MEMORANDUM
Date: November 10, 2014
To: Kathy Stecker
From: Narayan Rajbhandari and Adugna Kebede
CC: Tom Fransen, Nora Deamer, Ian McMillan, Heather Patt, and John Huisman
Subject: Trend Analyses of Nutrients in the Tar River, Tar-Pamlico River Basin

Introduction:
The Modeling and Assessment Branch (MAB) performed trend analysis in the Tar-Pamlico River Basin, focusing on data from the ambient monitoring station on the Tar River near Grimesland (O6500000) for the 1991 – 2002 and 1991 – 2008 timeframe in 2003 and 2009, respectively. This station is located approximately seven miles upstream of Washington (Figure 1.1). Results of the 2003 trend analysis indicated that both total nitrogen (TN) and total phosphorus (TP) concentrations were significantly decreasing (MTU, 2003). In contrast, results of the 2009 analysis indicated that there were no significant trends in both TN and TP concentrations (MTU, 2009).

In April 2014, the Basinwide Planning Branch (BPB) requested the MAB to perform a follow-up trend analysis of nutrient concentrations and loads for the 1991 – 2013 timeframe using data collected at the following five ambient stations (Figure 1.1) to evaluate progress towards meeting nutrient reduction goals.

Trend Analysis Study Sites
1. Tar River at SR 1565 near Grimesland (O6500000)
2. Tar River at NC 96 near Tar River (O0100000)
3. Fishing Creek at US 301 near Enfield (O4680000)
4. Tar River near Tarboro (O5250000)
5. Chicod Creek at SR 1960 near Simpson (O6450000)
Figure 1.1. Tar-Pamlico River Basin map showing the ambient and USGS stations used for trend analysis.

Statistical trend analysis was performed for concentrations of TN, TP, Total Kjeldahl Nitrogen (TKN), ammonia (NH$_3$-N), and nitrate plus nitrite (NO$_x$-N). TN is not directly measured and was calculated as NO$_x$-N plus TKN. For the 1991 – 2013 timeframe, there were more than 12 months of consecutive data missing at each station (Table 1.1), which could affect the results of the trend analysis.

Table 1.1. Study period for trend analysis.

<table>
<thead>
<tr>
<th>Ambient Stations</th>
<th>Trend Period</th>
<th>Data Missing Period</th>
<th>USGS Flow Station</th>
</tr>
</thead>
</table>

The MAB does not, however, recommend performing statistical trend analysis on load using the same method, because the confounding effects of naturally variable flow could lead to misleading results. Since human impacts, such as those achieved through implementation of best management practices or point source controls, would be captured by changes in concentration,
it is appropriate to evaluate concentration when conducting trend analyses. This provides insight into whether or not management actions have resulted in long-term changes in water quality.

While statistical trend analysis on nutrient loading is not recommended as appropriate, an alternative method, flow-normalized loading analysis, can be used to evaluate long-term changes in nutrient loading to the estuary. For this reason, assessments of flow-normalized (FN) annual nutrient loads at the study sites are presented. This analysis provides some useful information on changes associated with different flow regimes and nutrient constituents and provides insight into progress towards meeting the overall loading reduction goal and can help direct where further research is necessary.

As discussed above, this memo is divided into two parts. The first part deals with statistical trend analysis, and the second part with analysis of flow-normalized annual nutrient loads. The results of the flow-normalized loading analysis for the Tar River AMS station near Grimesland is presented in the main body of this report and the results for the other stations are provided in Appendix A. Tables and plots of TN and TP Loads estimated using the USGS LOEDEST Program are also provided in Appendix C for reference.

I. Statistical Trend Analysis

Summary:

Statistical trend analysis is performed to determine whether nutrient concentrations in the Tar-Pamlico River Basin are increasing or decreasing from 1991 through 2013. The Water Quality / Hydrology Graphics / Analysis System (WQHYDRO) software was used to evaluate trends in the basin.

The results of the trend analyses from 1991 through 2013 are summarized in Tables S-1.1 and S-1.2 below. The results show that ammonia (NH$_3$-N) concentrations were significantly decreasing in the basin at the ambient stations - O6500000 (Tar River), O4680000 (Fishing Creek), O5250000 (Tar River) and O6450000 (Chicod Creek). Nitrate and nitrite (NO$_x$-N) concentrations were significantly decreasing at all the ambient stations included in this study. Total Kjeldahl nitrogen (TKN) concentrations were significantly increasing at O6500000, O0100000 (Tar River), O4680000, and O5250000. Total nitrogen (TKN + NO$_x$-N) concentrations were significantly increasing at O6500000 and O4680000, and total phosphorus (TP) concentrations were significantly increasing at O0100000.

Table S-1.1. Summary of trend analysis results for flow-adjusted nutrient concentrations

<table>
<thead>
<tr>
<th>Constituents</th>
<th>O6500000 (Tar River)</th>
<th>O0100000 (Tar River)</th>
<th>O4680000 (Fishing Creek)</th>
<th>O5250000 (Tar River)</th>
<th>O6450000 (Chicod Creek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_3$-N</td>
<td>YES↓</td>
<td>NO</td>
<td>YES↓</td>
<td>YES↓</td>
<td>YES↓</td>
</tr>
<tr>
<td>NO$_x$-N</td>
<td>YES↑</td>
<td>YES↑</td>
<td>YES↑</td>
<td>YES↑</td>
<td>NO</td>
</tr>
<tr>
<td>TKN</td>
<td>YES↑</td>
<td>YES↑</td>
<td>YES↑</td>
<td>YES↑</td>
<td>NO</td>
</tr>
<tr>
<td>TN</td>
<td>YES↑</td>
<td>NO</td>
<td>YES↑</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>TP</td>
<td>NO</td>
<td>YES↑</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>
Table S-1.2. Percent change over study period for significant trends

<table>
<thead>
<tr>
<th>Constituents</th>
<th>O6500000 (Tar River)</th>
<th>O0100000 (Tar River)</th>
<th>O4680000 (Fishing Creek)</th>
<th>O5250000 (Tar River)</th>
<th>O6450000 (Chicod Creek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₃-N</td>
<td>-33.31</td>
<td>*</td>
<td>-39.05</td>
<td>-41.36</td>
<td>-38.19</td>
</tr>
<tr>
<td>NOₓ-N</td>
<td>-21.60</td>
<td>-160.05**</td>
<td>-57.75</td>
<td>-41.57</td>
<td>-56.98</td>
</tr>
<tr>
<td>TKN</td>
<td>55.40</td>
<td>37.29</td>
<td>60.13</td>
<td>44.39</td>
<td>*</td>
</tr>
<tr>
<td>TN</td>
<td>10.86</td>
<td>*</td>
<td>36.00</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>TP</td>
<td>*</td>
<td>35.83</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

* indicate the trend results are not statistically significant.

** Note that NOₓ-N values are highly variable at this location. While a 160% decrease could not actually occur, this result is statistically valid.

** Methods:**

The purpose of 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). 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. Therefore, in this study, the flow-adjusted concentration is estimated based on regression of concentration on some function of discharge to overcome the flow relatedness. The flow-adjusted concentration is then tested for a trend by using the Seasonal Kendall test to overcome seasonality. The basic procedures adopted for this study are as follows:

**Flow estimation**

Estimation of flow is essential to correct the concentration variation due to streamflow. Except at Grimesland, O6500000, all the remaining four stations have USGS gauge stations to measure daily flow (Table 1.1 and Figure 1.1). As described in DWQ_MTU (2003), flow data for 1991 - 2013 at Grimesland 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). Descriptive statistics of flow during the study periods are presented in Table 1.2 and plots of annual flow volume for these stations are provided in Appendix B.
### Table 1.2. Descriptive statistics of flow (cfs) at the study sites in the Tar River Basin

<table>
<thead>
<tr>
<th>Quantiles</th>
<th>O6500000 (Tar River)</th>
<th>O0100000 (Tar River)</th>
<th>O4680000 (Fishing Creek)</th>
<th>O5250000 (Tar River)</th>
<th>O6450000 (Chicod Creek)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>77361.00</td>
<td>10800.00</td>
<td>29200.00</td>
<td>70500.00</td>
<td>4860.00</td>
</tr>
<tr>
<td>99.5%</td>
<td>20977.46</td>
<td>2619.80</td>
<td>4270.00</td>
<td>18300.50</td>
<td>1200.25</td>
</tr>
<tr>
<td>97.5%</td>
<td>12305.00</td>
<td>999.85</td>
<td>2330.00</td>
<td>9760.25</td>
<td>359.00</td>
</tr>
<tr>
<td>90%</td>
<td>6014.47</td>
<td>273.00</td>
<td>863.00</td>
<td>4920.00</td>
<td>105.00</td>
</tr>
<tr>
<td>75%</td>
<td>2861.15</td>
<td>104.00</td>
<td>449.00</td>
<td>2300.00</td>
<td>43.00</td>
</tr>
<tr>
<td>50%</td>
<td>1379.00</td>
<td>34.00</td>
<td>230.00</td>
<td>1060.00</td>
<td>16.00</td>
</tr>
<tr>
<td>25%</td>
<td>522.92</td>
<td>7.00</td>
<td>88.00</td>
<td>377.00</td>
<td>4.30</td>
</tr>
<tr>
<td>10%</td>
<td>257.76</td>
<td>1.70</td>
<td>39.00</td>
<td>195.90</td>
<td>0.68</td>
</tr>
<tr>
<td>2.5%</td>
<td>101.09</td>
<td>0.32</td>
<td>17.00</td>
<td>98.98</td>
<td>0.00</td>
</tr>
<tr>
<td>0.5%</td>
<td>21.29</td>
<td>0.00</td>
<td>3.90</td>
<td>54.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0%</td>
<td>-52.43</td>
<td>0.00</td>
<td>0.21</td>
<td>28.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Mean</td>
<td>2535.91</td>
<td>137.52</td>
<td>422.25</td>
<td>2023.39</td>
<td>55.75</td>
</tr>
<tr>
<td>Std Dev</td>
<td>3945.73</td>
<td>433.24</td>
<td>836.88</td>
<td>3293.57</td>
<td>188.66</td>
</tr>
<tr>
<td>Std Err Mean</td>
<td>43.11</td>
<td>4.73</td>
<td>9.13</td>
<td>35.94</td>
<td>2.14</td>
</tr>
<tr>
<td>Upper 95% Mean</td>
<td>2620.41</td>
<td>146.79</td>
<td>440.15</td>
<td>2093.84</td>
<td>59.94</td>
</tr>
<tr>
<td>Lower 95% Mean</td>
<td>2451.41</td>
<td>128.26</td>
<td>404.35</td>
<td>1952.94</td>
<td>51.57</td>
</tr>
<tr>
<td>N</td>
<td>8378</td>
<td>8401</td>
<td>8399</td>
<td>8398</td>
<td>7794</td>
</tr>
</tbody>
</table>

### Trend Analysis

The Water Quality / Hydrology Graphics / Analysis System (WQHYDRO) software is used to evaluate trends for the selected Tar-Pamlico River Basin stations. The software is a multi-faceted computer program, which is capable of computing flow-adjusted concentration and the Seasonal Kendall test (Aroner, 2000). The model removes the concentration variation related to streamflow with flow-adjusted data by using a robust smoothing technique called Locally Weighted Scatterplot Smooth (LOWESS). The technique describes the relationship between concentration (Y) and flow (X) without assuming linearity or normality. The resulting residuals are considered flow-adjusted concentrations.

The WQHYDRO software also computes the Seasonal Kendall test both for serial correlation data (autocorrelation) and non-serial correlation data. A fundamental assumption of statistical procedures is that observations within or between samples are independent of one another. For that reason, any statistical test on serially correlated data would disclose wrong information. The model has an automatic provision for removing the serial correlation problem using an autocorrelation-corrected version of the Seasonal Kendall test. The technique is known as Seasonal Kendall with Correction (SKWC). For the non-serial correlation data, the model uses Seasonal Kendall without Correction (SKWOC) technique.
Test of Hypothesis

The Seasonal Kendall test as described above was applied to test a null hypothesis of no trend in NH$_3$-N, NOx-N, TKN, TN, and TP concentrations. An alternative hypothesis is that there was a trend. Upward trend (positive slope $\uparrow$) indicates degradation of water quality, whereas downward trend (negative slope $\downarrow$) indicates improvement of water quality. The hypothesis was tested at 95% confidence level.

Results:

I. Tar River at SR 1565 near Grimesland (O6500000)

The results of the Seasonal Kendall test for flow-adjusted concentrations of NH$_3$-N, NOx-N, TKN, TN, and TP at O6500000 are provided in Table 1.3. Except for TP, the results indicate that there were statistically significant trends for nitrogen. TN and TKN showed increasing trends in concentration, while NH$_3$-N and NOx-N showed decreasing trends.

The downward or upward trend slope in flow-adjusted concentration represents the median rate of change in flow-adjusted concentration for each statistically significant parameter. The trend slope can 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 12 months 1991-2012), and multiplying by 22 years (study period) and then 100 to convert it to a percent. Accordingly, reductions in the base median NH$_3$-N and NOx-N through 2013 are estimated to be 33% and 22%, respectively; and increases in TN and TKN are estimated to be 11% and 55%, respectively (Table 1.3).

Table 1.3. Result of Seasonal Kendall Trend Analysis for nutrient concentrations at Grimesland (1991-2013).

<table>
<thead>
<tr>
<th>Station</th>
<th>Water Quality Constituents</th>
<th>Seasonal Sen Trend Slope (mg/L/year)</th>
<th>Significant Trend at 95%</th>
<th>First 12 Month Median</th>
<th>Average % Change in Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>O6500000</td>
<td>NH$_3$-N</td>
<td>-0.00106</td>
<td>YES↓</td>
<td>0.07</td>
<td>-33.31</td>
</tr>
<tr>
<td></td>
<td>NOx-N</td>
<td>-0.00756</td>
<td>YES ↓</td>
<td>0.77</td>
<td>-21.60</td>
</tr>
<tr>
<td></td>
<td>TKN</td>
<td>0.01259</td>
<td>YES↑</td>
<td>0.50</td>
<td>55.40</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>0.00627</td>
<td>YES↑</td>
<td>1.27</td>
<td>10.86</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>*</td>
<td>NO</td>
<td>0.16</td>
<td>*</td>
</tr>
</tbody>
</table>

* indicate the trend results are not statistically significant.

II. Tar River at NC 96 near Tar River (O0100000)

The results of the Seasonal Kendall test for flow-adjusted concentrations of NH$_3$-N, NOx-N, TKN, TN, and TP at O0100000 are provided in Table 1.4. The results indicate that there were statistically significant trends for NOx-N, TKN and TP. TKN and TP showed increasing trends in concentration, while NOx-N showed a decreasing trend. The upward slopes of TKN and TP suggest that the average increase in median concentration represent a 37% and a 36%, respectively, over the 22 years of study period. Conversely, there was a 160% decrease in NOx-N concentration.
Table 1.4. Result of Seasonal Kendall Trend Analysis for nutrient concentrations at NC 96 (1991-2013).

<table>
<thead>
<tr>
<th>Stations</th>
<th>Water Quality Constituents (mg/L)</th>
<th>Seasonal Sen Trend Slope (mg/L/year)</th>
<th>Significant Trend at 95%</th>
<th>First 12 month Median</th>
<th>Average % Change in Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>O0100000</td>
<td>NH\textsubscript{3}-N</td>
<td>*</td>
<td>NO</td>
<td>0.035</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>NOx-N</td>
<td>-0.00291</td>
<td>YES↓</td>
<td>0.04</td>
<td>-160.05</td>
</tr>
<tr>
<td></td>
<td>TKN</td>
<td>0.00678</td>
<td>YES↑</td>
<td>0.4</td>
<td>37.29</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>*</td>
<td>NO</td>
<td>0.49</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>0.00057</td>
<td>YES↑</td>
<td>0.035</td>
<td>35.83</td>
</tr>
</tbody>
</table>

* indicate the trend results are not statistically significant.

** Note that NO\textsubscript{x}-N values are highly variable at this location. While a 160% decrease could not actually occur, this result is statistically valid.

III. Fishing Creek at US 301 near Enfield (O4680000)

The results of the Seasonal Kendall test for flow-adjusted concentrations of NH\textsubscript{3}-N, NO\textsubscript{x}-N, TKN, TN, and TP at O4680000 are provided in Table 1.5. There were statistically significant trends for nitrogen. TKN and TN showed increasing trends, while NH\textsubscript{3}-N and NO\textsubscript{x}-N showed decreasing trends. The upward slopes of TKN and TN suggest that the average increase in median concentration represent 60% and a 36%, respectively, over the 22 years of study period. Conversely, there were 39% and a 58% decreases in NH\textsubscript{3} and NO\textsubscript{x}-N concentrations, respectively.

Table 1.5. Result of Seasonal Kendall Trend Analysis for nutrient concentrations at US 301 (1991-2013).

<table>
<thead>
<tr>
<th>Stations</th>
<th>Water Quality Constituents (mg/L)</th>
<th>Seasonal Sen Trend Slope (mg/L/year)</th>
<th>Significant Trend at 95%</th>
<th>First 12 month Median</th>
<th>Average % Change in Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>O4680000</td>
<td>NH\textsubscript{3}-N</td>
<td>-0.00071</td>
<td>YES↓</td>
<td>0.04</td>
<td>-39.05</td>
</tr>
<tr>
<td></td>
<td>NOx-N</td>
<td>-0.00315</td>
<td>YES↓</td>
<td>0.12</td>
<td>-57.75</td>
</tr>
<tr>
<td></td>
<td>TKN</td>
<td>0.0082</td>
<td>YES↑</td>
<td>0.3</td>
<td>60.13</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>0.0072</td>
<td>YES↑</td>
<td>0.44</td>
<td>36.00</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>*</td>
<td>NO</td>
<td>0.05</td>
<td>*</td>
</tr>
</tbody>
</table>

* indicate the trend results are not statistically significant.

IV. Tar River near Tarboro (O5250000)

The results of the Seasonal Kendall test for flow-adjusted concentrations of NH\textsubscript{3}-N, NO\textsubscript{x}-N, TKN, TN, and TP at O5250000 are provided in Table 1.6. There were statistically significant trends for NH\textsubscript{3}, NO\textsubscript{x}-N, and TKN. NH\textsubscript{3}-N and NO\textsubscript{x}-N showed decreasing trends, while TKN showed an increasing trend. The downward slopes of NH\textsubscript{3}-N and NO\textsubscript{x}-N suggest that the average decrease in median concentrations were 41% and a 42%, respectively, over the 22 years of study period. Conversely, there was a 44% increase in TKN concentration.
Table 1.6. Result of Seasonal Kendall Trend Analysis for nutrient concentrations at Tarboro (1991-2013).

<table>
<thead>
<tr>
<th>Stations</th>
<th>Water Quality Constituents (mg/L)</th>
<th>Seasonal Sen Trend Slope (mg/L/year)</th>
<th>Significant Trend at 95%</th>
<th>First 12 month Median</th>
<th>Average % Change in Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>O5250000</td>
<td>NH₃-N</td>
<td>-0.00094</td>
<td>YES↓</td>
<td>0.05</td>
<td>-41.36</td>
</tr>
<tr>
<td></td>
<td>NOx-N</td>
<td>-0.00888</td>
<td>YES↓</td>
<td>0.47</td>
<td>-41.57</td>
</tr>
<tr>
<td></td>
<td>TKN</td>
<td>0.00807</td>
<td>YES↑</td>
<td>4.0</td>
<td>44.39</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>*</td>
<td>NO</td>
<td>0.96</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>TP</td>
<td>*</td>
<td>NO</td>
<td>0.13</td>
<td>*</td>
</tr>
</tbody>
</table>

* indicate the trend results are not statistically significant.

V. Chicod Creek at SR 1760 near Simpson (O6450000)

The results of the Seasonal Kendall test for flow-adjusted concentrations of NH₃-N, NOx-N, TKN, TN, and TP at O6450000 are provided in Table 1.7. There were no statistically significant trends for TKN, TN, and TP. The downward slopes of NH₃-N and NOx-N suggest that the average decreases in median concentration represent 38% and 57%, respectively, over the 22 years of study period.

Table 1.7. Result of Seasonal Kendall Trend Analysis for nutrient concentrations at SR 1760 (1993-2013).

<table>
<thead>
<tr>
<th>Stations</th>
<th>Water Quality Constituents (mg/L)</th>
<th>Seasonal Sen Trend Slope (mg/L/year)</th>
<th>Significant Trend at 95%</th>
<th>First 12 month Median</th>
<th>Average % Change in Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>O6450000</td>
<td>NH₃-N</td>
<td>-0.00592</td>
<td>YES↓</td>
<td>0.31</td>
<td>-38.19</td>
</tr>
<tr>
<td></td>
<td>NOx-N</td>
<td>-0.02279</td>
<td>YES↓</td>
<td>0.8</td>
<td>-56.98</td>
</tr>
<tr>
<td></td>
<td>TKN</td>
<td>*</td>
<td>NO</td>
<td>1</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>TN</td>
<td>*</td>
<td>NO</td>
<td>1.9</td>
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</tr>
<tr>
<td></td>
<td>TP</td>
<td>*</td>
<td>NO</td>
<td>0.42</td>
<td>*</td>
</tr>
</tbody>
</table>

* indicate the trend results are not statistically significant.

Conclusion:

Trend analyses for monthly measured concentrations of NH₃-N, NOx-N, TKN, TN, and TP were performed in the Tar River Basin at the following five ambient stations: O650000 (Tar River), O0100000 (Tar River), O4680000 (Fishing Creek), O5250000 (Tar River), and O6450000 (Chicod Creek). The WQHYDRO statistical program was used to test the null hypothesis that no trends in nutrient concentrations exist at the 95% confidence level.
Overall, TKN concentrations were significantly increasing, whereas NH$_3$-N and NOx-N concentrations were significantly decreasing in the Tar River. Since TKN is composed of ammonia and organic nitrogen, the increase in TKN must be explained by an increase in organic nitrogen. The increase in organic nitrogen is higher at the Tar River near Grimesland (O6500000) and Fishing Creek near Enfield (O4680000); there were also significantly increasing trends in TN concentrations at these locations. The result at O6500000 is in contrast to the 2003 trend analysis (1991 – 2002 time frame) and the 2009 trend analysis (1991 -2008 time frame), where there were respectively decreasing trend and no trend of TN concentrations.

Furthermore, there were no trends of TP concentrations, except in the Tar River at NC 96 (O0100000) where the concentrations were significantly increasing. The result for the Grimesland station (O6500000) is similar with the results of the 2009 trend analysis which showed that there was no significant trend in TP.

References:
II. Flow-Normalized Loading Analysis

Summary
Flow-normalized loading analysis provides useful insights on changes in annual nutrient loading including changes associated with different flow regimes and nutrient constituents. Flow-normalized estimates can be used in the evaluation of progress towards nutrient reduction goals and provide additional insight on the relative effectiveness of nutrient management measures implemented in a watershed.

Analyses of flow-normalized (FN) loading at selected Tar Pamlico River Basin stations were performed to evaluate long term loading trends using a spreadsheet-based tool. A location map and a brief description of the stations are provided in Section I of this report.

The results show that there was a reduction in flow-normalized loading of NOx-N for all the stations included in this analysis. There was a decrease in flow-normalized TKN loads in the first few five-year periods, but the TKN loads gradually increased afterwards in each watershed. The increase in TKN loading was primarily due to an increase in organic nitrogen. The flow-normalized NOx-N, TKN, TN, and TP loads in the Chicod Creek watershed for all five-year time periods were lower than the first five-year (1993-1997) period loads. Flow-normalized TN loading exhibited the combination of the patterns for NOx-N and TKN loadings.

The average flow-normalized loading reduction for all the five-year periods from 1992 to 2013 for four stations (O6500000, O0100000, O4680000, and O5250000) and 1994 to 2013 for Chicod Creek relative to the first five year period (1991-1995 for the four stations and 1993-1997 for Chicod Creek) load is provided in the Table S-2-1 below.

<table>
<thead>
<tr>
<th>Station</th>
<th>NH$_3$-N</th>
<th>NOx-N</th>
<th>TKN</th>
<th>TN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grimesland (O6500000)</td>
<td>-2%</td>
<td>-18%</td>
<td>13%</td>
<td>-3%</td>
<td>-7%</td>
</tr>
<tr>
<td>Tar River (O0100000)</td>
<td>10%</td>
<td>-20%</td>
<td>24%</td>
<td>10%</td>
<td>7%</td>
</tr>
<tr>
<td>Fishing Creek (O4680000)</td>
<td>-49%</td>
<td>-24%</td>
<td>13%</td>
<td>-2%</td>
<td>10%</td>
</tr>
<tr>
<td>Tar River (O5250000)</td>
<td>-17%</td>
<td>-20%</td>
<td>2%</td>
<td>-7%</td>
<td>7%</td>
</tr>
<tr>
<td>Chicod Creek (O6450000)</td>
<td>-73%</td>
<td>-33%</td>
<td>-24%</td>
<td>-28%</td>
<td>-22%</td>
</tr>
</tbody>
</table>

Overall, the current analyses show that substantial reduction of NOx-N loading occurred over the study period, but Org-N loading was not reduced as evidenced by the gradual increase in organic nitrogen in these watersheds. On average the TN loads decreased for all stations except for the Tar River station O0100000 for the study period. The TP loads decreased at station O6500000, and O6450000 and increased at stations O0100000, O4680000, and O5250000, on the average. A gradual increase in TN was observed in the most recent five-year periods at all stations. Similar increases were also observed for TP except at the Chicod Creek Station where it is decreasing.
Method
Assessment of trends in annual nutrient loads at selected Tar Pamlico River Basin stations were performed using flow-normalized (FN) concentrations and loads computed for flow intervals representing low, medium, and high flows. The description of the sites and the data used for this analysis are also provided in Part I. A spreadsheet-based tool was used for this analysis. Tables and plots of annual flow volumes at the USGS gages used for this analysis are presented Appendix B.

Flow-normalized estimates are designed to remove the effect of random stream flow-driven variations and are ideal for evaluating progress toward nutrient reduction goals (Sprague et al., 2011). Recent studies have demonstrated the use of flow-normalized loading assessments to evaluate effectiveness of management actions to reduce nutrients (Hirsch, 2012; Hirsch et al., 2010, Hirsch et al., 2011; Lebo et al., 2011; and Sprague et al., 2011). While some of these studies employed rigorous statistical methods for their analyses, the approach proposed by Lebo et al., (2011) used a simpler method and was selected for the current study. Lebo et al. (2011) used this approach to evaluate progress in achieving the Neuse TMDL reduction goal as well as changes in N fractions associated with different flow regimes. Their study evaluated nutrient loads at Clayton, Hookerton, Trenton, and Streets Ferry Stations in the Neuse River Basin. The same approach was employed to assess nutrient loads at the Fort Barnwell Station in the Neuse River Basin (MAB, 2013).

The current analysis was designed to replicate the same approach used by Lebo et al. (2011) for the data record from the five selected stations in the Tar Pamlico River Basin. Nutrient concentrations were estimated from the mean of available data and flow-weighted average concentrations. Nutrient loads for the long-term flow distribution were computed from the average concentration and the average flow volume calculated from the low, medium, and high flow intervals over the full period of record. The flow data summary for these intervals is given in Table S-2-2. The summary of the flow data used for this analysis for each station is provided in Table 1.2 in Part I of this report. A detailed description of this approach is presented in a peer-reviewed article by Lebo et al. (2011).

<table>
<thead>
<tr>
<th>DWR Station Number</th>
<th>USGS Flow Gage</th>
<th>Flow Period</th>
<th>Flow Averages (cfs)</th>
<th>Flow Period Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low</td>
<td>Middle</td>
</tr>
<tr>
<td>O0100000</td>
<td>2081500</td>
<td>1991-2013</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>O4680000</td>
<td>2083000</td>
<td>1991-2013</td>
<td>62</td>
<td>235</td>
</tr>
<tr>
<td>O5250000</td>
<td>2083500</td>
<td>1991-2013</td>
<td>281</td>
<td>1090</td>
</tr>
<tr>
<td>O6450000</td>
<td>2084160</td>
<td>1991-2013</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>O6500000</td>
<td>2084000</td>
<td>1991-2013</td>
<td>373</td>
<td>1417</td>
</tr>
</tbody>
</table>
Results

i. Flow-Normalized Loading - DWR Ambient Monitoring Station # O6500000 near Grimesland

Figures 2-1 and 2-2 show annual TN loading at Grimesland. The results show that annual TN loading at Grimesland ranged from 2.2 to 9.3 x 10^6 lbs/year for the 1991–2013 timeframe, with a median value of 4.6 x 10^6 lbs/year. Average contributions of Ammonia–N, NOx-N, and Org-N to the TN load for 1991–2013 period were 8, 45 and 47%, respectively. Organic Nitrogen was computed as TKN minus Ammonia. Overall, there was an increase in the contribution of the Org-N fraction and a decrease in that of the NOx-N fraction to TN loading at Grimesland for the study period (1991-2013). The Org-N contribution increased from 40% of TN for 1991–2002 period to 53% of TN for 2003–2013 period. The contribution from the high-flow fraction of Org-N increased from 50% of TN for the 1991-1995 period to 67% of TN for the 2009-2013 period. The NOx-N contribution decreased from 48% of TN for 1991–2002 period to 42% of TN for 2003–2013 period (Figure 2-1). The contribution from the low-flow fraction of Org-N decreased from 50% of TN for the 1991-1995 period to 33% of TN for the 2009-2013 period.

Figure 2-2 shows annual TN loading at Grimesland by flow interval. The average TN contributions (1991-2003) from low, middle, and high flow interval were 6, 20 and 74%, respectively. The annual TP loading at Grimesland ranged from 0.24 to 1.27 x 10^6 lbs/year, with a median value of 0.55 x 10^6 lbs/year (Figure 2-3). Figure 2-3 shows annual TP loading at Grimesland by flow interval. The average TP contributions from low, middle, and high flows were 6, 19 and 75%, respectively. The high-flow fraction of TP load increased from 76% for the 1991-1995 period to 83% for the 2009-2013 period. These results show that high flow events contribute substantially large amount of nutrients in this watershed.
In order to evaluate progress in achieving nutrient reduction goal set by the Tar Pamlico River Basin Nutrient Management Strategy, FN load estimated under long-term average flow conditions were compared to the average load for the 1991-1995 period (Figure 2-4). Five-year moving averages of NOx-N, TKN, TN and TP loads were computed and compared with the corresponding value for the 1991–1995 period.
The results of the FN loading analysis indicate reduction in FN NOx-N loading, but an increase in TKN loading. Flow-normalized NOx-N loading gradually decreased from the 1991-1995 period to the end of the study period. It reached a minimum value of -24.1% in the 1995-1999 time period. The average reduction achieved was approximately 18% for all periods beginning with 1992-1996 (Figure 2-4). Flow-normalized TKN loading at Grimesland decreased from the baseline period and reached the minimum values of -12.0% in the 1994-1998 period and increased substantially afterwards. Flow-normalized TKN loading has been consistently higher than the 1991-1995 period throughout the past 11 five-year periods and increased by about 24% during this period. Since Ammonia loading declined over the same time period, the increase in TKN loading was primarily due to an increase in the Org-N fraction. The recent increase in TKN flow normalized loadings appears to be mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx-N and TKN and has been lower than the corresponding 1991-1995 loading until the 2004-2008 period (Figure 2-4). Flow-normalized TN was lower than the 1991-1995 loading through the 2004-2008 period and has been higher than the 1991-1995 loading ever since. The flow-normalized TN loading decreased to a minimum value of -15.9% in the 1994-1998 period and increased gradually afterwards. The average reduction in flow-normalized TN loading for the periods ending in 2004-2008 was approximately 9%. The average increase in flow-normalized TN loading for the periods beginning in 2005-2009 and ending in 2009-2013 was approximately 13%.

Flow-normalized TP loading at Grimesland has been consistently lower than the corresponding 1991-1995 loading until the 2007-2011 period and then gradually increased (Figure 2-5). The flow-normalized TP loading decreased to a minimum value of -16.6% in the 2003-2007 period and increased gradually afterwards. The average reduction in flow-normalized TP loading for the periods ending in 2006-2010 was approximately 12%. The average increase in flow-normalized TP loading for the periods beginning in 2007-2011 and ending in 2009-2013 was approximately
The recent increase in flow normalized loadings of TP could be due to increases for the high flow intervals as well as the increases in TP concentration during recent years.

![Figure 2-5. Relative P Load Reduction- Comparison to 1991-1995](image)

**Average concentrations of N fraction and P by flow interval**

Table 2-1 show average concentrations of N fraction and P by flow interval at Tar River station near Grimesland. The results show that changes in N fractions exhibited marked differences for the different flow intervals at Tar River. While the average concentrations of the NOx-N fraction decreased more for the low and middle flow intervals than for high flows, the average concentrations of the TKN fraction increased more for the high flow intervals. For example, reductions in NOx-N for the 2009–2013 period from corresponding values for 1991–1995 were 22, 25, and 16%, respectively, for the low, middle, and high flow interval. Conversely, the increases in TKN concentrations for the 2009-2013 from the corresponding values for 1991-1995 were 39%, 26%, and 71%, respectively, for the low, middle, and high flow interval. The TN concentrations increased by 2% for the low flow intervals and increased by 28% for the high flow intervals. The average concentrations of TP decreased by 14% for the low flow intervals and increased by 43% for the high flow intervals during the same period.
Table 2-1. Average NO₃-N, TKN, TN, and TP concentrations (mg/l) at Tar River near Grimesland by five-year period and flow interval

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Period</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx-N</td>
<td>1991-1995</td>
<td>0.732</td>
<td>0.621</td>
<td>0.469</td>
</tr>
<tr>
<td>NOx-N</td>
<td>1996-2000</td>
<td>0.590</td>
<td>0.562</td>
<td>0.351</td>
</tr>
<tr>
<td>NOx-N</td>
<td>2001-2005</td>
<td>0.542</td>
<td>0.503</td>
<td>0.381</td>
</tr>
<tr>
<td>NOx-N</td>
<td>2006-2010</td>
<td>0.486</td>
<td>0.480</td>
<td>0.431</td>
</tr>
<tr>
<td>NOx-N</td>
<td>2009-2013</td>
<td>0.573</td>
<td>0.466</td>
<td>0.396</td>
</tr>
<tr>
<td>TKN</td>
<td>1991-1995</td>
<td>0.466</td>
<td>0.485</td>
<td>0.477</td>
</tr>
<tr>
<td>TKN</td>
<td>1996-2000</td>
<td>0.394</td>
<td>0.379</td>
<td>0.470</td>
</tr>
<tr>
<td>TKN</td>
<td>2001-2005</td>
<td>0.502</td>
<td>0.506</td>
<td>0.520</td>
</tr>
<tr>
<td>TKN</td>
<td>2006-2010</td>
<td>0.657</td>
<td>0.549</td>
<td>0.618</td>
</tr>
<tr>
<td>TKN</td>
<td>2009-2013</td>
<td>0.646</td>
<td>0.611</td>
<td>0.817</td>
</tr>
<tr>
<td>TN</td>
<td>1991-1995</td>
<td>1.198</td>
<td>1.105</td>
<td>0.946</td>
</tr>
<tr>
<td>TN</td>
<td>1996-2000</td>
<td>0.984</td>
<td>0.941</td>
<td>0.820</td>
</tr>
<tr>
<td>TN</td>
<td>2001-2005</td>
<td>1.044</td>
<td>1.008</td>
<td>0.901</td>
</tr>
<tr>
<td>TN</td>
<td>2006-2010</td>
<td>1.143</td>
<td>1.030</td>
<td>1.050</td>
</tr>
<tr>
<td>TN</td>
<td>2009-2013</td>
<td>1.219</td>
<td>1.078</td>
<td>1.213</td>
</tr>
<tr>
<td>TP</td>
<td>1991-1995</td>
<td>0.161</td>
<td>0.112</td>
<td>0.123</td>
</tr>
<tr>
<td>TP</td>
<td>1996-2000</td>
<td>0.116</td>
<td>0.100</td>
<td>0.107</td>
</tr>
<tr>
<td>TP</td>
<td>2001-2005</td>
<td>0.111</td>
<td>0.117</td>
<td>0.111</td>
</tr>
<tr>
<td>TP</td>
<td>2006-2010</td>
<td>0.147</td>
<td>0.107</td>
<td>0.104</td>
</tr>
<tr>
<td>TP</td>
<td>2009-2013</td>
<td>0.139</td>
<td>0.114</td>
<td>0.176</td>
</tr>
</tbody>
</table>

In summary, the FN loading analysis indicates that substantial reduction of NOx-N loading has been achieved over the study period, but organic Nitrogen loads have not been reduced. Total Nitrogen and total P loads were lower than the 1991-1995 loads for most five-year periods, but there were increases in both TN and TP loads in the three most recent five-year periods. The results of this analysis confirm the nutrient loading trends reported in recent studies (Lebo et al., 2011 and Alameddine et al., 2011).
References:


Appendix A
Flow-Normalized Loading Analysis
II. Flow-Normalized Loading Analysis

i. Flow-Normalized Loading - DWR AMS O0100000 – Tar River near Tar River

Figures 2-6 and 2-7 show annual TN loading at the Tar River DWR AMS O0100000 near Tar River. The results show that annual TN loading at this station ranged from 0.1 to 4.4 x 10^5 lbs/year for the 1991–2013 timeframe, with a median value of 1.9 x 10^5 lbs/year for (Figure 2.6). Average contributions of Ammonia–N, NOx-N, and Org-N to the TN load for 1991–2013 period were 6, 23 and 71%, respectively. Organic Nitrogen was computed as TKN minus Ammonia. Overall, there was an increase in the contribution of the Org-N fraction and a decrease in that of the NOx-N fraction to TN loading at Tar River for the study period (1991-2013). The Org-N contribution increased from 62% of TN for 1991–2000 period to 79% of TN for 2003–2013 period. The NOx-N contribution decreased from 30% of TN for 1991–2000 period to 17% of TN for 2003–2013 period (Figure 2-6). Figure 2-7 shows annual TN loading at Tar River by flow interval. The average TN contributions (1991-2003) from low, middle, and high flow interval were 1, 7 and 92%, respectively. The annual TP loading at Tar River ranged from 0.06 to 0.7 x 10^5 lbs/year, with a median value of 0.20 x 10^5 lbs/year (Figure 2-8). Figure 2-8 shows annual TP loading at Tar River by flow interval. The average TP contributions (1991-2003) from low, middle, and high flows were 0.6, 6.6 and 92.8%, respectively. These results show that high flow events contribute substantially large amount of nutrients in this watershed.
In order to evaluate progress in achieving nutrient reduction goal set by the Tar Pamlico River Basin Nutrient Management Strategy, FN load estimated under long-term average flow conditions were compared to the average load for the 1991-1995 period (Figure 2-9). Five-year moving averages of NOx-N, TKN, TN, and TP loads were computed and compared with the corresponding value for the 1991–1995 period.
The results of the FN loading analysis indicate reduction in FN NOx-N loading, but an increase in TKN loading. Flow-normalized NOx-N loading decreased from the 1991–1995 to the 1992-1996 period and increased back in the 1993-1997 period. It then continued to decrease and reached a minimum value of -50.9% in the 2005–2009 time period. The Flow-normalized NOx–N loadings for the period beginning in the 1993-1997 and ending in the 1997-2001 was higher than the corresponding loading in the 1991-1995 period and was lower thereafter. The average NO3–N reduction achieved was approximately 38% for all periods beginning with 1998–2002 (Figure 2-9). Flow-normalized TKN loading at Tar River decreased from the baseline period and reached the minimum value of -13.6% in the 1994-1998 period and increased gradually afterwards. Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period throughout the past 14 five-year periods and increased by about 33% during this period. Since Ammonia loading declined over the same time period, the increase in TKN loading was primarily due to an increase in the Org-N fraction. The recent increase in TKN flow normalized loadings appears to be mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx-N and TKN and has been consistently higher than the corresponding 1991-1995 beginning the 1995-1999 period ending with the 2009-2013 period. The FN TN loading decreased to a minimum value of -6.5% in the 1992-1996 period and increased gradually afterwards. The average increase in FN TN loading for the periods beginning in 1995-1999 ending in 2009-2013 was approximately 13% (Figure 2-9).

Flow-normalized TP loading at Tar River has been consistently lower than the corresponding 1991-1995 loading until the 1997-2001 period and then gradually increased and became higher than the 1991-1995 loading since the 2000-2004 period (Figure 2-10). The flow-normalized TP loading decreased to a minimum value of -16.6% in the 2003-2007 period and increased
gradually afterwards. The FN TP loading reached to a maximum value of 51.2% in the 2002-2006 period and declined afterwards, but remained higher than the 1991-1995 period loading. The average reduction in flow-normalized TP loading for the periods ending in 1999-2003 was approximately 17%. The average increase in flow-normalized TP loading for the periods beginning in 2000-2004 and ending in 2009-2013 was approximately 27%.

**Figure 2-10. Relative P Load Reduction-Comparison to 1991-1995**

Average concentrations of N fraction and TP by flow interval

Table 2-2 show average concentrations of N fraction and P by flow interval at Tar River. The results show that changes in N fractions exhibited marked differences for the different flow intervals at Tar River. While the average concentrations of the NOx-N fraction decreased more for the low and middle flow intervals than for high flows, the average concentrations of the TKN fraction increased more for the middle and high flow intervals. For example, reductions in NOx-N for the 2009-2013 period from corresponding values for 1991–1995 were 61, 12, and 32%, respectively, for the low, middle, and high flow interval. Conversely, the increases in TKN concentrations for the 2007-2011 from the corresponding values for 1991-1995 were 7%, 42%, and 44%, respectively, for the low, middle, and high flow interval. The TN concentrations decreased by 3% for the low flow intervals and increased by 20% for the high flow intervals. The average concentrations of TP decreased by 21% for low flow fraction and increased by 52% for the middle flow fraction during the same period.
Table 2-2. Average NO3–N, TKN, TN, and TP concentrations (mg/l) at Tar River near Tar River by five-year period and flow interval

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Period</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991-1995</td>
<td>NOx-N</td>
<td>0.064</td>
<td>0.159</td>
<td>0.215</td>
</tr>
<tr>
<td>1996-2000</td>
<td>NOx-N</td>
<td>0.058</td>
<td>0.148</td>
<td>0.222</td>
</tr>
<tr>
<td>2001-2005</td>
<td>NOx-N</td>
<td>0.050</td>
<td>0.120</td>
<td>0.157</td>
</tr>
<tr>
<td>2006-2011</td>
<td>NOx-N</td>
<td>0.044</td>
<td>0.071</td>
<td>0.124</td>
</tr>
<tr>
<td>2009-2013</td>
<td>NOx-N</td>
<td>0.025</td>
<td>0.140</td>
<td>0.147</td>
</tr>
<tr>
<td>1991-1995</td>
<td>TKN</td>
<td>0.386</td>
<td>0.392</td>
<td>0.462</td>
</tr>
<tr>
<td>1996-2000</td>
<td>TKN</td>
<td>0.368</td>
<td>0.289</td>
<td>0.474</td>
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<tr>
<td>2001-2005</td>
<td>TKN</td>
<td>0.423</td>
<td>0.441</td>
<td>0.609</td>
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<td>2006-2011</td>
<td>TKN</td>
<td>0.469</td>
<td>0.461</td>
<td>0.699</td>
</tr>
<tr>
<td>2009-2013</td>
<td>TKN</td>
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<td>0.663</td>
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<td>1991-1995</td>
<td>TN</td>
<td>0.450</td>
<td>0.551</td>
<td>0.677</td>
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<tr>
<td>1996-2000</td>
<td>TN</td>
<td>0.426</td>
<td>0.437</td>
<td>0.695</td>
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<tr>
<td>2001-2005</td>
<td>TN</td>
<td>0.473</td>
<td>0.561</td>
<td>0.766</td>
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<tr>
<td>2006-2011</td>
<td>TN</td>
<td>0.513</td>
<td>0.532</td>
<td>0.823</td>
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<tr>
<td>2009-2013</td>
<td>TN</td>
<td>0.437</td>
<td>0.695</td>
<td>0.810</td>
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<tr>
<td>1991-1995</td>
<td>TP</td>
<td>0.050</td>
<td>0.046</td>
<td>0.079</td>
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<tr>
<td>1996-2000</td>
<td>TP</td>
<td>0.047</td>
<td>0.034</td>
<td>0.060</td>
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<tr>
<td>2001-2005</td>
<td>TP</td>
<td>0.047</td>
<td>0.094</td>
<td>0.111</td>
</tr>
<tr>
<td>2006-2011</td>
<td>TP</td>
<td>0.057</td>
<td>0.057</td>
<td>0.098</td>
</tr>
<tr>
<td>2009-2013</td>
<td>TP</td>
<td>0.039</td>
<td>0.070</td>
<td>0.090</td>
</tr>
</tbody>
</table>

In summary, the FN loading analysis indicates that significant reduction of NOx-N loading has been achieved over the study period, but organic Nitrogen loads have not been reduced. Flow-normalized TN and TP loadings has been consistently higher than the corresponding 1991-1995 in recent periods. The results of this analysis confirm the nutrient loading trends reported in recent studies. (Lebo et al., 2011 and Alameddine et al., 2011).

ii. Flow-Normalized Loading -DWR AMS O4680000 – Fishing Creek near Enfield

Figures 2-11 and 2-12 show annual TN loading at the Fishing Creek DWR AMS O4680000 near Enfield. The results show that annual TN loading at this station ranged from 0.65 to 9.6 x 10^5 lbs/year for the 1991–2013 timeframe, with a median value of 4.2 x 10^5 lbs/year for (Figure 2-11). Average contributions of Ammonia–N, NOx-N, and Org-N to the TN load for 1991–2013 period were 9, 31 and 60%, respectively. Organic Nitrogen was computed as TKN minus
Ammonia. Overall, there was an increase in the contribution of the Org-N fraction and a decrease in that of the NOx-N fraction to TN loading at Fishing Creek for the study period (1991-2013). The Org-N contribution increased from 55% of TN for 1991–2001 period to 65% of TN for 2002–2013 period. The NOx-N contribution decreased from 33% of TN for 1991–2001 period to 28% of TN for 2002–2013 period. Figure 2-12 shows annual TN loading at Fishing Creek by flow interval. The average TN contributions (1991-2013) from low, middle, and high flow interval were 5, 16 and 79%, respectively. The annual TP loading at Fishing Creek ranged from 0.1 to $1.2 \times 10^5$ lbs/year, with a median value of $0.43 \times 10^5$ lbs/year (Figure 2-13). Figure 2-13 shows annual TP loading at Fishing Creek by flow interval. The average TP contributions (1991-2013) from low, middle, and high flows were 4, 19 and 77%, respectively. These results show that high flow events contribute substantially large amount of nutrients in this watershed.

Figure 2-11. Total N Load at the Fishing Creek Station (AMS O4680000)
In order to evaluate progress in achieving nutrient reduction goal set by the Tar Pamlico River Basin Nutrient Management Strategy, FN load estimated under long-term average flow conditions were compared to the average load for the 1991-1995 period (Figure 2-14). Five-year moving averages of NOx-N, TKN, TN, and TP loads were computed and compared with the corresponding value for the 1991–1995 period.

The results of the FN loading analysis indicate reduction in FN NOx-N loading, but an increase in TKN loading. Flow-normalized NOx-N loading decreased from the 1991–1995 to the end of
the study period. The Flow-normalized NOx-N loading reached a minimum value of -38.2% in the 1998–2002 time period and a maximum values of +2.2% in the 2006-2010 period. The Flow-normalized NO3–N loadings for all periods except the 2006-2010 period were lower than the corresponding loading in the 1991-1995 period. The average reduction in NOx-N achieved was approximately 24% for all periods. Flow-normalized TKN loading at Fishing Creek decreased from the 1991-1995 period and reached the minimum values of -21.0% in the 1994-1998 period and increased gradually afterwards. Flow-normalized TKN loading has been consistently higher than the 1991–1995 period throughout the past 14 five-year periods except in the 2005-2009 period and increased by about 21% during this period (Figure 2-14). Since Ammonia loading declined over the same time period, the increase in TKN loading was primarily due to an increase in the Org-N fraction. The recent increase in TKN flow normalized loadings appears to be mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx-N and TKN. The FN TN loading decreased to a minimum value of -21.5% in the 1994-1998 period and increased gradually afterwards reaching a maximum values of 34% in the 2008-2012 period. The average decrease in FN TN loading for the periods ending in 2005-2009 was approximately 8% and the average increase for the periods beginning in 2006-2010 and ending in 2009-2013 was about 19% (Figure 2-14).

Flow-normalized TP loading at Fishing Creek has been consistently lower than the corresponding 1991-1995 loading until the 1996-2001 period and then gradually increased and became higher than the 1991-1995 loading since the 2002-2007 period. The flow-normalized TP loading decreased to a minimum value of -16.2% in the 1994-1998 period and increased gradually afterwards. The FN TP loading reached to a maximum value of 35.2% in the 2009-2013 period. The average reduction in flow-normalized TP loading for the periods ending in 1996-2000 was approximately 9%. The average increase in flow-normalized TP loading for the
periods beginning in 1999-2003 and ending in 2009-2013 was approximately 21.0% (Figure 2-15).

Figure 2-15. Relative TP Load Reduction - Comparison to 1991-1995

Average concentrations of N fraction and P by flow interval

Table 2-3 show average concentrations of N fraction and P by flow interval at Fishing Creek. The results show that changes in N fractions exhibited marked differences for the different flow intervals at Fishing Creek. While the average concentrations of the NOx-N fraction decreased more for the low and middle flow intervals than for high flows, the average concentrations of the TKN fraction increased more for the high flow intervals. For example, reductions in NOx-N for the 2009-2013 period from corresponding values for 1991–1995 were 34, 35, and 29%, respectively, for the low, middle, and high flow interval. Conversely, the increases in TKN concentrations for the 2009-2013 from the corresponding values for 1991-1995 were 47%, 26% and 72%, respectively, for the low, middle and high flow interval. The TN concentrations increased by 19% and 33% for the low flow intervals and high flow intervals, respectively. The average concentrations of TP decreased by 5% for low flow fraction and increased by 44% for the high flow fraction during the same period.
Table 2-3. Average NO3–N, TKN, TN, and TP concentrations (mg/l) at Fishing Creek Station near Enfield by five-year period and flow interval

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Period</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx-N</td>
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<td>NOx-N</td>
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<td>NOx-N</td>
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<td>NOx-N</td>
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<td>TKN</td>
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<td>TP</td>
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<td>0.059</td>
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</table>

In summary, the FN loading analysis for the Fishing Creek station indicates that significant reduction of NOx-N loading has been achieved over the study period, but organic Nitrogen loads have not been reduced. Flow normalized TN and TP loads showed increasing trends in most recent periods. The results of this analysis confirm the nutrient loading trends reported in recent studies (Lebo et al., 2011 and Alameddine et al., 2011).

iii. Flow-Normalized Loading - DWR AMS O5250000 – Tar River near Tarboro

Figures 2-16 and 2-17 show annual TN loading at the Tar River DWR AMS O5250000 near Tarboro. The results show that annual TN loading at this station ranged from 0.74 to 6.2 x 10^6 lbs/year for the 1991–2013 timeframe, with a median value of 2.8 x 10^6 lbs/year for (Figure 2-
16). Average contributions of Ammonia–N, NOx-N, and Org-N to the TN load for 1991–2013 period were 7, 37 and 56%, respectively. Organic Nitrogen was computed as TKN minus Ammonia. Overall, there was a slight increase in the contribution of the Org-N fraction from 1991 to 2001 and a decrease from 2003 to 2013. There was a steady decrease in the NOx-N fraction to TN loading for the study period (1991-2013). The average Org-N contribution increased from 49% of TN for 1991–2001 period to 63% of TN for 2003–2013 period. The NOx-N contribution decreased from 41% of TN for 1991–2001 period to 33% of TN for 2003–2013 period (Figure 2-16). Figure 2-17 shows annual TN loading at Tar River near Tarboro by flow interval. The average TN contributions (1991-2013) from low, middle, and high flow interval were 5, 18 and 77%, respectively. The annual TP loading at Tar River near Tarboro ranged from 0.5 to 8.9 x 10^5 lbs/year, with a median value of 3.3 x 10^5 lbs/year (Figure 2-18). Figure 2-18 shows annual TP loading at this station by flow interval. The average TP contributions (1991-2013) from low, middle, and high flows were 4.4, 16.2 and 79.4%, respectively. These results show that high flow events contribute substantially large amount of nutrients in this watershed.
In order to evaluate progress in achieving nutrient reduction goal set by the Tar Pamlico River Basin Nutrient Management Strategy, FN load estimated under long-term average flow conditions were compared to the average load for the 1991-1995 period (Figure 2-19). Five-year moving averages of NOx-N, TKN, TN, and TP loads were computed and compared with the corresponding value for the 1991–1995 period.
The results of the FN loading analysis indicate reduction in FN NOx-N loading, but an increase in TKN loading. Flow-normalized NOx-N loading gradually decreased from the 1991–1995 and reached a minimum value of -35.1% in the 2005–2009 time period and increased afterwards. The Flow-normalized NOx-N loadings for all periods were lower than the corresponding loading in the 1991-1995 period. The average reduction achieved was approximately 20% for all periods. (Figure 2-19). Flow-normalized TKN loading at Tar River near Tarboro decreased from the 1991-1995 period and reached the minimum values of -23.7% in the 1994-1998 period and increased gradually afterwards. Flow-normalized TKN loading has been consistently higher than the 1991–1995 baseline period throughout the past 11 five-year periods and reached a maximum values of 37% in the 2009-2013 period. Ammonia loading declined over the same time period and the increase in TKN loading was primarily due to an increase in the Org-N fraction. The recent increase in TKN flow normalized loadings appears to be mainly due to increases for the high flow intervals.

Flow-normalized TN loading exhibited the combination of the patterns for NOx-N and TKN. The FN TN loading decreased to a minimum value of -18.9% in the 1994-1998 period and increased gradually afterwards reaching a maximum values of 13.1% in the 2008-2012 period. The FN TN loading was higher than the corresponding loading of the 1991-1995 period for the last three five-year periods. The average decrease in FN TN loading for the periods ending in 2006-2010 was approximately 11% and the average increase for the periods beginning in 2007-2011 ending in 2009-2013 was about 10% (Figure 2-19).

Flow-normalized TP loading at Tar River Station near Tarboro has been consistently lower than the corresponding 1991-1995 loading until the 1998-2002 period and then gradually increased and became higher than the 1991-1995 loading since the 1999-2003 period. The flow-normalized TP loading decreased to a minimum value of -15.6% in the 1994-1998 period and increased.
gradually afterwards. The FN TP loading reached to a maximum value of 27.5% in the 2000-2004 period. The average reduction in flow-normalized TP loading for the periods ending in 1998-2002 was approximately 7%. The average increase in flow-normalized TP loading for the periods beginning in 1999-2003 and ending in 2009-2013 was approximately 16.0% (Figure 2-20).

**Average concentrations of N fraction and P by flow interval**

Table 2-4 show average concentrations of N fraction and P by flow interval at Tar River near Tarboro. The results show that changes in N fractions exhibited marked differences for the different flow intervals at Tar River near Tarboro. While the average concentrations of the NOx-N fraction decreased more for the low and middle flow intervals than for high flows, the average concentrations of the TKN fraction increased more for the high flow intervals. For example, reductions in NOx-N for the 2009-2013 period from corresponding values for 1991–1995 were 21, 32, and 20%, respectively, for the low, middle, and high flow interval. Conversely, the increases in TKN concentrations for the 2009-2013 from the corresponding values for 1991-1995 were 21%, 6%, and 45%, respectively, for the low, middle, and high flow interval. The TN concentrations decreased by 3% for the low flow intervals and increased by 20% for the high flow intervals. The average concentrations of TP decreased by 27% for low flow fraction and increased by 32% for the high flow fraction during the same period.
Table 2-4. Average NO3–N, TKN, TN, and TP concentrations (mg/l) at Tar River near Tarboro by five-year period and flow interval

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Period</th>
<th>Low</th>
<th>Middle</th>
<th>High</th>
</tr>
</thead>
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<td>NOx-N</td>
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<td>0.404</td>
<td>0.327</td>
</tr>
<tr>
<td>NOx-N</td>
<td>1996-2000</td>
<td>0.507</td>
<td>0.443</td>
<td>0.266</td>
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<tr>
<td>NOx-N</td>
<td>2001-2005</td>
<td>0.295</td>
<td>0.301</td>
<td>0.269</td>
</tr>
<tr>
<td>NOx-N</td>
<td>2006-2011</td>
<td>0.401</td>
<td>0.255</td>
<td>0.229</td>
</tr>
<tr>
<td>NOx-N</td>
<td>2009-2013</td>
<td>0.437</td>
<td>0.276</td>
<td>0.263</td>
</tr>
<tr>
<td>TKN</td>
<td>1991-1995</td>
<td>0.39</td>
<td>0.53</td>
<td>0.49</td>
</tr>
<tr>
<td>TKN</td>
<td>1996-2000</td>
<td>0.30</td>
<td>0.38</td>
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<tr>
<td>TKN</td>
<td>2001-2005</td>
<td>0.43</td>
<td>0.45</td>
<td>0.52</td>
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<td>TKN</td>
<td>2006-2011</td>
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<td>0.54</td>
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<td>TKN</td>
<td>2009-2013</td>
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<td>TP</td>
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<td>TP</td>
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<td>0.087</td>
<td>0.100</td>
<td>0.117</td>
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</table>

In summary, the FN loading analysis indicates that significant reduction of NOx-N loading has been achieved over the study period, but organic Nitrogen loads have not been reduced. Flow normalized TN and TP loads showed increasing trends in most recent periods. The results of this analysis confirm the nutrient loading trends reported in recent studies (Lebo et al., 2011 and Alameddine et al., 2011).

iv. Flow-Normalized Loading - DWR AMS O4650000 – Chicod Creek near Simpson

Figures 2-21 and 2-22 shows annual TN loading at the Chicod Creek DWR AMS O4650000 near Simpson. The results show that annual TN loading at this station ranged from 0.12 to 3.34 x 10^5 lbs/year for the 1993–2013 timeframe, with a median value of 1.17 x 10^5 lbs/year for (Figure 2-21). Average contributions of Ammonia–N, NOx-N, and Org-N to the TN load for 1993–2013 period were 12.6, 42.8 and 44.6%, respectively. Organic Nitrogen was computed as TKN minus...
Ammonia. Overall, there was a slight decrease in the contribution of the Org-N fraction from 1993 to 2001 and an increase from 2002 to 2013. There was a steady decrease in the NOx-N fraction to TN loading for the study period (1993-2013). The Org-N contribution increased from 33% of TN for 1993–2002 period to 60% of TN for 2003–2013 period. The NOx-N contribution decreased from 48% of TN for 1993–2002 period to 35% of TN for 2003–2013 period (Figure 2-21). Figure 2-22 shows annual TN loading at Tar River near Simpson by flow interval. The average TN (1991-2013) contributions from low, middle, and high flow interval were 1, 7, and 92%, respectively. The annual TP loading at Chicod Creek ranged from 0.04 to 0.67 x 10⁵ lbs/year, with a median value of 0.26 x 10⁵ lbs/year (Figure 2-23). Figure 2-23 shows annual TP loading at Chicod Creek by flow interval. The average TP contributions from low, middle, and high flows were 2, 9, and 89%, respectively. These results show that high flow events contribute substantially large amount of nutrients in this watershed.
In order to evaluate progress in achieving nutrient reduction goal set by the Tar Pamlico River Basin Nutrient Management Strategy, FN load estimated under long-term average flow conditions were compared to the average load for the 1993-1997 period (Figure 2-24). Five-year moving averages of NOx-N, TKN, TN, and TP loads were computed and compared with the corresponding value for the 1993–1997 period.
The results of the FN loading analysis indicate reduction in FN NOx-N and TKN loadings relative to the 1993-1997 period. Flow-normalized NOx-N loading gradually decreased from the 1993–1997 period and reached a minimum value of -54.9% in the 2004–2008 time period and slightly increased afterwards. The Flow-normalized NOx–N loadings for all periods were lower than the corresponding loading in the 1993-1997 period. The average NOx-N load reduction achieved was approximately 33% for all periods (Figure 2-24). Flow-normalized TKN loading at Chicod Creek near Simpson gradually decreased from the 1993-1997 period and reached the minimum values of -41.3% in the 1997-2001 period and increased gradually afterwards. Flow-normalized TKN and NOx-N loadings have been consistently lower than the 1993–1997 time period throughout the study period. The average TKN load reduction achieved was approximately 24% for all periods (Figure 2-24). Ammonia loading declined over the same time period.

Flow-normalized TN loading exhibited the combination of the patterns for NOx-N and TKN. The FN TN loading decreased to a minimum value of -38.4% in the 2004-2008 period and increased gradually afterwards. The FN TN loading was consistently lower than the corresponding loading of the 1993–1997 period throughout the study period. The average decrease in FN TN loading for the periods ending in 2006-2010 was approximately 11% and the average increase for the periods beginning in 2007-2011 ending in 2009-2013 was about 10%. The average TN load reduction achieved was approximately 28% for all periods (Figure 2-24).

Flow-normalized TP loading at Chicod Creek Station near Simpson has been consistently lower than the corresponding 1993-1998 loading except in the 1994-1998 period. The flow-normalized TP loading decreased to a minimum value of -37.8% in the 1999-2003 period and increased gradually reaching a maximum values of -13.1 in the 2003-2007 period and declined afterwards.
The average reduction in flow-normalized TP loading for all periods was approximately 22%. The average increase in flow-normalized TP loading for the periods beginning in 1999-2003 and ending in 2009-2013 was approximately 16.0% (Figure 2-25).

![Relative TP Load Reduction - Comparison to 1993-1997](image)

**Figure 2-25. Relative TP Load Reduction - Comparison to 1993-1997**

Average concentrations of N fraction and P by flow interval

Table 2-5 show average concentrations of N fraction and P by flow interval at Chicod Creek. The results show that changes in N fractions exhibited marked differences for the different flow intervals at Chicod Creek. The average concentrations of the NOx-N fraction decreased more for the low and middle flow intervals than for high flows. Unlike the other stations included in this analysis, the average concentrations of the TKN fraction increased more for low and middle flow intervals and decreased for the high flow intervals. For example, reductions in NOx-N for the 2009-2013 period from corresponding values for 1991–1995 were 88, 68, and 42%, respectively, for the low, middle, and high flow interval. Conversely, the increases in TKN concentrations for the 2009-2013 from the corresponding values for 1991-1995 were 18% and 23%, respectively, for the low, middle flow intervals and decreased by 15% for the high flow intervals. The TN concentrations decreased by 13% for the low flow intervals and by 28% for the high flow intervals. The average concentrations of TP decreased by 44% and 37% for low flow fractions and high flow fractions, respectively, during the same period.
In summary, the FN loading analysis for the Chicod Creek indicates that substantial reductions of NOx-N, Organic Nitrogen, TN and TP loadings have been achieved over the study period, but organic Nitrogen loads have started to increase in recent periods.
Appendix B

Annual Flow Volume Plots for Selected Stations in the Tar Pamlico River Basin
Figure B-4. Flow volume at USGS gage 02084160 - Chicod Creek near Simpson
Appendix C
Tables and Plots of Loads Estimated using the USGS LOADEST Program
### Annual Total Nitrogen (TN) Load (lbs/yr)

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<th>O0100000</th>
<th>O4680000</th>
<th>O5250000</th>
<th>O6450000</th>
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<td>UCL*</td>
<td>Mean</td>
<td>LCL*</td>
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* LCL = 95% Lower Confidence Limit
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Figure C-1. Estimated TN Load using the USGS LOADEST Program

Figure C-1. Estimated TN Unit Area Load (UAL) using the USGS LOADEST Program
Figure C-1. Estimated TN Load using the USGS LOADEST Program

Figure C-1. Estimated TP Unit Area Load (UAL) using the USGS LOADEST Program