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Introduction
This report presents the results of the Toms Creek water quality assessment, conducted by the North Carolina Division of Water Quality (DWQ) with financing from the Clean Water Management Trust Fund (CWMTF). Toms Creek is considered impaired by the DWQ because it is unable to support an acceptable community of aquatic organisms, indicating that the stream does not fully support its designated uses. The goal of the assessment was to provide the foundation for future water quality restoration activities in the Toms Creek watershed by: 1) identifying the most likely causes of biological impairment; 2) identifying the major watershed activities and pollution sources contributing to those causes; and 3) outlining a general watershed strategy that recommends restoration activities and best management practices (BMPs) to address the identified problems.

Study Area and Stream Description
Toms Creek is a small tributary of the Neuse River located in northeastern Wake County (see map in Section 1) in DWQ subbasin 03-04-02. Approximately 0.5 square mile of the 4.7 square mile watershed lies within the town limits of Wake Forest, while the Rolesville corporate limits lie at the eastern boundary. Residential areas of varying density comprise approximately 28% of the watershed. Most remaining areas are forested, with only 6% of the drainage in row crops and 7% in other agricultural uses. An estimated 10% of the watershed is covered with impervious surfaces such as roads and buildings. The area is experiencing a rapid conversion to residential uses. The most intense development has occurred below Browns Lake, east of Ligon Mill Road. A bypass channel around the Browns Lake dam has created a large gully, 15-20 feet deep, that is an ongoing source of sediment to Toms Creek. The wastewater plant for the Deerchase subdivision (NPDES No. NC0063746) discharges to Toms Creek below Browns Lake. The facility has had periodic toxicity problems.

Based on benthic macroinvertebrate sampling in 1991, Toms Creek near Ligon Mill Road was rated Good. Sampling in 1995 and subsequently has indicated an impaired benthic community at this location and elsewhere below Browns Lake. The stream bed is comprised largely of unstable sand. Upper Toms Creek and Mill Creek, the largest tributary, are not impaired.

Approach
A wide range of data were collected to evaluate potential causes and sources of impairment. Data collection activities included: benthic macroinvertebrate sampling; assessment of stream habitat, morphology, and riparian zone condition; water quality sampling to evaluate stream chemistry and toxicity; and characterization of watershed land use, conditions and pollution sources. Data collected during the study are presented in Sections 2, 4, 5 and 6 of the report.

Conclusions
The most probable causes and sources of impairment, based upon an evaluation of all available data, are the following (see Section 7 for additional discussion):

1. Chlorine toxicity from the Deerchase wastewater treatment plant discharge;
2. Habitat degradation, manifested by sediment deposition and substrate instability.
While the watershed has experienced past agricultural sediment inputs, existing habitat degradation is related to more recent sediment sources, in particular, recently completed subdivisions and the gully at the outlet to Browns Lake. The channels of Toms Creek and its tributaries are incised and likely to be sensitive to future hydrologic change. There is a significant potential for sediment from new construction activities and inadequately controlled stormwater inputs from new development to contribute to continued habitat degradation in the watershed.

Management Strategies
The objective of efforts to improve stream integrity is to create water quality and habitat conditions to support a diverse and functional biological community in this suburbanizing area. While some development has occurred since Toms Creek last supported such a community in the early 1990s, the watershed has not been so highly modified as to preclude significant improvements in stream integrity. Mitigating the potential impacts of future development on watershed hydrology is critical, or improvements resulting from efforts to control current sources of impairment may be short lived.

The following actions are necessary to address current sources of impairment in Toms Creek and prevent future degradation (see Section 8 for additional details). Actions one through five are all essential to restoring and sustaining aquatic communities in the watershed. The remaining actions would also be useful but will result in limited improvement unless the preceding measures are also carried out.

1. **The Division of Water Quality should ensure that chlorine concentrations in the Deerchase WWTP effluent are reduced to nontoxic levels.** This facility will receive a
chlorine limit when its permit is reissued in 2002. Effluent and in-stream toxicity will be carefully evaluated to determine if further action is necessary.

2. **The gully at the outlet to Browns Lake should be rehabilitated** so that the side slopes are stable and are no longer a source of sediment to Toms Creek. It is likely that stabilization will be carried out by the owner of the lake in conjunction with planned retrofitting of the dam. If complete stabilization does not occur at that time, the problem should be otherwise addressed.

3. **More effective sediment and erosion control practices are essential in order to prevent future water quality deterioration related to new construction activities.** The Wake County Erosion and Sediment Control Program should review its current tools and their implementation to determine how erosion and sedimentation control efforts can be improved in this watershed.

4. **The Neuse River basin riparian buffer and stormwater rules and the new Phase II stormwater requirements must be fully and effectively implemented** to prevent channel erosion due to future hydrologic changes in the watershed.

5. **Effective development planning and stormwater management should be implemented throughout the watershed, including those areas not covered by the Neuse River basin stormwater rule or the Phase II stormwater requirements.** Wake County and municipal governments should enhance current stormwater protection efforts to ensure that post-construction stormwater runoff is managed to reduce the risk of channel erosion.

6. **Localized areas of bank erosion between Browns Lake and Ligon Mill Road should be stabilized using bioengineering techniques.**

7. **Riparian areas** in the Saint Andrews, Saint Andrews Plantation and Carriage Run subdivisions should be replanted with native woody vegetation where it has been removed.

8. **A watershed education program should be developed** and implemented with the goal of targeting homeowners in order to reduce current stream damage and prevent future degradation. This could be implemented in conjunction with existing or pending educational programs (e.g., Neuse River basin programs or Phase II efforts). At a minimum the program should include elements to address the following issues throughout the watershed:
   a) redirecting downspouts to pervious areas rather than routing these flows to driveways or gutters;
   b) protecting existing wooded riparian areas on ephemeral streams;
   c) replanting native riparian vegetation on perennial, intermittent and ephemeral channels where such vegetation is absent; and
   d) reducing and properly managing pesticide and fertilizer use.
Section 1
Introduction

This report presents the results of the Toms Creek water quality assessment, conducted by the North Carolina Division of Water Quality (DWQ) with financing from the Clean Water Management Trust Fund (CWMTF). Toms Creek is considered impaired by the DWQ because it is unable to support an acceptable community of aquatic organisms. The reasons for this condition have been previously unknown, inhibiting efforts to improve stream integrity in this watershed.

Part of a larger effort to assess impaired streams across North Carolina, this study was intended to evaluate the causes of biological impairment and to suggest appropriate actions to improve stream conditions. The CWMTF, which allocates grants to support voluntary efforts to address water quality problems, is seeking DWQ’s recommendations regarding the types of activities it could fund in these watersheds to improve water quality. Both the DWQ and the CWMTF are committed to encouraging local initiatives to protect streams and to restore degraded waters.

1.1 Study Area Description

Toms Creek is a small tributary of the Neuse River located in northeastern Wake County (Figure 1.1). The watershed drains approximately 4.7 square miles (12 square km). North Carolina’s 2000 303(d) list designates Tom Creek as impaired for its entire length, a distance of approximately 4 stream miles (6.4 km). Part of the area is within the Wake Forest corporate limits, and the Rolesville town limits lie on the eastern fringe. The majority of the watershed, however, falls within unincorporated areas of Wake County. While much of the watershed remains undeveloped, containing large areas of former agricultural land that have reverted to forest during the last century, the area is experiencing rapid conversion to residential uses, especially within the Wake Forest limits. Streams in the watershed are classified as C NSW (nutrient sensitive waters). Toms Creek lies within DWQ subbasin 03-04-02.

1.2 Study Purpose

The Toms Creek assessment is part of the Watershed Assessment and Restoration Project (WARP), a study of eleven watersheds across the state being conducted during the period from 2000 to 2002 with funding from the CWMTF (Table 1.1). The goal of the project is to provide the foundation for future water quality restoration activities in the eleven watersheds by:

1. Identifying the most likely causes of biological impairment (such as degraded habitat or specific pollutants);
2. Identifying the major watershed activities and sources of pollution contributing to those causes (such as streambank erosion or stormwater runoff from particular urban or rural areas); and
3. Outlining a watershed strategy that recommends restoration activities and best management practices (BMPs) to address the identified problems and improve the biological condition of the impaired streams.
This investigation focused primarily on aquatic life use support issues. It was intended to assess the major issues related to biological impairment as comprehensively as possible within the time frame of the study. While not designed to address other important issues in the Toms Creek watershed, such as bacterial contamination or flooding, the report discusses those concerns where existing information allows.

### Table 1.1 Study Areas Included in the Watershed Assessment and Restoration Project

<table>
<thead>
<tr>
<th>Watershed</th>
<th>River Basin</th>
<th>County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toms Creek</td>
<td>Neuse</td>
<td>Wake</td>
</tr>
<tr>
<td>Upper Swift Creek</td>
<td>Neuse</td>
<td>Wake</td>
</tr>
<tr>
<td>Little Creek</td>
<td>Cape Fear</td>
<td>Orange, Durham</td>
</tr>
<tr>
<td>Horsepen Creek</td>
<td>Cape Fear</td>
<td>Guilford</td>
</tr>
<tr>
<td>Little Troublesome Creek</td>
<td>Cape Fear</td>
<td>Rockingham</td>
</tr>
<tr>
<td>Upper Clark Creek</td>
<td>Catawba</td>
<td>Catawba</td>
</tr>
<tr>
<td>Upper Cullasaja River/ Mill Creek</td>
<td>Little Tennessee</td>
<td>Macon</td>
</tr>
<tr>
<td>Morgan Mill/Peter Weaver Creeks</td>
<td>French Broad</td>
<td>Transylvania</td>
</tr>
<tr>
<td>Mud Creek</td>
<td>French Broad</td>
<td>Henderson</td>
</tr>
<tr>
<td>Upper Conetoe Creek</td>
<td>Tar-Pamlico</td>
<td>Edgecombe, Pitt, Martin</td>
</tr>
<tr>
<td>Stoney Creek</td>
<td>Neuse</td>
<td>Wayne</td>
</tr>
</tbody>
</table>

### 1.3 Study Approach and Scope

Of the study’s three objectives, identification of the likely causes of impairment is a critical building block, since addressing subsequent objectives depends on this step (Figure 1.2). Determining the primary factors causing biological impairment is a significant undertaking that must address a variety of issues (see the Background Note “Identifying Causes of Impairment”). While identifying causes of impairment can be attempted using rapid screening level assessments, we have taken a more detailed approach in order to maximize the opportunity to reliably and defensibly identify causes and sources of impairment within the time and resource framework of the project. This provides a firmer scientific foundation for the collection and evaluation of evidence, facilitates the prioritization of problems for management, and offers a more robust basis for the commitment of resources. EPA’s recently published guidance for stressor identification envisions that causes of impairment be evaluated in as rigorous a fashion as is practicable (USEPA, 2000).
Figure 1.2  Overview of Study Activities

- **BIOLOGICAL IMPAIRMENT IDENTIFIED**

- **RECONNAISSANCE AND EVALUATION**
  - Compile existing data
  - Conduct additional biological sampling
  - Evaluate spatial extent of impairment
  - Carry out watershed scoping
  - Develop list of plausible causes of impairment

- **DATA ACQUISITION**
  - Biological Assessment
    - Benthos
    - Habitat
  - Stream Survey
    - Channel condition
    - Riparian condition
    - Pollution inputs
  - Chemical Sampling
    - Baseflow / Storm
    - Water / Sediment
  - Toxicity Analysis
    - Acute / Chronic
  - Watershed Characterization
    - Land use
    - Management
    - Source assessment

- **STRESSOR AND SOURCE ASSESSMENT**
  - Review Existing Evidence
  - Acquire Data for Stressor Evaluation
    - Evaluate Causes
      - Review lines of evidence
      - Apply strength of evidence approach
      - Prioritize causes
    - Identify Sources

- **MANAGEMENT STRATEGY DEVELOPMENT**
Degradation and impairment are not synonymous. Many streams and other waterbodies exhibit some degree of degradation, that is, a decline from unimpacted conditions. Streams that are no longer pristine may still support good water quality conditions and function well ecologically. When monitoring indicates that degradation has become severe enough to interfere significantly with one of a waterbody’s designated uses (such as aquatic life propagation or water supply), the Division of Water Quality formally designates that stream segment as impaired. It is then included on the State’s 303(d) list, the list of impaired waters in North Carolina.

Many impaired streams, including those that are the subject of this study, are so rated because they do not support a healthy population of fish or benthic macroinvertebrates (aquatic bugs visible to the naked eye). While standard biological sampling can determine whether a stream is supporting aquatic life or is impaired, the cause of impairment can only be determined with additional investigation. In some cases a potential cause of impairment is noted when a stream is placed on the 303(d) list, using the best information available at that time. These noted potential causes are generally uncertain, especially when nonpoint source pollution issues are involved.

A cause of impairment can be viewed most simply as a stressor or agent that actually impairs aquatic life. These causes may fall into one of two broad classes: 1) chemical or physical pollutants (e.g., toxic chemicals, nutrient inputs, oxygen-consuming wastes); and 2) habitat degradation (e.g., loss of in-stream structure such as riffles and pools due to sedimentation; loss of bank and root mass habitat due to channel erosion or incision). Sources of impairment are the origins of such stressors. Examples include urban and agricultural runoff.

The US Environmental Protection Agency defines causes of impairment more specifically as “those pollutants and other stressors that contribute to the impairment of designated uses in a waterbody” (USEPA, 1997, p 1-10). When a stream or other waterbody is unable to support an adequate population of fish or macroinvertebrates, identification of the causes of impairment thus involves a determination of the factors most likely leading to the unacceptable biological conditions.

All conditions which impose stress on aquatic communities may not be causes of impairment. Some stressors may occur at an intensity, frequency and duration that are not severe enough to result in significant degradation of biological or water quality conditions to result in impairment. In some cases a single factor may have such a substantial impact that it is the only cause of impairment, or clearly predominates over other causes. In other situations several major causes of impairment may be present, each with a clearly significant effect. In many cases, individual factors with predominant impacts on aquatic life may not be identifiable and the impairment may be due to the cumulative impact of multiple stressors, none of which is severe enough to cause impairment on its own.

The difficulty of developing linkages between cause and effect in water quality assessments is widely recognized (Fox, 1991; USEPA, 2000). Identifying the magnitude of a particular stressor is often complex. Storm-driven pollutant inputs, for instance, are both episodic and highly variable, depending upon precipitation timing and intensity, seasonal factors and specific watershed activities. It is even more challenging to distinguish between those stressors which are present, but not of primary importance, and those which appear to be the underlying causes of impairment. Following are examples of issues which must often be addressed.

- Layered impacts (Yoder and Rankin, 1995) may occur, with the severity of one agent masking other problems that cannot be identified until the first one is addressed.
- Cumulative impacts, which are increasingly likely as the variety and intensity of human activity increase in a watershed, are widely acknowledged to be very difficult to evaluate given the current state of scientific knowledge (Burton and Pitt, 2001; Foran and Ferenc, 1999).
- In addition to imposing specific stresses upon aquatic communities, watershed activities can also inhibit the recovery mechanisms normally used by organisms to ‘bounce back’ from disturbances.

1.3.1 Study Approach

The general conceptual approach used to determine causes of impairment in Toms Creek was as follows (see Foran and Ferenc, 1999; USEPA, 2000).

- **Identify the most plausible potential (candidate) causes** of impairment in the watershed, based upon existing data and initial watershed reconnaissance activities;
- **Collect a wide range of data** bearing on the nature and impacts of those potential causes; and
- **Characterize the causes of impairment** by evaluating all available information using a *strength of evidence approach*. The strength of evidence approach, discussed in more detail in Section 7, involves a logical evaluation of multiple lines (types) of evidence to assess what information supports or does not support the likelihood that each candidate stressor is actually a contributor to impairment.

Project goals extended beyond identifying causes of impairment, however, and included the evaluation of source activities and the development of recommendations to mitigate the problems identified. In order to address all three objectives, activities conducted in the Toms Creek watershed during this study were divided into three broad stages (Figure 1.2):

1. **An initial reconnaissance stage**, in which existing information was compiled and watershed reconnaissance conducted. At the conclusion of this stage the most plausible candidate causes of impairment were identified for further evaluation.
2. **A stressor-source evaluation stage** that included: collection of information regarding candidate causes of impairment; evaluation of all available information using a strength of evidence approach; investigation of likely sources (origins) of the critical stressors.
3. **The development of strategies** to address the identified causes of impairment.

1.3.2 Approach to Management Recommendations

One of the goals of this assessment was to outline a course of action to address the key problems identified during the investigation, providing local stakeholders, the CWMTF and others with the information needed to move forward with targeted water quality improvement efforts in this watershed. It is DWQ’s intent that the recommendations included in this document provide guidance that is as specific as possible given available information and the nature of the issues to be addressed. Where problems are multifaceted and have occurred over a long period of time, the state of scientific understanding may not permit all actions necessary to mitigate those impacts to be identified in advance. In such situations an iterative process of ‘adaptive management’ (Reckhow, 1997; USEPA, 2001) is required, in which those committed to stream improvement efforts begin with implementation of an initial round of management actions, followed by monitoring to determine what additional measures are needed.

Protection of streams from additional damage due to future watershed development or other planned activities is a critical consideration. In the absence of such protection, efforts to restore water quality by mitigating existing impacts will often be ineffective or have only a temporary impact. These issues were examined during the course of the study and addressed in the management recommendations.
Management recommendations included in this document are not intended to be institutionally prescriptive. It is not the objective of this study to specify particular administrative or institutional mechanisms for implementing remedial practices, but only to describe the types of actions that must occur to place Toms Creek on the road to improvement. It is DWQ’s hope that local governments and other stakeholders in the Toms Creek watershed will work cooperatively with each other and with state agencies to implement these measures in cost-effective ways.

The study did not develop TMDLs (total maximum daily loads) or establish pollutant loading targets. For many types of problems (e.g. most types of habitat degradation) TMDLs may not be an appropriate mechanism for initiating water quality improvement. Where specific pollutants are identified as causes of impairment, TMDLs may be appropriate and necessary if the problem is not otherwise addressed expeditiously.

1.3.3 Data Acquisition

While project staff made use of existing data sources during the course of the study, these were not adequate to fully address the goals of the investigation. Extensive data collection was necessary to develop a more adequate base of information. The types of data collected during the study included:

1. Macroinvertebrate sampling.
2. Assessment of stream habitat, morphology, and riparian zone condition.
3. Stream surveys--walking stream channels to identify potential pollution inputs and obtain a broad scale perspective on channel condition.
5. Bioassays to assess water column toxicity.
6. Watershed characterization--evaluation of watershed hydrologic conditions, land use, land management activities, and potential pollution sources.
Section 2
Description of the Toms Creek Watershed

2.1 Introduction

Toms Creek enters the Neuse River from the east a short distance downstream of the confluence between the Neuse and Smith Creek. The 2000 303(d) list describes Toms Creek as impaired for its entire length. The 4.7 square miles (12 square km) drained by Toms Creek is bounded roughly by US 401 on the south and Burlington Mills Road to the north. Ligon Mill Road and Forestville Road cut through the watershed in a north-south direction. Approximately one-half square mile of the watershed currently lies within the town limits of Wake Forest, while the Rolesville corporate limits lie at the eastern boundary. This section summarizes watershed hydrography and topography, describes current and historical land use, and discusses potential pollutant sources.

2.2 Streams

The headwaters of Toms Creek lie just west of the intersection of US 401 and Burlington Mills Road, at the western end of the Rolesville corporate limits. Mill Creek, the only major tributary to Toms Creek, rises northeast of the intersection of Forestville Road and US 401. At its confluence with Toms Creek below Ligon Mill Road, Mill Creek drains approximately 1.2 square miles (3.1 km), while the drainage area of Toms Creek immediately upstream of the confluence is 3.3 square miles (8.5 km). Toms Creek’s remaining tributaries are small and unnamed.

About midway in its course, the mainstem of Toms Creek has been dammed to create Browns Lake, an impoundment of approximately 30 acres (11.6 hectares) dating from the first half of the 20th century. Upstream of this lake, the stream flows through a variety of beaver impoundments for much of its length. Below Browns Lake, Toms Creek flows at moderate gradient for more than a mile before reaching another series of beaver impoundments and the confluence with Mill Creek, just prior to reaching the Neuse River. A number of small impoundments, probably constructed as farm ponds, lie on various tributary streams.

Land ownership along the Toms Creek mainstem is often in large tracts above Forestville Road and Browns Lake, as well as below Ligon Mill Road. Most creek-side properties between Browns Lake and Ligon Mill Road consist of 0.5 to 1.5-acre residential lots.

The watershed is not gaged. USGS regional low flow equations for this area predict a 7Q10 flow of approximately 1 cubic feet per second (cfs) at the mouth of the creek, though this does not account for the potential impact of Browns Lake on streamflows (Giese and Mason, 1991). Typical mean annual flows in this part of the state are approximately 1.1 cfs/square mile (Giese and Mason, 1991). Precipitation in Wake County averages 41.4 inches per year (Raleigh-Durham Airport).
2.3 Topography and Geology

Elevations drop rapidly from approximately 420 feet above mean sea level in the headwaters near Rolesville to 250 feet just upstream of Forestville Road. Elevations at Browns Lake dam and Ligon Mill Road are approximately 230 feet and 200 feet respectively. The gradient flattens out significantly below Ligon Mill Road, with elevations dropping only an additional 10-15 feet before the stream reaches the Neuse River.

The underlying geology of the entire watershed is granitic. The products of the weathering of this material are evident in the soil and stream substrate of the area. Soils are of the Appling-Louisburg-Wedowee association, which are somewhat excessively drained soils with a generally coarse subsoil with substantial sand. Helena, Louisburg and Durham soils are common. Wehadkee and Bibb soils, common in historic floodplain areas in this portion of the county, are found along Toms Creek and Mill Creek (Cawthorn, 1970; Daniels et al., 1999).

2.4 Land Cover in the Watershed

The distribution of land cover in the watershed is shown in Figure 2.1 and Table 2.1. This information, based on satellite imagery from 1998 and 1999, was taken from a data base developed by the US Environmental Protection Agency as part of a landscape characterization study of the Neuse River Basin. Forested areas covered approximately 56% of the watershed, including approximately 92 acres (3%) of forested wetlands associated primarily with beaver impoundments (Table 2.1). Only 6% of the drainage was in row crops in 1998-99, with 6.9% in other agricultural uses. Residential areas of varying density constituted 28% of existing land cover (residential areas account for virtually all development in the watershed). Watershed impervious area is estimated to be approximately 10 percent (see Appendix C for further information on the land cover data and imperviousness estimates). The most dense residential areas are clustered immediately east of Ligon Mill Road and below Browns Lake (Figure 2.1).

In the few years since the EPA data set was developed, additional land clearing and home construction have occurred in existing subdivisions in these areas. Production of tobacco and soybeans persists in a few areas of the upper watershed, though both have continued to decline.

A few convenience stores, a cabinet shop and a retail nursery constitute the only commercial activities in the watershed. There is no industrial development. The town of Wake Forest has purchased land below Ligon Mill Road for municipal sludge application. That land is adjacent to Toms Creek but outside of the flood-prone area. There is currently no other publicly owned land in the watershed, although the Town of Wake Forest has received a grant from the Clean Water Management Trust Fund to purchase land for a greenway and riparian buffer along Toms Creek between Ligon Mill Road and the Neuse River.
Table 2.1  
**Toms Creek Watershed: Current Land Cover**

<table>
<thead>
<tr>
<th>Category</th>
<th>Acres</th>
<th>Percent of Watershed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium-High Density Developed</td>
<td>200</td>
<td>6.6</td>
</tr>
<tr>
<td>Low Density Developed</td>
<td>657</td>
<td>21.8</td>
</tr>
<tr>
<td>Row Crops</td>
<td>181</td>
<td>6.0</td>
</tr>
<tr>
<td>Other Agricultural (hay, pasture, fallow)</td>
<td>208</td>
<td>6.9</td>
</tr>
<tr>
<td>Wooded</td>
<td>1625</td>
<td>53.8</td>
</tr>
<tr>
<td>Wetlands</td>
<td>92</td>
<td>3.0</td>
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<tr>
<td>Water</td>
<td>33</td>
<td>1.1</td>
</tr>
<tr>
<td>Other (barren land)</td>
<td>25</td>
<td>0.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3021</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: Land Use/Land Cover data developed by USEPA for Neuse River Basin. Based upon 1998-99 Spot 4 and Landsat 7 imagery. See Appendix C.

While low density residential development in the watershed has existed for some time, the pace and density of residential construction increased substantially during the late 1980s and the 1990s, when a number of subdivisions were completed in the Ligon Mill Road-Browns Lake area. The location of this development activity is shown in Figure 2.2. The most recent subdivisions (Table 2.2), located primarily within the Wake Forest limits, have typical lot sizes of about half an acre and receive town water and sewer services. Developments outside of the Wake Forest limits are generally of lower density and are served by private wells and septic systems, although the Deerchase subdivision operates a package wastewater treatment plant (WWTP). The newer subdivisions (Saint Andrews Plantation, Carriage Run) utilize traditional curb and gutter drainage while subdivisions under County jurisdiction are drained by grassed swales, although rock-lined ditches are used in some areas. During the fall of 2001, ground was broken for a new development adjacent to Browns Lake at the end of Kemble Ridge Drive.

Table 2.2  
**Selected Subdivisions Below Browns Lake**

<table>
<thead>
<tr>
<th>Name</th>
<th>Mean Lot Size (acres)</th>
<th>Approx. No. of Lots</th>
<th>Approx. Year Home Construction Began</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deerchase</td>
<td>0.8</td>
<td>154</td>
<td>1986</td>
<td>Between Burlington Mills Rd. and Browns Lake</td>
</tr>
<tr>
<td>Saint Andrews</td>
<td>1.2</td>
<td>26</td>
<td>1992</td>
<td>South of Toms Creek</td>
</tr>
<tr>
<td>Saint Andrews Plantation</td>
<td>0.6</td>
<td>90</td>
<td>1995</td>
<td>North of Toms Creek</td>
</tr>
<tr>
<td>Carriage Run</td>
<td>0.4</td>
<td>183</td>
<td>1995</td>
<td>East of Ligon Mill Rd.</td>
</tr>
<tr>
<td>Chesterfield Village</td>
<td>1.3</td>
<td>108</td>
<td>1984</td>
<td>East of Ligon Mill Rd. on Mill Creek</td>
</tr>
</tbody>
</table>


This area, like much of Wake County, has a long agricultural history. High levels of agricultural activity existed earlier in the 20th century. While changes in active cropland in the watershed
have not been quantified, comparison of aerial photographs as far back as the mid 1900s to those of today indicated that land under cultivation has decreased substantially. Additional declines probably occurred earlier in the 20th century. These historical changes were due to a complex set of social and economic factors affecting agricultural activities on a national and regional basis (Healy, 1985), and not in direct response to development pressures. Statistics on farm acreage in Wake County, obtained from the Wake Soil and Water Conservation District, provide a general picture of local trends (Table 2.3). Farm acreage in Wake County declined by almost 75% from 1945 to 1997, with about half of this decline occurring prior to 1964.

Table 2.3  Farmland Acreage in Wake County

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Farms</th>
<th>Land in Farms (acres)</th>
<th>Percent of County</th>
</tr>
</thead>
<tbody>
<tr>
<td>1945</td>
<td>6,044</td>
<td>417,680</td>
<td>76%</td>
</tr>
<tr>
<td>1954</td>
<td>5,770</td>
<td>355,926</td>
<td>64%</td>
</tr>
<tr>
<td>1964</td>
<td>2,753</td>
<td>265,538</td>
<td>48%</td>
</tr>
<tr>
<td>1974</td>
<td>1,755</td>
<td>204,443</td>
<td>37%</td>
</tr>
<tr>
<td>1987</td>
<td>1,003</td>
<td>128,571</td>
<td>23%</td>
</tr>
<tr>
<td>1997</td>
<td>772</td>
<td>113,201</td>
<td>20%</td>
</tr>
</tbody>
</table>

Source: US Bureau of the Census data obtained from Wake Soil and Water Conservation District

2.5  Sources of Pollution

2.5.1  Wastewater Discharges

The only wastewater facility in the watershed is the package plant for the Deerchase subdivision (NPDES No. NC0063746), which discharges directly to Toms Creek a few hundred meters below Brown Lake (see Figure 1.1). The watershed contains no permitted stormwater discharges or confined animal operations. The Deerchase discharge has a permitted wasteflow of 0.05 MGD (million gallons per day), or 50,000 gallons/day, with BOD₅ (five-day biochemical oxygen demand) and ammonia limits of 18 mg/L and 5 mg/L respectively. The summer 7Q10 at the outfall was estimated to be zero for permitting purposes. In 1998 a small fish kill was reported below the WWTP. The cause was never determined. Reportedly no water was flowing from the lake at the time.

Wastewater discharge rates reported by the plant have increased in steps over the years, with notable increases occurring in 1989 and 1996 (Table 2.4). Wake County staff indicate, however, that reported discharge data for the early and mid 1990s may not be reliable, and that the number of connections has not changed significantly since 1991. The facility has had periodic toxicity problems, experiencing at least one whole effluent toxicity failure in nine of the eleven years since the facility began reporting test results in 1991 (Table 2.4). Three or more failures occurred in four different years, as recently as 1999.
Table 2.4  Deerchase WWTP: Summary of Discharge and Toxicity Data, 1987-2001

<table>
<thead>
<tr>
<th>Year</th>
<th>Average Wasteflow (1000 gallons/day)</th>
<th>Whole Effluent Toxicity Bioassays: # of failures/#of tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>9.7</td>
<td>1/4</td>
</tr>
<tr>
<td>1992</td>
<td>12.8</td>
<td>3/6</td>
</tr>
<tr>
<td>1993</td>
<td>12.0</td>
<td>1/5</td>
</tr>
<tr>
<td>1994</td>
<td>8.5</td>
<td>0/5</td>
</tr>
<tr>
<td>1995</td>
<td>14.0</td>
<td>3/7</td>
</tr>
<tr>
<td>1996</td>
<td>23.4</td>
<td>1/5</td>
</tr>
<tr>
<td>1997</td>
<td>26.6</td>
<td>1/5</td>
</tr>
<tr>
<td>1998</td>
<td>23.3</td>
<td>3/8</td>
</tr>
<tr>
<td>1999</td>
<td>25.6</td>
<td>5/8</td>
</tr>
<tr>
<td>2000</td>
<td>24.4</td>
<td>0/4</td>
</tr>
<tr>
<td>2001</td>
<td>23.3 (through Sept.)</td>
<td>1/5</td>
</tr>
</tbody>
</table>

Effluent concentrations reported by the facility have not been unusual for a plant of this type, though total nitrogen and phosphorus concentrations are relatively low for a package plant (Table 2.5). BOD₅ concentrations averaged between 2.0 and 4.0 mg/L.

Total residual chlorine (TRC) concentrations have been substantial (Table 2.5). A strong chlorine odor was often observed at the discharge pipe during the study. Undissolved pellets were not uncommon both in the discharged effluent and in the stream reach below the discharge. The facility does not currently have a chlorine limit in its permit. Historically fecal coliform violations were common for this facility. These ceased in 1995 when typical chlorine levels increased from 0.1 mg/L to 0.2 mg/L. In 1996, average chlorine concentrations increased again to current levels (0.4 mg/L).

Table 2.5  Selected Average Effluent Concentrations for Deerchase WWTP, 1999-2001*

<table>
<thead>
<tr>
<th></th>
<th>Total Residual Chlorine (mg/L)</th>
<th>Ammonia-N (mg/L)</th>
<th>Total Nitrogen (mg/L)</th>
<th>Total Phosphorus (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average, 1999-2001</td>
<td>0.41</td>
<td>1.1</td>
<td>2.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Lowest Monthly Avg. 1999-2001</td>
<td>0.24</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Highest Monthly Avg. 1999-2001</td>
<td>0.59</td>
<td>2.6</td>
<td>7.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>

*2001 data through September
2.5.2 Nonpoint Source Inputs

Historic Issues. It is likely that pervasive sediment inputs from historic agricultural activities occurred in this watershed. A lack of topsoil and exposure of the underlying sandy horizons is apparent in much of the area. A former mill pond site on Mill Creek below Ligon Mill Road has been filled with sediment for an unknown period. A forested wetland, including some trees dating probably dating back to the first half of the 20th century, currently occupies the former pond site (Exhibit 2.1). Even streams in areas of the watershed that have been forested and relatively undisturbed for decades have substantial deposits of sandy material. While it has probably been some time since active erosion from cultivated land has been a major problem, there is little doubt that it was once important. For additional background on historical land use changes and their impact on stream condition, see the Background Note “Landscape History and Channel Alteration in the Piedmont Region”.

![Exhibit 2.1 Former mill pond on Mill Creek below Ligon Mill Road](image)

Current Agricultural Erosion. Only modest amounts of land are currently under cultivation in the watershed (less than 200 acres, according to 1998-99 satellite imagery), located primarily along Forestville Road and in the upper watershed. There is little evidence of sediment inputs from these areas and many fields have limited hydrologic connection to the channel network.

Recent Development in the Middle Watershed. Except for a few individual lots where construction is ongoing, land surfaces in areas of past development have been stabilized with vegetation, and erosion was observed infrequently during the study. In older subdivisions such as Chesterfield Village, examination of swales and storm channels showed no evidence of additional sediment accumulation or transport. Channels draining the more dense and recently constructed subdivisions (Saint Andrews Plantation and Carriage Run), however, still transport substantial amounts of sediment. This indicates both the substantial erosion that occurred during land clearing and construction and that Toms Creek will continue to receive the resulting sediment.
**Background Note: Landscape History and Channel Alteration in the Piedmont Region**

The condition of stream channels today depends not only on current watershed activities, but on historical land uses and management activities as well. The landscape of North Carolina’s Piedmont region, like much of the southern Piedmont, has been substantially altered over the past 200 years. These changes have had major impacts on past stream conditions and continue to affect how channel networks today react to ongoing watershed activities. While circumstances vary from one place to another, the basic outline of these historical changes is widely accepted (see Ferguson, 1997; Wilson, 1983; Jacobson and Coleman 1986; Simmons, 1993; Richter et al., 1995).

- Following widespread clearing of forests in the 19th century and subsequent intensive agricultural land use, extensive erosion of upland areas occurred throughout the southern Piedmont region. Conservation practices were virtually unknown prior to the 1930s (Trimble, 1974; Healy, 1985).
- The extent of cleared land peaked in the late 19th and early 20th centuries. For a variety of reasons, the amount of cultivated land in many parts of the Piedmont began to decline in the 1920s and 1930s, a trend that continues today. Much of this former cropland reverted to forest.
- With the advent of the soil conservation movement in the 1930s, tillage practices began to improve on the remaining cropland.
- During the period of most intensive agricultural activity, sediment filled many stream channels. The floodplains and lowland riparian corridors of many 3rd order and larger streams often aggraded (increased in elevation) by several feet to several meters in height due to the large volume of eroded soil transported from upland areas (e.g. see Wilson, 1983; Ferguson, 1997).
- Once upland erosion declined, streams began the process of removing the accumulated sediment. High sediment loads persisted for many years following the reduction in upland erosion as streams reworked the sediment stored on hill slopes and floodplains and within stream channels. (Meade, 1982; Meade and Trimble, 1974).
- In many rural areas streams have substantially recovered from this sedimentation. They have restabilized and may now support healthy populations of fish and macroinvertebrates. These streams have not necessarily returned to their former condition, however, but often remain incised and retain a more sandy appearance than previously. In other rural areas the process of recovery still continues.

In addition to the stresses imposed by historic agricultural impacts, many streams have also been channelized (straightened, deepened or realigned) to reduce flooding or to maximize the land available for farming. Channelization often induces substantial sedimentation due to subsequent stream downcutting and widening. In some cases entire channel networks, which had previously filled with sediment, were channelized and remain unstable decades later.

Many of these watersheds have since undergone, or are currently experiencing, significant development as the Piedmont continues to grow. The major hydrologic changes that accompany development and the resulting physical and biological deterioration of stream channels are well known. The impact of urbanization is often made worse, however, by the persistent effects of historical practices. Many streams are already incised and subject to ongoing bank erosion and sedimentation due to prior impacts from agricultural erosion and channel modification, leaving them extremely vulnerable to the altered hydrology brought on by urban and suburban growth. In highly impacted watersheds, the relative effects of these various disturbances can be difficult if not impossible to distinguish. It is clear, however, that the legacy of past land use practices is still with us, and that we cannot understand the current condition of many impaired streams without understanding the history of their watersheds.
Browns Lake Dam. Several decades ago (1980s or earlier) a bypass channel became established at the north side of the dam in the area of the emergency spillway, most likely during a storm event of unknown date. This channel has served as the primary outflow for the lake since that time and has carved a gully into the adjacent hillside, 15 to 20 feet deep (4.6-6.1 m) in places, as it flows downstream to the confluence with the now seldom used channel draining from the outflow pipe (Exhibit 2.2). This hill slope is currently unstable and mass failure processes regularly result in the deposition of sediment in the channel, which is then gradually moved downstream by the creek. Local residents and Wake Soil and Water District staff indicated that this erosion has probably been relatively constant over the past decade—the gully has been enlarging but likely has done so gradually rather than in response to dramatic events. The downstream movement of sediment from collapsing gully slopes probably occurs in pulses during substantial rainfall events. Local residents and Wake Soil and Water District staff reported that Hurricane Fran (September 1996) moved large quantities of sediment through the channel system.

A partial breach in the center area of the dam occurred when the dam was overtopped during hurricane Floyd in September 1999, sending another pulse of sediment into Toms Creek. The dam breach does not appear to be a significant source of new sediment at this time because of limited flow through the area and the presence of a small wetland between the breached area and Toms Creek. The owner is working with the Division of Land Resources (DLR) to obtain plan approval under the Dam Safety Program to repair damaged areas and restore appropriate spillway capacity. DLR regional staff indicate that the owner will likely be required to stabilize the gully as a part of this work.

During the fall of 2001 the water in the lake was drawn down to allow inspection of the dam. The draw-down occurred by progressive lowering of the saprolite sill at the upstream end of the bypass channel. This process released substantial sediment into Toms Creek, both via the significant deepening of the bypass channel itself and from the channel carved in the lake bed. Pulses of water and sediment likely passed downstream during this process, as evidenced by increases in stage of 1.5 to 2 feet (0.4 to 0.6 m) that were recorded during October and November of 2001—a period during which no rainfall occurred—and areas of fresh sediment deposition that appeared in Toms Creek above Ligon Mill Road. According to DLR regional staff, lowering of the lake level did not fall under dam safety regulations since the dam itself was not altered—the bypass channel that was deepened runs around the dam. Erosion control requirements should have been applicable, however, although it does not appear that any erosion and sediment control measures were implemented.

Other sources. Pollutant impacts from the upper watershed are unlikely given the primarily forested nature of the area and the presence of several impoundments, within which pollutants would be subject to dilution and a variety of physical, chemical and biological removal mechanisms. Inputs of pollutants such as nutrients and pesticides are possible from the recently completed subdivisions below Browns Lake. A retail nursery located on US 401 just below Burlington Mills Road is the only likely potential source of pollution in the upper watershed.
2.6 Trends in Land Use and Development

The Toms Creek drainage is evolving from a rural agricultural area to a residential watershed. Considerable development has occurred during the past 15 years. With 70 percent of the watershed undeveloped (forested or agricultural) the potential for additional change is substantial. Wake Forest and Rolesville continue to expand, and development in the north Raleigh area continues to move toward the Neuse River and beyond. The completion of Interstate 540 just south of the watershed is also likely to fuel residential growth.

Most of the watershed is covered by the Northeast Wake Area Land Use Plan (Wake County, 2001a). Most areas not currently within the planning jurisdictions (extra-territorial jurisdiction, or ETJ) of Wake Forest or Rolesville are included within those jurisdictions’ Urban Services Areas (USAs), indicating that County and municipal officials believe that Wake Forest and Rolesville will eventually extend water and sewer services to these areas (Figure 2.3). Short-term USAs (Figure 2.3) are areas where a municipality is expected to extend water and sewer lines within approximately five years. Extension of utilities to long term USAs is expected over a longer period. The Northeast Wake Area Land Use Plan anticipates that areas within Wake Forest’s USA will average three dwellings per acre once water and sewer lines are extended. The most recently completed subdivisions within the Wake Forest limits, Saint Andrews Plantation and Carriage Run, have average lot sizes of about one-half acre. Typical impervious levels for this type of development are in the 20 to 25% range (SCS, 1986; Cappiella and Brown, 2001). Areas within Rolesville’s USA are expected to be built at densities up to two dwellings per acre, once water and sewer lines are extended. Development occurring prior to the extension of water and sewer infrastructure is likely to occur at lower densities. The Wake County Water/Sewer Plan (Wake County, 1998) indicates plans to extend services to only a portion of this area during the next 20 years, so full build out may not occur for some time.
Most of the Mill Creek watershed and a small portion of the lower Toms Creek watershed are covered by the East Raleigh-Knightdale Area Land Use Plan (Wake County, 2001b). These areas have projected densities of less than 1.5 units/acre. A residential retail area is projected along US 401 in the headwaters of Mill Creek.

2.7 Regulatory Issues and Local Water Quality Activities

Erosion and sediment from construction in the watershed are regulated by Wake County, which has a delegated local program under North Carolina’s Sedimentation Pollution Control Act.

The buffer rules adopted by the State for the Neuse River basin apply throughout the watershed. These rules, requiring the preservation of existing buffers, apply to intermittent and perennial waterbodies shown on the most recent county soil survey maps or USGS 1:24,000 scale topographic maps. A minimum 50 foot (15 m) vegetated buffer is required on each side of a waterbody, the first 30 feet (9 m) of which must remain essentially undisturbed. Exemptions are allowed for various activities. The establishment of new buffers is not required unless the existing use of the buffer changes. Stormwater flows cannot be routed through the buffer in channelized form, but must be converted to sheet flow to provide an opportunity for infiltration and pollutant removal.

Portions of the watershed under the County’s planning jurisdiction are also subject to the Neuse River Basin Stormwater Rules, which require that nitrogen loading from new development be held to 3.6 pounds/acre per year. No net increase in peak flows leaving the site from predevelopment conditions is allowed for the 1-year 24-hour storm. Portions of the watershed under the Wake Forest and Rolesville planning jurisdictions are not currently subject to the stormwater rule. Neither the Neuse Buffer Rule nor the stormwater requirements have been in effect long enough to have affected the design or construction of existing neighborhoods in the Toms Creek watershed.

EPA has developed a Phase II stormwater program, mandating that small communities not previously subject to federal stormwater requirements apply for permit coverage. Communities in urbanized areas designated by the US Bureau of the Census must apply for stormwater permit coverage by March 2003. The federal regulations discuss development and implementation of comprehensive stormwater management programs including six minimum measures: 1) public education and outreach on stormwater impacts; 2) public involvement/participation; 3) illicit discharge detection and elimination; 4) construction site stormwater runoff control; 5) post-construction stormwater management for new development and redevelopment; and 6) pollution prevention/good housekeeping for municipal operations. The regulations also require state permitting authorities to implement designation criteria that would be applied to communities outside of federally designated urbanized areas. Communities meeting these criteria can also be brought into the Phase II program. While Wake Forest and Rolesville are not automatically designated for coverage under this program, they may potentially be regulated if designated by the state. State regulations to implement the Phase II stormwater program are currently under development.

Members of a citizens’ stream monitoring group have been sampling Toms Creek at various locations below Browns Lake since the mid 1990s. Both the Upper Neuse Basin Nonpoint
Source Team and the Wake Soil and Water Conservation District previously investigated the potential for stream restoration work in the watershed. The Town of Wake Forest has received a grant from the Clean Water Management Trust Fund to purchase land for a greenway and riparian buffer along Toms Creek between Ligon Mill Road and the Neuse River. Wake County is currently undertaking a countywide watershed management initiative. As part of the data collection effort for that project, consultants hired by Wake County have conducted a habitat evaluation of Toms Creek at Ligon Mill Road.
The study identified those factors that were plausible causes of biological impairment in the Toms Creek watershed using both biological assessment and watershed-based approaches. An evaluation of benthic community data and other biological and habitat indicators can point toward general types of impacts that may likely impact aquatic biota. These stressors were flagged for further investigation. Land uses and activities in the Toms Creek watershed were also examined to identify potential stressors for further evaluation.

### 3.1 Key Stressors Evaluated in the Toms Creek Watershed

The following were evaluated as the most plausible candidate causes of impairment in Toms Creek.

1. Habitat degradation due to sediment deposition and substrate instability. The channel system and floodplain have experienced massive sediment deposition. Habitat degradation manifests itself through the loss of pools and riffles and high levels of substrate instability. Further evaluation of sedimentation issues and identification of sediment sources was clearly warranted.

2. Potential toxicity due to the Deerchase WWTP discharge. Effluent toxicity test failures have not been unusual for this facility, suggesting potential in-stream impacts. Chlorine and ammonia are the most likely potential toxicants in small discharges of domestic waste.

3. Low dissolved oxygen (DO). While initial evaluation of benthic community structure did not indicate likely impacts due to low oxygen levels, the small size of the creek and the presence of a wastewater discharge provide conditions in which the potential impacts of oxygen-consuming wastes should be evaluated.

4. Pesticides. Given the modest density of residential development, the lack of commercial and industrial activity, and the low level of agricultural activity remaining in the watershed, it did not seem likely that stormwater borne pollutants (other than sediment) were a likely cause of impairment. Inputs of residential use pesticides are possible, however, and were evaluated.

5. Nutrients. An initial review of macroinvertebrate data indicated that nutrients were not a likely cause of impairment, but further evaluation was conducted due to the presence of the wastewater discharge. Even if nutrients are not a source of stream impairment in this watershed, nitrogen inputs from all watersheds in the Neuse River basin are important, given current eutrophication concerns in the estuary. Nutrient concentrations in Toms Creek were monitored to provide additional background data for nutrient reduction efforts.
Biological assessment (bioassessment) involves the collection of stream organisms and the evaluation of community diversity and composition to assess water quality and ecological conditions. Evaluation of habitat conditions at sampling locations is an important component of bioassessment.

Prior to this study, DWQ’s Biological Assessment Unit collected benthic macroinvertebrate samples from Toms Creek at SR 2044 (Ligon Mill Road) in 1991 and 1995. No other locations had been sampled prior to 2000. The stream was rated as Good in 1991, but declined to Fair in 1995. A large increase in sediment was noted in 1995, which eliminated the rocky riffles observed in 1991. The number of EPT taxa declined from 17 in 1991 to 10 in 1995 and a decline in intolerant taxa was observed.

Additional benthic community sampling was conducted during the present study for several purposes:

- To account for any changes in biological condition since the watershed was last sampled in 1995.
- To obtain more specific information on the actual spatial extent of impairment.
- To better differentiate between portions of the watershed contributing to biological impairment and those in good ecological condition.
- To collect additional information to support identification of likely stressors affecting the benthic community.

This section describes the approach to bioassessment used during the study and summarizes the results of this work. A more detailed analysis of the condition of aquatic macroinvertebrate communities in the Toms Creek watershed may be found in Appendix A.

### 4.1 Approach to Biological and Habitat Assessment

Benthic macroinvertebrate community samples were collected at six sites in the watershed, five locations on Toms Creek and one on Mill Creek (Figure 4.1). Sampling took place in May, July and August 2000, and in January and June 2001.

#### 4.1.1 Benthic Community Sampling and Rating Methods

Macroinvertebrate sampling was carried out using the general procedures outlined in the Division’s standard operating procedures (NCDWQ, 2001b). Reaches approximately 100 meters (328 feet) long were targeted, although the actual stream length sampled varied with site conditions. Standard qualitative sampling was used for most sites. This method included ten samples: two kick-net samples, three bank sweeps, two rock or log washes, one sand sample, one leafpack sample, and visual collections from large rocks and logs. At smaller stream sites the abbreviated Qual 4 and Qual 5 methods were used. The Qual 4, which has been used by DWQ...
to sample small streams for some time, involved four samples: one kick, one sweep, one leafpack and visual collections. The Qual 5 was similar to the Qual 4 but also includes a rock or log wash. Use of the Qual 5 was initiated part way through the study to allow for a better characterization of the midge population than is possible using the Qual 4. Organisms were identified to genus and/or species.

Two primary indicators or metrics are derived from macroinvertebrate community data: the diversity of a more sensitive subset of the invertebrate fauna is evaluated using EPT taxa richness counts; and the pollution tolerance of those organisms present is evaluated using a biotic index (BI). “EPT” is an abbreviation for Ephemeroptera + Plecoptera + Trichoptera (mayflies, stoneflies and caddisflies), insect groups that are generally intolerant of many kinds of pollution. Generally, the higher the EPT number, the more healthy the benthic community. A low biotic index value indicates a community dominated by taxa that are relatively sensitive to pollution and other disturbances (intolerant). Thus, the lower the BI number, the more healthy the benthic community.

Biotic index values are combined with EPT taxa richness ratings to produce a final bioclassification (Excellent, Good, Good-Fair, Fair or Poor). Final bioclassifications are used to determine if a stream is impaired. Streams with bioclassifications of Excellent, Good, and Good-Fair are all considered unimpaired. Those with Fair and Poor ratings are considered impaired.

Under current DWQ policy, streams under four meters in width are generally not formally rated but are evaluated qualitatively based on professional judgment. Small streams sampled using the Qual 4 method that have scores consistent with a Good-Fair or better rating are labeled as ‘not impaired’. An adequate data base has not yet been assembled to allow formal ratings to be applied to streams sampled using the Qual 5 method. These sites are evaluated based on professional judgement.

### 4.1.2 Habitat Assessment Methods

At the time benthic community sampling was carried out, stream habitat and riparian area conditions were evaluated for each reach using DWQ’s standard habitat assessment protocol for piedmont streams (NCDWQ, 2001b). This protocol rates the aquatic habitat of the sampled reach by adding the scores of a suite of local (reach scale) habitat factors relevant to fish and/or macroinvertebrates. Total scores range from zero (worst) to 100 (best). Individual factors include (maximum factor score in parenthesis):

- channel modification (5);
- in-stream habitat variety and area available for colonization (20);
- bottom substrate type and embeddedness (15);
- pool variety and frequency (10);
- riffle frequency and size (16);
- bank stability and vegetation (14);
- light penetration/canopy coverage (10); and
- riparian zone width and integrity (10).
4.2 Findings and Discussion

4.2.1 Description

Selected habitat and biological characteristics for each site sampled during the study are shown in Table 4.1, which also includes information on historical sampling. All sites were too small to be given a formal rating (bioclassification). A narrative summary of conditions at each current site follows. See Appendix A for additional details.

Toms Creek off the powerline trail, upstream of Forestville Road (SR 2049). This site was selected to assess conditions above Browns Lake, where there was little development. Other locations between this site and the Lake could not be sampled using existing protocols due to the presence of beaver impoundments. The site was accessed via a power line right of way off Forestville Road. No riffles were present, but other types of habitat were common. Banks were less than 0.15 meters (6 inches) in height. This site was isolated and likely had not experienced disturbance for many years. The riparian zone was wide and densely wooded. The sandy substrate and lack of riffles was probably due to agricultural sedimentation occurring decades ago. Although much sand remained, the stream has evolved into a stable system providing good habitat for benthic macroinvertebrates (Exhibit 4.1). This site exhibited remarkable taxa richness for a small Piedmont stream. Total taxa richness values were 45 when sampled in May 2000 and 53 in January 2001. BI values were the lowest of any site in the watershed, indicating the presence of many intolerant taxa. Despite its small size this reach was in the best biological condition of any site on the Toms Creek mainstem.

Toms Creek at Kemble Ridge Drive above the Deerchase WWTP discharge. This reach was sampled to assist with the evaluation of the impact of the discharge and was located between Browns Lake and the outfall. The stream channel at this location was deeply incised, with steep banks composed largely of sand. Sticks and leaf packs were rare and riffles were infrequent. Habitat in this reach was quite unstable with frequent substrate movement. Opportunities for
invertebrate colonization via drift were limited due to the lake immediately upstream. Much lower total taxa richness, EPT richness and EPT abundance values were found at this site than at the powerline trail. The benthic community in this reach was severely impacted. Poor habitat and substrate instability make it difficult for a permanent benthic community to become established.

Toms Creek at Kemble Ridge Drive below the Deerchase WWTP discharge. This reach was sampled to assist with the evaluation of the impact of the discharge and was located below the discharge mixing point. As was the case with the site above the discharge, in-stream habitat such as sticks and leafpacks was not common. Riffles were few, very small and comprised of gravel substrate. Sand deposits exceeded 1.2 meters (four feet) in depth in some places. Recently constructed residential lots extend down to the stream on the north side of the creek, providing poor riparian protection. The benthic community at this station was also severely degraded. EPT richness was similar to the site above the WWTP discharge, but other indicators indicated a more impacted community. Many *Chematopsyche* (caddisfly) specimens exhibited toxic effects associated with residual chlorine--tracheal gills were darkened and reduced in number (Camargo, 1991).

Toms Creek off Roxbury Drive. Located between the previous site and Ligon Mill Road, approximately opposite the end of Anderbrook Court, this reach was sampled because it possessed the best riffle habitat observed in Toms Creek. Several long riffles extended across the entire stream channel. Riffle substrate was very embedded, however, limiting the potential of this habitat type. Pools, undercut banks and root mats were also present, along with large amounts of sand. Though this site was in better biological condition than the two sites immediately upstream, the EPT taxa richness and BI still indicated a highly impacted community. Stoneflies were absent and many of those mayflies and caddisflies present were fairly insensitive taxa. It is probable that large amounts of sediment move through this reach during high flows, burying rocks and scouring benthic communities.

Toms Creek at SR 2044 (Ligon Mill Road). This site, located upstream of the bridge, was sampled to provide continuity with historical sampling and to provide a synoptic picture of the Toms Creek mainstem. The immediate area is developed, with several houses bordering the creek. The stream was about three meters wide and very sandy (Exhibit 4.2). Riffles observed during sampling in 1991 have not been noted since that time. One small riffle was present during sampling in 2000, but was covered in sand when the site was resampled in 2001. Many side bars comprised of coarse sand were present in this reach. The substrate is clearly dynamic and provided unstable habitat for colonization. The riparian area in the sampled reach was largely forested, but grassed yards immediately upstream from the sample site extended down to the stream bank. A habitat evaluation conducted in 2001 by Wake County also indicated degraded habitat and dominance by sand. A comparison of same season sampling events in 1991, 1995 and 2000, indicated a substantial decline in EPT richness between 1991 (17) and 1995 (10). Though rated Good in 1991 and Fair in 1995, these samples would be formally considered Not Rated today, due to DWQ’s current policy of not rating streams under four meters. The number and abundance of intolerant EPT taxa has declined and this reach remains impaired.
Mill Creek at SR 2044 (Ligon Mill Road). Located upstream of Ligon Mill Road, this site was selected to provide a synoptic evaluation of conditions in Mill Creek and to serve as a potential reference stream for Toms Creek (Exhibit 4.3). Like the Toms Creek sites, this location had a substrate comprised almost entirely of sand. Macroinvertebrate habitat consisted primarily of undercut banks and root mats. There were no riffles or snags. Banks heights were only about 0.3 to 0.5 meters (1 to 1.5 feet), allowing for macroinvertebrate access to bank habitats even during baseflow. The lack of incision allowed for energy during high flows to be dissipated outside of the channel. This reach had the highest EPT richness of any site in the watershed, and a BI second only to the most upstream Toms Creek site. Although the stream was too small to be given a rating at this location, BI and EPT richness values would support a rating of Good. Allowing for seasonal differences, EPT values are very close to those from the 1991 Toms Creek survey, illustrating the degradation that has occurred in Toms Creek. Although development occurred upstream from the Mill Creek site during the 1980s, it appears that the stream has had adequate time to recover and has not been subjected to the continued disturbance experienced by Toms Creek.
4.2.2 **Summary of Conditions and Nature of Impairment**

While the 2000 303(d) list describes Toms Creek as impaired for its entire length, data collected during this investigation indicates that the impairment is probably limited to the area below Browns Lake. Toms Creek in the Ligon Mill Road area experienced a sharp decline in the benthic community during the early to mid 1990s and remains impaired today. Other sites between Ligon Mill Road and Browns Lake were sampled during this study for the first time and also exhibit highly impacted communities with few EPT taxa and few intolerant species. This type of general decline is consistent with severe habitat degradation. The site immediately below the Deerchase WWTP discharge shows impacts from chlorine toxicity.

In contrast, sampled reaches on Mill Creek and the upper portion of Toms Creek, which have not experienced recent disturbance, support fairly diverse benthic communities despite the presence of a largely sandy substrate. While most sites lacked adequate riffle habitat, the Mill Creek and upper Toms Creek sites exhibited relatively stable conditions with ample bank and root mat habitat. Microhabitats such as sticks and leaf packs were present in Toms Creek at Ligon Mill Road, but were probably unstable due to frequent substrate movement.
### Table 4.1  Selected Benthic Community and Habitat Characteristics\(^1\), Toms Creek Study Sites

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Stream Width (m)(^2)</th>
<th>Avg. Depth (m)</th>
<th>Substrate: % sand and silt(^3)</th>
<th>Total Habitat Score (max. of 100)(^4)</th>
<th>In-stream Structure Score (max of 20)(^5)</th>
<th>EPT(^6) Taxa Richness</th>
<th>Biotic(^6) Index</th>
<th>Bioclassification(^*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toms Creek at powerline trail</td>
<td>5/11/00</td>
<td>1</td>
<td>0.1</td>
<td>100</td>
<td>63</td>
<td>15</td>
<td>14</td>
<td>4.98</td>
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<tr>
<td></td>
<td>1/31/01</td>
<td>1</td>
<td>0.1</td>
<td>90</td>
<td>68</td>
<td>17</td>
<td>17</td>
<td>5.02</td>
<td>Not Impaired*</td>
</tr>
<tr>
<td>Toms Creek upstream of WWTP</td>
<td>8/21/00</td>
<td>1</td>
<td>0.1</td>
<td>93</td>
<td>54</td>
<td>10</td>
<td>6</td>
<td>6.79</td>
<td>Not Rated*</td>
</tr>
<tr>
<td></td>
<td>1/31/01</td>
<td>1.5</td>
<td>0.2</td>
<td>70</td>
<td>47</td>
<td>10</td>
<td>6</td>
<td>6.71</td>
<td>Not Rated*</td>
</tr>
<tr>
<td>Toms Creek downstream of WWTP</td>
<td>1/31/01</td>
<td>1.5</td>
<td>0.2</td>
<td>80</td>
<td>38</td>
<td>10</td>
<td>6</td>
<td>7.26</td>
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</tr>
<tr>
<td>Toms Creek at Roxbury Rd.</td>
<td>6/20/01</td>
<td>3</td>
<td>0.1</td>
<td>50</td>
<td>74</td>
<td>14</td>
<td>12</td>
<td>6.00</td>
<td>Not Rated**</td>
</tr>
<tr>
<td>Toms Creek at Ligon Mill Rd.</td>
<td>8/21/91</td>
<td>3</td>
<td>0.1</td>
<td>90</td>
<td>17</td>
<td></td>
<td></td>
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<td>Good***</td>
</tr>
<tr>
<td></td>
<td>7/25/95</td>
<td>3</td>
<td>0.2</td>
<td>90</td>
<td>10</td>
<td></td>
<td></td>
<td>NA</td>
<td>Fair***</td>
</tr>
<tr>
<td></td>
<td>5/11/00</td>
<td>3</td>
<td>0.1</td>
<td>70</td>
<td>57</td>
<td>13</td>
<td>8</td>
<td>6.21</td>
<td>Not Rated*</td>
</tr>
<tr>
<td></td>
<td>7/6/00</td>
<td>2</td>
<td>0.1</td>
<td>90</td>
<td>57</td>
<td>15</td>
<td>11</td>
<td>NA</td>
<td>Not Rated*</td>
</tr>
<tr>
<td></td>
<td>6/20/01</td>
<td>3</td>
<td>0.1</td>
<td>90</td>
<td>48</td>
<td>9</td>
<td>13</td>
<td>5.99</td>
<td>Not Rated*</td>
</tr>
<tr>
<td>Mill Creek at Ligon Mill Rd.</td>
<td>5/12/00</td>
<td>1.5</td>
<td>0.1</td>
<td>95</td>
<td>55</td>
<td>12</td>
<td>20</td>
<td>5.49</td>
<td>Not Impaired*</td>
</tr>
</tbody>
</table>

1. Habitat data available for 2000 and 2001 samples only.
2. Wetted channel width at time of sampling.
3. Based on visual estimate of substrate size distribution.
4. See text for list of component factors.
6. See text for description.

* Qual 4 method. See text for discussion.
** Qual 5 method. See text for discussion.
*** Though rated in 1991 and 1995 these samples would be considered Not Rated today due to DWQ’s current policy of not rating streams under four meters.

NA. BI was not calculated. Qual 4 method used but only EPT species evaluated.
Water quality assessment provides information to evaluate whether chemical and physical conditions negatively affect benthic communities. Two broad purposes of this monitoring are:

1. To characterize water quality conditions in the watershed; and
2. To collect a range of chemical, physical and toxicity data to help evaluate the specific causes of impairment and to identify the sources.

This section summarizes the sampling and data collection methods used, and discusses key monitoring results. See Appendix B for a more detailed discussion of methodology and a more comprehensive presentation of results.

DWQ does not have an ambient monitoring station in this watershed. Historical data for a limited number of parameters were available from two sources. A citizens’ stream watch group has collected data from Toms Creek at several sites in the lower watershed that are within the study area. In-stream dissolved oxygen data are collected by the Deerchase WWTP operator as a requirement of the facility’s NPDES permit.

5.1 Approach to Chemical, Physical and Toxicity Sampling

Project staff collected surface grab samples on nine occasions between February and September 2001, two of which represented storm samples. Stream sampling was limited to the mainstem and focused on the portion of Toms Creek below the Browns Lake dam and upstream of Ligon Mill Road. Most sampling was geared toward determining the impact of the Deerchase WWTP on the creek. Five chronic toxicity tests and one acute test were performed during the study to assess whether toxic water quality conditions were present.

5.1.1 Site Selection

Data were collected at four locations, including three of the four benthic sampling sites on Toms Creek below Browns Lake and the Deerchase WWTP effluent (Figure 5.1):

- Toms Creek at Kemble Ridge Drive above the Deerchase WWTP discharge (TCTC02.2).
- Deerchase WWTP effluent channel (TCTC02.1), immediately below the end of the outfall pipe.
- Toms Creek at Kemble Ridge Drive below the Deerchase WWTP discharge (TCTC02), downstream of the outfall where the stream is fully mixed.
- Toms Creek at SR 2044 (Ligon Mill Road), upstream of the bridge (TCTC01).

5.1.2 General Approach

General Water Quality Characterization. One station at the downstream end of the study area (Toms Creek at Ligon Mill Road) was sampled on a near monthly basis to characterize water
quality conditions (see Section 5.2). A standard set of parameters similar to those evaluated at 
DWQ ambient stations was utilized (see Appendix B). Grab samples were collected during both 
baseflow and storm conditions. Baseflow periods were defined as those in which no measurable 
rain fell in the watershed during the 48-hour period preceding sampling. Storm samples were 
collected on the rising stage of the hydrograph. Fecal coliform samples were collected under 
baseflow conditions on five occasions between August 13 and September 18, 2001.

Stressor and Source Evaluation. Station locations for stressor identification sampling were 
linked closely to areas of known biological impairment (benthic macroinvertebrate sampling 
stations) and to specific watershed activities believed to represent potential sources of 
impairment. Sampling focused primarily on those physical and chemical parameters that initial 
watershed reconnaissance had indicated as plausible causes of biological impairment. Both 
storm and baseflow samples were collected, as appropriate to specific pollutants and sources.

Sampling at the three upstream stations focused primarily on potential WWTP impacts--chlorine 
and low dissolved oxygen. Total residual chlorine (TRC) was measured in the field using a 
Hach DPD colorimeter. Thirty two TRC tests were performed at four sites on the creek during 
the study period, all during baseflow conditions. Because of the presence of development in the 
watershed, sampling at Ligon Mill Road included a variety of other pollutants. These included:
MTBE (methyl tert-butyl ether); phenols; organochlorine pesticides; PCBs (polychlorinated 
biphenyls); PAHs (polycyclic aromatic hydrocarbons); base/neutral & acid organics; TPHs (total 
petroleum hydrocarbons); MBAS (methylene blue active substances, a subcategory of 
surfactants); select minor ions; and selected current use pesticides. For a complete list of 
analytes and summary data, refer to Appendix B.

Laboratory bioassays provide a method of assessing the presence of toxicity from either single or 
multiple pollutants and can be useful for assessing the cumulative effect of multiple chemical 
stressors. Ambient chronic toxicity tests (bioassays) were conducted to evaluate potential toxic 
impacts from the Deerchase WWTP. Tests were conducted above and below the outfall and at 
Ligon Mill Road. One acute ambient toxicity test was conducted at Ligon Mill Road during a 
storm event. The following specific tests were used: ambient tests for acute toxicity using 
protocols defined as definitive in USEPA document EPA/600/4-90/027F (USEPA, 1993) using 
Ceriodaphnia dubia with a 48-hour exposure; and ambient tests for chronic toxicity using the 
North Carolina Ceriodaphnia Chronic Effluent Toxicity Procedure (NC Division of Water 
Quality, 1998).

Hydrolab data sondes (multiparameter probes with a data-logging capability) were deployed for 
four three-day deployments—two in August and September 2000 and two in July and August 
2001. Dissolved oxygen (DO), pH, water temperature, and specific conductance were recorded 
every 15 minutes. The multiprobes were deployed simultaneously above and below the WWTP 
discharge and at the Ligon Mill Road site in order to evaluate daily patterns in those parameters.

Water Quality Benchmarks. In order to help evaluate whether a significant likelihood existed 
that observed concentrations may have a negative impact on aquatic life, measured 
concentrations were compared to EPA’s National Ambient Water Quality Criteria (NAWQC) for 
freshwater (USEPA, 1999) and Tier II benchmarks (USEPA, 1995). Metals benchmarks were 
adjusted for hardness where appropriate (USEPA, 1999). For chromium, the NAWQC for Cr VI 
was used. The use of NAWQC and other benchmarks is discussed in more detail in Appendix B.
Benchmarks were used for initial screening of potential impacts. Final evaluation of the likely potential for metals, and other analytes, to negatively impact aquatic biota considered all lines of evidence available, including toxicity bioassays and benthic macroinvertebrate data, in addition to data on analyte concentrations.

5.2 Water Quality Characterization

Stream discharge was typically low in Toms Creek. Stage measurements indicated a difference of less than 0.9 meters (three feet) between the lowest baseflow and the highest stormflow measurements taken at Ligon Mill Road during the study. The Deerchase WWTP discharge accounted for a substantial portion of the flow during dry periods. Just below the discharge, the stage rose less than 0.6 meters (two feet) at any time during the study.

Concentrations of nutrients and other conventional parameters for Toms Creek at Ligon Mill Road are summarized in Table 5.1. Metals are discussed in Section 5.3. Additional data on dissolved oxygen and other field parameters, based upon multiday data sonde deployments, are discussed in Appendix B.

- Median baseflow concentrations for total phosphorus and total nitrogen were 0.07 mg/L and 1.23 mg/L respectively. These are somewhat elevated above background levels for the Piedmont (Caldwell, 1992), but do not exceed levels in many other streams in the region (NCDWQ, 1999 and 2001a).
- Dissolved oxygen levels were typically adequate, ranging from 5.4 to 10.2 mg/L during the study period. DO differences between sites above and below the Deerchase discharge were typically less than 1 mg/L, with levels at Ligon Mill Road, 1.4 km (0.9 miles) below the outfall, only slightly higher. These data do not suggest the discharge was having a detrimental effect on DO at the Ligon Mill Road site.
- pH also appeared to be stable in the study area. Values at the Ligon Mill Road site ranged between 6.3 and 7.4 standard units. Readings above and below the discharge were approximately neutral and the discharge did not appear to be influencing pH at the Ligon Mill Road site significantly.
- Fecal coliform levels ranged from 45 to 120 col/100mL, with a geometric mean of 77. The North Carolina standard for fecal coliform in these waters is a geometric mean of 200 col/100 mL.
5.3 Stressor and Source Identification

5.3.1 Impacts of the Deerchase WWTP

The Deerchase plant’s self-monitoring data showed chronically high levels of effluent chlorine (see Section 2) though the location where samples were taken at the plant is unclear. After reviewing data on the facility’s effluent toxicity test failures, noting the persistent smell of chlorine in the area of the discharge, and observing undissolved pellets in the discharged effluent, staff collected data on total residual chlorine (TRC) concentrations at all four sampling locations during a variety of baseflow conditions to determine how extensively chlorine was present in the system. TRC levels above the discharge were consistently below the equipment’s detection limit of 0.01 mg/L. Measured effluent TRC concentrations were frequently at or above 4 mg/L, exceeding the range the equipment could accurately test without performing dilutions in the field. TRC ranged from 0.19 to 1.80 mg/L in Toms Creek below the outfall, with an average of 1.09 mg/L. At the Ligon Mill Road site, TRC concentrations ranged between 0.04 and 0.16 mg/L (Figure 5.2). See Appendix B for additional data.

According to EPA’s National Ambient Water Quality Criteria, acute chlorine concentrations greater than 0.019 mg/L and chronic concentrations greater than 0.011 mg/L are detrimental to at least 5% of species. The proposed standard for North Carolina is 0.017 mg/L. Thus observed baseflow chlorine concentrations were typically at least four times the chronic criterion concentration as far as 1.4 km (0.9 miles) below the discharge. The even higher concentrations observed closer to the discharge support the theory that chlorine is responsible for the caddisfly deformities described in Section 4.2.

Table 5.1  Toms Creek at Ligon Mill Road: Selected Monitoring Results

| PARAMETER | BASEFLOW | | | | | STORMFLOW | | | |
|-----------|----------|----------|----------|----------|----------|----------|----------|----------|
|           | No. Samples | Maximum | Minimum | Median | No. Samples | Maximum | Minimum | Median |
| Nutrients (mg/L) | | | | | | | | |
| Ammonia Nitrogen | 8 | 0.20 | < 0.10 | 0.10 | 2 | 0.10 | 0.10 | 0.10 |
| Total Kjeldahl Nitrogen | 8 | 2.20 | 0.40 | 1.05 | 2 | 1.10 | 0.10 | 0.60 |
| Nitrate+Nitrite Nitrogen | 8 | 0.97 | 0.05 | 0.19 | 2 | 0.39 | 0.18 | 0.29 |
| Total Phosphorus | 8 | 0.17 | 0.03 | 0.07 | 2 | 0.52 | 0.16 | 0.34 |
| Total Nitrogen | 8 | 2.47 | 0.59 | 1.23 | 2 | 1.49 | 0.28 | 0.89 |
| Other Conventional | | | | | | | | |
| Dissolved Oxygen (mg/L) | 7 | 10.2 | 5.4 | 6.8 | 1 | 6.9 *1 | | |
| pH (Standard Units) | 7 | 7.4 | 6.6 | 6.8 | 2 | 6.9 | 6.3 | 6.6 |
| Specific Conductance (µS/cm) | 6 | 101.5 | 61.2 | 82.2 | 2 | 92.3 | 72.4 | 82.4 |
| T h i d i t y (NTU) | 8 | 14.7 | 2.4 | 5.2 | 2 | 136.0 | 38.8 | 87.4 |
| Total Hardness (mg/L) | 7 | 40 | 15 | 20 | 2 | 15 | 13 | 14 |
| Calcium (mg/L) | 6 | 4.47 | 2.91 | 3.52 | 1 | 3.33 | 1 | |
| Magnesium (mg/L) | 6 | 1.23 | 0.85 | 1.07 | 1 | 1.24 | 1 | |

*1 Single value reported as maximum.
Five chronic toxicity tests using *Ceriodaphnia dubia* were conducted using ambient samples collected from Toms Creek. In March 2001, two tests were run simultaneously on samples collected above the discharge and below the discharge where the stream was completely mixed. Both bioassays passed with no associated mortality or observed reduction in reproduction. Chlorine measurement equipment was not available for these first two tests, so ambient TRC concentrations at that time are not known. A second pair of tests was performed in April 2001. While the bioassay conducted on the sample collected above the discharge passed, the sample below the discharge failed the first day due to 100% mortality of the test organisms. The in-stream TRC concentration at the time this sample was collected was 1.32 mg/L. Four days later, TRC in this sample was measured by the laboratory as 0.35 mg/L. This sample was collected at a time of ample spring baseflow, and thus did not represent worst case low flow conditions.

The final chronic test was conducted on samples collected in September 2001 at the Ligon Mill Road site. While no mortality was observed, this test failed due to significantly reduced reproduction. TRC values were 0.11 mg/L for the original sample and 0.15 mg/L for the renewal sample (a second ambient sample collected several days into the week-long chronic test). Although data on effects concentrations for *Ceriodaphnia dubia* were not found in the literature, two similar species, *Daphnia magna* and *Daphnia pulex*, demonstrate immobility and mortality at similar concentrations of chlorine. Kaniewska-Prus (1982) reported that *Daphnia magna* experienced immobility at 0.019-0.235 mg/L and mortality at 0.011-0.373 mg/L in 24-hour renewal toxicity tests. Cairns et al. (1978) reported LC₅₀s for *Daphnia magna* between 0.076-0.160 mg/L in 24-hour static toxicity tests and for *Daphnia pulex* between 0.005-0.140 mg/L in 24-hour static toxicity tests and 0.030-0.110 mg/L in 48-hour static toxicity tests. It is quite plausible that the chlorine concentrations found in the Toms Creek sample could be responsible for the observed effects on *Ceriodaphnia dubia*. 

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**Figure 5.2** Total Residual Chlorine Concentration at Ligon Mill Road, 2001
It is worth noting that residual chlorine volatilizes rapidly and much may be lost from a sample during transport to the laboratory and preparation of the sample for toxicity testing, as well as during the test itself. Test organisms are likely to be exposed to much lower levels of chlorine than were present in ambient waters at the time the sample was collected.

5.3.2 Other Concerns

Data for metals and pesticides are discussed below. Other potential toxicants (MTBE, phenols, organochlorine pesticides, PCBs, PAHs, base/neutral & acid organics, TPHs, MBAS) were not observed. Data are reported in Appendix B.

Metals. Concentrations of all metals detected at the Ligon Mill site are reported in Table 5.2, along with hardness-adjusted benchmarks (see appendix B for further discussion). Concentrations in a number of samples exceed NAWQC criteria, suggesting that metals toxicity may be a potential concern. Since total rather than dissolved concentrations were measured, however, the bioavailability of these substances is difficult to fully assess. Adjusting benchmarks for hardness only partially addresses this issue.

Metals such as aluminum, iron, manganese, copper and zinc are widespread in North Carolina’s waters. Potential effects on benthic macroinvertebrates are uncertain since organisms in a given locality may be adapted to local concentrations. In the upper Neuse River basin area, (Neuse subbasins 01-03) the DWQ has five ambient sampling locations on tributary streams that support relatively diverse benthic macroinvertebrate populations (bioclassification of Good-Fair or better). Concentrations of the above metals at these sites were commonly at or above levels observed in Toms Creek (Table 5.3).

Lead and cadmium are observed much less frequently at DWQ ambient stations, in part because the detection limits for laboratory analysis are significantly higher than those used for this study. None of the samples in this study had cadmium concentrations exceeding the detection limit of 2.0 µg/L commonly used for ambient sample analysis. Only one sample would have been detectable at the 10.0 µg/L limit commonly used for lead. Data collected by the United States Geological Survey (USGS) as part of the Triangle Water Supply Monitoring Project (Garrett et al., 1994), indicates that a number of sites supporting good or excellent macroinvertebrate populations (based on DWQ sampling) have observed lead and cadmium levels approaching or exceeding those measured in Toms Creek.

An acute bioassay conducted during the July 26, 2001 storm event showed no evidence of toxicity, lending support to a conclusion that ambient metals concentrations at that time were not sufficient to cause toxicity. A chronic bioassay conducted on the September 13, 2001 baseflow samples failed. Elevated chlorine was most likely the cause of toxicity, although aluminum and iron concentrations were also elevated during this sampling event. In general, while metals cannot be ruled out as problematic in Toms Creek, the case for chlorine toxicity is much more robust. Any impact of metals on stream biota will be easier to evaluate once the chlorine impacts have been mitigated.

Pesticides. Samples were analyzed for a broad range of current use pesticides (see Appendix B). None were detected in three baseflow samples. Two--diazinon and simazine--were detected in
one of two storm samples. Diazinon is an organophosphate insecticide sold under trade names such as Spectracide and Gardentox. Simazine is a triazine herbicide used for preemergent control of broad leaf weeds and sold under trade names such as Princep. Both are among pesticides frequently used by homeowners and found with increasing frequency in urban and suburban streams in North Carolina (Oblinger and Treece, 1996; Bales et al., 1999) and throughout the nation (Schueler, 1995; Hoffman et al., 2000).

The diazinon concentration observed was 0.11 µg/L, below the Tier II secondary acute screening value of 0.17 µg/L (see Appendix B). Formal screening values are unavailable for simazine, but the simazine concentration observed (0.33 µg/L) is well below thresholds suggested in the literature (see discussion in appendix B). An acute toxicity bioassay conducted on a sample collected at the same time as the pesticide samples showed no evidence of toxicity. Existing information thus does not suggest that the observed concentrations of these two pesticides was a problem, but additional sampling would be required to provide more conclusive evidence concerning their impact on Toms Creek.

### 5.3.3 Other Data Sources

In-stream DO levels above and below the Deerchase outfall, as reported in the facility’s self monitoring data, do not differ substantially, suggesting no cause for concern. Data collected by a local volunteer group for various locations between Browns Lake and Ligon Mill Road did not generally suggest water quality concerns, although high ammonia levels were measured in 1998 on the same day dead fish were observed in the stream below the discharge (see Section 2.5).
### Table 5.2  
Toms Creek at Ligon Mill Road: Total Metals Concentrations and NAWQC Values

<table>
<thead>
<tr>
<th>METAL</th>
<th>CHRONIC BENCHMARK</th>
<th>BASEFLOW 2/9/01</th>
<th>BASEFLOW 3/12/01</th>
<th>BASEFLOW 4/11/01</th>
<th>BASEFLOW 5/31/01</th>
<th>BASEFLOW 6/29/01</th>
<th>BASEFLOW 8/23/01</th>
<th>BASEFLOW 9/13/01</th>
<th>BASEFLOW 9/18/01</th>
<th>ACUTE BENCHMARK</th>
<th>STORMFLOW 7/26/01</th>
<th>STORMFLOW 9/24/01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td></td>
<td>87</td>
<td>79</td>
<td>107</td>
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<td>50</td>
<td>247</td>
<td>146</td>
<td>116</td>
<td>750</td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&lt; 0.1</td>
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<td>1.2</td>
</tr>
<tr>
<td>Chromium</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Copper</td>
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<td>-</td>
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<td>11</td>
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<td>2</td>
<td>-</td>
<td>&lt; 1</td>
<td>2.1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Iron</td>
<td>1,000</td>
<td>950</td>
<td>727</td>
<td>1,060</td>
<td>1,480</td>
<td>1,500</td>
<td>1,430</td>
<td>1,250</td>
<td>1,270</td>
<td>1,350</td>
<td>N/A</td>
<td>4,210</td>
</tr>
<tr>
<td>Lead</td>
<td>0.25</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>&lt; 1</td>
<td>6.4</td>
<td>10.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>120</td>
<td>70</td>
<td>69</td>
<td>78</td>
<td>87</td>
<td>109</td>
<td>121</td>
<td>96</td>
<td>97</td>
<td>92</td>
<td>2,300</td>
<td>600</td>
</tr>
<tr>
<td>Nickel</td>
<td>N/A</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>87</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Silver</td>
<td>N/A</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.13</td>
<td>-</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>22</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>22</td>
</tr>
</tbody>
</table>

1 Benchmark values were adjusted according to average hardness except for aluminum, chromium VI, iron and manganese for which no conversions were available (USEPA, 1999).
2 The chronic benchmark for cadmium was used instead of the acute value because hardness adjustment reduced it below the chronic level.
3 The more conservative chromium VI benchmark was used to make comparisons with total chromium concentrations.
4 A Tier II benchmark value (USEPA, 1995) was used because a NAWQC (USEPA, 1999) was not available.

* - Metal concentration was below detection limit. Detection limit was below benchmark except for lead. Detection limits are found in Appendix B.

### Table 5.3  
Total Metals Concentrations at Selected Ambient Stations in the Upper Neuse Basin, 1996-2000

<table>
<thead>
<tr>
<th>STATION LOCATION (Station Number)</th>
<th>Eno River at SR1004 (J0810000)</th>
<th>Eno River at US15/501 (J0770000)</th>
<th>Little River at SR1461 (J0820000)</th>
<th>Flat River at SR1614 (J1070000)</th>
<th>Middle Creek at NC50 (J5000000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BENTHOS RATING (2000)</td>
<td>GOOD</td>
<td>EXCELLENT</td>
<td>EXCELLENT</td>
<td>GOOD</td>
<td>GOOD-FAIR</td>
</tr>
<tr>
<td><strong>METAL (µg/L)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>Median</td>
<td>390</td>
<td>245</td>
<td>230</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>8,100</td>
<td>6,800</td>
<td>9,700</td>
<td>39,000</td>
</tr>
<tr>
<td>Iron</td>
<td>Median</td>
<td>800</td>
<td>715</td>
<td>745</td>
<td>920</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>8,500</td>
<td>4,300</td>
<td>17,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Manganese</td>
<td>Median</td>
<td>71</td>
<td>50</td>
<td>25</td>
<td>44</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>270</td>
<td>240</td>
<td>850</td>
<td>600</td>
</tr>
<tr>
<td>Copper</td>
<td>Median</td>
<td>3.1</td>
<td>3</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>23</td>
<td>25</td>
<td>19</td>
<td>140</td>
</tr>
<tr>
<td>Zinc</td>
<td>Median</td>
<td>15</td>
<td>13</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>160</td>
<td>100</td>
<td>66</td>
<td>89</td>
</tr>
</tbody>
</table>

Source: Basinwide Assessment Report, Neuse River Basin (NCDWQ, 2001c)
Section 6
Channel and Riparian Conditions

The characterization of stream habitat and riparian area conditions at benthic macroinvertebrate sampling sites, described earlier, provides information essential to the assessment of conditions in the Toms Creek watershed. However, a perspective limited to a small number of locations in a watershed may not provide an accurate picture of overall channel conditions, nor result in the identification of pollutant sources and specific problem areas. This study therefore undertook a broader characterization of stream condition by examining large sections of the Toms Creek channel network. This characterization is critical to an evaluation of the contribution of local and regional habitat conditions to stream impairment and to the identification of source areas and activities.

During the study project staff walked most of the Toms Creek channel from Forestville Road to the Neuse River. Much of this section was surveyed on numerous occasions. Selected sections of the channel above Forestville Road, as well as portions of Mill Creek and smaller tributaries, were also walked. This section summarizes channel and riparian conditions and discusses likely future changes in stream channels. A more detailed description of existing conditions is included in Appendix D.

6.1 Summary of Existing Conditions

Although Toms Creek is incised for much of its length, the stream retains a natural pattern and bank erosion is only moderate. Obvious evidence of channel modification is lacking except for several small riprapped stretches in residential areas below Browns Lake (Figure 6.1). Much of the riparian zone has intact woody vegetation, though increasingly residential lots are being cleared down to or near the banks. The most extensive areas with high erosion potential, located north of Roxbury Drive (Figure 6.1), consist of several stretches of bare vertical bank, each 40-60 feet (12.2 to 18.3 m) in length. Mass failures are uncommon except in the gully below Browns Lake.

Large volumes of sand fill much of the stream network. Sand deposits can exceed 4 feet (1.2 m) in depth. Given the underlying geology, streams in this area likely have a naturally sandy substrate. Clearly, however, this stream has experienced massive sediment deposition from multiple sources over many years. The picture that emerges from examining Tom Creek in its entirety, as well as Mill Creek and the former mill pond, is of a watershed that experienced significant inputs of agricultural erosion many decades ago, some of which still remain in the channel system. Subsequent inputs, which appear to be primarily limited to the area below Browns Lake, include erosion from a gully at the dam, inputs from residential construction, and some level of bank erosion. It is not possible to clearly distinguish between the relative impacts of these more recent disturbances.

While substantial aggradation has occurred in the past, repeated observation of the channel during the study indicates that Toms Creek is probably no longer aggrading. A number of bedrock ledges remained exposed for the duration of the study. The stream remains very dynamic with considerable sediment transport and frequent bar movement. It is likely that
Browns Lake and upstream beaver impoundments trap most inputs of coarse material from the upper watershed. This may increase the potential for sediment transport below the lake.

6.2 Future Changes

While there is substantial uncertainty about how the stream section below Browns Lake will evolve, in the absence of further watershed change and additional sediment inputs it seems most likely that significant incision would not occur, as numerous bedrock ledges serve as grade control. Riffles would become less embedded and additional pools would develop as the stream gradually removes some of the deposited sand, but a predominantly sandy substrate is likely to remain as it has in portions of the watershed that have not seen recent disturbance. The time frame over which this would occur is not clear, but it could require several decades. Additional sediment inputs would delay this recovery and assure the persistence of the current substrate instability.

The fate of the small tributaries to Toms Creek draining the Carriage Run and Saint Andrews Plantation subdivisions is uncertain. These tributaries currently contain sediment from the recent construction period, some portion of which will be gradually flushed into Toms Creek over a period of years. If sediment input were the only issue, these tributaries would probably stabilize in a few years after removing sufficient sediment to reach a quasi-equilibrium condition. However these developments, designed with traditional curb and gutter and a density of approximately two dwellings per acre, have significantly altered the hydrology of the areas draining to these streams. There is a substantial likelihood that these channels will incise and widen in response to increased stormwater volumes. This instability would result in additional sediment inputs into Toms Creek and could damage residential property. Bank erosion has already occurred in the Hampton Chase Court area. Impacts to these small streams have probably seriously degraded an important source of macroinvertebrate colonization for Toms Creek.

Though current bank erosion appears generally moderate, the steepness of the banks and sandy nature of the upper bank material results in a fairly high erosion potential for the main stem of Toms Creek between Browns Lake and Ligon Mill Road, and for much of Mill Creek. These streams will be highly vulnerable to future disturbance. Without proper stormwater controls for new development, increases in the frequency or duration of erosive flows will promote bank erosion and stream widening, initiating a long period of channel instability. Streams sensitive to future hydrologic changes are not unusual in much of North Carolina. [See the Background Note “Landscape History and Channel Alteration in the Piedmont Region”, presented in Section 2.]
This section analyzes the likely causes of impairment in the Toms Creek watershed, drawing upon the information presented earlier in this report. The sources or origin of these key stressors are also discussed.

### 7.1 Analyzing Causes of Impairment

The following analysis summarizes and evaluates the available information related to candidate causes of impairment in order to determine whether that information provides evidence that each particular stressor plays a substantial role in causing observed biological impacts. A strength of evidence approach is used to assess the evidence for or against each stressor and draw conclusions regarding the most likely causes of impairment. Causes of impairment may be single or multiple. All stressors present may not be significant contributors to impairment. [See the Background Note “Identifying Causes of Impairment”, presented in Section 1, for additional discussion.]

#### 7.1.1 A Framework for Causal Evaluation—the Strength of Evidence Approach

A ‘strength of evidence’ or ‘lines of evidence’ approach involves the logical evaluation of all available types (lines) of evidence to assess the strengths and weaknesses of that evidence in order to determine which of the options being assessed has the highest degree of support (USEPA, 1998; USEPA, 2000). The term ‘weight of evidence’ is sometimes used to describe this approach (Burton and Pitt, 2001), though this terminology has gone out of favor among many in the field because it can be interpreted as requiring a mathematical weighting of evidence.

This section considers all lines of evidence developed during the course of the study using a logical process that incorporates existing scientific knowledge and best professional judgment in order to consider the strengths and limitations of each source of information. Lines of evidence considered include benthic macroinvertebrate community data, habitat and riparian area assessment, chemistry and toxicity data, and information on watershed history, current watershed activities and land uses and pollutant sources. The ecoepidemiological approach described by Fox (1991) and USEPA (2000) provides a useful set of concepts to help structure the review of evidence. The endpoint of this process is a decision regarding the most probable causes of the observed biological impairment and identification of those stressors that appear to be most important. Stressors are categorized as follows:

- **Primary cause of impairment.** A stressor having an impact sufficient to cause biological impairment. If multiple stressors are individually capable of causing impairment, the primary cause is the one that is most critical or limiting. Impairment is likely to continue if the stressor is not addressed. All streams will not have a primary cause of impairment.
• **Secondary cause of impairment.** A stressor that is having an impact sufficient to cause biological impairment but that is not the most critical or limiting cause. Impairment is likely to continue if the stressor is not addressed.

• **Cumulative cause of impairment.** A stressor that is not sufficient to cause impairment acting singly, but that is one of several stressors that cumulatively cause impairment. A primary cause of impairment generally will not exist. Impairment is likely to continue if the various cumulative stressors are not addressed. Impairment may potentially be addressed by mitigating some but not all of the cumulative stressors. Since this cannot be determined in advance, addressing each of the stressors is recommended initially. The actual extent to which each cause should be mitigated must be determined in the course of an adaptive management process.

• **Contributing stressor.** A stressor that contributes to biological degradation and may exacerbate impairment but is not itself a cause of impairment. Mitigating contributing stressors is not necessary to address impairment, but should result in further improvements in aquatic communities if accomplished in conjunction with addressing causes of impairment.

• **Potential cause or contributor.** A stressor that has been documented to be present or is likely to be present, but for which existing information is inadequate to characterize its potential contribution to impairment.

• **Unlikely cause or contributor.** A stressor that is likely not present at a level sufficient to make a notable contribution to impairment. Such stressors are likely to impact stream biota in some fashion but are not important enough to be considered causes of or contributors to impairment.

### 7.1.2 Candidate Stressors

As outlined in Section 3, the primary candidate causes of impairment evaluated were

- low dissolved oxygen (DO);
- potential toxicity due to the Deerchase WWTP discharge;
- habitat degradation due to sediment deposition and substrate instability;
- nutrients; and
- pesticides.

Elevated metals concentrations were identified during the course of the study and are also discussed.

### 7.1.3 Review of Evidence

Toms Creek is impaired below Browns Lake. Biological sampling indicates that the stream, though subject to some degradation, was not impaired as recently as 1991. Biological condition declined sometime between August 1991 and July 1995, and the stream has remained impaired (see Section 4). The stream does not appear to be impaired above the lake. The creek was not sampled below Ligon Mill Road, but the watershed in this downstream section is almost entirely forested and is not a likely source of additional stressors. Mill Creek, the major tributary to Toms Creek, is not considered impaired based upon benthic macroinvertebrate community data.
Low dissolved oxygen (DO). Low dissolved oxygen was considered as a candidate cause of impairment due to the small size of the creek, with the potential for low summer streamflows, and the presence of the Deerchase wastewater discharge. Two lines of evidence are relevant here: water quality monitoring data and benthic community data. Neither provides any support for low DO impacts. Benthic community composition is not consistent with pervasive impacts from low DO levels. Monitoring of dissolved oxygen levels in Toms Creek at a variety of times and locations below the wastewater discharge provided no evidence of low DO levels (Section 5), even during low flow, warm weather conditions. Low dissolved oxygen is an unlikely contributor to impairment.

Potential toxicity due to the Deerchase WWTP discharge. The record of toxicity tests conducted on the Deerchase WWTP effluent, required under the facility’s NPDES permit, indicated numerous failures over the past 11 years (Section 2), raising the issue of whether in-stream impacts exist. Chlorine and ammonia are the most likely potential toxicants in a small discharge of domestic wastewater such as this one. Relevant lines of evidence include toxicity bioassays, chemical analyses and biological data. It is worth noting that chlorine is extremely volatile. TRC concentrations to which test organisms were exposed during laboratory bioassays are not representative of in-stream TRC concentrations.

Ambient chronic toxicity tests conducted during the course of the study confirm the presence of in-stream toxicity during baseflow conditions both immediately below the discharge mixing point and at Ligon Mill Road (Section 5). *Chematopsyche* caddisflies collected at the macroinvertebrate station immediately below the discharge exhibited deformities that have been previously associated with chlorine toxicity (Section 4). Chlorine levels at the time of toxicity test failure, as well as on numerous other occasions, far exceeded benchmarks for expected impacts on aquatic macroinvertebrates (Section 5). It was not uncommon to observe undissolved chlorine pellets in the stream below the discharge. The facility’s self monitoring data indicates that effluent ammonia levels were occasionally high enough to be potentially problematic (see Section 2), but high in-stream levels of ammonia were not confirmed during the study. The presence of chlorine was so pervasive that the likelihood of ammonia impacts is very difficult to evaluate.

The Mill Creek and upper Toms Creek benthic community sampling stations, which are not subject to the influence of the WWTP discharge, show healthy benthic communities. The site immediately above the outfall is also not subject to that influence, but is subject to more extreme channel instability than the other two sites and has limited opportunities for colonization given the presence of the lake immediately upstream and a poor benthic community immediately downstream.

While a strong case can be made that chlorine toxicity is a problem at the present time, the extent to which such impacts occurred prior to 1995, when the decline in the benthic community was first observed in Toms Creek, is less clear. Examination of the record of toxicity tests conducted on effluent during that period indicates that a number of failures did occur. While the discharge rate reported by the facility during that time was typically about half current levels, Wake County staff indicated that data from that period was probably not reliable and that the actual discharge rate likely did not vary significantly from current levels (Section 2).
Habitat degradation due to sediment deposition and substrate instability. Initial reconnaissance indicated that the channel system and floodplain had experienced massive sediment deposition. Further evaluation of sedimentation issues and identification of sediment sources was clearly warranted.

Habitat is poor at all Toms Creek locations sampled below Browns Lake, including a station just above the WWTP discharge. Riffles are buried or highly embedded and pools are small. The stream bed is composed largely of sand and is subject to frequent movement, proving a poor substrate for macroinvertebrate colonization (Sections 4 and 6). The generalized decline observed in the benthic macroinvertebrate community at Ligon Mill Road is consistent with the impacts of severe habitat degradation (Section 4). Loss of riffle habitat was observed between 1991 and 1995, when the decline in the benthic community occurred.

In the headwaters of Toms Creek and in Mill Creek, stable microhabitat is more common and the benthic community is much more diverse, despite a sandy substrate and a lack of riffles. Observation indicates that less sediment is probably moving through these reaches than is the case in Toms Creek below Browns Lake (Sections 2 and 6 and Appendix D). These areas have not experienced recent disturbance from either agriculture or residential development.

Significant construction activity occurred in the Toms Creek drainage between 1991 and 1995. Much of the Saint Andrews subdivision was constructed during this period, and land clearing and road construction for the Saint Andrews Plantation and Carriage Run subdivisions had begun (Section 2). The likelihood of sediment inputs to Toms Creek during the 1990s is supported by aerial photos from the period and the current condition of tributaries draining these subdivisions. Sediment inputs from Hurricanes Fran and Floyd occurred in 1996 and 1999 respectively. While these storms may have contributed to conditions observed during the study, they are not responsible for the decline in the benthic community, which occurred prior to 1996.

Nutrients. An initial review of macroinvertebrate data indicated that nutrients were not a likely cause of impairment, but further evaluation was conducted due to the presence of the wastewater discharge. Nitrogen and phosphorus concentrations in Toms Creek (Section 5) were above background levels but were not unusually high compared to other Piedmont streams. The biological response of free-flowing streams to nutrients is highly variable, and depends upon shading, stream velocity and other factors. It is thus difficult to use in-stream nutrient concentrations to determine whether nutrients are a cause of benthic impairment. Further interpretation of macroinvertebrate data indicated that benthic community composition in Toms Creek is not consistent with significant impacts due to organic enrichment or nutrient inputs (Section 4). Prolific levels of algal growth were not observed in the stream. Nutrients are an unlikely contributor to impairment in Toms Creek.

Pesticide inputs. While agriculture has been declining in the watershed and little cropland remains, the potential for pesticide impacts was examined due to the increase in residential development. Diazinon and simazine, pesticides commonly used in residential lawn care and insect control products, were detected in Toms Creek in one of five samples. Observed concentrations did not exceed established benchmarks (Section 5) and an acute bioassay conducted on samples collected at the same time passed. Although available data are not adequate to fully characterize pesticide concentrations in Toms Creek, existing information does
not provide a strong indication that a problem exists. It is unlikely that pesticides are contributing to impairment at the present time.

**Metals.** A number of metals were periodically present at levels exceeding hardness-adjusted screening benchmarks, though high concentrations were not observed during the sampling event at Ligon Mill Road in which toxicity test failures occurred (Section 5). Metals bioavailability is difficult to evaluate based on existing data. Concentrations observed were generally lower than levels often measured in ambient stations in the upper Neuse basin that support diverse benthic macroinvertebrate communities. Metals toxicity does not seem likely. If necessary, the issue of potential metals toxicity should be revisited after chlorine problems are addressed.

### 7.1.4 Conclusion

Chlorine toxicity is considered a primary cause of impairment. Multiple lines of evidence support a conclusion that toxic impacts due to residual chlorine discharged from the Deerchase WWTP occurred during the study. No relevant evidence supports a contrary conclusion. Evidence that toxic impacts were responsible for the initial decline in biological condition observed in Toms Creek 1995 is less conclusive.

Habitat degradation due to severe sedimentation and substrate instability is also a cause of impairment. Current conditions, watershed history and circumstantial evidence suggest that sediment inputs have impacted benthos since the 1990s. The confounding effects of historic sedimentation and present chlorine impacts complicate an assessment of the importance of recent sediment inputs, but the evidence points toward habitat degradation as at least an important secondary cause of biological impairment.

### 7.2 Sources of Impairment

Effluent from the Deerchase WWTP is the only source of chlorine. The reasons for habitat degradation are multiple. As discussed in Sections 2 and 6, agriculture was an important sediment source historically, but has not been significant for some time. The most important recent sources are construction activities in newly completed subdivisions below Browns Lake and continued erosion in the gully and bypass channel around the Browns Lake dam. Moderate bank erosion occurs at some locations, but this is probably a less substantial source.

### 7.3 Other issues of Concern

With the construction of the Carriage Run and Saint Andrews Plantation subdivisions, and to a lesser extent with the prior construction of Deerchase, tributaries draining to Toms Creek between Browns Lake and Ligon Mill Road have been significantly impacted. Substantial sediment inputs have occurred, the streams have been straightened or riprapped in some areas, and these channels now receive concentrated flow from curb and gutter drainage systems. Riparian zones have often been cleared of woody vegetation as these streams pass through residential areas. These streams drained an area of mature forest prior to recent construction and, though small, would have served as at least a seasonal source of macroinvertebrate recolonization for the mainstem of Toms Creek. Recent development has seriously
compromised this ecological function. Such colonization sources are important to the ability of a stream like Toms Creek to recover quickly from disturbance (see the Background Note “The Stress-Recovery Cycle”). The drainage system of Mill Creek is more intact, with tributary streams experiencing minimal recent disturbance.

### Background Note: The Stress-Recovery Cycle

Even in relatively pristine streams, aquatic organisms are exposed to periods of stress. Natural stresses due to high flows during storms, low flows during hot dry summer periods or episodic large sediment inputs (e.g. from slope failures in mountain areas or breaching of beaver dams) can have significant impacts on stream communities. Although aquatic communities in high quality streams may be impacted by such disturbances, and some species may be temporarily lost from particular sites, populations are able to reestablish themselves—often very quickly—by recolonization from less impacted areas or refugia (see Yount and Niemi, 1990; Niemi et al., 1990). This process can involve recolonization from backwater areas, interstitial zones (spaces between the cobble and gravel substrate), the hyporheic zone (underground habitats just below the stream bed surface layer) or other available microhabitats. Repopulation from headwaters or tributary streams not impacted by the disturbance can also occur. For insects aerial recolonization is important as well.

Without robust mechanisms of recovery, even streams subjected to relatively modest levels of disturbance would be unable to support the diversity of aquatic organisms that they often do (Sedell et al., 1990; Frissell, 1997). This balance between local elimination followed by repopulation is critical to the persistence of fish, macroinvertebrates and other organisms in aquatic ecosystems, and is part of what we mean when we say that these creatures are “adapted” to their environment.

It is now commonly recognized that as watersheds experience increased human activity, stream biota are subjected to higher levels of stress. This can include both an increased frequency, duration or intensity of ‘natural’ types of disturbance, such as high flows, as well as completely new stresses, such as exposure to chlorinated organic chemicals. We less often realize, however, that many of these same activities often serve to inhibit those mechanisms that allow streams to recover from disturbances—in particular movement and recolonization (Frissell, 1997). For example, as watersheds develop:

- channel margin and backwater refugia may be eliminated as bank erosion or direct channel modification (channelization) make channel conditions more uniform and habitat less diverse;
- edge habitat, such as root mats, may be unavailable to biota due to lowered baseflows;
- access to interstitial and hyporheic areas may be limited by sediment deposition;
- impoundments may limit or eliminate drift of organisms from upstream;
- small headwater and tributary streams may be eliminated (culverted or replaced with storm drain systems);
- remaining headwater and tributary streams may be highly degraded (e.g. via channelization, removal of riparian vegetation, incision and widening due to increased stormflows, or decreased baseflows);
- aerial recolonization of macroinvertebrates may be diminished by the concomitant or subsequent degradation of streams in adjacent watersheds; and
- fish migration is often limited by culverts or other barriers.

As human activity intensifies, aquatic organisms are thus subjected to more frequent and more intense periods of stress, while at the same time their ability to recover from these stresses is severely compromised. It is the interaction between these two processes that results in the failure of many streams to support an acceptable population of fish or macroinvertebrates.

Efforts to restore better functioning aquatic communities in degraded streams must consider strategies to both reduce the stresses affecting stream biota and to protect and restore potential refugia and other sources of colonizing organisms. Under some conditions, the lack of adequate recolonization sources may delay or impede recovery. Protecting existing refugia and those relatively healthy areas that remain in impacted watersheds should be an important component of watershed restoration efforts (McGurrin and Forsgren, 1997; Frissell, 1997).
As discussed in the previous section, the primary causes of impairment in Toms Creek are
toxicity due to chlorine in the effluent of the Deerchase WWTP and habitat degradation caused
by sediment deposition and substrate instability. Future development in this watershed will also
threaten Toms and Mill Creeks due to the potential for additional sediment inputs during
construction and modification of watershed hydrology (hydromodification). This section
discusses how these problems can be addressed. A summary of recommendations is included at
the end of the section.

8.1 Addressing Current Causes of Impairment

The objective of efforts to improve stream integrity is to restore water quality and habitat
conditions to support a diverse and functional benthic macroinvertebrate community in this
suburbanizing area. While some development has occurred since Toms Creek last supported
such a community in the early 1990s, the watershed has not been so highly modified as to
preclude significant improvements in stream integrity. A return to the relatively unimpacted
conditions that probably existed prior to widespread agriculture is unlikely, but Toms Creek can
potentially support a much healthier community than it does today.

8.1.1 Toxic Impacts from the Deerchase Discharge

Toxicity due to high chlorine concentrations is a problem in Toms Creek. Occasional toxic
conditions due to elevated ammonia levels may also occur, although the extent of the chlorine
impacts make this difficult to evaluate. Since the Deerchase facility is currently discharging at
about half permitted levels, impacts are likely to worsen if wasteflows increase under current
operating conditions. Additionally, baseflows may decline once the planned retrofitting of the
Browns Lake dam has been carried out. For the entire time the wastewater plant was been
discharging, outflow from the lake has occurred through a channel cut around the dam, not
through the intended outlet structure. Observation suggests that discharge from the lake now
occurs more or less continuously, even during the summer. Once the outfall structure is
rehabilitated and drainage becomes more typical of other small impoundments, outflow may
become intermittent during summer dry periods, providing less (or no) dilution.

It is the responsibility of the Division of Water Quality to insure that chlorine levels in the
Deerchase WWTP effluent are reduced to nontoxic levels. The NPDES permit for this facility is
scheduled for renewal in 2002. A chlorine limit will be included in the new permit. Installation
of dechlorination equipment may be appropriate. DWQ will continue to monitor the situation
closely. In-stream chlorine monitoring may be necessary, since in-stream impacts were evident
during the study despite the fact that the facility passed most of its effluent toxicity tests during
this period. If evidence of in-stream toxicity persists after chlorine concentrations are reduced,
potential ammonia impacts will be evaluated.
Toms Creek is a small stream to serve as receiving waters for a wastewater discharge. Removal of the discharge from Toms Creek and connection to the Wake Forest system, which lies in close proximity to the outfall line, is the best long term option.

8.1.2 Habitat Degradation Due to Sedimentation and Substrate Instability

If the supply of new sediment is reduced below the sediment transport capacity of the stream, Toms Creek will gradually remove quantities of accumulated sediment through natural processes, resulting in more stable habitat conditions. It will likely take a number of years for this to occur, as a substantial volume of sediment is currently stored in the channels of Toms Creek and its tributaries. Now that construction has been largely completed in the Saint Andrews Plantation and Carriage Run subdivisions, erosion in the area below Browns Lake has been greatly reduced. Currently the major sources of sediment to Toms Creek are a) inputs from tributaries draining the recently completed developments; b) the gully at the outlet to Browns Lake; and c) several areas of stream bank erosion identified previously (Section 6).

The tributaries will gradually remove accumulated sediment until a stable condition is reached. Efforts to remove this material directly would be expensive and would require access to a substantial number of residential lots, through which the tributaries flow. Allowing these streams to remove sediment naturally is the most viable option. Efforts undertaken now to limit stormwater flows from existing impervious areas would minimize the possibility that these tributaries will incise due to recent hydrologic changes in their watersheds. Encouraging property owners to redirect downspouts to pervious areas such as yards or wooded areas rather than routing these flows to driveways or gutters is one simple practice that could be implemented.

The gully and bypass channel currently draining Brown Lake must be rehabilitated. Retrofitting of the dam is planned for the near future. The dam owner is working with the Division of Land Resources (DLR) to obtain plan approval under the Dam Safety Program to repair damaged areas and restore appropriate spillway capacity. DLR regional staff indicate that the owner will likely be required to stabilize the gully as a part of this work. If rehabilitation is not fully addressed during dam repairs, it must be completed thereafter. Side slopes could be stabilized by hardening in place, but it would be less expensive and more conducive to long term stability to grade the side slopes to a stable angle and revegetate the area. The precise nature of the necessary work will depend on what specifically is accomplished in conjunction with dam retrofitting. The length of the entire bypass channel does not exceed 600 feet, of which the deep gully comprises perhaps one third. At $100 per foot, a generous rate for this work, the total cost for the entire bypass channel would be approximately $60,000.

It would be helpful though not essential to repair the areas of severe bank erosion between the wastewater discharge and Ligon Mill Road, discussed in Section 6. These areas total several hundred feet in length and could probably be stabilized relatively inexpensively using volunteer labor if the project were coordinated by Wake Soil and Water Conservation District staff or other qualified personnel.
Woody riparian vegetation has been removed from numerous lots along the Toms Creek mainstem in the Saint Andrews and Saint Andrews Plantation subdivisions. Homeowners must be encouraged to replant native riparian vegetation in these areas.

8.2 Addressing Future Threats

About 30% of the Toms Creek watershed is currently developed. As discussed in Section 2, development is likely in the remainder of the watershed over the next several decades. If new development were to occur at similar densities (approximately 2 houses/acre), using similar design approaches (e.g. traditional curb and gutter), a lack of hydrologic controls (e.g. stormwater infiltration and detention practices), and the same sedimentation and erosion control practices as recently completed subdivisions, continued stream degradation in Toms Creek would be likely. Addressing these future threats is essential. Otherwise, improvements resulting from efforts to control current sources of impairment may be short lived or may never materialize. Additional portions of Toms Creek may become impaired. Fortunately new and pending regulations will help to assure that future development occurs in a less environmentally damaging fashion than recent growth. The adequacy of these regulations is discussed below.

Mill Creek, which currently supports a relatively healthy macroinvertebrate community, is also at risk of impairment from the sediment inputs and hydrologic changes that could result from future growth. Though likely to be developed at lower densities than most of the Toms Creek watershed (see Section 2), much of Mill Creek, like Toms Creek, is incised and can be expected to be sensitive to hydromodification. The two streams are in close proximity in the Ligon Mill Road area and further downstream. Mill Creek currently serves as a source of aerial macroinvertebrate colonization for Toms Creek, so degradation of the biological condition of this tributary would have implications for both streams.

8.2.1 Sediment from New Construction

Significant future sediment inputs would prolong habitat instability even if existing sources of sediment are addressed. The recent construction of several new subdivisions below Browns Lake resulted in substantial sediment inputs into Toms Creek. It seems unlikely that the coarse material washed into Toms Creek and its tributaries has been discharged from properly designed, installed and maintained sediment control devices. The large quantities of coarse sediment suggest that substantial erosion took place during construction and that important sediment control practices were not properly implemented or maintained. Additional sediment inputs from new developments can be expected if future sediment and erosion control practices mirror those of the past.

In the years since the most recent subdivisions below Browns Lake were permitted, Wake County has worked to improved its erosion and sedimentation control program. An evaluation of the extent to which these changes may prevent the types of impacts observed in the past is beyond the scope of this study. The County itself is in the best position to conduct such an evaluation. However, effective enforcement of sediment and erosion control regulations on the part of Wake County will be essential to the prevention of additional sediment inputs from construction activities. The development of improved practices or design approaches may also be beneficial. The CWMTF could consider working cooperatively with regulatory agencies and
willing developers to install and monitor innovative approaches that could supplement or serve as alternatives to current practices and requirements.

The Neuse buffer regulations should also help prevent sediment inputs if they are properly implemented. These regulations do not apply to ephemeral streams, however, which are an important part of the channel network and receive drainage from substantial areas. Education of landowners regarding the benefits of riparian vegetation and discouraging removal of additional riparian vegetation would be useful both in areas being developed under the Neuse buffer regulations and in existing developments.

**8.2.2 Hydromodification Due to Increased Stormflows**

As new development occurs in the Toms Creek watershed, it is likely that stormflows will increase with the expansion of associated impervious areas. Both peak discharges as well as the frequency and duration of high velocity flows can be expected to increase and to impact channel stability. Existing conditions in a watershed can greatly affect a stream’s vulnerability to these hydrologic changes (Bledsoe and Watson, 2001). As discussed in Section 6 and Appendix D, Toms Creek is incised in many reaches, has poor vegetative protection in some locations, and has areas of moderate bank erosion. Though the channel system as a whole is laterally stable at present, the stream is likely to be highly sensitive to any increase in storm runoff. Given these conditions, the channel will be prone to substantial bank erosion if significant hydrologic change occurs in the watershed. Some incision may occur, but would be limited by frequent bedrock outcrops. Stream widening is the more likely scenario. This would negatively affect aquatic habitat by continued sedimentation and increased levels of scour and substrate instability. This prognosis also applies to Mill Creek, which has recovered sufficiently from prior disturbances to support a relatively diverse benthic community despite retaining a sandy substrate.

New development will be subject to a number of recently implemented or pending regulatory efforts, including the buffer and stormwater rules now in force in the Neuse River basin. The buffer rule (see Section 2), which applies throughout the Toms Creek watershed, requires a minimum 50-foot vegetated buffer on each side of all perennial and intermittent streams and the maintenance of diffuse flow for any stormwater routed into the buffer. Portions of the watershed under county planning jurisdiction are also subject to the Neuse stormwater rule, which requires that nitrogen loading from new development be held to 3.6 pounds/acre/year, and that there be no net increase in peak flows leaving the site from predevelopment conditions for the 1-year 24-hour storm. Those parts of the watershed under the Wake Forest and Rolesville planning jurisdictions are not currently subject to the Neuse stormwater requirements. Wake Forest and Rolesville are also not among the communities automatically designated (based on US Bureau of the Census data) for coverage under the Phase II stormwater program. North Carolina is currently developing designation criteria for including additional communities in this program. Once the final criteria have been developed, Wake Forest and Rolesville may be reviewed for coverage under the Phase II program.

Whether adherence to these requirements will be sufficient to prevent degradation of the vulnerable channels in Toms and Mill Creeks is difficult to predict. The efficacy of these regulations will depend in part on how effectively they are implemented and how much of the watershed is covered by the rules.
To avoid significant channel erosion, it is critical that effective stormwater management occur throughout the Toms Creek watershed, whether this takes place under the Neuse stormwater rules, the Phase II program, local regulations or voluntary efforts. It is also important that stormwater management not be limited to peak flow attenuation. Peak flow based approaches are not likely to control the total volume of stormwater, and will probably not prevent destabilization in a vulnerable stream that is already incised and is sensitive to future disturbance (MacRae, 1997; Booth, 2000; Bledsoe and Watson, 2001).

One approach would be to rely on existing regulations for now, and take further action when deemed appropriate based on observed future channel instability. It is likely, however, that a significant time lag would occur both a) between the onset of any instability and a decision that additional measures are necessary, and b) between any policy decision and the actual application of those measures to new development activities. By that time, substantial damage is likely that would be difficult to remedy.

The risk to Toms Creek would be substantially reduced if Wake County and municipal governments develop a comprehensive approach to stormwater management covering the entire watershed. Such an approach could draw on a variety of planning and management tools (Caraco et al., 1998). Beneficial actions would include: promotion of development design approaches that minimize the generation of storm runoff; promotion of infiltration practices, to the extent practicable given local soils and conditions; exploration of retrofit opportunities for existing developed areas; limited use of the allowed exemption to the Neuse stormwater rules for development activities which are projected to increase in peak flows by 10 percent or less. Both regulatory and voluntary incentive-based approaches should be explored. Whatever actions are taken, their effectiveness in preventing channel degradation should be monitored.

8.2.3 Pesticides and Nutrients from Residential Areas

Pesticides are not currently a cause of impairment, but they are present in Toms Creek and may increase as more of the watershed is developed. Nitrogen and phosphorus inputs do not currently cause major problems in Toms Creek, but do contribute to the nutrient loading to the Neuse River. Educational efforts directed at homeowners in the watershed would be useful to reduce usage of pesticides and fertilizers and/or improve application methods.

8.3 A Framework for Improving and Protecting Stream Integrity

Restoring and protecting streams can seldom be accomplished in a single step, but requires an iterative process in which sequential actions are taken over time in conjunction with an effort to monitor changes in stream condition. An organizational framework for ongoing watershed management is essential in order to provide oversight over the implementation of projects, to evaluate how current restoration and protection strategies are working, and to plan for the future. While state agencies can play an important role in this undertaking, planning is often more effectively initiated and managed at the local level. Coordination between appropriate local governments (Wake County, Wake Forest, Rolesville and Raleigh) and involvement of a broad range of stakeholders must be important components of this process. Wake County is currently involved in a major watershed management initiative. The ongoing planning structure that will
emerge from this process may provide a suitable organizational home for water quality improvement and protection in the Toms Creek watershed.

8.4 Summary of Watershed Strategies for Toms Creek

The following actions are necessary to address current sources of impairment in Toms Creek, and prevent future degradation. Mitigating the potential impacts of future watershed development on watershed hydrology is critical, or improvements resulting from efforts to control current sources of impairment may be short lived. Actions one through five are all essential to restoring and sustaining aquatic communities in the watershed. The remaining actions would also be useful but will result in limited improvement unless the preceding measures are also carried out.

1. The Division of Water Quality should ensure that chlorine concentrations in the Deerchase WWTP effluent are reduced to nontoxic levels. This facility will receive a chlorine limit when its permit is reissued in 2002. Effluent and in-stream toxicity will be carefully evaluated to determine if further action is necessary.

2. The gully at the outlet to Browns Lake should be rehabilitated so that the side slopes are stable and are no longer a source of sediment to Toms Creek. It is likely that stabilization will be carried out by the owner of the lake in conjunction with planned retrofitting of the dam. If complete stabilization does not occur at that time, the problem should be otherwise addressed.

3. More effective sediment and erosion control practices are essential in order to prevent future water quality deterioration related to new construction activities. The Wake County Erosion and Sediment Control Program should review its current tools and their implementation to determine how erosion and sedimentation control efforts can be improved in this watershed.

4. The Neuse River basin riparian buffer and stormwater rules and the new Phase II stormwater requirements must be fully and effectively implemented to prevent channel erosion due to future hydrologic changes in the watershed.

5. Effective development planning and stormwater management should be implemented throughout the watershed, including those areas not covered by the Neuse River basin stormwater rule or the Phase II stormwater requirements. Wake County and municipal governments should enhance current stormwater protection efforts to ensure that post-construction stormwater runoff is managed to reduce the risk of channel erosion.

6. Localized areas of bank erosion between Browns Lake and Ligon Mill Road should be stabilized using bioengineering techniques.

7. Riparian areas in the Saint Andrews, Saint Andrews Plantation and Carriage Run subdivisions should be replanted with native woody vegetation where it has been removed.

8. A watershed education program should be developed and implemented with the goal of targeting homeowners in order to reduce current stream damage and prevent future degradation. This could be implemented in conjunction with existing or pending educational programs (e.g., Neuse River basin programs or Phase II efforts). At a minimum the program should include elements to address the following issues throughout the watershed:
   a) redirecting downspouts to pervious areas rather than routing these flows to driveways or gutters;
   b) protecting existing wooded riparian areas on ephemeral streams;
c) replanting native riparian vegetation on perennial, intermittent and ephemeral channels where such vegetation is absent; and

d) reducing and properly managing pesticide and fertilizer use.
Section 9
References Cited


