Executive Summary

Assessment Report: Biological Impairment in the Little Creek Watershed

Cape Fear River Basin
Orange County, N.C.

June 2003

North Carolina Department of Environment and Natural Resources
Division of Water Quality
Planning Branch

Prepared for the Clean Water Management Trust Fund

Introduction

This report presents the results of the Little Creek water quality assessment, conducted by the North Carolina Division of Water Quality (DWQ) with financing from the Clean Water Management Trust Fund (CWMTF). Little Creek and its tributaries Bolin and Booker Creeks have been considered impaired by the DWQ because they are unable to sustain an acceptable community of aquatic organisms, indicating that these streams do not fully support their designated uses. The goal of the assessment is to provide the foundation for future water quality restoration activities in the Little 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

Located in Orange and Durham Counties, Little Creek flows into the New Hope arm of B. Everett Jordan Lake, draining a 24.6-square mile area in subbasin 03-06-06 of the Cape Fear River basin (see Figure 1.1). The 19.9-square mile area studied as part of the current investigation consists of Little Creek and its tributaries upstream of Pinehurst Drive in Chapel Hill. Approximately 12.5 square miles (63 percent) of the study area is located in the Town of Chapel Hill and 1.9 square miles (10 percent) in the Town of Carrboro.

Two major tributaries, Booker Creek and Bolin Creek, drain the majority of the study area. Little Creek forms at the confluence of these streams, near the downstream terminus of the study area. The watershed includes extensive areas of residential and commercial development, as well as a portion of the campus of the University of North Carolina at Chapel Hill (UNC). As of 1999, impervious areas such as roads and buildings covered approximately 15 percent of the study area. Most undeveloped land lies in the upper portion of the Bolin Creek watershed.

The upper three quarters of the study area lies in the Carolina Slate Belt, and streams here exhibit the narrow valleys and rocky substrates associated with this geologic zone. Little Creek and the downstream reaches of Booker and Bolin Creek are located in a Triassic basin and exhibit its characteristic broad floodplains and sandy substrates. Visual assessment suggests that most streams downstream of East Franklin Street were channelized (straightened and dredged) in the past. An OWASA (Orange Water and Sewer Authority) sewer easement follows Booker, Bolin and Little Creeks for much of their length. The study area is described in more detail in Section 2.

Bolin Creek is classified as C NSW (nutrient sensitive waters) upstream of East Franklin Street (US 15-501 Business), and WS-IV NSW from East Franklin Street to Little Creek. Booker Creek and its tributaries are classified as B NSW upstream of the Eastwood Lake dam, C NSW from Eastwood Lake to East Franklin Street, and WS-IV NSW from East Franklin Street to Little Creek. Little Creek within the study area is classified as WS-IV-NSW. North Carolina's 303(d) list records the following portions of these streams as impaired: Bolin Creek from US 15-501 Business to Little Creek; Booker Creek for its entire length; and Little Creek for its entire length, including those portions of the Creek below the study area.

Approach

A wide range of data was collected to evaluate potential causes and sources of impairment. Data collection activities included: benthic macroinvertebrate sampling; fish sampling (Bolin Creek only); assessment of stream habitat, morphology, and riparian zone condition; water quality sampling to evaluate stream chemistry and toxicity; sediment sampling; characterization of watershed land use, conditions and pollution sources. Data collected by the Towns of Carrboro and Chapel Hill were also available. Precipitation levels were below normal in 2001 and the first half of 2002, when most field work for the study was conducted, limiting opportunities for storm sampling. Data collected during the study are presented in Sections 2, 4, 5 and 6 of the report.

Conclusions

Based on historical information and data collected during the study, the extent of biological impairment in the study area can be summarized as follows (see Sections 4 and 7):

- Little Creek remains impaired for its entire length in the study area, a condition that has been evident since the stream was first sampled by DWQ in 1993.
- When Bolin Creek was first sampled at East Franklin Street in 1986, the benthic community was reasonably diverse, and the stream, though showing indications of impact, was not considered impaired. Impairment was evident when the stream was next sampled in 1993 and has persisted at this downstream site. Upstream sites supported a reasonably intact benthic fauna until 2000, when impairment became evident as far upstream as Waterside Drive in Carrboro, located between Homestead Road and Estes Drive Extension. It is probably too soon to evaluate whether this decline in the benthic community is persistent, or was due to a specific perturbation from which this portion of the stream will yet recover. Currently, only the upper portion of Bolin Creek (Homestead Road) appears to support an adequate benthic fauna. Fish communities in Bolin Creek are not impaired.
- Booker Creek is impaired for its entire length, although the stream is generally too small (<4 meters in width) to receive a formal rating. The portion of Booker Creek above Eastwood Lake is likely impacted by naturally low summer streamflows in addition to human-induced problems.

Aquatic organisms in Little Creek and its tributaries are heavily impacted by multiple stressors associated with the high levels of development in the watershed. Multiple stressors are characteristic of most developed watersheds, although sometimes a single stressor can be identified as being of primary importance in causing impairment. In this watershed, however, the relative contribution of these stressors could not generally be clearly differentiated based on the available data. Major causes and sources of impairment are as follows (see Section 7):

- Habitat degradation manifested in sedimentation and a lack of organic microhabitat (leaf packs, sticks, root mats and other natural organic material) can be considered a cause of impairment in Little Creek and in Bolin and Booker Creeks below East Franklin Street. It is probably not a primary limiting factor for benthos further upstream, where the available habitat should be able to support more diverse benthic communities than are currently present. The portion of Bolin Creek between Bolinwood Drive and East Franklin Street is transitional in terms of habitat quality, with sediment deposition and bank instability increasing toward East Franklin Street.

- Excessive substrate and stream bank scouring occurs due to the increased storm runoff volumes and velocities associated with the high levels of development in much of the watershed. This contributes to impairment of the macroinvertebrate community both by degrading habitat (through the flushing of organic material and contribution to stream bank erosion) and by dislodging organisms.
- The removal of riparian vegetation and, in the area below East Franklin Street, past channel modification also contribute to habitat degradation.
- Biological data and bioassay results indicate that toxicity is a likely contributor to impairment in much of the watershed, especially at the lower end of the study area and in Crow Branch. The specific pollutants responsible for this toxicity cannot be identified from the available data and may be variable.
- Sources of toxic pollutants in the lower part of the study area include runoff from the developed portions of the watershed and inputs from specific events (e.g., spills and underground storage tank leaks). The specific pollutants causing toxic conditions in Crow Branch have not been clearly identified, but elevated conductivity levels have been measured in the creek at the two inactive UNC hazardous waste sites, and these facilities are the most plausible source of the problem.
- The causes of impairment in the portion of Bolin Creek between Airport Road and Waterside Drive are less clear than in the downstream section of Bolin Creek. In-stream habitat is adequate. Some effects of toxicity and scour are likely, although these impacts appear less pronounced than in lower Bolin Creek, and likely decline significantly at the upstream end of this section.
- Low flow conditions during the summer of 2002, and resultant low dissolved oxygen (DO) levels, were extremely stressful to biota. While low DO concentrations occur periodically in more typical years, biological community data provide little evidence that these conditions, though a concern, are normally severe enough to be considered a cause of impairment. Ongoing DO impacts appear most likely in lower Booker Creek and in Little Creek.
- The underlying Carolina Slate Belt geology in the drainage of upper Booker Creek and its tributaries supplies little baseflow during the summer, limiting biological potential in this portion of the watershed.
- The lack of summer outflows from Eastwood Lake contributes to impairment in lower Booker Creek by exacerbating summer low flow conditions associated with the underlying geology and the urban nature of the drainage area. The dam also limits downstream macroinvertebrate recolonization.
- Future development is likely to result in further habitat degradation if post-construction stormwater volumes are not effectively controlled.

Recommendations

The recommendations summarized below address specific causes of impairment. These factors have a joint impact on stream conditions, however, and many management activities have multiple impacts as well. Remedial actions are likely to be most cost-effective if implemented in a coordinated fashion based upon a restoration plan developed by local governments and other stakeholders.

The following actions are necessary to address current sources of impairment in the Little Creek watershed and prevent future degradation. Recommendations are discussed in more detail in Section 8. The intent of these recommendations is to describe the types of actions necessary to

improve conditions in the study area, not to specify particular administrative or institutional mechanisms for implementing remedial practices.

These actions are most likely to be undertaken effectively if a reliable long-term source of funding is available. Possible sources include grants, stormwater utility fees, or other local government financing mechanisms. The Town of Chapel Hill is currently developing a stormwater utility that will include program elements to address water quality and quantity with a comprehensive stormwater and floodplain management program.

Actions one through five are all essential to the restoration of aquatic communities in the watershed. Action six is essential to the prevention of stormwater impacts from future development. The additional recommended actions will result in limited improvement unless these are accomplished.

1. **Feasible and cost-effective stormwater retrofit projects should be implemented to mitigate the hydrologic effects of existing development** (increased stormwater volumes and increased frequency and duration of erosive and scouring flows). This should be viewed as a long-term process. Although there are many uncertainties, costs of at least $1 million per square mile can probably be anticipated.
   a) Over the short-term, currently feasible retrofit projects should be identified and implemented. The most densely developed areas should be given priority for the evaluation of retrofit opportunities. These areas include: the central business district of Chapel Hill; portions of downtown Carrboro and the UNC campus; and the broad commercial area that includes University Mall and Eastgate Shopping Center.
   b) In the longer term, additional retrofit opportunities should be sought out in conjunction with infrastructure improvements and redevelopment of existing developed areas.
   c) The most densely developed areas should be given priority for the evaluation of retrofit opportunities.
2. **A strategy to address toxic inputs should be developed and implemented, including a variety of source reduction and stormwater treatment methods**. As an initial framework for planning toxicity reduction efforts, the following general approach is proposed:
   a) Development and implementation of a broad set of source reduction activities focused on: reducing nonstorm inputs of toxicants; reducing pollutants available for washoff during storms; and managing water to reduce storm runoff. Suggestions for potential source reduction practices are provided in Section 8.
   b) Implementation of stormwater treatment BMPs, aimed primarily at pollutant removal, at appropriate locations.
   c) Development of a stormwater and dry weather sampling strategy in order to facilitate the targeting of pollutant removal and source reduction practices.
   d) Implementation of available BMP opportunities for control of stormwater volume and velocities. Recommended above to improve aquatic habitat potential, these BMPs can also remove toxicants from the stormwater system. Suggestions for potential source reduction practices are provided.
3. **Appropriate remediation should be undertaken at the two UNC hazardous waste disposal sites to address toxicity in Crow Branch. Additional investigation may be necessary to determine the most likely toxicants involved**.
4. **Stream channel restoration activities should be implemented in the lower portion of the study area, in conjunction with stormwater retrofit BMPs, in order to improve aquatic**

habitat. Priority areas include: the entire mainstem of Little Creek within the study area; Bolin Creek below East Franklin Street; Booker Creek below Old Oxford Road; and the 500-foot reach of Booker Creek below the Lake Ellen spillway (a total channel length of approximately 3.2 miles). Smaller sections of upstream channel may also benefit from restoration.

5. **OWASA and the Towns of Chapel Hill and Carrboro should cooperate in improving the condition of riparian vegetation along sanitary sewer rights of way and greenways. Future riparian area disturbance should be limited to the minimum extent necessary to maintain infrastructure.** More generally, property owners should be encouraged to re-establish native woody riparian vegetation along streams where it has been removed, and to limit future disturbance.
6. **Prevention of further channel erosion and habitat degradation will require effective post-construction stormwater management for all new development in the study area**. Channels in this watershed are most likely to be protected from the hydrologic impacts of new development if post-construction stormwater requirements include:
   a) Active promotion of infiltration practices, low impact development (LID) practices and other approaches to limit stormwater volume.
   b) Extended detention of the 1-year or 2-year 24-hour storm or alternative criteria to address geomorphically relevant flows.
   c) A threshold for the use of stormwater controls that is no higher than 10 percent built-upon area. To prevent existing unstable conditions from deteriorating further, post-construction stormwater control requirements should be applied to all but the lowest density development.
7. Activities recommended to address organic loading include the identification and elimination of illicit discharges (required under the Phase II stormwater program); education of homeowners, commercial applicators, and others regarding proper fertilizer use; street sweeping; catch basin clean-out practices; and the installation of additional BMPs targeting biochemical oxygen demand (BOD) and nutrient removal at appropriate sites.
8. Improved efforts by OWASA to prevent sewer overflows and address leaking sewer lines will be critical to reducing nutrient inputs and potential ammonia toxicity from these sources.
9. The technical, economic and regulatory feasibility of implementing minimum releases from Eastwood Lake should be explored.
10. Effective enforcement of sediment and erosion control regulations on the part of Orange County and the NC Division of Land Resources will be essential to the prevention of additional sediment inputs from construction activities. Increased attention to the phasing of construction activities and to the rapid establishment of stabilizing vegetation is also important.

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8. Improved efforts by OWASA to prevent sewer overflows and address leaking sewer lines will be critical to reducing nutrient inputs and potential ammonia toxicity from these sources.
9. The technical, economic and regulatory feasibility of implementing minimum releases from Eastwood Lake should be explored.
10. Effective enforcement of sediment and erosion control regulations on the part of Orange County and the NC Division of Land Resources will be essential to the prevention of additional sediment inputs from construction activities. Increased attention to the phasing of construction activities and to the rapid establishment of stabilizing vegetation is also important.

Section 1
Introduction

This report presents the results of the Little Creek water quality assessment, conducted by the North Carolina Division of Water Quality (NCDWQ) with financing from the Clean Water Management Trust Fund (CWMTF). Little Creek and several of its tributaries are considered impaired by the DWQ because they are 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

Little Creek drains a 24.6-square mile area in subbasin 03-06-06 of the Cape Fear River basin (Figure 1.1). Little Creek begins at the confluence of its major tributaries, Booker Creek and Bolin Creek (approximately one-half mile downstream of US 15-501 Bypass in Chapel Hill), and flows in a southwesterly direction for approximately 6.1 miles before emptying into B. Everett Jordan Lake. The 19.9-square mile area studied as part of the current investigation consists of Little Creek and its tributaries upstream of Pinehurst Drive in Chapel Hill. The entire study area is located within Orange County, with the exception of a few acres in the easternmost portion of the area which are located in Durham County. Approximately 12.5 square miles (63 percent) of the study area are located in the Town of Chapel Hill, 1.9 square miles (10 percent) in the Town of Carrboro, and the remaining 5.5 square miles (27.6 percent) in unincorporated areas of Orange County.

1.2 Study Purpose

The Little 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 pollutant inputs).
2. Identifying the major watershed activities and *sources* of pollution contributing to those causes (such as stream bank erosion or stormwater runoff).
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 Little Creek watershed, such as bacterial contamination or flooding, the report discusses those concerns where existing information allows.

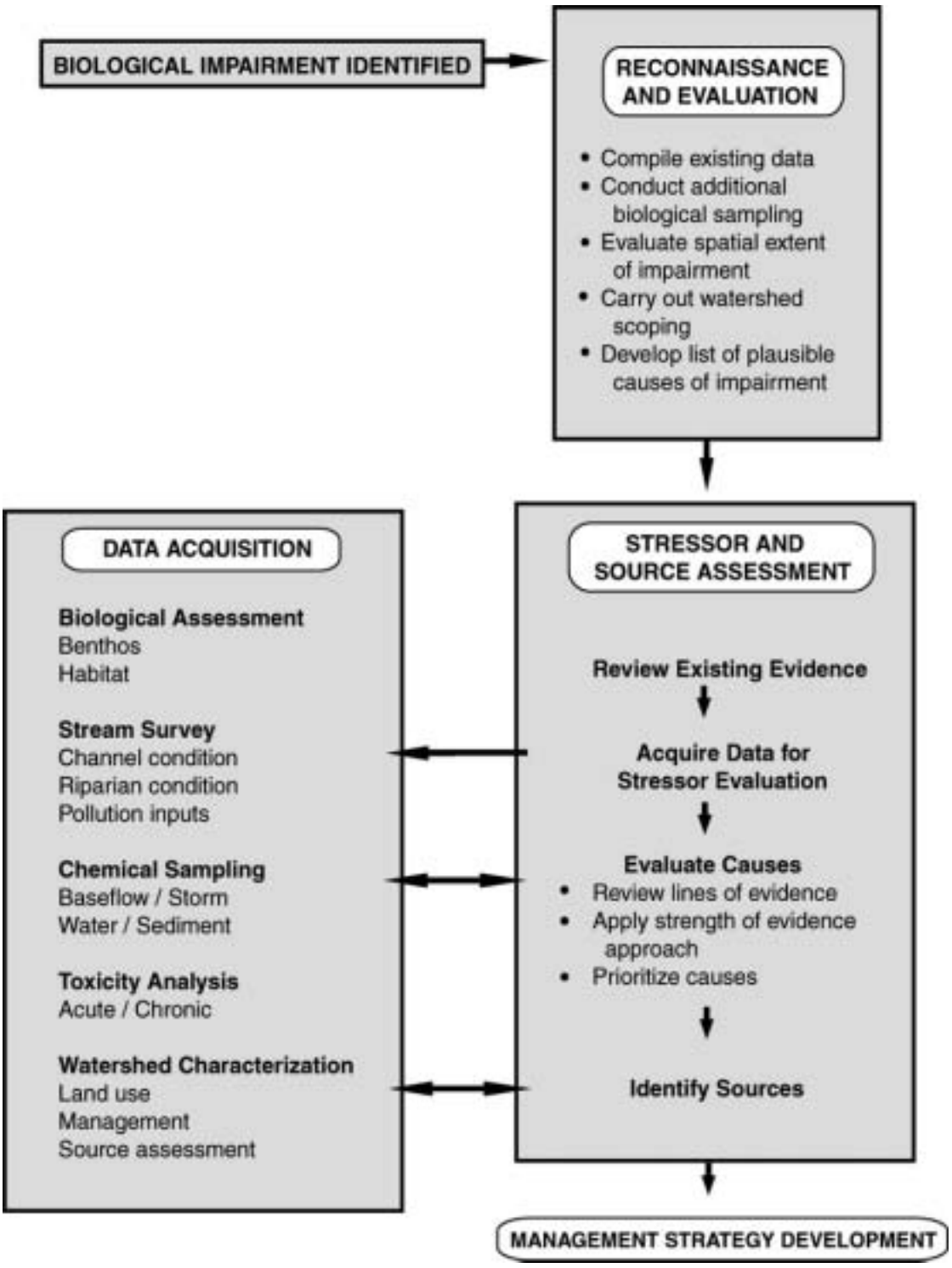
Table 1.1 Study Areas Included in the Watershed Assessment and Restoration Project

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

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, this study has taken a more detailed approach 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



☞ **Background Note: Identifying Causes of Impairment**

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 significantly interfere 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 insects 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, pp. 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.

For further information on use support and stream impairment issues, see the website of DWQ's Basinwide Planning Program at http://h2o.enr.state.nc.us/basinwide/; A *Citizen's Guide to Water Quality Management in North Carolina* (NCDWQ, 2000); EPA's *Stressor Identification Guidance Document* (USEPA, 2000).

1.3.1 Study Approach

The general conceptual approach used to determine causes of impairment in Little 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 data* bearing on the nature and impacts of those potential causes.
- *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. To address all three objectives, activities conducted in the Little 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 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.

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 Little Creek on the road to improvement. It is DWQ's hope that local governments and other stakeholders in the Little Creek watershed will work cooperatively with each other and with state agencies to implement these measures in cost-effective ways.

Developing TMDLs (total maximum daily loads) or establishing pollutant loading targets is beyond the scope of this study. 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 cause 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 and fish 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.
4. Chemical sampling of stream water quality.
5. Bioassays to assess water column toxicity.
6. Chemical sampling and bioassays of stream sediment.
7. Watershed characterization--evaluation of watershed hydrologic conditions, land use, land management activities, and potential pollution sources.

Section 2
Description of the Little Creek Watershed

2.1 Introduction

The study area (Figure 2.1) consists of Little Creek and its tributaries upstream of Pinehurst Drive in Chapel Hill, and comprises 19.9 square miles of the 24.6-square mile watershed. Little Creek proper begins near the bottom of the study area and drains less than 1.5 square miles above Pinehurst Drive. The major tributaries of Little Creek, Bolin Creek (12.0 square miles) and Booker Creek (6.5 square miles), drain the majority of the study area.

Over seven-tenths of the study area lies within the limits of the Towns of Chapel Hill (2001 population, 51,598) and Carrboro (2000 population, 16,782). Of the 5.5 square miles within unincorporated areas of Orange County, all but 0.45 square miles lie within the zoning jurisdiction of Chapel Hill and Carrboro.

Most field work for the study was conducted in 2001 and 2002. This section summarizes watershed hydrography and topography, describes current and historical land use, and discusses potential pollutant sources.

2.2 Streams

Bolin Creek

The headwaters of Bolin Creek are located northwest of the intersection of Homestead Road (SR 1777) and Old NC 86 (SR 1109), north of Carrboro. Bolin Creek is joined by the following named tributaries, in order from upstream to downstream: Jones Creek, Jolly Branch, Tanbark Branch, and Battle Branch. Bolin Creek is dammed several times in its headwaters, most notably to form Lake Hogan, a 12-acre impoundment located just downstream of Old NC 86. Bolin Creek begins in a fairly undeveloped area and drains progressively more urban and developed areas in Carrboro and Chapel Hill as it flows towards its confluence with Booker Creek.

Bolin Creek is approximately eleven miles long, mostly located within the planning jurisdiction of Carrboro. The 12-square mile watershed includes about half of Carrboro's downtown commercial district, the majority of Chapel Hill's central business district and approximately 146 acres of the University of North Carolina at Chapel Hill (UNC) campus (primarily draining to Battle Branch). The stream also drains a variety of residential areas in Chapel Hill and Carrboro, and the dense commercial district along Estes Drive near University Mall.

An OWASA (Orange Water and Sewer Authority) sanitary sewer easement parallels the Creek for much of its length, and a paved greenway path maintained by the Town of Chapel Hill follows the creek between Airport Road and the Chapel Hill Community Center, a distance of approximately two miles.

Bolin Creek is classified as C NSW above East Franklin St. (US 15-501 Business), and WS-IV NSW from East Franklin Street to Little Creek. North Carolina's 303(d) list records Bolin Creek

as impaired from US 15-501 Business to Little Creek. Sediment is listed as the historical cause of impairment, with urban runoff and storm sewers listed as potential sources.

Booker Creek

The headwaters of Booker Creek rise southwest of the intersection of Airport Road (NC 86) and Weaver Dairy Road in Chapel Hill. Booker Creek is joined by two named tributaries: Cedar Fork and Crow Branch. The mainstem of Booker Creek has been dammed to create Lake Ellen (surface area of seven acres, built in 1961) and, further downstream, Eastwood Lake. Built in 1937, Eastwood Lake has a normal pool surface area of approximately 47 acres and drains a 2835-acre watershed.

Unlike Bolin Creek, which drains progressively more developed areas as it flows downstream, the Booker Creek watershed is largely developed throughout, except for the Crow Branch drainage and a portion of the headwaters which is currently under development. Aside from the Timberlyne Shopping Center area along Weaver Dairy Road, development is primarily residential upstream of East Franklin Street. Almost all of the subwatershed lies within the Chapel Hill town limits.

An OWASA (Orange Water and Sewer Authority) sewer easement follows Booker Creek for much of its length, and a paved greenway path maintained by the Town of Chapel Hill follows the Creek from below Eastwood Lake to Eastgate Shopping Center.

Booker Creek and its tributaries are classified as B NSW upstream of the Eastwood Lake dam, C NSW from Eastwood Lake to US 15-501 Business, and WS-IV NSW from US 15-501 Business to Little Creek. North Carolina's 303(d) list records Booker Creek as impaired for its entire length (5.4 miles). The cause of impairment had not been determined prior to the current study. Urban runoff and storm sewers are listed as potential sources.

Little Creek proper

Little Creek drains approximately 1.5 square miles as it flows from its origin at the confluence of Booker and Bolin Creeks to the downstream terminus of the study area at Pinehurst Drive in Chapel Hill. The area drained by Little Creek proper is primarily residential, although it includes a small portion of the Chapel Hill Country Club. The Army Corps of Engineers has a flowage easement extending upstream to 245 feet mean sea level (msl), near the confluence of Bolin and Booker Creeks. The easement is designed to hold floodwaters from B. Everett Jordan Lake.

Little Creek within the study area is classified as WS-IV-NSW. North Carolina's 2000 303(d) List records Little Creek as biologically impaired for its entire length, including those portions of the Creek below the study area. Habitat degradation is listed as the likely cause of impairment, with urban runoff and storm sewers listed as potential sources.

Beaver impoundments are common in Little Creek and in the lower reaches of Booker and Bolin Creeks.

Streamflow and precipitation

In September 1999, Tropical Storm Dennis and Hurricane Floyd brought some of the largest amounts of precipitation and most severe flooding on record. Precipitation at the University of North Carolina at Chapel Hill for the month of September 1999 was 24.0 inches, compared with

a historic average of 3.9 for the month of September (1948-2000 period of record) (Southeast Regional Climate Center at http://cirrus.dnr.state.sc.us). However, drought conditions prevailed during the entire study period. Data from Raleigh-Durham Airport (RDU) indicate precipitation 93 percent of normal in 2000, 82 percent of normal in 2001, and 81 percent of normal during January-August 2002. Monthly data from RDU (Figure 2.2) indicate particularly low rainfall during the spring and early summer of 2002. Precipitation at UNC-CH show a similar pattern (Table 2.1), although data are missing for one or more days in a number of months.

Table 2.3 Study Period Precipitation and Departure from Normal, University of North Carolina (Station 311677)

Year	Precipitation (inches)	% of Normal
Historic average 1948-2000	46.2	–
2000	42.5	92%
2001	37.8	82%
January-August 2002*	21.5	67%

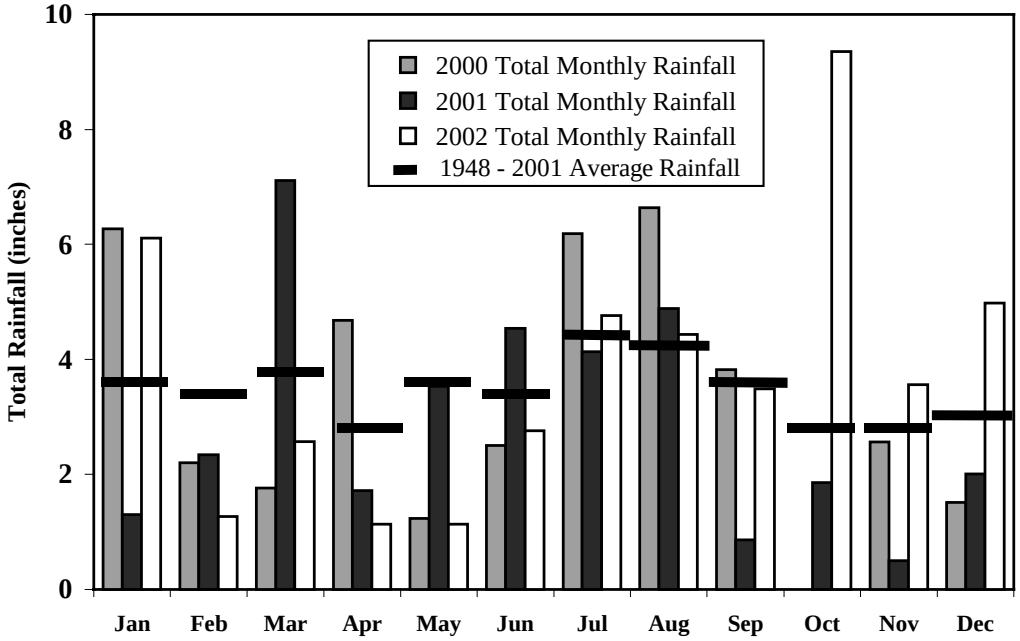
* Compared to 1948-2000 average for January-August of 32.3 inches.

Source: Southeast Regional Climate Center, 2002 (http://water.dnr.state.sc.us/climate).

The only stream gage in the watershed is located on Battle Branch, a small tributary of Bolin Creek. The gage, operated by the USGS in cooperation with the City of Chapel Hill since 1996, drains a 0.42-square mile area. The period of record was not sufficient to provide information on long-term patterns.

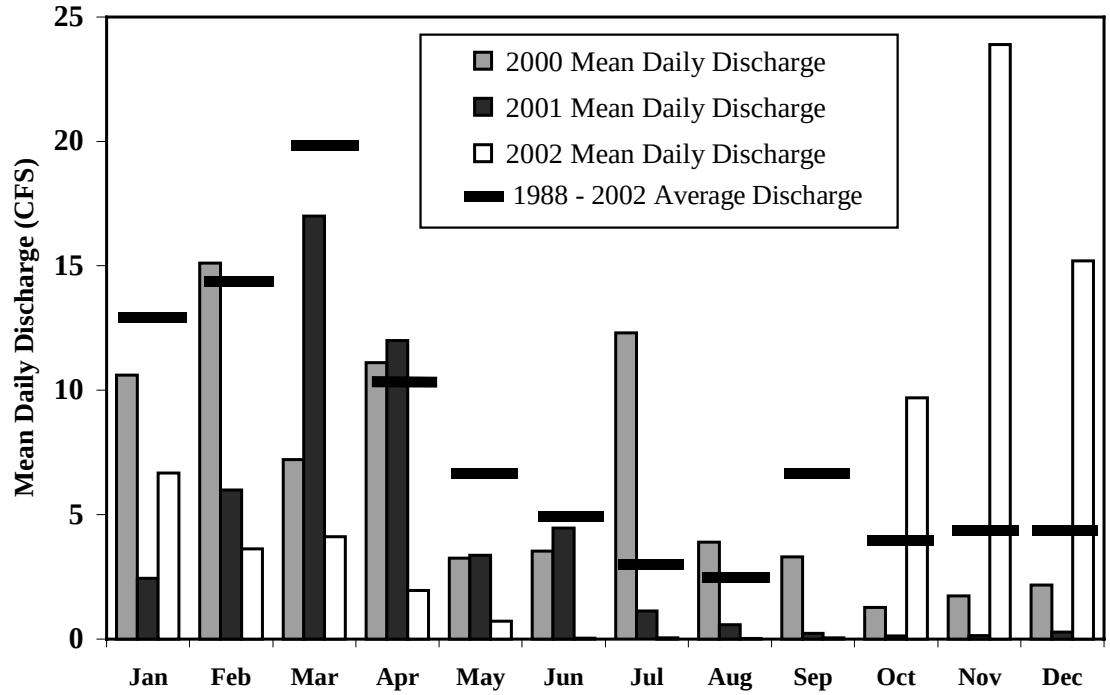
Data from the gage in the adjacent Morgan Creek Watershed (Morgan Creek at NC 54, Station 02097464), with a 14-year period of record, indicate discharge was 81 percent of normal in 2000, 51 percent of normal in 2001, and 71 percent of normal in 2002. This gage has a drainage area of 8.4 square miles and is located in the Carolina Slate Belt. Monthly data (Figure 2.3) show that discharge was below normal for most months during the study period except for the fall of 2002. The effects of the cumulative rainfall deficit were evident during the summer of 2002, when a discharge of zero was recorded for a total of 35 days, the only time zero discharge has been recorded at this gage.

Figure 2.2 Rainfall at Raleigh Durham Airport (Station 317069)



Source: Southeast Regional Climate Center (http://cirrus.dnr.state.sc.us)

Figure 2.3 Stream Discharge in Morgan Creek at NC 54 (Station 02097464)



Source: United States Geological Survey

2.3 Topography and Geology

Topography in the upstream portions of the watershed is typical Piedmont rolling hills dissected by stream drainages. Elevations in the headwaters of Booker Creek and Bolin Creek are 530 and 580 feet above mean sea level (msl), respectively. The steepest slopes are found parallel to drainageways in the upper watershed. Relief is limited from approximately East Franklin Street to the downstream terminus of the study area.

Two geological zones underlie the Little Creek watershed (Figure 2.1). The upper 78 percent of the watershed, including most of the Bolin Creek drainage and more than half of Booker Creek, is underlain by the metavolcanic and metaigneous rock of the Carolina Slate Belt. The area approximately downstream of Franklin Street in the Bolin Creek drainage and downstream of Eastwood Lake in the Booker Creek drainage is underlain by the sedimentary rock of a Triassic basin. Both of these geologies produce relatively low baseflows, with the water yield of the Triassic basin the lowest in the state (Giese and Mason, 1991). Slate belt streams tend to have relatively narrow valleys and coarse (rocky) substrate, while Triassic basin streams have broad floodplains and a characteristic sandy substrate (Exhibits 2.1 and 2.2).

Soils in the Carolina Slate Belt are diverse, with many belonging to either the Georgeville-Herndon-Tatum association, the Appling-Helena association, or the Iredell-Enon association (Dunn, 1977). Triassic basin soils, often of the White Store-Creedmoor association, are sandier and less cohesive.

Exhibit 2.1 Carolina Slate Belt substrate and channel, upper study area

Exhibit 2.2 Triassic basin substrate and channel, lower study area

2.4 Land Cover in the Watershed

Recent land cover estimates for the Little Creek watershed (Table 2.2 and Figure 2.4), derived from July 1999 Landsat Enhanced Thematic Mapper Imagery by Maunz (2002), indicate that the study area is approximately 47 percent developed, while 39 percent remains in forest and 13 percent is grass and fields. Developed areas account for more of the land cover in the Booker Creek watershed (57 percent) than in the Bolin Creek drainage (39 percent), while developed areas cover 69 percent of the portion of the study area draining to Little Creek proper.

Table 2.2 Land Cover Distribution and Impervious area in the Little Creek Study Area, 1999

Land Cover Category	Entire Study Area (19.94 square miles)	Bolin Creek (11.98 square miles)	Booker Creek (6.49 square miles)	Little Creek Source to Pinehurst Dr. (1.47 square miles)
	%	%	%	%
Forest	38.78	43.87	33.38	21.12
Grass/fields	12.33	15.45	7.73	7.18
High Density Developed	12.70	10.81	16.85	9.69
Low Density Developed	34.47	28.57	39.78	59.12
Water	0.47	0.16	1.06	0.42
Wetlands	1.26	1.20	1.20	2.47
Total	**100.00**	**100.00**	**100.00**	**100.00**
Percent Impervious Area	**15%**	**14%**	**17%**	**19%**

Source: Land Cover from 1999 Landsat Enhanced Thematic Mapper Imagery; see Maunz (2002) and Geraci (2002) for description of data set and methodology. Imperviousness estimated by Tetra Tech, Inc. from 1998-99 data (see text).

Impervious areas (areas such as rooftops, roads and parking lots that prevent infiltration of precipitation into the soil) cover an estimated 15 percent of the study area as a whole, 14 percent of the Bolin Creek subwatershed, and 17 percent of the Booker Creek catchment (Table 2.2). Imperviousness is higher in the densely developed lower portion of the study area (26 percent in the portion of Booker Creek below Eastwood Lake, and approximately 25 percent in the Bolin Creek watershed downstream of Estes Drive Extension). These estimates were developed by Tetra Tech, Inc. for the NC Wetlands Restoration Program, using data on building and driveway footprints, roadway areas and other impervious surfaces provided by local governments in the study area. The local government data were derived from 1998-99 aerial photography. Though these data sources did not include information for all types of impervious areas (e.g., driveways in rural areas were excluded), the estimated percentages provide a reasonable approximation of the general extent of impervious coverage at the time of the aerial photography.

Research indicates that stream ecosystems begin to show evidence of degradation when the total impervious area in a watershed reaches approximately 10 percent. Ecological effects can generally be expected to become severe when total impervious area reaches about 25 percent

(Arnold and Gibbons, 1996; Booth and Jackson, 1994; Schueler, 1994). Effects associated with increased impervious area include: increased stream temperature; increased stormwater volume and flooding; declines in infiltration and baseflow; increased bank erosion and habitat degradation; and increased pollutant loading (Lopez-Collado and Doley, 1997).

Though some large forested tracts exist in the upper Bolin Creek drainage, most of the watershed has been zoned for residential development. Substantial commercial areas exist in the study area, including: portions of downtown Carrboro; most of the central business district of Chapel Hill; University Mall; Eastgate Shopping Center and surrounding development in the East Franklin Street-Fordham Blvd. corridor; Timberlyne Shopping Center and adjacent commercial activity along Weaver Dairy Road. A portion of the UNC-CH campus also drains to Bolin Creek. While agricultural uses were once widespread in the study area, they are now extremely limited. A small number of livestock are pastured in the upper Bolin Creek drainage, near Old Highway 86.

Protected natural areas in the watershed are few and include two Triangle Land Conservancy properties: the Lloyd-Andrews Historic Farmstead, a 121-acre farm on upper Bolin Creek protected by a conservation easement; and the Timberlyne property, a six-acre tract near Booker Creek. A small portion of the Blackwood Division of Duke University Forest extends into the Bolin Creek watershed on its northern border, near Eubanks and Rogers Roads.

2.5 Historic Issues

Historic issues of note in the study area include changes in land use and stream channelization. While data are not available to evaluate land cover and land changes in the watershed quantitatively, it is clear from aerial photography that land use and cover have changed significantly over the past half century. Orange County has a long agricultural heritage. Until the mid 20th Century, development in southern Orange County was largely confined to the core areas of Carrboro and Chapel Hill. Agriculture was a major activity in the watershed, and large areas were in pasture and row crops. As was the case throughout the southern Piedmont, extensive land clearing and poor soil conservation practices created long lasting impacts on soils and alluvial systems (see Background Note: "Landscape History and Channel Alteration in the Piedmont Region"). Unlike many areas in the Piedmont, cultivated acreage in Orange County did not begin to decline significantly until the mid-1940s. By the early 1950s, these changes were visible in the landscape. A North Carolina geography book published at that time described conditions in Orange County as follows: "After 200 years of cultivation, large portions of the acreage have been abandoned to grow up in pine and hardwoods, and this wooded wasteland is a conspicuous along most of the main highways" (Sharpe, 1954). Agriculture in the county has continued its decline, with farmland decreasing from 187,000 acres in 1957 to 67,000 in 1997.

In recent decades, both existing agricultural and reforested areas have been cleared to accommodate increasing population and development. For example, development of the large commercial area including University Mall and Eastgate Shopping Center began in the 1950s on the site of the Conner dairy farm. Development of the farm property began in 1952-53 when the first segment of US 15-501 Bypass cut through the farm. In the later 1950s, the Ridgefield Park and Briarcliff subdivisions were built on the former farm on opposite sides of the bypass. Eastgate Shopping Center opened in 1960 and University Mall in 1974 (Eyre, 2002).

The last significant agricultural activity in the watershed was the Hogan Farms dairy, in the upper Bolin Creek watershed, which operated into the 1990s. The former farm site is being converted to a large residential subdivision.

Development in many of the most densely developed portions of the watershed pre-dated both stormwater management and riparian buffer requirements. As a result, streams in these areas are sometimes bordered by high density land use and are consequently subject to direct pollutant inputs.

Visual assessment suggests that much of Little Creek as well as those portions of Bolin Creek and Booker Creek downstream of East Franklin Street were channelized at some point (Exhibit 2.3). Channelization, which involves straightening, deepening and widening the stream, was a fairly common practice in the Piedmont. In agricultural settings, channelization was used to drain flat bottomlands for the benefit of agriculture. In urban settings, the motivation for channelization was primarily to allow for straight rights-of-way for streets, railroads, and sewer and water lines. In 1996, the Chapel Hill Parks and Recreation Department modified the reach of Bolin Creek just upstream of East Franklin Street to install a retaining wall along the greenway.

Exhibit 2.3 Straight, uniform channel characteristic of channelized reaches, lower Bolin Creek

2.6 Sources of Pollution

2.6.1 Permitted Discharges

The study area contains no permitted NPDES (National Pollution Discharge Elimination System) wastewater dischargers other than seven single family residences, located primarily in the upper Bolin Creek watershed (Figure 2.5). Discharge of treated wastewater from on-site single family systems is sometimes used in areas where traditional septic systems cannot be installed due to

low soil permeability. These systems function by piping household wastewater through on-site subsurface sand filters prior to discharge to surface waters. Depending on the age of the system, wastewater may also be chlorinated before discharging to the stream. Single family residence systems in Orange County are inspected every three years. Two of the seven systems in the study area were cited by the county for violations during 2000-2002, and the violations reported to DWQ. As of April 2003, the problems had not yet been corrected.

The University of North Carolina-Chapel Hill Hazardous Waste Materials Facility (HWMF) is currently the only facility in the study area required to operate under an NPDES stormwater permit (NCS000201). A review of records from this facility indicated no record of violations. The HWMF consolidates hazardous materials from the UNC-CH campus and provides up to one year of on-site storage. It is located on Estes Drive Extension and discharges stormwater to an unnamed tributary of Bolin Creek (Figure 2.5). The facility was first permitted in August 1994 and is required to perform monitoring for selected parameters during representative storm events. A review of DWQ records indicated no permit violations.

2.6.2 Nonpoint Sources

The full range of urban activities and pollution sources are of potential concern in the study area. These include: roads, parking lots, rooftops, lawns, industrial areas, hazardous material sites, landfills, residential and commercial areas, construction sites etc. Pollutants which have been associated with these activities include oils, antifreeze, pesticides, nutrients, heavy metals, volatile and semi-volatile organic compounds, solvents (e.g., Bales et al., 1999; Burton and Pitt, 2001). Potential sources of pollution in the study area are discussed below.

a. New Construction

During the period of the project, major residential construction projects were ongoing in the upper Bolin Creek drainage (e.g., Hogan Farms development) and in the headwaters of Booker Creek, upstream of Homestead Park. More scattered construction occurred elsewhere in the study area. A review of January 2000 through December 2002 records at the Orange County Planning and Inspection Department Erosion Control Division indicated that a total of four Notices of Violations (NOVs) were issued during that period. A number of these involved sediment that had moved beyond the construction site, although the extent to which sediment from these locations reached streams has not been documented.

While Orange County has a proactive program, sediment can still reach streams prior to site inspection and during the period allotted for correcting violations. In addition, although erosion and sediment control measures, where appropriately constructed and maintained, can significantly reduce the amount of sediment that would otherwise reach nearby streams, these measures do not necessarily mitigate all impacts, particularly in the context of extensive and long-term land disturbance.

Several recent construction projects that were completed prior to the study period merit mention as well. During the mid to late 1990s, ongoing construction in the portion of the Booker Creek watershed upstream of Airport Road transformed the relatively undeveloped headwaters of this stream into a densely developed area. Projects occurring during this period included several new

subdivisions, a church, a Chapel Hill town park (Homestead Park), and the widening of Airport Road. Elsewhere in the Booker Creek drainage, East Chapel Hill High School was constructed during this same period. Staff in the Chapel Hill Planning, Parks and Recreation, and Engineering Departments, the Orange County Erosion Control Division and the North Carolina Division of Land Quality report increases in in-stream sediment, particularly in the upper reaches of Booker Creek, during this period. Homeowners near Lake Ellen have attributed changes in the lake (e.g., a shift from open water to wetland in the downstream portion of the lake and the development of a delta at the upstream end) to sediment from land disturbance during this period. Likewise, many homeowners near Eastwood Lake have attributed increased siltation in that impoundment to this construction activity. Although sediment inputs are now much reduced, impacts at the time may have been considerable, and some of this sediment is likely still within the channel system.

b. Existing Developed Areas

Residential development. Extensive residential development occurs widely in the study area. Many of these areas use traditional curb and gutter drainage, and stormwater BMPs are largely absent (Exhibit 2.4). Activities and pollution sources in residential areas that can potentially contribute to water quality degradation are diverse and include: direct modification of stream channels and riparian vegetation (especially along small tributaries); use of lawn and garden fertilizers; pesticides used in turf and pest management; pet waste; vehicle washing and maintenance; pollutants from building materials (e.g., roofs and siding) and roadways.

Commercial, institutional and industrial development. Commercial, institutional and industrial activity in the watershed is considerable (see Figure 2.6 and Section 2.4). The 2001 North Carolina Manufacturer's Register lists 28 manufacturing sites within the study area. The range of products and services listed for these facilities includes: engraving, coffee roasting, printing, book typesetting and binding, rescue equipment, wooden picture frames, furniture, jewelry, industrial robot and automated product testing equipment, low vision aids, commercial signs, laboratory glassware and equipment manufacturing (North Carolina Manufacturer's Register, 2001).

The majority of this development predates recent stormwater management requirements and lacks adequate water quality and quantity controls. BMPs have recently been installed in several existing commercial areas (e.g., an infiltration area behind Eastgate Shopping Center and several detention areas adjacent to University Mall) and on the UNC campus.

Roads and parking areas. Roads, driveways and parking lots are an integral part of the urban environment. One recent study (Cappiella and Brown, 2001) found that such "car habitat" accounted for a substantial portion of impervious cover in developed areas. Car habitat exceeded building footprints in all urban land use categories, accounting for between 55 percent and 75 percent of total impervious area. Storm runoff from streets, highways and parking areas has been recognized as an important contributor of metals and organic chemicals to urban streams from sources such as tire and brake pad wear, vehicle exhaust, oil and gas leaks, and pavement wear (Bannerman et al., 1993; Young et al., 1996; Lopes and Dionne, 1998; van Metre et al., 2000; USEPA, 2002).

Exhibit 2.4 New construction in the Parkside subdivision in Booker Creek drainage, upstream of Airport Road

The study area includes the US 15-501 corridor and a variety of other traffic arteries. Traffic on 15-501 Bypass (Fordham Blvd.) south of Estes Drive increased from an average of 20,300 vehicles per day in 1980 to 40,000 in 1997 (Town of Chapel Hill, 2000). Traffic on Airport Road, north of Estes Drive, increased from 13,300 to 26,500 vehicles per day during this same period.

Golf Courses. Portions of the Chapel Hill Country Club drain to Little Creek near the downstream end of the study area, though most of the golf course is located downstream of Pinehurst Drive. Turf management activities such as fertilization and pesticide application are potential sources of chemical inputs to streams, especially after storms, depending upon the management practices used.

c. Sanitary Sewer Leaks and Overflows

The Orange Water and Sewer Authority (OWASA) provides water and sewer services to areas within the Chapel Hill and Carrboro limits. Virtually the entire length of Little Creek within the study area, Booker Creek, Bolin Creek, as well as significant portions of many tributaries are paralleled by sewer right-of-ways. Spills of raw sewage (bypasses) can occur at manholes due to blockages of these sewer lines or to overflows caused by stormwater infiltration or mechanical malfunction. Underground leakage, can also occur, especially in older lines. For the years 2000-2002, eight spills of untreated sewage reaching surface waters were reported to DWQ by OWASA (Table 2.3). Leaks in privately-maintained sewer lines can also occur. Several specific spills during the study period are discussed in subsequent sections.

Table 2.3 Reported OWASA Sewage Spills to Little Creek and Tributaries, January 2000—December 2002

Date	Receiving Stream	Volume (gallons)	Cause
2/07/00	Ditch to Bolin Creek 808 Old Mill Road	500	Sanitary sewer overflow
2/07/00	Bolin Creek Hayes Street Apt. 76	750	Sanitary sewer overflow
6/17/00	Cedar Fork Countryside Pump Station	3,000	Sanitary sewer overflow
6/26/00	Bolin Creek 620 Sugarberry Road	500	Pump station
8/20/00	UT to Booker Creek Velma Road	25	Sanitary sewer bypass
5/09/02	Booker Creek Easement near Piney Mt. Road	5,000	Sanitary sewer bypass
	Bolin Creek Estes Park Apartments	400	Sanitary sewer bypass
8/30/02	Cedar Creek Kingston Drive Easement	100	Sanitary sewer bypass

Source: DWQ Nondischarge Compliance Unit records; Orange Water and Sewer Authority.

* Volume reported is the estimated volume from the time OWASA becomes aware of spill, and may not account for the entire spill volume.

d. Leaking Underground Storage Tanks.

Leaking underground storage tanks (LUSTs) are a potential source of contamination to ground and surface waters. Records at the NC Division of Waste Management (DWM) Underground Storage Tank Section indicate that 114 LUST incidents were reported in the study area between 1987 and 2002. These incidents involved both commercial and non-commercial LUSTs containing gasoline, kerosene, diesel fuel and home heating oil. Forty-six of these sites have been closed or remediated and sixty-eight remain active. DWM staff consider sites rated Intermediate or High Risk to be a potential threat to surface waters. Ten of the sixty-eight active sites in the study area are rated Intermediate or High Risk (see Appendix D for map and additional information). Two LUST sites of particular concern are the Eastgate Amoco Station in the Eastgate Shopping Center (UST# RA-1578/UST Incident # 10045) and the Sunrise Biscuit Kitchen at 1305 East Franklin Street (UST# RA-2841/UST Incident 18629).

Soil and groundwater contamination by petroleum hydrocarbons was discovered at the Eastgate Amoco site in January 1992. Sampling during that year indicated BTEX concentrations (benzene, toluene, ethyl benzene and xylenes) of 0.007 ppm in Booker Creek (EPA Test Method 602). Booker Creek runs through a culvert under the Eastgate Shopping Center, and part of the gas station is located on top of the culvert. An assessment indicated that kerosene, fuel oil and gasoline were leaking from three tanks at the site. The tanks were removed and remediation was performed. Later monitoring indicated that free product was still present at the site, and remediation was reactivated in 1997. The remediation system was destroyed in a flood in 2000,

and no remediation has occurred at the site since that time. Groundwater sampling conducted in 2000 indicated that the benzene, MTBE and other pollutants had spread over an area that included the culverted creek. MTBE in Booker Creek was present at a concentration of 1.19 µg/L.

The Sunrise Biscuit Kitchen is located adjacent to where Bolin Creek crosses East Franklin Street. Contamination was discovered at the site in March 1998, when strong petroleum odors were noticed coming from bore holes dug during construction of the Bolin Creek Greenway. The release area is approximately 100 feet from Bolin Creek. Groundwater sampling in July 1998 revealed concentrations of benzene, ethylbenzene and xylenes exceeding North Carolina's Groundwater Quality Standards. DWM staff indicate that levels of soil and groundwater contamination appear to be moderate, but sufficient investigation has not been completed to confirm this and the site remains a concern due to its proximity to the Creek. In 1999, DWM requested that a Comprehensive Site Assessment be conducted. The report has not been submitted and the responsible party has failed to respond to notices requesting that work be completed. DWM has contacted the consultant in charge of the site to see why the report was never submitted.

e. Inactive Hazardous Waste Sites

Two inactive hazardous waste disposal sites are located on UNC property adjacent to Crow Branch just west of Airport Road (Figure 2.6): the University of North Carolina-Chapel Hill Old Sanitary Landfill Site (OSLS), and the Airport Road Waste Disposal Area (ARWDA). Data have been collected about these facilities for approximately the past 15 years. Much of this material is available online (at **http://townhall.townofchapelhill.org/uncwastereport.htmat**) and will not be reviewed here in detail. Each facility is discussed briefly below.

The University of North Carolina-Chapel Hill Old Sanitary Landfill Site (NCD980557615). The 35-acre OSLS received municipal waste from the Town of Chapel Hill and from UNC-CH, along with waste chemicals generated by university laboratories, during its operation from the late 1950s until about 1975. The OSLS operated prior to passage of the federal Resource Conservation and Recovery Act (RCRA). There were no regulations limiting the type of household or other waste that could be deposited in the landfill.

According to NC Division of Waste Management records, approximately 4,000 to 5,000 pounds of municipal waste were buried at the site each year. Additionally, UNC buried approximately 7,500 cubic feet of waste chemicals. Chemical waste from University laboratories was buried at the bottom of trenches dug for municipal waste disposal with burials occurring on an "as needed" basis in whichever portion of the landfill was currently active. Containers of waste were reported to have been broken during the initial burials and incidents of spontaneous combustion and explosion have been reported at the site.

The OSLS is currently in the Inactive Hazardous Waste Site Program of the North Carolina Division of Waste Management Superfund Section. Various investigations have been conducted beginning about 1990. A Phase II Screening Site Investigation (SSI), which also included the ARWDA, was conducted in 1991 for the North Carolina Department of Environment, Health and Natural Resources. The SSI recommended that the site be moved to the next stage of the remedial process since there was a potential health risk to area residents as a result of

contaminated groundwater and soils. A Phase I Remediation Investigation was conducted at the site by Rust Environment & Infrastructure in 1997, and ongoing monitoring continues.

The University of North Carolina Airport Road Waste Disposal Area (NCD980557623). The 0.2-acre ARWDA was operated by the University between 1973 and 1979 as a disposal area for chemical waste generated at UNC laboratories. The site is reported to contain 20,000 cubic feet of various chemical wastes. Most chemicals were reportedly packaged in breakable containers and buried in 18 trenches at a depth of 8 to 12 feet. In 1985, samples from three groundwater-monitoring wells indicated the presence of chloroform, methyl chloride and benzene. On-site groundwater monitoring conducted between 1984 and 1992 confirmed that groundwater at the site was contaminated with volatile organic compounds (VOCs) and/including elevated concentrations of benzene, chloroform, methylene chloride, as well as manganese and several tentatively identified semi-volatile organic compounds. Monitoring wells located down gradient of the site indicate that contaminants appear to be migrating in the direction of Crow Branch.

Summary of recent data and planned action. Additional groundwater samples in and around the landfill sites have been collected on numerous occasions over the past decade, and water samples in Crow Branch have also been sampled. No attempt will be made here to describe these data, which are documented in a number of reports (e.g., Rust Environment, 1997; Pace Analytical, 2001; Arcadis, 2003). Groundwater wells on the landfill sites, including locations adjacent to Crow Branch, have consistently indicated contamination by a variety of volatile organic compounds (VOCs). The most recent round of groundwater sampling, conducted in October 2002, found a wide variety of organic contaminants, many above groundwater standards (Arcadis, 2003). Landfill leachate samples have shown extremely high conductivity values. Samples collected in 1997 indicated some values in excess of 2000 μS/cm, with values over 1000 common (Rust Environment, 1997). Typical conductivity values in the surrounding area are generally around 100 μS/cm.

Surface water samples conducted in Crow Branch in 1997 for a limited selection of analytes found acetone levels as high as 7 μg/L and chlorobenzene at 2 μg/L (Rust Environment, 1997). EPA has not established aquatic life National Ambient Water Quality Criteria (NAWQC) for these analytes, but observed concentrations were well below Tier II chronic criteria of 1500 μg/L for acetone and 64 μg/L for chlorobenzene (see Appendix B for additional information on Tier II criteria and NAWQC).

Since 1995, the University of North Carolina has collected quarterly surface water samples from Crow Branch. None of the samples collected thus far have indicated elevated concentrations of VOCs.

Surface water sampling conducted by UNC on July 19, 2001 found total dissolved solids (TDS) of 100 mg/L at an upstream site, while median TDS at five sites located downstream adjacent to the landfills was 440 mg/L (Pace Analytical, 2001). Ammonia at the upstream site was measured at 0.37 mg/L, while the median ammonia concentration at five downstream locations was 4.9 mg/L, with levels as high as 8.2 mg/L recorded. No volatile organic compounds (EPA Method 8260) were detected in surface waters at this time.

The University plans to restart negotiations with the North Carolina Department of Environment and Natural Resources (NC DENR) for clean up of the site. Previous negotiations were discontinued in 1997 when the University could not identify a way to fund remediation.

f. Other Sources

KSP Dry Cleaners (NCD981863327-DSCA SITE ID. No. 68-0001). In March 1992, a spill was reported at the KSP dry cleaning establishment, located in the Eastgate Shopping Center in Chapel Hill. The site is located approximately 130 feet northeast of Booker Creek. The spilled material was identified as waste dry cleaning solvent, specifically perchloroethylene, or PCE. Thirty tons of PCE-contaminated soil were removed from the site in April 1992. The project came under the control of the NCDWM's Inactive Hazardous Sites Program in 1993. After additional investigation identified soil and groundwater contamination, a remediation system was installed in October 1996.

In January 2000, it was concluded that the remediation system was effective in reducing contamination in areas where the aquifer was more permeable, but provided limited reduction in contaminant concentrations near the source area. A modified system began operation in February 2001. Groundwater sampling showed that the contamination was confined to the shallow aquifer.

On May 23, 2001, two surface water samples were collected from Bolin Creek. Results (EPA Method 8260B) indicated PCE, TCE, DCE and vinyl chloride to be below detection levels (Source: NC Division of Waste Management, Inactive Hazardous Waste Sites, Dry Cleaning Solvent Act Program).

Eastwood Lake draining and dredging. In response to substantially decreased lake volume, excessive aquatic weed growth and reported algal blooms, a draining and dredging project was initiated in Eastwood Lake in 2001 (Exhibit 2.5). The project, funded by the Homeowner's Association, involved draining the lake, sediment removal, and construction of a forebay to capture sediment before it enters the main portion of the lake.

In order to prevent the transport of sediment to downstream areas, a coffer dam was to be used during draining and dredging activities. In July 2001, a substantial storm occurred prior to installation of the dam. This caused a large volume of lake bed sediment to be transported over the dam and into Booker Creek (Exhibit 2.6). Officials at the Orange County Erosion Control Division ordered a cleanup of the site. Approximately 120 tons of sediment was removed manually due to site constraints. Despite these actions, impacts to the stream were apparent through late 2001. Water samples collected by DWQ from Booker Creek immediately downstream of the dam on September 5, 2001 (approximately seven weeks after the incident) indicated a total suspended solids (TSS) concentration of 1900 mg/L and turbidity of 940 NTUs.

Exhibit 2.5 Eastwood Lake after draining, pre-dredging.

Exhibit 2.6 Booker Creek below Eastwood Lake after coffer dam failure

Pollutants in Floodway and Floodplain Areas. As noted earlier, dense development and extensive impervious areas lie between Franklin Street and Fordham Boulevard (US Hwy 15-501 Bypass). This area once contained significant amounts of poorly drained forest and wetland, but was later filled in to facilitate the development of University Mall and other commercial areas. The area is now prone to flooding. The low topography combined with the intense level of development make this area a potentially important source of pollutants. On several occasions, DWQ staff have noticed debris, spray painting equipment and automobile oil stored in close proximity to creeks. The Town of Chapel Hill has notified at least one business in the Eastgate Shopping Center of the need to remove to hazardous materials from the regulatory floodway.

☞ **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.

2.7 Trends in Land Use and Development

Most of the currently undeveloped portions of the study area are within the planning jurisdictions of Carrboro and Chapel Hill (Figure 2.7), primarily within Carrboro's Northern Transition Area in the upper Bolin Creek drainage. While land use regulations in Chapel Hill and Carrboro increasingly emphasize in-fill development, the undeveloped portion of the watershed is likely to change rapidly over the next decade. Most of this development is likely to be residential, the major exception being UNC's Carolina North Tract (formerly the Horace Williams Tract).

The Carolina North Tract covers 965 acres in Chapel Hill northwest of the intersection of Airport Road and Estes Drive, on the divide between the Bolin Creek and Crow Branch drainages. The tract currently includes the Horace Williams Airport, the two inactive hazardous waste sites discussed earlier, and large wooded areas. Several preliminary plans for the site have been developed, and have included research centers, mixed use commercial developments and public-private research projects. The university has established several advisory committees to explore a new plan for the property, with guiding principles expected to be prepared by late spring of 2003.

Once the remainder of the watershed is developed, total watershed imperviousness is likely to increase significantly from the estimated 1999 level of 15 percent (Section 2.4).

2.8 Regulatory Issues and Local Water Quality Activities

Sediment and erosion control. Orange County has a delegated local program under North Carolina's Sedimentation Pollution Control Act. The Erosion Control Division of the Orange County Planning and Inspection Department regulates erosion and sediment from private construction throughout the County. Publicly funded projects (e.g., projects undertaken by UNC or local governments) are regulated by the North Carolina Division of Land Resources.

Chapel Hill development ordinances and water quality monitoring. Chapel Hill's recently adopted Land Use Management Ordinance (January 2003) requires that most new development in the study area implement stormwater controls so that stormwater runoff volume leaving the site post-development does not exceed predevelopment volume for the local two-year, 24-hour storm. This may be achieved by hydrologic abstraction, recycling, reuse and other accepted methods. The ordinance also requires the post-development runoff rate leaving the site not exceed the pre-development rate for the local one-year, two-year, and 25-year, 24-hour storm events. Stormwater treatment is required to remove an annual average of 85 percent of total suspended solids from post-development runoff resulting from the first one inch of precipitation. Land disturbance within the stream channel of any ephemeral stream is prohibited unless explicitly authorized by issuance of a Zoning Compliance Permit.

The Town of Chapel Hill's Resource Conservation District (RCD) zoning applies to all intermittent and perennial streams. The RCD defines three stream corridor zones, each 50 feet in width: the stream side zone, the managed use zone and the upland zone. The stream side zone begins at the stream bank and extends for a distance of 50 horizontal feet; the managed use zone extends 50 feet from the edge of the stream side zone; and the upland zone extends 50 feet from

the managed use zone (or out to the RCD elevation, whichever is greater). The RCD elevation is base flood elevation plus three feet (measured horizontally or vertically, whichever is more restrictive). All three zones are required along perennial streams. Other perennial water bodies and intermittent streams require only the 50-foot stream side zone.

Prior to the current Land Use Ordinance, RCD stream corridor widths were: 100 feet measured horizontally from each perennial stream bank (for streams draining more than one square mile) or base flood elevation plus two feet (whichever was more restrictive); 75 feet horizontally from each perennial stream bank (for streams draining less than one square mile); and 50 feet horizontally from perennial stream banks (for parcels developed between 1984 and 1987).

The Town of Chapel Hill conducts monthly water quality monitoring at 13 locations in Chapel Hill and Carrboro through its Stormwater Quality Monitoring Program (SQMP). Monitoring locations in the area of the current study include: Booker Creek at Piney Mountain Road, NC 86 (Airport Road) and Willow Drive; Bolin Creek at Village Drive, East Franklin Street and Pathway Drive (Pathway Drive is located in Carrboro but is included in Chapel Hill's monitoring program by agreement between Chapel Hill and Carrboro,); and Little Creek above Pinehurst Drive. Data from this program are presented in Section 5.

Carrboro development ordinances and water quality monitoring. Carrboro's current Land Use Management Ordinance (1999) requires that new development in the study area result in no stormwater damage to upstream or downstream properties for the 100-year and 25-year storm, respectively. The no damage provisions are applicable to projects on the basis of the type of project permit required. Under the town's permitting scheme, smaller projects of limited impact are reviewed and approved administratively (zoning permit), with stormwater requirements applying only to larger scale projects requiring quasi-judicial review and approval (conditional use or special use permits). Developments requiring special use or conditional use permits must implement other measures to mitigate potential downstream impacts, including stream scouring and water quality concerns. While the town can impose a range of requirements to meet these provisions, the standard conditions in Carrboro's Storm Drainage Design Manual specify that detention should be provided so that the post-development peak flow leaving the site for the 25-year storm does not exceed the pre-development peak. BMPs that meet the North Carolina stormwater specifications may be used to meet the town's water quality requirements.

Most portions of Bolin Creek and its tributaries within Carrboro's jurisdiction are located in the town's Northern Transition Area (excepting upper portions of Jolly Branch and the first unnamed tributary upstream of Jolly Branch on the northern bank). Within the Northern Transition Area, riparian buffer widths of 100 feet are required along Bolin Creek (from the edge of the floodplain, or if no floodplain has been demarcated, from the edge of the water, plus allowances for slope). Sixty-foot buffers from the edge of the stream are required for perennial and intermittent streams draining more than 50, but less than 640 acres. For intermittent and perennial streams draining less than 50 acres, riparian buffers must be 30 feet wide on each side of the stream (measured from the edge of the stream bank) or five times the average width of the stream, whichever is larger.

The Town of Carrboro instituted quarterly benthic sampling at several sites on upper Bolin Creek in 2000. The town's Environmental Advisory Board has expressed an interest in using the data

as the foundation for determining how to improve water quality in Bolin Creek and other town waterways. Results are discussed in Section 4.

University of North Carolina-Chapel Hill development requirements. The University of North Carolina is required to comply with Chapel Hill's Office Institutional 4 (O-I4) zoning category. Before any buildings can be approved in an O-I4 zone, the Chapel Hill Town Council must approve a Development Plan that provides details on the proposed development and on the steps that will be taken to mitigate any impacts.

UNC is currently drafting a stormwater master plan to comply with the town's regulations. According to UNC staff, the plan will emphasize re-use and infiltration strategies. Several BMPs have already been installed or are currently under construction. These include: pervious parking lots at the Park and Ride Lot on NC 54 (next to the Friday Center) and at the remote parking lot addition on Estes Drive Extension; a green roof at the Carrington Nursing School on South Columbia Street; an infiltration bed under the playing fields off South Road; and a 70,000-gallon underground cistern designed to capture rainwater falling on the School of Government and the indoor track buildings.

State Stormwater Regulations. EPA's Phase II stormwater program has mandated that designated communities, not previously covered by federal stormwater requirements, apply to state agencies for permit coverage by March 2003. This requirement applies to Chapel Hill, Carrboro and Orange County. The Phase II program is also applicable to the University of North Carolina at Chapel Hill, because it operates a storm sewer system within a covered urban area. In October 2002, the NC Environmental Management Commission passed a temporary rule governing implementation of the Phase II program in the state. Communities covered by Phase II requirements are required to develop and implement a comprehensive stormwater management program that includes the following six 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.

Jordan Lake Nutrient Management Strategy and TMDL. Rivers and streams draining to B. Everett Jordan Lake were classified as nutrient sensitive waters (NSW) by the NC Environmental Management Commission (EMC) in 1983. The nutrient management strategy subsequently adopted for the lake imposed total phosphorus limits of 2.0 mg/L on wastewater dischargers in the Jordan Lake drainage with permit limits of 50,000 gallons per day or more. The strategy did not include specific loading targets or measures to reduce nonpoint source inputs. In 1997, the General Assembly passed House Bill 515 (the Clean Water Responsibility and Environmentally Sound Policy Act), resulting in additional phosphorus and nitrogen limits on wastewater dischargers. Seven local governments received an extension to comply with the nitrogen limits and funded the development of a nutrient response model for the lake. The EMC approved the model in July 2002, and it can now be used to develop nutrient loading targets for the lake. DWQ is currently working with stakeholders to develop a nutrient management strategy for the lake and its watershed. A draft management strategy document should be developed by the spring of 2004.

The 2002 303(d) list (NCDWQ, 2002) rates several portions of the reservoir -- including the New Hope River arm of Jordan Lake, to which Little Creek empties -- as impaired due to excessive chlorophyll *a* levels. To address this impairment, DWQ is in the process of developing a nutrient TMDL (Total Maximum Daily Load) for the impaired portions of the lake. The TMDL must include loading targets for both point sources and nonpoint sources of nutrients. The current schedule calls for the submission of the TMDL to EPA by March-April 2005.

Morgan Creek/Little Creek Local Watershed Plan. In October 2002, the North Carolina Wetlands Restoration Program (NC WRP) initiated a Local Watershed Planning process in the Little Creek watershed and the adjacent Morgan Creek watershed. The NC WRP is a nonregulatory program housed in the NC Department of Environment and Natural Resources. Program goals include protecting and improving water quality, habitat and floodwater prevention functions within watersheds across the state. The Program works to accomplish these goals through Local Watershed Planning and the implementation of wetlands, stream and riparian buffer restoration projects.

The Cape Fear River Assembly was contracted by the NCWRP to recruit the stakeholders for the Morgan Creek/Little Creek planning process and to facilitate stakeholder team meetings. Stakeholder team participants represent: local government, agriculture, wildlife/aquatic habitat, academic and local community environmental group interests. Based on a consensus driven process, this team will work with the NCWRP and Tetra Tech, Inc. (contracted by the NCWRP) to integrate local experiences and information into a watershed assessment. This process will include the identification of viable and practical solutions to address identified watershed problems. Solutions can include wetlands, stream and riparian restoration projects, BMPs, preservation or conservation opportunities, habitat protection and restoration projects, as well as policy recommendations.

DWQ's assessment of Little Creek and the NCWRP's Local Watershed Plan (LWP) are complementary efforts, but the two initiatives have distinct emphases. The current DWQ study is primarily a technical assessment of why impaired streams are not meeting expectations for aquatic life uses. The NCWRP effort encompasses a wider geographic area and a broader range of objectives and is incorporating extensive stakeholder involvement. Results of the current DWQ assessment will be utilized in the NCWRP planning process. The LWP is scheduled to be completed by July 2004.

Local watershed groups and associations. A number of groups are active in the watershed. Among these are the Haw River Assembly, the Orange-Chatham County Chapter of the Sierra Club, the Lake Ellen Homeowners' Association and the Friends of Bolin Creek.

The Haw River Assembly is a nonprofit grassroots organization founded in 1982 to protect and restore the Haw River and Jordan Lake. The group conducts periodic water quality monitoring and has taken an active interest in water quality issues throughout the Cape River basin and the southeast.

The Orange-Chatham County Chapter of the Sierra Club has been active in reviewing Chapel Hill and UNC ordinances and development plans. It is currently conducting an initial pilot

habitat restoration on a small section of Bolin Creek. The project is envisioned as a long-term project that will include groups from the various neighborhoods adjacent to the creek.

Incorporated in 1985, the Lake Ellen Homeowners' Association (LEHA) was established to protect and maintain the dam, spillway, water quality, and immediate environs of Lake Ellen. The dam was deemed to be substandard by state inspection officials in 1985, and homeowners in the Lake Ellen vicinity donated funds to upgrade the dam. In addition to focusing on lake protection, the LEHA also participates with local and state officials on a variety of community issues.

Friends of Bolin Creek (FOBC) is a nonprofit grassroots group dedicated to preserving Bolin Creek and adjoining lands and habitats. The group is encouraging cooperative efforts between Chapel Hill, Carrboro, UNC and Orange County in developing a greenway and protected park along the entire creek corridor, and is advocating for the development of a Bolin Creek Corridor Open Space Master Plan. The FOBC has identified the 29-acre Adams Tract, located north of Estes Drive Extension in Carrboro, as a high priority protection site.

University studies. Professors Philip Berke of the UNC Department of City and Regional Planning and Nancy White of the College of Design at North Carolina State University are undertaking several research and design projects in the study area. The first study examines how the compact development concept can be integrated into local land use planning initiatives, and compares stormwater runoff impacts of compact development to the impacts of conventional low-density development. Part of this study examines the extent to which hydrologic and land use mitigation measures are integrated into the design of two prominent forms of compact developments -- new urbanism and cluster development -- based on a survey of development projects in four states (Maryland, North Carolina, South Carolina, Virginia). Another part of the effort involves modeling to examine the water quality impacts of several compact and low-density development design scenarios for a demonstration watershed. A portion of the Lake Ellen (upper Booker Creek) watershed is being used for this analysis.

The second project involves the development and implementation of a site design and stormwater management plan for a 46 unit co-housing project in Carrboro named Pacifica. This project is intended to investigate the use of low impact development (LID) site design techniques to mitigate both stormwater pollution impacts and impacts associated with hydrologic change. The Pacifica site design facilitates the "treatment train" approach for stormwater management as recommended by LID. Stormwater volume will be managed and treatment provided using cisterns, bioretention areas, grassy swales, infiltration trenches, level spreaders, irrigation pond and a riparian buffer. Pre and post construction monitoring will be conducted to evaluate water quality and water quantity impacts. Knowledge gained from this site will be transferable to Piedmont communities interested in LID and other innovative approaches to avoiding stormwater impacts.

Section 3
Potential Causes of Biological Impairment

The study identified those factors that were plausible causes of biological impairment in the Little 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 Little Creek watershed were also examined to identify potential stressors for further evaluation.

3.1 Key Stressors Evaluated in the Little Creek Watershed

Little Creek is a highly impacted watershed and water quality degradation is widespread. The following were evaluated as the most plausible candidate causes of impairment in the study area.

1. Habitat degradation--sedimentation. Sedimentation can impact habitat through the loss of pools, burial or embedding of riffles, and potentially high levels of substrate instability. Excess sedimentation was historically listed as a problem parameter for Bolin Creek on the 303(d) list, and thus, merited further evaluation. Sedimentation in Eastwood Lake and Lake Ellen has also been ongoing concerns.

2. Habitat degradation-- lack of key microhabitat. Preliminary watershed investigations indicated that while habitat conditions are quite variable in the watershed, important microhabitats for benthic macroinvertebrates -- such as woody debris, leaf packs and root mats -- may be present in limited amounts in some areas. The extent, cause, and biological implications of habitat degradation needed further evaluation. Habitat degradation was historically listed as a problem parameter for Little Creek on the 303(d) list.

3. Hydromodification--scour due to stormflows. Highly developed watersheds, such as the Little Creek drainage, often experience rapid changes in streamflows and increased velocities during storms. High levels of impervious cover result in increased volume and energy of stormflows, which can dislodge aquatic macroinvertebrates and flush some microhabitats from the stream. Scour also contributes to bed and bank erosion, increasing the supply of sediment to downstream areas.

4. Toxicity. Much of the watershed is highly developed, with both residential and commercial uses. There is a significant potential for a wide variety of toxicants to enter streams during rain events or site-specific accidents. These toxicants include metals, pesticides and a range of other organic chemicals. Because of the wide range of potential toxicants and source activities in this watershed, toxicity merits further evaluation as a potential cause of impairment. An initial review of the benthic community data for Little Creek indicated potential impacts from toxic inputs (see Section 4).

5. Low dissolved oxygen/organic and nutrient enrichment. Dissolved oxygen (DO) is critical to aquatic communities. DO concentrations in streams are influenced by numerous factors, including the rate of reaeration and inputs of organic matter and inorganic nutrients from both

natural and anthropogenic sources. Organic enrichment can affect stream biota in several ways. Organic material in the form of leaves, sticks, and other materials provides a food source for aquatic microbes and serves as the base of the food web for many small streams. When microbes feed on organic matter, they consume oxygen in the process and make nutrients available to primary producers, especially periphyton. Macroinvertebrates feed on the microbial community and are, in turn, consumed by fish.

These processes are natural and essential to the health of small streams. However, excessive amounts of organic matter (oxygen-consuming wastes and nutrients) from human or animal waste can increase the microbial activity to levels that significantly reduce the amount of oxygen in a stream. Excessive inorganic nutrient inputs can also impact stream biology, promoting excessive algal activity, which can further reduce DO concentrations. Adequate dissolved oxygen is essential to aquatic communities; only certain aquatic invertebrates are able to tolerate low oxygen levels. These excessive organic materials also serve as food for certain aquatic invertebrate groups that can dominate the invertebrate community. Excess organic and nutrient loading can thus result in a distinct change in community composition due to both a change in food source and low dissolved oxygen levels.

Historical data collected by the Town of Chapel Hill indicated low DO levels at several sites in the watershed, indicating the need for further evaluation. Even if nutrients are not a source of stream impairment in this watershed, nutrient inputs are of interest due to current eutrophication concerns in B. Everett Jordan Lake.

Section 4
Biological Conditions and Stream Habitat

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 various sites in the Little Creek watershed in 1986, 1993 and 1998. Bolin Creek was rated Good-Fair at East Franklin Street in 1986, when the watershed was first sampled.

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

- To account for changes in biological condition since the watershed was last sampled in 1998.
- To determine 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 identify potential stressors affecting the benthic community.

DWQ conducted fish community sampling in Bolin Creek in 1998 and again during this study.

This section describes the approach to bioassessment used during the study and summarizes the results of this work. Benthic macroinvertebrate sampling conducted by the Town of Carrboro at a number of locations in Bolin Creek is also summarized. A more detailed analysis of the condition of aquatic macroinvertebrate communities in the Little Creek watershed may be found in Appendix A.

4.1 Approach to Biological and Habitat Assessment

DWQ collected benthic macroinvertebrate community samples during 2000-2002 (predominately in 2001) at nine locations in the study area: one site on Little Creek, three sites on Booker Creek, four sites on Bolin Creek and in Tanbark Branch, a tributary of Bolin Creek (Figure 4.1 and Table 4.1). Fish community samples were collected in three Bolin Creek locations.

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, 2001a). Reaches approximately 100 meters (328 feet) long were targeted, although the actual stream length sampled varied with site conditions. Standard qualitative ("full scale") 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 leaf pack 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 leaf pack 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 healthier 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 healthier 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.

Historical sampling sometimes used methods other than those described above. At some sites a modified Qual 4 (termed EPT method) was used in which Qual 4 sampling procedures were used but only EPT taxa were identified.

The use of *Chironomus* mentum (mouth structure) deformities is a good tool for toxicity screening (Lenat, 1993). At least 20-25 *Chironomus* are evaluated for deformities and a numeric "toxic score" is computed for each site. Based on this score, sites are classified as Nontoxic, Fair/Toxic or Poor/Toxic. In the Little Creek watershed, sufficient numbers of *Chironomus* for the deformity analysis were only collected at one location and date—in Little Creek at Pinehurst Drive in March 2001.

4.1.2 Fish Community Sampling and Rating Methods

A 600-foot reach was sampled at each location using two backpack electrofishing units. Most fish were measured (total length), examined (for sores, fin damage, etc.) and released. Fish not readily identifiable in the field were returned to the laboratory for examination. Young-of-year fish were collected but not included in the analysis. The condition of the fish community was assessed using the North Carolina Index of Biological Integrity (NCIBI). Using 12 parameters or metrics, the NCIBI incorporates information about species richness and composition, trophic composition, fish abundance and fish condition. These metrics are combined into a total score

that is used to assign an NCIBI classification, using the same range of classifications (Excellent to Poor) used for macroinvertebrate community analyses. Field methods and NCIBI procedures are detailed in DWQ's standard protocol for fish community sampling (NCDWQ, 2001c).

4.1.3 Habitat Assessment Methods

At the time benthic community and fish sampling were carried out, stream habitat and riparian area conditions were evaluated for each reach using DWQ's standard habitat assessment protocol for piedmont streams (NCDWQ, 2001a). 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 Results and Discussion

4.2.1 Benthic Macroinvertebrates

Selected habitat and biological characteristics for each site sampled during the study are shown in Tables 4.1 and 4.2, respectively, which also include selected information on historical sampling. Many 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.

Little Creek

Little Creek at Pinehurst Drive. This site is located at the lower end of the study area, about a mile downstream of the confluence of Bolin Creek and Booker Creek, and immediately upstream of Pinehurst Drive (Exhibit 4.1). Riffle habitats were absent and the channel slope was low, similar to a coastal plain stream. This is not unusual for Triassic basin sites. The sample site was characterized by massive amounts of sand (85 percent of the substrate) and a small amount of gravel and silt. Habitat was extremely degraded. Channel bars were abundant and extensive erosion areas were present on both banks. Few sticks and leaf packs were found and undercut banks and root mats were also rare. Extensive riparian disturbance was evident. Riprap was placed along part of the left bank, and beaver impoundments are periodically built, destroyed and rebuilt upstream.

EPT richness values have been low here since DWQ first sampled this reach in 1993, and no stoneflies have ever been found at this site. Abundance values were also very low and the chironomid assemblage suggested toxicity. BI values (7.33 in March 2001) were among the

highest in the watershed, and this site received a bioclassification of Poor in 1998 and 2001. A midge deformity analysis was conducted on the March 2001 sample. The score (160) was extremely high and most of the *Chironomus* menta were massively deformed, indicating severe toxicity problems at this location.

Bolin Creek and Tributaries

Bolin Creek upstream of East Franklin Street (Exhibit 4.2). This is the most downstream site sampled on Bolin Creek and the first site DWQ sampled in the Little Creek watershed (1986). This reach is located in the transition zone between the Carolina Slate Belt and Triassic basin geology. Habitat is degraded here, though much better than downstream at the Little Creek sampling station. Boulders and cobbles were abundant and two riffle areas extended the width of the stream. Pools were partially filled with loose sand, but riffle embeddedness was not severe. Undercut banks and root mats were present, though not abundant. Some sticks and leaf packs were found, though large organic debris was absent. Erosion areas were present on both banks and riparian vegetation was lacking on one side of the stream, where a greenway trail runs.

The benthic community declined at this site sometime between 1986 and 1993. EPT richness values for spring full scale samples fell sharply from 28 in 1986 to 13 in 1998 and 4 in 2001. BI values also increased (from 6.08 in 1986 to approximately 7 in 2001), indicating a loss of intolerant organisms. While six stonefly taxa were collected in 1986, no more than one has been collected since. The chironomid community assemblage indicates possible toxicity (see Appendix A). Although *Chironomus* was present in 2001, the number of specimens was not sufficient for a midge deformity analysis.

Bolin Creek at Bolinwood Drive. This site, located downstream from the Airport Road crossing and immediately upstream of Bolinwood Drive, had not been sampled by DWQ prior to the current study (Exhibit 4.3). The reach, located in the Carolina Slate Belt, contained a riffle area consisting of rubble extending across the creek, and a good mix of gravel, cobble and boulders was present. Some sand and silt deposits were present, but riffle embeddedness, though variable, was not severe. Undercut banks and root mats were common and were available for colonization (submerged). Some erosion areas were present on both banks. The riparian zone on both banks was narrow because the paved greenway trail runs along one bank and a lawn area on the other. A service station, stores and a parking lot are adjacent to the stream at Airport Road.

Both sampling events (March 2001 and 2002) yielded similar results, with an EPT richness of 5, the highest BI values (7.49 in March 2002) in the watershed and a Poor bioclassification. No stoneflies were found, and the mayflies and caddisflies present were tolerant. As was the case downstream at East Franklin Street, the chironomid community indicated possible toxicity. Sufficient *Chironomus* were not collected for a midge deformity analysis. Habitat scores of 76 and 69 do not indicate severe habitat problems. It is unlikely that habitat condition at this site is a major contributor to the observed biological degradation.

Bolin Creek at Village Drive. This site is just upstream of Village Drive, located between Estes Drive and Chapel Hill's Umstead Park (Exhibit 4.4). The reach lies upstream of all significant commercial areas in the watershed, though substantial residential development exists. Riffles were well defined and embeddedness was not severe. Undercut banks and root mats were available for colonization and sticks and leaf packs were generally abundant. Both banks

exhibited areas of erosion. The right bank had the greatest potential for failure due to sparse vegetation between the creek and Umstead Drive.

The benthic community was similar in 1993 and 1998, with relatively diverse EPT taxa (richness of 23-24) and low EPT BI values. The site received a bioclassification of Good in 1998. The benthic community has declined sharply since then and was rated either Fair or Poor when sampled on several occasions in 2001 and 2002. Both EPT richness and abundance were substantially reduced, while the BI increased. Intolerant stoneflies abundant or common in 1993 and 1998 were rare or absent in 2001. The chironomid community in February 2001 indicated potential toxicity, but this assemblage was not present in the two other samples collected at this site during the study. Habitat is good at this site and does not likely contribute to the decline in the benthic community.

Bolin Creek at SR 1777 (Homestead Road). This is the most upstream sample site on Bolin Creek and is considered the reference site for the study because of the Good rating here in 1993 and 1998 (Exhibit 4.5). Though there is development upstream of Homestead Road and thus the site does not represent an undisturbed watershed, it serves as a useful comparison to the downstream sites draining more extensively developed areas. The reach contains multiple well-defined rock riffles. While undercut banks and root mats were common, snags and other organic habitat were limited. The riparian zone is forested on one bank, while the other is largely lawn. The amount of sand and silt has remained relatively constant since the site was first sampled in 1993.

This reach had the most diverse macroinvertebrate fauna of any site in the watershed sampled during the study, though its bioclassification of Good-Fair (July 2001) reflected a decline from previous samples at this location. The community was even more degraded in February 2001 (see Appendix A), but was not rated due to the narrow stream width.

Tanbark Branch in Umstead Park. This small tributary was sampled in Umstead Park, about 150 meters upstream from its confluence with Bolin Creek and downstream of the Village Road sampling station (Exhibit 4.6). The site had diverse coarse substrates and included a riffle extending the width of the stream. Embeddedness was in the 40 to 80 percent range. Sticks and leaf packs were common, though undercut mats and root mats were rare, as would be expected in a shallow stream (0.1 meter). Banks were unstable, and specific conductance was extremely high at 299 µmhos/cm. A sewer line runs parallel to the stream, which drains part of downtown Carrboro, including the Carr Mill Mall area.

Though not rated due to its size, the benthic community here has highly degraded. This site had the lowest EPT taxa richness in the study area and the lowest EPT abundance in the Bolin Creek watershed. The only EPT taxa found was the tolerant caddisfly *Cheumatopsyche*. The midge assemblage indicated potential toxicity, as was the case in Bolin Creek downstream from this location. Given the small drainage area of this tributary and it's highly developed nature, baseflows are likely rather low and the stream may dry up during some periods, a situation likely exacerbated by the drought period during which this sample was collected (March 2002).

Booker Creek

Booker Creek at Willow Drive, near Walnut Street. This is the most downstream site sampled on Booker Creek and had not been sampled prior to the current study (Exhibit 4.7). The sample

reach is located downstream of Willow Drive and adjacent to Walnut Street, less than one-half mile upstream of the confluence with Bolin Creek. A sewer line right of way parallels the creek, which is incised and has been channelized. This Triassic basin site is characterized by large amounts of sand and unstable banks. Habitat is probably worse than at any other site sampled in the study area (overall scores of 38 and 39). Rock riffles were absent, although some sticks, snags, and root mats were available for benthos colonization.

Though not rated due to its width, benthic fauna were sparse at this site and BI values were among the highest in the watershed. This impacted site had no stoneflies. The midge community in one of the two samples indicated potential toxicity.

Booker Creek at Piney Mountain Road. This site, first sampled in 1998, is approximately one-third mile downstream from Lake Ellen in a residential section of Chapel Hill (Exhibit 4.8). The habitat here was better than at other sites sampled on Booker Creek. In-stream habitat consisted mainly of rocks, with some sticks and leaf packs. Undercut banks and root mats were rare. The riparian zone along one bank was intact and heavily wooded, while the wooded riparian area on the other side was narrower due to a road.

The benthic community was highly degraded here, although the site was too small for a formal rating. EPT richness ranged from 4 to 7 for two samples collected in 2001. Lake Ellen is probably retaining much of the sand and sediment this reach would receive, which helps to keep gravel and rubble in the reach available for benthic colonization. However there is little or no flow at this site during dry periods.

Booker Creek at Barbara Court. This is the headwater site for Booker Creek (Exhibit 4.9) and is located a short distance downstream of Airport Road (NC 86). Riffle habitat is good here, though few other habitat types are available. Booker Creek is very shallow (0.1 meters) at this location, which does not allow for undercut bank and root mat habitats. Organic habitat was sparse.

Macroinvertebrates collected were few and stress tolerant. Given the small watershed size at the site and the underlying Carolina Slate Belt geology, this reach likely dries up or is subject to very low flow during portions of the summer, even during non-drought years. These largely natural stressors may limit the benthic community at this site, regardless of other impacts. Considerable construction activity (residential development, the widening of Airport Road and the construction of a new public park) has occurred in recent years.

Additional observations

Both excessive periphyton growth and heavy filamentous algal growth were observed during sampling at two Bolin Creek sites--Bolinwood Drive and Village Drive. Excessive periphyton growth was observed in Bolin Creek at Homestead Road. Exposed bedrock was notable at all sampling locations on Bolin Creek and in Booker Creek at Barbara Court.

Table 4.1 Selected Site and Habitat Characteristics at Little Creek Watershed Benthic Sampling Sites, 2001-2002*

Location	Site Drainage Area (square miles)	Date	Total Score (of 100)	Channel Modific. (of 5)	In-stream Habitat Variety and Area (of 20)	Bottom Substrate Type and Embedded. (of 15)	Pool Variety (of 10)	Riffle Freq. and Size (of 16)	Bank Stabil. and Veget. (of 14)	Canopy (of 10)	Riparian Zone (of 10)
Little Creek at Pinehurst Drive	19.9	3/1/01 7/11/01	44 36	5 5	8 8	3 3	8 3	0 0	4 4	10 7	6 6
Bolin Creek at East Franklin Street	10.6	3/1/01 7/10/01	60 57	4 4	13 15	15 8	10 6	14 7	7 7	2 7	5 3
Bolin Creek at Bolinwood Dr.	9.3	3/1/01 3/14/02	76 69	4 3	14 11	13 8	10 10	14 14	10 12	10 7	1 4
Bolin Creek at Village Drive	7.2	2/27/01 7/10/01 3/14/02	86 66 71	5 2 4	15 13 11	15 8 8	10 4 4	16 16 12	10 9 9	10 10 7	5 4 6
Bolin Creek at Homestead Road (SR 1777)	4.7	2/27/01 7/10/01	79 65	5 4	15 15	13 10	10 4	16 12	8 8	7 7	5 5
Booker Creek at Willow Drive	6.2	2/21/01 7/10/01	39 38	4 2	7 8	3 3	8 4	0 0	4 8	10 10	3 3
Booker Creek at Piney Mt. Rd.	2.4	2/21/01 7/11/01	80 72	5 5	13 11	8 10	10 6	16 14	8 10	9 10	8 6
Booker Creek at Barbara Ct.	1.1	2/21/01 7/10/01	68 57	5 4	14 6	12 8	6 2	16 16	5 5	7 10	3 6
Tanbark Br. at Umstead Park	<1	3/14/02	67	5	15	10	6	14	10	2	5

* See NCDWQ (2001a) for sample habitat form and specific criteria.

Table 4.2 Selected Benthic Community and Stream Characteristics, Little Creek Watershed Sampling Sites

Location	Date	Method[1]	Stream Width (m)[2]	Substrate % silt and sand[3]	Habitat Score (max. of 100)[4]	EPT[5] Taxa Richness	EPT Abundance[6]	EPT Biotic Index[5]	Biotic Index[5]	Midge Deformity Score[5]	Bioclass-ification[5]
Little Creek at Pinehurst Drive	2/10/93	FS	4	100		7	16	4.69	7.13	160 (Poor)	Fair
	2/2/98	EPT	5	95		5	7	4.84	-		Poor
	3/1/01	FS	5	95	44	5	16	4.96	7.33		Poor
	7/11/01	Q5	3	95	36	5	18	6.36	-		Not Rated
Bolin Creek at East Franklin Street	4/29/86	FS	3	30		22	145	4.34	6.08		Good-Fair
	2/10/93	FS	6	50		8	32	5.34	6.53		Fair
	2/2/98	EPT	6	80		3	22	6.66	-		Poor
	3/11/98	FS	6	55		13	42	6.00	6.28		Fair
	3/1/01	FS	5	40	60	4	33	5.94	7.06		Poor
	7/10/01	FS	4	30	57	4	31	6.95	6.88		Poor
Bolin Creek at Bolinwood Dr.	3/1/01	FS	5	20	76	5	25	6.39	7.32		Poor
	3/14/02	FS	7	30	69	5	18	6.88	7.49		Poor
Bolin Creek at Village Drive	4/1/93	EPT	5	30		23	88	3.90	-		Good-Fair
	2/26/98	FS	9	20		24	91	3.93	5.10		Good
	2/27/01	FS	5	10	86	5	35	5.82	7.00		Poor
	7/10/01	FS	6	20	66	9	36	6.64	6.61		Fair
	3/14/02	FS	6	10	71	7	38	6.42	7.00		Fair
Bolin Creek at Homestead Road (SR 1777)	4/1/93	EPT	4	35		22	76	4.46	-		Good
	3/11/98	EPT	4	45		22	90	4.23	-		Good
	4/6/00	EPT	4	30		24	157	5.05	-		Good
	2/27/01	Q4	3	25	79	14	61	6.04	6.40		Not Rated
	7/10/01	FS	5	20	65	24	112	5.18	5.96		Good-Fair
Booker Creek at Willow Drive.	2/21/01	Q4	3	90	39	3	7	5.26	7.20		Not Rated
	7/10/01	Q5	3	90	38	7	25	6.04	6.91		Not Rated
Booker Creek at Piney Mt. Rd.	3/11/98	EPT	3	20		9	36	5.80	-		Not Rated
	2/21/01	Q5	3	40	80	7	37	6.40	6.26		Not Rated
	7/11/01	Q5	3	10	72	4	40	6.62	6.41		Not Rated
Booker Creek at Barbara Ct.	2/21/01	Q4	2	10	68	4	24	6.60	7.33		Not Rated
	7/10/01	Q5	2	10	57	3	30	7.00	6.56		Not Rated
Tanbark Br. at Umstead Dr.	3/14/02	Q5	3	30	67	1	10	6.20	-		Not Rated

1. FS = full scale (standard qualitative); Q4 = Qual 4; Q5 = Qual5. See text for discussion.
2. Wetted channel width at time of sampling.
3. Based on visual estimate of substrate size distribution.
4. Habitat data available for 2001-2002 samples only; see text for list of component factors.
5. See text for description. EPT taxa Richness is seasonally corrected.
6. Number of individual EPT organisms collected.

4.2.2 Fish Community

In 1998, DWQ sampled the fish community in Bolin Creek off Estes Drive (SR 1750) across from University Mall. Twelve species were collected and the community was rated Good-Fair. This site was resampled in October 2001 as a part of the current study. Two additional reaches were sampled at that time: Bolin Creek at Airport Road (NC 86), located just upstream from the benthic community sampling station at Bolinwood Drive; and Bolin Creek at Homestead Road (SR 1777), the most upstream benthic community sampling station (Tracy, 2001). The Estes Drive (University Mall) site again received a rating of Good-Fair (Table 4.3), while the two upstream locations were rated Good. Although the downstream site off Estes Drive was not considered impaired, it had a high percentage of diseased fish in 2001. Intolerant (sensitive) species were absent at all sites, although fish communities in the stream as a whole showed a high level of species diversity and fish abundance. For additional information on specific NCIBI metrics, see Tracy (2001).

Table 4.3 NCIBI Fish Community Scores and Selected Metrics for Bolin Creek Sites, May 1998 and October 2001

Parameter	Site			
	Homestead Road October 2001	**Airport Road October 2001**	**off Estes Drive October 2001**	**off Estes Drive May 1998**
No. Species	12	20	20	12
No. Fish	263	563	604	436
Total NCIBI Score	46	50	44	40
NCIBI Class	Good	Good	Good-Fair	Good-Fair

Source: Tracy, 2001

4.3 Other Macroinvertebrate Data

Other benthic invertebrate data available for the watershed include data collected by Geraci from the UNC-CH Curriculum in Ecology and data collected for the Town of Carrboro by Ecological Consultants.

Geraci (2002) sampled 12 sites throughout the Little Creek watershed in 2001. Collection methods differed from those used by DWQ, making direct comparison of results difficult. Only bank and riffle habitats were sampled. Composite (bank plus riffle) EPT taxa richness was generally low, ranging from 3 to 9 in Bolin Creek, from 2 to 5 in Booker Creek and 5 in Little Creek. Land cover (percent forest) at both the site drainage area and the riparian zone scales was found to be associated with benthic diversity.

In September 2000, the Town of Carrboro began collecting benthic macroinvertebrate community data at three locations in Bolin Creek (Figure 4.1): at Estes Drive (just upstream of the DWQ Village Drive sampling site); upstream at Waterside Drive; and the most upstream

location at Homestead Road, which was also sampled by DWQ. DWQ's full scale (standard qualitative) method was used for all collections (see Section 4.1.1 for description). Results were generally similar to those from DWQ samples (Table 4.4). The two downstream sites (Waterside Drive and Estes Drive) generally received Bioclassifications of Fair in 2000 and 2001, while the Homestead Road site was rated Good-Fair during these years. The September 2002 sample showed a decline in EPT taxa richness and an increase in the BI at all three locations, resulting in a Fair rating at Homestead Road, and a Poor rating at the other sites. This decline was attributed to the extremely low streamflows caused by the drought (Ecological Consultants, 2002). The September 2000 sample (but not the other collections) for the Waterside Drive and Estes Drive sites reflected an abundance of oligochaetes, which may reflect organic enrichment (Ecological Consultants, 2001b).

Table 4.4 Town of Carrboro Benthic Community Data, Bolin Creek, 2000-2002

Location	Date	EPT[1] Taxa Richness	Biotic Index[1]	Bioclassification [1]
Bolin Creek at Homestead Road	Sept. 2002	10	7.22	Fair
	June 2001			Good-Fair
	Mar. 2001	16	6.41	Good-Fair
	Dec. 2000	17	6.22	Good-Fair
	Sept 2000	16	6.23	Good-Fair
Bolin Creek at Waterside Drive	Sept. 2002	6	7.37	Poor
	June 2001			Fair
	Mar. 2001	10	6.69	Fair
	Dec. 2000	12	6.45	Fair
	Sept 2000	9	6.14	Fair
Bolin Creek at Estes Drive.	Sept. 2002	6	7.47	Poor
	June 2001			Fair
	Mar. 2001	10	6.26	Fair
	Dec. 2000	9	6.04	Fair
	Sept 2000	4	6.43	Poor

[1] DWQ full scale method used for all sampling. See text for description.

Source: September 2002 data -- Ecological Consultants (2002); June 2001 data -- Ecological Consultants (2001b); other dates -- Ecological Consultants (2001a).

4.4 Summary of Conditions and Nature of Impairment

Extent of impairment. North Carolina's 303(d) list rates Little Creek and Booker Creek as impaired for their entire lengths and Bolin Creek as impaired below Franklin Street. Macroinvertebrate community data collected during this project indicates that this remains an accurate description for Little Creek (although the lowest portion of Little Creek is below the study area and was not sampled). Booker Creek also remains impaired for its entire length, although bioclassifications were not assigned because all reaches sampled were less than four meters in width. In Bolin Creek, however, it appears that impairment now extends much further upstream than previously documented (to Village Drive, based upon DWQ sampling and to Watershed Drive based upon Carrboro sampling; DWQ did not sample at Waterside Drive). Whether impairment in the Village Drive-Waterside Drive segment is persistent or transitory is unclear, as discussed below.

Little Creek. The benthic macroinvertebrate community in Little Creek indicated impairment when first sampled at Pinehurst Drive in 1993. Impairment continues at this site and habitat conditions are extremely degraded. Community composition indicates potential toxic impacts and midge deformity analysis revealed the presence of massive deformities, reinforcing this conclusion.

Bolin Creek. When Bolin Creek was first sampled at East Franklin Street in 1986, the benthic community was reasonably diverse, though there were clear indications of biological degradation (bioclassification of Good-Fair). Impairment was evident when this site was next sampled in 1993, and the overall status of the benthic community has changed little since that time. Benthic macroinvertebrate communities further upstream in Bolin Creek appeared relatively intact until 2000 and 2001 (Town of Carrboro and DWQ data, respectively). Sampling from this period indicated that the Village Drive site experienced the same decline in diversity documented in lower Bolin Creek in 1993. Impaired benthic communities were also apparent upstream at Estes Drive Extension and at Waterside Drive, which had not been sampled previously. The uppermost sampling site at Homestead Road did not experience this dramatic change, although the site did decline from Good to Good-Fair, indicating increasing stress. Midge community composition indicated the likelihood of at least intermittent toxic impacts at all sites sampled by DWQ except Homestead Road.

The decline observed at Village Drive (and the similar condition evident at Estes Drive Extension and Waterside Drive) does not appear to be due to the drought (the benthic community at Homestead Road remained relatively diverse in July 2001), though it is possible that the worsening drought impeded recovery at this site. Further sampling will be required to determine whether the observed decline is persistent or was due to a perturbation from which this portion of the stream will yet recover.

The fish community was relatively healthy in middle and upper Bolin Creek (Airport Road and Homestead Road sites). Signs of stress (e.g., diseased fish) were evident downstream at East Franklin Street, although the fish community at this site would not be considered impaired. It appears that whatever factors have led to deterioration in the benthos of Bolin Creek have had a lesser impact on fish communities.

Booker Creek. Except for the Piney Mountain Road site (sampled in 1998), benthic communities in Booker Creek had not been sampled previously. Sampling during the current study indicated low diversity and dominance by tolerant taxa over the entire length of the stream. The benthic community at Willow Drive, below US 15-501, indicated potential toxic impacts. Several sampling sites on Booker Creek, at Piney Mountain Road and Barbara Court, drain relatively small areas (2.4 and 1.1 square miles, respectively). The Carolina Slate Belt geology underlying this area provides limited baseflow (Giese and Mason, 1991). In slate belt streams of this size, stress due to low streamflows (including severe reduction in available habitat area) can be expected during summers, even during nondrought years, and probably serves to limit biological potential. Tanbark Branch, a small tributary to Bolin Creek, is also subject to these influences.

Drought impacts. Carrboro sampling in September 2002 indicated further decline at the three sites sampled, all of which were at or above Estes Drive Extension. This decline probably reflects the impacts of the drought, which gradually worsened during the period of study. As

discussed in Section 2, stream discharge during the summer of 2002 was extremely low in the area. DWQ did not sample Homestead Road in 2002. Those sites DWQ did sample in 2002 (Bolin Creek at Bolinwood Drive and Village Drive) did not show a clear decline from the previous year, but these sites were sampled in March, before conditions worsened. DWQ sampling in the adjacent Morgan Creek watershed (Morgan Creek at NC 54) and at other piedmont sites indicated that the drought had a significant impact on stream macroinvertebrates by the summer of 2002 (DWQ Biological Assessment Unit data).

Habitat and geological influences. In-stream habitat in Bolin Creek was generally adequate at sites located in the Carolina Slate Belt (roughly upstream of East Franklin Street), and there is no evidence that substrate composition has changed dramatically in recent years. Good riffle habitat was generally available, as was some bank habitat. Organic habitat such as leaf packs, sticks and larger debris was more variable. Habitat was poor at the two sites located in the Triassic basin (Little Creek at Pinehurst Drive and Booker Creek at Willow Drive), where massive sediment deposition was evident and in-stream habitat of all types was sparse. Bolin Creek at East Franklin Street, located in the area of transition between the two geological areas, is intermediate, with more degraded habitat than the upstream Carolina Slate Belt sites.

Exhibit 4.1 Little Creek above Pinehurst Drive

Exhibit 4.2 Bolin Creek above East Franklin Street

Exhibit 4.3 Bolin Creek at Bolinwood Drive

Exhibit 4.4 Bolin Creek at Village Drive

Exhibit 4.5 Bolin Creek above Homestead Road

Exhibit 4.6 Tanbark Branch in Umstead Park

Exhibit 4.7 Booker Creek below Willow Drive

Exhibit 4.8 Booker Creek at Piney Mountain Road

Exhibit 4.9 Booker Creek at Barbara Court

Section 5
Chemical and Toxicological Conditions

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.
2. To collect a range of chemical, physical, and toxicity data to help evaluate the specific causes of impairment and to identify sources.

This section summarizes data collection methods and discusses key monitoring results. See Appendix B for additional discussion of methodology and results.

5.1 Chemical, Physical, and Toxicity Sampling Methods

5.1.1 General Methodology

Watershed Water Quality Characterization

A site on Little Creek at the downstream terminus of the study area and sites near the downstream end of Booker Creek and Bolin Creek were sampled to provide an overall picture of water quality in the watershed. Water samples were collected and field parameters were measured at baseflow and during storms. Baseflow was defined as a period in which no measurable rain fell in the watershed during the 48 hours preceding sampling. Baseflow sampling provides an indication of water conditions to which organisms may potentially be exposed for an extended period. Storms bring a large influx of runoff that may carry toxicants and nutrients. Storm samples were collected during the rising stage of the hydrograph, while water levels were still increasing.

A drought affected the entire watershed throughout the study period (see Section 2). During portions of the summer of 2002 there was no visible flow at some study sites. Baseflow samples were not collected during these times. Extremely low precipitation during the primary sampling period (January-August, 2002) limited the number of storm samples that could be collected.

Stressor and Source Evaluation

Samples were collected at a variety of locations to identify the major chemical and physical stressors to which the aquatic biota are exposed, to evaluate toxicity, and to assess major pollution sources. Station locations were linked to areas of known biological impairment (benthic macroinvertebrate sampling stations) and to watershed activities believed to represent potential sources of impairment.

Sampling primarily focused on those physical and chemical parameters that preliminary investigations indicated merited investigation as plausible causes of biological impairment. Given the land use in the watershed (see Section 2), sampling included a variety of pollutants typically found in urban environments:

- metals;
- organochlorine pesticides and polychlorinated biphenyls (PCBs; EPA Method 608);
- selected current use pesticides (GC/MS-gas chromatography/mass spectroscopy);
- PAHs (polycyclic aromatic hydrocarbons; EPA Method 610);
- phenols (EPA Method 604);
- semi-volatile organics (EPA Method 625);
- MBAS (methylene blue active substances, an indicator of anionic surfactants);
- TPH (total petroleum hydrocarbons); and
- MTBE (methyl tertiary-butyl ether, a gasoline additive).

Laboratory toxicity 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. Acute toxicity tests were conducted on water samples taken during storms, while chronic tests were conducted on samples taken at baseflow. The water flea, *Ceriodaphnia dubia*, is the indicator organism used for both the acute tests, which last for 48 hours and measure mortality, and the chronic tests, which last for seven days and examine reproductive rates. Acute toxicity tests used the protocols described in the USEPA document EPA/600/4-90/027F (USEPA, 1993). Chronic toxicity tests used the North Carolina *Ceriodaphnia* Chronic Effluent Toxicity Procedure (North Carolina Division of Water Quality, 1998). Ten chronic and eight acute tests were conducted.

Multiparameter probes with a data logging capacity (data sondes) were deployed on three dates for periods as long as seven days. The data sondes were programmed to record pH, dissolved oxygen, specific conductance (standardized to 25^{o} C) and temperature at 15-minute intervals.

Extended in-stream monitoring to evaluate long-term exposure to pollutants was conducted using semi-permeable membrane devices (SPMDs). These are passive sampling devices that accumulate hydrophobic organic pollutants to which the devices are exposed during deployment (see Appendix B for additional details). SPMDs were deployed at three sites for seven days in August 2002.

Bed sediment was collected from Little Creek at Pinehurst Drive. Sediments were analyzed for pesticides, metals, PAHs, PCBs, semi-volatile organic pollutants and chronic toxicity. A forty-two day chronic toxicity bioassay was performed using *Hyallela azteca* as described in ASTM (2000) and USEPA (2000b).

Water and Sediment Benchmarks

To evaluate whether 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.

Sediment data were compared to sediment benchmarks used by the DWQ Aquatic Toxicology Unit (see Appendix B). They were grouped into conservative and non-conservative ranges in the manner of MacDonald et al. (2000). Conservative ranges ('no or low effects' benchmarks) are threshold values, below which there is a low probability of toxicity. Region 4 USEPA values are

included in the conservative values, but they are also presented separately because the DWQ Aquatic Toxicology Unit uses these as initial screening benchmarks. Non-conservative ranges ('probable effects' benchmarks) are values above which there is a high probability of toxicity. If a measured value falls between the low value of the conservative range and the high value of the non-conservative range, it is possible that it is toxic, with higher concentrations indicating an increased probability of toxicity.

Benchmarks were used for initial screening of potential impacts. Final evaluation of the potential for pollutants to negatively impact aquatic biota considered all evidence, including toxicity bioassays, benthic macroinvertebrate data and data on analyte concentrations.

5.1.2 Site Selection

Chemical/physical sampling sites (Figure 5.1 and Table 5.1) were chosen for accessibility, proximity to benthic invertebrate sampling sites, and proximity to potential stressor sources. Those sites that were monitored for benthic invertebrates were also described in Section 4. There was some overlap between sites sampled during the study and sites sampled by the Town of Chapel Hill. The Chapel Hill sites are also described below.

Little Creek at Pinehurst Drive (LCLC01). This station was located at the downstream end of the study area, immediately upstream of Pinehurst Drive. Grab samples were analyzed for the pollutants described in Section 5.1.1. A data sonde was also used to obtain data from this site. Monitoring at this site also included benthic invertebrate sampling, sampling of bed sediment, and chemical monitoring by the Town of Chapel Hill (#6 Little).

Bolin Creek at Fordham Boulevard / US Highway 15-501 Bypass (LCBN01). This was the most downstream site in Bolin Creek, located approximately 0.9 miles upstream of LCLC01. Grab samples were analyzed for the pollutants listed in Section 5.1.1. A data sonde was also deployed.

Bolin Creek at East Franklin Street (LCBN02). This site was approximately 1.6 miles upstream of LCLC01. It is located at the downstream end of a greenway that has a paved trail along the riparian area on the south bank. Grab samples were analyzed for the pollutants described in Section 5.1.1. This monitoring site was also assessed for benthic invertebrates and the Town of Chapel Hill assessed water chemistry here (#5 Bolin).

Bolin Creek at Bolinwood Drive (LCBN02A). This biological monitoring station was located approximately 2.6 miles upstream of LCLC01, approximately a quarter mile from the beginning of the greenway at Airport Road.

Bolin Creek at Airport Road (LCBN03). This site, located approximately 2.9 miles upstream of LCLC01, was used for SPMD and data sonde deployment.

Bolin Creek at Village Drive (LCBN04). This sampling site in Bolin Creek was located approximately 3.6 miles upstream from LCLC01. Grab samples were analyzed for the pollutants described in Section 5.1.1. Monitoring at this site also included benthic invertebrate sampling, data sonde deployment, and chemical monitoring by the Town of Chapel Hill (#4 Bolin).

Table 5.1 Part A - Summary of Monitoring Approaches Used at Primary Sampling Sites, Little and Bolin Creeks

Station Code	Location	Monitoring Approach						
		Benthic Invertebrates	Water Chemistry	Toxicity (Water)	Sediment Quality	SPMD[1]	Data Sonde[2]	Chapel Hill Water Chemistry
Little Creek								
LCLC01	Little Creek at Pinehurst Drive	√	√	√	√			√ #6 Little
Bolin Creek								
LCBN01	Bolin Creek at US Hwy 15-501 Bypass / Fordham Boulevard		√	√			√	
LCBN02	Bolin Creek at East Franklin Street (Greenway)	√	√	√		√	√	√ #5 Bolin
LCBN02A	Bolin Creek at Bolinwood Drive	√						
LCBN03	Bolin Creek at Airport Road / NC 86					√	√	
LCBN04	Bolin Creek at Village Drive	√	√	√		√	√	√ #4 Bolin
LCBN04A	Bolin Creek at Umstead Park		√	√				
LCBN06	Bolin Creek at Homestead Road / SR1777	√	√	√				
LCBNTB01	Tanbark Branch at Umstead Park	√						
#11 Bolin	Bolin Creek at Pathway Drive							√ #11 Bolin

Table 5.1 Part B - Summary of Monitoring Approaches Used at Primary Sampling Sites, Booker Creek

Station Code	Location	Monitoring Approach						
		Benthic Invertebrates	Water Chemistry	Toxicity (Water)	Sediment Quality	SPMD[1]	Data Sonde[2]	Chapel Hill Water Chemistry
Booker Creek								
LCBK01	Booker Creek below Willow Drive	√[3]	√	√			√	√ #13 Booker
LCBK02A	Unnamed tributary to Booker Creek near Ephesus Church Road		Field + MTBE					
LCBK03	Booker Creek behind Eastgate Shopping Center		Field only				√	
LCBK04	Booker Creek at East Franklin Street		Field only				√	
LCBK07	Booker Creek at Piney Mountain Road	√						√ #8 Booker
LCBK08	Booker Creek at Barbara Court	√						
#12 Booker	Booker Creek at Airport Road / NC 86							√ #12 Booker
LCBKCB01	Crow Branch upstream of Airport Road / NC 86		√					
LCBKCB02	Crow Branch downstream of Airport Road / NC 86			√				

1 SPMD is a semi-permeable membrane device used to detect hydrophobic organic contaminants over a seven-day period.

2 Data sonde is a multi-probe field data recorder that sampled at 15-minute intervals for up to seven days.

3 Site is located across from Walnut Street.

Bolin Creek at Umstead Park (LCBN04A). This site was located at the confluence of Bolin Creek and Tanbark Branch in Umstead Park, less than 0.25 miles downstream of the Village Drive site. Grab samples were analyzed and toxicity was also assessed during a nearby sanitary sewer leak.

Tanbark Branch at Umstead Park (LCBNTB01). This sampling location was located on Tanbark Branch 150 meters upstream of the confluence with Bolin Creek. Biological monitoring was conducted at this site.

Bolin Creek at Homestead Road / SR1777 (LCBN06). This site was the most upstream sampling site in Bolin Creek, approximately 6.3 miles from LCLC01. It is located less than one mile downstream of a large housing development under construction near Bolin Creek and Hogan Lake. Several grab samples from this site were analyzed for potential chemical stressors. This site was also a biological monitoring station.

Bolin Creek at Pathway Drive (#11 Bolin). This site was located was approximately 4.7 miles upstream from the integrator station (LCLC01). The Town of Chapel Hill conducted all sampling at this location.

Booker Creek at Willow Drive (LCBK01). This was the furthest downstream site sampled on Booker Creek, approximately 1.2 miles upstream of LCLC01. Samples collected at US 15-501 Bypass, a short distance upstream, are also included. This area is downstream of Eastgate Shopping Center. Grab samples were analyzed for the pollutants described in Section 5.1.1. Monitoring at this site also included benthic invertebrate sampling, data sonde deployment, and chemical monitoring by the Town of Chapel Hill (#13 Booker).

Unnamed tributary to Booker Creek near Ephesus Church Road (LCBK02A). This small tributary drains into Booker Creek near US 15-501 Bypass. Field parameters and MTBE were measured at this site.

Booker Creek behind Eastgate Shopping Center (LCBK03). This sampling site was located in Booker Creek immediately downstream of Eastgate Shopping Center. Field parameters were measured at this site and a data sonde was also deployed.

Booker Creek at East Franklin Street (LCBK04). This sampling site was immediately upstream of Eastgate Shopping Center. Field parameters were measured at this site and a data sonde was also deployed.

Booker Creek at Piney Mountain Road (LCBK07). This site was approximately 3.8 miles upstream of LCLC01. This was a biological monitoring station and the Town of Chapel Hill routinely monitors the water chemistry at this site (#8 Booker).

Booker Creek at Barbara Court (LCBK08). This site in the headwaters of Booker Creek is approximately 4.9 miles upstream of LCLC01. There is substantial new residential development in the surrounding area. Benthic macroinvertebrate sampling was conducted here.

Booker Creek at Airport Road / NC 86 (#12 Booker). This is located a short distance upstream from the Barbara Court site (LCBK08). The Town of Chapel Hill conducted all sampling at this location.

Crow Branch upstream of Airport Road (LCBKCB01). This sampling site was located on Crow Branch, a tributary of upper Booker Creek. Several inactive UNC-CH hazardous waste disposal sites lie adjacent to the stream (see Section 2). Grab samples were collected at this site for water chemistry analysis.

Crow Branch downstream of Airport Road (LCBKCB02). This sampling site was located on Crow Branch between Airport Road and the confluence of Booker Creek. Water toxicity samples were collected in two areas in this reach, one immediately below Airport Road and one above the confluence of Crow Branch and Booker Creek.

5.2 Water Quality Characterization

Field parameter and turbidity data collected during the study at downstream sites in Little, Bolin and Booker Creeks are summarized in Table 5.2, along with data collected by the Town of Chapel Hill at these same locations.

Specific conductance was elevated at all three sites, likely a reflection of pollutant inputs to the watershed. During the one storm sampled, specific conductance was measured at over 400 µS/cm in Booker Creek at LCBK01, an unusually elevated level for storm conditions. Specific conductance levels were generally lower further upstream in Bolin Creek where development is less intense. For example, specific conductance measured during benthic macroinvertebrate sampling averaged 159 µS/cm in Bolin Creek at East Franklin Street, but 110 µS/cm upstream at Homestead Road (see Appendix A).

Typical pH levels were around 7 SU, with little variability. Turbidity was highly variable. During a storm the turbidity of Booker Creek at Willow Drive was 540 NTU. Mean turbidity measured by DWQ during baseflow in Little Creek at Pinehurst Drive exceeded the North Carolina standard of 50 NTUs, although this is based on only a few samples. Data collected by the Town of Chapel Hill do not show baseflow violations of the turbidity standard at this site.

Average concentrations of dissolved oxygen (DO) did not violate North Carolina standards except at LCLC01, where data collected by Chapel Hill indicated mean levels below the NC daily average standard of 5.0 mg/L (the instantaneous standard is 4.0 mg/L). As will be discussed later (Section 5.3), low DO concentrations were commonly observed during the summer months. Differences between the baseflow DO concentrations measured by DWQ and the Town of Chapel Hill may be a result of the differing sampling methods; staff from Chapel Hill measured DO even during periods of no flow while DWQ only measured when there was observable streamflow.

Table 5.2 Mean Values (and standard errors) for Selected Parameters at Downstream Sites on Little, Bolin and Booker Creeks[1]

Parameter	Study Data August 2001 – August 2002		Town of Chapel Hill August 2001 – August 2002
	Baseflow	Storm	Baseflow
Little Creek at Pinehurst Drive (LCLC01)			
Dissolved Oxygen (mg/L)	9.64 ± 1.77 (5)	5.60 ± 0.00 (1)	4.83 ± 1.07 (11)
pH (Standard Units)	7.46 ± 0.36 (4)	7.10 ± 0.00 (1)	7.18 ± 0.07 (11)
Specific Conductance (µS/cm)	179.7 ± 15.1 (5)	200.7 ± 0.00 (1)	202.9 ± 20.8 (11)
Turbidity (NTU)	51.4 ± 40.8 (3)	132.0 ± 0.00 (1)	18.1 ± 5.3 (13)
Bolin Creek at East Franklin Street (LCBN02)			
Dissolved Oxygen (mg/L)	9.20 ± 0.97 (8)	4.93 (1)	6.44 ± 1.30 (11)
pH (Standard Units)	7.35 ± 0.17 (7)	6.80 (1)	7.33 ± 0.05 (11)
Specific Conductance (µS/cm)	199.0 ± 13.2 (8)	231.4 (1)	190.8 ± 10.5 (11)
Turbidity (NTU)			3.3 ± 0.4 (13)
Booker Creek at Willow Drive (LCBK01)			
Dissolved Oxygen (mg/L)	8.44 ± 1.06 (7)	4.08 (1)	5.43 ± 1.10 (11)
pH (Standard Units)	7.36 ± 0.11 (6)	6.85 ± 0.15 (2)	7.31 ± 0.04 (11)
Specific Conductance (µS/cm)	208.8 ± 7.6 (7)	411 (1)	232.2 ± 16.3 (11)
Turbidity (NTU)		540 (1)	14.7 ± 1.8 (13)

[1] Number of samples in parentheses. Blanks indicate that data were not available.

5.3 Stressor and Source Identification

Given the complexities of land use and management in this developed watershed, a wide range of chemical and physical stressors could potentially impact water quality in streams within the study area, including toxicants, nutrients, and low dissolved oxygen. Results pertaining to water column toxicity are reported in Section 5.3.1, sediment toxicity in 5.3.2, dissolved oxygen (DO) and nutrients in 5.3.3, and fecal coliform bacteria in 5.3.4.

5.3.1 Water Column Toxicity

This section presents the results of bioassays conducted on water column samples, followed by a discussion of organic pollutants, metals, and other toxicants.

a. Bioassays

Ten long-term bioassays (chronic) for toxicity were conducted on baseflow samples (Table 5.3). Additionally, a total of eight acute bioassays for toxicity were conducted during three storm events and one sanitary sewer spill (Table 5.4). All of the acute toxicity bioassays passed (Table

5.4), indicating that test organism mortality did not occur during any of these events, although sub-lethal effects could have been present. Both of the chronic bioassays conducted on samples collected in Crow Branch showed evidence of toxicity (Table 5.3). A test conducted on a November 13, 2001 sample failed with a 36 percent reduction in *Ceriodaphnia* reproduction. A June 2002 sample had a statistically significant 17 percent reduction in reproduction. This indicates the existence of toxic conditions even though DWQ's criterion of 20 percent or greater reduction in reproduction was not met. The 20 percent criterion is used by DWQ to decrease the probability of falsely reporting toxic results within the regulatory framework (permitting of wastewater discharges) for which the protocol was developed. Similarly, one of two chronic bioassays conducted on samples from Booker Creek at LCBK01 showed evidence of toxicity (statistically significant reduction in reproduction of 18 percent, though not meeting the 20 percent criterion for formal test failure). Chronic bioassays conducted in Little and Bolin Creek did not indicate toxicity, though the number of tests was limited (Table 5.3). Several of the Bolin Creek tests were "invalid" because the test was run without the use of a renewal sample. This likely decreased the ability of the test to detect sub-lethal toxicity, due to physical and chemical changes resulting from long-term storage of the sample, and reduced the potential to detect intermittent effects.

Chemical sampling was not conducted in conjunction with the toxic situations described above for Booker Creek and Crow Branch, so data on concentrations of potential toxicants at those times are not available. However elevated conductivity levels in the first Crow Branch sample tested for toxicity may be high enough to cause or contribute to toxicity. Specific conductance was 1020 µS/cm in the original sample and 1120 µS/cm in the renewal sample. Conductivity at this level, which is indicative of a significant level of chemical inputs (though it is non-specific as to the specific analytes involved), could potentially contribute to toxicity by causing ionic imbalances in aquatic organisms. Two inactive UNC hazardous waste landfills (see Section 2) lie adjacent to Crow Branch, just upstream of the sampling sites. UNC has observed unusually high conductivity and total dissolved solids levels in this area (Section 2).

On February 15, 2002, DWQ staff measured specific conductance in Crow Branch at several locations near the landfills. There was a dramatic and sudden increase in conductance associated with the Airport Road Waste Disposal Area. Specific conductance was 100 µS/cm above the landfill sites, 223 µS/cm part way through the site, as high as 974 µS/cm further downstream in the landfill site and 596 µS/cm at the most downstream location evaluated, just above Airport Road. These results point to the landfill area as a source of high conductivity inputs, although the particular constituents responsible are not known.

Table 5.3 Chronic Toxicity Bioassay Results, Water Column Samples*

Sampling Date	Little Creek at Pinehurst Drive	Bolin Creek at Fordham Boulevard / US Hwy 15-501	Bolin Creek at East Franklin Street	Bolin Creek at Village Drive	Bolin Creek at Homestead Road / SR 1777	Booker Creek at Willow Drive	Crow Branch downstream of Airport Road / NC 86
	LCLC01	LCBN01	LCBN02	LCBN04	LCBN06	LCBK01	LCBKCB02
September 13, 2001	PASS						
November 13, 2001							**FAIL**
April 23, 2002		INVALID[2]	PASS			PASS	
June 25, 2002						PASS[1]	PASS[1]
August 13, 2002			PASS[3]	PASS[3]	PASS[3]		

* A "pass" indicates that the average reproduction in test samples was determined to have been decreased by less than 20 percent, and that average reproduction is not statistically different from average control organism reproduction. Blanks indicate that samples were not collected. See Appendix B for additional test data.

[1] Statistically significant reduction in reproduction observed, but reduction did not meet DWQ's 20% threshold for test 'failure'.

[2] Invalid due to control failure. See Appendix B.

[3] Test passed in terms of reproduction, but was run without a renewal sample which was not collected due to rain.

Table 5.4 Acute Water Toxicity Bioassay Results, Water Column Samples*

Sampling Date	Little Creek at Pinehurst Drive	Bolin Creek at Fordham Boulevard / US Hwy 15-501	Bolin Creek at East Franklin Street	Bolin Creek at Umstead Park	Booker Creek at Willow Drive
	LCLC01	LCBN01	LCBN02	LCBN04A	LCBK01
May 13, 2002			PASS		PASS
May 30, 2002				PASS	
July 25, 2002		PASS			PASS
August 16, 2002	PASS		PASS		PASS

* A 'pass' indicates that there was no significant mortality. Blanks indicate that samples were not collected. See Appendix B for additional test data.

b. Pesticides

Grab samples. Seven current use pesticides were detected in grab samples collected during the study (Table 5.5). Atrazine was detected at a concentration of 0.17 µg/L in a storm sample from Bolin Creek at East Franklin Street on August 16, 2002. Atrazine concentrations are well below EPA draft chronic and acute criteria levels (Great Lakes Environmental Center and University of Wisconsin, 2001) of 12.35 µg/L and 351.2 µg/L, respectively. The other pesticides were detected using a broad scan GC/MS method (Table 5.7) that is less exact in determining concentrations. Chloroxylenol, DEET, and bromacil were detected in samples but it was not possible to quantify concentrations. Bromacil is an herbicide and kinoprene is an insect juvenile hormone analog. DEET (an insect repellant) and anthraquinone (a goose repellant) were also detected. Chloroxylenol is an anti-microbial used in adhesives and paints, while o-phenylphenol is a germicide and fungicide used on citrus fruits and some vegetables. Established toxicity benchmarks are not available for these pesticides, however all were well below any estimated effects levels (LC_{50} or EC_{50} values) available in the literature (see Appendix B).

A complete listing of pesticides tested for is shown in Appendix B. Organochlorine pesticides and polychlorinated biphenyls (PCBs) were not detected in grab samples. Laboratory analysis was not available during the study for some pesticides commonly used in urban areas (e.g., glyphosate).

Table 5.5 Pesticides Detected in Grab Samples in the Little Creek Watershed[1]

Analyt (µg/L)	May 13, 2002 (storm)			August 13, 2002 (baseflow)			August 16, 2002 (storm)		
	LCBN01	LCBN02	LCBK01	LCBN02	LCBN04	LCBN06	LCLC01	LCBN02	LCBK01
Current Use Pesticides									
atrazine	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	**0.17**	< 0.005
o-phenylphenol	< 0.1	< 0.1	**0.81**	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
anthraquinone	**2.7**	< 0.1	**4.8**	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
kinoprene	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	**0.1**	**0.05**	< 0.1
chloroxylenol	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	**detected**	< 0.1	< 0.1	< 0.1
DEET	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	**detected**	< 0.1	**detected**	< 0.1
bromacil	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	**detected**
Other Organic Compounds									
acetaminophen	**0.29**	< 0.1	**0.37**	< 0.1	< 0.1	< 0.1	< 0.1	**0.09**	**0.13**
caffeine	**0.52**	**1.4**	**6.2**	**0.11**	< 0.1	**0.12**	< 0.1	**0.2**	**0.37**
carbazole	**1.8**	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

[1] Atrazine was detected using quantitative GC/MS method. Other parameters were measured using broad scan GC/MS methods. In some instances, analytes were detected but concentrations could not be quantified. These are listed as "detected". Table includes only sampling events for which at least one analyte was detected. Samples collected on 9/13/01, 2/19/02, 3/26/02, 4/23/02 (baseflow samples) and 7/25/02 (storm event) did not exceed the detection limits for any compound and are not included.

SPMDs. Long-term monitoring with semi-permeable membrane devices (SPMDs) was conducted in the late summer of 2002 at three sites in Bolin Creek (LCBN02, LCBN03, LCBN04). Concentrations from SPMDs represent an average concentration over the entire deployment period and are an excellent indication of the hydrophobic organic contaminants to which the sampling site was exposed. The devices were deployed for seven days and analyzed for a range of organic contaminants. Analytes detected included: the current use pesticide chlorpyrifos, organochlorine pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and benzothiazole, a rubber and plastic additive. Due to dropping water levels, the devices were exposed to the air for a portion of the deployment period and concentrations could not be reliably estimated. A list of analytes detected is included in Appendix B.

c. Other Organic Compounds

In addition to pesticides, organic contaminants analyzed included: phenols, total petroleum hydrocarbons (TPH), methyl tertiary-butyl ether (MTBE), methylene blue active substances (MBAS), polycyclic aromatic hydrocarbons (PAH), and base, neutral and acid organics. Phenols and TPHs were not detected. PAHs were detected at several sites during one storm. Several base, neutral, and acid organics were detected in Booker Creek. MTBE and MBAS were found throughout the lower portion of the watershed**.**

Acetaminophen and caffeine were detected in a number of storm samples (Table 5.5), indicating inputs from either runoff or sewer overflows.

MTBE. Methyl tertiary-butyl ether, MTBE, is a gasoline additive that is highly soluble in water. It can enter surface waters from leaks in underground storage tanks, gasoline runoff from spills or automobile accidents, and consumer disposal of 'old' gasoline. Despite the absence of detectable total petroleum hydrocarbons, MTBE was detected frequently (Table 5.6) in both Booker and Bolin Creek. MTBE was detected more frequently in Booker Creek than in Bolin Creek, though it is difficult to generalize from the data available. MTBE was detected in two out of three storm samples collected from Booker Creek at LCBK01, downstream of Eastgate Shopping Center.

Several other sites were screened for MTBE on a few occasions but it was not detected (see Appendix B). These sites included an unnamed tributary leading into Booker Creek near Eastgate Shopping Center, Crow Branch above Airport Road (LCBKCB02), Bolin Creek at Airport Road (LCBN03), Bolin Creek at Village Drive (LCBN04), and Bolin Creek at Homestead Road (LCBN06).

MTBE toxicity benchmarks for aquatic life have not been established. Toxicity bioassays were conducted in conjunction with several sampling events (April 23 and May 13, 2002) but MTBE was not detected on these occasions.

Table 5.6 MTBE (methyl tertiary-butyl ether) at Selected Sampling Sites in the Little Creek Watershed

Sampling Date	Little Creek at Pinehurst Drive (LCLC01) (µg/L)	Booker Creek at Willow Drive (LCBK01) (µg/L)	Bolin Creek at 15-501 Bypass (LCBN01) (µg/L)	Bolin Creek at East Franklin Street (LCBN02) (µg/L)
Baseflow				
9/13/01	< 1.00	**8.10**		< 1.00
1/2/02	< 1.00	< 1.00		**2.39**
2/5/02	< 1.00	< 1.00		**4.31**
2/19/02	< 1.00	**3.19**		< 1.00
3/26/02		**1.62**		< 1.00
4/23/02		< 1.00	< 1.00	< 1.00
Storm				
2/6/02		**2.24**		< 1.00
5/13/02		< 1.00	< 1.00	< 1.00
7/25/02		**1.01**	< 1.00	

PAHs. Polycyclic aromatic hydrocarbons were detected during a storm on May 13, 2002 (Table 5.7). Eight PAHs were detected in Booker Creek at Willow Drive (LCBK01). Only benzo(a)anthracene was detected in Bolin Creek at 15-501 (LCBN01) and East Franklin Street (LCBN02). The Tier II criteria for benzo(a)anthracene are 0.49 µg/L acute and 0.027 µg/L chronic. Concentrations at all three sites are more than an order of magnitude above the acute benchmark. Benchmarks are not available for the other analytes. However comparisons to LC_{50} values from the literature revealed several that several compounds (pyrene, chrysene) were present in Booker Creek at concentrations potentially toxic to invertebrates. Concentrations at the Bolin Creek sites did not exceeded the LC_{50}s. Toxicity bioassays were conducted on samples collected at LCBN02 and LCBK01 during this event and did not indicate the presence of toxic conditions.

PAHs were also detected during SPMD deployments in Bolin Creek, but concentrations could not be quantified. PAHs are a byproduct of incomplete combustion. Common sources include vehicle exhaust, tire and pavement wear, and fires (wildfires, burning trash, and wood stoves). PAHs can enter streams in stormwater runoff, via atmospheric deposition, or during spills.

Table 5.7 Polycyclic Aromatic Hydrocarbons Detected and Their Toxicity Values

PAHs (µg/L)	May 13, 2002 Stormflow			Literature Data			
	LCBN01	LCBN02	LCBK01	Species	Endpoint	Concentration	Reference
phenanthrene	< 5.00	< 5.00	**6.12**	*Chironomus tentans*	LC_{50}	490 µg/L	Millemann et al., 1984
fluoranthrene	< 5.00	< 5.00	**6.95**[1]	*Chironomus tentans*	LC_{50}	12.6 µg/L	Hatch, 1999
						250 µg/L	Suedel, 1996
pyrene	< 5.00	< 5.00	**5.95**[1]	*Daphnia magna*	LC_{50}	4 µg/L	Kagan et al., 1985
benzo(a)anthracene	**5.75**	**8.41**	**18.5**	*Daphnia pulex*	LC_{50}	10 µg/L	Trucco, et al., 1983
chrysene	< 5.00	< 5.00	**5.26**[1]	*Daphnia magna*	LT_{50}	0.7 µg/L for 23.98 hrs.	Newsted and Giesy, 1987
benzo(b)fluoranthene	< 5.00	< 5.00	**16.8**				None Available
benzo(k)fluoranthene	< 5.00	< 5.00	**6.36**[1]				None Available
indeno(1,2,3-cd)pyrene	< 5.00	< 5.00	**7.75**				None Available

[1] Analysis by EPA method 610 had different results: fluoranthrene 850; pyrene 6.46; chrysene 17.2; and benzo(k)fluoranthene < 5.00.

MBAS. Methylene blue active substances (MBAS), an indicator of anionic surfactants, were detected frequently in the Little Creek watershed (Table 5.8). Concentrations were highest and detections most frequent in Booker Creek at Willow Drive (LCBK01). Little Creek frequently had lower concentrations than either Booker Creek or Bolin Creek. The origin of these surfactants is not known. Possibilities include car washing (including home washing) and pavement degreasing, among other sources. The highest concentration observed was 0.254 mg/L in Booker Creek at Willow Drive (LCBK01) on July 25, 2002. A bioassay conducted during this event did not indicate toxic conditions.

A screening benchmark is not available for MBAS. The toxicity of specific surfactants varies, and the laboratory test for MBAS does not identify which anionic surfactants are present. The common anionic surfactant linear alkylbenzene sulfonate (LAS) can be toxic at concentrations as low as 0.025 mg/L (Kimerle, 1989). The lack of toxic effect at the MBAS concentrations observed in the Little Creek watershed may be explained by the nature of the specific surfactants present (e.g., predominant substances may be less toxic than LAS), by the loss of surfactants during laboratory bioassay procedures, or by analytical interferences.

Table 5.8 Concentrations of Methylene Blue Active Substances (MBAS) in the Little Creek Watershed

Date	**Little Creek at Pinehurst Drive (LCLC01)** (mg/L)	**Booker Creek at Willow Drive (LCBK01)** (mg/L)	**Crow Branch upstream of Airport Road (LCBKCB01)** (mg/L)	**Bolin Creek at 15-501 Bypass (LCBN01)** (mg/L)	**Bolin Creek at East Franklin Street (LCBN02)** (mg/L)
Baseflow					
9/13/01	**0.117**	**0.115**			< 0.025
2/5/02	< 0.025	< 0.025			< 0.025
2/19/02	< 0.025	**0.053**	**0.061**		< 0.025
3/26/02		< 0.025			< 0.025
4/23/02	< 0.025	**0.066**			**0.070**
Storm					
2/6/02	< 0.025	**0.269**			**0.100**
5/13/02	< 0.025	< 0.025		< 0.025	**0.075**
7/25/02		**0.254**		**0.113**	

Blanks indicate that samples were not collected.

d. Metals

Natural geological sources provide inputs of some metals via soil and groundwater. In central North Carolina, for example, substantial iron and aluminum inputs are not unusual, even in relatively unimpacted watersheds. Human activity in developed watersheds results in many additional sources of metals. Motor vehicles, for example are an important source of copper, zinc and cadmium (from tailpipe exhaust and from tire, break and clutch wear). Building siding, roofing and gutters are also common metals sources, as are construction (soil erosion) and a variety of industrial and commercial activities. Metals from these sources can be washed into streams during storms. Illegal discharges to the storm sewer system can also be a source of metals, while atmospheric deposition (e.g., of pollutants emitted by motor vehicles) can also be an important pathway for some metals.

Trace metals were commonly found throughout the Little Creek watershed. Baseflow and stormflow data for primary sampling sites are shown in Tables 5.9 and 5.10, respectively. Data collected at additional sites are presented in Appendix B. Arsenic and mercury were not detected in the watershed. Chromium was detected only during storms.

Aluminum, iron, and manganese often exceeded their National Ambient Water Quality Criteria (NAWQC) benchmarks (EPA criteria for the protection of aquatic life; see Section 5.1.1) during baseflow throughout the Little Creek watershed. Silver and lead exceeded their NAWQC benchmark in Little Creek at Pinehurst Drive during one baseflow sample on January 2, 2002. Baseflow samples from Bolin Creek on April 23, 2002 and August 13, 2002 showed a trend of increasing concentrations of a number of metals from upstream to downstream (see Appendix

B). Despite the high concentration of metals throughout the watershed, all of the chronic toxicity bioassays from Little Creek, Bolin Creek, and Booker Creek passed (Table 5.3).

Storm sampling was limited by below normal rainfall during the study period. Of the three storms sampled, benchmarks were exceeded only in Booker Creek at Willow Drive (LCBK01) on May 13, 2002. This site is immediately downstream of Eastgate Shopping Center. Aluminum, copper, and zinc exceeded their benchmarks during this storm. A toxicity bioassay conducted during this event did not indicate the presence of acutely toxic conditions (test organism mortality). Comparisons of metal concentrations at various sites during individual storms indicate that Booker Creek typically has higher concentrations of metals than Bolin Creek.

The Town of Chapel Hill analyzed monthly baseflow samples for copper, zinc and lead (Table 5.11). Lead was not detected during the time period examined (August 2001 - August 2002). Copper and zinc did not exceed EPA criteria. Since Chapel Hill did not analyze samples for hardness, hardness-adjusted EPA criteria were derived using typical harness values from DWQ sampling in the study area.

Metals such as aluminum, iron, manganese, copper, and zinc are widespread in North Carolina's waters. Observed concentrations of aluminum, copper, and zinc in the Little Creek watershed do not appear to differ greatly from the concentrations of nearby slate belt streams which have Good to Excellent bioclassifications and for which water chemistry data are available (Table 5.12). However, median iron concentrations are higher in Little Creek and Booker Creek than in the other nearby streams, and manganese concentrations are higher throughout the Little Creek watershed. Caution must be used in making these comparisons; however, since the data from the current study are based on a much smaller set of observations than the ambient data (for which figures are based upon five years of monthly observations), and thus, would be less likely to reflect the entire range of concentrations experienced by these streams.

Since total rather than dissolved concentrations of metals were measured, bioavailability is difficult to fully assess. Adjusting benchmarks for hardness only partially addresses this issue. The potential effects of metals on benthic macroinvertebrates are uncertain, since organisms in a given locality may be adapted to local concentrations. Bioassays were conducted with samples that exceeded the NAWQC benchmarks for several metals, but did not indicate toxicity.

Table 5.9 Total Metal Concentrations at Baseflow and NAWQC Chronic Values

a. Little Creek at Pinehurst Drive (LCLC01). Metal concentrations are in µg/L and hardness values are in mg/L. Bold type indicates values that exceed National Ambient Water Quality Criteria (NAWQC). NAWQC values vary according to water hardness for cadmium, copper, lead, nickel, and zinc. The range of values for the NAWQC is given for the hardness values measured. Tier II values are used for silver and manganese, for which NAWQC are not available.

	NAWQC Chronic Values (µg/L)	**9/13/01** LCLC01 (µg/L)	**1/2/02** LCLC01 (µg/L)	**2/5/02** LCLC01 (µg/L)	**2/19/02** LCLC01 (µg/L)
Aluminum	87	**202**	**266**	**165**	**163**
Arsenic	150	< 5	< 5	< 5	< 5
Cadmium	1.4 – 2.1	< 0.1	0.1	< 0.1	< 0.1
Chromium	11	< 1	< 1	< 1	< 1
Copper	5.0 – 7.8	3	5[1]	< 1	< 1
Iron	1000	**1470**	**2000**	**1410**	944
Lead	1.2 – 2.4	< 1	**3**	< 1	< 1
Manganese	120	**367**	**390**	**279**	**152**
Mercury	0.77	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	28.0 – 43.6	< 1	2	< 1	< 1
Silver	0.36	< 0.5	**2.6**	< 0.5	< 0.5
Zinc	64.3 – 100.2	3.2	15.5	4.4	6.8
Hardness		70 mg/L	81 mg/L	61 mg/L	48 mg/L

[1] NAWQC of copper with a hardness value of 81 mg/L is 7.8 µg/L.

Table 5.9 Total Metal Concentrations at Baseflows and NAWQC Chronic Values

b. Bolin Creek at East Franklin Street (LCBN02). Metal concentrations are in µg/L and hardness values are in mg/L. Bold type indicates values that exceed the National Ambient Water Quality Criteria (NAWQC). NAWQC values varied according to water hardness for cadmium, copper, lead, nickel, and zinc. The range of values for the NAWQC is given for the hardness values measured. Tier II values are used for silver and manganese, for which NAWQC are not available.

	NAWQC Chronic Values (µg/L)	**1/ 2/02** LCBN02 (µg/L)	**2/ 5/02** LCBN02 (µg/L)	**2/19/02** LCBN02 (µg/L)	**3/26/02** LCBN02 (µg/L)	**4/23/02** LCBN02 (µg/L)	**8/13/02** LCBN02 (µg/L)
Aluminum	87	**237**	**165**	**130**	**212**	59	22
Arsenic	150	< 5	< 5	< 5	< 5	< 5	< 5
Cadmium	1.8 – 2.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Chromium	11	< 1	< 1	< 1	< 1	< 1	< 1
Copper	6.8 – 7.9	< 1	< 1	< 1	2	< 1	< 1
Iron	1000	**1630**	**1640**	581	602	677	**1020**
Lead	2.0 – 2.5	< 1	< 1	< 1	< 1	2	< 1
Manganese	120	**236**	**283**	50	81	**131**	**284**
Mercury	0.77	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	38.1 – 44.1	< 1	< 1	< 1	< 1	< 1	< 1
Silver	0.36	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Zinc	87 – 101	10.5	4	< 0.1	3.7	< 0.1	3.2
Hardness		69 mg/L[1]	69 mg/L[1]	69 mg/L[1]	69 mg/L[1]	69 mg/L[1]	82 mg/L

[1] Hardness values were not available for these samples. Average hardness of all Bolin Creek samples was used to calculate adjusted NAWQC.

Table 5.9 Total Metal Concentrations in Baseflows and NAWQC Chronic Values

c. Booker Creek at Willow Drive (LCBK01). Metal concentrations are in µg/L and hardness values are in mg/L. Bold type indicates values that exceed the National Ambient Water Quality Criteria (NAWQC). NAWQC values varied according to water hardness for cadmium, copper, lead, nickel, and zinc. The range of values for the NAWQC is given for the hardness values measured. Tier II values are used for silver and manganese, for which NAWQC are not available.

	NAWQC Chronic Values (µg/L)	**8/9/01** LCBK01 (µg/L)	**10/4/01** LCBK01 (µg/L)	**1/ 2/02** LCBK01 (µg/L)	**2/ 5/02** LCBK01 (µg/L)	**2/19/02** LCBK01 (µg/L)	**3/26/02** LCBK01 (µg/L)	**4/23/02** LCBK01 (µg/L)
Aluminum	87	**430**	**310**	40	**146**	**172**	**779**	**2240**
Arsenic	150	< 10	< 10	< 5	< 5	< 5	< 5	< 5
Cadmium	1.8	< 2	< 2	< 0.1	< 0.1	< 0.1	< 0.1	0.5
Chromium	11	< 25	< 25	< 1	< 1	< 1	< 1	< 1
Copper	6.5 – 6.8	2.3	4.7	< 1	1	< 1	1	< 1
Iron	1000	**1600**	**1300**	443	575	**1470**	**1480**	**4230**
Lead	1.9 – 2.0	< 10	< 10	< 1	< 1	< 1	< 1	**6**
Manganese	120	**470**	**290**	87	99	**277**	**288**	**1670**
Mercury	0.77			< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	37 – 38	< 10	< 10	< 1	< 1	< 1	< 1	2
Silver	0.36	< 5	< 5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Zinc	84 – 87	< 10	17	< 0.1	1.9	4.9	6.4	15.1
Hardness		66 mg/L	69 mg/L[1]	69 mg/L[1]	69 mg/L[1]	69 mg/L[1]	69 mg/L[1]	69 mg/L[1]

[1] Hardness values were not available for these samples. Average hardness of all Bolin Creek samples was used to calculate adjusted NAWQC.

Table 5.10 Total Metal Concentrations During Storm Events and NAWQC Acute Values (µg/L) in Little Creek, Bolin Creek, and Booker Creek

Bold type indicates values that exceed the National Water Quality Criteria (NAWQC). NAWQC values varied according to water hardness for cadmium, copper, lead, nickel, and zinc. The range of values for the NAWQC is given for the hardness values measured. Tier II values are used for silver and manganese, for which NAWQC are not available.

	Acute Criteria (µg/L)	Little Creek		Bolin Creek					Booker Creek			
		2/6/02 LCLC01 (µg/L)	**8/16/02** LCLC01 (µg/L)	**5/13/02** LCBN01 (µg/L)	**7/25/02** LCBN01 (µg/L)	**2/6/02** LCBN02 (µg/L)	**5/13/02** LCBN02 (µg/L)	**8/16/02** LCBN02 (µg/L)	**2/6/02** LCBK01 (µg/L)	**5/13/02** LCBK01 (µg/L)	**7/25/02** LCBK01 (µg/L)	**8/16/02** LCBK01 (µg/L)
Aluminum	750	277	209	182	395	207	529	50	350	**8040**	493	58
Arsenic	340	< 5	< 5	< 5	-5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Cadmium	1.4 – 5.4	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.6	< 0.1	0.2	0.5	< 0.1	0.1
Chromium	16	< 1	< 1	< 1	5	< 1	< 1	< 1	1	4	6	< 1
Copper	5.2 – 16.4	2	3	4	**25**	2	8[1]	3	3	**30**	10	3
Iron	N/A	1340	3780	970	868	588	1950	392	1500	5280	464	728
Lead	21.5 – 101	< 1	5	1	20	< 1	7	< 1	< 1	30	15	< 1
Manganese	2300	245	1130	438	298	92	288	100	252	1210	339	660
Mercury	1.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	193 – 540	< 1	< 1	< 1	3	< 1	1	< 1	< 1	5	4	2
Silver	0.7 – 5.4	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Zinc	49 – 138	4	53.5	16.8	**58**[1]	6.6	37	26.5	6.2	**160**	50.8	76[2]
Hardness		64 mg/L	70 mg/L	62 mg/L	35 mg/L	69 mg/L[2]	69 mg/L[2]	74 mg/L	69 mg/L[2]	69 mg/L[2]	38 mg/L	118 mg/L

[1] The zinc criteria value for water with a hardness of 35 mg/L is 49 mg/L.

[2] Hardness values were not available for these samples. Average hardness of all of the Bolin Creek samples was used to calculate adjusted NAWQC values.

Table 5.11 Mean Metals Concentrations (and standard errors), Town of Chapel Hill Sampling Sites in the Little Creek Watershed, August 2001 to August 2002

Metal (µg/L)	Sampling Location						
	#6 Little	**#5 Bolin**	**#4 Bolin**	**#11 Bolin**	**#13 Booker**	**#8 Booker**	**#12 Booker**
Copper	4.0 ± 1.0 (3)	3.7 ± 1.3 (3)	3.7 ± 1.3 (3)	3.8 ± 0.7 (6)	3.7 ± 1.3 (3)	< 10 ± 0.0 (3)	3.7 ± 1.3 (3)
Lead	< 5 ± 0.0 (3)	< 5 ± 0.0 (3)	< 5 ± 0.0 (3)	< 5 ± 0.0 (6)	< 5 ± 0.0 (3)	< 5 ± 0.0 (3)	< 5 ± 0.0 (3)
Zinc	10.3 ± 2.9 (3)	7.7 ± 2.2 (3)	9.3 ± 3.8 (3)	8.3 ± 2.2 (6)	9.7 ± 3.7 (3)	9.0 ± 2.1 (3)	4 (3)

Source: The Town of Chapel Hill

Table 5.12 Selected Median Metal Concentrations in the Little Creek Watershed and at Nearby DWQ Ambient Stations with Bioclassifications of Good or Excellent, 1996 – 2000[1]

Station Location (Station Number)			This Study at Baseflow			Eno River at SR1004 (J0810000)	Eno River at US 15/501 (J0770000)	Little River at SR1461 (J0820000)	Flat River at SR1614 (J1070000)
			LCLC01	LCBN01	LCBK01				
Benthos Rating (2000)						**GOOD**	**EXCELLENT**	**EXCELLENT**	**GOOD**
Metal (µg/L)	Aluminum	Median	183.5	147.5	310	390	245	230	430
		Maximum	266	237	2240	8100	6800	9700	39000
	Iron	Median	1440	848	1470	800	715	745	920
		Maximum	2000	1640	4230	8500	4300	17000	20000
	Manganese	Median	323	184	288	71	50	25	44
		Maximum	390	283	1670	270	240	850	600
	Copper	Median	1.8	< 1	1	3.1	3	2	2.5
		Maximum	5	2	4.7	23	25	19	140
	Zinc	Median	5.6	3.4	4.9	15	13	12	11
		Maximum	15.5	10.5	17	160	100	66	89

[1] Ambient station data are from NCDWQ (2001b). Detection limits for other metals the ambient stations were too high for useful comparison to samples from this study.

5.3.2 Bed Sediment Toxicity

a. Bioassays

Bed sediment toxicity and chemistry were evaluated in Little Creek at Pinehurst Drive (LCLC01) because the benthic community composition and severe *Chironomus* deformities at this location indicated potential toxic impacts (Section 4 and Appendix A). Sandy and fine (depositional) sediments were collected in August 2001 analyzed separately for toxicity (42-day test using the amphipod *Hyallela azteca).* The test utilized six outcome measures, including survival and length at various points and reproduction at the end of the test (see Appendix B). A statistically significant decrease ($P = 0.042$) in survival at 35 days was observed in one of the tests, but no other endpoints clearly indicated toxicity. Although reproduction in the depositional sediments of Little Creek appeared to be considerably below reproduction in the control sample, this difference was not statistically significant (see Appendix B).

b. Pesticides and Organic Compounds

Chemical analyses of sediments detected several pesticides and other organic compounds that may cause toxicity (Table 5.13). Gamma-chlordane, 4,4'-DDE (a breakdown product of DDT), and total DDT's were detected in depositional sediments at concentrations within the lower portion of the conservative benchmark range. These are organochlorine pesticides that are no longer registered for sale. The PAHs pyrene and fluroanthene were detected in sandy sediments at concentrations within the conservative benchmark range. It is possible, though not probable, that these concentrations could result in toxic impacts on aquatic organisms. Depositional sediments exceeded EPA's Region 4 benchmark for pyrene and fluoranthene. Like other PAHs, pyrene and fluoranthene are byproducts of incomplete combustion and bind readily to sediments and particulate matter.

c. Metals

Nine metals were detected in both sandy sediments and depositional sediments (see Appendix B). Sandy sediments contained concentrations of cadmium that were higher than the lowest conservative benchmark (0.6 mg/kg dry weight, compared to the conservative benchmark range of 0.583 to 1.2 mg/kg). However, depositional sediments did not contain any metals at concentrations exceeding the conservative benchmarks. It is possible though not likely that cadmium in sandy sediments is contributing to toxicity in Little Creek.

Sediment chemistry results provide evidence that sediment toxicity is possible in Little Creek, but the probability of toxicity does not appear to be high.

Table 5.13 Organic Pollutants Detected in Bed Sediment in Little Creek at Pinehurst Drive (LCLC01)

Pollutant	Concentration (µg/Kg dry wt.) in Sandy Sediment	Concentration (µg/Kg dry wt.) in Depositional Sediment	Benchmark Values (µg/Kg)[1]		
			Conservative	Non-Conservative	EPA Region 4
Chlorinated Pesticides and PCB's					
hexachlorobenzene	-	0.39	10	6 - 240	NA
alpha-chlordane	-	0.44	0.5 – 7	4.79 - 147	0.5
gamma-chlordane	-	**0.52**	0.5 – 7	4.79 - 147	0.5
trans-nonachlor	-	0.19			
4,4'-DDT	-	0.09	1.19	4.77 – 25	1.19
4,4'-DDD	-	0.14	1.22 to 8	7.81 to 60	1.2
4,4'-DDE	-	**1.60**	1.42 to 5	6.75 to 374	2.07
Total DDTs	-	**1.83**	1.58 to 7	25 to 4450	1.58
Sum of PCB's	-	2.69	10 to 70	180 to 5300	21.6
Other Organic Compounds					
pyrene[2]	**198**	**486**	44.27 to 330	500 to 8500	330
fluoranthene[3]	**228**	**480**	31.46 to 750	750 to 10200	330

[1] Benchmark values are adjusted for Total Organic Carbon (TOC) where appropriate. See Appendix B.

[2] Pyrene was detected at 127 µg/kg with EPA method 8100 (PAH) and 198 µg/kg with EPA method 8270 (semi-volatile compounds) in sandy sediments. In depositional sediments, pyrene was detected at 406 µg/kg with EPA method 8100 (PAH) and 486 µg/kg with EPA method 8270 (semi-volatile compounds).

[3] Fluoranthene was detected at 203 µg/kg with EPA method 8100 (PAH) and 228 µg/kg with EPA method 8270 (semi-volatile compounds) in sandy sediments. In depositional sediments, fluoranthene was detected at 349 µg/kg with EPA method 8100 (PAH) and 480 µg/kg with EPA method 8270 (semi-volatile compounds).

Blanks indicate that benchmark is not available.

Dashes indicate that the compound was not detected.

5.3.3 Dissolved Oxygen and Nutrients

a. Dissolved Oxygen

Field measurements during the study indicated that DO was adequate on average, although daytime levels between 4 and 5 mg/L were recorded (Table 5.14). Booker Creek did not flow for much of the summer of 2002, and was reduced to a series of discontinuous pools even below US 15-501 Bypass near its mouth. DWQ did not sample during these times, but severe DO impacts are likely and obvious habitat loss occurred due to contraction of the wetted channel. Data from multiparameter probes (data sondes) deployed for multiday periods indicated extremely low DO levels in the Franklin Street area in August 2002 (Table 5.14). Data sonde results indicated adequate DO concentrations during winter deployments.

More extensive sampling data covering a longer time period are available from the Town of Chapel Hill. DO data for the warmer months (April through October), when low DO stress is most likely to occur, were examined for the five-year period from 1998 to 2002 (Table 5.15). These data indicate that median April-October DO concentrations below the NC daily average

standard of 5 mg/L occurred in Little Creek and in lower Booker Creek. Concentrations below state standards occurred at every site, though frequencies varied. Most low concentrations occurred in 2002, when all sites had median concentrations below the NC instantaneous standard of 4 mg/L during the April-October period. Some measurements were made when stream discharge was zero or near zero in these streams and only stagnant pools were available for sampling. Severe impacts on stream organisms are likely under these conditions. Low DO concentrations also occurred during 2002 in Morgan Creek at Highway 54, a site west of Carrboro that historically had a bioclassification of 'Good' to 'Excellent'. Excluding 2002, concentrations below 4 mg/L were infrequent, though summer concentrations below 5 mg/L were not unusual in Little Creek and in Booker Creek at Willow Drive.

Table 5.14 Dissolved Oxygen Concentrations (mg/L) from Static Sampling and Continuous Sampling

Site Code[1]	Flow or Date	Mean ± s.e.	Minimum	Maximum	N
Static Sampling (Grab)					
Little Creek					
LCLC01	Baseflow	9.64 ± 1.77	4.90	14.06	5
	Stormflow	5.60 ± 0.00			1
Bolin Creek					
LCBN01	Baseflow	9.40 ± 0.00			1
LCBN02	Baseflow	9.20 ± 0.97	5.63	12.59	8
	Stormflow	4.93 ± 0.00			1
LCBN04	Baseflow	5.58 ± 0.00			1
LCBN06	Baseflow	6.54 ± 0.00			1
Booker Creek					
LCBK01	Baseflow	8.44 ± 1.06	4.67	12.15	7
	Stormflow	4.08 ± 0.00			1
LCBK02A	Baseflow	7.59 ± 1.82	5.77	9.41	2
LCBK03	Baseflow	5.04 ± 0.00			1
LCBK04	Baseflow	6.60 ± 0.00			1
Continuous Sampling (data sonde)[2]					
Bolin Creek					
LCBN01	12/31/01	7.40 ± 0.01	6.88	8.11	425
LCLBN01A[3]	9/27/01	5.37 + 0.06	4.81	6.70	79
LCBN02	8/16/02	4.02 ± 0.05	1.89	7.14	686
LCBN03	8/16/02	5.87 ± 0.07	3.97	7.57	222
LCBN04	12/31/01	13.45 ± 0.01	12.41	14.24	852
Booker Creek					
LCBK01	12/31/01	6.64 ± 0.02	5.69	7.73	850
LCBK03	12/31/01	12.02 ± 0.04	10.05	13.51	849
LCBK04	9/27/01	6.44 ± 0.02	6.12	6.89	172

[1] See Table 5.1 for explanations of the site codes.

[2] At least sporadic precipitation occurred during every deployment except for the September 27, 2001 deployment.

[3] Located at Bolin Creek and Willow Drive.

Table 5.15 Dissolved Oxygen Concentrations at Selected Sites Sampled by the Town of Chapel Hill, April Through October 1998-2002

Sampling Site[1]	1998-2002				2002		
	Median (mg/L)	Lowest (mg/L)	# and % < 4 mg/L[3]	# and % < 5 mg/L[3]	Median (mg/L)	Lowest (mg/L)	# and % < 4 mg/L[3]
Little Ck. at Pinehurst Dr. (LCLC01 / #6 Little)	4.9	1.3	7 of 30 (23%)	16 of 30 (53%)	2.4	1.3	5 of 7 (71%)
Bolin Ck. at E. Franklin St. (LCBN02 / #5 Bolin)	6.6	1.5	4 of 30 (13%)	7 of 30 (23%)	2.5	1.5	4 of 7 (57%)
Bolin Ck. at Village Dr. (LCBN04 / # 4 Bolin)	7.4	2.0	5 of 28 (18%)	6 of 28 (21%)	3.5	2.0	4 of 6 (67%)
Booker Ck. at Willow Dr. (LCBK01 / #13 Booker)[2]	4.6	1.6	7 of 18 (39%)	10 of 18 (56%)	3.6	1.6	6 of 7 (86%)
Booker Ck. at Piney Mt. Rd. (LCBK07 / #8 Booker)	6.9	< 0.1	5 of 29 (17%)	7 of 29 (24%)	3.1	<0.1	5 of 7 (71%)
Morgan Ck. at Hwy. 54 (# 7 Morgan)	6.4	2.1	6 of 30 (20%)	8 of 30 (27%)	3.8	2.1	5 of 7 (71%)

[1] DWQ and Chapel Hill site codes shown in parentheses.
[2] Sampling of Booker Ck. at Willow Drive did not begin until 2000.
[3] North Carolina DO standards are 4 mg/L for instantaneous measurements and 5 mg/L as a daily average.
Source: The Town of Chapel Hill

b. Nutrients

The Town of Chapel Hill conducts nutrient sampling during baseflow periods at a number of locations throughout the study area. Data from August 2001 to August 2002 (Table 5.16) indicate that mean total phosphorus and total nitrogen concentrations were at or near the upper values suggested by the USEPA (USEPA, 2000c) for relatively unimpacted streams in the piedmont ecoregion (0.03 mg/L and 0.6 mg/L, respectively). Phosphorus levels were elevated at the most downstream sampling sites in Little Creek and Booker Creek at Willow Drive. Total nitrogen was also elevated at these sites as well as at the Airport Road sampling location on Booker Creek.

The Chapel Hill data do not include storms. Limited storm sampling conducted by DWQ during the study suggests that nitrogen and phosphorus concentrations increase significantly during storms (Table 5.17), but too few events were sampled to draw firm conclusions. Concentrations of total kjeldahl nitrogen (TKN) were substantial during the storms sampled.

A sanitary sewer spill on May 9, 2002 in the easement along Booker Creek at Piney Mountain Road spilled approximately 5000 gallons of raw sewage into the creek (see Section 2). Water samples collected by the Town of Chapel Hill (not included in Table 5.16) during the spill had extremely high concentrations of ammonia (12.8 mg/L), total nitrogen (17.9 mg/L) and total phosphorus (1.9 mg/L). These concentrations are substantially higher than typical baseflow levels. The in-stream ammonia concentration during the spill far exceeded EPA's temperature and pH specific chronic ammonia criterion (1.7 mg/L for the measured pH of 7.7 SU and temperature of 25.6 degrees C) and approached the pH specific acute criterion of 14.4 mg/L (USEPA, 1999b).

Table 5.16 Mean Baseflow Nutrient Concentrations and Standard Errors in the Little Creek Watershed from August 2001 to August 2002

Nutrient (mg/L)	Town of Chapel Hill Sampling Location						
	#6 Little	#5 Bolin	#4 Bolin	#11 Bolin	#13 Booker	#8 Booker	#12 Booker
	Pinehurst Dr.	E. Franklin St.	Village Dr.	Pathway Dr.	Willow Dr.	Piney Mt. Rd.	Airport Rd.
Total Phosphorus	0.10 ± 0.01 (5)	0.04 ± 0.01 (6)	0.06 ± 0.03 (6)	0.04 ± 0.01 (12)	0.12 ± 0.04 (5)	0.03± 0.01 (5)	0.03 ± 0.01 (6)
Ammonia Nitrogen	0.09 ± 0.03 (5)	0.06 ± 0.02 (6)	0.04 ± 0.02 (6)	0.03 ± 0.01 (12)	0.30 ± 0.17 (5)	0.24 ± 0.01 (5)	0.05 ± 0.02 (6)
Total Kjeldahl Nitrogen	0.52 ± 0.14 (5)	0.22 ± 0.05 (6)	0.22 ± 0.06 (6)	0.24 ± 0.03 (13)	0.72 ± 0.32 (5)	0.28 ± 0.05 (5)	0.32 ± 0.12 (6)
Nitrate + Nitrite Nitrogen	0.29 ± 0.20 (5)	0.19 ± 0.04 (6)	0.25 ± 0.07 (6)	0.18 ± 0.04 (13)	0.13 ± 0.05 (5)	0.21 ± 0.12 (5)	0.64 ± 0.50 (6)
Total Nitrogen	0.78 ± 0.33 (3)	0.35 ± 0.08 (6)	0.41 ± 0.11 (6)	0.37 ± 0.07 (13)	0.80 ± 0.32 (5)	0.46 ± 0.13 (5)	0.96 ± 0.54 (6)

Source: The Town of Chapel Hill

Table 5.17 Nutrient Concentrations in Storm Samples from Little, Bolin and Booker Creeks

Nutrient (mg/L)	Little Creek at Pinehurst Drive (LCLC01)	Bolin Creek at East Franklin Street (LCBN02)	Booker Creek at Willow Drive (LCBK01)	
	August 16, 2002	August 16, 2002	July 25, 2002	August 16, 2002
Total Phosphorus	0.21	0.05	0.41	0.03
Ammonia Nitrogen	0.10	< 0.1	0.40	0.10
Total Kjeldahl Nitrogen	1.40	1.00	2.80	2.50
Nitrate + Nitrite Nitrogen	0.06	0.48	0.78	0.30

5.3.4 Fecal Coliform

DWQ did not perform fecal coliform sampling during the investigation, other than one occasion following a sanitary sewer spill, since these bacteria are primarily a human health concern and the focus of the study was on aquatic life impacts.

Based on data collected by the Town of Chapel Hill (Table 5.18), high fecal coliform levels appear to be a problem only in Booker Creek at Willow Drive (#13 Booker), which had a geometric mean of 248 cfu/100 ml. This suggests that violations of the state standard of 200 colonies/100 ml may occur at this site, but does not constitute a formal violation of the standard. The NC fecal coliform standard is 200 colonies/100 ml based upon at least 5 consecutive samples collected within a 30-day period (membrane filter count).

Booker Creek and its tributaries upstream of the dam at Eastwood Lake are the only streams in the study area which are Class B waters (primary recreation). The two sampling sites in these waters (#8 Booker at Piney Mountain Road, and #12 Booker, at Airport Road) did not show evidence of likely violations of the fecal coliform standard during the time period examined, although levels exceeding 200cfu/100 ml occurred occasionally at both sites.

Table 5.18 Geometric Means of Baseflow Fecal Coliform, August, 2001 to August, 2002

Geometric Mean (n=13)	Town of Chapel Hill Sampling Location						
	#6 Little	#5 Bolin	#4 Bolin	#11 Bolin	#13 Booker	#8 Booker	#12 Booker
Fecal Coliform (cfu/100 ml)	97.3	113.2	76.2	51.7	248.0	68.1	87.1

Source: The Town of Chapel Hill.

On May 30, 2002 DWQ collected water samples downstream of a sanitary sewer leak into a sewer draining to Tanbark Branch. Fecal coliform was measured at 450 cfu/100 ml.

Section 6
Channel and Riparian Conditions

The characterization of stream habitat and riparian area condition at benthic macroinvertebrate sampling sites, described earlier, provides information essential to the assessment of conditions in the Little Creek study area. 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 Little 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 course of this study, project staff walked approximately 20 miles of channel including: the full length of Little Creek within the study area; the full length of Booker Creek and Cedar Fork; most of Crow Branch and portions of unnamed tributaries to Booker Creek; Bolin Creek from its confluence with Booker Creek to Homestead Road and selected reaches upstream of Homestead Road; Battle Branch, Tanbark Branch and the majority of Jolly Branch, and selected portions of Jones and Buckhorn Branch. Several of these reaches were surveyed on numerous occasions.

Project staff walked the identified sections of channel while carrying out the following tasks:

- Observing overall channel stability, noting specific areas of sediment deposition, severe bank erosion, evidence of channelization and similar attributes.
- Observing overall riparian area condition and the nature of surrounding land use.
- Identifying wastewater discharge pipes, stormwater outfalls, other piped inputs or withdrawals, and tributary inflows.
- Observing visual water quality conditions (odors, surface films, etc).
- Noting specific areas where pollutants are or may be entering the stream (dump sites, land clearing adjacent to the stream, etc).
- Identifying specific areas that may be candidates for channel restoration or BMPs.
- Providing digital photo documentation of key features.
- Conducting formal habitat assessments at representative reaches, as appropriate.

This section summarizes channel and riparian conditions and discusses likely future changes in stream channels. Results of several geomorphic assessments conducted by North Carolina State University (NCSU) as a part of this study are also summarized, as well as assessment work conducted for the Town of Chapel Hill.

6.1 Summary of Existing Conditions

6.1.1 Overall Channel and Riparian Condition

As discussed in Section 2, the upper three-fourths of the watershed is underlain by the Carolina Slate Belt. The area approximately downstream of East Franklin Street in the Bolin Creek drainage and downstream of Eastwood Lake in the Booker Creek drainage is underlain by the sedimentary rock of a Triassic basin (Figure 6.1). Slate belt streams tend to have relatively narrow valleys and floodplains, while the terrain of the Triassic basin is broad and flat, with wide floodplains and extensive swamps. The floodplains of state belt streams often widen abruptly when entering the Triassic basin (Daniels et al., 1999). While slate belt streams have narrow alluvial fills (shallow bedrock) and abundant slate fragments, Triassic basin streams have a characteristic sandy substrate.

Conditions in the study area are consistent with these expectations (see photos in Section 2). Coarse substrate is abundant in the Carolina Slate Belt (CSB), and largely lacking in the Triassic basin, where median substrate size is generally low. Booker Creek is characterized by a relatively narrow valley in most of the CSB area. The valleys of both Booker and Bolin Creeks broaden considerably once the streams enter the Triassic basin, and slopes decrease.

Channel Conditions. Many streams in the study area are incised, though incision is generally low to moderate. The history of this incision is not clear, and some of it may predate the development of the last half-century. The shallow bedrock and high channel roughness in the Carolina Slate Belt portion of the watershed limits incision. The presence of Eastwood Lake likely also has served to protect the downstream channels of Booker Creek from the hydrologic impacts of upstream development by mitigating high flows to some degree.

Bank erosion is common, although the severity of erosion varies greatly. Many areas have limited bank protection but may be eroding only slowly due to the cohesive soils often comprising the lower banks and the stabilizing influence of roots associated with the mature woody vegetation that is frequently present. Although mass failure (bank collapse) is occurring at some locations, and the stream is clearly evolving in response to the alteration of watershed hydrology by development (Exhibit 6.1), the channel network as a whole is not grossly unstable. The mainstems of Bolin and Booker Creeks appear to maintain their natural sinuosity in many areas, although some reaches have been channelized, as discussed below.

Substrate was generally heterogeneous in the Carolina Slate Belt, while the lack of coarse material at sites well within the Triassic basin resulted in fairly homogenous substrate. This is likely due to both the limited coarse material supplied by Triassic basin geology, and the lower slopes in these downstream areas, which result in a lower sediment transport capacity and allow for eroded material from upstream to accumulate in the channel.

As discussed earlier (see Background Note "Landscape History and Channel Alteration in the Piedmont Region", presented in Section 2), streams in this watershed likely experienced large sediment inputs from erosion of cultivated lands in the 19th and early 20th Century. While this sediment is largely gone from the channel system, its impact is evident in floodplain aggradation

in the lower gradient portions of the watershed (e.g., the greenway areas of Bolin and Booker Creeks) (see Maunz, 2002).

Riparian Conditions. The mainstems of Little, Bolin and Booker Creeks in the study area are bordered by a wooded riparian buffer for most of their length, though the width and integrity of the buffer varies greatly. OWASA sewer lines parallel these streams extensively. While the sewer line right of way (ROW) sometimes lies far enough from the stream to allow for a wooded buffer of 30 feet or more, the ROW often runs in close proximity to the stream (Exhibits 6.2 and 6.3), allowing for only a narrow line of trees along the top of the stream bank. Paved greenway trails maintained by the Town of Chapel Hill parallel Bolin Creek from Airport Road to the Chapel Hill Community Center across from University Mall (Bolin Creek Greenway) and follow Booker Creek from below Eastwood Lake to East Franklin Street (Lower Booker Creek Greenway). Where the greenway is directly adjacent to the stream, riparian vegetation is limited (Exhibit 6.4).

Buildings and paved areas impinge directly on the mainstems in only a few areas, most notably along Bolin Creek between Airport Road and Bolinwood Drive (Exhibit 6.5), along Estes Drive across from the Community Center, and along Umstead Drive, which closely borders the creek for the entire length of the road.

The quality of the riparian vegetation is often poor, with invasive species such as privet (*Ligustrum sp*.) abundant along streams throughout the watershed. These species appear to be out-competing native woody seedlings in many areas, with potential implications for the future composition of canopy vegetation (Maunz, 2002).

Aquatic Habitat. A more extensive assessment of stream habitat indicated that the evaluation of benthic macroinvertebrate sampling sites (Section 4) provides an accurate picture of habitats in the larger system.

In-stream habitat was generally adequate at sites located in the Carolina Slate Belt, where the substrate was diverse. Riffles are common, and usually have only low to moderate embeddedness. Other in-stream habitat types were more variable. Bank habitat (root mats) was sometimes inaccessible due to erosion or channel incision, but was available at many locations. Some organic habitat (e.g., leaf packs, sticks and larger debris) was present at most sites, though the amount and diversity of organic material was sometimes limited.

In-stream habitat in the Triassic basin portion of the study area was dramatically different. Unstable sandy substrate predominates and massive deposition was widespread (Exhibit 6.6). Riffles are rare (and sometimes the result of riprap in the stream) and in-stream habitat of all types was limited. While benthic macroinvertebrate communities can develop in stable sand communities, the sandy substrate in Little Creek and Lower Booker and Bolin Creeks is subject to frequent movement, limiting its habitat potential.

NCSU Geomorphic Assessments. As a part of this study, DWQ contracted with the Stream Restoration Institute at North Carolina State University (NCSU) to conduct a morphological evaluation and restoration feasibility study of two reaches in Bolin Creek (Figure 6.1):

- along the greenway between Airport Road and Bolinwood Drive;
- in front of the Community Center Park near University Mall.

These evaluations included a visual assessment of stream morphology, pebble counts, longitudinal and cross-sectional surveys and other field activities (NCSU, 2002). Bank pins and permanent cross-sections were installed so that future changes in channel morphology can be monitored. Table 6.1 summarizes basic geomorphic parameters for the three reaches. The restoration implications of this work are addressed in Section 8.

The reach below Airport Road is a steep gradient Rosgen B4 channel with abundant cobble and gravel (see Appendix C for a description of Rosgen stream classifications). Riprap and rubble have been used for stabilization along the south bank. The stream has access to a broad floodway along the greenway on the north bank and is minimally incised. The channel is straight in this reach, though low sinuosity is typical of B streams and the reach is vertically and laterally stable. This reach does not currently need channel restoration, although riparian vegetation is often limited and in need of enhancement.

The downstream reach at the Chapel Hill Community Center, located in the Triassic basin, is a low gradient C channel. Extensive bar development was evident, bank erosion was widespread, and the stream was laterally unstable. It appears that this portion of Bolin Creek, which is paralleled by Estes Drive on one side and an OWASA right-of-way on the other, was straightened at some point. The channel is now attempting to reestablish sinuosity through lateral migration and meander development. Channel restoration is recommended at this site, although there are numerous constraints that will pose a challenge for restoration. These include sewer lines that parallel and cross the stream, the bridge into the Community Center, businesses and parking areas along Estes Drive, which extend almost to the top of the bank in places. High entrenchment ratios indicate ready access to broad flood prone area in both reaches.

Table 6.1 Selected Geomorphic Characteristics of Two Bolin Creek Reaches Evaluated by NCSU

	Reach 1 Bolin Creek Below Airport Road	**Reach 2 Bolin Creek in Community Center Park**
Width/Depth Ratio [1]	15	15
Entrenchment Ratio [2]	2.2	>2.2
D_{50} (mm) [3]	11 (medium gravel)	6 (fine gravel)
Slope (%)	2.1	0.045
Sinuosity [4]	1.0	1.0
Rosgen Stream Type [5]	B4	C4c
Bank Height Ratio [6] (range)	1.2-2.2	1.0-1.0

Source: NCSU, 2002

1 Bankfull width/mean bankfull depth
2. Floodprone area width/bankfull channel width
3. Median diameter of channel material
4. Valley slope/channel slope
5. Rosgen (1996)
6. Low bank height/ max bankfull depth

Chapel Hill Assessments. Several UNC-CH graduate students [Maunz (2002) and Geraci (2002)] recently conducted geomorphic and riparian assessments at a number of sites in the watershed (Figure 6.1) in conjunction with the Town of Chapel Hill. Selected results are shown in Table 6.2. These assessments, together with the NCSU work described above, confirm the general differences in slope and substrate described earlier for slate belt and Triassic basin streams.

Rosgen stream classifications were not determined for the study reaches, but width/depth ratios indicate significant variability in channel morphology. The available data (Table 6.1) and visual observation by DWQ staff suggest that E, C and B channels are common in the watershed.

GIS analysis of riparian zones (90-foot width on each bank) found that land cover other than forest comprised 25 to 40 percent of the riparian zone at most of the sites assessed.

Table 6.2 Riparian and Geomorphic Data Collected for the Town of Chapel Hill, 2001-02

Site	Map ID[1]	Width/Depth Ratio[2]	Channel Slope	D_{50} (mm)[3]	% Forest in Riparian Zone[4]
Little Creek above Pinehurst Drive*	1	8.8	<0.01	9	73%
Battle Branch near Sugarberry Road	2	8.3	0.86%		94%
Bolin Creek in Greenway above East Franklin Street	3	12.1	0.32%	50 [5]	73%
Bolin Creek at Umstead Park	4	14.0	0.67%	55	72%
Bolin Creek at Pathway Drive	5	12.2	0.91%	100	74%
Bolin Creek at Homestead Road (SR 1777)	6	6.8	1.85%	32	71%
Booker Creek at Willow Drive*	7	--	--	2.5	--
Booker Creek in Greenway above East Franklin Street*	8	8.4	0.36%	30	70%
Booker Creek below Eastwood Lake	9	21.4	1.86%	--	68%
Booker Creek at Piney Mt. Road	10	9.5	0.79%	55	63%
Booker Creek at Homestead Park	11	5.9	0.85%	--	50%

Source: Maunz, 2002, except for D_{50} (Geraci, 2002).

[1] Map ID refers to location of site in Figure 6.1.

[2] Bankfull width/mean bankfull depth.

[3] Median diameter of channel material based on pebble count.

[4] Based on GIS analysis of land cover in 90-foot riparian zone on each bank.

[5] Measurement made at E. Franklin Street.

* Triassic basin site.

6.1.2 Other Field Observations

Bolin Creek. On May 30, 2002, a break in a private lateral sewer line allowed untreated sewage to leak to a storm sewer flowing to Bolin Creek just downstream of Tanbark Branch (Exhibit 6.7). Samples collected at the site indicated elevated turbidity (90 NTUs), fecal coliform (450 cfu/100 ml) and specific conductance (235 (µS/cm). A depression in dissolved oxygen (DO) was recorded at the confluence of Bolin Creek and Tanbark Branch (3.86 mg/L), although the DO concentration recovered to 7.03 mg/L approximately 0.7 miles downstream at Airport Road. An acute toxicity bioasssay conducted on a sample collected during the event did not indicate toxic conditions (see Section 5).

Tanbark Branch. During a field investigation in January 2003, a milky discharge from a culvert behind Southern States in downtown Carrboro was observed. The origin and nature of the discharge was not evident, but it does not appear to be due to a sanitary sewer leak or overflow. The channel of Tanbark Branch is relatively stable, despite the dense development in its small catchment. This can likely be attributed to the fact that much of the catchment has been developed for decades, providing adequate time for the channel to adjust to the new hydrologic regime.

Booker Creek below Lake Ellen. Booker Creek has cut a ravine, more than 20 feet deep in places, below Lake Ellen (Exhibit 6.8). The ravine, which is approximately 150 feet long, developed because the lake was constructed so that the spillway did not discharge into the historic stream channel. This initiated the development of a new channel below the spillway. The ravine is still widening, serving as a source of sediment to downstream areas. Severe bank erosion is also evident in the portions of Booker Creek around the ravine.

Removal of beaver impoundments and stream blockage. Beaver impoundments are common in the watershed, particularly in Little Creek and the lower reaches of Booker and Bolin Creeks. Although impoundments are often left in place, the Town of Chapel Hill Department of Public Works removes beaver impoundments and other obstructing material when necessary to restore streamflow and prevent flooding. While removal may be warranted, removal methods appear to cause unnecessarily extensive damage (Exhibit 6.9). Most of this damage appears to result from the use of heavy equipment use in the stream channel, on stream banks and in riparian areas. Impacts observed include stream bank damage and destabilization, in-stream sediment deposition, and destruction of bank and riparian vegetation.

6.1.3 Channelization and Hydrologic Impacts

Visual assessment suggests that streams in the lower portion of the study area were channelized decades ago, including Bolin Creek below Franklin Street, most portions of Booker Creek below Eastwood Lake and much of Little Creek itself (Exhibit 6.10). Booker Creek is culverted underneath Eastgate Shopping Center, which was completed in 1960. Widespread channelization is not evident in the upper portions of Bolin and Booker Creeks, but has occurred locally (e.g., in conjunction with the sewer right of way).

While channelization of portions of a stream can often lead to systemic incision due in part to changes in stream slope (Schumm et al., 1984; Darby and Simon, 1999), such systemic changes

are not apparent in this watershed, probably due to periodic bedrock outcrops that serve as grade control in much of Bolin and Booker Creek. Below East Franklin Street, incision is currently limited by a combination of factors, including high sediment supply from upstream and limited sediment transport capacity to due to low channel slopes.

Over the past half century, development has expanded from the historic cores of Chapel Hill and Carrboro to include a large portion of the watershed. The resulting buildings, roadways and other impervious areas have significantly altered the hydrologic regime of many streams in the watershed. The stream channel must now accommodate stormflows that have a shorter duration, but higher flow rates, than before. These new conditions add further erosive stresses on stream banks.

During much of the study period, water levels in Eastwood Lake were drawn down to allow for sediment removal and the installation of a forebay at the head of the lake (Section 2). Under normal summer conditions outflow from the lake occurs only intermittently, resulting in lower flows at these times than would be likely without the impoundment. Water levels in these impoundments were below the level of the principal spillway for much of the summer except during the periods immediately following precipitation sufficient to fill the lakes. As streamflows decline, the channel habitat available to benthic organisms declines and the accessibility of bank habitat decreases.

6.2 Future Changes

Stream channels in the watershed are still responding to the altered hydrologic conditions brought about by the substantial development of the past several decades. Ongoing development, most notably in upper Booker and Bolin Creeks, will result in further hydrologic change. Channel adjustment will likely continue for several decades until the channel has attained a morphology in equilibrium with the new hydrologic conditions. In the Carolina Slate Belt portion of the watershed (roughly above East Franklin Street), additional incision may occur in some portions of Booker and Bolin Creeks, but this will be limited by the frequent areas of already-exposed bedrock. Signs of active incision were not evident in the mainstem of Booker and Bolin Creeks during the project. Further stream widening is the most likely scenario above East Franklin Street, although the rate of widening in much of the mainstem may continue to be slowed to some degree by bank vegetation and cohesive lower bank material. Incised streams that have begun widening generally continue to do so until the channel width is sufficient to allow for the stabilization of slumped banks and a new geomorphic floodplain develops within the incised channel (Schumm et al., 1984; Simon 1989; Simon and Darby, 1999). As widening occurs, bank habitat may become unavailable to benthic organisms. Baseflow water depths will become shallower, potentially resulting in increased temperatures and lower dissolved oxygen levels. Implementation of additional management measures to effectively control and limit runoff from new development could mitigate these impacts to some degree.

In Little Creek proper and in Booker and Bolin Creeks below East Franklin Street, extensive sediment deposits fill the channel and grade control is limited. The potential for additional incision is much greater in these areas as the watershed continues to develop and the frequency and duration of erosive flows increases. Incision is currently impeded by the extensive sediment supply from upstream, and by the low gradient (stream channel slope) in this area. However, if

this supply is reduced in the future (due to completion of construction and eventual stabilization of upstream channels) below the transport capacity of these downstream reaches, further incision is possible.

Exhibit 6.1 Bank failure along outside bend of Bolin Creek, in greenway above E. Franklin Street

Exhibit 6.2 Limited riparian vegetation along sewer right of way, Bolin Creek below Homestead Road

Exhibit 6.3 Disturbed riparian zone along Battle Branch in sewer easement

Exhibit 6.4 Poor riparian zone on Bolin Creek along greenway

Exhibit 6.5 Parking area adjacent to Bolin Creek below Airport Road

Exhibit 6.6 Sediment deposition in lower Booker Creek

Exhibit 6.7 Sewage spill in Bolin Creek May 30, 2002

Exhibit 6.8 Ravine in Booker Creek below Lake Ellen, upstream view

Exhibit 6.9 Impacts to riparian area following beaver impoundment removal—lower Bolin Creek

Exhibit 6.10 Both Bolin (left) and Booker (right) Creeks channelized at their confluence.
Note: Higher turbidity in Booker Creek following moderate rain event.

Section 7
Analysis and Conclusions - Causes and Sources of Impairment

This section analyzes the likely causes of impairment in the Little 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 major candidate causes of impairment investigated were:

- habitat degradation -- sedimentation;
- habitat degradation -- lack of microhabitat;
- hydromodification due to scour;
- toxicity due to nonpoint source impacts; and
- low dissolved oxygen/organic and nutrient enrichment.

The impact of impoundments is also discussed.

7.1.3 Review of Evidence

Little Creek is impaired for its entire length in the study area, a condition that has been evident since the stream was first sampled by DWQ in 1993. When Bolin Creek was first sampled by DWQ (at East Franklin Street in 1986), the benthic community was reasonably diverse and the stream, though showing indications of impact, was not considered impaired. Impairment was evident when the stream was next sampled in 1993 and has persisted at this site. An upstream site at Village Drive supported a reasonably intact benthic fauna until 2001, and impairment was evident as far upstream as Waterside Drive (sampling by Town of Carrboro) over the last several years. It remains unclear whether the observed decline in this area is persistent or was due to a specific perturbation from which this portion of the stream will yet recover. At this time, benthic communities in Bolin Creek remain unimpaired only at the most upstream sampling location at

Homestead Road. Booker Creek has previously been considered impaired for its entire length. All Booker Creek sites sampled during this project were too small (<4 meters wide) to assign a bioclassification using existing DWQ criteria, but all locations exhibited a highly impacted benthic community, and are considered impaired. The portion of Booker Creek above Eastwood Lake is likely impacted by naturally low summer streamflows in addition to human-induced problems. Fish communities, sampled only in Bolin Creek, are not impaired.

a. Habitat degradation—sedimentation, lack of microhabitat

Sedimentation was listed as a problem parameter for Bolin Creek on the 303(d) list, and thus, merited further evaluation. Initial observations during the current study revealed highly variable habitat in the watershed, with poor microhabitat conditions evident in some areas. Relevant lines of evidence include benthic macroinvertebrate community data, habitat and geomorphic evaluation, and watershed history and characteristics.

As noted above, historic sampling at a number of locations indicated a decline in biological condition in Bolin Creek near Franklin Street between 1986 and 1993, and upstream in the Village Drive/Estes Drive area between 1998 and 2000. Changes in stream habitat during this period cannot be evaluated, since habitat evaluation data are not available for the earlier sampling events. However, information on substrate composition (based on visual assessment) did not suggest that major changes occurred at the East Franklin Street and Village Drive sites during the above periods (Section 4).

Construction of the first phase of the Bolin Creek Greenway, between Airport Road and Elizabeth Street (upstream of Franklin Street), began in the spring of 1992. The impact of this activity on conditions at the Franklin site are not known. Construction of the second phase (downstream of Elizabeth Street) occurred in 1998 and 1999. This likely had some direct effect on the Franklin Street sampling site, where construction of the trail involved installation of a retaining wall extending down to the creek (see Exhibit 6.4 in Section 6).

Stream surveys and habitat assessments conducted in conjunction with biological sampling indicated that massive sediment accumulation and resulting habitat degradation is evident in Little Creek near Pinehurst Drive and in Booker Creek at Willow Drive (Section 4). Other field investigations revealed that such sedimentation is widespread in lower Booker (below East Franklin Street) and lower Bolin Creeks (below East Franklin Street) and for all of Little Creek within the study area (Section 6). Riffle habitat is virtually nonexistent in these areas and unstable sand substrate predominates. In the remainder of Bolin and Booker Creeks, however, substantial sedimentation is not widespread, especially above Bolinwood Drive, though local accumulations may occur. Riffles are common and most are not highly embedded. While sedimentation contributes to habitat degradation to some degree in these areas, there is no evidence that sedimentation per se is severe enough to be considered a cause of impairment in most of Bolin and Booker Creeks. The section of Bolin Creek between East Franklin Street and Bolinwood Drive appears to be transitional in terms of sedimentation, with significant deposition occurring intermittently, especially in the downstream portion of this area. Substantial sedimentation is also evident in several small tributaries (Battle Branch, and an unnamed tributary entering Booker Creek from the north below Eastwood Lake).

It is evident from observation and from the condition of channel bars and stream banks that Booker and Bolin Creeks carry a substantial sediment load. For the most part, however, these streams appear to have the transport capacity to carry this load without resulting in widespread severe depositional problems in streams above East Franklin Street. However, this sediment is deposited in the lower reaches of these streams and in Little Creek, causing severe habitat degradation in these areas. Sediment deposition has been an ongoing concern in Lake Ellen and in Eastwood Lake, which was dredged during the study period. Though not currently evident as a cause of biological degradation in upper Booker Creek, sediment may have contributed to past impacts and currently contributes to aesthetic and resource concerns.

In addition to habitat degradation due to sedimentation, the sites in the lower portion of the study area suffer from an almost complete lack of organic microhabitat (e.g., leaf packs, sticks and larger debris) due to scouring, and limited bank/root mat habitat due to extensive bank instability (Sections 4 and 6). Some organic habitat is available at most locations further upstream. While often not optimal, organic habitat in these upstream areas provides habitat diversity to complement the abundant riffles and other rocky substrate. Benthos are impaired is several such areas (e.g., Booker Creek at Piney Mountain Road, and Bolin Creek at Bolinwood Drive and at Village Drive), implying that factors other than in-stream habitat condition (e.g., water quality problems such as toxicity) are likely impacting the benthic community there. Even at sites with better habitat, in-stream habitat conditions, though adequate, were not optimal. Relatively high habitat scores at these sites reflect good riffle habitat and a lack of channelization, but some organic habitat types were often limited. Organic microhabitat was seldom abundant and often limited at many Bolin Creek and Booker Creek sites, despite the availability of organic inputs from the surrounding area.

Channelization is widespread in the lower portion of the watershed (below East Franklin Street). Habitat is poor in these areas, which generally have uniform channels, little habitat diversity, no riffles and very low baseflow velocities.

Synopsis. Habitat degradation manifested in sedimentation and a lack of organic microhabitat can be considered a cause of impairment in Little Creek and in Bolin and Booker Creeks below the East Franklin Street area, but is probably not a primary limiting factor for benthos further upstream. In these upstream areas, the available habitat should be able to support more diverse benthic communities than are currently present. Booker Creek is a small stream at the biological sampling locations above Eastwood Lake (at Barbara Court and Piney Mountain Road). The limited drainage area at these sites and low baseflow supplied by the Carolina Slate Belt geology provide little discharge during the summer, resulting in severe habitat limitation (contraction of available habitat due to limited discharge). This likely limits the biological potential of the upper Booker Creek watershed.

b. Toxicity due to nonpoint source impacts

Toxicity was evaluated as a cause of impairment because an initial review of the available benthic community data indicated potential toxic impacts. The highly developed nature of the watershed was also a concern, with the potential for a wide variety of toxicant sources. Five lines of evidence are relevant: water chemistry data, in-stream bioassay data; sediment chemistry and bioassay data; watershed characteristics; and benthic community data.

Virtually all benthic macroinvertebrate samples collected in the watershed during the study period, except those at the Bolin Creek site at Homestead Road, exhibit high biotic index (BI) or EPT BI values, indicating the prevalence of organisms tolerant of a variety of stressors. In DWQ samples collected from Little Creek, Booker Creek at Willow Drive and a number of Bolin Creek locations, the midge assemblage indicated potential toxic impacts (Section 4). In Little Creek at Pinehurst Drive, a midge deformity analysis produced a score of 160 (see Section 4), indicating a high level of toxicity for the single sampling event yielding sufficient *Chironomus* to conduct the test (scores of 80 or more indicate significant toxicity).

Water column bioassays did not provide evidence of toxicity in Little and Bolin Creeks during the events sampled. However both chronic bioassays conducted in Crow Branch, a tributary of Booker Creek, indicated toxicity, as did one of two chronic bioassays conducted on samples collected from Booker Creek at Willow Drive (Section 5). The specific pollutant(s) responsible for this toxicity could not be determined with the available data.

Watershed characteristics -- including imperviousness levels of approximately 25 percent in the lower study area and traffic volumes exceeding 20,000 vehicles per day on several major roads (see Section 2) -- suggest the potential for loading of many pollutants. Numerous metals and synthetic organic pollutants were found in water samples, although whether observed levels are likely to cause toxicity is not clear. Aluminum, iron and manganese commonly exceeded screening values during baseflow (Section 5), although high levels of these metals are common in North Carolina, even in streams that support relatively diverse benthic populations. Zinc and copper were also commonly measured, though observed concentrations did not exceed benchmark levels, except for one storm sample from Booker Creek. Silver exceeded screening values in one baseflow sample from Little Creek, while lead exceeded benchmarks in one baseflow sample each from Little and Booker Creeks. Only total metals concentrations were analyzed and bioavailability could not be evaluated analytically. Bioassays were conducted on some of the samples with high metals concentrations and all passed.

Benzo(a)anthracene and several other polycyclic aromatic hydrocarbons were detected in a storm sample from Booker Creek (Willow Drive) at concentrations exceeding expected ecological effects thresholds, but a bioassay did not confirm acutely toxic conditions (test organism mortality).

Pesticides are frequently found 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). However, few current use pesticides were detected in the Little Creek watershed during the current study. The insecticide chlorpyrifos was detected in Bolin Creek during one passive sampler deployment and atrazine was also detected. Both were well below benchmark values. A number of other pesticides were found on a few occasions at low concentrations (Section 5). Little is known about the toxicity of some of these compounds.

The in-stream ammonia concentration (12.8 mg/L) during a 2002 sanitary sewer spill in Booker Creek exceeded EPA chronic criteria (1.7 mg/L) and approached the acute criteria of 14.4 mg/L (Section 5). While the frequency with which such concentrations occur is not known, this event indicates the potential for spills to have potential toxic impacts on stream biota.

Due to unusually low precipitation during the study period, only a few storms were sampled. It is unlikely that the limited number of samples collected during the study captured the full variability in pollutant concentrations normally experienced by these streams, and higher levels of contaminants probably periodically occur. For more than 20 organic compounds analyzed, screening values were lower than laboratory detection limits (Appendix B). Whether these analytes were present in concentrations likely to be toxic is thus unknown.

Toxic impacts, especially if caused by storm inputs, can be episodic and difficult to identify. One cannot rule out toxicity due to the occurrence of spills or infrequent incidents that occurred between sampling events. Additionally, determining how laboratory bioassays apply to the in-stream context is sometimes not straightforward. While laboratory bioassays are very useful in integrating the impacts of multiple pollutants (accounting for cumulative effects), laboratory conditions often will not reflect actual in-stream exposures (or other conditions) or account for the full range of biological responses (Burton and Pitt, 2001; Herricks, 2002). For example, stream organisms may experience multiple stresses over an extended period of time (such as repeated pulse exposures to various pollutants), a situation difficult to duplicate in laboratory bioassays. While difficult to assess, the long-term cumulative effects of frequent exposures is likely to be important (Burton and Pitt, 2001). Also, volatile toxicants can escape from a sample and result in toxicity test conditions that are not representative of in-stream toxicant levels.

Sediment chemistry analyses and bioassays were performed on samples from Little Creek at Pinehurst Drive. Chemical analyses identified a number of metals and several chlorinated pesticides no longer registered for sale. Observed concentrations and bioassay results did not provide strong evidence of toxic conditions. While sediment toxicity cannot be ruled out based upon these results, it does not appear highly likely.

Synopsis. Evidence bearing on potential toxicity is diverse and difficult to synthesize. However, bioassessment and bioassay data collected during the study support a conclusion that toxic conditions occur at least occasionally in much of the watershed and that impacts are likely prevalent in downstream areas. The benthic community composition (midge assemblage) indicates likely toxic impacts in much of the watershed and midge deformities in Little Creek provide additional biological evidence of impacts at the lower end of the study area. Toxicity bioassays documented toxic conditions during specific sampling events in Crow Branch and Booker Creek. The specific pollutants responsible for this toxicity cannot be identified from the available data and may be variable. Indicators of toxicity in the upper part of the impaired portion of Bolin Creek (the Village Drive-Estes Drive area) are more intermittent than further downstream.

c. Low dissolved oxygen/organic and nutrient enrichment

Low dissolved oxygen and enrichment by organic wastes and inorganic nutrients were evaluated as potential causes of impairment because historical data collected by the town of Chapel Hill indicated occasional low DO concentrations. Relevant lines of evidence include: benthic community data, water quality monitoring data and field observations of stream condition.

Though benthic communities at most sites were dominated by organisms tolerant of a variety of stressors, community composition in samples collected by DWQ did not indicate the presence of taxa indicative of low dissolved oxygen impacts or organic loading, with the exception of Little

Creek, where the abundance of *Chironomus* in one sample indicated potential enrichment. Samples collected by Ecological Consultants for the Town of Carrboro found an abundance of oligochaetes at several Bolin Creek sites in a September 2000 sample (but not in other samples at the sites), potentially indicating organic enrichment at that time. DWQ did not conduct macroinvertebrate sampling during the summer of 2002, when drought conditions were most extreme. Fish sampling in Bolin Creek in the fall of 2001 indicated a relatively healthy community, with no evident impact of low DO concentrations on the fish community at that time.

Monitoring of dissolved oxygen levels provided evidence that DO concentrations below the North Carolina instantaneous standard of 4 mg/L were common throughout the study area during 2002 (Section 5), when baseflow levels were unusually low and some streams stopped flowing for part of the summer. This was true even at a control site in the adjacent Morgan Creek watershed (Morgan Creek at NC 54, sampled by the Town of Chapel Hill), which has limited upstream impacts and historically good benthic community ratings. Low DO concentrations occurred occasionally during other years at most sites, probably due in part to naturally low summer baseflows. Little Creek and lower Booker Creek (at Willow Drive), which have little gradient and limited reaeration, appear to have the most consistently low DO levels.

Several sanitary sewer leaks and overflows occurred during the study period, providing periodic inputs of nutrients and oxygen-consuming wastes.

Field observations indicated high levels of vigorous periphyton or filamentous algal growth at many Bolin Creek Sites and in Tanbark Branch (see Sections 4 and 6). Nitrogen and phosphorus levels are above background levels, although the biological response of free-flowing streams to nutrient loading 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.

Synopsis. Record low flow conditions during the summer of 2002, and resultant low DO levels, were extremely stressful to biota. Concentrations of 4 mg/L were not unusual during this period and Booker Creek stopped flowing for portions of the spring and summer. These represent extreme conditions, however. While low DO concentrations occur periodically in more normal years, biological community composition data provide little evidence that these conditions, while a concern, are severe enough to be considered a cause of impairment. DWQ's biological sampling was completed prior to the worst drought conditions (summer 2002). Sampling at Homestead Road in 2001 (and at other Piedmont sites sampled by DWQ as part of its bioassessment program) did not indicate drought impacts to stream biota at that time. Ongoing DO impacts appear most likely in lower Booker Creek and in Little Creek, where the low gradient and lack of riffles provides little opportunity for reaeration. It is difficult to differentiate the importance of the various factors that can contribute to low DO concentrations: nutrient and organic enrichment; low baseflows resulting from urbanization of the watershed; and drought. It seems likely, however, that nutrient and organic enrichment are at least intermittent and localized contributors to low DO levels.

d. Stormflow scour

Scour (excessive removal of organisms and microhabitat during storms) was evaluated as a potential cause of impairment in Little Creek due to the highly developed nature of the watershed. Relevant lines of evidence include habitat and riparian area assessments, stream observation during storms and watershed characteristics.

Observation indicated that water levels and velocities in both Booker and Bolin Creek changed rapidly during the onset of storm events, and that exposure of the stream to high velocity flows was commonplace, with substantial movement of bed substrate and organic microhabitat. Where incision is substantial, the energy of the stream is confined within the banks except during large storms. It is evident that much of the stream has substantial sediment transport capacity, especially above Bolinwood Drive, as many reaches do not appear to be experiencing long-term accumulation despite significant sediment supply from eroding banks and other sources. The large suspended sediment load could exacerbate the direct scouring effect on stream biota by contributing to the dislodging of benthic organisms. Dislodging of organisms can be expected with increased frequency and severity compared to less developed portions of the watershed (e.g., Bolin Creek at Homestead Road), which likely experience less frequent and intense periods of scouring flows.

In addition to its direct impact on biota, scour can also result in loss of habitat such as leaf packs and other organic material. As noted above, organic microhabitat was often limited in the downstream portion of the study area, given the nature of the riparian zone. Scour from frequent high-velocity flows is a likely contributor to this situation. Scouring flows are also a key contributor to bank erosion and stream instability.

Flooding has been a persistent problem in the lower gradient portions of the watershed, notably in Eastgate Shopping Center, the Estes Drive/University Mall area, and along Little Creek proper. These problems underscore the frequency of high flows.

Impervious surfaces cover about 17 percent of the Booker Creek watershed and 14 percent of the Bolin Creek watershed, with downstream portions of both areas experiencing higher percentages (Section 2). Many pervious areas have been highly modified, and have lost some of their previous infiltration capacity. Much development predates current stormwater control requirements. Increases in total stormwater runoff volume, as well as in the frequency and duration of high velocity streamflows, can generally be expected under these conditions. Scour is less likely in the upper portion of Bolin Creek. The watershed above Estes Drive Extension was only about 7 percent impervious in 1999 (see Section 2 for data source), a level at which significant hydrologic impacts would not be expected.

Synopsis. Taken as a whole, these observations suggest that substrate scouring likely occurs frequently in Booker Creek, Little Creek, and lower Bolin Creek, and can be expected to contribute to both habitat degradation and the dislodging of organisms. While difficult to isolate from other factors associated with a developed watershed, scour is likely an important and pervasive stressor that contributes to impairment of the macroinvertebrate community. Based on the extent of watershed development, it is likely that scouring in Bolin Creek decreases above Village Drive and is not likely an important factor above approximately the Watershed Drive area.

e. Hydromodification due to dams

Eastwood Lake lies on Booker Creek above East Franklin Street. Approximately 4.4 square miles of the 6.5-square mile Booker Creek drainage (67 percent of the watershed) drains to this impoundment. Booker Creek is dammed to create a smaller impoundment, Lake Ellen, further upstream. Dams can impact downstream aquatic communities in a number of ways, including: prevention of downstream colonization of aquatic populations; lower downstream water levels when the dam is not spilling; changes in temperature and dissolved oxygen; and changes in the type of food available to downstream organisms. Dams also alter sediment transport, trapping much of the coarser material supplied by the watershed (see NCDWQ, 2003, for additional discussion of potential dam impacts).

Lack of flow over the dam at Eastwood Lake is common during the summer, exacerbating low flow conditions already impacted by the underlying geology and the urban nature of the drainage area, with resultant impacts on habitat availability and dissolved oxygen. Impacts on macroinvertebrate drift likely occur, but the present effect of this on Booker Creek is probably limited by the fact that many of the areas above the lake are densely developed, and streams in these areas support limited benthic communities.

While these impacts cannot be readily differentiated from those of lower urban baseflows and organic enrichment, it is likely that lowered water levels below the dam is an important stressor to biological communities in lower Booker Creek and is a cumulative cause of impairment. On a more limited scale, these impacts exist in upper Booker Creek due to Lake Ellen.

Dams on Bolin Creek likely also have some impact, but these are located in the headwaters and impound only a small area. Tributaries below the dams currently provide adequate streamflow and macroinvertebrate recolonization.

7.1.4 Conclusion

Aquatic organisms in Little Creek and its tributaries are heavily impacted by multiple stressors associated with the high levels of development in the watershed. Multiple stressors are characteristic of most developed watersheds, although sometimes a single stressor can be identified as being of primary importance in causing impairment. In this watershed, however, the relative contribution of these stressors cannot be clearly differentiated based on the available data. Toxic impacts, scour, and habitat degradation due to sedimentation and limited microhabitat, and hydromodification due to impoundments are all considered to be stressors that cumulatively cause impairment in various portions of the watershed, as summarized in Table 7.1. Low DO/nutrient and organic enrichment is a contributing stressor in these areas.

The issues are less clear-cut in the portion of Bolin Creek upstream of East Franklin Street, especially upstream of Airport Road, where habitat is generally at least adequate. As discussed in Section 4, the recent decline in the benthic community in the Village Drive area (and the similar condition of the benthic community as far upstream as Waterside Drive) does not appear to be due to the drought. However, it is probably too soon to evaluate whether the observed decline is persistent, or was due to a specific perturbation from which this portion of the stream will yet recover. Based on the information currently available, toxicity and scour are considered

cumulative causes of impairment in this segment, although indicators of toxicity (midge community composition) appear intermittent at Village Drive, and scour is less likely in the upper portion of this section. The cause of impairment at the Village Drive site and at the sites sampled by Carrboro further upstream remains uncertain, although it is clear that impacts are not due to habitat degradation. Habitat degradation is increasingly evident in the lower portion of this area (below Bolinwood Drive).

In the upper Booker Creek watershed (above Eastwood Lake), clear indications of toxicity are limited to Crow Branch. Low summer baseflows due to the small catchment size, exacerbated by the high levels of development in the watershed, are likely more significant here than in more downstream mainstem areas.

Table 7.1 Key Stressors in Impaired Portions of the Little Creek Watershed

Stressor	Impaired Stream Section				
	Little Creek	Bolin Creek		Booker Creek	
	Source to Pinehurst Dr.	East Franklin St. to mouth	Waterside Dr. to East Franklin St.	Eastwood Lake[1] to mouth	Source to Eastwood Lake[1]
Toxicity	C	C	C[2]	C	C[3]
Habitat degradation (sedimentation and lack of microhabitat)	C	C	-	C	C[4]
Scour	C	C	C[5]	C	C
Low DO/enrichment	CS	CS	CS	CS	CS
Impoundments	-	-	-	C	C

C = cumulative cause of impairment; CS = contributing stressor. See Section 7.1.1 for definition of terms.

[1] Not formally considered impaired due to small stream size, but most important stressors are noted.

[2] Toxicity may be intermittent in the upper portion of this section.

[3] Toxicity in Crow Branch (tributary of Booker Creek).

[4] Degradation manifested by habitat contraction during dry weather due to the small drainage area and geologic factors.

[5] Scour effects diminish in upper end of this section.

7.2 Sources of Impairment

Toxicants. Storm sampling was limited due to the lack of precipitation during the sampling period and storm pollutants are thus not well characterized in this watershed. It is likely that a variety of toxicants impact the stream at various times and that the cumulative impact of these contaminants is a significant issue. Diverse source areas exist throughout this highly developed watershed, including residential, commercial and institutional areas, golf courses, and vehicular sources). Contaminants likely enter the stream via a variety of pathways, including storm runoff, seepage from contaminated groundwater, periodic spills or unpermitted discharges to the storm sewer system.

Vehicles can be major source of metals and hydrocarbons. Characteristics of the Little Creek watershed--major commercial areas with parking, dense residential areas and street networks, major transportation arteries with high traffic volumes--indicate that it likely has significant vehicular inputs.

The most densely developed areas are at greatest risk for inputs of stormborne toxicants. These areas include: the central business district of Chapel Hill; the portion of downtown Carrboro draining to Bolin Creek; the portion of the UNC-CH campus within the study area; and the broad commercial area that includes University Mall and Eastgate Shopping Center. The Eastgate Shopping Center area is a particular concern. The highest levels of PAHs, MTBE and MBAS found in the watershed were measured in Booker Creek in this area (Section 5). In addition to the potential for storm runoff inputs, Eastgate Shopping Center is also affected by contamination from several leaking underground storage tanks, and active remediation of a spill of dry cleaning solvents.

High ammonia levels in a sewer spill in Booker Creek during 2002 (Section 5.3.3) indicate the potential for spills of sufficient magnitude to cause occasional toxic conditions.

While the reason for toxicity in Crow Branch has not been clearly identified, large increases in conductivity and total dissolved solids have been documented in-stream adjacent to the two inactive UNC hazardous waste sites (Section 2). Given this, as well as the limited development or other human activity in this catchment, inputs from the landfill sites appear to be the most likely source of the problem, although the specific analytes involved remain unclear.

Scour and habitat degradation. EPA defines hydromodification (source category 7000) as the alteration of the hydrologic characteristics of surface waters resulting in degradation of resource conditions (USEPA, 1997). While channelization (alteration of channel morphology, dredging) has impacted some reaches in the study area, the type of hydromodification of primary importance in this watershed is the alteration of watershed hydrology by increased impervious area and the installation of a storm drainage system associated with development of the watershed. Much rainfall that previously infiltrated into the soil or gradually flowed into streams through feeder channels now falls on impervious areas and is collected by storm sewers which efficiently route runoff to major streams. The resulting increase in stormwater volumes and the frequency and duration of erosive flows is the major factor causing scouring and habitat degradation (sedimentation and loss of organic habitat).

These hydrologic impacts are due to the cumulative effects of development throughout the watershed. While the most densely developed areas have the greatest potential to yield stormwater inputs, more moderate density development also contributes to the problem.

While much sediment observed in the stream at present likely has its origins within the channel system, inputs of sediment from eroding upland areas have probably been important over the past several decades.

Riparian zone degradation, often associated with the sewer line right of way and to a lesser extent paved greenway trails, also contributes to habitat degradation through the loss of native woody vegetation that helps maintain bank stability and contributes organic material to the channel.

Organic and inorganic nutrient enrichment/low dissolved oxygen. It was not possible to distinguish clearly between the impacts of organic/nutrient loading, the effects of drought, and urban hydrologic impacts. Urbanization can affect DO levels due to lower baseflows and wider baseflow channels that contribute to lower velocities and result in lower water levels that are more easily subject to heating. Potential sources of biochemical oxygen demand (BOD) and inorganic nutrients are ubiquitous in a developed watershed such as this one and include leaking sewer lines or sewer spills, illegal discharges to the storm drain system, fertilizer inputs from managed turf areas, atmospheric nitrogen sources, and a variety of organic debris (both trash and natural material). Specific contributors of organic inputs were not evaluated, and it is likely that loadings to streams in the watershed are primarily the result of a multitude of smaller sources rather than a few large inputs. Given the proximity of miles of sanitary sewer line to the stream channel, the potential for leaks and overflows is a concern. In-stream impacts of several such events were documented during the study (Sections 5 and 6).

Though BOD was not measured in the Little Creek watershed, BOD levels are generally elevated in urban stormwater runoff. A study of stormwater data collected by North Carolina cities (CH2M HILL, 2000) indicated that BOD_5 (five-day BOD) levels in runoff from medium density residential areas was almost twice as high as BOD_5 in runoff from undeveloped areas (mean event concentration of 7.5 mg/L vs. 4.3 mg/L). Institutional, commercial and industrial areas had mean storm event concentrations ranging from 11 to 17 mg/L.

7.3 Other issues of Concern

Drought. As discussed in Section 2, precipitation and streamflows in the area were below normal during much of the study period, although conditions became most severe during the first nine months of 2002. Available biological data indicate that the drought probably did not have a significant impact on benthic and fish communities in the piedmont during the early years of the drought period, but that substantial impacts on biota occurred by the summer of 2002. It is expected that sites which have historically been in good biological condition (e.g., Bolin Creek at Homestead Road; see Section 4) will eventually recover from this disturbance. In general, the below normal precipitation may negatively impact dissolved oxygen levels, but would also be expected to lessen storm-driven loading of pollutants to the channel system.

Recolonization sources. Macroinvertebrate recolonization potential from within the watershed is a concern, especially in the Booker Creek drainage. Downstream drift of benthic organisms is a very important mechanism for the maintenance of benthic macroinvertebrate populations, allowing for more rapid recovery from disturbance than other mechanisms such as aerial recolonization (Waters, 1972; Williams and Hynes, 1976). In the Booker Creek drainage, development extends to the headwaters. While development is limited in the drainage of Crow Branch, upper Booker Creek's major tributary, this stream is likely affected by toxicity. Eastwood Lake and Lake Ellen interfere with macroinvertebrate drift, and the tributary catchments downstream of the dam are densely developed. The lack of quality upstream sources of colonization contributes to biological degradation in Booker Creek by altering the balance between disturbance and recovery (see the Background Note "The Stress-Recovery Cycle"). Tributaries in the lower half of the Bolin Creek drainage (e.g., Tanbark Branch and Battle Branch) have been severely impacted by development and likely can serve as only a limited recolonization source for Bolin Creek. While the macroinvertebrate community in upper Bolin

Creek (Homestead Road and above) remains relatively healthy, this portion of the watershed is developing rapidly. Preservation of the biotic integrity of this area is critical to the recovery of downstream areas. If development significantly compromises the ecological function of these areas, the recovery of Bolin and Little Creeks will be more difficult.

Thermal impacts. This study did not investigate the potential thermal impacts of watershed development on stream organisms. Stream biota can be subject to stress from the increased heating characteristic of the urban environment (warmer ambient water temperatures due to a generally warmer landscape), or to rapid increases in temperature (especially during summer storms) as rainfall hitting hot paved surfaces is heated and rapidly transported to streams. Discharges from shallow wet ponds can contribute water with elevated temperatures, if there is sufficient time for heating before discharge (Horner et al., 1994; Burton and Pitt, 2001). The loss of tree canopy coverage in areas experiencing riparian zone modification also contributes to increased water temperatures. It is likely that these factors serve as an additional stressor to aquatic organisms in urban watersheds in North Carolina, but the importance of thermal impacts was not specifically evaluated in Little Creek.

Flooding. Though beyond the scope of this study, the flooding of commercial and residential properties in the lower gradient portions of the study area (Eastgate Shopping Center, the Estes Drive/University Mall area, and along Little Creek proper) is an important concern of watershed residents and has had significant economic consequences. The stormwater volumes that contribute to this problem are also key contributors to the scour and habitat degradation discussed earlier.

Broader impacts. Sediment, nutrients and toxicants from the Little Creek watershed are transported to Jordan Lake, where they can have negative resource impacts. The New Hope arm of the lake, into which Little Creek empties, is impaired due to elevated chlorophyll *a* levels caused by high nutrient inputs. The Little Creek watershed will be included in the nutrient TMDL to be developed by DWQ by 2005 and a nutrient management strategy is being developed for the entire lake (Section 2).

☞ **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).

Section 8
Improving Stream Integrity in Little Creek: Recommended Strategies

As discussed in the previous section, Little Creek and its tributaries are impaired by the cumulative impacts of toxicity, scour, habitat degradation and (in Booker Creek) hydromodification due to impoundments. Future development will also pose a threat to streams in the watershed due to the potential for additional sediment inputs during construction and modification of watershed hydrology that will yield increased stormflows. 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 more diverse and functional biological community in Little Creek and its tributaries. Because of the widespread nature of biological degradation and the highly developed character of the watershed, bringing about substantial water quality improvement will be a tremendous challenge. Yet the watershed has not been so highly modified as to preclude improvements in stream integrity. A return to the relatively unimpacted conditions that existed prior to widespread agriculture and urbanization is unlikely, but Little Creek and its tributaries can potentially support a healthier biological community than they do today. Additionally, the quantities of sediment and other pollutants transported to Jordan Lake can be reduced.

As discussed in Section 7, while the key factors causing impairment in Little Creek have been identified, their interrelationship remains unclear. Additionally, there are inherent uncertainties regarding how individual BMPs cumulatively impact receiving water chemistry, geomorphology, and habitat (Shields et al., 1999; Urbonas, 2002), and in how aquatic organisms will respond to improved conditions. For these reasons, the intensity of management action necessary to bring about a particular degree of biological improvement cannot be established in advance. This section describes the types of actions needed to improve biological conditions in the Little Creek watershed, but the mix of activities that will be necessary – and the extent of improvement that will be attainable – will only become apparent over time as an adaptive management approach is implemented (see Section 8.3). Management actions are suggested below to address individual problems, but many of these actions are interrelated (e.g., particular BMPs or systems of BMPs can be designed to serve multiple functions).

8.1.1 Hydromodification Due to Scour

Frequent periods of high-velocity stormflow dislodge benthic organisms and contribute to habitat degradation by removing organic microhabitat and causing bank instability. This will continue unless some of the hydrologic impacts of existing development can be abated. Existing stormwater BMPs serve to mitigate the problem to a limited extent. Much development occurred prior to any BMP requirements. Additional stormwater controls in existing developed areas are

necessary to partially restore watershed hydrology by reducing runoff volume and reducing the frequency and duration of erosive flows.

Stormwater retrofits are structural stormwater measures (best management practices or BMPs) for urban watersheds intended to lessen accelerated channel erosion, promote conditions for improved aquatic habitat and reduce pollutant loads (Claytor, 1999). A range of practices, including a variety of ponds and infiltration approaches, may be appropriate depending on local conditions. Practices installed to reduce hydrologic impacts will also provide varying degrees of pollutant removal.

Stormwater retrofit options. Available structural and nonstructural retrofit practices to reduce hydrologic impacts and remove pollutants have been discussed widely in the literature (e.g., ASCE, 2001; Horner et al., 1994; USEPA, 2002) and detailed in state BMP manuals (e.g., NCDWQ, 1999; Maryland Department of the Environment, 2000). Some of these include:

- bioretention;
- infiltration structures (porous pavement, infiltration trenches and basins);
- vegetative practices to promote infiltration (swales, filter strips);
- 'run on' approaches (regrading) to promote infiltration;
- reducing hydrologic connectivity (e.g., redirecting of downspouts to pervious areas);
- education to promote hydrologic awareness;
- changes in design/construction standards;
- stormwater wetlands;
- detention ponds; and
- retention ponds;

Determining which BMPs (or which combination of practices) will be most feasible and effective for a particular catchment depends on numerous site-specific issues, including: drainage patterns; size of potential BMP locations; treatment volume needed considering catchment size and imperviousness; soils; location of existing infrastructure; and other goals (e.g., flood control, pollutant removal). Considerations in the identification of retrofit sites are discussed by Schueler et al. (1991) and Claytor (1999).

DWQ encourages the consideration of a wide range of practices and approaches, with an emphasis on low impact development (LID) techniques. LID focuses on integrating stormwater management into site and building design, rather than relying primarily on the collection and storage of storm runoff (Prince Georges County DER, 2000). Ponds of various types are probably the stormwater BMP most commonly used in North Carolina. Detention alone does not reduce stormwater volume, however, though the rate and timing of discharge can be controlled. While reducing peak flows and preventing some flood damage, detention can increase the duration of mid-level flows, thereby increasing the potential for bank erosion. It is important to carefully consider infiltration practices, including both structures and 'behavioral' changes such as redirecting downspouts to pervious areas. While there are clearly limits to the usefulness of infiltration -- based on soils, water table levels and other factors (Livingston, 2000) -- these practices are often underused. Design approaches to minimize runoff volume are also important tools (Caraco et al., 1998; Prince George's County DEP, 2000). Some retrofit methods may have negative side effects that must be carefully considered. For example, regional wet ponds, though they may remain a viable alternative in some situations, can disrupt recolonization, alter

the food/energy source available to downstream biota, and, depending upon design and operation, reduce or eliminate downstream baseflows (Maxted and Shaver, 1999; Schueler, 2000a).

Recommendation. What is feasible or cost-effective in the way of retrofitting a developed watershed like Little Creek is constrained by existing conditions. Conditions change, however, and a long-term commitment to partially restoring watershed hydrology will be necessary to create opportunities and take advantage of the available options. To have a biologically meaningful impact on watershed hydrology, cost-effective projects will likely have to be sought out and implemented over an extended time frame. Opportunities for stormwater retrofits should be identified and prioritized. Redevelopment and infill projects will provide opportunities to mitigate the shortcomings of previous development.

1. Short-term. Over the next decade, the towns of Chapel Hill and Carrboro, as well as UNC, can investigate retrofit possibilities and implement those that are feasible given current infrastructure and financial constraints. This should include both upgrades of existing BMPs and the identification of viable projects in areas developed without stormwater controls. The most densely developed areas should be given priority for the evaluation of retrofit opportunities, although the extensive infrastructure and built upon areas may be a severe constraint in locating cost-effective options. These areas include: the central business district of Chapel Hill; portions of downtown Carrboro and the UNC campus; and the broad commercial area that includes University Mall and Eastgate Shopping Center.

2. Mid-term. Road realignment, sewer line and bridge replacement and other infrastructure projects will likely make feasible other retrofit opportunities over the next 10-20 years. Such projects can be pursued and the search for retrofit opportunities can be integrated into the capital improvement planning process.

3. Long-term. Over a more extended period, cost-effective restoration opportunities are likely as portions of the watershed are redeveloped incrementally (Ferguson et al., 1999). An ongoing awareness of retrofit needs and changes in development regulations may be necessary to help create and take advantage of these opportunities.

Costs. Stormwater retrofit costs are difficult to estimate until specific practices and locations have been selected. Unit costs vary greatly with the size of the area treated. Using data from the mid 1990s, Schueler (2000b) reported that typical costs for stormwater ponds were about $5,000 per impervious acre treated for projects covering 100 impervious acres but $10,000 per impervious acre treated for projects treating 10 impervious acres. Treating a single acre costs an average of $25,000 or more.

Only gross estimates of total costs are possible. Claytor (1999) suggests that a minimum of 50 percent of a watershed be retrofitted. Thus, for example, a two-square mile watershed that is 25 percent impervious has approximately 320 impervious acres (2 square miles, or 1280 acres, times an imperviousness of 25 percent). Assuming a typical cost of $10,000 per impervious acre, it would take approximately $1.6 million to retrofit 160 impervious acres. This approaches $1 million per square mile of total watershed area, assuming the retrofitting relies primarily on ponds. This estimate, based on data that are now a decade old, should be used only as a general

indication of the likely scale of effort that may be necessary, assuming a sufficient number of viable retrofit projects can be identified. Actual total costs may be higher or lower depending on many factors, including the types of BMPs used and the scale of each project. Some cost reduction may be possible if retrofits are planned and implemented in conjunction with anticipated capital improvements and infrastructure enhancements. The potential connection between watershed restoration and infrastructure issues has been increasingly recognized by local governments (e.g., City of Austin, 2001; Montgomery County DEP, 2001).

8.1.2 Toxic Impacts

While biological evidence points to the importance of toxic impacts, especially in the lower watershed, the particular pollutants or mix of pollutants of primary concern remains unclear. Long-term impacts of repeated exposures may be important, and the most critical toxicants may vary with time, associated with specific events. Source areas likely lie throughout developed portions of the watershed.

Two broad approaches can be used to address toxic impacts: structural BMPs to remove pollutants from stormwater, and primarily nonstructural source reduction methods to prevent pollution inputs (NVPDC, 1996; Heaney et al., 1999; USEPA, 2002). These approaches are not mutually exclusive and a multifaceted strategy drawing on both approaches will be more effective than a more narrowly focused effort. A general conceptual strategy to address toxicity in the Little Creek watershed is outlined below. This should be viewed only as an initial framework for planning and implementing toxicity reduction efforts. Ongoing planning and strategy reassessment will be necessary to refine the scope and nature of management efforts.

1. Development and implementation of a broad set of source reduction activities. Since removing pollutants from stormwater can be difficult and expensive, pollution prevention activities are crucial. Among activities that could be considered for inclusion in a pollution prevention efforts are the following:

- Reducing nonstorm inputs of toxicants by:
    a) identification and elimination of illicit discharges (actions required under the new Phase II stormwater program);
    b) review of existing information on groundwater contamination (see Section 2) and implementation of appropriate remediation measures if warranted;
    c) verification that industrial, institutional and commercial floor drains empty to the sanitary sewer system or appropriate treatment facilities;
    d) education of homeowners and others regarding the use of cleaning agents and the proper disposal of motor oil and antifreeze; and
    e) education of industrial, institutional and commercial operation and maintenance staff regarding proper use of storm drains and the implications of dumping.
- Reducing pollutants available for washoff during storms by:
    a) education of homeowners, grounds staff, and commercial applicators regarding appropriate pesticide use;
    b) provision of technical assistance to golf course staff regarding appropriate pesticide usage; and

c) outreach and technical assistance to industrial, institutional and commercial facilities regarding materials storage practices; spill prevention procedures; and spill control and cleanup procedures.

- Managing water to reduce storm runoff by:
  a) routing roof drains and pavement to available pervious areas where feasible (may require some regrading);
  b) encouraging the use of other infiltration techniques; and
  c) proper maintenance of existing BMPs.

2. Implementation of stormwater treatment BMPs, aimed primarily at pollutant removal, at appropriate locations. A wide range of conventional BMPs can be used to remove pollutants from stormwater runoff (see ASCE, 2001). For example infiltration practices, constructed wetlands, vegetated swales and various types of ponds can remove a substantial percentage of metals. Results of additional monitoring (see below) will be important in targeting these BMPs, although some likely "hot spots" (areas of intense activity or high risk) could be identified without water quality sampling. Proprietary treatment systems can be considered where adequate space is not available for conventional stormwater BMPs.

3. Development of a stormwater and dry weather toxics sampling strategy for the watershed. Selection of particular BMPs can proceed more efficiently if better information on specific target pollutants and source areas is available. Such information would also aid in the targeting of source reduction efforts. To address these needs, a monitoring strategy should be developed based upon further watershed reconnaissance.

4. Implementation of available BMP opportunities for control of stormwater volume and velocities. Recommended earlier in order to reduce scour impacts and improve aquatic habitat potential, these BMPs will also remove toxicants from the stormwater system (the extent of removal will vary depending upon the specific structures and pollutants involved).

The condition of residential lawns and commercial grounds in this watershed strongly suggests that turf chemicals are likely applied in substantial quantities. Education for property owners, maintenance staff of commercial facilities, and commercial applicators regarding pesticide use should be a priority.

Addressing vehicle related pollution will be a particular challenge. BMPs to treat parking lot and roadway runoff will likely be feasible at some locations. Source control may have to wait for changes in vehicle or component design (e.g., changes in brake pad composition).

Development of specific pollution prevention and control strategies is beyond the scope of this study. Some elements of a strategy could probably be implemented by enhancing or redirecting existing program activities. In other cases new initiatives may be necessary. While state agencies such as DWQ and the Division of Pollution Prevention and Environmental Assistance (DPPEA) can play a role, planning and implementation of a strategy is likely to be more effective if carried out by local governments, agencies and stakeholders. Chapel Hill, Carrboro, Orange County, OWASA and UNC all have important roles to play in this process, including meeting the requirements of the Phase II stormwater program.

The source of toxicity in Crow Branch has not been positively identified, but the two UNC hazardous waste disposal sites are the most likely source. Appropriate remediation activities should be undertaken at these facilities. Additional investigation may be necessary to determine the most likely toxicants involved.

While OWASA's spill prevention program was not evaluated as a part of this project and the frequency of spills resulting in toxic conditions cannot be established with the data available, data from one event during the course of the study indicate the potential for toxic impacts. Effective spill prevention efforts on the part of OWASA are necessary to reduce the potential for toxicity due to ammonia or other raw sewage constituents.

8.1.3 Hydromodification Due to Dams

Removal of the dams at Eastwood Lake and Lake Ellen would obviously be the most effective way to eliminate the negative impacts of these impoundments on stream biota (restriction of organism movement, low flows and dissolved oxygen). This is not likely to be a viable alternative given the amenity value of the impoundments. Additionally, Eastwood Lake is serving to treat stormwater pollutants to some degree, and its removal would necessitate finding a way to replace this removal capacity in a watershed in which still greater stormwater treatment and control are needed. Without removal of the dam, some types of impacts (e.g., interference with macroinvertebrate drift and fish migration) could likely not be mitigated.

The Division of Land Resources regulates dam construction and maintenance under the Dam Safety Law of 1967 and minimum release requirements can be established to protect aquatic life. Dams built before 1967 are not exempt from this law. The technical, economic and regulatory feasibility of implementing minimum releases from Eastwood Lake should be explored. Voluntary release agreements may also be an option.

8.1.4 Habitat Degradation

This section outlines a general approach to improving habitat conditions in the Little Creek watershed and discusses more specific recommendations for initiating restoration efforts.

Background. Habitat deterioration in the lower portion of the study area is driven by: long-term adjustments to past channel modification; the hydrologic impacts of recent and ongoing development; and riparian zone modification and the loss of stabilizing native vegetation. In the absence of further management actions, substantial channel adjustment (erosion and subsequent downstream deposition), with resulting poor habitat for aquatic organisms, will likely continue until development in the watershed slows. Given adequate time, the stream would develop a channel morphology in equilibrium with the stabilized hydrologic conditions of the watershed. The alternative to waiting for the channel to develop a stable form on its own is to proactively restore a stable channel morphology in currently unstable reaches.

Once channel stability is restored, sediment would be reduced and aquatic habitat would improve, though the extent of improvement is likely to be limited by hydrologic conditions. The hydrologic regime in the urban environment can produce frequent periods of high velocity scouring flows. Low baseflows and a wide baseflow channel may also limit biological potential.

Partial restoration of watershed hydrology--the mitigation of some of the hydrologic impacts of existing development--is often a prerequisite for substantial improvement of urban stream habitat. Recommended stormwater quantity retrofit measures were discussed above.

General Approach. Both stream channel restoration and stormwater retrofits to control stormwater volume and reduce the frequency and duration of erosive flows are necessary to address the poor habitat (channel) conditions in the lower study area. Specifically:

1. The following areas, a total channel length of approximately 3.2 miles, should eventually be restored to a stable morphology: the entire mainstem of Little Creek within the study area; Bolin Creek below East Franklin Street; Booker Creek downstream of Old Oxford Road (below Eastwood Lake); and the 500-foot reach of Booker Creek below the Lake Ellen spillway.
2. Channel instability is evident along portions of the Bolin Creek Greenway between Bolinwood Drive and East Franklin Street. These areas should be further evaluated for restoration.
3. Tributaries in the lower watershed should also be further evaluated for restoration.
4. Habitat is generally adequate further upstream on Booker and Bolin Creek, but local areas of instability exist and could potentially benefit from bank stabilization, both improving local habitat and reducing sediment loading to downstream areas. This project did not attempt to identify specific areas.
5. Riparian vegetation should be improved, as discussed below.
6. Channel restoration and stormwater BMPs should be implemented in an integrated fashion so that both channel morphology and watershed hydrology problems are addressed using a coordinated approach.
7. Given the scope of the problem, restoration efforts must be implemented incrementally over an extended period of time. Ongoing planning will be a necessity.

Since overall channel morphology is unstable in the lower watershed, simple bank stabilization will not be effective in addressing existing problems. Stream channel restoration is necessary to re-establish a stable channel dimension (cross-section), pattern (sinuosity and planform) and longitudinal profile (slope). While other options exist (see NCSU, 2002), the most feasible approach to the restoration of most channels in this watershed is probably to construct appropriate floodplain area and channel form within the existing channel (Rosgen priority 2 or priority 3 approach). The specific restoration strategy selected will depend upon the stream corridor width available (belt width), among other factors (NCSU, 2001 and 2002; Rosgen, 1997).

Habitat in the unstable portions of the lower study area will be difficult to restore as long as sediment loads (from upstream bank erosion and upland construction activities) and upstream stormwater inputs are not better controlled. Short-term goals should therefore focus on sediment reduction efforts and mitigation of upstream hydrologic impacts to the extent feasible. Minimization of the hydrologic impacts from new development should also be a priority, as discussed in Section 8.2.

Riparian vegetation. Native woody riparian vegetation along streams in the watershed should be re-established where it has been removed, especially along the sewer right of way and greenways. This would help ensure an adequate supply of woody material to the stream and

improve bank stability. OWASA and the Towns of Chapel Hill and Carrboro should work to improve the condition of riparian vegetation along sewer rights of way and greenways, and should limit future riparian area disturbance to the minimum extent necessary to maintain infrastructure. Property owners along smaller streams should be encouraged to reestablish woody vegetation and avoid modification of streams. Additionally, riparian vegetation is often of poor quality, even in wooded areas, due to dominance by non-native species. Non-native invasive species such as privet (*Ligustrum sp*.) should be replaced with native woody vegetation in order to promote bank stability and enhance nutrient removal.

Channel restoration costs and constraints. The restoration of channel stability and aquatic habitat in the study area will be a major undertaking in terms of technical planning, project implementation, finances and organizational coordination. Stream work would be implemented gradually over many years, constituting a major logistical challenge that will require patience, resources and an oversight team dedicated to this activity. The presence of a sewer line right of way along much of Little, Booker and Bolin Creeks will be an advantage in terms of access but a constraint in terms of restoration options. Based on the recent experience of the North Carolina Wetlands Restoration Program (Haupt et al., 2002) and a number of Maryland counties that have active restoration programs (Weinkam et al., 2001), costs of at least $200 per linear foot (about $1 million per mile) should be expected for the restoration of urban stream channels.

8.1.5 Low Dissolved Oxygen/ Organic and Nutrient Enrichment

As described in Section 7, it has not been possible to distinguish between the impacts of organic/nutrient loading and urban hydrologic impacts on dissolved oxygen. The impacts of urbanization (e.g., lower baseflows, wider and shallower baseflow channels) can be addressed primarily by retrofit practices that encourage infiltration of stormwater and by channel restoration, both of which have already been discussed. Whether it is feasible to increase infiltration sufficiently to improve baseflows is unknown, but this is likely to be a difficult task in a highly developed watershed.

Nutrient and organic loading can be addressed in a variety of ways. Stormwater treatment and source reduction activities intended to address other problems (see above) are likely to reduce nutrient and BOD inputs. Additional BMPs targeted specifically at these pollutants may be warranted at high loading areas identified during subsequent investigation. Organic and nutrient loading can also be reduced via established practices such as: the identification and elimination of illicit discharges; education of homeowners, commercial applicators, golf courses and others regarding proper fertilizer use; street sweeping; and catch basin clean-out practices. The identification and elimination of illicit connections is required under the Phase II stormwater program. Continued efforts by OWASA to prevent sewer overflows and address leaking sewer lines will be necessary to prevent loadings from these sources. The nutrient TMDL for the New Hope arm of Jordan Lake and the lakewide nutrient strategy to be developed in the near future (see Section 2) will further address nitrogen and phosphorus loading issues in the Little Creek study area.

8.2 Addressing Future Threats

Much of the upper portion of the Bolin Creek watershed, located primarily in Carrboro's Northern Transition Area, is currently lightly developed, although more intensive development is likely here over the next several decades (Section 2). The largest undeveloped area in the Booker Creek watershed is UNC's Carolina North Tract, for which development planning is underway. Without a focused effort to mitigate the hydrologic impacts of these developing areas and assure effective sediment and erosion control practices during construction, additional water quality and habitat degradation is likely in Bolin and Booker Creeks, their tributaries, and downstream in Little Creek. Addressing these future threats is essential, or improvements resulting from efforts to control current sources of downstream impairment may be short-lived or may never materialize.

A decline in the biological condition of headwaters and tributaries may result in the classification of additional stream segments as impaired. Additionally, those areas that currently support a relatively diverse benthic community are critical to the recovery of impaired areas, since they can serve as sources of recolonization. The preservation and enhancement of these healthier areas is essential to the recovery of the larger system.

8.2.1 Sediment from New Construction

Significant future sediment inputs would prolong habitat degradation in the lower study area even if existing sources of sediment are addressed. While bank instability is probably a primary source of sediment in the watershed, inputs from construction activities can also be substantial, particularly in the case of large projects.

Effective enforcement of sediment and erosion control regulations on the part of the Orange County erosion control program (and the NC Division of Land Resources, for publicly funded construction such as UNC and NC Department of Transportation projects) will be essential to the prevention of additional sediment inputs from construction activities. Orange County is already known for its proactive approach to sediment and erosion control. An evaluation of current sediment and erosion control practices is beyond the scope of this study, but development of improved erosion and sediment control practices may be beneficial and Orange County should be encouraged to continue to enhance its program. Observation suggests that additional emphasis on erosion prevention--for example, greater attention to the phasing of construction activities and to the rapid establishment of stabilizing vegetation--would be useful in reducing potential sediment impacts. 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.

8.2.2 Hydromodification Due to Increased Stormflows

Over the next several decades, overall imperviousness in the watershed is likely to increase as the Bolin Creek headwaters area and the Crow Branch catchment develop. Without effective stormwater management, both peak discharges as well as the frequency and duration of high velocity flows can be expected to increase and to negatively affect channel stability. Existing

conditions in a watershed can greatly affect a stream's vulnerability to these hydrologic changes (Bledsoe and Watson, 2001). As discussed previously, some stream banks in the study area are in poor condition and prone to erosion, making them highly sensitive to any increase in stormflow. Given these conditions, increased bank erosion (and incision, for channels below East Franklin Street) is likely if additional hydrologic change occurs in the watershed (Section 6). Streams draining currently undeveloped areas, now relatively stable in most cases, are likely to deteriorate.

Carrboro currently requires that new development in its Northern Transition Area implement stormwater measures to prevent upstream or downstream impacts (see Section 2). These requirements apply to essentially all development in the Carrboro portion of the study area, regardless of density, with the exception of those developments that require only administrative level permits. While the Town can impose a range of requirements to meet these provisions, the standard conditions in Carrboro's Storm Drainage Design Manual specify that detention should be provided so that the post-development peak flow leaving the site for the 25-year storm does not exceed the pre-development peak. While this design standard will have some flooding and water quality benefits, it is unlikely to adequately protect stream channels from the hydrologic impacts of development. Smaller, more frequent stream discharges, especially those in the range of the 1.5-year recurrence interval, are the most critical for sediment transport processes and channel stability (Wolman and Miller, 1960; Federal Interagency Stream Restoration Working Group, 1998).

Chapel Hill's recently adopted Land Use Management Ordinance requires that most new development in the study area implement stormwater controls so that stormwater runoff volume leaving the site post-development does not exceed predevelopment volume for the 2-year 24-hour storm. Additionally, the post-development runoff rate leaving the site cannot exceed pre-development rates for the 1-year, 2-year and 25-year 24-hour storm events. The Town encourages the use of Low Impact Design option. The Chapel Hill requirements should be adequate to control geomorphically relevant discharges and provide substantial protection to downstream channels from hydrologic impacts.

Chapel Hill, Carrboro and Orange County are among the communities automatically designated for coverage under the Phase II stormwater program (see Section 2). UNC is also subject to these requirements. All of these jurisdictions will be required to meet or exceed the stormwater control requirements in North Carolina's rules implementing the Phase II program (control of the 1-year 24-hour storm for development with built-upon area exceeding 24 percent). The 1-year 24-hour storm requirement should provide much better channel protection than the 25-year storm requirement that is standard practice in Carrboro (see Brown and Caraco, 2001, for a discussion of channel protection). Chapel Hill requirements already exceed this and apply to all levels of imperviousness. However, it is now widely accepted that development below the 24 percent built-upon area threshold can result in significant hydrologic change. A variety of studies (e.g., Schueler, 1994; Bledsoe and Watson, 2001) indicate that impacts to channel morphology and stream habitat occur at levels of imperviousness as low as 10 percent. Given that channel stability and habitat degradation in much of Booker and Bolin Creeks are already problematic, it is important that additional hydrologic change in the watershed be minimized. Otherwise, existing impairment will be prolonged or exacerbated.

Channels in this watershed are most likely to be protected from the hydrologic impacts of new development if post construction stormwater requirements include:

1. Active promotion of low impact development (LID) practices to limit stormwater volume and emulate pre-development hydrology (e.g., bioretention areas and other practices to promote infiltration; see Prince Georges County DER, 2000).
2. Extended detention of the 1-year or 2-year 24-hour storm or alternative criteria to address geomorphically relevant flows (see Brown and Caraco, 2001; Maryland Department of the Environment, 2000).
3. A threshold for the use of stormwater controls that is no higher than 10 percent built-upon area. To prevent existing unstable conditions from deteriorating further, post-construction stormwater control requirements should be applied to all but the lowest density development.

It would also be useful to identify wetland and riparian restoration projects or other watershed-based efforts to mitigate for post-construction stormwater impacts (from both new and existing development) that will not otherwise be controlled.

8.2.3 Riparian Buffers

The protection of riparian buffers is critical to limiting the hydrologic impacts of development and to the attenuation of pollutant inputs. Whether accomplished through incentives or regulatory measures, it is important to protect existing forested riparian buffers along perennial, intermittent and ephemeral streams. Both Carrboro and Chapel Hill have relatively stringent buffer protection requirements (Section 2). It is important to the health of streams in the watershed that these regulations are effectively enforced, and that disturbance of areas along all streams, including ephemeral streams, is discouraged.

8.3 A Framework for Improving and Protecting Stream Integrity

Watershed restoration of the type necessary to significantly improve Little, Bolin and Booker Creeks is clearly ambitious, but has become more common over the past decade. Local governments and watershed-based organizations have increasingly sought to plan and implement long-term restoration and management strategies that integrate channel, riparian and watershed measures to address stream issues in an integrated fashion. The most long-standing example is probably the restoration of the Anacostia River in the Washington, DC area, for which planning was initiated in the 1980s (Anacostia Restoration Team, 1991; Metropolitan Washington COG, 1998; Galli, 1999; Schueler and Holland, 2000). Among the other local areas that have begun to address these issues are Austin, Texas (City of Austin, 2001); Atlanta, Georgia (CH2M HILL, 1998); and Montgomery County, Maryland (Montgomery County DEP, 2001).

Restoration projects of this scale require an iterative process of ‘adaptive management’ (Reckhow, 1997; USEPA, 2001). Considering the scope of activities, logistical complexities and scientific uncertainties it is not possible to anticipate all necessary actions in advance. An initial round of management actions must be planned and implemented, the results of those activities monitored over time, and the resulting information used as the basis for planning subsequent efforts. Additional measures should be implemented as appropriate. Improvement in stream condition is likely to be incremental.

An organizational framework for ongoing watershed management is essential to provide oversight over project implementation, 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. A coordinated planning effort involving local governments in the watershed, UNC, OWASA, and a broad range of other stakeholders, will be critical if conditions in the study area are to be improved. This effort must include the development of a long-term vision for protecting and restoring the watershed, as well as the specific work that will be necessary to support an adaptive management approach to planning and implementing projects to move toward that vision. The joint effort initiated by local governments to study comprehensive stormwater and floodplain management needs in southern Orange County (Cooperating Technical Partnership) can be an important building block for that effort. The framework being developed as part of the local watershed planning process initiated by the NC Wetlands Restoration Program in the Morgan Creek and Little Creek watersheds (see Section 2) could also serve to facilitate this process.

8.4 Summary of Watershed Strategies for Little Creek

The recommendations summarized below address specific causes of impairment. These factors have a joint impact on stream conditions, however, and many management activities have multiple impacts as well. Remedial actions are likely to be most cost-effective if implemented in a coordinated fashion based upon a restoration plan developed by local governments and other stakeholders.

The following actions are necessary to address current sources of impairment in the Little Creek watershed and prevent future degradation. The intent of these recommendations is to describe the types of actions necessary to improve conditions in the study area, not to specify particular administrative or institutional mechanisms for implementing remedial practices.

These actions are most likely to be undertaken effectively if a reliable long-term source of funding is available. Possible sources include grants, stormwater utility fees, or other local government financing mechanisms. The Town of Chapel Hill is currently developing a stormwater utility that will include program elements to address water quality and quantity with a comprehensive stormwater and floodplain management program.

Actions one through five are all essential to the restoration of aquatic communities in the watershed. Action six is essential to the prevention of stormwater impacts from future development. The additional recommended actions will result in limited improvement unless these are accomplished.

1. **Feasible and cost-effective stormwater retrofit projects should be implemented to mitigate the hydrologic effects of existing development** (increased stormwater volumes and increased frequency and duration of erosive and scouring flows). This should be viewed as a long-term process. Although there are many uncertainties, costs of at least $1 million per square mile can probably be anticipated.
   a) Over the short-term, currently feasible retrofit projects should be identified and implemented. The most densely developed areas should be given priority for the

evaluation of retrofit opportunities. These areas include: the central business district of Chapel Hill; portions of downtown Carrboro and the UNC campus; and the broad commercial area that includes University Mall and Eastgate Shopping Center.

b) In the longer term, additional retrofit opportunities should be sought out in conjunction with infrastructure improvements and redevelopment of existing developed areas.

c) The most densely developed areas should be given priority for the evaluation of retrofit opportunities.

2. **A strategy to address toxic inputs should be developed and implemented, including a variety of source reduction and stormwater treatment methods**. As an initial framework for planning toxicity reduction efforts, the following general approach is proposed:
   a) Development and implementation of a broad set of source reduction activities focused on: reducing nonstorm inputs of toxicants; reducing pollutants available for washoff during storms; and managing water to reduce storm runoff. Suggestions for potential source reduction practices are provided.
   b) Implementation of stormwater treatment BMPs, aimed primarily at pollutant removal, at appropriate locations.
   c) Development of a stormwater and dry weather sampling strategy in order to facilitate the targeting of pollutant removal and source reduction practices.
   d) Implementation of available BMP opportunities for control of stormwater volume and velocities. Recommended above to improve aquatic habitat potential, these BMPs can also remove toxicants from the stormwater system.
3. **Appropriate remediation should be undertaken at the two UNC hazardous waste disposal sites to address toxicity in Crow Branch. Additional investigation may be necessary to determine the most likely toxicants involved**.
4. **Stream channel restoration activities should be implemented in the lower portion of the study area, in conjunction with stormwater retrofit BMPs, in order to improve aquatic habitat.** Priority areas include: the entire mainstem of Little Creek within the study area; Bolin Creek below East Franklin Street; Booker Creek below Old Oxford Road; and the 500-foot reach of Booker Creek below the Lake Ellen spillway (a total channel length of approximately 3.2 miles). Smaller sections of upstream channel may also benefit from restoration.
5. **OWASA and the Towns of Chapel Hill and Carrboro should cooperate in improving the condition of riparian vegetation along sanitary sewer rights of way and greenways. Future riparian area disturbance should be limited to the minimum extent necessary to maintain infrastructure.** More generally, property owners should be encouraged to re-establish native woody riparian vegetation along streams where it has been removed, and to limit future disturbance.
6. **Prevention of further channel erosion and habitat degradation will require effective post-construction stormwater management for all new development in the study area**. Channels in this watershed are most likely to be protected from the hydrologic impacts of new development if post-construction stormwater requirements include:
   a) Active promotion of infiltration practices, low impact development (LID) practices and other approaches to limit stormwater volume.
   b) Extended detention of the 1-year or 2-year 24-hour storm or alternative criteria to address geomorphically relevant flows.
   c) A threshold for the use of stormwater controls that is no higher than 10 percent built-upon area. To prevent existing unstable conditions from deteriorating further, post-

construction stormwater control requirements should be applied to all but the lowest density development.

7. Activities recommended to address organic loading include: the identification and elimination of illicit discharges (required under the Phase II stormwater program); education of homeowners, commercial applicators, and others regarding proper fertilizer use; street sweeping; catch basin clean-out practices; and the installation of additional BMPs targeting BOD and nutrient removal at appropriate sites.
8. Improved efforts by OWASA to prevent sewer overflows and address leaking sewer lines will be critical to reducing nutrient inputs and potential ammonia toxicity from these sources.
9. The technical, economic and regulatory feasibility of implementing minimum releases from Eastwood Lake should be explored.
10. Effective enforcement of sediment and erosion control regulations on the part of Orange County and the NC Division of Land Resources will be essential to the prevention of additional sediment inputs from construction activities. Increased attention to the phasing of construction activities and to the rapid establishment of stabilizing vegetation is also important.

Section 9
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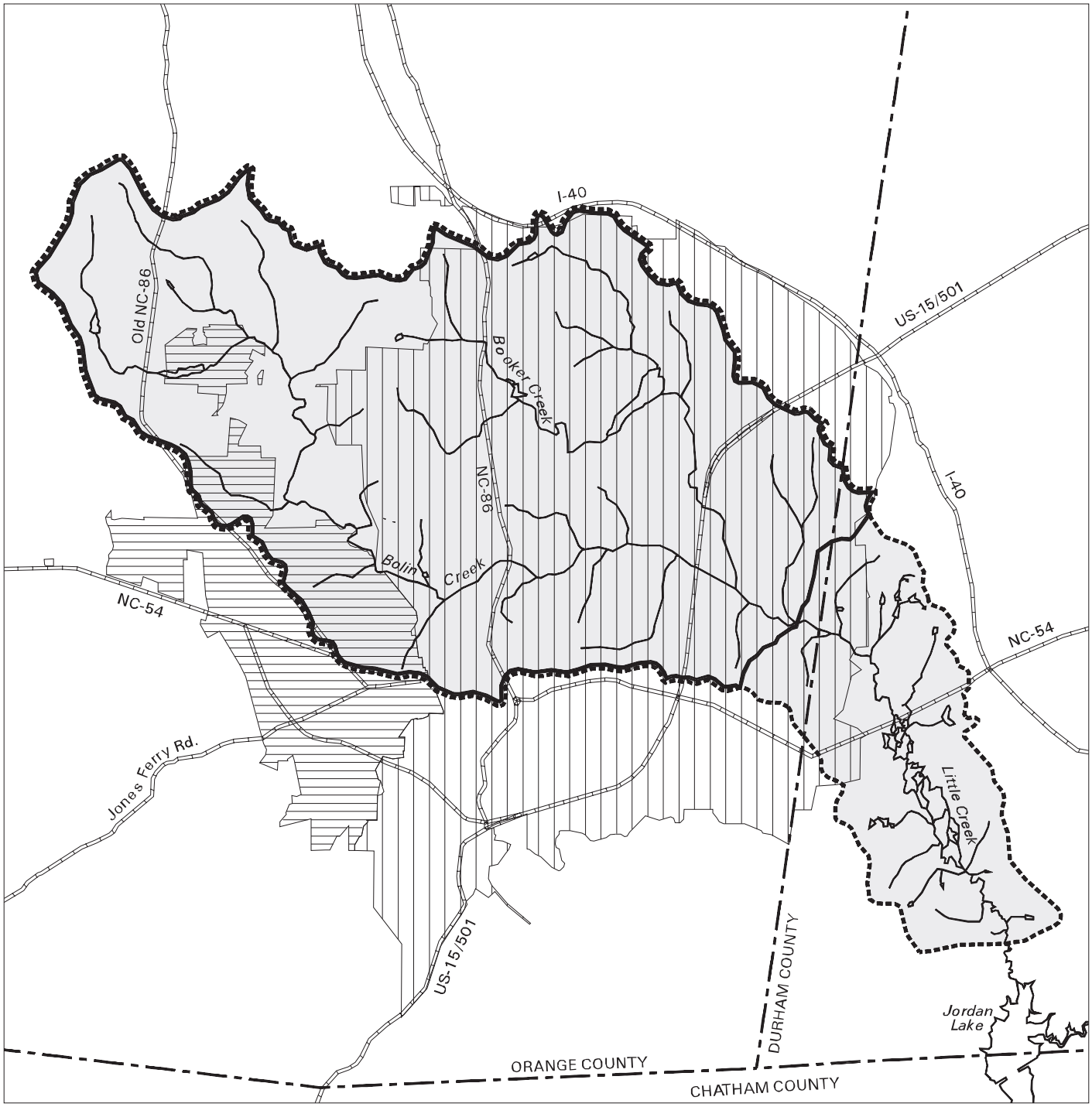
Figure 1.1

Little Creek Watershed - Cape Fear River Basin



LEGEND

- Watershed
- Study Area
- Carrboro
- Chapel Hill
- Hydrography
- Major Roads
- County Boundary

State Vicinity Map

County Vicinity Map

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CGIA

SCALE 1:80,000

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Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 2.1

Little Creek Study Area - Hydrologic Features

LEGEND

- Study Area
- Carrboro
- Chapel Hill
- Subwatershed Boundary
- Hydrography
- Major Roads
- County Boundary
- Geology

State Vicinity Map

County Vicinity Map

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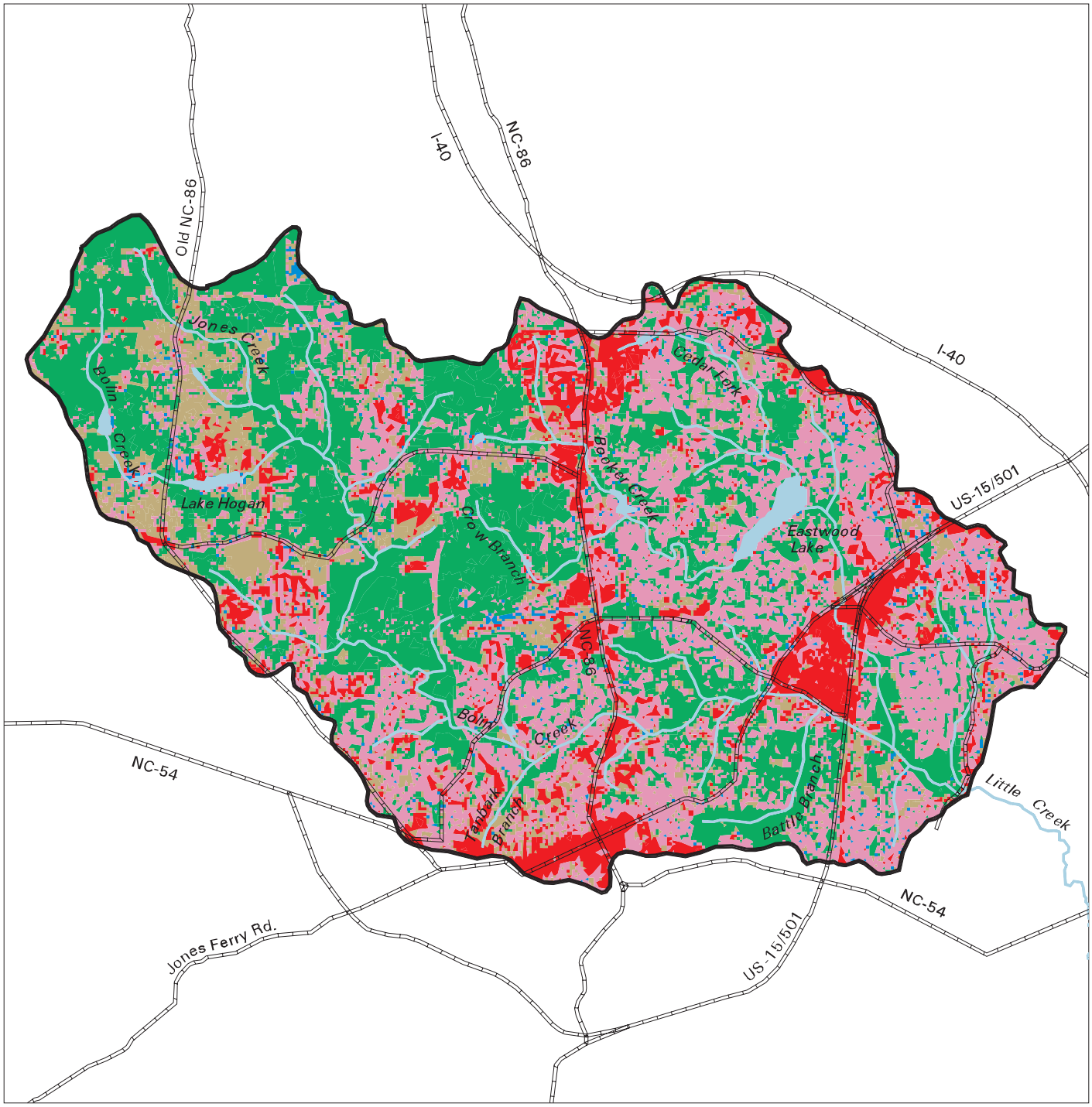
Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 2.4

Little Creek Study Area - Land Cover



LEGEND

- Forest
- Grass/Fields
- High Density Developed
- Low Density Developed
- Water
- Wetlands

State Vicinity Map

County Vicinity Map

SCALE 1:65,000

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Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 2.5

Little Creek Study Area - NPDES Permits

LEGEND

- Study Area
- Hydrography
- Major Roads
- County Boundary
- ⊕ Single Family Residence Wastewater Permit
- ▲ Stormwater Permit

State Vicinity Map

County Vicinity Map

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SCALE 1:85,000

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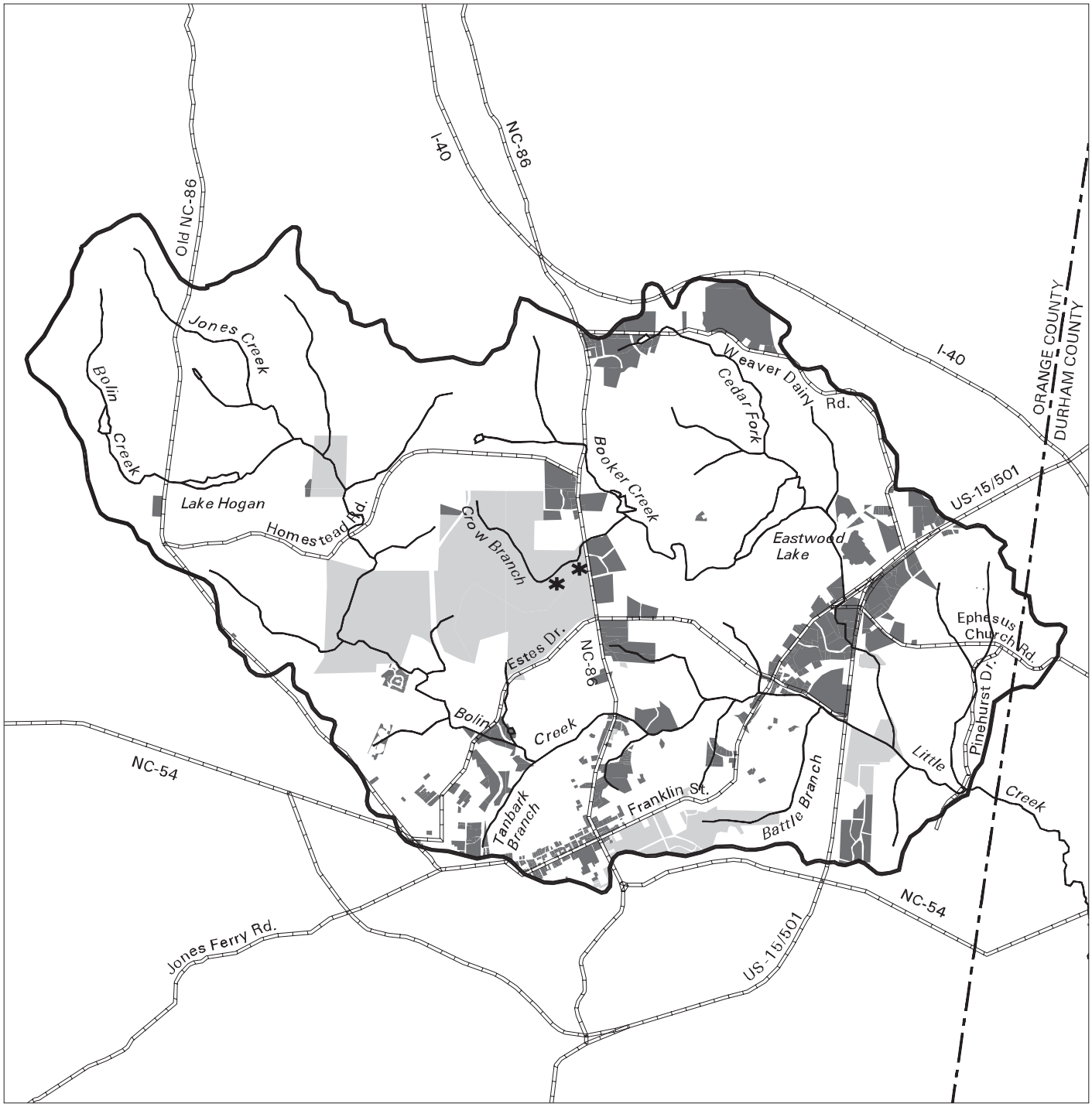
Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 2.6

Little Creek Study Area - UNC Property & Areas Zoned for Commercial Use



LEGEND

- Study Area
- UNC Property
- Areas Zoned For Commercial Use
- Hydrography
- Major Roads
- County Boundary
- ✱ Inactive UNC-CH Hazardous Waste Site

State Vicinity Map

County Vicinity Map

SCALE 1:65,000

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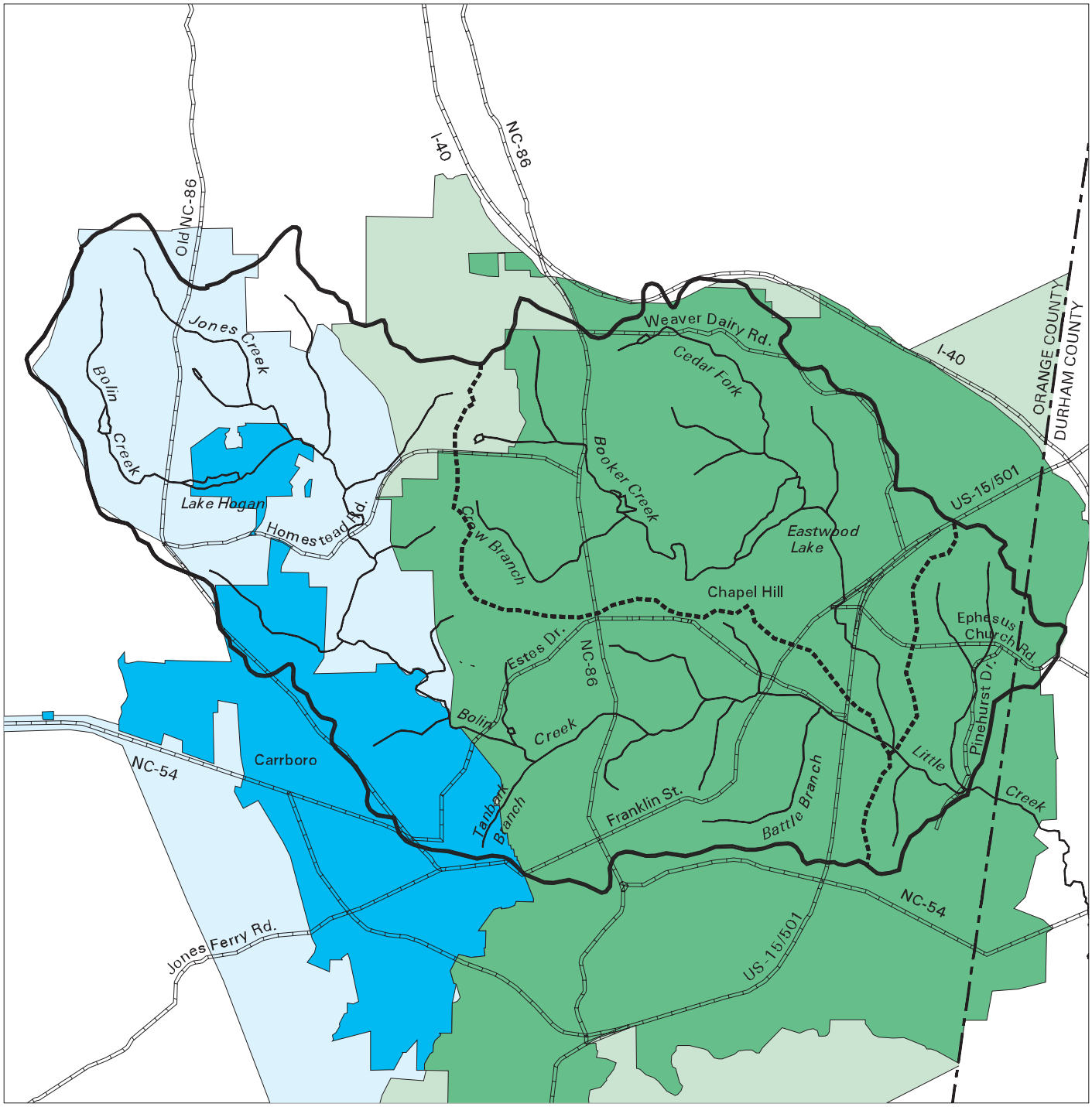
Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 2.7

Little Creek Study Area - Planning Jurisdictions



LEGEND

Corporate Limits — Carrboro, Chapel Hill

Planning Jurisdictions

Study Area

Subwatershed Boundary

Hydrography

Major Roads

County Boundary

State Vicinity Map

County Vicinity Map

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SCALE 1:65,000

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Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 4.1

Little Creek Study Area - Benthic Macroinvertebrate Sampling Sites

LEGEND

- Study Area
- Hydrography
- Major Roads
- County Boundary
- DWQ Benthic Sampling Site
- Town of Carrboro Benthic Sampling Site
- Geology

1 - Little Creek at Pinehurst Dr.
2 - Bolin Ck. at E. Franklin St
3 - Bolin Ck. at Bolinwood Dr.
4 - Tanbark Br. in Umstead Park
5 - Bolin Ck. at Village Dr.
6 - Bolin Ck. at Estes Dr.
7 - Bolin Ck. at Waterside Dr.
8 - Bolin Ck. at Homestead Rd
9 - Booker Ck. at Willow Dr.
10 - Booker Ck. at Piney Mt. Rd.
11 - Booker Ck. at Barbara Ct.

County Vicinity Map

SCALE 1:85,000

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Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 5.1

Little Creek Study Area - Water Quality Monitoring Stations

LEGEND

- Study Area
- Hydrography
- Major Roads
- County Boundary
- DWQ Water Quality Monitoring Station
- Town of Chapel Hill Water Quality Monitoring Station

LCBK01 - Booker Ck. at Willow Dr.
LCBK02A - UT near Ephesus Ch. Rd.
LCBK03 - Booker Ck. behind Eastgate
LCBK04 - Booker Ck. at E. Franklin St.
LCBKCB01 - Crow Br. above Airport Rd.
LCBKCB02 - Crow Br. below Airport Rd.
LCBN01 - Bolin Ck at 15-501
LCBN02 - Bolin Ck. at E. Franklin St.
LCBN03 - Bolin Ck. at Airport Rd.
LCBN04 - Bolin Ck. at Village Dr.
LCBN04A - Bolin Ck. at Umstead Park
LCBN06 - Bolin Ck. at Homestead Rd.
LCBK07 - Booker Ck. at Piney Mt. Rd.
LCLC01 - Little Ck. at Pinehurst Dr.
#11 Bolin - Bolin Ck. at Pathway Dr.
#12 Booker - Booker Ck. at Airport Rd.

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Map Produced by the N.C. Center for Geographic Information and Analysis

Figure 6.1

Little Creek Study Area - Riparian & Geomorphic Survey Sites

LEGEND

- Study Area
- Hydrography
- Major Roads
- County Boundary
- Geology
- ◇ Chapel Hill Riparian/Geomorphic Survey Site
- • NCSU Geomorphic Survey Site

1 - Little Ck. above Pinehurst Dr.
2 - Battle Br. near Sugarberry Rd.
3 - Bolin Ck. in Greenway
4 - Bolin Ck. at Umstead Park
5 - Bolin Ck. at Pathway Drive
6 - Bolin Ck. at Homestead Rd.
7 - Booker Ck. at Willow Dr.
8 - Booker Ck. in Greenway
9 - Booker Ck. below Eastwood L.
10 - Booker CK. Piney Mt. Rd.
11 - Booker Ck. in Homestead Pk.
12 - Bolin Ck. in Community Center Pk.
13 - Bolin Ck. below Airport Rd.

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Map Produced by the N.C. Center for Geographic Information and Analysis

Appendix A

Benthic Macroinvertebrate Sampling

Division of Water Quality

Watershed Assessment and Restoration Project

October 10, 2002

MEMORANDUM

To:	Jim Blose
Through:	Trish MacPherson
From:	John Giorgino
Subject:	Macroinvertebrate sampling of the Little Creek Watershed including Bolin Creek and Booker Creek, Orange County, 2001-2002

BACKGROUND

Little Creek is located in Orange County in Cape Fear River (CPF) subbasin 06. The study watershed is approximately 24.6 square miles and lies within the Carolina Slate Belt and the Triassic Basin ecoregions. Little Creek forms at the confluence of Bolin Creek and Booker Creek (Figure 1). Impaired benthic communities can be found at all sites, except the uppermost site sampled on Bolin Creek (SR 1777). Although these streams have been sampled in the past, the focus of this study is to determine reasons for impairment.

The Booker Creek headwater is about 0.5 miles south of the intersection of Interstate 40 and Airport Road in Chapel Hill. The creek starts just west of Airport Road and generally flows southeasterly into two impoundments: Lake Ellen and Eastwood Lake. Between these two impoundments, the creek flows under Piney Mountain Road, the site of a bridge washout during a flash flood in July 2000. After exiting Eastwood Lake, Booker Creek flows southward under Franklin Street and under Eastgate Shopping Center. The creek then flows along more parking areas and under US 15-501 where it joins Bolin Creek about 0.7 miles downstream.

The Bolin Creek benthos study area begins at SR 1777 (Homestead Road), about 1.8 miles west of Airport Road. From this point, Bolin Creek flows south then east under Airport Road to East Franklin Street. From East Franklin Street, Bolin Creek flows southeast under US 15-501, until it meets Booker Creek to form Little Creek. Little Creek then flows southeasterly through Chapel Hill Country Club, and then to Jordan Lake, approximately 4 miles downstream.

As part of the WARP study, fish communities were also assessed at 3 sites on Bolin Creek. One of the sites was also a benthic sample site. The fish community study is included in the final WARP report as a separate appendix.

STUDY SITES

Bolin Creek Sites

Bolin Creek at SR 1777 (Homestead Road)

This is the most upstream sample site on Bolin Creek and is considered the reference site for the study because of the historically Good rating here. This site was sampled on 4/1//93, 3/11/98, 4/6/00, 2/27/01 and 7/10/01. In the sampling reach, there are multiple well-defined rock riffles. Undercut banks and root mats are common, but snags, sticks and leaf packs were rare. The site is only forested on the left bank, and the entire right bank along the sample reach is a grassy area that extends down from a private residence.

There is a large housing project (including a lake) upstream of this site. There are many houses already constructed with more to be built. This may be one cause of the slight decline in taxa and bioclassification since 2001 compared to previous years. However, the amount of sand and silt has remained somewhat constant since the site was first sampled in 1993. Specific conductance was 106 µmhos/cm on 2/27/01 and 114 µmhos/cm on 7/10/01.

Figure 1. Little Creek Watershed Study Sites

Bolin Creek at Village Drive and Umstead Drive

This site is located just upstream of Village Drive, and was sampled on 4/1/93, 2/26/98, 2/27/01, 7/10/01 and 3/14/02. The site is characterized by significant amounts of boulder, rubble and some gravel and sand. Undercut banks and root mats were available for colonization. Sticks and leaf packs were more abundant in 2/01 and 3/02 than during the 7/01 sample. This is a general trend in most streams with good flow because of the leaf fall (including dead branches) in autumn and the flushing that takes place by the summer. Rock riffles were well defined with little embeddedness. Both banks exhibited erosion areas. The right bank had the greatest potential for failure due to sparse vegetation (the creek runs parallel to Umstead Drive). There is some indication of old channelization, possibly from the construction of Umstead Drive. Specific conductance was 116 µmhos/cm on 2/27/01, 119 µmhos/cm on 7/10/01 and 123 µmhos/cm on 3/14/02.

Bolin Creek at Bolinwood Drive

This site was sampled on 3/1/01 and 3/14/02. It is located less than ½ mile downstream from the Airport Road crossing, and immediately upstream of Bolinwood Drive. Airport Road has a service station, stores and a parking lot adjacent to the stream on the left bank. A sign on the right bank, at the entrance to a greenway that runs along that side of the creek indicates that the greenway floods.

The sample site had a riffle area consisting of rubble that extended across the creek. The substrate in the sample reach had a good mix of gravel, cobble and boulders with some embeddedness. Sand and silt deposits did not appear to be excessive. Undercut banks and root mats were common and were available for colonization because they were completely

submerged. Some erosion areas were present on both banks, but generally the vegetation was diverse with healthy root systems. The riparian zone on both banks was very narrow because the paved greenway trail runs along the right bank and a lawn area is on the left bank. Specific conductance was 135 μmhos/cm on 3/1/01 and 134 μmhos/cm on 3/14/02.

Bolin Creek at East Franklin Street

This is the most downstream site sampled on Bolin Creek and it is the most urbanized site sampled. It was sampled just upstream of East Franklin Street on 4/29/86, 2/10/93, 2/2/98, 3/11/98, 3/1/01 and 7/10/01. Abundant boulders and rubble characterize this reach. Pools are filled with loose sand. Some sticks and leafpacks were found, as were undercut banks and root mats. The two riffle areas sampled extended the width of the stream. Embeddedness was not severe, probably due to the relatively fast flow due to a grade change. Erosion areas were present on both banks. The left bank exhibited the highest potential for failure because of the sparse vegetation and lack of trees. The greenway trail parallels the left bank. The right bank contained some small trees and shrubs and appeared generally healthy. Specific conductance was 151 μmhos/cm on 3/1/01 and 167 μmhos/cm on 7/10/01.

Booker Creek Sites

Booker Creek at Barbara Court

This site was sampled on 2/21/01 and 7/10/01. This is the headwater site for Booker Creek and was accessed at a residential back yard adjacent to a gas line right-of-way. Just upstream from here, Booker Creek flows under Airport Road (widened to 4 lanes in 2000). This area has a significant amount of new and current residential construction. Despite the headwater location and small size (2 meters), similar flow was observed at both winter and summer sampling events. The creek is very shallow here (0.1 meters) which does not allow for undercut bank and root mat habitats. Riffles were composed of boulders and rubble. There were very few sticks and leafpacks and no snags or logs. A conversation with the landowner indicated that the creek often decreases to a trickle in the dry summer months, but is very flashy after a storm event. Specific conductance was 77 μmhos/cm on 2/21/01 and rose to 157 μmhos/cm on 7/10/01.

Booker Creek at Piney Mountain Road

This site is just downstream from Lake Ellen and is surrounded by subdivisions. Instream habitat consisted mainly of rocks, with some sticks and leafpacks. Lake Ellen is probably trapping much of the sediment that would be transported to the site. Undercut banks and root mats were rare. The riparian zone along the right bank was intact and heavily wooded. The left bank paralleled Piney Mountain Road, which reduced the riparian zone. When sampled in 2/01, the flow was considered normal. In 7/01, the flow was low and it was difficult to locate good habitat to sample, especially leaf packs. Specific conductance was 215 μmhos/cm on 2/21/01 and 174 μmhos/cm on 7/11/01.

The area just downstream from the sample site was disturbed prior to the 2/21/01 survey because of a newly constructed bridge. On 7/24/00 there was flash flooding in Booker Creek, which destroyed the Piney Mountain Road Bridge and flooded the Eastgate Shopping Center (located between East Franklin Street and US 15-501).

Booker Creek at Walnut Street

This site was sampled on 2/21/01 and 7/11/01. This is the most downstream site sampled on Booker Creek, and is located less than ½ mile downstream from US 15-501. Eastgate Shopping Center is on the east side of US 15-501. Parking areas in some sections of the shopping center are located along the left bank of Booker Creek, as was a sewer line right of way that ran along the creek. This section is deeply incised, exhibited high erosion, and had a poorly vegetated riparian zone to mitigate high flows.

The sample site is characterized by large amounts of sand. Some sticks, snags, and root mats were available for benthos colonization. The only riffle found for a kick sample consisted of woody debris. Specific conductance ranged from 166 to 171 μmhos/cm in 2001.

Little Creek Site
Little Creek at Pinehurst Drive

This site was sampled on 2/10/93, 2/22/98, 3/1/01 and 7/11/01. This site is located about a mile downstream of the confluence of Bolin Creek and Booker Creek, and immediately upstream of Pinehurst Drive. The reach is also immediately upstream of the Chapel Hill Country Club and about 3 miles above Jordan Lake. The sample site was characterized by massive amounts of sand (85% of the substrate) and a small amount of gravel and silt. Sandbars were abundant in the channel. Few sticks and leaf packs were found and undercut banks and root mats were also rare. Riffle habitats were absent and the channel slope was low, similar to a coastal stream. Extensive erosion areas were present on both banks. Vegetation was mostly grass with a few trees and shrubs. Extensive disturbance from construction was apparent. Riprap was placed along the left bank for 30-40 meters and trees had been cut along the bank area for at least 125 meters. Ditches appeared to be recently cut in the flood plain. Specific conductance was 170 μmhos/cm on 3/1/01 and 124 μmhos/cm on 7/11/01.

Bolin Creek Tributary
Tanbark Branch at Umstead Drive

This site was sampled on 3/14/02. Tanbark Branch flows into Bolin Creek just below the Bolin Creek at Village Drive site. The sample site is located about 150 meters upstream from the confluence. Although the reach is located within a wooded park, the headwaters are located in downtown Carrboro, north of Carr Mill Mall. A sewer line runs parallel to the stream. The site had a good mix of substrates including a trace of silt. Sticks and leaf packs were common, but undercut mats and root mats were rare as could be expected in a shallow stream (0.1 meter). The riffle was made up of rubble and extended the width of the stream. Embeddedness was in the 40%-80% range. Banks were not stable, and had erosion areas present with only small trees present. Specific conductance was extremely high at 299 μmhos/cm.

METHODS
Benthic macroinvertebrates were collected using the Division of Water Quality's standard qualitative sampling procedure (N.C. Division of Water Quality, April 2001) at the following sites: Bolin Creek / SR 1777 site on 7/10/01, the Bolin Creek / Village Drive site in 1998, 2001 and 2002, the Bolin Creek / Bolinwood Drive site in 2001 and the Bolin Creek / East Franklin Street site for all years except 1998. The standard qualitative sampling method was also used at the Little Creek / Pinehurst Drive site on 2/10/93 and 3/1/01. This method includes 10 composite samples: 2 kick-net samples, 3 bank sweeps, 2 rock or log washes, 1 sand sample, 1 leafpack sample, and visual collections from large rocks and logs. The purpose of these collections is to inventory the aquatic fauna and produce an indication of relative abundance for each taxon.

The Bolin Creek / SR 1777 site on 2/27/01, the Booker Creek / Barbara Court site on 2/21/01, the Booker Creek Piney Mt. Road site on 2/21/01 and the Booker Creek / Walnut Street site on 2/21/01 were all sampled using a modification of the Division of Water Quality's standard qualitative sampling procedure called a Qual 4. This type of collection is intended to assess between-station differences in water quality. Four composite samples were taken at each of these sites: 1 kick, 1 sweep, 1 leafpack and 1 visual collections. All taxa were collected and identified at the above Qual 4 sites.

A Qual 5 sample was done at the Booker Creek / Barbara Court site on 7/10/01, the Booker Creek Piney Mt. Road site on 7/11/01, the Booker Creek / Walnut Street site on 7/10/01 and the Little Creek / Pinehurst Drive site on 7/11/01. It differs from a Qual 4 by adding a rock and log wash to help add more midges to the sample.

EPT samples were collected from the Bolin Creek / SR 1777 site on 4/1/93, 3/11/98 and 4/6/00. EPT samples were also collected from the Bolin Creek / East Franklin Street site on 2/2/98. On Little Creek, an EPT sample was collected on 2/2/98. The same sampling technique as a Qual 4 was used, however only EPT taxa were collected.

Several data-analysis summaries (metrics) can be produced from standard qualitative samples to detect water quality problems. These metrics are based on the idea that unstressed streams and rivers have many invertebrate taxa and are dominated by intolerant species. Conversely, polluted streams have fewer numbers of invertebrate taxa and are dominated by tolerant species. The diversity of the invertebrate fauna is evaluated using taxa richness counts; the tolerance of the stream community is evaluated using a biotic index. EPT taxa richness (EPT S) is used with DWQ criteria to assign water quality ratings (bioclassifications). "EPT" is an abbreviation for Ephemeroptera + Plecoptera + Trichoptera, insect groups that are generally intolerant of many kinds of pollution. Higher EPT taxa richness values usually indicate better water quality. Water quality ratings also are based on the relative tolerance of the macroinvertebrate community as summarized by the North Carolina Biotic Index (NCBI). Both tolerance values for individual species and the final biotic index values have a range of 0-10, with higher numbers indicating more tolerant species or more polluted conditions. Water quality ratings assigned with the biotic index numbers were combined with EPT taxa richness ratings to produce a final bioclassification, using criteria for piedmont streams.

EPT abundance (EPT N) and total taxa richness calculations also are used to help examine between-site differences in water quality. When the EPT taxa richness rating and the biotic index differ by one bioclassifaction, the EPT abundance value was used to produce the final site rating.

Although EPT collections are usually limited to intolerant "EPT" groups, all taxa were collected and identified at the Qual 4 sites. The result was a taxa list and some indication of relative abundance.

With EPT and Qual 4 procedures, the rating of small streams (3 meters or less) using a size correction factor is reserved for unimpacted high quality mountain streams only. A Not Impaired rating is given if the stream would receive a bioclassification of Good-Fair or better using DWQ criteria for larger streams. Small streams that would have a minimum bioclassification of Fair or Poor continue to be Not Rated. Currently, the Qual 5 method is not rated, because it is not known how many additional EPT taxa come from the additional wash and whether EPT sample criteria are valid when applied to this method.

RESULTS AND DISCUSSION

Results of this study and previous studies in the Little Creek watershed are summarized and attached in Appendices I (Bolin Creek Station Summary), II (Booker Creek Station Summary) and III (Little Creek Station Summary). All the benthic macroinvertebrate taxa collected are listed in Appendices IV, V and VI inclusive. Taxa are listed as R (rare: 1-2 found), C (common: 3-9 found) and A (abundant: 10 or more found).

Bolin Creek Sites

Bolin Creek at SR 1777 (Homestead Road)

The SR 1777 location was selected as the reference site for the watershed study. EPT collections in the spring of 1993, 1998 and 2000 had EPT richness values of 24, 23 and 26 respectively, which resulted in Good bioclassifications. When sampled in the winter of 2001 (Qual 4), EPT richness was 17, but with seasonal corrections dropped to 14. The reduced stream width at that time resulted in no rating. The summer sample in 2001 (Full Scale) yielded an EPT richness of 24, and a Good-Fair bioclassification. (Table 1). Water quality at this site has generally remained constant despite some shifting in the presence or absence of intolerant taxa (related to sample season). There was some slight degradation (using the BI) during the 7/01 investigation, but follow up sampling is needed to confirm this.

The stonefly fauna at this site is richer than other sites in the study area. Nine taxa have been found from 1993 through 2001. The winter stonefly, *Isoperla namata* was found in all winter and spring samples, while *Clioperla clio* was found in 2000 and 2001. *Perlesta* was collected in all samples except 2/01.

Table 1. Bolin Creek at SR 1777 Benthos Results

Date	4/1/93	3/11/98	4/6/00	2/27/01	7/10/01
Sample Season	Spring	Spring	Spring	Winter	Summer
Total Taxa Richness	-	-	-	82	87
EPT Richness[1]	24(22)	23(22)	26(24)	17(14)	24
EPT Abundance	76	90	157	61	112
Biotic Index	-	-	-	6.40	5.96
EPT BI	4.46	4.23	5.05	6.04	5.18
Bioclassification	Good	Good	Good	NR	Good-Fair
Width (meters)	4	4	4	3	5
Sample Type	EPT	EPT	EPT	Qual 4	Full Scale

[1] Number in parenthesis is seasonally corrected value

Although there is some construction upstream from this site, the land cover in this catchment is primarily forested with low-density housing. Higher density housing and other land disturbing activities including runoff from impervious surfaces become more common downstream.

The differences in the presence or absence of intolerant taxa at SR 1777 were noted between investigations. Table 2 lists the taxa and the season they are most abundant (W-winter, S-spring, SU-summer, F-fall, All-present year round) in the piedmont of North Carolina.

Table 2. Presence or absence of intolerant EPT taxa at SR 1777

Date	4/1/93	3/11/98	4/6/00	2/27/01	7/10/01
Sample Season	Spring	Spring	Spring	Winter	Summer
Acentrella ampla(W,S)		C	C		
Caenis (W,S,SU)		C	A	C	C
Stenacron pallidum(S,SU)		A			
Acroneuria abnormis (All)	R	R			
Allocapnia (W)				C	
Amphinemura (S)	A		C		
Clioperla clio (W)			R	C	
Eccoptura xanthenes (All)	R				C
Isoperla namata (W)	C	C	C	R	
Isoperla transmarina (S)	R				
Leuctra (SU)					R
Perlesta (S,SU)	C	C	A		C
Chimarra (All)		C	A	C	A
Sample Type	EPT	EPT	EPT	Qual 4	Full Scale

Bolin Creek at Village Drive

This site is above the central business district of Chapel Hill, and can be considered the end of the transition zone from forested, lower density housing to higher density residential land use.

Prior to the current investigation, the Village Drive site had been sampled in 1993 and 1998 (Table 3). In those years, the intolerant stoneflies *Acroneuria abnormis, Amphinemura*. and *Isoperla namata* were abundant or common, but were rare or absent in 2001. The intolerant mayfly *Acentrella ampla* was also abundant or common both years. *Stenacron pallidum* was found in 1993 (rare) and *Caenis* was found in 1998 (common). Curiously, the ubiquitous mayfly *Stenonema modestum* was abundant in 1993 and was not found again until July 2001 (rare) and March 2002 (common). The intolerant caddisfly *Chimarra* was common in 1998. Despite the difference in sample type and season, there is little difference in taxa between 1993 and 1998. Changes in water quality based on the benthic community are apparent after 1998, when EPT taxa richness dropped dramatically from 24-26 in the 1990's to 6-9 in 2001 and 2002.

The chironomids *Cricotopus bicinctus*, *Cricotopus infuscatus*, *Rheocricotopus robacki* and the *Conchapelopia* group were common or abundant in February 2001. This assemblage indicates potential toxicity. However, the summer 2001 sample and spring 2002 sample did not have any indicator species that could point to a specific water quality problem.

Table 3. Bolin Creek at Village Drive Benthos Results

Date	4/1/93	2/26/98	2/27/01	7/10/01	3/14/02
Sample Season	Spring	Winter	Winter	Summer	Spring
Total Taxa Richness	-	59	54	52	40
EPT Richness[1]	24(23)	26(24)	6(5)	9	7(7)
EPT Abundance	88	91	35	36	38
Biotic Index	-	5.10	7.00	6.61	7.00
EPT BI	3.90	3.93	5.82	6.64	6.42
Bioclassification	Good-Fair	Good	Poor	Fair	Fair
Width (meters)	5	9	5	6	6
Sample Type	EPT	Full Scale	Full Scale	Full Scale	Full Scale

[1] Number in parenthesis is seasonally corrected value

Bolin Creek at Bolinwood Drive

Both sampling events (3/01 and 3/02) yielded very similar results, with only a few taxa changes. No stoneflies were found, and the mayflies and caddisflies present were tolerant. EPT richness was only 5 for both samples (Table 4), and a Poor bioclassification was assigned to both samples. There were no taxa that might indicate organic loading (such as sewage intrusion), however the chironomids *Cricotopus bicinctus*, *Cricotopus infuscatus* and the *Conchapelopia* group were found in both samples. Once again, this assemblage indicates potential toxicity. Although *Chironomus*. was found in 2001, there were not enough specimens to conduct a midge deformity analysis.

It is unlikely that habitat condition at this site is a major contributor to the observed biological degradation. Habitat scores of 76 and 69 do not indicate severe habitat problems. There is a definite "urban development gradient" along Bolin Creek, with increasing development from upstream to downstream. Less forested land, coupled with more impervious surfaces and roads are possibly contributing to toxic runoff during storm events. As stated in the site description, the heavily used Airport Road is just upstream from this site where a service station and parking areas are adjacent to the left bank. Additionally, roads and parking areas from adjacent apartment complexes border both banks at the site.

Table 4. Bolin Creek at Bolinwood Drive Benthos Results

Date	3/1/01	3/14/02
Sample Season	Spring	Spring
Total Taxa Richness	46	41
EPT Richness[1]	5(5)	5(5)
EPT Abundance	25	18
Biotic Index	7.32	7.49
EPT BI	6.39	6.88
Bioclassification	Poor	Poor
Width (meters)	5	7
Sample Type	Full Scale	Full Scale

[1] Number in parenthesis is seasonally corrected value

Bolin Creek at East Franklin Street

Prior to the current investigation, samples have been collected from this location 4 times: 1986, 1993, and twice in 1998 (Table 5).

Benthic community composition indicates that water quality declined at this site sometime between 1986 and 1993. The ongoing decline in water quality is further illustrated when comparing spring Full Scale samples from 1986, 1998 and 2001. EPT richness values fell sharply from 28 in 1986, to 13 in 1998 and 4 in 2001. A similar chironomid community was found here as at Bolinwood Drive, possibly indicating toxicity.

Six stonefly taxa were collected in 1986, and three were common or abundant (*Amphinemura*, *Isoperla holochlora* and *Perlesta*). *Acroneuria abnormis* (non-winter species) and *Isoperla namata* (intolerant winter species) were each rare in 1998. The mayfly *Stenonema modestum* was abundant in 1986, and was not collected again until July 2001 (rare).

Two surveys were done in 1998 because the EPT sample in February was taken under low flow conditions which was may have resulted in low EPT richness and abundance values. The second survey done in March was after high flows, which may have also had an effect on those values (downstream drift). The March survey was a Full Scale sample, so higher EPT richness and abundance values were to be expected.

Table 5. Bolin Creek at East Franklin Street Benthos Results

Date	4/29/86	2/10/93	2/2/98	3/11/98	3/1/01	7/10/01
Sample Season	Spring	Winter	Winter	Spring	Spring	Summer
Total Taxa Richness	89	32	-	37	53	41
EPT Richness[1]	28(22)	8(8)	4(3)	13(13)	4(4)	4
EPT Abundance	145	32	22	42	33	31
Biotic Index	6.08	6.53	-	6.28	7.06	6.88
EPT BI	4.34	5.34	6.66	6	5.94	6.95
Bioclassification	Good-Fair	Fair	Poor	Fair	Poor	Poor
Width (meters)	3	6	6	6	5	4
Sample Type	Full Scale	Full Scale	EPT	Full Scale	Full Scale	Full Scale

[1] Number in parenthesis is seasonally corrected value

Booker Creek Sites

Booker Creek at Barbara Court

There were no specific assemblages of indicator species apparent at this headwater site (too small to rate), although all the species found are considered tolerant and EPT richness is low (Table 6). Despite some stream flow at each survey, the little amount of water present did not typically allow for good benthic habitat. Undercut banks, root mats, riffles and pool areas were equally degraded by a lack of water and human disturbance (sewer line and residential yards). Here, the benthic community (total taxa richness and EPT richness) is probably being compromised by lack of habitat due to minimal streamflow. Potential toxic impacts or organic intrusion may also occur. This area is undergoing significant residential development, which can carry toxic stormwater runoff and can change the hydrology of the catchment. Also, the newly widened Airport Road is just upstream from the site.

Table 6. Booker Creek at Barbara Court Benthos Results

Date	2/21/01	7/10/01
Sample Season	Winter	Summer
Total Taxa Richness	31	45
EPT Richness	4	3
EPT Abundance	24	30
EPT BI/BI	6.60/7.33	7.00/6.56
Bioclassification	NR	NR
Width (meters)	2	2
Sample Type	Qual 4	Qual5

Booker Creek at Piney Mountain Road

This portion of Booker Creek is within a moderately dense residential area, below Lake Ellen. The habitat here was better (score of 80) than other sites sampled on Booker Creek, and as good or better than other sites in the study. Lake Ellen is probably retaining sand and sediment, which is helping to keep gravel and rubble in the reach available for benthic colonization. However, during dry periods, there is little to no flow at this site.

The effect of low summer flow may be reflected in the large decline in EPT taxa richness from 8-10 in winter/spring to 4 in summer (Table 7). Additionally, there are no assemblages of abundant indicator species that may point to any specific problems. The site is not rated (NR) because of size (<4 meters) and sample type (see Methods for Qual 5 explanation).

Table 7. Booker Creek at Piney Mountain Road Benthos Results

Date	3/11/98	2/21/01	7/11/01
Sample Season	Spring	Winter	Summer
Total Taxa Richness		39	35
EPT Richness[1]	10(9)	8(7)	4(4)
EPT Abundance	36	37	40
Biotic Index	-	6.26	6.41
EPT BI	5.80	6.40	6.62
Bioclassification	NR	NR	NR
Width (meters)	3	3	3
Sample Type	EPT	Qual5	Qual5

[1] Number in parenthesis is seasonally corrected value

Booker Creek at Walnut Street

Prior to the present investigation, this site had never been sampled (Table 8). It is located within a bottomland hardwood forest, along a sewer line right-of-way that is just upstream from the confluence with Bolin Creek. The site is highly developed with both commercial and residential property. Abundant areas of impervious surfaces in the form of roads and parking lots dominate the immediate upstream land use.

This impacted site had no stoneflies, and *Stenonema modestum* and *Cheumatopsyche* were abundant only in the summer sample. *Progomphus obscurus* typical of very sandy habitat was common. The highly tolerant *Argia* and *Calopteryx* were abundant. The chironomids *Cricotopus bicinctus*, and *Conchapelopia* group were common and abundant in the February sample which may indicate toxicity.

Considering the land use at this site, the benthic community probably does not go through the stress-recovery cycles typical of most urban streams (no opportunity for recovery). Shopping center parking lots practically at streamside are contributing toxic runoff to the creek during storm events. Additionally, the massive amounts of sand at this site appear to be the culmination of upstream human disturbance. Habitat in general is very poor.

Table 8. Booker Creek at Walnut Street Benthos Results

Date	2/21/01	7/10/01
Sample Season	Winter	Summer
Total Taxa Richness	33	51
EPT Richness	3	7
EPT Abundance	7	25
Biotic Index	7.20	6.91
EPT BI	5.26	6.04
Bioclassification	NR	NR
Width (meters)	3	3
Sample Type	Qual 4	Qual5

Little Creek Site

Little Creek at Pinehurst Drive

This site was sampled in 1993 and 1998. Low flow conditions often exist here because of beaver dams. The 1998 survey characterized the site with severe bank erosion, poor soil binding and massive amounts of sedimentation. In the 2001 survey, benthic habitat appeared to have degraded further. Major disturbance was noted at the site. Rip-rap was placed along the left bank where trees and underbrush had been cut. There appeared to be an attempt to widen the floodplain. This “construction” activity has severely eroded the left bank adding even more silt and sand to the channel. No stoneflies have ever been found at this site. EPT richness values have remained very low regardless of sample type or season. Abundance values are also very low reflecting low flow conditions or a scouring of substrate during high flow conditions (storm events). The spring 2001 sample was taken during relatively higher flow conditions. The chironomid community found at this site also suggests toxicity.

Lenat (1993) developed a method to evaluate the effects of toxicity and organic loading in streams using mentum deformities of *Chironomus* larvae. *Chironomus* collected here were used to examine toxicity through tabulation of deformities. A “toxic score” of 50 is typical of significant toxicity and a Fair rating. A “toxic score” of 100 is typical of high toxicity and a Poor rating. This site had a “toxic score” of 160, however only 10 specimens were examined. Most of the *Chironomus* menta were massively deformed, indicating very severe toxicity problems at this site.

Table 9. Little Creek at Pinehurst Drive Benthos Results

Date	2/10/93	2/2/98	3/1/01	7/11/01
Sample Season	Winter	Winter	Spring	Summer
Total Taxa Richness	37		45	27
EPT Richness	7	5	5	5
EPT Abundance	16	7	16	18
Biotic Index	7.13	-	7.33	
EPT BI	4.69	4.84	4.96	6.36
Bioclassification	Fair	Poor	Poor	NR
Width (meters)	4	5	5	3
Sample Type	Full Scale	EPT	Full Scale	Qual 5

Tributary

Tanbark Branch at Umstead Drive

This is a very small tributary that flows into Bolin Creek at Umstead Road, just below the Village Drive site. It probably ceases to flow during dry periods. As a result, the benthos sample taken during the drought of 2002 may not be representative of the fauna possible during normal flow periods. At the time of the survey, the flow was considered low despite a recent rain.

Of special concern here was the extremely high specific conductance at 299 µmhos/cm. The sewer line along the branch may be leaking. The chironomids *Cricotopus bicintus* (common), *Cricotopus infuscatus* (common), and *Conchapelopia* group (common) were found again, possibly indicating toxicity. The only EPT taxa found was the caddisfly *Cheumatopsyche*, which is very tolerant.

Table 10. Tanbark Branch at Umstead Drive Benthos Results

Date	3/14/02
Sample Season	Spring
Total Taxa Richness	16
EPT Richness	1
EPT Abundance	10
Biotic Index	
EPT BI	6.20
Bioclassification	NR
Width (meters)	3
Sample Type	Qual 5

SUMMARY AND CONCLUSIONS

Data collected in 1986 on Bolin Creek at East Franklin Street indicated a Good-Fair bioclassification. These early data can almost be considered a benchmark, after which the benthic community reflected a decline in water quality in the center of Chapel Hill.

Subsequent sampling took place in 1993 on Bolin Creek at SR1777, Bolin Creek at Village Road, Bolin Creek at East Franklin Street and Little Creek at Pinehurst Drive. Data collected then suggested degradation to the benthic community from upstream to downstream in the watershed. Development and human disturbance also follows that gradient.

By 1998, the benthic community in Bolin Creek at the East Franklin Street site reflected a Poor bioclassification. The upstream sites at SR 1777 and Village Drive were still maintaining a benthic community that indicated little change in water quality. Booker Creek at Piney Mountain Road was sampled for the first time in 1998. Considering the location below Lake Ellen, good habitat and low EPT values suggested problems with low flow. Little Creek at Pinehurst Drive has been severely impacted since 1993.

When the present study began to survey the Little Creek watershed in 2001, the decline in water quality from upstream to downstream was no longer apparent. With the exception of the Bolin Creek at SR 1777 site, water quality in relation to the benthic community appears to be about the same regardless of the sample site. Table 11 summarizes the most current EPT richness and abundance values at sites on Bolin Creek, Booker Creek and Little Creek during summer surveys (Bolinwood Drive was only sampled in the spring).

Table 11. Comparison of sites on Bolin Creek, Booker Creek and Little Creek

	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Booker Cr	Booker Cr	Booker Cr	Little Cr
Location	SR 1777	Village Rd	Bolinwood Dr	E Franklin St	Barbara Ct	Piney Mt Rd	Walnut St	Pinehurst Dr
Date	7/10/01	7/10/01	3/14/02	7/10/01	7/10/01	7/11/01	7/10/01	7/11/01
Sample Season	Summer	Summer	Spring	Summer	Summer	Summer	Summer	Summer
EPT Richness	24	9	5	4	3	4	7	5
EPT Abundance	112	36	18	31	30	40	25	18
EPT BI	5.18	6.64	6.88	6.88	7.00	6.62	6.04	6.36
Biotic Index	5.96	6.61	7.49	6.88	6.56	6.41	6.91	6.81
Bioclassification	Good-Fair	Fair	Poor	Poor	NR	NR	NR	NR
Width (meters)	5	6	7	4	2	3	3	3
Sample Type	Full Scale	Full Scale	Full Scale	Full Scale	Qual 5	Qual 5	Qual 5	Qual 5

- Although data suggests that slight declines at the Bolin Creek SR 1777 site may have occurred during the past several years, this reach has maintained good benthic diversity. Instream habitat has not indicated an increase in sand or silt deposits, despite development upstream. There have been no indicators of toxicity or organic loading in this partially forested catchment. Less human disturbance and lack of commercial areas are probably helping to maintain the water quality here.

- The Bolin Creek / Village Drive site underwent benthic community degradation sometime after 1998. EPT richness sharply declined and BI values rose. The February 2001 sample detected the chironomid assemblage of *Cricotopus bicinctus, Cricotopus infuscatus* and *Conchapelopia* group, which indicated toxicity. Instream habitat here can be considered adequate; however, apartment complexes, parking areas and Umstead Drive along the right bank surround the reach. The wooded appearance along the reach disguises many of the impervious surfaces. Sampling in 2002 indicated that degraded conditions have persisted, with no evidence of recovery.

- The Bolin Creek / Bolinwood Drive site is within a commercial and residential area. The assemblage of similar chironomids also indicated toxicity at this site. Instream habitat was adequate. This reach exhibited a less wooded appearance than upstream sites, and is surrounded by roads and apartment complexes.

- The East Franklin Street site is within one of many commercial districts in Chapel Hill. Benthic community / water quality degradation became apparent early, sometime after 1986. Habitat is poor here. The chironomid assemblage found in March 2001 suggests toxicity.

- The headwater site at Booker Creek and Barbara Court has poor instream habitat and generally low flow conditions barring storm events. These two factors are probably having the greatest effect on the benthic community, so this community may not be a useful indicator of water quality. The headwater catchment is undergoing extensive development.

- Booker Creek at Piney Mountain Road has good instream habitat. This site is located just below Lake Ellen, which greatly limits flow at this reach and may be adversely affecting the benthic community, which again may not be good indicator of water quality.

- The most downstream site on Booker Creek, the Walnut Street site has extremely poor habitat and possible toxicity. The site is characterized by large amounts of sand and is located just downstream from an extensive shopping area and busy road.

- Located below the confluence of Bolin Creek and Booker Creek, Little Creek at Pinehurst Drive is characterized by low flow conditions, massive amounts of sand and extensive bank erosion. Mentum deformities of *Chironomus* larvae sampled here resulted in a toxic score of 160, indicating very severe toxicity problems.

Development around the East Franklin Street site has not changed substantially since the earliest sample was taken there (1986). Significant human disturbance has taken place north and east of the downtown area, which appear to be affecting the entire watershed. During storm events, runoff from the many roads and parking areas have changed the hydrology of the studied streams. Toxic substances such as gasoline, oil and pesticides are probably in the runoff. Loss of benthic habitat in conjunction with runoff from impervious surfaces seems to be major contributing factors to the decline in the biological community in the Little Creek watershed.

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cc: Jimmie Overton

Appendix I. Bolin Creek and Tributary Site Summaries

	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Bolin Cr	Tanbark Br
	SR 1777	SR 1777	SR 1777	SR 1777	SR 1777	Village Rd	Village Rd	Village Dr	Village Dr	Village Dr	Bolinwood D	Bolinwood D	Franklin St	Franklin St	Franklin St	Franklin St	Franklin St	Franklin St	Umstead Rd
	4/1/93	3/11/98	4/6/00	2/27/01	7/10/01	4/1/93	2/26/98	2/27/01	7/10/01	3/14/02	3/1/01	3/14/02	4/29/86	2/10/93	2/2/98	3/11/98	3/1/01	7/10/01	3/14/02
Community																			
Ephemeroptera	7	9	15	9	11	10	12	2	5	4	2	2	15	5	1	8	2	2	0
Plecoptera	6	3	4	3	3	3	6	2	1	0	0	0	6	0	1	1	0	0	0
Trichoptera	11	11	7	5	10	11	8	2	3	3	3	3	7	3	2	4	2	2	1
Coleoptera	0	0	0	5	9	0	3	3	4	3	0	0	8	1	0	0	5	5	1
Odonata	0	0	0	7	8	0	4	4	4	3	3	4	9	4	0	8	6	4	2
Megaloptera	0	0	0	2	2	0	1	0	0	0	0	0	1	2	0	0	0	0	0
Diptera: Chironomidae	0	0	0	30	25	0	9	28	19	16	24	19	24	9	0	7	23	17	7
Misc. Diptera	0	0	0	4	5	0	4	3	5	4	4	2	6	3	0	4	3	5	2
Oligochaeta	0	0	0	1	2	0	4	3	4	1	7	4	5	3	0	1	5	1	2
Crustacea	0	0	0	5	2	0	4	2	1	3	1	2	2	1	0	2	2	0	0
Mollusca	0	0	0	9	8	0	3	2	5	3	2	5	4	1	0	1	4	4	1
Other	0	0	0	2	2	0	1	3	1	0	0	0	1	0	0	1	1	1	0
Total Taxa Richness				82	87		59	54	52	40	46	41	89	32		37	53	41	16
EPT Richness	24	23	26	17	24	24	26	6	9	7	5	5	28	8	4	13	4	4	1
EPT Abundance	76	90	157	61	112	88	91	35	36	38	25	18	145	32	22	42	33	31	10
Biotic Index				6.4	5.96		5.10	7.00	6.61	7.00	7.32	7.49	6.08	6.53		6.28	7.06	6.88	6.99
EPT BI	4.46	4.23	5.05	6.04	5.18	3.90	3.93	5.82	6.64	6.42	6.39	6.88	4.34	5.34	6.66	6.00	5.94	6.95	6.20
Bioclassification	Good	Good	Good	NR	Good-Fair	Good-Fair	Good	Poor	Fair	Fair	Poor	Poor	Good-Fair	Fair	Poor	Fair	Poor	Poor	NR
Habitat																			
Stream Width	4	4	4	3	5	5	9	4.5	6	6	5	7	3	6	6	6	4.5	4	3
Channel Width				5	6			5.5	8	9	11	11					7	7	
Depth																			
Average	0.2	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.4	0.3	0.4	0.3	0.1
Maximum	0.8	1	0.8	1.5	0.5	0.8	0.7	1.5	0.8	1.1	1.2	0.8			0.7	0.7	1.5	1.3	0.3
Flow / Current	Moderate	Moderate	Moderate	Moderate	Normal	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate		Moderate		Moderate	Moderate	Normal	Low
Bank Height				2.5	1.8			3	2.5	3	4	4					4	3.5	1.0
Bank Angle				70	90			70	70	70	70	50					70	70	90
Bank Erosion	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate		Severe	Severe	Severe	Moderate	Severe	Severe
Canopy %	80	60	50	65	50	70	65	80	70	40	75	60	8	60	60	60	20	60	20
Canopy Type																			Hardwood
Pedostemum	Moderate	None	None	None	None	Moderate	None	None	None	None	None	None		None	None	None	None		Abundant
Aufwuchs	Abundant	Abundant	None	None	None	Abundant	Moderate	Moderate	None	Abundant	Abundant	Abundant		Abundant	None	None	Moderate		Abundant
Tribs Present?			None	None	None		Yes	None	None	None	None	None					None	None	None
Substrate (%)																			
Boulder	15	20	30	25	35	25	35	35	40	30	20	10	40	20	0	0	10	30	20
Rubble	35	20	10	30	25	30	35	35	25	30	30	30	20	20	5	20	30	20	25
Gravel	15	15	30	40	20	15	15	20	15	30	30	30	10	10	15	25	20	20	25
Sand	35	40	20	20	20	25	20	10	20	10	15	20	30	40	80	55	30	20	20
Silt	0	5	10	5	0	5	0	0	0	0	5	10	0	10	0	0	10	10	10
Other																			
Habitat Score				79	65			86	66	71	76	69					60	57	67
Chem																			
Temp				9.3	22		11.0	10.7	23.1	13.0	9.0	12.2		8.1	8.0		10.1	25.3	16.8
DO mg/l				9.5	5.8		11.7	9.6	6.4	11.3	9.3	10.5		14.2	12.4		7.8	4.9	12.0
Cond				106	114		62.0-84.0	116	119	123	135	134		120.0	73.0		151	167	299
pH		6.2		6.8	6.8		7.4	7.6	6.2	8.1	7.2	7.9		7.9	7.3		7.2	7.3	8.8
Location / General																			
Basin	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06
County	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE	ORANGE
Latitude	355637	355637	355637	355637	355637	355522	355522	355522	355522	355522	355529	355529	355540	355540	355540	355540	355540	355540	355513
Longitude	790518	790518	790518	790518	790518	790400	790400	790400	790400	790400	790315	790315	790206	790206	790206	790206	790206	790206	790353
Collection card	6146	7514	8102	8379	8466	6145	7517	8380	8467	8704	8381	8703	3750	6087	7481	7513	8382	8468	8705
Sample Type	EPT	EPT	EPT	Qual 4	Full Scale	EPT	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	Full Scale	EPT	Full Scale	Full Scale	Full Scale	Qual 5

Appendix II. Booker Creek Site Summaries

	BOOKER CR	BOOKER CR	BOOKER CR	BOOKER CR	BOOKER CR	BOOKER CR	BOOKER CR
	Barbara Ct	Barbara Ct	Piney Mt Rd	Piney Mt Rd	Piney Mt Rd	Walnut St	Walnut St
	2/21/01	7/10/01	3/11/98	2/21/01	7/11/01	2/21/01	7/10/01
Community							
Ephemeroptera	2	1	3	4	2	2	4
Plecoptera	0	0	3	1	0	0	0
Trichoptera	2	2	4	3	2	1	3
Coleoptera	1	5	0	3	4	1	3
Odonata	3	6	0	3	5	2	12
Megaloptera	0	1	0	0	0	0	1
Diptera: Chironomidae	13	19	0	10	13	17	15
Misc. Diptera	3	4	0	3	3	2	5
Oligochaeta	2	2	0	2	2	4	1
Crustacea	2	0	0	2	0	1	2
Mollusca	1	3	0	5	3	3	4
Other	2	2	0	2	1	0	1
Total Taxa Richness	31	45		39	35	33	51
EPT Richness	4	3	10	8	4	3	7
EPT Abundance	24	30	36	37	40	7	25
Biotic Index	7.33	6.56		6.26	6.41	7.2	6.91
EPT BI	6.60	7.00	5.80	6.40	6.62	5.26	6.04
Bioclassification	NR	NR	Fair	NR	NR	NR	NR
Habitat							
Stream Width	1.5	2	4	2.5	3	3	3
Channel Width	2.5	3		4.0	4.0	8.0	8.0
Depth							
Average	0.1	0.1	0.2	0.2	0.1	0.2	0.1
Maximum	0.3	0.4	0.5	0.4	0.2	0.4	0.3
Flow / Current	Normal	Moderate	High	Moderate	Low	Normal	Low
Bank Height	1	1.5		2	4	2	2
Bank Angle	90	70		70	70	70	90
Bank Erosion	Severe	Severe	None-Moderate	None-Moderate	None	Severe	Severe
Canopy %	60	60	70	75	70	75	80
Canopy Type	Hardwoods	Hardwoods					Hardwoods
Pedostemum	None	None	None	None	None	None	None
Aufwuchs	None	None	Abundant	None	None	None	None
Tribs Present?	None	None		Yes	Yes	None	None
Substrate (%)							
Boulder	60	55	35	15	40	0	0
Rubble	30	20	25	20	30	0	0
Gravel	Trace	15	20	25	20	10	10
Sand	10	5	20	40	10	90	80
Silt	0	5	0	0	0	0	10
Other							
Habitat Score	68	57		80	72	39	38
Chem							
Temp	9.8	26.7		11.4	24.4	11.1	25
DO mg/l	8.9	5.9		9.5	5	8.5	3.5
Cond	77	157		215	174	166	171
pH	7.5	7.3	7	7.9	7.5	7.4	7
Location / General							
Basin	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06	CPF06
County	ORANGE	ORANGE	ORANGE	WAKE	WAKE	ORANGE	ORANGE
Latitude	355655	355655	355630	355630	355630	355543	355543
Longitude	790323	790323	790300	790259	790259	79119	79119
Collection Card	8394	8469	7512	8396	8470	8395	8471
Sample Type	Qual 4	Qual 5	EPT	Qual 4	Qual 5	Qual 4	Qual 5

Appendix III. Little Creek Site Summaries

	LITTLE CR	LITTLE CR	LITTLE CR	LITTLE CR
	Pinehurst Drive	Pinehurst Drive	Pinehurst Drive	Pinehurst Drive
	2/10/93	2/2/98	3/1/01	7/11/01
Community				
Ephemeroptera	5	3	4	3
Plecoptera	0	0	0	0
Trichoptera	2	2	1	2
Coleoptera	1	0	2	1
Odonata	4	0	6	6
Megaloptera	0	0	0	0
Diptera: Chironomidae	15	0	20	13
Misc. Diptera	1	0	2	1
Oligochaeta	4	0	5	1
Crustacea	3	0	1	0
Mollusca	2	0	2	2
Other	0	0	2	1
Total Taxa Richness	37		45	27
EPT Richness	7	5	5	5
EPT Abundance	16	7	16	18
Biotic Index	7.13		7.33	
EPT BI	4.69	4.84	4.96	6.36
Bioclassification	Fair	Poor	Poor	
Habitat				
Stream Width	4	5	5	3
Channel Width			6	9
Depth				
Average	0.3	0.7	0.2	0.2
Maximum	0.8	0.9	1.2	0.3
Flow / Current	Moderate	Moderate	Normal	Low
Bank Height			2	2
Bank Angle			80	70
Bank Erosion	Severe	Moderate	Severe	Severe
Canopy %	90	80	80	60
Canopy Type	Mixed Hardwoods			
Pedostemum	None	None	None	None
Aufwuchs	Moderate	None	None	None
Tribs Present?				Yes
Substrate (%)				
Boulder	0	0	0	0
Rubble	0	0	0	0
Gravel	0	5	5	5
Sand	90	90	85	85
Silt	10	5	10	10
Other				
Habitat Score			44	36
Chem				
Temp	6.3	7	12	26
DO mg/l	12.5	12.3	8.5	4.5
Cond	130	80	170	124
pH	7.5	7.2	7.5	6.6
Location / General				
Basin	CPF06	CPF06	CPF06	CPF06
County	ORANGE	ORANGE	ORANGE	ORANGE
Latitude	355502	355502	355504	355504
Longitude	790048	790048	790045	790045
Collection Card	6086	7482	8383	8472
Sample Type	Full Scale	EPT	Full Scale	Qual 5

Appendices IV-VI (taxa lists) are available from NC Division of Water Quality upon request. Please contact Trish MacPherson (trish.macpherson@ncmail.net).

Appendix B
Water Quality Conditions

Appendix B
Water Quality Conditions

A wide range of chemical, physical, and toxicological analyses were conducted in the Little Creek watershed during the course of this study. This appendix presents selected methodological information and summarizes monitoring results.

Section 1. Methodology

1.1 Summary of Water Column Sampling Methods

The approach used in this study differs from many commonly used sampling frameworks because the primary goal was not to characterize typical conditions or to estimate pollutant loads, but to provide information to help evaluate whether particular stressors are likely contributors to biological impairment. The timing and location of sampling were selected to identify critical conditions such as periods of low dissolved oxygen or exposure to toxicants.

Chemical, physical, and toxicity monitoring was conducted by collecting water samples during baseflow and storm conditions. For general characterization purposes, a standard set of parameters similar to the parameters used by DWQ at ambient stations was utilized (primarily nutrients, metals, and physical parameters). The drought conditions that existed during much of the study period provided only limited opportunities for storm sampling. For purposes of stressor identification, water samples were also analyzed for potential organic contaminants, including pesticides, phenols, polycyclic aromatic hydrocarbons, semi-volatile organics, surfactants, total petroleum hydrocarbons, and MTBE. Toxicity bioassays, both acute and chronic, were conducted on water samples (see Section 5 of the main text for documentation of methods).

Pesticides were analyzed using a variety of methods. A quantitative gas chromatograph/mass spectrophotometer (GC/MS) technique tested for a set list of 37 current use pesticides (quantitative GC/MS). A broad scan GC/MS technique tested for a list of more than 300 analytes. These analytes are listed in Section 3 of this appendix.

Semipermeable membrane devices (SPMDs) were used on a limited basis at several sites. These devices consisted of a pre-extracted polyethylene membrane deployed in the stream inside a plastic mesh enclosure. SPMDs collect hydrophobic organic compounds to which the device is exposed during the deployment period (e.g., Huckins et al, 1993; Hofelt and Shea, 1997; Meadows et al, 1998). Laboratory analysis of SPMDs was conducted for PAHs, PCBs, organochlorine pesticides, and selected current use pesticides. These devices were deployed in cooperation with the NCSU Department of Environmental and Molecular Toxicology. Average concentrations over the deployment period were calculated by NCSU.

Specific sampling methods are documented in the project's *Standard Operating Procedures for Chemical, Physical and/Toxicity Monitoring* (NCDWQ, 2001a) and are not described here. Sampling sites are described in Section 5 of the main text and shown on Figure 5.1.

1.2 Summary of Bed Sediment Sampling Methods

Sediment toxicity was evaluated to determine if it was a likely contributor to degradation of the benthic macroinvertebrate community of Little Creek at Pinehurst Drive, where benthic community composition and midge deformity analysis indicated likely toxic impacts.

Analysis was conducted on composites of multiple grab samples collected from the top 5 cm of the substrate. In the target reach, sediment was collected for analysis from two distinct substrate areas: (1) *sand substrate* locations of the type sampled by DWQ during standard macroinvertebrate sampling (NCDWQ, 2001b); (2) *fine depositional areas* such as pools, backwaters, and channel margins. Sediment collected from sand sampling and depositional sampling areas was analyzed separately. See the project standard operating procedures document for additional details (NCDWQ, 2001a).

Toxicity was evaluated using long term (42 day) laboratory bioassays using the amphipod *Hyalella azteca*, conducted according to the procedures outlined by USEPA (2000). Other analyses conducted included organochlorine pesticides (modified EPA method 8081A), PCBs (modified EPA method 8082), PAHs (modified EPA method 8270C), semivolatile organics (EPA method 8270C), metals, current use pesticides (broad scan GC/MS), total organic carbon (TOC), and particle size distribution.

1.3 Toxicity Benchmarks

When performing ecological risk assessments and water quality evaluations, contaminants are often compared to screening benchmarks to determine if the reported concentrations of those contaminants are high enough to warrant further consideration. In this study, toxicological benchmarks derived for the protection of aquatic life were used to screen observed contaminant concentrations for potential ecological effects. Laboratory detection limits were also compared to benchmark values.

Benchmark screening values denote thresholds of elevated risk, but do not predict actual impacts in particular situations. Actual site-specific and event-specific impacts depend upon the interaction of numerous factors, including the level, timing and duration of exposure; the form and bioavailability of the particular chemicals (often dependent on pH or other variables); and simultaneous exposure to other stressors.

Water. Many different sources of screening benchmarks exist, with differing levels of conservatism. A detailed discussion of these can be found in Suter and Tsao (1996). The primary screening benchmarks used in the Little Creek watershed assessment were: 1) EPA's acute and chronic National Ambient Water Quality Criteria (NAWQC) for freshwater (USEPA, 1999); and 2) EPA's Tier II values (USEPA, 1995). The acute NAWQC were established by EPA to correspond to concentrations that would cause less than 50 percent mortality in five

percent of the exposed populations in a brief exposure. The chronic NAWQC are the acute values divided by the geometric mean of at least three median lethal concentrations (LC_{50}). Tier II values were developed by EPA as part of the Great Lakes Program (USEPA, 1995) for use with chemicals for which NAWQC are not available. They are based on fewer data than are required to establish NAWQC.

In this study, NAWQC for priority pollutants were taken from EPA's online Water Quality Standards Database (http://www.epa.gov/wqsdatabase/). NAWQC for non-priority pollutants, which are not included in the online database, were taken from USEPA (1999). Tier II values and other benchmarks were obtained from the ecological benchmark listing available through the Risk Assessment Information System operated by the Oak Ridge National Laboratory (http://risk.lsd.ornl.gov/homepage/eco_tool.shtml).

Where no benchmarks were available, a search of the toxicological literature was performed using EPA's online ecotoxicology database, ECOTOX (http://www.epa.gov/ecotox/). Observed concentrations were compared to effects level values for freshwater aquatic animals.

NAWQC for many metals (cadmium, chromium III, copper, lead, nickel, silver, and zinc) are a function of water hardness. NAWQC are reported by EPA for a hardness of 100 mg/L and must be adjusted for site-specific hardness levels. In this study, benchmarks for all of the above metals except chromium were adjusted for hardness using the formulas recommended by the USEPA (1999). Hardness was either calculated from the calcium and magnesium concentrations or measured in a laboratory and the lowest value was used. The NAWQC for chromium VI (which does not require hardness adjustment) was used instead of chromium III, since the former provides a more conservative screening level. For cadmium the chronic benchmark was used instead of the acute value because hardness adjustment reduced the acute value below the chronic level. NAWQC were not available for silver and manganese, so Tier II values were used instead.

NAWQC for many metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver and zinc) are calculated as the concentration of dissolved metals in the water column. Comparison of the ambient total metals concentrations measured in this study to dissolved metals criteria is a conservative approach in that less than 100 percent of a metal in any particular ambient sample may be in dissolved form. This approach is appropriate for initial screening purposes. 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.

Observed pollutant concentrations can also be compared to the North Carolina's Water Quality Standards (NCWQS) for freshwater aquatic life, which are important regulatory benchmarks. The present study, however, is concerned not with regulatory compliance but with assessing the risks of site-specific, and sometimes event-specific impacts. The NAWQC are more appropriate for this purpose. NAWQC were based solely on data and scientific judgments on the relationship between pollutant concentrations and environmental and human health effects, and do not reflect considerations of technological feasibility or economic impact (USEPA, 1999). They allow for the specific evaluation of either chronic or acute concerns and for the

consideration of site specific conditions (e.g., by adjusting metals criteria for local hardness levels).

Of the current use pesticides detected in water samples during the study, NAWQC or other benchmarks were available only for atrazine (see Section 5) and chlorpyrifos (detected by SPMD). Ecological effects levels for the other pesticides detected were investigated based upon a review of the available research, including searches of EPA's ECOTOX database (Table B.1). All pesticide concentrations measured during this study were well below the LC_{50} or EC_{50} values reported in the literature.

Sediment. Sediment data were compared to a set of sediment benchmarks used by the DWQ Aquatic Toxicology Unit and included those of Region 4 USEPA (Waste Management Division Sediment Screening Values for Hazardous Waste Sites, available at http://www.epa.gov/region04/waste/ots/ecolbul.htm#tbl3), Florida Department of Environmental Protection (McDonald, 1994), Ontario Ministry of the Environment (MOE) (1993), Long et al (1995), NOAA's Screening Quick Reference Tables (SQuiRT) (Buchman 1999), and Oak Ridge National Laboratory's toxicological benchmarks document (Jones et al, 1997). They were grouped into conservative and non-conservative ranges in the manner of MacDonald et al (2000) (Table B.2). Conservative ranges are sets of threshold values, below which there is low probability of toxicity. Region 4 USEPA values are included in the set of conservative values, but they were also individually used for comparison because the DWQ Aquatic Toxicology Unit uses these as initial screening benchmarks. Non-conservative ranges are sets of probable values, above which there is a high probability of toxicity. If a measured value falls between the low value of the conservative range and the high value of the non-conservative range, toxicity is possible and the probability of toxicity increases with concentration.

Both the Upper Effects Threshold (UET) values (NOAA SQuiRT) and Ontario Severe Effects Levels (SEL) for organic contaminants were adjusted for site-specific total organic carbon (TOC). Published UET values were listed for sediments with 1 percent TOC; a site-specific UET was derived by multiplying the published value by the site-specific percent TOC as in Jones et al (1997). Published SEL values are in μg/g organic carbon. To derive a site-specific benchmark in mg/kg sediment (dry weight), the SEL was adjusted with site-specific TOC as described in the Ontario Ministry of the Environment's sediment benchmark document (1993).

Table B.1 Toxicity Values for Pesticides Detected in Water Samples That Lack Established Benchmarks

Pesticide	Pesticide Description	CAS Number	Max. Conc. -- This Study (µg/L)	Species	Endpoint, Duration	Concentration (µg/L)	Reference
anthraquinone	Geese repellant used by airports, golf courses, and landfills	84651	4.8	*Daphnia pulex*	Behavior; 24 hours	24.9	Allred and Giesy, 1985
bromocil	Herbicide for use on brush and grasses in non-croplands	314409	Detected but not quantified	*Daphnia magna*	EC_{50}; 48 hours	0.121	Office of Pesticide Programs, 2000
chloroxylenol	Antimicrobial and fungicide used in cleaning products and paints	88040	Detected but not quantified	*Daphnia magna*	EC_{50}; 48 hours	7.7	Office of Pesticide Programs, 2000
DEET	Insect repellant used on human skin, clothing, and for veterinary use	134623	Detected but not quantified	*Daphnia magna*	EC_{50}; 48 hours	75	Office of Pesticide Programs, 2000
kinoprene	Insect juvenile hormone analog for use on indoor plants	67533202	0.1	No data identified			
o-phenylphenol	Germicide and fungicide used on citrus fruits and vegetables	90437	0.81	*Daphnia magna*	LC_{50}; 48 hours	710	Maas, 1982
				Daphnia pulex	LD_{50}; 18 hours	46.9	Bowman et al., 1981

Table B.2 Sources of Sediment Benchmarks for Conservative and Non-conservative Screening Ranges

Conservative	Non-conservative
Region 4 EPA Ecological Screening Values	
Hyallela Threshold Effects Levels (via NOAA SQuiRT[1])	Upper Effects Threshold (via NOAA SQuiRT[1])
Threshold Effects Levels (via NOAA SQuiRT[1])	Apparent Effects Thresholds (via NOAA SQuiRT[1])
	Probable Effects Levels (via NOAA SQuiRT[1])
No Effects Levels (Ontario MOE)	Severe Effects Levels (Ontario MOE)
Low Effects Levels (Ontario MOE)	
Effects Range-Low (MacDonald & Long)	Effects Range-Median (MacDonald & Long)
Threshold Effects Levels (FL DEP)	Probable Effects Levels (FL DEP)
	Apparent Effects Thresholds (WA State) [3]
Threshold Effects Concentrations (EPA ARCS[2]) [3]	Probable Effects Concentrations (EPA ARCS[2]) [3]
No Effects Concentrations (EPA ARCS[2]) [3]	
NOAA Effects Range-Low[3]	NOAA Effects Range-Median[3]

[1]SQuiRT=Screening Quick Reference Tables
[2]ARCS=Assessment and Remediation of Contaminated Sediments Program
[3]via Oak Ridge National Laboratory's toxicological benchmarks document

1.4 Laboratories

This study utilized a number of laboratories to obtain services for the necessary range of chemical, physical and biological analyses:

- Environmental Chemists (Wilmington, NC)--chemical/physical analysis;
- Paradigm Analytical Laboratory (Wilmington, NC)--chemical analysis;
- Southern Testing (Rocky Mount, NC)--chemical analysis;
- Division of Water Quality Laboratory (Raleigh, NC)--chemical and biological analysis;
- NCSU Department of Environmental and Molecular Toxicology (Raleigh, NC)—pesticides (broad scan and qualitative GC/MS), PCBs (sediment), SPMDs;
- Simalabs International (Burlington, NC)--toxicity bioassay (water); and
- USGS Columbia Environmental Research Center (Columbia, MO)--toxicity bioassay (sediment).

Consult the project standard operating procedures document for additional details (NCDWQ, 2001a).

Section 2 Results

Key chemical, physical, and toxicity monitoring results were discussed in Section 5 of the main text. Supplemental information on selected issues is presented below, followed by a summary of analytical results for all primary sampling stations. Descriptions of the site codes are given in Table 5.1 of the main text.

2.1 Water Column Data

a. Toxicity Bioassays

Detailed summaries of the results from water column bioasssays are shown in Table B.3 for chronic bioassays and Table B.4 for acute bioassays. A chronic toxicity failure was observed in a sample from Crow Branch upstream of Airport Road (LCBKCB01) on November 13, 2001. Two other chronic bioassays had a significant decrease in *Ceriodaphnia* reproduction, but they did not exceed the 20 percent or greater decrease in reproduction that DWQ requires for a formal test "failure". The 20 percent criterion is used to decrease the potential for reporting false positive effects. The two sites with depressed reproduction were Crow Branch downstream of Airport Road (LCBKCB02) and Booker Creek downstream of Eastgate Shopping Center (LCBK01), both on June 25, 2002. See Section 5 of the main text for additional discussion.

b. Semi-Permeable Membrane Devices (SPMD)

SPMDs were deployed at three sites in Bolin Creek (LCBN02, LCBN03, and LCBN04) for seven days in August 2002 and analyzed for pesticides, PCBs, and PAHs. Due to dropping water levels, the devices were exposed to the air for a portion of the deployment period and concentrations could not be reliably estimated. A list of analytes detected is shown in Table B.5. Most of these were found at all three sites.

c. Metals

Trace metals were commonly found throughout the Little Creek watershed as described in Section 5.3.1. Table B.6 presents additional metals concentration comparisons for infrequently sampled sites. Comparisons between upstream and downstream sites in Bolin Creek during baseflow conditions could be made on two dates, April 23, 2002 and August 13, 2002. On these occasions, concentrations of numerous metals increased from upstream to downstream (Table B.7). There were two exceptions to this trend. During the August sampling, manganese was less concentrated at the downstream site. On April 23, 2002 the downstream site on Bolin Creek at Fordham Boulevard had a higher concentration of lead than farther upstream.

Table B.3 Chronic (7-day) Toxicity Bioassay Results for Little Creek Watershed

Site ID	Sample dates	Sample Type	Test Result	Mean Control reprod.	Mean Sample reprod.	Sample %reprod vs. control	Control CV, %	Control MSD	Control PMSD	pH	COND, µmhos/cm	Notes
Bolin Creek												
LCBN06	8/13/02, *	Grab	**PASS***	28.2	30.0	106	8.687	na	na	7.73, 7.57 *	103, *	*INVALID, 2nd sample not collected, Day 5 renewal performed with 1st sample
LCBN04	8/13/02, *	Grab	**PASS***	21.9	23.9	109	20.723	na	na	7.89, 7.57 *	331, *	*INVALID, 2nd sample not collected, Day 5 renewal performed with 1st sample
LCBN02	8/13/02, *	Grab	**PASS***	27.6	25.8	93.5	11.408	na	na	7.76, 7.63 *	241, *	*INVALID, 2nd sample not collected, Day 5 renewal performed with 1st sample
LCBN02	4/23/02, 4/26/02	Grab	**PASS**	27.7	31.8	115	9.417	na	na	7.50, 7.51	205, 208	
LCBN01	4/23/02	---	**---**	---	---	---	---	---	---	---	---	INVALID, <80% controls with 3 broods
Booker Creek												
LCBK01	6/25/02, 7/1/02	Grab	**PASS***	27.0	22.1	81.8	12.535	na	na	7.19, 7.34	416, 313	*Ambient reproduction indicated statistically significant decrease, but did not meet DWQ ≥20.0% effect criteria for failure; ambient CV = 30.532% [ATU data]
LCBK01	4/23/02, 4/26/02	Grab	**PASS**	21.8	19.7	90.4	12.782	na	na	7.03, 7.62	268, 258	
Crow Branch												
LCBKCB01	11/13/01, 11/16/01	Grab	**FAIL**	27.8	17.8	64.3	9.235	5.128	18.5	7.37, 7.36	1020, 1120	4/12 ambient samples did not release 3rd brood-delayed release (control = 100% with 3rd brood); 21.5% decrease in ambient brood 1+2 reproduction vs. controls, 50% decrease in ambient 3rd brood reproduction vs. controls [ATU data]
LCBKCB02	6/25/02, 7/1/02	Grab	**PASS***	26.3	21.9	83.2	10.781	2.634	10.0	6.84, 7.00	183, 208	*Ambient reproduction indicated statistically significant decrease, but did not meet DWQ ≥20.0% effect criteria for failure [ATU data]
Little Creek												
LCLC01	9/13/01, 9/16/01	Grab	**PASS**	27.2	27.3	100	20.455	na	na	7.37, 7.41	206, 211	92% controls produced 3rd brood

Pass/Fail test using *Ceriodaphnia dubia*. CV = coefficient of variation; NC DWQ upper limit set at 40.0% for valid test. PMSD = percent MSD, PMSD = MSD/(control mean reproduction) * 100
MSD = minimum significant difference; (control mean) – MSD = significant change in sample response. na = not available, MSD not able to be calculated from test data

Table B.4 Little Creek Watershed Acute (48-Hour) Toxicity Results*

Site ID	Sample date	Sample type	Result, LC_{50}, %	Treatment % Mortality Data	% Control Mortality	pH	COND., µmhos/cm
Bolin Creek							
LCBN04A	5/30/02	Grab	>100	0% @ 100%	0	7.34	201
LCBN02	8/16/02	Grab	>100	0% @ 100%	0	7.35	234
LCBN02	5/13/02	Grab	>100	0% @ 100%	0	7.55	168
LCBN01	7/25/02	Grab	>100	0% @ 100%	0	7.32	104
LCBN01	5/13/02	Grab	>100	0% @ 100%	0	7.61	222
Booker Creek							
LCBK01	8/16/02	Grab	>100	0% @ 100%	0	7.19	428
LCBK01	7/25/02	Grab	>100	0% @ 100%	0	7.11	124
LCBK01	5/13/02	Grab	>100	0% @ 100%	0	7.57	213
Little Creek							
LCLC01	8/16/02	Grab	>100	0% @ 100%	0	7.25	199

*Full range (multi-concentration) test using *Ceriodaphnia dubia*

Table B. 5 Pesticides, PCBs, and PAHs Collected on Semi-Permeable Membrane Devices in the Little Creek Watershed*

Current Use Pesticides (Quantitative GC/MS)	PAHs	PAHs Continued
chlorpyrifos	Naphthalene	Phenanthrene
Current Use Pesticides (Broad Scan GC/MS)	2-Methylnaphthalene	Anthracene
benzothiazole	1-Methylnaphthalene	1-Methylphenanthrene
Organochlorine Pesticides	Biphenyl	C1 - Phenanthrenes/Anthracenes
hexachlorobenzene	Acenapthylene	C2 - Phenanthrenes/Anthracenes
heptachlor	Acenapthene	C3 - Phenanthrenes/Anthracenes
alpha-chlordane	Dibenzofuran	Fluoranthrene
gamma-chlordane	2,3,5-Trimethylnaphthalene	Pyrene
4,4'-DDE	C1 - Naphthalenes	C1 - Fluoranthenes/Pyrenes
	C2 - Naphthalenes	Retene
PCBs	C3 - Naphthalenes	Benz[a]anthracene
PCB 52	C4 - Naphthalenes	Chrysene
PCB 44	Fluorene	C1 - Chrysenes
PCB 66	1-Methylfluorene	Benzo[b]fluoranthene
PCB 101	C1 - Fluorenes	Benzo[k]fluoranthene
PCB 153	C2 - Fluorenes	Benzo[e]pyrene
PCB 138	C3 - Fluorenes	Benzo[a]pyrene
	Dibenzothiophene	Perylene
	C1 - Dibenzothiophenes	Indeno[1,2,3-c,d]perylene
	C2 - Dibenzothiophene	Dibenz[a,h]anthracene
	C3 - Dibenzothiophene	benzo[g,h,i]perylene
		Coronene

* Concentrations could not be estimated. See text.

Table B.6 Total Metal Concentrations in Bolin Creek and Crow Branch during Baseflow[1]

	Chronic Criteria (µg/L)	Bolin Creek			Crow Branch
		4/23/02 LCBN01 (µg/L)	**8/13/02** LCBN04 (µg/L)	**8/13/03** LCBN06 (µg/L)	**2/19/02** LCBKCB01 (µg/L)
Aluminum	87	72	21	18	16
Arsenic	150	< 5	< 5	< 5	< 5
Cadmium	1.1 – 2.9	< 0.1	< 0.1	< 0.1	< 0.1
Chromium	11	< 1	< 1	< 1	< 1
Copper	3.9 – 11.4	< 1	< 1	< 1	< 1
Iron	1000	**1080**	522	146	**2570**
Lead	0.9 – 4.3	< 1	< 1	< 1	< 1
Manganese	120	**462**	**615**	75	**1260**
Mercury	0.77	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	22.0 – 63.4	< 1	< 1	< 1	< 1
Silver	0.36	< 0.5	< 0.5	< 0.5	< 0.5
Zinc	50.4 – 145.7	< 0.1	1.8	< 0.1	8.3
Hardness		69 mg/L[2]	126 mg/L	36 mg/L	69 mg/L[2]

1 Bold type indicates values that exceed the National Water Quality Criteria (NAWQC). NAWQC values varied according to water hardness for cadmium, copper, lead, nickel, and zinc. The range of values for the NAWQC is given for the hardness values measured.

2 Hardness values were not available, so the average hardness of all of the Bolin Creek samples was used to calculate the NAWQC values.

Table B.7 Comparisons of Baseflow Metal Concentrations in Bolin Creek from Upstream to Downstream on April 23, 2002 and August 13, 2002

	Chronic Criteria (µg/L)	April 23, 2002		August 13,2002		
		LCBN02 (µg/L)	LCBN01 (µg/L)	LCBN06 (µg/L)	LCBN04 (µg/L)	LCBN02 (µg/L)
Aluminum	87	59	72	18	21	22
Arsenic	150	< 5	< 5	< 5	< 5	< 5
Cadmium	1.1 – 3.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Chromium	11	< 1	< 1	< 1	< 1	< 1
Copper	3.9 – 11.4	< 1	< 1	< 1	< 1	< 1
Iron	1000	677	**1080**	146	522	**1020**
Lead	0.9 – 4.3	**2**[1]	< 1	< 1	< 1	< 1
Manganese	120	**131**	**462**	75	**615**	**284**
Mercury	0.77	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Nickel	22 – 63	< 1	< 1	< 1	< 1	< 1
Silver	0.36	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Zinc	50 – 146	< 0.1	< 0.1	< 0.1	1.8	3.2
Hardness		69 mg/L[2]	69 mg/L[2]	36 mg/L	126 mg/L	82 mg/L

1 The NAWQC for lead in water with a hardness of 69 mg/L is 1.98 µg/L.

2 Hardness values were not available, so the average hardness of all of the Bolin Creek samples was used to calculate the NAWQC values.

2.2 Bed Sediment Data

a. Toxicity Bioassay

Sediment bioassays conducted on bed sediments collected from Little Creek at Pinehurst Drive evaluated a number of biological endpoints (Table B.8). The depositional (fine sediment) areas contained a high percentage of sand and relatively little organic carbon (Table B.9). There was a statistically significant reduction in survival at the 35 day endpoint for the sand sample (P = 0.042). However, none of the other survival endpoints, body length, or reproduction relative to the control were statistically significant at $P = 0.05$. The number of young in the depositional sample appears to be considerably reduced compared to the control sample and the sand sample, but this difference was not statistically significant at $P = 0.05$.

Table B.8 Response of *Hyalella azteca* to Bed Sediment Samples from Little Creek at Pinehurst Drive (LCLC01) and a Control Sediment[1]

Sample	28-day Survival	28-day Length[2]	35-day Survival	42-day Survival	42-day Length[2]	42-day # of young Per Female
Control	98 (1.01)	4.49 (0.05)	98 (1.64)	95 (1.80)	5.25 (0.06)	8.28 (1.11)
Little Ck- Sand	90 (3.27)	5.01 (0.08)	85 (2.89)*	85 (2.89)	5.94 (0.11)	7.40 (2.26)
Little Ck- Depositional	98 (1.64)	5.03 (0.10)	98 (2.50)	98 (2.50)	5.51 (0.07)	6.05 (0.43)

[1] Means (standard error in parentheses). Sampled August 2001.
[2]Starting body length of amphipods = 2.10 (0.07) mm.
* Indicates difference statistically significant at $P < 0.05$.

Table B.9 Physical Characteristics of Bed Sediment Samples, Little Creek at Pinehurst Drive (LCLC01)

Location	Total Organic Carbon (%)	Water (%)	Particle Size (%)			Sediment Class
			Sand	Silt	Clay	
Control	1.25	40	53	17	30	Loam
Little Ck- Sand	0.04	24	86	12	2	Sand
Little Ck- Depositional	0.38	28	76	15	9	Sandy Loam

b. Bed Sediment Chemistry

Data on pesticides and other organic compounds were summarized in Section 5 of the main text. Trace metals were detected in both sandy sediments and depositional sediments (Table B.10). Sandy sediments contained cadmium at concentrations that were higher than the lowest conservative benchmark value. Lead was present in the depositional sediments at levels above the conservative benchmark range, but below the non-conservative (probable effects) range. Toxicity from lead is possible at this concentration, though not highly likely.

Table B.10 Metals Detected in Bed Sediment in Little Creek at Pinehurst Drive (LCLC01)

Metal[1]	Concentration (mg/Kg dry wt.) in Sandy Sediment	Concentration (mg/Kg dry wt.) in Depositional Sediment	Benchmark Values (mg/Kg)[2]		
			Conservative	Non-Conservative	EPA Region 4
Aluminum	3280.0	3530.0	25500	58030 to 73160	--
Cadmium	**0.6**	0.4	0.583 to 1.2	3 to 41.1	0.676
Chromium	12.4	8.4	26 to 81	90 to 370	52.3
Copper	6.6	7.5	16 to 35.7	54.8 to 270	18.7
Iron	11100	6320	20000 to 188400	40000	--
Lead	10.4	**62.1**	30 to 46.7	68.7 to 396	30.2
Manganese	310.0	237.0	460 to 1673	819 to 11000	--
Nickel	6.2	3.4	15.9 to 39.6	35.9 to 75	15.9
Zinc	29.6	35.6	98 to 159	271 to 1532	124

1. Antimony, arsenic, beryllium, mercury, selenium, silver, and thallium were not detected.
2. Conservative ranges ('no or low effects' benchmarks) are threshold values below which there is low probability of toxicity. Non-conservative ranges ('probable effects' benchmarks) are sets of values above which there is a high probability of toxicity.

2.3 Data Sonde Deployments

Data logging multiparameter probes (data sondes) were deployed on three dates for up to seven days, and were programmed to take readings at 15 minute intervals. The number of sites used for each deployment varied from two to four. Data for portions of some deployment periods were not used due to probe fouling or other equipment malfunction.

Dissolved oxygen results are discussed in Section 5.3.3 of the main text. Water temperature, pH, and conductivity were also measured with the data sondes (Table B.11). Generally, the temperature did not vary much between sites; the greatest difference was 1.7 degrees between the maximum temperatures at LCBN04 and LCBN03 during the August 16, 2002 deployment (26.3^{o} C versus 28.0^{o} C). The maximum temperature recorded was 28.0^{o} C from Bolin Creek at Airport Road (LCBN03) during the August 16, 2002 deployment. The pH in the watershed was close to neutral, ranging only from 6.25 (at LCBK01 during the 12/31/01 deployment) to 7.26 (at LCBK04 during the 9/27/01 deployment). Specific conductance was highly variable, ranging from 99.1 µS/cm (at LCBN03 during the 8/16/01 deployment) to 1496.0 µS/cm (at LCBN01 during the 12/31/01 deployment).

Conductivity was particularly high during the December 31, 2001 deployment. A snow storm occurred during this period, and during the subsequent melting of the snow the conductivity rose sharply at all sites, increasing by as much as a factor of 8.5 (at LCBN01). This is most likely a result of inputs of salt used to control roadway icing. Figure B.1 illustrates the typical pattern of specific conductance observed during this period. Snow began falling on 1/2/02 at 17:36 and it snowed throughout the day on 1/3/02. On 1/4/02 and 1/5/02 the air temperature was above freezing during the day. Rain and freezing rain fell periodically during 1/6/02.

Figure B.1 Specific Conductance in Little Creek at Pinehurst Drive, January 2-9, 2001

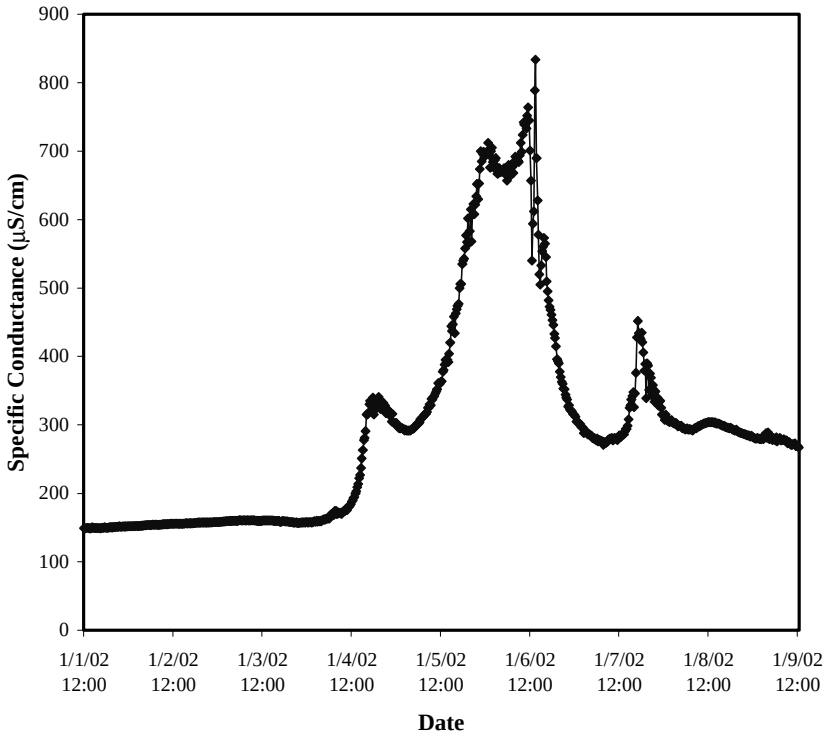

Figure B.2 documents an increase in conductance and a decline in dissolved oxygen as flows in Bolin Creek declined in August 2002. A storm occurred several hours prior to the deployment, raising water levels slightly during what had been an usually dry summer. The large daily fluctuations in dissolved oxygen observed were not typical of other deployments.

Figure B.2 Dissolved Oxygen and Specific Conductance in Bolin Creek (LCBN02), August 2002

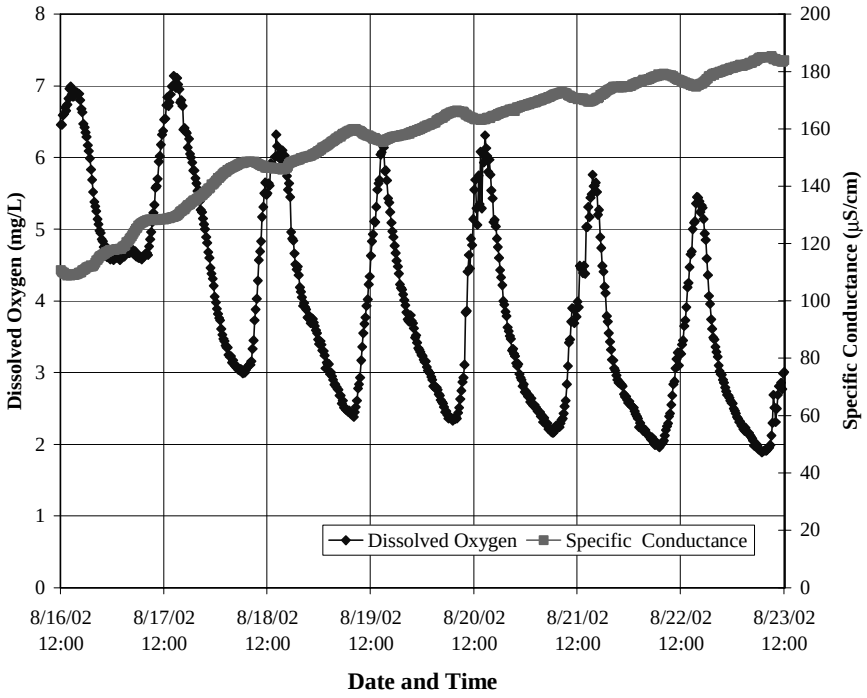

Table B.11 Summary of Results from Data Sonde Deployments[1]

Site Code	Start Date	Temperature (°C)			Specific Conductance (µS/cm)			pH (SU)			Dissolved Oxygen (mg/L)			N
		Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	
Little Creek														
LCLC01	12/31/01	1.9	0.2	4.3	282.8	147.4	834.0	6.90	6.60	7.06				850
Bolin Creek														
LCBN01	12/31/01	2.1	0.4	3.7	347.7	175.4	1496.0	7.53	7.25	7.61	7.40	6.88	8.11	425
LCBN01A	9/27/01	16.8	15.8	17.3	158.0	154.3	163.4	6.75	6.66	6.79	5.37	4.81	6.70	79
LCBN02	8/16/02				155.8	108.8	185.4	6.80	6.58	7.03	4.02	1.89	7.14	686
LCBN03	8/16/02	25.2	23.5	28.0	138.2	99.1	163.4	6.69	6.55	6.86	5.87	3.97	7.57	222
LCBN04	12/31/01	1.0	-0.1	3.4	147.7	108.2	496.0	7.37	6.79	7.56	13.45	12.41	14.24	852
	8/16/02	24.5	22.9	26.3	120.0	62.6	182.5				4.43	1.58	7.95	680
Booker Creek														
LCBK01	12/31/01	2.0	0.2	4.5	324.3	164.8	1264.0	6.75	6.25	6.91	6.64	5.69	7.73	850
LCBK03	12/31/01	1.9	0.1	4.0	286.5	145.4	1165.0	6.85	6.57	6.97	12.02	10.05	13.51	849
LCBK04	9/27/01	15.9	14.9	16.6	173.2	161.3	182.0	7.21	7.03	7.26	6.44	6.12	6.89	172

1 Measurements were recorded at 15-minute intervals. Blanks indicate data were not available for the applicable parameter.

2.4 Summary of Chemical and Physical Data

Tables B.12 to B.27 summarize the physical and chemical data collected at the primary sampling locations described in section five of the main text. Column headings for these tables are given below:

N	Number of samples or measurements
# Det	Number of samples at or above the minimum analytical reporting level
Max	Maximum value
Min	Minimum value
Mean	Mean
S.E.	Standard Error

Values below the minimum analytical reporting limit are shown in the table as a minimum value (Min) less than the specified reporting limit (e.g., "< 5.0").

In calculating means, values below detection limits were assigned a value of half the detection limit.

When only a single sample was analyzed and the value exceeded the reporting limit, the value is reported in the "Mean" column.

For each analysis for pesticides or other organic compounds (broad scan GC/MS, quantitative GC/MS, or EPA Methods) only the analytes measured at or above the minimum analytical detection limits are shown in the following tables. If all analytes were below detection limits, "all bdl" is listed in the parameter column. A complete list of analytes and detection limits for organic and pesticide analyses in included in Section 3 of this Appendix.

In Tables B.12 through B.27, "Current Use Pesticides" refers to analysis of 37 current use pesticides using quantitative GC/MS methods (see Table B.29). "Compounds detected by Broad Scan Methods" refers to analysis of over 300 current use pesticides and other compounds using broad scan GC/MS methods (see Table B.28).

Table B.12 Water Quality Summary for Little Creek at Pinehurst Drive (LCLC01)

Parameter	Baseflow						Storm					
	N	# Det	MIN	MAX	Mean	S.E.	N	# Det	MIN	MAX	Mean	S.E.
Field Parameters												
Water Temperature (°C)	5	N/A	3.1	25.9	12.4	4.6	1	N/A			23.8	
Specific Cond. (µS/cm)	5	N/A	133.9	206.4	179.7	15.1	1	N/A			200.7	
D.O. (mg/L)	5	N/A	4.90	14.06	9.64	1.77	1	N/A			5.60	
D.O. (% Saturation)	5	N/A	57.3	98.1	83.9	7.8	1	N/A			65.9	
pH (Standard Units)	4	N/A	6.55	8.21	7.46	0.36	1	N/A			7.10	
Nutrients (mg/L)												
Ammonia Nitrogen	1	1			0.1		1	1			0.1	
Total Kjeldahl Nitrogen	1	1			1.3		1	1			1.4	
Nitrate + Nitrite Nitrogen	1	0			<0.025		1	1			0.06	
Total Phosphorus	1	1			0.09		1	1			0.21	
Turbidity (NTU)	3	N/A	9.18	133	51.4	40.8	1	N/A			132	
Miscellaneous Inorganics (mg/L)												
Measured Hardness	3	N/A	66	81	72	4.5	2	N/A	66	70	68	2.0
Calculated Hardness[1]	3	N/A	48	70	60	6.4	2	N/A	64	70	67	3.4
Total Suspended Residue	3	N/A	4.9	100	40.7	29.8	1	N/A			44.0	
Total Dissolved Solids	3	N/A	21.2	120	86.4	32.6	1	N/A			11.2	
Ions (mg/L)												
Calcium	3	3	12.6	19.0	15.9	1.8	2	2	17.1	18.8	17.9	2.3
Magnesium	3	3	4.11	5.58	4.91	0.43	2	2	5.11	5.71	5.41	0.52
Potassium	3	3	1.85	3.02	2.28	0.37	1	1			2.07	
Sodium	3	3	10.8	12.3	11.57	0.43	1	1			13.1	
Bromide	1	0			< 0.05							
Chloride	1	1			14.1							
Fluoride	1	1			0.079							
Nitrate	1	1			0.11							
Nitrite	1	0			< 0.01							
Orthophosphate	1	0			<0.01							
Sulfate	1	1			12.1							
Phenols via EPA Method 604 (µg/L)												
All bdl	4	0			< 5		1	0			< 5	
Polycyclic Aromatic Hydrocarbons via EPA Method 610 (µg/L)												
All bdl	4	0			< 2 - < 5		1	0			< 2	
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl	4	0			< 5 - < 10		2	0			< 5 - < 10	

Table B.12 Continued (LCLC01)

Parameter	Baseflow						Storm					
	N	# Det	MIN	MAX	Mean	S.E.	N	# Det	MIN	MAX	Mean	S.E.
Total Petroleum Hydrocarbons (mg/L)												
Gas	4	0			< 0.24		1	0			< 0.24	
Diesel	4	0			< 0.1		1	0			< 0.1	
MTBE (µg/L)	4	0			< 1							
Organochlorine Pesticides & PCB's via EPA Method 608 (µg/L)												
All bdl	1	0			< 0.5 - < 2.5							
Current Use Pesticides (µg/L)												
All bdl	2	0			< 0.005		1	0			< 0.005	
Compounds detected by Broad Scan Methods (µg/L)												
All bdl except:												
Kinoprene	2	0			< 0.10		1	1			0.10	
MBAS (mg/L)	3	1	< 0.025	0.117	0.047	0.035	1	0			< 0.025	
Metals (µg/L)												
Aluminum	4	4	163	266	199.0	24.1	2	2	209	277	243	34
Arsenic	4	0			< 5		2	0			< 5	
Cadmium	4	1	< 0.1	0.1	0.063	0.012	2	0			< 0.1	
Chromium	4	0			< 1		2	0			< 1	
Copper	4	2	< 1.0	5	2.25	1.09	2	2	2	3	2.5	0.5
Iron	4	4	944	2000	1456	216	2	2	1340	3780	2560	1220
Lead	4	1	< 1.0	3	1.125	0.625	2	1	< 1	5	2.75	2.25
Manganese	4	4	152	390	297	53.9	2	2	245	1130	687.5	442.5
Mercury	4	0			< 0.2		2	0			< 0.2	
Nickel	4	1	< 1.0	2	0.875	0.375	2	0			< 1	
Silver	4	1	< 0.5	2.6	0.669	0.64	2	0			< 0.5	
Zinc	4	4	3.2	15.5	7.48	2.78	2	2	4	53.5	28.75	24.75

1 Hardness was calculated by the formula:
Hardness = [Calcium concentration in mg/L]*2.497+[Magnesium concentration in mg/L]*4.116.

Table B.13 Water Quality Summary for Bolin Creek at Fordham Boulevard (LCBN01)

Parameter	Baseflow						Storm					
	N	#Det	Min	Max	Mean	S.E.	N	#Det	Min	Max	Mean	S.E.
Field Parameters												
Water Temperature (°C)	1	N/A			19.4		2	N/A	22	25.6	23.8	1.8
Specific Cond. (µS/cm)	1	N/A			207							
D.O. (mg/L)	1	N/A			9.4							
D.O. (% Saturation)	1	N/A			96.0							
pH (Standard Units)							1	N/A			6.6	
Nutrients (mg/L)												
Ammonia Nitrogen							1	1			0.6	
Total Kjeldahl Nitrogen							1	1			2.80	
Nitrate + Nitrite Nitrogen							1	1			0.57	
Total Phosphorus							1	1			0.14	
Turbidity (NTU)							2	2	11.3	160	85.6	74.4
Miscellaneous Inorganics (mg/L)												
Calculated Hardness[1]							2	2	35	62	49.0	13.6
Measured Hardness							2	2	29	70	49.3	20.6
Total Suspended Residue							2	2	13	252	132.5	119.5
Total Dissolved Solids							2	2	138	589	363.5	225.5
Ions (mg/L)												
Calcium							2	2	8.94	16.4	12.67	3.73
Magnesium							2	2	3.08	5.18	4.13	1.05
Potassium							1	1			4.07	
Sodium							1	1			12.6	
Phenols via EPA Method 604 (µg/L)												
All bdl	1	0			< 5							
Polycyclic Aromatic Hydrocarbons via EPA Method 610 (µg/L)												
All bdl except:												
Benzo(a)anthracene	1	0			< 5.0		1	1		5.75		
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl	1	0			< 5 - < 10		2	0			< 5 - < 10	
Total Petroleum Hydrocarbons (mg/L)												
Gas	1	0			< 0.24		2	0			< 0.24	
Diesel	1	0			< 0.1		2	0			< 0.1	
MTBE (µg/L)	1	0			< 1.0		2	0			< 1.0	

Table B.13 Continued (LCBN01)

Parameter	Baseflow						Storm					
	N	#Det	Min	Max	Mean	S.E.	N	#Det	Min	Max	Mean	S.E.
Organochlorine Pesticides & PCB's via EPA Method 608 (μg/L)												
All bdl	1	0			< 0.5 - < 2.5		1	0			< 0.2 - < 1.0	
Current Use Pesticides (μg/L)												
All bdl	1	0			< 0.005		2	0			< 0.005	
Compounds detected by Broad Scan Methods (μg/L)												
All bdl except:												
Acetaminophen	1	0			< 0.10		2	1	< 0.10	0.29	0.17	0.12
Anthraquinone	1	0			< 0.10		2	1	< 0.10	2.70	1.38	1.32
Caffeine	1	0			< 0.10		2	1	< 0.10	0.52	0.28	0.24
Carbazole	1	0			< 0.10		2	1	< 0.10	1.80	0.92	0.88
MBAS (mg/L)	1	0			< 0.025		2	1	< 0.025	0.113	0.063	0.050
Metals (μg/L)												
Aluminum	1	1			72		2	2	182	395	288.5	106.5
Arsenic	1	0			< 5		2	0			< 5	
Cadmium	1	0			< 0.1		2	1	< 0.1	0.2	0.125	0.075
Chromium	1	0			< 1.0		2	1	< 1.0	5.00	2.75	2.25
Copper	1	0			< 1.0		2	2	4	25	14.5	10.5
Iron	1	1			1080		2	2	868	970	919	51
Lead	1	0			< 1.0		2	2	1	20	10.5	9.5
Manganese	1	1			462		2	2	298	438	368	70
Mercury	1	0			< 0.2		2	0			< 0.2	
Nickel	1	0			< 1.0		2	1	< 1.0	3	1.75	1.25
Silver	1	0			< 0.5		2	0			< 0.5	
Zinc	1	0			< 0.1		2	2	16.8	58	37.4	20.6

1 Hardness was calculated by the formula:
Hardness = [Calcium concentration in mg/L]*2.497+[Magnesium concentration in mg/L]*4.116.

Table B.14 Water Quality Summary for Bolin Creek at Franklin Street (LCBN02)

Parameter	Baseflow						Storm					
	N	#Det	Min	Max	Mean	S.E.	N	#Det	Min	Max	Mean	S.E.
Field Parameters												
Water Temperature (°C)	8	N/A	3.2	27.7	15.125	3.26	2	N/A	22	23.2	22.6	0.6
Specific Cond. (µS/cm)	8	N/A	152.2	257.8	198.9	13.2	1	N/A			231.4	
D.O. (mg/L)	8	N/A	5.63	12.59	9.20	0.97	1	N/A			4.93	
D.O. (% Saturation)	8	N/A	71.6	98.6	86.05	3.88	1	N/A			64.8	
pH (Standard Units)	7	N/A	6.71	7.98	7.35	0.17	1	N/A			6.8	
Nutrients (mg/L)												
Ammonia Nitrogen	1	0			< 0.1		1	0			< 0.1	
Total Kjeldahl Nitrogen	1	1			0.6		1	1			1.0	
Nitrate + Nitrite Nitrogen	1	1			0.09		1	1			0.48	
Total Phosphorus	1	1			0.04		1	1			0.05	
Miscellaneous Inorganics (mg/L)												
Calculated Hardness[1]	1	N/A			82		1	N/A			74	
Ions (mg/L)												
Calcium	1	1			22.6		1	1			19.2	
Magnesium	1	1			6.28		1	1			6.39	
Polycyclic Aromatic Hydrocarbons via EPA Method 610 (µg/L)												
All bdl except: Benzo(a)anthracene	6	0			< 5		2	1	< 5	8.41	5.45	2.96
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl	7	0			< 5 - < 10		3	0			< 5 - < 10	
Total Petroleum Hydrocarbons (mg/L)												
Gas	5	0			< 0.24		2	0			< 0.24	
Diesel	7	0			< 0.1		2	0			< 0.1	
MTBE (mg/L)	6	2	< 1.0	4.31	1.45	0.65	2	0			< 1.0	
Organochlorine Pesticides & PCB's via EPA Method 608 (µg/L)												
All bdl	3	0			< 0.5 – < 2.5							
Current Use Pesticides (µg/L)												
All bdl except: Atrazine	3	0			< 0.005		2	1	< 0.005	0.17	0.086	0.083

Table B.14 Continued (LCBN02)

Parameter	Baseflow						Storm					
	N	#Det	Min	Max	Mean	S.E.	N	#Det	Min	Max	Mean	S.E.
Compounds detected by Broad Scan Methods (µg/L)												
All bdl except:												
Acetaminophen	3	0			< 0.1		2	1	< 0.1	0.09	0.07	0.02
Caffeine	3	1	< 0.1	0.11	0.07	0.02	2	2	0.20	1.4	0.80	0.60
DEET	3	0			< 0.1		2	1	< 0.1	*	*	
Kinoprene	3	0			< 0.1		2	1	< 0.1	0.05	0.05	0.00
MBAS (mg/L)	5	1	< 0.025	0.07	0.024	0.012	2	2	0.075	0.100	0.088	0.012
Metals (µg/L)												
Aluminum	6	6	22	237	137.5	34.5	3	3	50	529	262.0	141.0
Arsenic	6	0			< 5		3	0			< 5	
Cadmium	6	0			< 0.1		3	1	< 0.1	0.6	0.23	0.18
Chromium	6	0			< 1.0		3	0			< 1.0	
Copper	6	1	< 1.0	2	0.75	0.25	3	3	2	8	4.33	1.86
Iron	6	6	581	1640	1025	203.4	3	3	392	1950	976.7	489.9
Lead	6	1	< 1.0	2	0.75	0.25	3	1	< 1	7	2.67	2.17
Manganese	6	6	50	284	177.5	42.3	3	3	92	288	160	64.0
Mercury	6	0			< 0.2		3	0			< 0.2	
Nickel	6	0			< 1		3	1	< 1	1	0.67	0.17
Silver	6	0			< 0.5		3	0			< 0.5	
Zinc	6	4	< 0.1	10.5	3.6	1.6	3	3	6.6	37	23.4	8.9

1 Hardness was calculated by the formula:
Hardness = [Calcium concentration in mg/L]*2.497+[Magnesium concentration in mg/L]*4.116.
* Analyte detected but not quantified.

Table B.15 Water Quality Summary for Bolin Creek at Airport Road (LCBN03)

Parameter	Sewer Leak						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters												
Water Temperature (°C)	1	N/A			21.7							
Specific Cond. (µS/cm)	1	N/A			228.2							
D.O. (mg/L)	1	N/A			7.03							
D.O. (% Saturation)	1	N/A			79.5							
pH (Standard Units)	1	N/A			7.05							
MTBE (µg/L)							1	0			< 1	

Table B.16 Water Quality Summary for Bolin Creek at Village Drive (LCBN04)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters												
Water Temperature (°C)	1	N/A			25.5							
Specific Cond. (µS/cm)	1	N/A			337.8							
D.O. (mg/L)	1	N/A			5.58							
D.O. (% Saturation)	1	N/A			68.9							
pH (Standard Units)	1	N/A			7.15							
Nutrients (mg/L)												
Ammonia Nitrogen	1	1			0.1							
Total Kjeldahl Nitrogen	1	1			1.3							
Nitrate + Nitrite Nitrogen	1	1			0.13							
Total Phosphorus	1	1			0.03							
Miscellaneous Inorganics (mg/L)												
Calculated Hardness[1]	1	N/A			126							
Ions (mg/L)												
Calcium	1	1			26.8							
Magnesium	1	1			14.3							
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl	1	0			< 5 - < 10							
Total Petroleum Hydrocarbons (mg/L)												
Gas	1	0			< 0.24							
Diesel	1	0			< 0.1							
MTBE (µg/L)	1	0			< 1		1	0			< 1	
Current Use Pesticides (µg/L)												
All bdl	1	0			< 0.005							
Compounds detected by Broad Scan Methods (µg/L)												
All bdl	1	0			< 0.10							

1 Hardness was calculated by the formula:
Hardness = [Calcium concentration in mg/L]*2.497+[Magnesium concentration in mg/L]*4.116.

Table B.16 Continued (LCBN04)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Metals (µg/L)												
Aluminum	1	1			21							
Arsenic	1	0			< 5							
Cadmium	1	0			< 0.1							
Chromium	1	0			< 1							
Copper	1	0			< 1							
Iron	1	1			522							
Lead	1	0			< 1							
Manganese	1	1			615							
Mercury	1	0			< 0.2							
Nickel	1	0			< 1							
Silver	1	0			< 0.5							
Zinc	1	1			1.8							

Table B.17 Water Quality Summary for Bolin Creek at Umstead Park during a Sanitary Sewer Leak (LCBN04A)

Parameter	Sewer Leak					
	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters						
Water Temperature (°C)	1	N/A			21.9	
Specific Cond. (µS/cm)	1	N/A			187.8	
D.O. (mg/L)	1	N/A			3.86	
D.O. (% Saturation)	1	N/A			44.3	
pH (Standard Units)	1	N/A			7.18	
Nutrients (mg/L)						
Ammonia Nitrogen	1	1			0.17	
Total Kjeldahl Nitrogen	1	1			0.51	
Nitrate + Nitrite Nitrogen	1	1			0.34	
Total Phosphorus	1	1			0.09	
Turbidity (NTU)	1	N/A			90	
Fecal Coliform (cfu/100ml)	1	1			450	
BOD_5 (mg/L)	1	0			< 1	

Table B.18 Water Quality Summary for Bolin Creek at Homestead Road (LCBN06)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters												
Water Temperature (°C)	1	N/A			24.3							
Specific Cond. (µS/cm)	1	N/A			102.3							
D.O. (mg/L)	1	N/A			6.54							
D.O. (% Saturation)	1	N/A			78.2							
pH (Standard Units)	1	N/A			6.84							
Nutrients (mg/L)												
Ammonia Nitrogen	1	0			< 0.1							
Total Kjeldahl Nitrogen	1	1			1.3							
Nitrate + Nitrite Nitrogen	1	1			0.62							
Total Phosphorus	1	0			< 0.02							
Miscellaneous Inorganics (mg/L)												
Calculated Hardness[1]	1	N/A			36							
Ions (mg/L)												
Calcium	1	1			8.66							
Magnesium	1	1			3.56							
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl	1	0			< 5 - < 10							
Total Petroleum Hydrocarbons (mg/L)												
Gas	1	0			< 0.24							
Diesel	1	0			< 0.1							
MTBE (µg/L)	1	0			< 1							
Current Use Pesticides (µg/L)												
All bdl	1	0			< 0.005							
Broad Scan Pesticides (µg/L)												
All bdl except:												
Caffeine	1	1			0.12							
Chloroxylenol	1	1			*							
DEET	1	1			*							

Table B.18 Continued (LCBN06)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Metals (µg/L)												
Aluminum	1	1			18							
Arsenic	1	0			< 5							
Cadmium	1	0			< 0.1							
Chromium	1	0			< 1.0							
Copper	1	0			< 1.0							
Iron	1	1			146							
Lead	1	0			< 1.0							
Manganese	1	1			75							
Mercury	1	0			< 0.2							
Nickel	1	0			< 1.0							
Silver	1	0			< 0.5							
Zinc	1	0			< 0.1							

1 Hardness was calculated by the formula:
Hardness = [Calcium concentration in mg/L]*2.497+[Magnesium concentration in mg/L]*4.116.
* Analyte detected but not quantified.

Table B.19 Water Quality Summary for Booker Creek at Willow Drive (LCBK01)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters												
Water Temperature (°C)	7	N/A	3.1	24.0	15.5	3.18	3	N/A	22	24.1	23.2	0.62
Specific Cond. (µS/cm)	7	N/A	188.3	246.1	208.8	7.6	1	N/A			411.0	
D.O. (mg/L)	7	N/A	4.67	12.15	8.44	1.06	1	N/A			4.08	
D.O. (% Saturation)	7	N/A	49.5	98.5	81.4	6.9	1	N/A			48.5	
pH (Standard Units)	6	N/A	7.02	7.65	7.36	0.11	2	N/A	6.70	7.00	6.85	0.15
Nutrients (mg/L)												
Ammonia Nitrogen	1	1			0.37		2	1	0.1	0.4	0.25	0.15
Total Kjeldahl Nitrogen	1	1			0.93		2	1	2.5	2.8	2.65	0.15
Nitrate + Nitrite Nitrogen	1	1			0.18		2	1	0.3	0.78	0.54	0.24
Total Phosphorus	1	1			0.05		2	1	0.03	0.41	0.22	0.19
Turbidity (NTU)							1	1			540	
Miscellaneous Inorganics (mg/L)												
Measured Hardness	1	N/A			66.0		1	N/A			37.8[2]	
Calculated Hardness[1]	1	N/A			70.1		1	N/A			118	
Total Suspended Residue							1	N/A			519	
Total Dissolved Solids							1	N/A			664	
Ions (mg/L)												
Calcium	1	1			19.0		1	1			37.0	
Magnesium	1	1			5.5		1	1			6.22	
Sodium	1	1			10.0							
Phenols via EPA Method 604 (µg/L)												
All bdl	5	0			< 5		1	0			< 5	
Polycyclic Aromatic Hydrocarbons via EPA Method 610 (µg/L)												
All bdl except:												
Phenanthrene	6	0			< 2 -< 5		2	1	< 5	6.15	4.32	1.82
Fluoranthrene	6	0			< 2 -< 5		2	1	< 5	805.0	403.8	401.2
Pyrene	6	0			< 2 -< 5		2	1	< 5	6.46	4.48	1.98
Benzo(a)anthracene	6	0			< 2 -< 5		2	1	< 5	18.5	10.5	8
Chrysene	6	0			< 2 -< 5		2	1	< 5	17.2	9.85	7.35
Benzo(b)fluoranthene	6	0			< 2 -< 5		2	1	< 5	16.8	9.65	7.15
Indeno(1,2,3-cd)pyrene	6	0			< 2 -< 5		2	1	< 5	7.75	5.12	2.62

Table B.19 Continued (LCBK01)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl except:												
Benzo(k)fluoranthene	6	0			< 5		4	1	< 5	6.36	3.46	0.96
Bis(2-ethylhexyl)phthalate	6	1	< 5	9.26	4.04	1.12	4	0			< 5	
Chrysene	6	0			< 5		4	1	< 5	5.26	3.19	0.69
Fluoranthene	6	0			< 5 - < 10		4	1	< 5	6.95	3.61	1.11
Pyrene	6	0			< 5		4	1	< 5	5.95	3.36	0.86
Total Petroleum Hydrocarbons (mg/L)												
Gas	5	0			< 0.24		3	0			< 0.24	
Diesel	6	0			< 0.1		3	0			< 0.1	
MTBE (µg/L)	6	3	< 1	8.1	2.40	1.22	3	2	< 1	2.24	1.25	0.52
Organochlorine Pesticides & PCB's via EPA Method 608 (µg/L)												
All bdl	3	0			< 0.5 - < 2.5		1	0			< 0.2 - < 1.0	
Current Use Pesticides (µg/L)												
All bdl	2	0			< 0.005		3	0			< 0.005	
Compounds detected by Broad Scan Methods (µg/L)												
All bdl except:												
Acetaminophen	2	0			< 0.1		3	2	< 0.1	0.37	0.18	0.10
Anthraquinone	2	0			< 0.1		3	1		4.80	1.63	1.58
Bromacil	2	0			< 0.1		2	1	< 0.1	*	*	
Caffeine	2	0			< 0.1		3	2	< 0.1	6.20	2.21	2.00
o-phenylphenol	2	0			< 0.1		3	1	< 0.1	0.81	0.30	0.25
MBAS (mg/L)	5	3	< 0.025	0.115	0.052	0.019	3	2	< 0.025	0.269	0.178	0.083

Table B.19 Continued (LCBK01)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Metals (µg/L)												
Aluminum	7	7	40	2240	588.1	290.2	4	4	58	8040	2235.2	1937.0
Arsenic	7	0			< 5 - < 10		4	0			< 5	
Cadmium	7	1	<0.1-<2	0.5	0.38	0.17	4	3	< 0.1	0.5	0.21	0.10
Chromium	7	0			< 1 - < 25		4	3	< 1	6	2.88	1.30
Copper	7	4	< 1	4.7	1.5	0.58	4	4	3	30	11.5	6.38
Iron	7	7	443	4230	1585.4	473.7	4	4	464	5280	1993	1117.5
Lead	7	1	<1–<10	6	2.57	0.98	4	2	< 1	30	11.5	7.05
Manganese	7	7	87	1670	454.4	208.5	4	4	252	1210	615.2	216.8
Mercury	5	0			< 0.2		4	0			< 0.2	
Nickel	7	1	<1–<10	2.0	2.0	0.80	4	3	< 1	5	2.88	1.01
Silver	7	0			< 0.5 - < 5		4	0			< 0.5	
Zinc	7	5	<0.1 - <10	17	7.19	2.43	4	4	6.2	160	73.2	32.3

1 Hardness was calculated by the formula:
Hardness = [Calcium concentration in mg/L]*2.497+[Magnesium concentration in mg/L]*4.116.
Calculated and measured hardness values pertain to samples collected on different dates.
* Detected but not quantified.

Table B.20 Water Quality Summary for an un-named tributary to Booker Creek on Ephesus Road (LCBK02A)

Parameter	Baseflow						Eastwood Lake Draining					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters												
Water Temperature (°C)	1	N/A			15.1		1	N/A			23.2	
Specific Cond. (µS/cm)	1	N/A			316.1		1	N/A			264.1	
D.O. (mg/L)	1	N/A			9.41		1	N/A			5.77	
D.O. (% Saturation)	1	N/A			93.2		1	N/A			68	
pH (Standard Units)	1	N/A			7.19		1	N/A			6.85	
MTBE (µg/L)	1	0			< 1							

Table B.21 Water Quality Summary for Booker Creek behind Eastgate Shopping Center during the Eastwood Lake draining (LCBK03)

Parameter	Eastwood Lake Draining					
	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters						
Water Temperature (°C)	1	N/A			23	
Specific Cond. (µS/cm)	1	N/A			180.5	
D.O. (mg/L)	1	N/A			5.04	
D.O. (% Saturation)	1	N/A			60.4	
pH (Standard Units)	1	N/A			7.05	

Table B.22 Water Quality Summary for Booker Creek at East Franklin Street during the Eastwood Lake draining (LCBK04)

Parameter	Eastwood Lake Draining					
	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters						
Water Temperature (°C)	1	N/A			23.6	
Specific Cond. (µS/cm)	1	N/A			172.2	
D.O. (mg/L)	1	N/A			6.6	
D.O. (% Saturation)	1	N/A			76	
pH (Standard Units)	1	N/A			6.94	

Table B.23 Water Quality Summary for Booker Creek at Eastwood Lake Outfall (LCBK05)*

Parameter	Eastwood Lake Draining						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Water Temperature (°C)	1	N/A			22.0							
Turbidity (NTU)	1	1			940							
Total Suspended Residue (mg/L)	1	1			1900							
MTBE (µg/L)							1	0			< 1	

*Site not shown on map (Figure 5.1) in the main text.

Table B.24 Water Quality Summary for Booker Creek in Eastwood Lake during Eastwood Lake Draining (LCBK06)

Parameter	Eastwood Lake Draining					
	N	#Det	MIN	MAX	Mean	S.E.
Total Suspended Residue (mg/L)	1	1			1800	

Table B.25 Water Quality Summary for an un-named tributary to Booker Creek near Eastgate Shopping Center behind Bruegger's Bagels (LCBKT2)*

Parameter	Baseflow						Storm Flow					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Water Temperature (°C)							1	N/A			22.0	
MTBE (µg/L)							1	0			< 1	

*Site not shown on map (Figure 5.1) in the main text.

Table B.26 Water Quality Summary for Tanbark Branch during sanitary sewer leak (LCBNTB01)

Parameter	Sewer Leak					
	N	#Det	MIN	MAX	Mean	S.E.
Field Parameters						
Water Temperature (°C)	1	N/A			22.1	
Specific Cond. (µS/cm)	1	N/A			235.7	
D.O. (mg/L)	1	N/A			6.31	
D.O. (% Saturation)	1	N/A			72.7	
pH (Standard Units)	1	N/A			7.25	

Table B.27 Water Quality Summary for Crow Branch (LCBKCB01)

Parameter	Baseflow						Storm					
	N	#Det	MIN	MAX	Mean	S.E.	N	#Det	MIN	MAX	Mean	S.E.
Phenols via EPA Method 604 (µg/L)												
All bdl	1	0			< 5							
Polycyclic Aromatic Hydrocarbons via EPA Method 610 (µg/L)												
All bdl	1	0			< 5							
Base/Neutral and Acid Organics via EPA Method 625 (µg/L)												
All bdl	1	0			< 5 - < 10							
Total Petroleum Hydrocarbons (mg/L)												
Gas	1	0			< 0.24							
Diesel	1	0			< 0.1							
MTBE (µg/L)	1	0			< 1							
MBAS (mg/L)	1	1			0.061							
Metals (µg/L)												
Aluminum	1	1			16							
Arsenic	1	0			< 5							
Cadmium	1	0			< 0.1							
Chromium	1	0			< 1							
Copper	1	0			< 1							
Iron	1	1			2570							
Lead	1	0			< 1							
Manganese	1	1			1260							
Mercury	1	0			< 0.2							
Nickel	1	0			< 1							
Silver	1	0			< 0.5							
Zinc	1	1			8.3							

Section 3 Pesticides and Organic Analyses: Analyte Lists

Lists of analytes for pesticide and organic analyses used in this study are presented in Tables B.28 through B.37.

Table B.28 Current Use Pesticides Analyzed by Broad Scan GC/MS Method

Acephate	Cycluron	Fluometuron	Phorate
Acetochlor	Cyprofuram	Fluorodifen	Phosalone
Alachlor	D (2,4) methylester	Flurecol-butyl	Phosmet
Aldrin	DDD-o,p'	Fluridone	Phosphamidon
Allethrin	DDD-p,p'	Flurochloridone	Phoxim
Ametryn	DDE-o,p'	Folpet	Pindone
Amidithion	DDE-p,p'	Fonofos	Piperonyl butoxide
Aminocarb	DDT-o,p'	Formothion	Pirimicarb
Amitraz	DDT-p,p'	HCH-alpha	Pirimiphos-ethyl
Anilazine	Demephion	HCH-beta	Pirrmiphos-methyl
Anthraquinone	Demeton	HCH-delta	Prochloraz
Aramite	Demeton-s-methyl	Heptachlor	Procymidone
Atrazine	Desmetryn	Heptachlorepoxid-cis	Profenofos
Atrazine desethyl	Dialifos	Heptachlorepoxid-trans	Profluralin
Atrazine desisopropyl	Di-allate	Heptenophos	Promecarb
Azobenzene	Diazinon	Hexabromobenzene	Prometon
Azamethiphos	Dichlobenil	Hexachlorobenzene	Prometryn
Azinphos-ethyl	Dichlofenthion	Hexachlorophene	Propachlor
Azinphos-methyl	Dichlofluanid	Imazilil	Propanil
Aziprotryne	Dichlone	Iodofenphos	Propargite
Barban	Dichloro(4,4')dibenzophenone	Ioxynil	Propazine
Benalaxyl	Dichloroaniline (2,3-)	Iprodione	Propetamphos
Bendiocarb	Dichloroaniline (2,5-)	Isazophos	Propham
Benfluralin	Dichlorobenzene (1,2-)	Isocarbamid	Propiconazole
Benodanil	Dichlorophenol (2,4-)	Isofenphos	Propoxur
Bentazone	Dichlorprop methylester	Isomethiozin	Propyzamide
Benzoylprop-ethyl	Dichlorvos	Isopropalin	Prothiophos
Bifenox	Diclobutrazol	Landrin (3,4,5-)	Prothoate
Biphenyl	Diclofop-methyl	Lenacil	Pyrazophos
Bitertanol	Dicloran	Lindane	Pyridate
Bromacil	Dicofol	Malaoxon	Pyroquilon
Bromocylclen	Dicrotophos	Malathion	Quinalphos
Bromophos	Dieldrin	MCPA	Quinomethionate
Bromophos-ethyl	Dimefox	Mcpa methylester	Quintozene
Bromopropylate	Dimethachlor	Mecarbam	Secbumeton
Bupirimate	Dimethametryn	Mecoprop	Simazine
Butachlor	Dimethipin	Mecoprop methylester	Simetryn
Butralin	Dimethoate	Metamitron	Sulfotepp
Buturon	Dinobuton	Metazachlor	Sulprofos
Butylate	Dinoseb	Methacriphos	Swep

Table B.28 Continued

Captafol	Dinoseb acetate	Methamidophos	T (2,4,5..) Methylester
Captan	Dinoterb	Methazole	Tebutam
Carbaryl	Dioxathion	Methidathion	Tecnazene
Carbetamide	Diphenamid	Methoprotryne	Tepp
Carbofuran	Dipropetryn	Methoxychlor	Terbazil
Carbophenothion	Disulfoton	Metobromuron	Terbumeton
Carboxin	Ditalimphos	Metolachlor	Terbuthylazine
Chloraniformethan	Dnoc	Metribuzin	Terbutryn
Chlorbenside	Dodemorph	Mevinphos	Tetrachlorvinphos
Chlorbromuron	Endosulfan sulfate	Mirex	Tetradifon
Chlorbufam	Endosulfan-alpha	Molinate	Tetramethrin
Chlordane	Endosulfan-beta	Monalide	Tetrasul
Chlordimeform	Endrin	Monocrotophos	Thiabendazole
Chlorfenprop-methyl	Epn	Monolinuron	Thiobencarb
Chlorfenson	Etaconazole	Naled	Thiometon
Chlorfenvenphos	Ethalfluralin	Napropamide	Thionazin
Chlorflurecol-methyl	Ethiofencarb	Nitralin	Thioquinox
Chloridazon	Ethiolate	Nitrapyrin	Tiocarbazil
Chlormephos	Ethion	Nitrofen	Tolclofos-methyl
Chlorobenzilate	Ethofumesate	Nitrothal-isopropyl	Tolylfluanid
Chloroneb	Ethoprophos	Norflurazon desmethyl	Tri-allate
Chloropropylate	Etridiazole	Nuarlmol	Triadimefon
Chlorothalonil	Etrimfos	Omethoate	Triadimenol
Chlorpropham	Fenamiphos	Oxadiazon	Triamiphos
Chlorpyrifos	Fenarimol	Oxadixyl	Triazophos
Chlorpyrifos-methyl	Fenazaflor	Oxycarboxin	Trichlorfon
Chlorthal-dimethyl	Fenchlorphos	Oxydemeton-methyl	Trichloroacetophenon (1,2,4-)
Chlorthiamid	Fenitrothion	Paraoxon	Trichlorobenzene (1,2,4-)
Chlorthion	Fenproplmorph	Parathion	Trichloronat
Chlorthiophos	Fenson	Parathion-methyl	Trichlorophenol (2,3,5-)
Chlozolinate	Fensulfothion	Pebulate	Trichlorophenol (2,3,6-)
Coumaphos	Fenthion	Penconazole	Trichlorophenol (2,4,5-)
Crotoxyphos	Fenvalerate	Pendimethalin	Tridiphane
Crufomate	Flamprop-isopropyl	Pentachlorobenzene	Trietazine
Cyanazine	Fluazifop-p-butyl	Pentanochlor	Trifluralin
Cyanofenphos	Flubenzimine	Perthane	Vamidothion
Cyanophos	Fluchloralin	Phenkapton	Vernolate
Cycloate	Flumetralin	Phenthoate	Vinclozolin

Note: Detection limit for Broad Scan GC/MS compounds is 0.10 ug/L

Table B.29 Current Use Pesticides Analyzed by Quantitative GC/MS Method

2,4 d	Cyanazine	Ethoprop	Pebulate
2,6-diethylanaline	Dacthal	Fenamiphos	Pendimethalin
Alachlor	Deethylatrazine	Flumetralin	Permethrin
Atrazine	Deisopropylatrazine	Fonofos	Prometon
Benfluralin	Diazinon	Malathion	Prometryn
Butylate	Dicamba	Methyl parathion	Simazine
Carbaryl	Dimethoate	Metolachlor	Tebuthiuron
Carbofuran	Disulfoton	Metribuzin	Terbufos
Chlorothalonil	Eptc	Molinate	Trifluralin
Chlorpyrifos	Ethalfluralin	Napropamide	

Note: Detection limit for quantitative GC/MS compounds is 0.005 µg/L

Table B.30 Phenols and their Quantitation Limits (EPA Method 604) (µg/L)

4-Chloro-3-methylphenol	5.0	2-Nitrophenol	5.0
2-chlorophenol	5.0	4-nitrophenol	5.0
2,4-dichlorophenol	5.0	Pentachlorophenol	5.0
2,4-dimethylphenol	5.0	Phenol	5.0
2,4-dinitrophenol	5.0	2,4,6-trichlorophenol	5.0
2-Methyl-4,6-dinitrophenol	5.0		

Table B.31 Chlorinated Pesticides and their Quantitation Limits Analyzed by Electron Capture Detection (EPA Method 608) (µg/L)

Alachlor	< 0.08	DDD, pp	< 0.01	Methoxychlor, pp	< 0.05
Aldrin	< 0.01	DDE, op	< 0.02	Mirex	< 0.02
Atrazine	< 1.50	DDE, pp	< 0.01	Trans-nonachlor	< 0.01
BHC-alpha	< 0.01	DDT, op	< 0.02	Oxychlordane	< 0.03
BHC-beta	< 0.01	DDT, pp	< 0.01	Mixed-permethrin	< 0.60
BHC-delta	< 0.01	Dieldrin	< 0.01	Propachlor	< 0.15
BHC-gamma(lindane)	< 0.01	Endosulfan I	< 0.01	Tecnazene	< 0.01
Chlordane, technical	< 0.30	Endosulfan II	< 0.01	Toxaphene	< 1.50
Chlordane-alpha	< 0.01	Endosulfan sulfate	< 0.01	Trifluralin	< 0.02
Chlordane-gamma	< 0.02	Endrin	< 0.01	Arochlor 1016	< 0.50
Chlordene	< 0.01	Endrin andehyde	< 0.01	Arochlor 1221	< 0.50
Chlorneb	< 0.10	Endrin ketone	< 0.02	Arochlor 1232	< 0.50
Chlorobenzilate	< 0.30	Ethazole	< 0.03	Arochlor 1242	< 0.50
Chlorpyrifos	< 0.03	Heptachlor	< 0.01	Arochlor 1248	< 0.50
Chlorothalonil	< 0.01	Heptachlor epoxide	< 0.01	Arochlor 1254	< 0.50
DCPA	< 0.01	Hexachlorobenzene	< 0.01	Arochlor 1260	< 0.50
DDD, op	< 0.03	Malathion	< 0.10	Arochlor 1262	< 0.50

Table B.32 Polycyclic Aromatic Hydrocarbons and their Quantitation Limits (EPA Method 610) (μg/L)

Acenaphthene	<5.0	Chrysene	<5.0
Acenaphthylene	<5.0	Dibenzo(a,h)anthracene	<5.0
Anthracene	<5.0	Fluoranthene	<5.0
Benzo(a)anthracene	<5.0	Fluorene	<5.0
Benzo(a)pyrene	<5.0	Indeno(1,2,3-c,d)pyrene	<5.0
Benzo(b)fluoranthene	<5.0	Naphthalene	<5.0
Benzo(k)fluoranthene	<5.0	Phenanthrene	<5.0
Benzo(g,h,i,)perylene	<5.0	Pyrene	<5.0

Table B.33 Base/Neutral and Acid Organics and their Quantitation Limits (EPA Method 625) (μg/L)

Acenaphthlene	<5.0	Chrysene	<5.0	Hexachlorobenzene	<5.0
Acenaphthylene	<5.0	Di-n-butylphthalate	<5.0	Hexachlorobutadiene	<5.0
Anthracene	<5.0	Di-n-octylphthalate	<5.0	Hexachlorocyclopentadiene	<5.0
Benzo(a)anthracene	<5.0	Dibenzo(a,h)anthracene	<5.0	Hexachloroethane	<5.0
Benzo(a)pyrene	<5.0	1,2-dichlorobenzene	<5.0	Indeno(1,2,3-c,d)pyrene	<5.0
Benzo(b)fluoranthene	<5.0	1,3-dichlorobenzene	<5.0	Isophorone	<5.0
Benzo(g,h,i,)perylene	<5.0	1,4-dichlorobenzene	<5.0	N-nitrosodi-n-propylamine	<10.0
Benzo(k)fluoranthene	<5.0	3,3'-dichlorobenzidine	<10.0	N-nitrosodiphenylamine	<10.0
Bis(2-chloroethoxy)methane	<10.0	2,4-dichlorophenol	<10.0	Naphthalene	<5.0
Bis(2-chloroethyl)ether	<10.0	Diethylphthalate	<5.0	Nitrobenzene	<10.0
Bis(2-chloroisopropyl)ether	<10.0	2,4-dimethylphenol	<5.0	2-nitrophenol	<10.0
Bis(2-ethylhexyl)phthalate	<5.0	Dimethylphthalate	<5.0	4-nitrophenol	<10.0
4-bromophenyl phenyl ether	<5.0	4,6-dinitro-2-methylphenol	<10.0	Pentachlorophenol	<10.0
Butylbenzylphthalate	<5.0	2,4-dinitrophenol	<10.0	Phenanthrene	<10.0
4-chloroanilime	<5.0	2,4-dinitrotoluene	<5.0	Phenol	<10.0
4-chloro-3-methylphenol	<10.0	2,6-dinitrotoluene	<5.0	Pyrene	<5.0
2-chloronaphthalene	<5.0	Fluoranthene	<5.0	1,2,4-trichlorobenzene	<5.0
2-chlorophenol	<10.0	Fluorene	<5.0	2,4,6-trichlorophenol	<10.0
4-chlorophenyl phenyl ether	<5.0				

Table B.34 Analytes with Detection Limits above Acute and/or Chronic Screening Benchmarks*

Chemical	Analytical Method	Detection Limit (µg/L)	Acute Benchmark (µg/L)	Chronic Benchmark (µg/L)
BHC, gamma- (Lindane)	GC/MS Broad Scan	0.1	0.95	0.08
Chlordane	GC/MS Broad Scan	0.1	2.4	0.0043
Chlordane	EPA 608	0.01	2.4	0.0043
Chloropyrifos	GC/MS Broad Scan	0.1	0.083	0.041
Demeton	GC/MS Broad Scan	0.1		0.1
Diazinon	GC/MS Broad Scan	0.1	0.17	0.043
Dieldrin	GC/MS Broad Scan	0.1	0.24	0.056
Endrin	GC/MS Broad Scan	0.1	0.086	0.036
Heptachlor	GC/MS Broad Scan	0.1	0.52	0.0038
Heptachlor	EPA 608	0.01	0.52	0.0038
Malathion	GC/MS Broad Scan	0.1		0.1
Methoxychlor	GC/MS Broad Scan	0.1		0.03
Parathion	GC/MS Broad Scan	0.1	0.065	0.013
4,4'-DDT	GC/MS Broad Scan	0.1	1.1	0.001
Toxaphene	EPA 608	1.5	0.73	0.0002
Anthracene	EPA 610/625	5	13	0.73
Benzo(a)anthracene	EPA 610/625	5	0.49	0.027
Benzo(a)pyrene	EPA 610/625	5	0.24	0.014
4-Bromophenyl Phenyl Ether	EPA 625	5		1.5
2,4-Dinitrophenol	EPA 625	10	62	6.2
Hexachlorobutadiene	EPA 625	5	9	0.93
Hexachlorocyclopentadiene	EPA 625	5	0.7	0.07
2,4,6-Trichlorophenol	EPA 625	10	32	3.2
PCBs	EPA 608	0.5		0.014

*The sources of actue and chronic benchmarks are EPA NAWQC (primary source) and EPA Tier II (secondary source). If neither of these sources had benchmarks, then EPA Region 4 benchmarks were used.

Table B.35 SPMD PCBs Analyzed by Modified EPA Method 8082*

PCB 8	PCB 105
PCB 18	PCB 138
PCB 28	PCB 126
PCB 52	PCB 187
PCB 44	PCB 128
PCB 66	PCB 180
PCB 101	PCB 170
PCB 77	PCB 195
PCB 118	PCB 206
PCB 153	PCB 209

*Note: Detection limit=0.025 ng/L

Table B.36 SPMD Chlorinated Pesticides analyzed by Modified EPA Method 8081A*

alpha BHC	beta Endosulfan
beta BHC	Endosulfan sulfate
gamma-BHC (lindane)	Endrin
delta BHC	Endrin aldehyde
Hexachlorobenzene	Endrin ketone
Heptachlor	Methoxychlor
Heptachlor epoxide	Mirex
alpha Chlordane	4,4'-DDT
gamma Chlordane	4,4'-DDD
trans-Nonachlor	4,4'-DDE
Aldrin	2,4'-DDT
Dieldrin	2,4'-DDD
alpha Endosulfan	2,4'-DDE

*Note: Detection limit=0.025 ng/L

Table B.37 SPMD PAHs Analyzed by Modified EPA Method 8270C*

Napthalene	1-Methylphenanthrene
2-Methylnapthalene	C1 - Phenanthrenes/Anthracenes
1-Methylnapthalene	C2 - Phenanthrenes/Anthracenes
Biphenyl	C3 - Phenanthrenes/Anthracenes
2,6-Dimethylnapthylene	C4 - Phenanthrenes/Anthracenes
Acenapthylene	Fluoranthrene
Acenapthene	Pyrene
Dibenzofuran	C1 - Fluoranthenes/Pyrenes
2,3,5-Trimethylnapthalene	Retene
C1 - Napthalenes	Benz[a]anthracene
C2 - Napthalenes	Chrysene
C3 - Napthalenes	C1 - Chrysenes
C4 - Napthalenes	C2 - Chrysenes
Fluorene	C3 - Chrysenes
1-Methylfluorene	C4 - Chrysenes
C1 - Fluorenes	Benzo[b]fluoranthene
C2 - Fluorenes	Benzo[k]fluoranthene
C3 - Fluorenes	Benzo[e]pyrene
Dibenzothiophene	Benzo[a]pyrene
C1 - Dibenzothiophenes	Perylene
C2 - Dibenzothiophene	Indeno[1,2,3-c,d]perylene
C3 - Dibenzothiophene	Dibenz[a,h]anthracene
Phenanthrene	benzo[g,h,i]perylene
Anthracene	Coronene

*Note: Detection limit=0.025 ng/L

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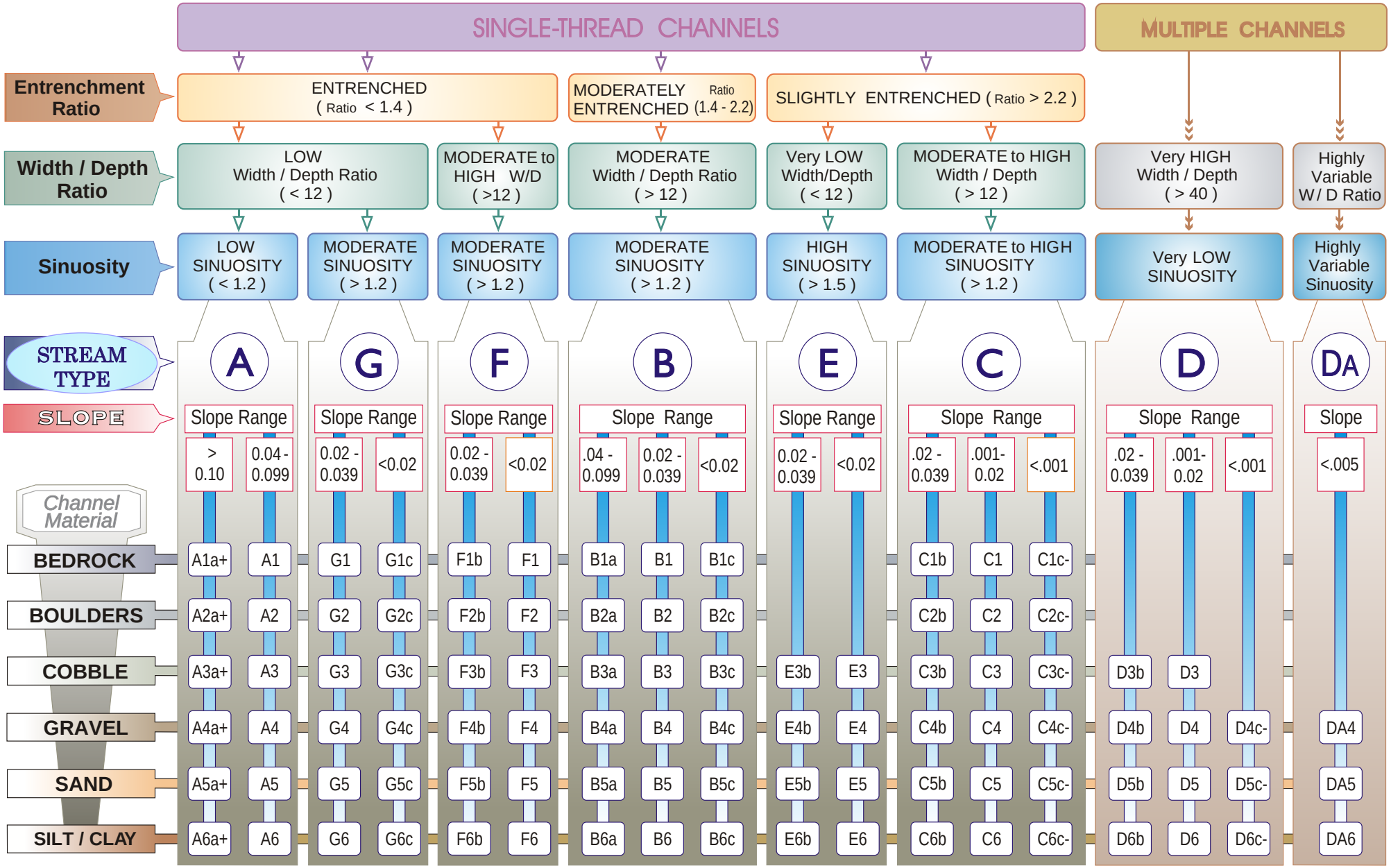
The Key to the Rosgen Classification of Natural Rivers



KEY to the *ROSGEN* CLASSIFICATION of NATURAL RIVERS.

As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

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Appendix D

Intermediate and High Risk UST Incidents

Intermediate and High Risk Underground Storage Tank Incidents, Little Creek Study Area

Incident Number*	Date Occurred	Site Name and Address	Priority	Contamination	Summary
21868	11/30/99	The Pantry # 3089 1501 E Franklin Street Chapel Hill	I	Groundwater	Free product detected in groundwater in 1999. Intermediate risk ranking will likely change to low risk when next monitoring report is received, as sampling events conducted between 1999 and present and have shown no free product. Absence of free product for over a year would allow site to be ranked as low risk and allow closure of site.
23586	5/12/00	Residence 106 Windsor Circle Chapel Hill	H	Soil	Site is ranked high risk due to location of one water supply well within 1000 feet of contamination. Level of contamination presently under investigation.
26022	5/13/02	Residence 3712 Ginger Road Chapel Hill	H	Soil and Groundwater	Site ranked high risk due to presence of two water supply wells within 1000 feet of contamination. Limited Site Assessment (LSA) report shows groundwater contamination above NC groundwater quality standards (15A NCAC 2L) and soil at NC residential maximum contaminant concentration level. Soil and groundwater contamination levels considered moderate. Cleanup standards remain stringent due to continued well use. Upcoming Comprehensive Site Assessment Report (CSA) will define extent of contamination
26040	1/3/01	UNC Morehead Planetarium 222 E Franklin Street Chapel Hill	H	Soil and groundwater	Site ranked High risk due to presence of three water supply wells within 1000 feet of contamination source. Wells used for irrigation only. Groundwater contamination is above NC groundwater quality standards (15A NCAC 2L). Some soil contamination will likely be excavated and disposed of. However, some of the soil contamination is beneath the building foundation. Contaminant levels for both soil and groundwater considered moderate, but because wells will remain operative, site will remain high risk and clean up levels will remain more stringent.

10045	1/29/92	Amoco # 228 Eastgate Shopping Center Franklin Street Chapel Hill	I	Soil and groundwater	Site ranked Intermediate risk due presence of free product. High levels of groundwater contamination. Groundwater sampling conducted in February 2000 detected benzene, ethylbenzene, xylenes, MTBE and lead above NC groundwater quality standards (15A NCAC 2L). See Section 2 of main text for additional details.
18629	3/18/98	Sunrise Biscuit Kitchen 1305 E Franklin Street Chapel Hill	I	Soil and Groundwater	Site is of particular concern due to location within 100 feet of Bolin Creek. Groundwater sampling conducted in 1998 detected benzene, ethylbenzene and xylenes above NC groundwater standards (15A NCAC 2L). Site considered "stagnant" because responsible party not responding to notices requesting work be conducted. See Section 2 of main text for additional details.
14054	11/21/94	UNC-CH Service Station 109 Airport Drive Chapel Hill	I	Groundwater	Groundwater samples collected in February 1999 indicate benzene, diisopropyl ether, ethylene, benzene and MTBE above NC groundwater quality standards (15A NCAC 2L). Two monitoring wells not sampled due to presence of free product in wells.
22628	3/31/98	Run-In-Jims 800 Airport Road Chapel Hill	I	Soil and groundwater	Contamination considered moderate, ranked Intermediate due to location within 25 feet of Bolin Creek. Monitoring at closure indicated one petroleum type contaminant (C11-C22 aromatic hydrocarbon class) exceeding NC groundwater quality standard (15A NCAC 2L).
16584	4/1/96	Residence 202 E Poplar Ave. Carrboro	H	Soil and groundwater	Ranked high risk due to location of water supply well within 1250' of site.
22712	10/5/00	Orange Plumbing 307 E Main St. Carrboro	H	Groundwater	Site ranked high risk due to location of six private wells within 1500 feet of contamination source. Tanbark Branch within 700 feet of contamination source. Soil TPHs exceeded state's groundwater quality standard (15A NCAC 2L).

*See Figure D.1
I = Intermediate Risk, H = High Risk
Source: NC Division of Waste Management

Figure D.1

Little Creek Study Area - High & Intermediate Priority UST Incidents

LEGEND

- Study Area
- Hydrography
- Major Roads
- County Boundary
- × UST Incident

State Vicinity Map

County Vicinity Map

SCALE 1:85,000

0 1 2 MILES

Map Produced by the N.C. Center for Geographic Information and Analysis