

Trends in Nutrient Loading to the Pamlico River Estuary

Pamlico River Estuary TMDL

A Total Maximum Daily Load (TMDL) is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that load among the various sources of that pollutant. Pollutant sources are characterized as either point sources or nonpoint sources. In 1995, the EPA approved the estuarine response modeling reported in the 1994 Basinwide Plan as the TMDL for nutrients in the Pamlico River Estuary.

Due to a combination of hydrologic conditions and nutrient inputs from upstream, the estuary from Washington downstream to Saint Claire Creek has and continues to experience excessive algal activity. Estuary response modeling was conducted to determine appropriate nutrient reduction goals, described in detail in the [1994 Basinwide Plan](#). DWQ applied the model under the 1991 calibration conditions as well as under various nutrient reduction scenarios and plotted the results for a site located near Washington in order to evaluate possible management strategies. The model was calibrated under relatively high nutrient loading conditions, but also represented the typical estuary impairment conditions, where chlorophyll a violations occurred 18% of the time. However, 1991 was a much dryer than average year; 1991 mean annual flow measured at the USGS Tarboro gauging station was 1,249 cfs, whereas the average annual flow from 1897-2009 was 2,226 cfs. In wetter years, both nutrient loading and estuary response will differ from dry-year results. Therefore, the modeling results were evaluated within the context of the model calibration.

The model recommendations include an instream reduction goal of 30% for total nitrogen (TN) (1,361,000 kg/yr target) and maintenance of existing total phosphorus (TP) loading (180,000 kg/yr) at Washington. The model indicated that point sources contribute only 5% of the total nitrogen in the entire basin and approximately 8% of the total nitrogen in the basin upstream from the estuary. Nonpoint sources therefore account for 92% of the TN loading. Based on the overall annual TN reduction goal of 583,000 kg/yr at Washington from all sources, annual point and nonpoint source reduction goals at Washington are as follows:

Point Sources = 46,640 kg/yr (583,000 kg/yr x .08)

Nonpoint Sources = 536,350 kg/yr (583,000 kg/yr x .92)

Reductions in nutrient inputs may take time to detect in measured loading, due to year-to-year variability in precipitation and flow. Based on the results of recent trend analysis (see trend analysis summary below) in the basin, it is evident that it will take more time to discern a 30 percent decrease in load to the estuary. The Pamlico River Estuary will continue to be monitored to determine if the chlorophyll a criterion is met and the Tar-Pamlico River will continue to be monitored to determine if the 30 percent TN load reduction and no increase in TP load from the 1991 level is being achieved. This information will help direct adaptive management in TMDL compliance activities.

Trend Analysis

Introduction

The DWQ's Modeling and TMDL Unit performed a trend analysis of annual nutrient loads and concentrations focused on data from the ambient monitoring station O6500000, between 1991–2008, to evaluate progress towards meeting TMDL reduction goals. This station is located at Grimesland, which is approximately 7-miles upstream of Washington. Currently, there is enough data to perform statistical analysis of daily load. DWQ does not recommend performing trend analysis on annual load because the effects of flow could lead to confounding results.

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.

Methods

Daily load was calculated as measured concentration multiplied by average daily flow and converted to units of kilograms per day. For the 1991-2008 time frame, 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 (NH₃), and nitrite+nitrate (NO₂+NO₃). TN was not directly measured, but was calculated as NO₂+NO₃ plus TKN. Due to the lack of a stream gage at Grimesland, flow data were 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).

The WQStat Plus model was used to evaluate trends in TP, TN, TKN, NH₃, and NO₂+NO₃ 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, NH₃, and NO₂+NO₃ are provided in Table 6-1. The results indicate that there were statistically significant trends for NH₃, NO₂+NO₃, and TKN. There was no statistically significant trend for TN or TP. TKN showed an increasing trend in concentration, while both NH₃ and NO₂+NO₃ showed decreasing trends.

Trend slope (seasonal sen trend slope) represents the median rate of change in flow-adjusted concentrations and is shown in Table 6-1 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 NO₂+NO₃ concentrations.

TABLE 6-1. 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%
NH ₃ (mg/L)	-0.002	Yes	0.07	-45%
NO ₂ +NO ₃ (mg/L)	-0.01	Yes	0.77	-28%

X= slope was not significant and therefore not reported

Daily Load

The results of the Seasonal Kendall test for daily loads of TP, TN, TKN, NH₃, and NO₂+NO₃ are provided in Table 6-2. Daily average flow was also trend tested to check for bias. The results indicate that there were statistically significant decreasing trends in NH₃ and NO₂+NO₃ daily loads. There was no statistically significant trend for TKN, TN, or TP. As shown in Table 6-2, there was a statistically significant decreasing trend for flow. Therefore, even though there is a statistically significant decreasing trend for NH₃ and NO₂+NO₃ flow adjusted concentrations (Table 6-1), it is possible that the decreasing trends for NH₃ and NO₂+NO₃ 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 6-2 for each statistically significant parameter.

TABLE 6-2. RESULTS OF SEASONAL KENDALL LOAD TREND ANALYSIS

PARAMETERS	SEASONAL SEN TREND SLOPE (KG/D/YEAR)	SIGNIFICANT TREND AT 95%
TP (kg/day)	x	No
TN (kg/day)	x	No
TKN (kg/day)	x	No
NH ₃ (kg/day)	-8.84	Yes
NO ₂ + NO ₃ (kg/day)	-44.37	Yes

cfs per year

Flow (cfs)	-20	Yes
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X= slope was not significant and therefore not reported

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 in Figure 6-1. Annual total precipitation is also provided for comparison. As shown in Figure 6-1, 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.

FIGURE 6-1. TIME SERIES OF ANNUAL LOAD OF TP (KG/YEAR) WITH TOTAL ANNUAL PRECIPITATION PROVIDED FOR COMPARISON

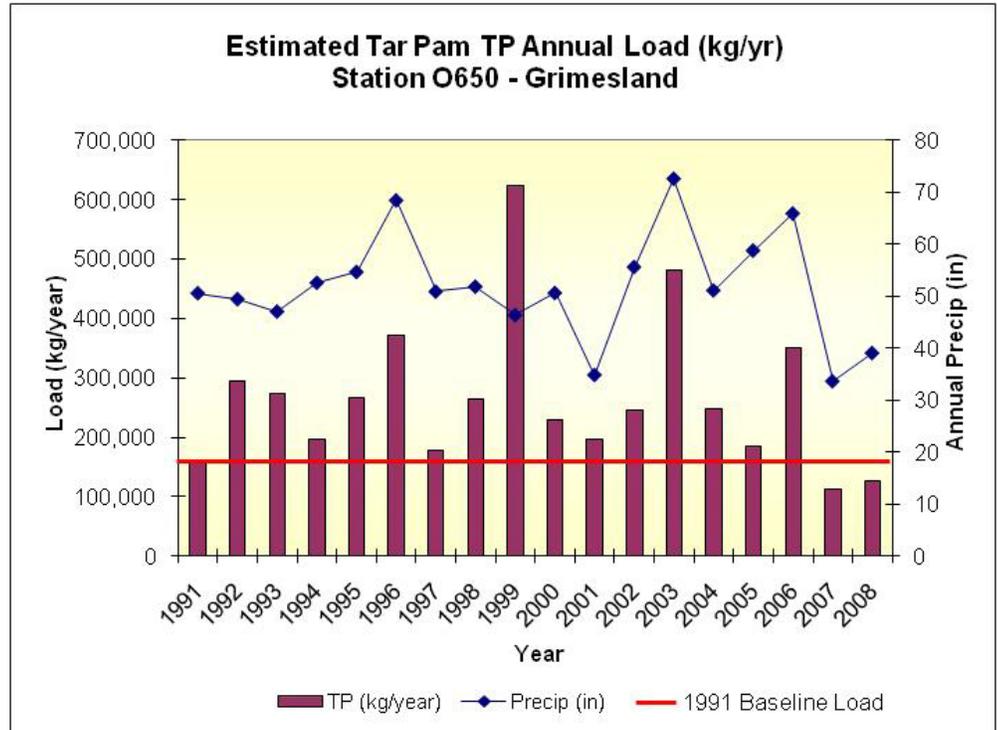
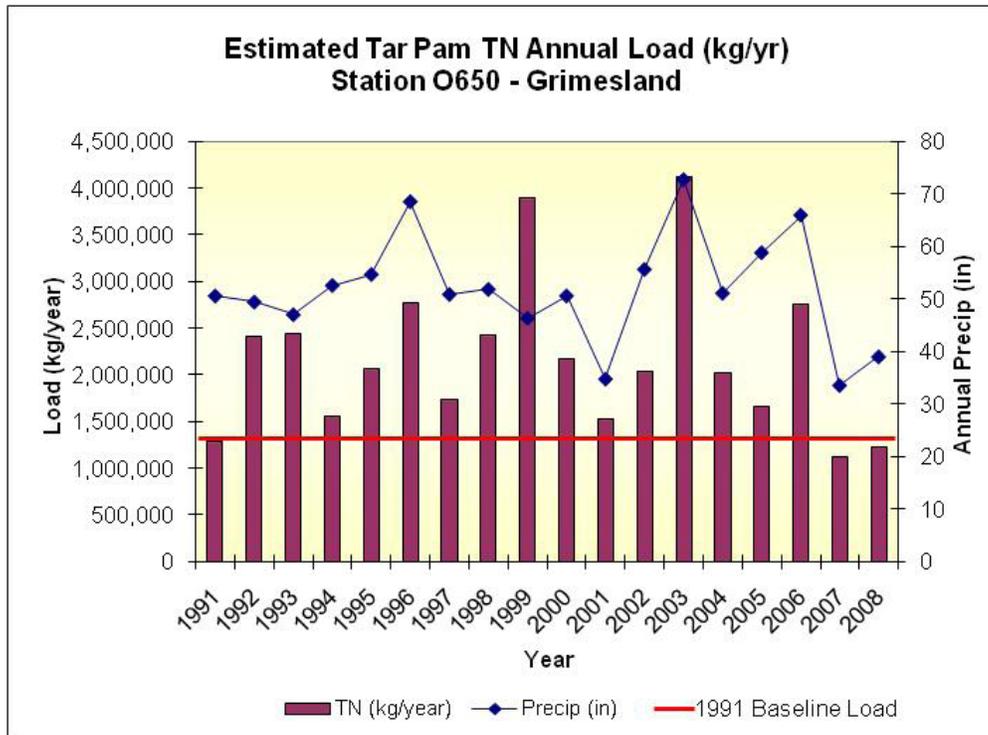


FIGURE 6-2. TIME SERIES OF ANNUAL LOAD OF TN (KG/YEAR) WITH TOTAL ANNUAL PRECIPITATION PROVIDED FOR COMPARISON



The TN annual load time series is provided below in Figure 6-2. 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.

Conclusion

Trend analyses of TP, TN, TKN, NH₃, and NO₂+NO₃ 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 6-3.

TABLE 6-3. SUMMARY OF TREND ANALYSIS RESULTS FOR CONCENTRATIONS AND DAILY LOADS

1991-2008		
CONSTITUENT	CONCENTRATION	DAILY LOAD
TP	No trend	No trend
TN	No trend	No trend
NH ₃	Decreasing	Decreasing
NO ₂ +NO ₃	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.

Further analyses of the nitrogen series indicates that the increasing trend in TKN concentrations cancels out the decreasing trends observed for NO₂+NO₃ concentrations, resulting in no trend for TN. TKN is comprised of NH₃ and organic nitrogen. Because there was a decreasing trend observed for NH₃, the increase in TKN is likely explained by an increase in organic nitrogen.

Trend Analysis Discussion & Next Steps

Based on the trend analyses the TN 30% loading reduction goal has not been reached and the TP load has exceeded the 1991 maintenance level. There is also no decrease in TN or TP concentrations trends. Reevaluation of the TMDL is justified when the 30% TN instream load reduction has been achieved and chlorophyll a standards are still not being met.

Even though significant efforts have been taken by point sources and the agricultural community to reduce their collective nutrient loading, the implementation of the NSW strategy has thus far not resulted in meeting water quality standards in the Pamlico River Estuary. The decrease in annual loads of TP and TN below the baseline levels as shown in Figures 6-1 and 6-2, during the drought years of 2007-2008, suggest recent nutrient loading to the estuary is likely a result of nonpoint source contributions. The NSW strategy accounts for aspects of agriculture and stormwater nonpoint source contributions however, it is recognized that some nonpoint sources may have not been accounted for or are exceeding the original source contributions. Specifically, looking at the different forms of nitrogen, organic nitrogen has increased and thus warrants identifying sources and reducing inputs of organic nitrogen throughout the basin.

By expanding the analysis outside of the TMDL compliance point and focusing on specific watersheds with dominant land use types, staff may be able to better gauge the effectiveness and progress of strategy implementation. For this reason it will be necessary to conduct additional trend analyses on tributaries within the basin that represent predominately agriculture and urban watersheds respectively. While we believe that further analyses of existing data and additional years of data collection will provide greater certainty as to the effect of the strategy on the estuary, we also recognize other basin factors (e.g., groundwater, atmospheric deposition, nutrient recycling) may contribute to the results seen in these analyses and conditions in the estuary.