient concentrations or daily loads exist at the 95% confidence level. The results are summarized below in Table 3.

Table 3. Summary of Trend Analysis Results for concentrations and daily loads.

Constituent	1991-2008	
	Concentration	Daily Load
TP	No trend	No trend
TN	No trend	No trend
Ammonia	Decreasing	Decreasing
NO2+NO3	Decreasing	Decreasing
TKN	Increasing	No trend
Flow	-----	Decreasing

The results of the trend analyses indicate that, from 1991 through 2008, concentrations of TP and TN show no trend in the Tar River at Station O650000. This is in contrast to the decreasing trends observed in the 2003 trend analysis of 1991 through 2002 data.

Further analyses of the nitrogen series indicates that the increasing trend in TKN concentrations cancels out the decreasing trends observed for nitrate/nitrate concentrations, resulting in no trend for TN. TKN is comprised of ammonia and organic nitrogen. Because there was a decreasing trend observed for ammonia, the increase in TKN must be explained by an increase in organic nitrogen.

References

Helsel and Hirsch, 2002. "Chapter A3: Statistical Methods in Water Resources." In "Book 4, Hydrologic Analysis and Interpretation." United States Geological Survey.

Kennedy, Todd, 2003. Trend Analysis of Nutrient Loading in the Tar-Pamlico Basin. Division of Water Quality Internal Memo.

APPENDIX A.

Division of Water Quality Internal Memo
Todd Kennedy, 2003. Trend Analysis of Nutrient Loading in the Tar-Pamlico Basin.

**NC Division of Water Quality
Planning Branch**

MEMORANDUM

To: Michelle Woolfolk
From: J. Todd Kennedy
CC: Rich Gannon
Cam McNutt
Date: 5/23/03
Re: Trend Analysis of Nutrient Loading in the Tar-Pamlico Basin

Introduction

In 1989, the EMC classified the Tar-Pamlico River Basin as nutrient sensitive (NSW) due to excessive algal blooms and fish kills in the upper Pamlico Estuary. This designation required the state to develop a nutrient management strategy. The initial strategy focused primarily on point source discharges. A revised strategy in 1992 set out to establish a nutrient reduction goal and a nutrient trading program with nonpoint sources. Phase I of the strategy was implemented between 1991 and 1994. Implementation of Phase II began in 1995. Mandated rules by the EMC to achieve the nonpoint source nutrient reduction goals across the basin went into effect in 2000 and 2001.

Based on the estuarine modeling completed during Phase I, a 30 percent reduction in total nitrogen loads to the estuary from 1991 conditions (baseline) was set as an interim goal in Phase II, along with no increase in phosphorus loads. These goals are adaptable as progress and conditions warrant.

This analysis will evaluate the trends in nutrient loading in the Tar-Pamlico Basin from 1991 to 2002. While many trend assessment methods are available, a nonparametric trend test, the Seasonal Kendall test, often performs better than other parametric methods for data sets that are commonly non-normal, vary seasonally, and contain outliers and censored values. Future work may include quantification of annual nutrient loads and trend analysis of water quality constituents in the estuary.

Methods

The Seasonal Kendall test, a generalization of the Mann-Kendall test, is used to detect monotonic trends in water quality data (Helsel and Hirsch 1992). The null hypothesis is that no trend exists. If the p value indicates significance at the 95% confidence level, then a trend exists. The rate of change over time is computed using a seasonal Sen slope estimator, expressed as a change in units per year. Trend slope is a measure of monotonic change during the selected study period.

The primary challenge in trend analysis is to separate the components of observed variability to distinguish human impact from natural variability. Accordingly, it is generally easier and more

powerful to discern trends using flow-adjusted concentrations rather than loads over a decade scale due to weather-related variability in loads. The component of variation related to stream flow is removed with flow-adjusted data by using a robust smoothing technique called LOWESS (Locally Weighted Scatterplot Smooth). The method describes the relationship between concentration (Y) and flow (X) without assuming linearity or normality. The resulting residuals are considered flow-adjusted concentrations. Further, the Seasonal Kendall test reduces the adverse effect of seasonal differences by making comparisons of data from similar seasons (months in this case).

While the test is robust with respect to many violations of statistical assumption, autocorrelation is not one of them. Autocorrelation or serial correlation can be understood as follows: a measurement at one time period reflects the concentration at a previous time period; or in other words the "extra" data do not provide any new information. Appropriate adjustments during analysis must be made to deal with this. Therefore, the data are checked for lag-1 autocorrelation. If significant, an autocorrelation-corrected version of the Seasonal Kendall test is used.

The nutrient reduction goal for the Tar-Pamlico is based on loading at Washington. While water quality and flow monitoring data is available for this site, frequent reverse flows occur (Figure 1). The severity of the drought over the past three years likely contributed to these occurrences. Given the potential problems associated with trend evaluation in this setting, a site approximately 7 miles upstream at Grimesland (O6500000) was chosen. This ambient site has sufficient historical data that can be used for trend analysis.

Nutrient data from Grimesland (NO_x, TKN, and TP) were obtained from the ambient database. Total Nitrogen (TN) was calculated as NO_x plus TKN. There were no data available for 1995. Censored values were few in number (less than 5%) and were assigned a value of ½ the reporting limit. The change in reporting levels by ESB is not expected to have much effect on the analysis, as differences in detection levels for pre-2001 and post-7/25/01 are not large. Since robust procedures are used, data collected during and immediately following Hurricane Fran in 9/96 did not have large effects on the analysis.

Due to the lack of a stream gage at Grimesland, flow data must be generated. The closest upstream gage is approximately 13 miles at Greenville (USGS 02084000). However, since continuous flow has only been collected since 1997 at this site, a relationship between flow at Tarboro (USGS 02083500), where flow has been collected since 1896, was established through log-linear regression to generate a longer term flow series for Greenville (1991-2002), and adjusted slightly by a drainage area ratio to obtain estimated flow at Grimesland.

Results

Considerable autocorrelation existed in the daily flow data sets from Tarboro and Greenville. Therefore, only every 14th set of daily observations was used to fit the regression model. A similar procedure was used in work by Stow and Borsuk (2003) in the Neuse. This was checked by testing for significant correlation in the lagged residuals of the model using Kendall tau and Spearman rho. The final transformed data regression (Figure 2) was

$$\ln (\text{Greenville Flow in cfs}) = 0.385 + 0.965 \ln (\text{Tarboro Flow in cfs}).$$

The R² and transformed standard error were 0.98 and 0.20, respectively. Daily flow estimates at Greenville were obtained via exponentiation and adjusted with a retransformation bias correction

(Koch and Smillie 1986). Finally, flow at Grimesland (Figure 3) was generated by multiplying the estimated Greenville flow by a drainage area (DA) ratio of 1.07 (Grimesland DA divided by Greenville DA). The estimated DA at Grimesland is 2,816 mi². Estimated average and median daily flows at Grimesland (1991-2002) were 2756 cfs and 1416 cfs, respectively.

The drainage area at Washington is 3,080 mi², which includes 243 mi² in subbasin 03-03-06. The Robersonville WWTP discharges into this subbasin. Between Grimesland and Washington, dischargers include the Washington WWTP and National Spinning, for a total of 5.5 MGD.

The need to use flow-adjusted concentrations rather than loads is first illustrated using a simple log-linear regression of nutrient load and flow at Grimesland. Regression results indicated that 97% and 92% of variability in TN and TP load, respectively, could be explained by flow.

Times series plots for nutrients are given in Figures 4 through 7. A visual inspection of the annual boxplots indicates that a downward trend in nutrient concentrations may exist. Further testing will help to remove the influence of exogenous variables and determine if a significant trend associated with human intervention truly exists.

LOWESS plots for TN and TP against flow are presented in Figures 8 and 9. The residuals of the LOWESS smooths were tested using the Seasonal Kendall test. Seasonal Kendall with correction for lag-1 serial correlation was used for TN (Figure 10). Serial correlation correction was not necessary for TP (Figure 11). Tabular results of the tests are shown below in Table 1.

The results indicate significant, negative trends in flow-adjusted concentrations for both TP and TN. Trend slopes represent the median rate of change in flow-adjusted concentrations, and serve as an approximation to actual temporal variations after natural variability has been removed. Over the selected study period of 1991-2002, the estimated decrease in TP and TN concentration based on the seasonal Sen slope times 12 years are 0.046 mg/L and 0.203 mg/L, respectively.

The downward trend in flow-adjusted concentrations can also be expressed as a combined percentage over the study period. This was calculated by dividing the trend slope by the base median concentration (over the first 24 months 1991-1992), and multiplying by 12 years and then 100 to convert it to a percent. Accordingly, reductions in the base median TP and TN through 2002 are estimated to be 33% and 18%, respectively.

Table 1. Result of Seasonal Kendall Trend Analysis Using Flow-Adjusted Nutrients at Grimesland (1991-2002).

	p value	Significant Trend?	Seasonal Sen trend slope mg/L/yr	95% CL around trend slope mg/L/yr	% Change in the Median per year	Median of Unadjusted Data 1991-2002 mg/L	Base Median 1991-1992 mg/L
TN	0.0197	yes	-0.0169	-0.0325 to -0.0030	-1.83%	0.925	1.13
TP	0.0006	yes	-0.0038	-0.0058 to -0.0013	-3.78%	0.100	0.14

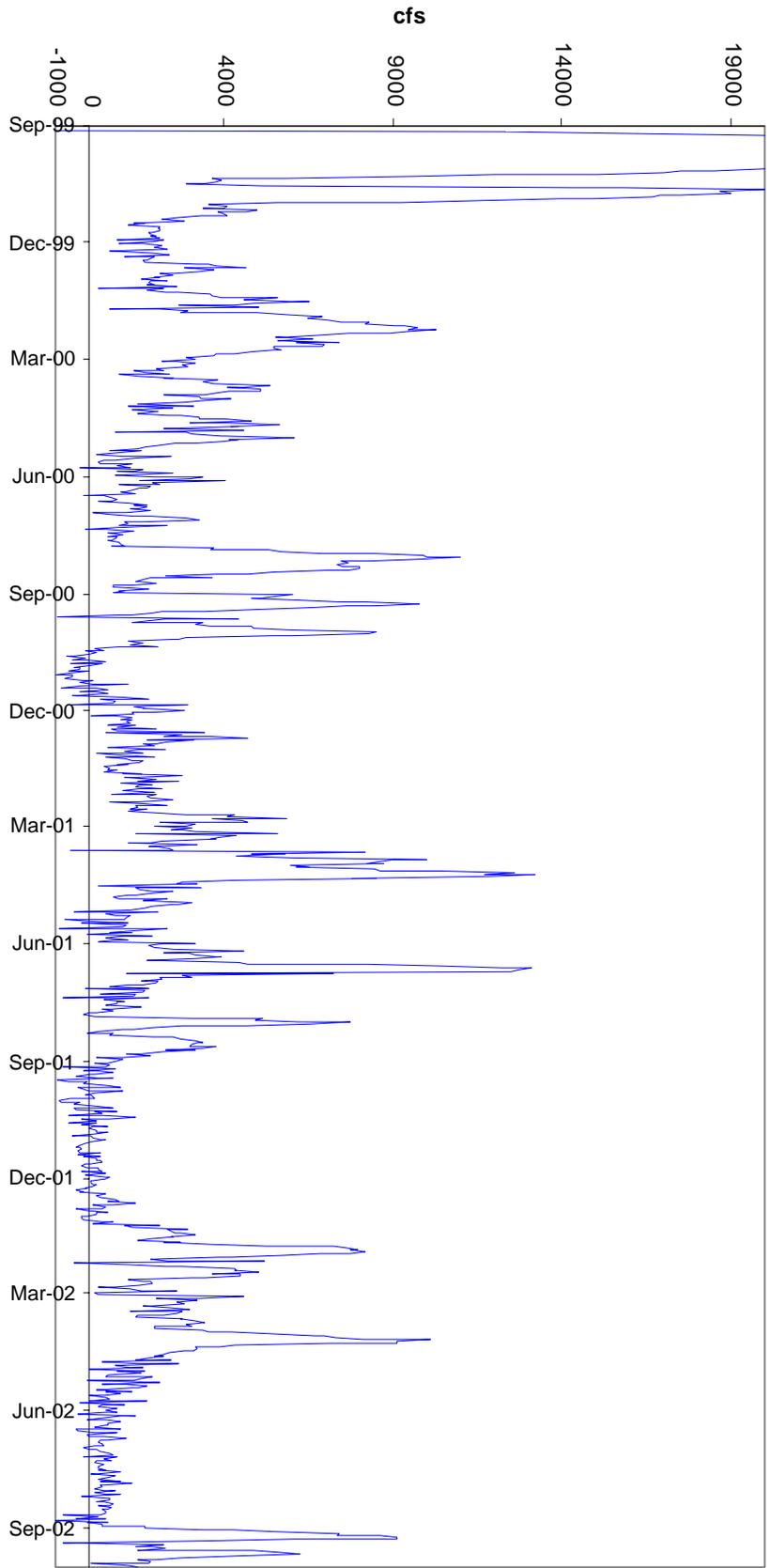
References

Helsel, D.R. and R.M. Hirsch. 1992. Statistical Methods in Water Resources. Elsevier, Amsterdam.

Koch, R.W. and G.M. Smillie. 1986. Bias in hydrologic prediction using log-transformed regression models. *Water Resources Bulletin* 22(5):717-723.

Stow, C.A. and M.E. Borsuk. 2003. Assessing TMDL effectiveness using flow-adjusted concentrations: A case study of the Neuse River, NC. *Environmental Science and Technology* 37 (10): 2043-2050.

Figure 1.



Washington

Figure 2.

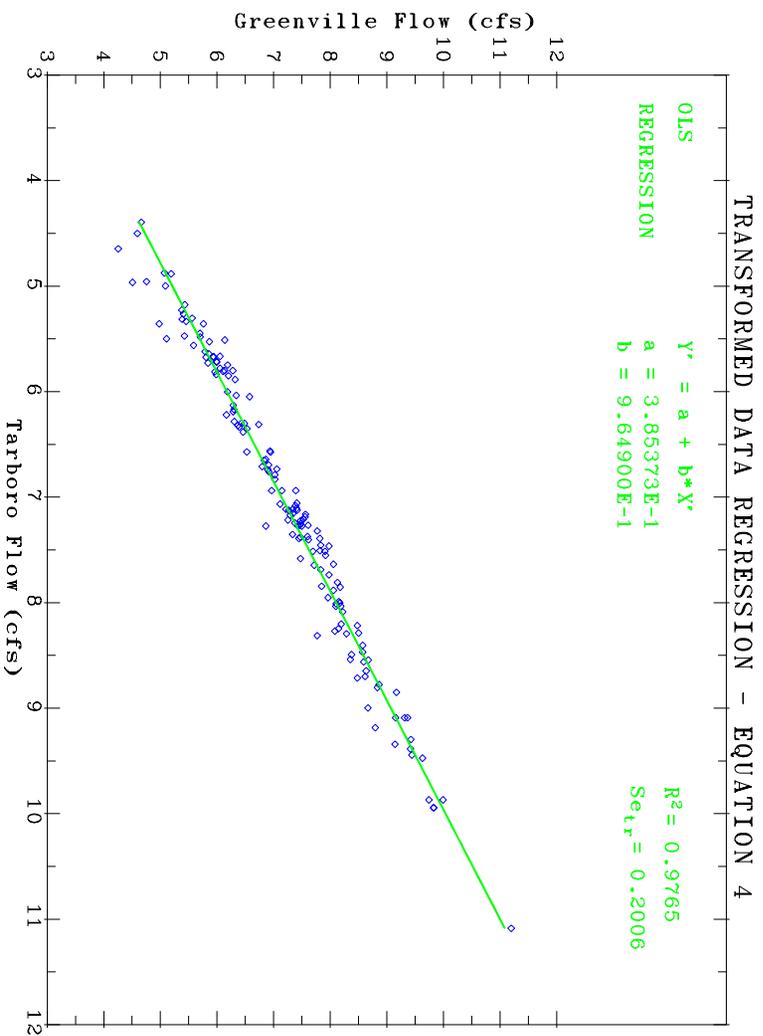


Figure 3.

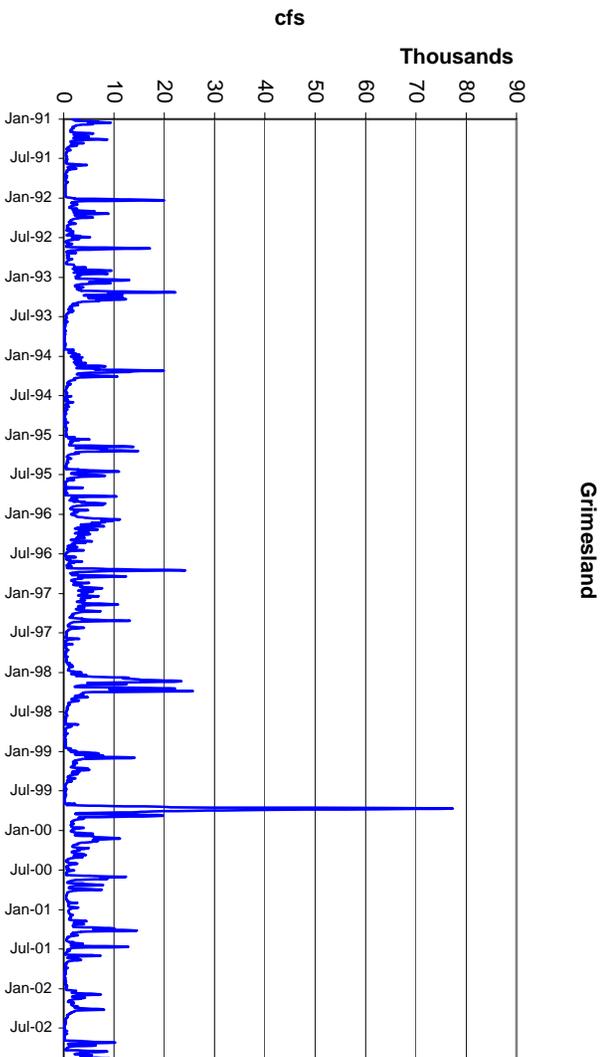


Figure 4.

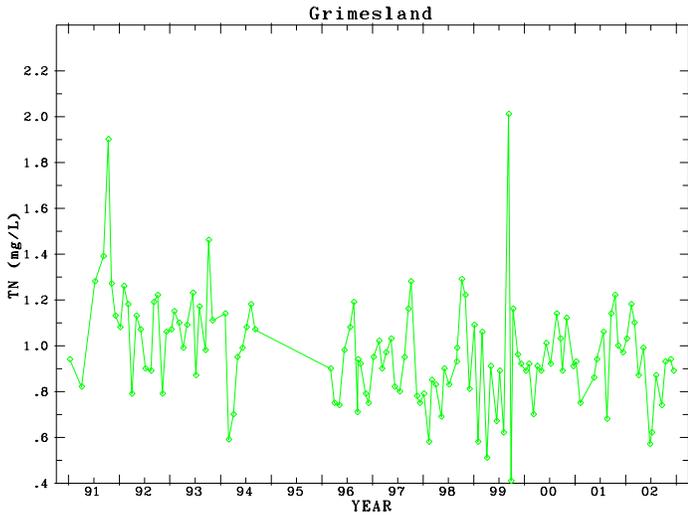


Figure 5.

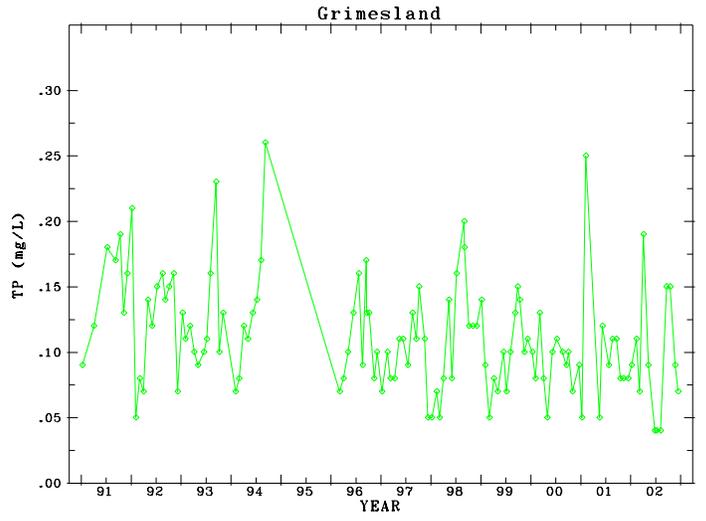


Figure 6.

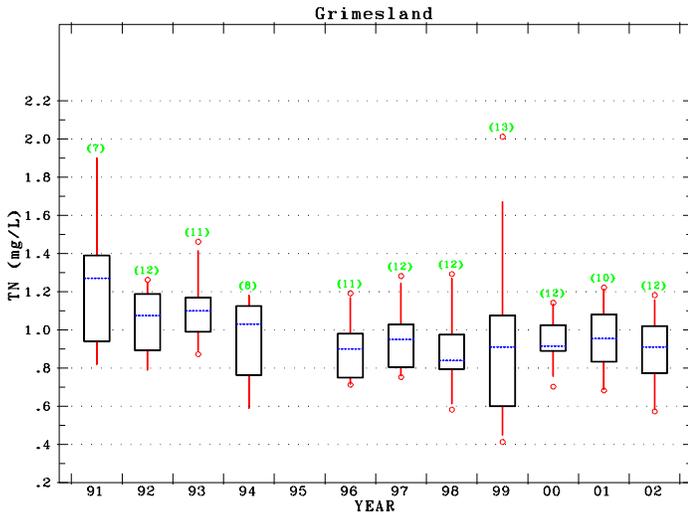


Figure 7.

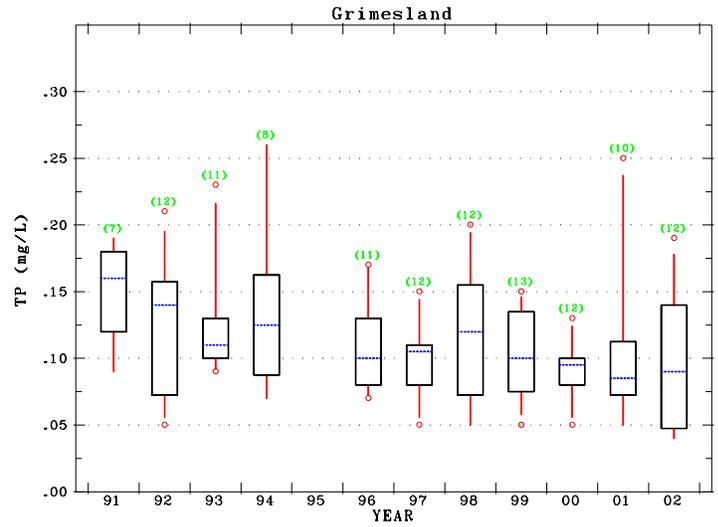


Figure 8.

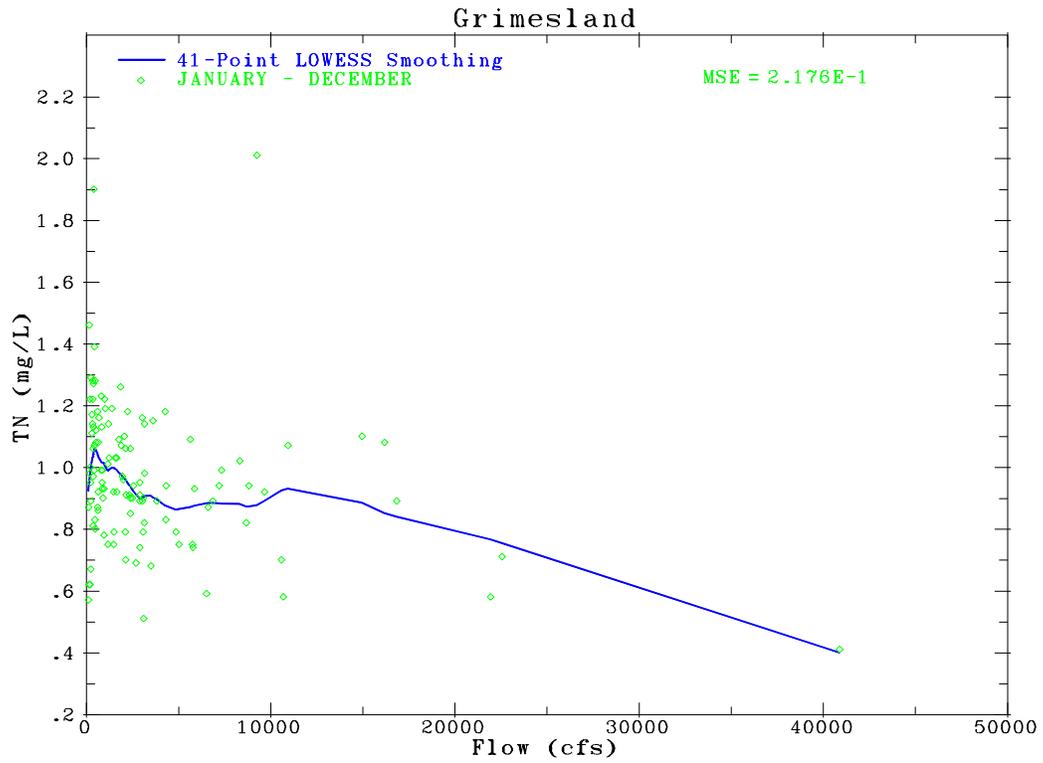


Figure 9.

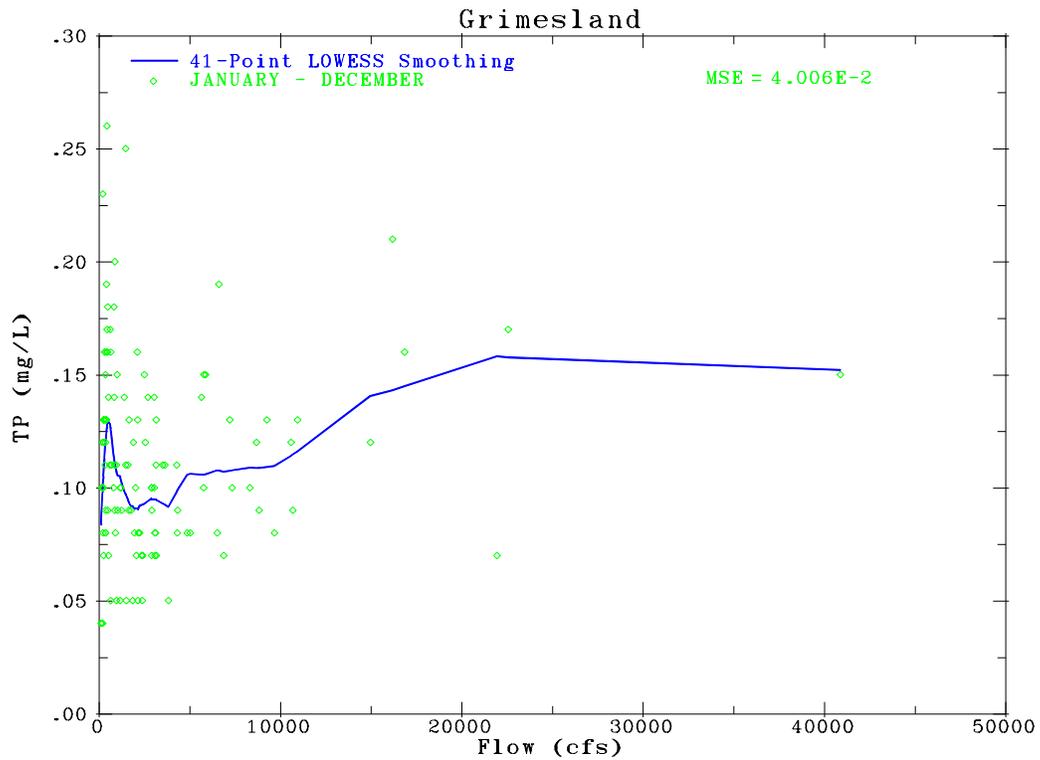


Figure 10.

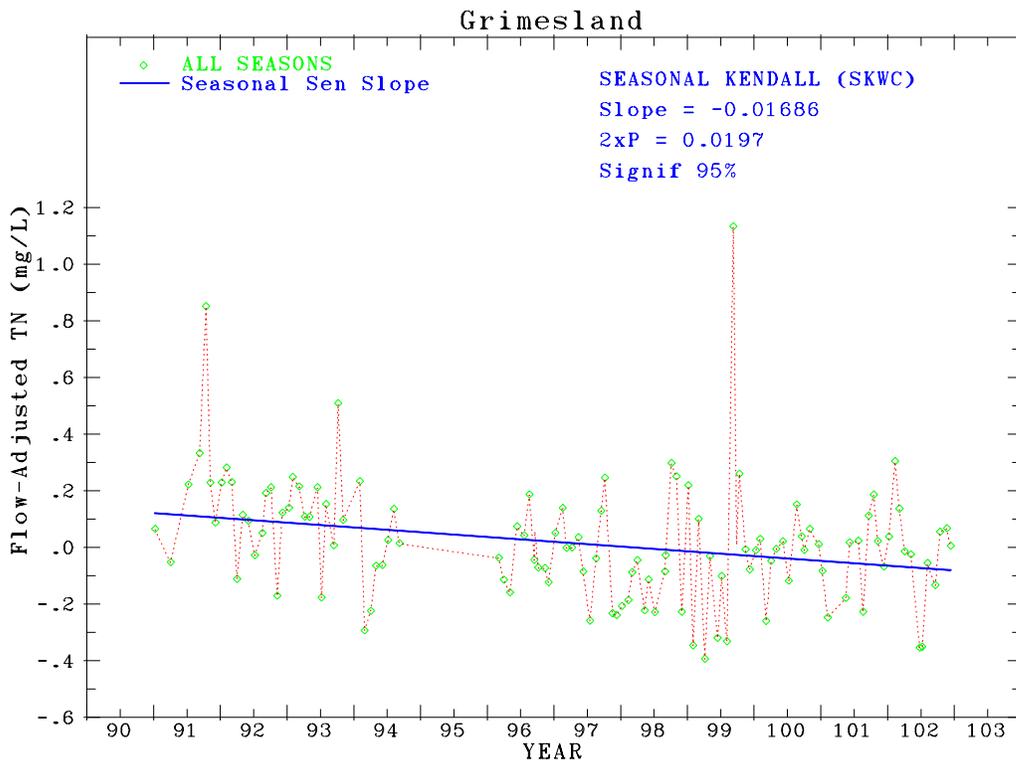


Figure 11.

