Changes in land use/management and water quality in the Long Creek watershed
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ABSTRACT: Surface water in the Long Creek watershed, located in western Piedmont region of North Carolina, was monitored from 1993 to 2001. The 8,190 ha watershed has undergone considerable land use and management changes during this period. Land use surveys have documented a 60 percent decrease in cropland area and a more than 200 percent increase in areas being developed into new homes. In addition, more than 200 conservation practices have been applied to the cropland and other agricultural land that remains in production. The water quality of Long Creek was monitored by collecting grab samples at four sites along Long Creek and continuously monitoring discharge at one site. The monitoring has documented a 70 percent reduction in median total phosphorus (TP) concentrations, with little reductions in nitrate and total Kjeldahl nitrogen, or suspended sediment levels. Fecal coliform (FC) and streptococci (FS) levels declined significantly downstream as compared to upstream during the last four years of monitoring. This decrease was attributed to the implementation of waste management practices and livestock exclusion fencing on three dairy operations in the watershed. Annual rainfall and discharge increased steadily until peaking in the third year of the monitoring period and varied while generally decreasing during the last four years of the project. An array of observation, pollutant concentration, and hydrologic data provide considerable evidence to suggest that the implementation of BMPs in the watershed have significantly reduced phosphorus and bacteria levels in Long Creek.

(KEY TERMS: land use; water quality; nonpoint source pollution.)

INTRODUCTION

The Long Creek watershed is the site of a nine year comprehensive watershed project initiated in 1993 to improve stream water quality while documenting the effectiveness of nonpoint source pollution controls. The project is one of 22 comprehensive, watershed monitoring projects in the U.S. Environmental Protection Agency (USEPA) Nonpoint Source National Monitoring Program (Osmond et al., 1997). Long Creek drains an 8,190 ha watershed located in the Piedmont physiographic region of southwestern North Carolina. The watershed geology is typical of this area of the Piedmont with a saprolite layer of varying thickness overlaying fractured igneous and metamorphic rock. Soils in the watershed are generally well drained and have a loamy surface layer underlain by a clay subsoil. The topography of the watershed is generally hilly with land slopes of 5 to 15 percent.

The creek has documented water quality degradation caused by sediment, bacteria, and nutrients (NCDEM, 1989). Potential pollution sources to Long Creek include agriculture (livestock and crop production), mining, forestry, urban runoff, septic system outflow, and streambank erosion. Approximately 20,060 m$^3$ of animal waste and 21,950 m$^3$ of municipal sludge is applied to agricultural land in the watershed annually.

During the late 1980s and early 1990s economic and environmental factors combined to encourage producers to retire marginal or highly erodible land from agricultural production and implement conservation practices on land remaining in production. Also, since the early 1990s, several state laws and regulations have been enacted to address agricultural pollution sources, with particular emphasis on animal waste management. Current rules require that confined animal operations, including those with at least 250 swine or 100 cattle, have no discharges to waters of the state, submit to annual inspections, and have an approved comprehensive waste management plan. From a federal prospective, the 1985 to 1996 Farm Bills protects highly erodible land by denying benefits to producers not in compliance with conservation provisions. The Farm Bills and several incentive

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programs have combined to provide the impetus for extensive implementation of best management practices (BMPs) in the Long Creek watershed.

The objective of this study was to assess the effect of the implementation of BMPs and changes in land use on the water quality of Long Creek. Accomplishing this objective requires that a change in water quality can be documented and then that the change can be related to the implementation of BMPs (Spooler and Line, 1993). While many monitoring projects have attempted to relate BMP implementation to improvement in water quality, relatively few, especially for watersheds greater than several hundred hectares, have succeeded (Hallberg et al., 1983; Gale et al., 1993; Schilling and Thompson, 2000). The difficulties often include insufficient treatment of nonpoint sources to effect a water quality change, an inability to adequately track changes in land use and management, insufficient duration of monitoring to detect subtle or delayed changes, or an inadequate monitoring design (Gale et al., 1993). These difficulties were only somewhat overcome in this study.

METHODS

Land use surveys of the 8,190 ha watershed to site I were conducted in 1988 and 1998. The survey consisted of driving around the watershed during the growing season and identifying the land use on the open land. The survey was focused on agricultural or recently converted agricultural land. Therefore, land that had been in woods or residential homes for several years was not surveyed directly, but the extent of this land use was computed by subtracting the area of the land surveyed from the total watershed area as computed from maps. Some open land (less than 100 ha) was not visible from a public road; therefore, it was categorized as unknown (Table 1). Because of the remote location, the land use on most of the land classified as unknown probably did not change during the study. The area of urban/industrial land use was determined from county land zoning maps.

Land management practices or BMPs were also tracked (Table 2). The most common in terms of number or area treated BMPs are listed; however, many more BMPs were implemented in the watershed. Although the timing and locations of many of the BMPs were not readily available, records and observation indicates that most of the BMPs were implemented from 1989 to 1994 in the headwater area of Long Creek or upstream of site H (Figure 1).

A combination of weekly, biweekly, and monthly grab sampling along the main stem of Long Creek was used to document changes in water quality. The number of monitoring sites and frequency of sampling was limited by available funding. The locations of the five sites on Long Creek (H, A, B, C, and I) were decided based on access and pollutant sources. Site H was upstream of all the dairy farms (bacteria and organic nutrient sources) and downstream of most of the cropland sediment sources. Sites B and C were bracketing the tributary that drains the largest dairy farm in the watershed and Site I was downstream of all dairies, and near a discharge gaging station that had 50+ years of data.

For most of the project duration, Sites H, B, and C were sampled weekly from December through May of each year, and then monthly for the rest of the year while Sites A and I were sampled only bi-weekly from December through May and monthly the rest of the year. The increased sampling frequency during the December through May period was due to the expected increase in agricultural activity associated with crop planting in the spring. The sampling frequency

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</thead>
<tbody>
<tr>
<td>Row crops</td>
<td>806</td>
<td>324</td>
<td>9.8</td>
<td>4.0</td>
<td>-5.8</td>
<td></td>
</tr>
<tr>
<td>Hayland/pasture</td>
<td>1,368</td>
<td>1,229</td>
<td>16.7</td>
<td>15.0</td>
<td>-1.7</td>
<td></td>
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<tr>
<td>Residential (new)</td>
<td>10</td>
<td>230</td>
<td>0.1</td>
<td>2.8</td>
<td>+2.7</td>
<td></td>
</tr>
<tr>
<td>Tree farm</td>
<td>0</td>
<td>142</td>
<td>0.0</td>
<td>1.7</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Idle land</td>
<td>404</td>
<td>642</td>
<td>4.9</td>
<td>7.8</td>
<td>+2.9</td>
<td></td>
</tr>
<tr>
<td>Strip mine</td>
<td>105</td>
<td>105</td>
<td>1.3</td>
<td>1.3</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Unknown</td>
<td>204</td>
<td>233</td>
<td>2.5</td>
<td>2.8</td>
<td>+0.3</td>
<td></td>
</tr>
<tr>
<td>Urban and Industrial</td>
<td>463</td>
<td>463</td>
<td>5.7</td>
<td>5.7</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>Residential (old) &amp; Forest</td>
<td>4,830</td>
<td>4,822</td>
<td>59.0</td>
<td>58.9</td>
<td>-0.1</td>
<td></td>
</tr>
<tr>
<td>Total Area</td>
<td>8,190</td>
<td>8,190</td>
<td></td>
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TABLE 2. Selected Conservation Practices Installed in the Long Creek Watershed.

<table>
<thead>
<tr>
<th>Conservation Practice</th>
<th>Number</th>
<th>Applied Units</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient Management</td>
<td>28</td>
<td>130</td>
<td>ha</td>
</tr>
<tr>
<td>Conservation Tillage</td>
<td>51</td>
<td>229</td>
<td>ha</td>
</tr>
<tr>
<td>Crop Rotation</td>
<td>82</td>
<td>884</td>
<td>ha</td>
</tr>
<tr>
<td>Diversion</td>
<td>6</td>
<td>1,082</td>
<td>m</td>
</tr>
<tr>
<td>Field Border</td>
<td>49</td>
<td>16,933</td>
<td>m</td>
</tr>
<tr>
<td>Pasture/Hayland Management</td>
<td>24</td>
<td>79</td>
<td>ha</td>
</tr>
<tr>
<td>Streambank/Shoreline Protection</td>
<td>6</td>
<td>2,102</td>
<td>m</td>
</tr>
<tr>
<td>Terrace</td>
<td>19</td>
<td>23,187</td>
<td>ha</td>
</tr>
<tr>
<td>Waste Utilization</td>
<td>22</td>
<td>71</td>
<td>ha</td>
</tr>
<tr>
<td>Livestock Exclusion Fencing</td>
<td>4</td>
<td>13,000</td>
<td>m</td>
</tr>
</tbody>
</table>

was increased to bi-weekly during the June through November period during the last three years when additional resources became available. Samples collected from Site H were not analyzed for nitrogen and phosphorus due to the emphasis on erosion and sediment control in the headwaters, or water supply sub-watershed area of the watershed and limited resources.

Figure 1. Map of Long Creek Watershed and Sampling Sites.

Grab samples were collected at each site and transported on ice to the laboratory within six hours, where they were analyzed for nitrite+nitrate nitrogen (NO$_3$+NO$_2$), total Kjeldahl nitrogen (TKN), TP, and total suspended solids (TSS) concentrations using methods 353.1, 351.2, and 365.4 from USEPA (1983) for NO$_3$+NO$_2$, TKN, and TP and 2540D from APHA et al. (1989) for TSS. Samples were also analyzed within six hours for FC and FS using methods 9222D and 9230C, respectively, from APHA et al. (1990).

Duplicate, split, blank, and spiked samples were prepared and analyzed to verify the quality and representativeness of the samples. Nine duplicate samples were collected during the period of monitoring. The average of the differences in concentrations between duplicates was less than 10 percent of the mean concentration of duplicate samples for all parameters. To illustrate, the mean concentration of TKN for all 18 duplicate samples was 0.53 mg/L while the average of the differences between samples was 0.005 mg/L, which was 0.9 percent of the mean of all the duplicates. Further, the differences in the log transformed data were found to be not significantly different than zero (0.05 level of significance) using a paired t-test. This was the case for all parameters including NO$_3$+NO$_2$, TKN, TP, TSS, FC, and FS indicating that the samples were repeatable and representative of the water in Long Creek. Additionally, five samples were split and analyzed by an environmental laboratory of Duke Power. Statistical analysis of results from both labs indicated that there was no significant difference (0.05 level of significance) between NO$_3$+NO$_2$, TKN, and TP concentrations; TSS, TS, FC, and FS analyses were not conducted. Six trip blanks of distilled water were prepared and carried around during sampling trips. Analysis of these samples documented NO$_3$+NO$_2$, TKN, TP, TSS, FC and FS levels at or below the minimum detection limit (MDL) for all samples except one. The one exception had a TKN concentration of 0.24 mg/L, which was only slightly greater than the MDL for TKN of 0.15 mg/L.

Continuous precipitation, which was almost exclusively in the form of rainfall, measurements were made using three recording raingages located near the middle of the watershed (Figure 1). Due to delayed installation and equipment failure, rainfall data for the first year of the project (April 1993 to March 1994) had several gaps (60 days total) which were filled in with data from another raingage located in the eastern part of the county. For other years, daily rainfall data for the watershed were computed.
as the average of the working gages. Daily mean discharge was computed from continuous stage measurements recorded at Site 1. The stage recording equipment and a stream stage-discharge rating table at Site 1 were maintained by the U.S. Geological Survey.

RESULTS AND DISCUSSION

Land Use/Management

Both land use and land management changed significantly since the beginning of the monitoring project in 1993. Unfortunately, the first land use survey did not coincide with the start of the monitoring. While the two surveys provide a good picture of land use changes for the period, they do not document the timing of the changes. Observation and local records indicate that much of the land use and management changes occurred prior to or near the beginning (1991 to 1994) of the monitoring project.

As shown in Table 1, the area of row crops, which included cotton, corn, soybeans, sorghum/milo, and small grain, decreased by 5.8 percent during the ten year period between surveys. Most of this decrease was caused by fewer acres in soybeans and small grain. While no surveys were conducted during the ten year period, observation indicates that much of the decrease in row crop acreage occurred during the first half of the period when the Conservation Reserve Program (CRP) and economic factors combined to cause a reduction in row crop acreage. In addition, federal and state incentive programs were targeted to highly erodible land resulting in this land being removed from intensive cultivation or being treated with conservation practices.

The acreage in hayland/pasture declined slightly during the period and also decreased as a percentage (16.7 to 15.0 percent) of the watershed area. Some of the pasture/hayland area was converted to residential lots, which increased from 10 to 230 ha. There were several new home developments at various stages in the watershed, but only those that were actively building structures or roads were included in the new residential category.

There was a considerable increase in the tree farming acreage during the project. Much of this land, which was planted in pine trees, was taken out of row crop production as a result of the CRP. It is not known how much of this land was adjacent to waterways; however, at least 5 ha of cropland directly adjacent to Long Creek and the water supply intake was converted to a natural area with trees in 1995. The amount of idle land, defined as fields grown up in more than 50 percent weeds and woody vegetation, also increased during the period to 7.8 percent of the watershed. The extent of strip mine and unknown land remained about the same during the period. The areas associated with the last two categories were estimated based on maps and total area and not by actual observation.

Concerning land management, much of the land remaining in agricultural production had conservation practices implemented on it sometime between 1987 and 1998. While the entire list of practices, which numbers more than 340, is too numerous to include here, the most extensively used practices, implemented between 1994 and 1998, are shown in Table 2. The number of practices is shown in column 2 while the extent of the practice or the area of land treated by the practice is shown in column 3. Other practices not shown in the table included waste management systems, conservation cover planting, and grassed waterways. Many of these practices were installed prior to or in the first year (1993) of the project, during a period of relatively intense conservation activity after the passage of the 1985 Farm Bill and state legislation.

From a nutrient and bacteria perspective, the most important BMPs implemented have probably been waste management systems, nutrient management, and livestock exclusion. Of the three dairies currently operating in the watershed only one had a waste storage pond at the beginning of the project and it was somewhat undersized. During the project, holding ponds were installed at all three dairies to properly contain the waste until land application. Nutrient management plans were written for each dairy to help minimize excess application of nutrients to cropland fields. More than 13 km of streambank fencing was installed to exclude beef and dairy cows from direct access to streams. These BMPs have likely reduced direct nutrient and bacteria inputs to surface waters from the more than 20,000 m³ of animal waste generated in the watershed.

Water Quality Monitoring

In order to assess changes over time, monitoring data were grouped by monitoring year and summarized. Since monitoring started in April 1993, all successive years started in April also. Because the frequency of sampling was less during summer and fall (June through November) this period had fewer data and because Sites A and I were sampled less frequently, they only had 19 samples per year compared to 32 for Sites H and C. Sampling results from Sites B and C were nearly the same; therefore, for clarity, only results from Site C were presented.
A summary, in the form of boxplots, of the concentrations of TKN for Sites A, C, and I grouped by project year is shown in Figure 2. Project years began in April and ended in March; therefore, the label 93-94 represents the period April 1993 to March 1994. As indicated by the length of the boxes (hatched area) and the differences in medians, the TKN concentrations were variable between years. Medians ranged from 0.22 to 0.34 mg/L, with no definitive trend between sites or years, except that in most years, the median concentration at Site A was less than at Sites C and I.

To facilitate trend analysis, TKN concentrations were sorted by site and log transformed. The significance of a linear regression relationship between TKN concentrations and time was evaluated using analysis of variance (ANOVA). This statistical test was used to determine if the regression adequately explains a significant amount (P less than 0.001) of the variation in TKN concentrations over time. The statistical tests indicated that there was no significant relationship between TKN concentrations and time for Sites A, C, or I even though the box plot appears to show a slight increase during the last two years. Additional years of monitoring would be necessary to confirm an increase in TKN concentrations. Because there was no documented change over time, it appears that the changes in land use and land management had no significant effect on TKN concentrations.

Organic nitrogen or TKN in water can come from many sources, but high concentrations in streams often indicate contamination from untreated animal waste. At the moderate to relatively low levels of TKN documented at Sites A, C, and I, the TKN could be coming from many sources that were unaffected by the BMPs implemented in the watershed. Concerning the level of TKN, the concentrations of TKN in Long Creek are generally greater than the level of organic nitrogen (0.11 mg/L) found in unpolluted streams of the western Piedmont of North Carolina (USGS, 1982). All but one of the annual medians prior to the 1999 to 2000 year were less than the level (0.3 mg/L) considered ample for accelerated algal growth in water (USEPA, 1976); however, medians generally were greater than 0.3 mg/L in the 1999 to 2000 and following year.

Annual median concentrations of NO₂+NO₃ ranged from 0.36 to 0.53 mg/L with the highest median of 0.53 mg/L occurring at Site C during the 95-96 monitoring year. While median NO₂+NO₃ concentrations are variable, it appears that a decrease in concentrations at Sites A, C, and I occurred during the last four years (Figure 3). An ANOVA of NO₂+NO₃ concentrations for each site over time suggested that there was a significant (P less than 0.001) negative relationship for Sites A, C, and I, indicating a significant decrease in NO₂+NO₃ concentrations. The decrease in NO₂+NO₃ concentrations at Sites A and I during the last four years was considerably greater than Site C.
within the range (0.3 to 0.5 mg/L) associated with NPS impacts (Omernik, 1977). Also, more recent monitoring has established a national background NO$_3$ concentration of 0.6 mg/L indicating that stream with concentrations greater than 0.6 mg/L are considered to have been adversely affected by human activities in a variety of land use settings (USGS, 1999). The median concentrations at Sites A, C, and I were well below the national background level, indicating that nitrate levels in Long Creek were not seriously affected by human activities such as agriculture in the watershed.

The annual medians for total nitrogen (TN) in Long Creek, or the sum of TKN and NO$_2$+NO$_3$, ranged from 0.63 to 0.89 mg/L. These medians are less than the national background level (1.0 mg/L) for TN in streams across the U.S. (USGS, 1999). Total nitrogen concentrations that were generally less than background levels indicated that nitrogen pollution was not a serious problem in the watershed.

A boxplot of TP concentrations is shown in Figure 4. Both the variability and annual medians of TP concentrations appear to have decreased considerably during the first three years of monitoring (93-94 to 95-96). The medians for the three sites decreased from 0.18 to 0.22 mg/L in the 93-94 year to the method detection limit (MDC) of 0.05 mg/L in the 96-97 year. The MDC was lowered to 0.01 mg/L during the 97-98 year. Because half the MDC (0.025 mg/L) was used for concentrations less than the MDC, the medians for several years are shown as 0.025 mg/L. Median concentrations remained near 0.025 mg/L for all three sites for the 96-97 and 97-98 years until they began to trend up slightly in the 98-99 year and continued at about the same level through the 00-01 year. An ANOVA of TP concentrations versus time suggested a significant (P less than 0.001) relationship, thereby indicating a significant decrease in TP concentrations with time.

The median TP concentrations are much higher than unpolluted streams (0.01 mg/L) of western North Carolina (USGS, 1982), but are less than the range (0.03 to 0.05 mg/L) reported for streams impacted by NPSs (Omernik, 1977). The median TP concentrations were considerably less than the national background level (0.1 mg/L) or the USEPA desired level of 0.1 mg/L for the prevention of nuisance plant growth in streams not discharging directly into lakes or impoundments (USGS, 1999). Using the recent background level of 0.1 mg/L, the TP levels in Long Creek have decrease below background or NPS impact levels. This reduction is particularly significant for Long Creek as it is a tributary to Lake Wylie, which has been classified as eutrophic due mostly to high phosphorus loading (Hughes et al., 2000).

Given that NPS pollutants usually decrease coincidently with changes in land use/management and TKN concentrations did not decrease, the relatively large decrease in TP was further investigated. The relatively high levels of 93-94 were compared to those of a previous study in which grab samples were collected monthly at Sites C and I during 1992 and analyzed at a local laboratory. The median TP concentrations at both sites were 0.15 mg/L for 1992, which was similar to the elevated levels for 1993 to 1994 reported in this project. During 1994 and later in 1996, grab samples were split and analyzed at separate laboratories. Analysis of variance of the five split samples indicated no significant difference between the two labs. The possibility that sampling occurred during higher discharge rates in 93-94 and 94-95 as compared to the other years was also investigated. The daily mean discharge at Site I for the day of sample collection was plotted versus the TP concentration of the sample. As indicated the discharge rates on sampling days in 93-94 and 94-95 do not appear to be greater than the other two year periods. However, the levels of TP during many of the sampling days in 93-94 and 94-95 are generally greater than later years even at relatively low discharge rates. The data also showed that there was not a strong relationship between discharge and concentrations of TP, particularly during the 93-94 and 94-95 periods. Thus, these data provide additional evidence that the decrease in TP concentrations was real and not a result of inaccurate laboratory analysis or sampling anomalies.
In addition to Sites A, C, and I, grab samples collected from Site H were analyzed for TSS. Boxplots of the TSS concentrations at Site H appear with Sites A, C, and I on Figure 5. Median concentrations of TSS at Sites A, C, and I were remarkably consistent (6 to 7 mg/L) throughout the first five years of the project while medians at Site H were consistently 1 to 3 mg/L less than A, C, or I. The annual median TSS concentrations at A, C, and I decreased during the last three years. Median concentrations at Sites A and C were even less than at the upstream Site H during the 99-00 and 00-01 years. An ANOVA suggested that there was a significant (P < 0.001) negative relationship between TSS concentrations and time at Sites A, C, and I, but not at Site H. This indicates a reduction in TSS inputs downstream of Site H; however, the TSS concentrations at Site I remained slightly greater than those at Site H until the last year.

A boxplot of FC (FS not shown, but similar) for Sites H, A, C, and I is shown in Figure 6. The FC and FS levels were highly variable during the first four years of the project and somewhat less variable during the last four years (97-01). During the first four years of monitoring, yearly median FC levels at Site H ranged from 540 to 630 cfu/100 ml while medians for the other sites were 1.5 to three times greater. The high levels and variable nature of the FC and FS levels particularly at Sites C and I was an indication of untreated animal waste entering Long Creek between the sites. During the fifth through eighth years of monitoring, both the median and number of extreme levels of FC and FS at Sites A, C, and I compared to Site H declined such that in years seven and eight median levels at Sites C and I were less than at Site H.

An ANOVA of FC and FS levels versus time for each site suggested that there was a significant (P < 0.001) decline over time for both FC and FS at Sites C and I. No significant relationship was suggested at Sites H and A, thereby indicating decreased bacteria inputs between Sites H and C. An ANOVA with least significant difference tests were conducted on log transformed data from each year to confirm this trend. By making within year comparisons, climatic effects should be minimized since all the sites experienced the same climatic inputs. The more conservative Bonferroni T test was used for pairwise comparisons because all sites did not have the same number of samples. For FC, comparisons between Sites H and C were significant at the 0.05 level for the first five years and comparisons between Sites H and I were significant for years two through four, while no significant differences were found in the last three years. Hence, the FC at Sites C and I were generally greater than Site H during the first five years and about the same during the last three, indicating that FC inputs between the sites were significantly reduced during the project. While the FS data are less definitive, they tend to support the FC data.
Land Use/Management Effect on Water Quality

With the change in land use and the extensive implementation of BMPs in the watershed an associated improvement in water quality over the eight years of monitoring was expected. Because the BMP implementation began before the monitoring started and implementation continued during the monitoring period, the timing and magnitude of the decrease in pollutant concentrations associated with BMP implementation is difficult to determine. In the case of nitrogen, statistical analysis of TKN concentrations suggested no significant change over time, even though visual observation indicates a slight increase. Given the improved handling and treatment of animal waste in the watershed a decrease in TKN levels was expected; however, TKN can originate from many sources that were not effected by the BMPs implemented in the watershed.

Although the NO$_2$+NO$_3$ concentrations decreased significantly at Sites A, C, and I over time, concentrations at Site C were considerably higher than Sites A or I during the last two years. Elevated NO$_2$+NO$_3$ concentrations at Site C were likely the result of continued high concentrations of NO$_2$+NO$_3$ in a small tributary, which enters Long Creek just upstream of Site C (Figure 1). The tributary drains the pasture and farmstead area of a large dairy, which contains several dairy waste storage ponds. The median NO$_2$+NO$_3$ concentrations at Site E along the tributary were 3.3 to 4.1 mg/L during the 99-00 and 00-01 years. The relatively low discharge of 99-00 and probably 00-01 made the influence of the tributary greater considering that the average discharge of the tributary is normally at least 100 times less than the discharge of Long Creek at Site C, but during times of drought is likely a greater percentage of the discharge in the creek. Nevertheless, the NO$_2$+NO$_3$ concentrations in Long Creek have declined in the last four years. The decrease may be attributed to nutrient management, which was applied to more than 125 ha of remaining cropland, improved animal waste management and utilization implemented on each remaining dairy farm, and many hectares of cropland that were converted to other less fertilizer intensive uses.

Concentrations of TP at all three sites decreased significantly during the monitoring period (Figure 3). The annual median concentrations in the first year (93-94) were well above the national background level of 0.1 mg/L (USGS, 1999), indicating a relatively high level of TP, but decreased to a median (less than 0.05 mg/L) well below the background level during the last three years of monitoring. The high concentrations of TP during the first year of this project were similar to monthly grab sampling conducted by the Gaston Quality of Natural Resources Commission (QNRC) during 1992 at Sites C and I, which had median TP concentrations of 0.15 and 0.16 mg/L, respectively. While this data was collected by various personnel and analyzed by a different laboratory, the results confirm the high level of TP in Long Creek near the start of this project. The elevated concentrations of TP indicated that, because there were no permitted or apparent point sources in the watershed, NPS inputs of TP to Long Creek were excessive and further, implementing BMPs should reduce TP significantly. Since TP concentrations decreased similarly at all three sites, most of the reduction probably occurred upstream of Site A. In addition, because land use upstream of Site A was primarily agricultural cropland and this cropland received the majority of BMPs during the late 1980s and early 1990s, a reasonable to assumption would be that the BMPs reduced TP input to Long Creek.

Regarding phosphorus inputs, cropland in this and other watersheds in North Carolina have long been fertilized, based loosely on crop nitrogen needs resulting in excess phosphorus application. This is particularly apparent on cropland receiving animal waste and domestic sewage sludge applications, which occurred on much of the cropland within the watershed during the early 1990s. Several soil samples collected from a typical waste application field in the watershed have contained on average 340 mg P/kg soil. Eroded soils with phosphorus levels this high would certainly contribute to elevated levels of TP in Long Creek. Conversely, the implementation of conservation practices on cropland and enrolling land into the CRP would have the potential to dramatically reduce TP levels in Long Creek. As summarized previously, 142 ha of cropland were enrolled in the CRP and planted in trees and hundreds of conservation practices were implemented on the remaining cropland. Additionally, a biosolids application facility was created to manage sewage sludge application to pasture and cropland more effectively.

Along with the decrease in TP and the implementation of conservation practices a concurrent decrease in TSS would be expected as TSS and TP levels are often correlated. Statistically significant decreases in TSS levels occurred at Sites A, C, and I, but not at Site H. Given that many of the conservation practices were implemented upstream of Site H, a decrease in TSS at Site H was expected. Possible explanations for this is that most of the decrease in TSS levels occurred prior to the start of monitoring or that grab samples alone are not accurately representing the TSS levels at the site. The QNRC monitoring of 1992 documented median TSS concentrations of 11 and 13 mg/L at Sites C and I. These levels were 4 to 7 mg/L greater than the
medians for Sites C and I during the years of this project. While these data are not for Site H, they provide evidence that TSS levels were higher in Long Creek prior to the start of monitoring in the 93-94 year.

Other evidence of reduced TSS loading to Site H includes Universal Soil Loss Equation (USLE) estimates for cropland erosion in the watershed area upstream of the Bessemer City water supply intake (Site H on Figure 1), have decreased more than 50 percent from preproject levels compared to 1995 levels. Also, the frequency of dredging of the backwater area upstream of a small dam across Long Creek about 200 m downstream of Site H (Figure 1) decreased. This backwater area was historically dredged to maintain a pool near the municipal water supply intake and to keep the intake from becoming plugged with sediment. Prior to 1995, this area was dredged two to three times per year to remove approximately 122 to 190 m$^3$ of deposited sediment annually. After 1995 the frequency of dredging has been reduced to once per year or less. This indicates a reduced sediment load in the upper reaches of Long Creek after 1995.

The decrease in TSS concentrations at Sites A, C, and I occurred primarily after the 97-98 year. There were relatively few conservation practices implemented in 97-98 so the reason for the decrease was probably not entirely NPS related. During the spring of 1998, the surface or strip mine located upstream of Site A (Figure 1) ceased operation and therefore, stopped pumping tailings water into the tributary to Long Creek. In addition, 15 km of eroding stream banks and 5.3 ha of cropland bordering Long Creek were stabilized in 1995 and 1996. The combination of decreased TSS inputs from the mine tailings and stabilization of critical areas likely resulted in the decrease in TSS concentrations at Sites A, C, and I.

The conservation practices implemented on cropland upstream of Site H were expected to have little, if any effect on FC and FS levels at Site H. In fact, annual median levels of FC and FS at Site H were relatively consistent during the period of monitoring ranging from 240 to 720 chf/100 ml with no discernable trend. However, FC levels at downstream Sites C and I decreased significantly with respect to Site H for the last three years. Dairy waste holding ponds and waste irrigation systems were installed on the three operating dairy farms between Sites H and C in 1994, 1995, and 1997, thereby containing waste from more than 600 dairy cows. In addition, livestock exclusion fencing was installed on a tributary draining the largest dairy in 1996. Monitoring on this tributary, which enters Long Creek just upstream of Site C (Figure 1), documented a 90 percent decrease in FC and FS levels following the exclusion fencing. The decrease in annual median and upper quartiles for FC and FS levels at Sites C and I are indicators of improved handling and treatment of animal wastes during the last four years of the project.

The closure of the surface mine (Figure 1) may have reduced FC and FS levels in Long Creek due to the loss of waterfowl habitat associated with the closing. Large tailings ponds once used by the mine to treat effluent were allowed to drain, thereby eliminating bacteria input from a large number of waterfowl.

**Climate Effects**

In relating water quality and NPS control or BMP implementation data, changes in climatic conditions must be considered. Often changes in water quality can result from changes in rainfall alone and not from land use/management changes. Summary statistics of the rainfall data and discharge at Site I were computed for each monitoring year (Table 3) to compare with trends in pollutant concentrations over time. The average daily rainfall was computed by dividing the total annual rainfall (Table 3, column 4) by the number of days of measurable (greater than 0.25 mm) rainfall (column 2). Generally, the average daily rainfall was considered a measure of the size of storms occurring during the year and therefore, along with the total rainfall may be an indicator of runoff and NPS pollutant concentrations as they are runoff dependent. As expected the year (April 1995 to March 1996) with the highest average daily rainfall (12 mm) and greatest rainfall accumulation (1,360 mm) also had the highest average daily mean discharge (1.30 m$^3$/s) and the greatest total annual discharge (Table 3, column 6). The ratio of runoff discharge to rainfall (column 7) ranged from 0.20 to 0.42 with the April 1997 to March 1998 year having the highest ratio. This year had the greatest amount of rainfall falling in winter (426 mm), which contributed to the high runoff/rainfall ratio given that evaporation and water use by plants is lowest during this period.

The average of the daily mean discharges for each year ranged from 0.49 to 1.30 m$^3$/s. The last year (April 2000 to March 2001) was not included because only part of the data for this year was available. Analysis of variance of the discharge data indicated that there were significant differences between years (P less than 0.01) whether they resulted in the changes in TP and FC levels will be discussed further.

The decrease in TP levels from the 93-94 to 95-96 years (Figure 3) may be, at first glance, attributed to increases in annual discharge (Table 3, column 6), which may have the effect of diluting pollutant levels. However, the continued low levels of TP during subsequent years of decreasing discharge suggest that the decline in TP levels was not the result of increased
discharge. The slight increase in TP concentrations during the last three years of monitoring may be attributed to lower discharge, but these increases are much less than the decreases during the first three years. The relatively low levels of TP during several years of varying discharge indicate that the decrease in TP was likely the result of changes in land use/management.

While annual rainfall and discharge are often good indicators, the occurrence of large storms also affects the movement of NPS pollutants. Dividing the number of days of rain (Table 3, column 2) by the total annual rainfall (Table 3, column 4) provides a measure of the size of storms throughout the year as indicated by the average daily rainfall in Table 3. During the six years of relatively low TP concentrations, there were three years of greater or equal average daily rainfalls as compared to the first two years of higher TP levels and three years of lesser indicating that the decreases in TP concentrations were not related to the occurrence of large rainfall events.

The decrease in bacteria levels at downstream Sites A, C, and I during the last four years of monitoring (97-98 to 00-01) occurred while average annual rainfall and discharge for the period were generally less than the first four years. The consistent levels of bacteria at Site H throughout the period indicate that decreases in rainfall and discharge during the last four years were not significantly large as to be the sole cause of lower bacteria levels at Sites C and I. Also, the period of four years is sufficiently long to encompass a wide range of rain events and discharges, which tend to reduce the influence of weather.

Like bacteria, TSS levels at Sites A, C, and I appeared to decrease during the last three years of the monitoring period, although pairwise comparisons similar to those of FC and FS suggested no significant differences in any of the eight years. As stated previously the closing of the surface mine likely resulted in slight lower TSS concentrations and not changes in climate.

### SUMMARY

The Long Creek watershed has undergone considerable land use and management changes over the past eight years. Land use surveys have documented a decrease in cropland area and increases in idle land and new home construction. In addition, more than 200 conservation practices have been applied to the remaining cropland and nutrient animal waste management BMPs have been implemented on all dairy farms that remain in production. Weekly, bi-weekly, and monthly grab samples have been collected from five sites along Long Creek since April, 1993. The grab samples have documented a 70 percent reduction in median annual TP concentrations, small apparent reductions in NO$_2$+NO$_3$ and TSS, and no reductions in TKN levels. Bacteria levels declined significantly in the last four years. Rainfall and discharge increased steadily until peaking in the third year of the monitoring period and decreased at varying rates thereafter. The varied rainfall and discharge totals for years of decreasing pollutant concentrations indicated that the decreases in TP, FC, and FS levels were not the result of natural hydrologic variability. The decrease in TP levels was attributed to a combination of a decrease in cropland acreage, improved handling of animal waste and sewage sludge, and an increase in conservation measures implemented on remaining cropland. This combination has also resulted in less sediment in Long Creek as evidenced by a
decrease in the frequency dredging at the Bessemer City water supply intake.

The decrease in FC bacteria levels at downstream sites A, C, and I can be attributed to improved handling and disposal of animal waste and the draining of tailings ponds as a result of the closure of a surface mine in the watershed. Statistical analyses confirmed a significant reduction in downstream as compared to upstream FC levels during the last four years of the project. Thus, the array of observation, pollutant concentration, and hydrologic data provide considerable evidence to suggest that the implementation of BMPs in the watershed have significantly reduced phosphorus and bacteria levels in Long Creek.

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LITERATURE CITED


