Assessment Report: Biological Impairment in the Little Troublesome Creek Watershed

Cape Fear River Basin
Rockingham County, N.C.

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Executive Summary

Introduction

This report presents the results of the Little Troublesome 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 Troublesome Creek is considered impaired by the DWQ because it is unable to sustain an acceptable community of aquatic organisms, indicating that the stream does not fully support its designated uses. The goal of the assessment is to provide the foundation for future water quality restoration activities in the Little Troublesome 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

Little Troublesome Creek is located in Rockingham County, in subbasin 03-06-01 of the Cape Fear River Basin (see figure in Section 1). From its headwaters within the City of Reidsville, the stream flows southward for approximately seven miles, joining the Haw River near Williamsburg, NC. The upper half of the 12.6 square mile watershed lies within Reidsville, where a mixture of residential, commercial and industrial uses predominate. The lower half of the watershed is less developed, with significant agricultural and residential uses. As of 1993, impervious surfaces covered approximately 12% of the watershed, with higher levels (21%) evident within the Reidsville limits than elsewhere (3.7%). Many past water quality concerns centered upon the Reidsville wastewater treatment plant discharge, which was relocated to the Haw River in 1998. Primarily in the first half of the twentieth century, the lower third and upper third of Little Troublesome Creek were channelized (dredged and straightened) to improve agricultural drainage and facilitate urban infrastructure. The watershed is described further in Section 2.

Benthic macroinvertebrate communities are impaired throughout the mainstem of Little Troublesome Creek. Habitat is generally poor. The stream bed is comprised largely of unstable sand deposits and bank erosion is common.

Approach

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

Conclusions

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

1. Widespread habitat degradation, manifested by extensive sedimentation and instability, is a primary cause of the impaired biological conditions throughout the watershed. This habitat degradation is due to a combination of factors that have been at work for a number of decades: a) the direct effects of channelization (channel dredging and straightening); b) subsequent stream channel instability due to gradual morphological adjustment to channelized conditions; and c) changes in watershed hydrology following increased development in the upper watershed.
2. Organic enrichment (organic loading and nutrients) is an important stressor to the benthic community at a number of locations and is considered an additional cause of impairment. Likely sources include storm inputs and sanitary sewer infiltration in the upper watershed. Lower than average streamflows experienced during the period of the study may have exacerbated these impacts.
3. Toxicity from nonpoint sources is also an additional source of impairment. Specific toxicants and their sources have not been clearly identified, although the most likely source area is the more developed upper half of the watershed.

Recommendations

The most important factors leading to impairment in the study area are systemic in nature. Addressing these problems will require actions that are similarly broad in scope. Mitigating the potential impacts of future watershed development on watershed hydrology is also critical, or improvements resulting from efforts to control current sources of impairment may be short lived.

The following actions are necessary to address current sources of impairment in Little Troublesome Creek and prevent future degradation (see Section 8 for additional details). The intent of these recommendations is to describe the types of actions necessary to improve conditions in Little Troublesome Creek, not to specify particular administrative or institutional mechanisms for implementing remedial practices. Actions one through six are all essential to the restoration of aquatic communities throughout the Little Troublesome Creek study area. Actions seven through nine are important in order to protect streams in the watershed from the impacts of new development. The remaining actions would also be useful to improve water quality but will result in limited improvement unless the first six are also accomplished.

1. **Over the long run, extensive stream channel restoration activities and stormwater retrofit BMPs should be implemented in much of the watershed in order to improve aquatic habitat**. This will involve a substantial effort that would likely take several decades to fully implement:
   a) Much of Little Troublesome Creek, as well as a few tributary channels, should be restored to a stable morphology.
   b) BMPs to reduce stormwater runoff volume and partially restore watershed hydrology should be implemented in the existing developed areas of the Little Troublesome headwaters, the tributary draining portions of downtown Reidsville, and other areas of dense development, such as the existing industrial park.
2. **These activities should be implemented deliberately and incrementally over time**.
   a) Work should be carried out first in tributary and headwaters subwatersheds. Restoration of the mainstem of Little Troublesome Creek should be approached later when upstream sediment sources have been reduced and upstream hydrologic conditions have been mitigated to the extent practical.

b) Channel restoration and stormwater BMPs must be implemented in an integrated fashion so that both channel morphology and watershed hydrology problems are addressed using a coordinated approach in each subwatershed.
c) Local governments and other stakeholders must develop the cooperative organizational framework necessary to carry out the watershed planning, project design, implementation and monitoring activities that will be necessary to sustain this effort over time.
d) Since it is difficult for restored stream channels to maintain stability and proper sediment transport in the presence of active beaver impoundments, a strategy for managing beaver impacts should be developed in conjunction with detailed restoration plans.

3. **The eight square mile subwatershed consisting of Little Troublesome Creek above NC 87 should serve as the focus for initial planning and project activities**. Costs are likely to exceed $1 Million per square mile of watershed. Activities should include:
   a) Developing specific plans for three distinct subareas: the downtown tributary watershed, where the most concentrated commercial land use is located; the Little Troublesome Creek headwaters above the tributary confluence; and the area between the tributary confluence and NC 87, which drains industrial areas on the south side of Reidsville.
   b) Implementing appropriate retrofit opportunities to control runoff volume and velocities from existing developed areas in each of these three catchments. The selection of specific BMP types and locations will require additional planning and site specific engineering evaluations.
   c) Restoring the mainstem of the creek to a stable morphology from Richardson Drive to the confluence with the downtown tributary.
   d) Further evaluating the necessity for restoration of the creek from the tributary confluence down to NC 87. Much of this section has progressed further towards a stable state than the other channelized portions of the stream and can potentially be left to stabilize naturally without imposing a substantial sediment load on downstream reaches.
   e) Evaluating and implementing channel restoration opportunities on tributaries.
   f) Encouraging property owners along all streams to replant native riparian vegetation.
4. **The headcut in Little Troublesome Creek downstream of SR 2598 should be stabilized as soon as practicable**. Although restoration of the stream channel in this area is probably not appropriate until upstream issues have been addressed, stabilization of the headcut is advisable in the short run to prevent its continued migration upstream. Further migration of the headcut would serve as a continuing source of sediment and make eventual restoration more costly.
5. **Actions recommended above and activities already planned to address other problems or regulatory requirements are likely to reduce organic and nutrient loading** to some extent, perhaps substantially. These include: stormwater retrofits intended to control stormwater volumes and velocities; activities undertaken to address fecal coliform sources under the recently developed TMDL; Reidsville's actions under the new collection systems permit to assess the condition of its sanitary sewer system. **Local and state agencies should be encouraged to give these activities a high priority**. Periodic biological monitoring should be undertaken to evaluate whether indicators of organic enrichment decline and whether further action is necessary.
6. **Additional data should be obtained to more narrowly define the nature and source of toxicants impacting Little Troublesome Creek and the downtown tributary**. Planned or recommended activities (e.g., BMPs intended to control stormwater volumes or fecal coliform TMDL implementation efforts) may reduce toxicant inputs to some degree.

Additional pollution control efforts may well be necessary. Some source control measures (such as enhanced practices at industrial facilities and municipal operations facilities) would be relatively easy to implement in the short-term and should be an important component of a toxics strategy. Other BMPs (such as structural stormwater treatment practices) will be difficult to plan or implement efficiently without further information. Periodic monitoring should be carried out to determine if ongoing activities lead to improvements in the benthic community.

7. Post-construction stormwater management should be required for all new development in the watershed in order to prevent further channel erosion and continued habitat degradation due to additional uncontrolled stormwater inputs. These requirements are more likely to be effective if they include the active promotion of infiltration practices and other approaches to limit stormwater volume, and extended detention of the 1-year 24-hour storm, or alternative criteria to address geomorphically relevant flows.
8. Whether accomplished through incentives or regulatory means it is important that existing riparian buffers be protected.
9. Effective enforcement of sediment and erosion control regulations on the part of the Division of Land Resources will be essential to the prevention of additional sediment inputs from construction activities. Development of improved erosion and sediment control practices may be beneficial.
10. An area of active channel erosion in the tributary draining the Equity Drive area on the east side of Reidsville should be stabilized. Controlling industrial stormwater runoff is a necessary first step in this process.
11. A watershed education program should be developed and implemented with the goal of targeting homeowners and managers of commercial and industrial facilities in order to reduce current stream damage and prevent future degradation. At a minimum, the program should include elements to address the following issues:
    a) redirecting downspouts to pervious areas rather than routing these flows to driveways or gutters;
    b) protecting existing wooded riparian areas on ephemeral streams;
    c) replanting native riparian vegetation on perennial, intermittent and ephemeral channels where such vegetation is absent; and
    d) reducing and properly managing pesticide and fertilizer use.

Section 1
Introduction

This report presents the results of the Little Troublesome 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 Troublesome Creek is considered impaired by the DWQ because it is unable to support an acceptable community of aquatic organisms. The reasons for this condition, especially upstream of the former Reidsville wastewater outfall, 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 Troublesome Creek is located in Rockingham County, in subbasin 03-06-01 of the Cape Fear River Basin (Figure 1.1). From its headwaters within the City of Reidsville, the stream flows southward before joining the Haw River near Williamsburg, NC. The area under current study consists of the entire Little Troublesome Creek watershed (hydrologic unit 03030002010030). Little Troublesome Creek has a length of seven miles and a drainage area of 12.6 square miles. About 52% of the drainage area is within the city limits of Reidsville, while the remainder is suburban and rural.

1.2 Study Purpose

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

1. Identifying the most likely *causes* of biological impairment (such as degraded habitat or specific pollutants).
2. Identifying the major watershed activities and *sources* of pollution contributing to those causes (such as stream bank erosion or stormwater runoff from particular urban or rural areas).
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 Troublesome 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, we have taken a more detailed approach in order to maximize the opportunity to reliably and defensibly identify causes and sources of impairment within the time and resource framework of the project. This provides a firmer scientific foundation for the collection and evaluation of evidence, facilitates the prioritization of problems for management, and offers a more robust basis for the commitment of resources. EPA's recently published guidance for stressor identification envisions that causes of impairment be evaluated in as rigorous a fashion as is practicable (USEPA, 2000).

1.3.1 Study Approach

The general conceptual approach used to determine causes of impairment in Little Troublesome 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. In order to address all three objectives, activities conducted in the Little Troublesome Creek watershed during this study were divided into three broad stages (Figure 1.2):

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

1.3.2 Approach to Management Recommendations

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

Protection of streams from additional damage due to future watershed development or other planned activities is a critical consideration. In the absence of such protection, efforts to restore water quality by mitigating existing impacts will often be ineffective or have only a temporary impact. These issues were examined during the course of the study and addressed in the management recommendations.

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

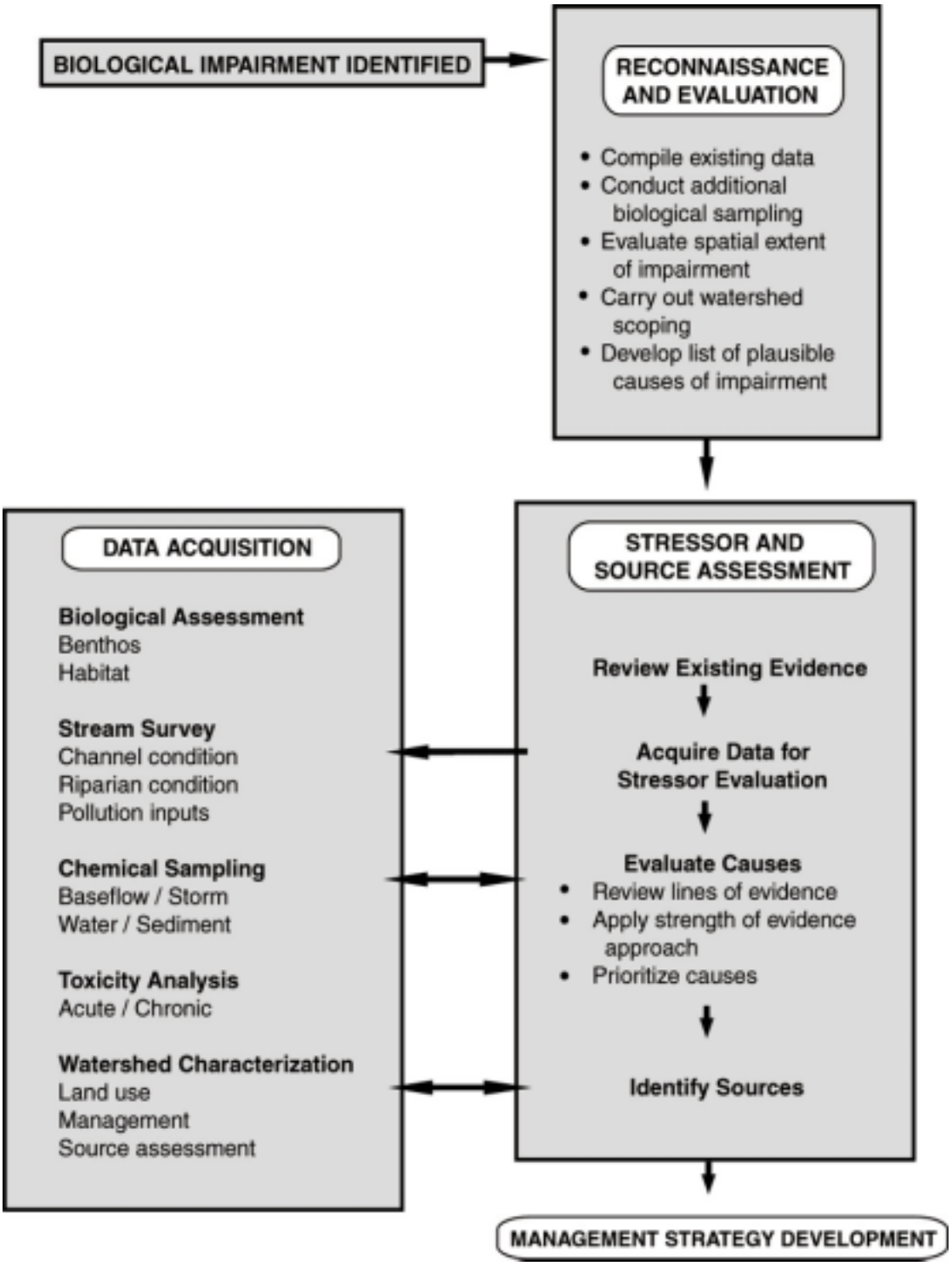
The study did not develop TMDLs (total maximum daily loads) or establish pollutant loading targets. For many types of problems (e.g., most types of habitat degradation), TMDLs may not be an appropriate mechanism for initiating water quality improvement. Where specific pollutants are identified as causes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

1.3.3 Data Acquisition

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

1. Macroinvertebrate sampling;
2. Assessment of stream habitat, morphology, and riparian zone condition;
3. Stream surveys--walking stream channels to identify potential pollution inputs and obtain a broad scale perspective on channel condition;
4. Chemical sampling of stream water quality;
5. Bioassays to assess water column toxicity;
6. Chemical analyses and bioassays of stream sediment; and
7. Watershed characterization--evaluation of watershed hydrologic conditions, land use, land management activities, and potential pollution sources.

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 bugs visible to the naked eye). While standard biological sampling can determine whether a stream is supporting aquatic life or is impaired, the cause of impairment can only be determined with additional investigation. In some cases, a potential cause of impairment is noted when a stream is placed on the 303(d) list, using the best information available at that time. These noted potential causes are generally uncertain, especially when nonpoint source pollution issues are involved.

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

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

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

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

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

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

Section 2
Description of the Little Troublesome Creek Watershed

2.1 Introduction

The study area (Figure 1.1) consists of Little Troublesome Creek and its tributaries from its source to its confluence with the Haw River. Little Troublesome Creek has a length of seven miles and a drainage area of 12.6 square miles (32 square kilometers). About 52% of the Little Troublesome Creek drainage area is within the city limits of Reidsville; coincidentally about 50% of Reidsville's area (2000 population 14,485) is within the Little Troublesome Creek drainage, with the remainder draining to the Dan River. This section summarizes watershed hydrography and topography, describes current and historical land use, and discusses potential pollutant sources.

2.2 Streams

The watershed is relatively narrow, and the mainstem of Little Troublesome Creek is joined only by small, unnamed tributaries. The largest of these drains a 0.9 square mile portion of the older section of Reidsville, including part of the downtown area, flowing south to join the mainstem downstream of Scales Street. No significant man-made impoundments are present on the mainstem of Little Troublesome Creek, although many farm ponds (one to ten acres) and a few small stormwater detention ponds (0.1 to one acre) are present on headwater tributaries. Beaver impoundments are present at various locations on the mainstem (Figure 2.1), and appear to be increasing in number.

Little Troublesome Creek is classified by the State of North Carolina as C, NSW (nutrient sensitive waters). The NSW classification applies to all streams in the watershed of Jordan Lake.

North Carolina's 2000 303(d) List records Little Troublesome Creek as biologically impaired for its entire length. The reasons for biological impairment had not been determined prior to the study, although the Reidsville wastewater discharge was believed to contribute to impairment in the lower portion of the stream prior to November 1998, when the discharge was relocated to the Haw River.

Much of Little Troublesome Creek was channelized during the 1900s. Channelization involved straightening, deepening and widening the stream, and was a fairly common practice in the Piedmont. While no written documentation of the channelization could be located in NRCS files (Natural Resource Conservation Service) or elsewhere, visual examination of the stream (Section 6) indicated that the channelized areas extend from the mouth of the creek to about one half mile below SR 2598, and from about one half mile above NC 87 to Richardson Drive in Reidsville. According to Mr. Robert Carter, historian at the Rockingham County Library in Wentworth, rural reaches of the stream were channelized early in the 20th century in order to drain the flat bottomlands for the benefit of agriculture and to reduce malarial mosquito habitat. Before channelization, farmers could not cultivate the bottomlands due to flooding and drainage

problems. These problems had increased due to massive sedimentation caused by clearing and plowing the uplands in the watershed.

In urban settings such as Reidsville, the motivation for channelization was primarily to allow for straight rights-of-way for streets, railroads, sewer lines and water lines. Aerial photographs of the Reidsville area indicated that the channelization of the mainstem of Little Troublesome Creek upstream of Scales Street occurred after 1955. For the other parts of the stream, examination of these photos was inconclusive, but pointed toward channelization before 1938, the date of the earliest aerial photos available.

2.3 Topography and Geology

The headwaters of Little Troublesome Creek are just south of NC 65/87 and West Morehead Street in Reidsville, at an elevation of about 825 feet above mean seal level. Topography is typical Piedmont rolling hills, highly dissected by stream drainages. The underlying geology in the drainage area is biotite gneiss and schist of the Milton Belt; soils are sandy and very erodable. The upper portion of the stream, upstream of the Reidsville wastewater treatment plant, has a stream gradient of approximately 29 feet per mile. The gradient is only 9 feet per mile in the middle and lower portions of the stream.

Precipitation at the Piedmont Triad International Airport (PTIA) in Greensboro averages 42.3 inches (1074 millimeters) per year (1933-2001 period of record), with a fairly even distribution among months. Precipitation during much of the study period was below normal, with only 27.3 inches recorded during 2001. Precipitation levels during 2000 were near normal (38.6 inches for the year as a whole), although ten inches of rain fell during September and most other months were significantly drier than average. The Southeast Regional Climate Center reported a 20-inch precipitation deficit at the PTIA from October 2000 to March 2002 (http://water.dnr.state.sc.us/climate).

There is no stream gage in the watershed. Stream discharge in this area averages 0.9 cubic feet per second (cfs) per square mile on an annual basis, and streams are less prone to become dry during drought conditions, compared to streams in many other portions of the North Carolina Piedmont (Geise and Mason, 1991). Drainage areas of one square mile or less in this part of the state are generally sufficient to support 7Q10 flows greater than zero (Geise and Mason, 1991). Observations after moderate storm events indicated that the stream rises and falls (by two to four feet) fairly quickly in the upper, more urbanized, portion of Little Troublesome Creek. Storm impacts on stream stage were more moderate in the lower half of the study area. The lower gradient of the middle section of the stream, along with the beaver dams in this section, allows high flows to spread laterally and slow their velocity. Data from a nearby stream gage (Reedy Fork at Oak Ridge, near Greensboro) indicate flows averaging 67% of normal during 2001.

Soils that make up the riparian zones (parallel and adjacent) of the mainstem and small tributaries of Little Troublesome Creek are poorly to moderately drained, and fine sandy loam in texture. These soils, from the Chewacla, Congaree and Wehadkee Series, are nearly level, floodplain soils formed in recent acidic alluvium. For the most part, the riparian zones, as defined by the soil type, are no greater than 200 feet in width with many stream stretches bordered by more narrow zones. Soils that make up the balance of the watershed area are acidic,

deep, well-drained upland type sandy clays and clay loam located on moderately steep ridgetops and sideslopes. These upland soils are in the Hiwassee-Cecil Association (Sherrill, 1992).

2.4 Land Use in the Watershed

Starting in the mid-1800s, the entire area was cleared of trees and then intensively farmed for tobacco, corn and small grains. Significant erosion of topsoils occurred, especially on the steeper topography. Subsequent planting of pine trees on these gullied slopes, along with natural reversion of old fields to forestland, has reduced the loss of soil to the streams. Much of the soil eroded from hillsides was deposited in the floodplains of streams like Little Troublesome Creek (Jurney and Davis, 1926), and these floodplains or bottomlands are now quite favorable sites for pasture. Textile manufacturing and tobacco warehousing and manufacturing were introduced into the Reidsville area around 1900 (Butler, 1982) and were a significant part of the area's industrial base through much of the 20th Century.

Current land use in the watershed is a mixture of urban and built-up areas, pastureland, forestland and cultivated cropland (Figure 2.2). The lower portion of the study area has substantial forest, pastureland and cropland. The distribution of land cover within the Little Troublesome Creek watershed, estimated from 1992 satellite imagery as part of the USGS National Land Cover Data, is shown in Table 2.1. Notable aspects of land use in the study area include:

- Development (residential, commercial and industrial areas) is significant, accounting for 28% of the land use. Development is concentrated in the upper half of the drainage area.
- Agriculture (pasture/hay and row crops) accounts for 21% of the area, concentrated in the lower half of the drainage area.
- Forest and wetlands account for 49% of the total area.

As of 1993, impervious surfaces (areas such as rooftops, roads and parking lots that prevent infiltration of precipitation into the soil) covered approximately 12% of the watershed, with higher levels (21%) evident within the Reidsville limits than elsewhere in the watershed (3.7%). The highest level of imperviousness (35%) occurs in the tributary watershed draining downtown. (Impervious area estimated by Tetra Tech, Inc. from 1993 aerial photography and other data. See Appendix C for additional information.)

In the upper drainage, imperviousness has reached the approximate levels where severe impacts to stream biota can be expected (Schueler, 1994). Stormwater management practices (e.g., retention ponds or infiltration practices), which could slow the rate of storm runoff from these impervious areas, have been employed at some of the more recent commercial development projects in the Little Troublesome Creek drainage (see Section 2.7).

Table 2.1 Land Use in the Little Troublesome Creek Watershed—1992

Land Use Category	Square Miles	% of Area
Open Water	0.06	0.5
Low Intensity Residential	2.1	16.4
High Intensity Residential	0.4	3.2
Commercial/Industrial	1.0	8.3
Bare Rock/Sand/Clay	0.02	0.2
Forest	6.0	47.7
Pasture/Hay	0.8	6.4
Row Crops	1.8	14.2
Other (Managed) Grasses	0.2	1.9
Wetlands	0.1	1.2
TOTAL	12.6	100.0

Source: USGS National Land Cover Data (based on 1992 imagery). See Appendix C.

2.5 Sources of Pollution

2.5.1 Point Sources

Wastewater Discharges. Until November 1998, the City of Reidsville's municipal wastewater treatment plant (NPDES Permit No. NC0024881) discharged treated wastewater into the mainstem of Little Troublesome Creek upstream of NC 87 (Freeway Drive). At this time, the discharge was relocated to the Haw River, just downstream of NC 150, thus bypassing Little Troublesome Creek. The facility is now permitted to discharge treated effluent to Little Troublesome Creek only during emergency situations, such as power failure or failure of the discharge line leading to the Haw River outfall. One such incident was reported during 2000 and 2001. A pipe rupture on June 23 and 24, 2001 resulted in the discharge of 4.02 million gallons of treated effluent to Little Troublesome Creek.

The WWTP is permitted to discharge up to a monthly average of 7.50 million gallons per day (MGD) of treated wastewater, and currently receives up to 2.88 MGD of pretreated industrial wastewater (38% of total flow). The 12 contributing industrial facilities represent diverse operations: four are metals finishing; three are rubber and plastics; two are textiles; one is canmaking; one is cigarette manufacturing; and one is food processing. This facility treats domestic and industrial wastewaters from the entire City of Reidsville, although only about half of the city is within the watershed.

Sand Dredging. Upstream of Mizpah Church Road, a small sand mining site was observed during a stream survey (Section 6). This operation disturbs less than one acre of stream, and thus, does not require permitting. Operators typically use dragline dredges at such sites to extract sand for use as a building material. When in active operation, these dredges increase

turbidity--and potentially mobilize pollutants attached to clay and silt particles--in the local area and for some distance downstream.

2.5.2 Nonpoint Sources

In the upper drainage, the full range of urban activities and pollution sources are of potential concern: roads, parking lots, rooftops, lawns, industrial areas, construction sites, etc. The list of pollutants which have been documented to increase with urbanization includes oils, antifreeze, tars, soaps, fertilizers, pesticides, solvents and salts (e.g., Bales et al., 1999; Burton and Pitt, 2001). Potential sources of pollution in the study area are discussed below.

Construction. Commercial, institutional and residential development has occurred in the watershed over the past decade, especially in Reidsville, although few large construction projects were evident during the period of the study. Major areas of construction activity included:

- Shopping centers and small commercial sites along US 29A on the west side of Reidsville.
- Initial phases of construction for the Reidsville Technology and Industrial Park located north of NC 87 bypass on the southwest side of Reidsville (Figure 2.3).
- The widening of portions of Barnes Street in Reidsville, south of Turner Drive.

Erosion and sediment control measures are commonly observed at construction sites throughout the watershed. While these structures and practices, where appropriately constructed and maintained, can significantly reduce the amount of sediment that would otherwise reach nearby streams during the course of construction, actual practices are often not adequate to prevent stream impacts. During this project, extensive sediment impacts were not observed, although rainfall during the study period was well below average, as noted earlier.

Industrial Stormwater. Seven industrial facilities, all located within the Reidsville corporate limits, have active stormwater permits in the watershed, all but two operating under general permits (see Table 2.2 and Figure 2.3). The general stormwater permits under which most of these facilities operate provide some measure of water quality protection, but do not require water quantity controls. Several other large industrial facilities are located in the study area which are not required to have stormwater permits. These unpermitted facilities also have large roof areas and large paved parking lots which would add to surface runoff during storms.

Reidsville requires BMPs to control the quantity and timing of stormwater for new development that exceeds 10,000 square feet of impervious area (see Section 2.7). Most existing development predates this requirement, however, and lacks such practices.

Commercial and Residential Stormwater. Commercial and residential areas constitute over 20% of the study area. As is the case with industrial areas, stormwater BMPs are required for newly constructed commercial development and residential subdivisions which create more than 10,000 square feet of impervious area. Stormwater ponds, infiltration areas and other practices are rarely observed in existing housing developments, warehouses and other large areas of impervious surfaces. Some newer shopping centers do have stormwater ponds. Most of these areas, especially in the upper watershed, are served by storm sewers. Given the overall level of

imperviousness in the upper watershed, hydrologic impacts on Little Troublesome Creek and its tributaries are likely, as are increased inputs of stormborne pollutants.

Table 2.2 Stormwater Permits, Little Troublesome Creek Watershed

General Stormwater Permits			
Permit No.	**Facility**	**Industry**	**Stream**
NCG060101	Boehme Filatex Inc.	Food Processing	UT to Little Troublesome Ck.
NCG030295	Ball Metal Beverage Container Corp.	Metal Fabrication	UT to Little Troublesome Ck.
NCG060007	Equity Group—NC Division	Food Processing	UT to Little Troublesome Ck.
NCG170176	Unifi, Inc.—Reidsville	Textiles	Reidsville MSSS to Little Troublesome Creek
NCG050242	Zarn Inc.—Southeast Industries (Ensley Corp.)	Plastics	Reidsville MSSS to Little Troublesome Creek
Individual Stormwater Permits			
Permit No.	**Facility**	**Industry**	**Stream**
NCS000030	Air Products and Chemicals, Inc.	Chemicals	UT to Little Troublesome Ck.
NCS000085	Safety Kleen (TS)	Refuse Systems	UT to Little Troublesome Ck.

Agriculture. Although agricultural activity is declining in the study area, it continues to be important in the lower part of the watershed. Land cover data from 1992 (Table 2.1) indicated approximately 1150 acres of row crops and 500 acres in pasture and hay. Current row crop acreage is estimated to be about one-fourth of the 1992 level, while pasture/hay acreage is approximately unchanged (personal communication, 2002, John Timmons, NRCS Rockingham County). Hay, tobacco, wheat, soybeans and corn are the primary crops cultivated. Conservation practices such as field borders and low tillage approaches are commonly used, and cropland does not appear to be a major source of sediment to Little Troublesome Creek.

There are no confined animal operations within the study area. Livestock populations within the Little Troublesome Creek drainage area have been estimated as follows: 275 beef cattle; 50 horses; 12 sheep; and 100 ostrich (NCDWQ, 2002).

As part of the NC Division of Soil and Water Conservation's Agricultural Sediment Initiative, the Rockingham Soil and Water Conservation District recently evaluated potential sediment impacts from the county's agricultural areas. Significant sources of agricultural sediment were not identified in the Little Troublesome Creek watershed, although some problem areas were identified in the neighboring Troublesome Creek drainage.

Underground storage tanks (USTs). UST incident information from the NC Division of Waste Management's database was reviewed, and Regional UST staff and Rockingham County Health Department personnel were contacted in order to evaluate the extent of contamination associated with leaking USTs and the potential for surface water discharge. Over the past ten years, USTs have been removed and assessments performed at 24 sites within the watershed. These incidents

involved both commercial and non-commercial USTs that contained petroleum products (gasoline, diesel fuel and kerosene) for resale, farm or residential use. Seventeen sites remain active. Most of these are located in the older portions of Reidsville, especially in the area draining to the tributary draining the downtown area. None of the incidents appear to involve a discharge to surface waters.

Other nonpoint sources. Almost the entire upper drainage area is served by Reidsville's sanitary sewer system. Throughout much of the upper drainage, Little Troublesome Creek and its tributaries are paralleled by sewer rights-of-way. Spills of raw sewage (bypasses) can occur at manholes due to blockage of these sewer lines or to overflows caused by stormwater infiltration or mechanical malfunction. For the two-year period from January 2000 through December 2001, eight such spills were reported to DWQ by Reidsville, although none of these occurred within the Little Troublesome Creek watershed. Two spills within the watershed did occur during January 2002, indicating the sporadic and unpredictable nature of these events.

Besides spills or bypasses, the sewage collection system can experience chronic leaks that can result in stream pollution. The age, condition and precise location of many of the system's collection lines are unknown, particularly in older portions of town. Given the age of the system and the types of pipe material in common use in the first half of the 20th century, the potential for leakage is considerable.

The City of Reidsville estimates that there are approximately 500 to 600 septic systems within its boundaries. How many of these are within the Little Troublesome Creek watershed is not known.

2.5.3 Historical Issues

Like many other piedmont streams, Little Troublesome Creek has been subject to sediment inputs and direct channel modification for over 100 years (see the background note "Landscape History and Channel Alteration in the Piedmont Region"). Erosion due to clearing of the uplands for agriculture was so pervasive in the late 1800s and early 1900s that sediment inputs raised the level of the stream bed and increased the frequency of flooding. The fertile bottomlands along Little Troublesome Creek were slow to drain and farmers in these areas could no longer cultivate their fields. It is likely that this sedimentation had a major impact on stream habitat and aquatic life.

This sedimentation was one of the major reasons for the dredging and channelization of stream, discussed earlier. By drastically modifying the channel morphology, this channel modification has had a negative effect on stream habitat that still persists. The indirect effects of channelization can be considerable and are discussed in Section 6 and Appendix D.

2.6 Trends in Land Use and Development

Land use in the watershed has historically been dominated by agriculture, but residential, commercial and industrial development has been important since World War II. Harvested cropland in Rockingham County was estimated as 25,500 acres in 2001 (NC Department of

Agriculture and Consumer Services, Agricultural Statistics Division, at http://www.ncagr.com/stats), compared to estimates of 75,000 acres in 1900 (Butler, 1982). The population of the county totaled almost 92,000 in 2000, or 162 per square mile, slightly lower than the statewide average of 165 per square mile (US Census Bureau, at http://quickfacts.census.gov). Reidsville's 2000 population was 14,485 (US Census Bureau, at http://www.ci.reidsville.nc.us).

Recent population growth has been relatively low in Rockingham County, increasing by only 6.8% between 1990 and 2000 compared to a 21.4% increase for the state as a whole (US Census Bureau, at http://quickfacts.census.gov). Reidsville's population grew by18% during the same decade. This was due primarily to the annexation of already developed areas. The Reidsville Planning Department estimates that the 1990-2000 growth rate without annexation was less than 5% (Michael Pearce, personal communication). The population of the Little Troublesome Creek watershed has declined in recent years, dropping from 7996 in 1990 to 7780 in 2000 (Source: Piedmont Triad Council of Governments). The US 29 and 29A corridors, north from Greensboro, have experienced development of commercial and light industrial facilities in recent years, and that trend is expected to continue into the foreseeable future. Residential development, both high density (apartment/condominium) and low density, will also expand to occupy currently undeveloped land.

2.7 Regulatory Issues and Local Water Quality Activities

Local ordinances. Rockingham County and Reidsville have floodplain ordinances. Floodplain construction is not prohibited, but the finished floor of structures must be two feet above the level of the 100-year flood.

Reidsville currently has in place stormwater requirements for new development, originally passed in 1995. Nonagricultural building activities that result in the creation of either 10,000 new square feet of impervious area or 50% imperviousness require the development of a drainage plan approved by the city. Detention of stormwater runoff is required to maintain flows at predevelopment levels for the ten-year storm. The stormwater detention requirement can be waived for developments with new impervious area of less than 20,000 square feet if a state-registered professional engineer certifies that there will be no adverse impacts on downstream properties. The stormwater requirement is most commonly met using dry detention basins. While the city's stormwater and drainage requirements may result in some water quality benefits, it is likely that their primary impact is to limit downstream flood peaks.

State stormwater and sanitary sewer regulations. The Little Troublesome Creek watershed is not currently subject to any state stormwater regulations, although this may change in the near future. EPA has developed a Phase II stormwater program, mandating that small communities not previously subject to federal stormwater requirements apply for permit coverage. Communities in urbanized areas designated by the US Bureau of the Census must apply for stormwater permit coverage by March 2003. Reidsville is not included on the list of such areas. The federal regulations require state permitting authorities to implement designation criteria that would be applied to communities outside of federally designated urbanized areas. Communities meeting these criteria can also be brought into the Phase II program. In October 2002, the NC Environmental Management Commission passed a temporary rule governing the implementation of the Phase II program in the state. Under this rule, the designation process will be

implemented in accordance with the schedule for development of the Division's basinwide water quality plans. The Cape Fear River Basinwide Water Quality Plan will next be revised in 2005. At that time DWQ will evaluate whether additional jurisdictions in the Cape Fear River basin (i.e. jurisdictions other than those federally designated) should be reviewed for inclusion in the Phase II program. Stormwater runoff from Reidsville has been identified in a Total Maximum Daily Load (see below) as contributing to violations of the State water quality standard for fecal coliform in Little Troublesome Creek. For this reason, and because of its current population and density, DWQ is likely to consider Reidsville for inclusion in the Phase II program.

The federal Phase II regulations require subject communities to develop and implement comprehensive stormwater management programs including the following six minimum measures: 1) public education and outreach on stormwater impacts; 2) public involvement/participation; 3) illicit discharge detection and elimination; 4) construction site stormwater runoff control; 5) post-construction stormwater management for new development and redevelopment; and 6) pollution prevention/good housekeeping for municipal operations.

As required by current regulations, the City of Reidsville has submitted a permit application to DWQ for its sanitary sewer collection system, which includes 88 miles of gravity sewers. The permit will require the city to conduct systematic mapping of its collection system, including pipe material, and approximate pipe age—details that are not currently available. It will also require inspections of the system and reports to DWQ on its condition, along with plans for repair or refurbishment. Detailed plans for repair or refurbishment of specific sections of the system are not yet available. The city also has a newly instituted grease ordinance intended to reduce the flushing of oils and grease into the sewer system, thereby, reducing the frequency of blockages and spills.

Fecal coliform TMDL. DWQ has developed a Total Maximum Daily Load (TMDL) for Little Troublesome Creek for fecal coliform bacteria, which has historically exceeded NC Water Quality Standards (membrane filter count of 200 colonies/100ml based on at least five consecutive samples collected during a 30-day period) both above and below the former WWTP discharge point (NCDWQ, 2002). The TMDL considers runoff and other sources in the Reidsville area to be important contributors of fecal coliform and proposes a 40% reduction in fecal coliform loading from these sources.

The Piedmont Triad Council of Governments, in cooperation with the City of Reidsville and others, has applied to the USEPA for a grant under the Section 319 program to develop an implementation plan for the fecal coliform TMDL. The proposed project would involve the identification of sources in the Reidsville area (including stormwater sources, leaky sewer pipes and other sources), the identification of appropriate BMPs, and the development of a plan that prioritizes proposed management actions. The proposal has been approved by the DWQ and will be recommended to the USEPA for approval later in 2002.

NC Wetlands Restoration Program planning efforts. In 2002, the NC Wetlands Restoration Program (NCWRP), an agency in the Department of Environment and Natural Resources, initiated a nonregulatory local watershed planning effort in the Little Troublesome Creek and neighboring Troublesome Creek watersheds. The local watershed plan (LWP) is a comprehensive planning process in which NCWRP is working with local stakeholders to:

- inventory water quality, flooding and habitat problems in the two watersheds;
- identify solutions, including stream and wetland restoration opportunities, and appropriate best management practices; and
- implement strategies for restoring and protecting streams and wildlife.

DWQ's assessment of Little Troublesome Creek and the NCWRP's 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 range of objectives and will incorporate extensive stakeholder involvement, including the identification of specific subwatersheds where the implementation of restoration projects and/or stormwater BMPs could achieve the greatest benefit. Results of the DWQ assessment will be utilized in the NCWRP planning process. The LWP is scheduled to be completed by the fall of 2003, with specific project implementation efforts to follow over the next several years.

Other activities and concerns. Local and regional citizen groups have expressed concern about water quality problems in Little Troublesome Creek and the Haw River for a number of years. Many of the concerns relate to municipal wastewater discharges, which include industrial inputs. Reidsville's WWTP, which was rerouted to the Haw River in late 1998, had recurring whole effluent toxicity test failures in the early and mid-1990s, but has a good compliance record in recent years. With the removal of the WWTP discharge from Little Troublesome Creek, residents along the creek have noted less foam and less dark color in the water. The Haw River Assembly, a citizens groups founded to protect the Haw River and Jordan Lake, conducts periodic water quality monitoring in Little Troublesome Creek.

Eutrophic conditions in B. Everett Jordan Lake, downstream on the Haw River, have been evident for a number of years. To address eutrophication in this lake, DWQ developed a point and nonpoint nutrient control strategy for the Haw/Cape Fear watershed. Under this plan, the Reidsville WWTP would be required to meet nutrient reduction limits upon expansion. For further information on the strategy, see the current Cape Fear River Basinwide Water Quality Management Plan (NCDWQ, 2000b).

☛ 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.

Section 3
Potential Causes of Biological Impairment

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

3.1 Key Stressors to be Evaluated in the Little Troublesome Creek Watershed

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

1. Habitat degradation. Initial reconnaissance indicated that much of the mainstem of Little Troublesome Creek can be characterized as follows:

- banks are severely eroding (Exhibit 3.1);
- bottom substrate consists almost entirely of unstable, shifting sand (Exhibit 3.2);
- channel is straight in most reaches, with few bends (Exhibit 3.3);
- water depth is largely uniform—few pools and riffles; and
- bank habitat and organic microhabitat are limited at many locations.

These characteristics create an inhospitable environment for aquatic invertebrates and fish, even if water quality factors are favorable. A shifting sandy bottom is a suitable habitat for only a few types of aquatic organisms; the abundance and variety of organisms is generally higher in streams with a mix of rocks, wood, leaves and roots on the stream bottom. Similarly, a variety of depths and current velocities in the stream provides habitat for more kinds of aquatic life than the straight, shallow waters typical of Little Troublesome Creek.

2. Organic and nutrient enrichment . Organic enrichment can affect stream biota in several ways. Organic matter in the form of leaves, sticks and other materials provide a food source for microbes in streams and serve 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. Macroinverterbrates 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. 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

loading can thus result in a distinct change in community composition due to both a change in food source and low dissolved oxygen levels.

An initial review of the benthic community data available early in the study for Little Troublesome Creek did not clearly indicate impacts from nutrient or organic loading. However given the presence of potential sources and the low gradient of some portions of the stream, the potential impacts of organic enrichment were also evaluated. The scarcity of riffles and low stream gradient in many areas could be a concern, possibly limiting reaeration in the creek. Similarly, the occurrence of beaver dams on the mainstem of the creek could influence dissolved oxygen concentrations. Wastewater flows formerly made up a substantial proportion of the total streamflow, especially during dry weather.

Even if nutrients are not a likely source of stream impairment in this watershed, nutrient inputs from all watersheds in the Haw River drainage are important, given current eutrophication concerns in B. Everett Jordan Lake and in the Cape Fear River downstream. Monitoring data will provide additional information to facilitate nutrient reduction efforts in the Jordan Lake drainage.

3. Toxic chemicals. Approximately 28% of the study area is developed, including substantial drainage area from industrial areas in the upper half of the watershed. There is a significant potential for a wide variety of toxicants to enter streams during rain events or site specific mishaps (see Section 2.6). These include metals, pesticides and a range of other organic chemicals. Agricultural chemicals, including herbicides and insecticides, are potential contaminants in the lower watershed. Reidsville's treated wastewater is also a potential source of toxicants when it is routed to Little Troublesome Creek on an emergency basis. Because of the wide range of potential toxicants and source activities in this watershed, toxicity merits further evaluation as a potential cause of impairment.

Exhibit 3.1 Bank erosion along Little Troublesome Creek

Exhibit 3.2 Shifting sand bottom; staff is 4 ½ feet long.

Exhibit 3.3 Straightened channel downstream of Scales Street

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 Little Troublesome Creek at several sites in the study area. Macroinvertebrate surveys were conducted at locations immediately above and below the WWTP discharge point in 1987, 1992 and 1994. All rated Fair, indicating that the stream was subject to considerable stress even above the WWTP discharge.

Stresses from the discharge were evident downstream of the immediate discharge area. Macroinvertebrates at SR 2598 and SR 2600, in the lower half of the study area, were rated Poor in 1985 and 1998, respectively. A fish community assessment in April 1998 rated SR 2600 Fair, and a follow-up survey in October 1998 rated it Poor. All of these surveys were performed while the Reidsville WWTP was discharging into Little Troublesome Creek.

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

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

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

4.1 Approach to Biological and Habitat Assessment

Biologists surveyed macroinvertebrate communities and aquatic habitat at four locations on the mainstem of Little Troublesome Creek (Figure 4.1), one location on an unnamed tributary stream, and one location on a reference stream outside of the study area. Sites are described in Section 4.2. The reference stream does not necessarily represent undisturbed conditions, but serves as a comparison site in a less impacted watershed within the same ecoregion and general geology as Little Troublesome Creek. Sampling occurred in August 2000 and in April and July 2001.

Ideally, sites would be located both upstream and downstream of all major sources of potential stress to aquatic organisms, such as urbanization in Reidsville, significant construction sites and agricultural areas in the lower study area. This was not feasible due to the widespread nature of potential nonpoint source inputs and the fact that the headwaters of Little Troublesome Creek are within the city limits of Reidsville.

4.1.1 Benthic Community Sampling and Rating Methods

Macroinvertebrate sampling was carried out using the general procedures outlined in the Division's standard operating procedures (NCDWQ, 2001b). Reaches approximately 100 meters (328 feet) long were targeted, although the actual stream length sampled varied with site conditions. Standard qualitative sampling was used for most sites. This method included ten samples: two kick-net samples, three bank sweeps, two rock or log washes, one sand sample, one leaf pack sample, and visual collections from large rocks and logs. At smaller stream sites the abbreviated Qual 4 method was used. The Qual 4 involved four samples: one kick, one sweep, one leaf pack and visual collections. Organisms were identified to genus and/or species.

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

Biotic index values are combined with EPT taxa richness ratings to produce a final bioclassification (Excellent, Good, Good-Fair, Fair or Poor). Final bioclassifications are used to determine if a stream is impaired. Streams with bioclassifications of Excellent, Good and Good-Fair are all considered unimpaired. Those with Fair and Poor ratings are considered impaired. *Under current DWQ policy, streams under four meters in width are generally not formally rated but are evaluated qualitatively based on professional judgment*. Small streams sampled using the Qual 4 method that have scores consistent with a Good-Fair or better rating are labeled as 'not impaired'.

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 "toxic score" is computed for each site. DWQ data have shown the percent deformities for sites rated Excellent, Good and Good-Fair averaged about 5%, with a mean toxic score of about 7. Sites with Fair and Poor bioclassifications with stressors considered nontoxic were combined into a polluted/nontoxic group, with a deformity rate of 12% and a mean toxic score of 18. "Nontoxic" conditions for this group include solely organic discharges (animal wastes) and natural organic loading (swamps). Finally, sites affected by a toxic stressor had higher deformity rates. A Fair/Toxic group had a 25% deformity rate and a mean toxic score of 52. A further significant increase was seen for the Poor/Toxic group: mean deformity rate = 45%, mean toxic score =

100. In Little Troublesome Creek, sufficient numbers of *Chironomus* for the deformity analysis were only collected at one location and date—NC 87 in July 2001.

4.1.2 Habitat Assessment Methods

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

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

4.2 Findings

4.2.1 Description

Selected habitat and biological characteristics for each site sampled during the study are shown in Table 4.1, which also includes information on historical sites not sampled during this investigation. Some streams 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.

<u>Little Troublesome Creek Mainstem</u>:

- *Little Troublesome Creek above Scales Street* in Reidsville was identified after the other sites had been sampled and was chosen for its areas of relatively good substrate compared to other portions of Little Troublesome Creek. The substrate was a mix of gravel, sand, bedrock, boulder and cobble. Leafpacks were abundant. A single riffle was present, along with shallow pools, but bank erosion was severe. While too small to rate, Little Troublesome Creek was fairly degraded at this upstream location. Benthos were sparse.
- *Little Troublesome Creek at Industrial Drive* in Reidsville, located ¼ mile downstream of the Scales Street site, was chosen for its location above the Reidsville WWTP and above a major tributary draining an older section of Reidsville. The substrate was mostly sand. Riffles were absent, while only shallow pools and runs were present. The banks were high and riprapped and moderate erosion was evident. Similar to the Scales Street site, the location was too small for a formal rating but clearly supported only an impacted benthic population dominated by tolerant organisms.

- *Little Troublesome Creek at NC 87 (Freeway Drive)* was chosen for its mid-watershed location, downstream of the Reidsville urban area and WWTP. It was sampled in August 2000 and July 2001. The substrate was mostly sand, with some boulder and rubble provided by riprap that had fallen into the stream. Leafpacks and other organic substrate were minimal. The presence of riffles varied with beaver activity, while bank erosion was moderate to severe. This site had a more diverse benthic population than the upstream sites, but was still impaired, receiving a Fair rating for both sampling dates. Both toxicity and organic enrichment were indicated at this location, as evidenced by the presence/absence of various indicator species. A midge deformity score of 30 indicated slightly toxic conditions.
- *Little Troublesome Creek at SR 2600 (Mizpah Church Road)* was chosen for its location at the downstream end of the study area, and available data from previous studies. The substrate was mostly unstable sand. Leafpacks and other organic substrate were more abundant than at upstream locations. The banks were high and steep, and bank erosion was moderate. This site was sampled three times during the study, receiving a rating of Fair each time. Though the benthic community was degraded here, both EPT richness and BI values were improved compared to the upstream NC 87 location. Some organisms indicative of low dissolved oxygen conditions were noted here.

Tributary:

- *Unnamed tributary location upstream of Turner Road* in Reidsville was chosen because it is a significant tributary and has substantial development upstream, draining an older portion of Reidsville with considerable commercial and industrial activity. The substrate was primarily sand, with gravel and silt. Small riffles were present, but runs were dominant. Bank erosion was severe. The stream was too small to rate, but its numerical scores were worse than any of the other locations sampled. Indicators of both toxicity and organic enrichment were present here as evidenced by the species composition.

Reference:

- *Rock House Creek at SR 2127 near Wentworth, NC* (not shown on Figure 4.1; see map in Appendix A) was chosen as a comparison site because it is in the same ecoregion and general geologic area as Little Troublesome Creek, and because of the limited amount of urbanization in its watershed. Rock House Creek is a tributary to the Dan River in the Roanoke River Basin. The sample site is located northwest of Reidsville in Rockingham County. The substrate was largely sand and silt, with abundant sticks, logs and leaves. Some riffles and pools were present, while bank erosion was moderate. Habitat and geomorphic features, including sandbars, appeared more stable than at Little Troublesome Creek locations. It received a bioclassification of Good/Fair, which is considered not impaired. The benthic community at this location was clearly more diverse and abundant than at any of the Little Troublesome Creek locations.

4.2.2 Summary of Conditions and Nature of Impairment

Habitat throughout the study area was relatively poor. The stream bottom contained a high percentage of sand at most sampling locations; only the location above Scales Street (furthest upstream) on the mainstem had a small reach of good riffle habitat, although even this reach was

likely impacted by sand moving down from upstream reaches. On the mainstem of Little Troublesome Creek in particular, sand was ubiquitous, filling pools and covering riffles and other bottom structure. Sand deposits sometimes exceeded 1.3 meters (4 feet) in depth. Deadfall trees created the only eddies and pools; stream reaches without fallen trees typically consisted of a few inches of clear water flowing over a flat sand bottom. Beaver impoundments were common, and some were breached and rebuilt numerous times during the study period. The stream showed signs of historic channelization at the Scales Street, Industrial Drive and SR 2600 locations.

The results of the current benthic macroinvertebrate surveys indicated that the benthic communities of Little Troublesome Creek were impaired for the entire length of the stream and were generally in Fair condition. The biological condition in the lower mainstem has improved from Poor to Fair since removal of the WWTP discharge in late 1998, but remains impaired. EPT diversity was found to be generally low and BI values indicated the presence of many organisms adapted to diverse stresses. The composition of the benthic community provided some indication that organic enrichment may be a stress factor in the middle and lower parts of the mainstem, as well as the tributary draining the downtown area. *Chironomus* deformity analysis indicated likely toxic impacts at the NC 87 site in mid-watershed, while community composition was indicative of toxicity at this location and at the tributary site.

Table 4.1 Selected Benthic Community and Habitat Characteristics[1], Little Troublesome Creek Study Sites

Location	Date	Stream Width (m) [2]	Avg. Depth (m)	Substrate: % sand and silt [3]	Habitat Score (100 max) [4]	EPT [5,6] Taxa Richness	Biotic Index [5,6]	Bioclassification [5]
UT to Little Troublesome Creek above Turner Road	4/11/2001	2	0.1	85	40	3	7.81	NOT RATED*
Little Troublesome Creek at City Park above Scales Street	4/12/2001	3	0.2	45	73	8	6.16	NOT RATED*
Little Troublesome Creek at Industrial Drive	8/23/2000	3	0.1	90	50	7	6.68	NOT RATED*
Little Troublesome Creek immediately above WWTP	12/1/1987	5	0.2	80		14	6.82	FAIR
	1/8/1992	4.5	0.2	85		8	6.84	FAIR
	11/16/1994	4	0.1	80		14	6.59	FAIR
Little Troublesome Creek immediately below WWTP	12/1/1987	5	0.3	90		10	7.02	FAIR
	1/8/1992	4.5	0.3	80		7	6.94	FAIR
	11/16/1994	5	0.2	85		7	7.27	FAIR
Little Troublesome Creek at NC 87	8/23/2000	5	0.1	85	37	12	7.27	FAIR
	7/9/2001	5	0.5	85	45	6	7.34	FAIR
Little Troublesome Creek at SR 2598	5/2/1985	5	0.3	100		3	7.93	POOR
Little Troublesome Creek at NC 2600	7/6/1998	7	0.2	80	49	3	7.6	POOR
	8/22/2000	5	0.2	90	61	12	6.67	FAIR
	4/11/2001	5	0.2	90	47	12	6.65	FAIR
	7/9/2001	5	0.1	80	46	10	6.84	FAIR
Rock House Creek at SR 2127 Wentworth, NC	4/12/2001	5	0.2	75	73	19	5.2	GOOD-FAIR

1. Habitat data available for 1998-2001 samples only.
2. Wetted channel width, in meters, at time of sampling.
3. Based on visual estimate of substrate size distribution.
4. See text for list of component factors.
5. See text for description.
6. EPT Taxa Richness and Biotic Index values are seasonally corrected.

* Qual 4 method. See text for discussion.

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

The DWQ conducts ambient monitoring (regular monthly sampling) on Little Troublesome Creek at Mizpah Church Road (SR 2600) in Rockingham County (station no. 02093423).

5.1 Approach to Chemical, Physical and Toxicity Sampling

5.1.1 General Approach

General Water Quality Characterization. One integrator station, located near the downstream end of the watershed, was sampled on a near monthly basis to characterize water quality conditions (see Section 5.1.2 for site location). Samples were collected nine times between January and October 2001. A standard set of parameters similar to those evaluated at DWQ ambient stations was utilized (see Appendix B, Table B.1). Grab samples were collected during both baseflow and storm conditions. Baseflow periods were defined as those in which no measurable rain fell in the watershed during the 48-hour period preceding sampling. Storm samples were collected on the rising stage of the hydrograph. Fecal coliform samples were collected under baseflow conditions on five occasions between August 8 and September 11, 2000.

Stressor and Source Evaluation. Samples were collected at a variety of locations in order to identify major chemical/physical stressors to which aquatic biota are exposed, evaluate toxicity and assess major pollution sources. Station locations for stressor identification sampling were linked to areas of known biological impairment (benthic macroinvertebrate sampling stations) and to watershed activities believed to represent potential sources of impairment. A majority of the sampling occurred at two locations within the mainstem. Both storm and baseflow samples were collected during a monitoring period extending from January to October 2001.

Sampling focused primarily on those physical and chemical parameters that preliminary investigations indicated merited investigation as plausible causes of biological impairment. As discussed in Section 3, these included low dissolved oxygen, nutrients and toxicity from a variety of potential sources. Because of the diverse land use in the Little Troublesome Creek watershed

and the wide variety of activities that could potentially result in toxicity, storm event sampling included a wide range of pollutants, including:

- metals;
- chlorinated pesticides and PCBs (polychlorinated biphenyls; 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 tert-butyl ether).

Ambient toxicity tests (bioassays) were conducted on samples collected at selected benthic macroinvertebrate sampling sites to evaluate whether toxic conditions were present. Multiple tests were conducted at each site evaluated. Laboratory bioassays provide a method of assessing the presence of toxicity from either single or multiple pollutants and can be useful for assessing the cumulative effect of multiple chemical stressors. Acute tests were conducted on storm samples, while chronic tests were conducted on samples collected during nonstorm periods. The following specific tests were used: ambient tests for acute toxicity using protocols defined as definitive in USEPA document EPA/600/4-90/027F (USEPA, 1993) using *Ceriodaphnia dubia* with a 48-hour exposure; ambient tests for chronic toxicity using the North Carolina *Ceriodaphnia* Chronic Effluent Toxicity Procedure (NC Division of Water Quality, 1998). All toxicity test samples were collected and transported in glass containers.

Field measurements (pH, dissolved oxygen, specific conductance standardized to 25 degrees C and temperature) were made on numerous occasions throughout the watershed to further characterize water quality conditions and to investigate potential stressor source areas. Data sondes--multiparameter probes with a data logging capability--were deployed simultaneously for four days in August 2001 at four locations in the watershed. Dissolved oxygen (DO), pH, water temperature and specific conductance were recorded every 15 minutes during this period.

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 two locations for 21-day periods during October and November 2001. No rainfall occurred during the first deployment period. One storm event occurred during the second period. The SPMDs were analyzed for PAHs, PCBs, chlorinated pesticides and selected current use pesticides.

Bed sediment was collected at one location and analyzed for pesticides, metals, PAHs, PCBs and semivolatile organic pollutants. Chronic toxicity bioassay testing was conducted on the sediment to evaluate potential toxicity. A forty-two day test was performed using *Hyallela azteca* as described in ASTM (2000) and USEPA (2000b).

<u>Water and Sediment Benchmarks</u>. In order to help evaluate whether a significant likelihood existed that observed concentrations may have a negative impact on aquatic life, measured

concentrations were compared to EPA's National Ambient Water Quality Criteria (NAWQC) for freshwater (USEPA, 1999) and Tier II benchmarks (USEPA, 1995). Metals benchmarks were adjusted for hardness where appropriate (USEPA, 1999). For chromium, the NAWQC for Cr VI was used. The use of NAWQC and other benchmarks is discussed in more detail in Appendix B.

Sediment data were compared to a set of 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 effects' benchmarks) 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 are also presented by themselves because the DWQ Aquatic Toxicology Unit uses these as initial screening benchmarks. Non-conservative ranges ('probable effects' benchmarks) are sets of 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 likely potential for pollutants to negatively impact aquatic biota considered all lines of evidence available, including toxicity bioassays and benthic macroinvertebrate data, in addition to data on analyte concentrations

5.1.2 Site Selection

Primary sampling stations (Figure 5.1 and Table 5.1) were chosen based on several criteria: accessibility, proximity to benthic sampling sites, proximity to key sources and source areas. These sites are listed below. Some were also sampled for benthic macroinvertebrates and were described in Section 4.

- *Little Troublesome Creek at SR 2600 (LTLT01*). This site was located at the downstream end of the study area, south of Reidsville, and served as the integrator location. Stressor identification sampling and toxicity sampling were also conducted at this site because of its location downstream of several agricultural fields. This site was a biological monitoring location and a DWQ ambient station (station no. 02093423).
- *Little Troublesome Creek at SR 2598 (LTLT02)*. This site was located approximately 2.0 miles above LTLT01. Monitoring at this location was limited primarily to field parameters, and it served as one of the stations where multi-probe data logging devices were deployed. This is also a historic DWQ biological monitoring location.
- *Little Troublesome Creek at NC 87 (LTLT03)*. This site was 1.5 miles upstream of LTLT02 near the southern boundary of Reidsville. Monitoring at this location was intended to identify major stressors and evaluate biological indicators of toxicity. This was also a biological monitoring location.
- *Little Troublesome Creek above Reidsville WWTP emergency outfall (LTLT04)*. This sampling point is located 1.3 miles upstream from LTLT03. Monitoring at this location was limited to current use pesticides and field parameters.
- *Little Troublesome Creek at Industrial Drive (LTLT05)*. This site is located 0.5 mile upstream from LTLT04. Monitoring at this location was intended to evaluate major stressors

associated with the urban area of Reidsville. This site is also a biological monitoring location.

- *UT to Little Troublesome Creek 0.5 mile downstream of Turner Road (LTLT06).* This site is located 0.5 mile upstream from LTLT04. Monitoring at this location was limited to field parameters and metals to evaluate stressors associated with commercial areas of Reidsville.
- *UT to Little Troublesome Creek at Equity Drive (LTLT08).* This sampling point is located below the culvert at Equity Drive in Reidsville, at the eastern side of the watershed. Measurements were limited to field parameters and metals to evaluate drainage from Equity Foods.

Table 5.1 Summary of Monitoring Approaches Used at Primary Sampling Sites

		Monitoring Approach					
Station Code	**Location**	**Benthos**	**Water Chemistry[1]**	**Toxicity (water)**	**Bed Sediment**	**SPMD[2]**	**Data Sonde[3]**
LTLT01	Little Troublesome Ck. at SR 2600 (Mizpah Church Rd.)	✓	✓ +	✓		✓	✓
LTLT02	Little Troublesome Ck. at SR 2598 (Cook Florist Rd.)						✓
LTLT03	Little Troublesome Ck. at NC 87 (Freeway Drive)	✓	✓	✓	✓	✓	✓
LTLT04	Little Troublesome Ck. above Reidsville WWTP emergency outfall		✓				
LTLT05	Little Troublesome Ck. at Industrial Drive	✓	✓				✓
LTLT06	UT to Little Troublesome Ck. 0.5 mile downstream of Turner Road		✓				
LTLT07	UT to Little Troublesome Ck. at Turner Road	✓					
LTLT08	UT to Little Troublesome Ck. at Equity Drive		✓				
LTLT09	Little Troublesome Ck. at Scales Street	✓					
LTRH01	Rock House Ck. at SR 2127	✓					

Note: For comprehensiveness this table includes both chemical/physical and benthic community sampling locations.

[1] Includes sample collection and/or regular field measurements. Field parameters were also measured at all benthic community sites at the time samples were collected.

[2] SPMD--semi-permeable membrane device.

[3] Data sonde--programmable multi-probe and field data recorder.

\+ Integrator station and DWQ ambient monitoring station.

5.2 Water Quality Characterization

During the period between January and October 2001 six baseflow and three stormflow samples were collected at the integrator station (Little Troublesome Creek at SR 2600--LTLT01) in order to provide a general picture of water quality in the study area. Selected results are shown in

Table 5.2 and are presented in more detail in Appendix B. Data from the ambient station (02093423) located at the same site are included for comparative purposes. Ambient monitoring events cannot be differentiated into baseflow and stormflow, but predominately represent nonstorm conditions.

Table 5.2 Median Values of Selected Parameters, Little Troublesome Creek at SR 2600

Parameter	Study Data LTLT01		Ambient Station Data #02093423	
	Baseflow	Stormflow	November 1998 - August 2001[1]	January 1997 - October 1998[2]
Dissolved Oxygen (mg/L)	7.3	7.1	8.5	8.5
pH (s.u.)	7.1	6.9	6.8	6.8[3]
Specific Conductance (µS/cm)	124	121	114	340
Turbidity (NTU)	12	34	14	11
Total Phosphorus (mg/L)	0.10	0.11	0.10	0.22
Ammonia Nitrogen (mg/L)	0.1	0.1	0.07	0.07
TKN (mg/L)	0.7	1.4	0.4	0.6
Nitrate + Nitrite Nitrogen (mg/L)	0.36	0.44	0.45	0.89

1. Reidsville WWTP discharges to the Haw River. Number of observations (n) varies from 19 – 24.
2. Reidsville WWTP discharges to Little Troublesome Creek upstream of the sampling location. N varies from 14 – 22.
3. Includes pH data for 1997 only. Data for 1998 not available.

- Dissolved oxygen levels at SR 2600 were generally adequate during both storm and baseflow conditions.
- Typical baseflow specific conductance at the integrator station (124 µg/L) was somewhat elevated compared to reference conditions at Rockhouse Creek (81 µS/cm). Significantly lower median values (one-third previous levels) were evident at the ambient station following removal of the discharge.
- Turbidity levels during storm conditions were only slightly elevated and well below those observed during storm conditions upstream at LTLT03 (median of 300 NTU, n =2). This could be the result of beaver ponds and lower gradients downstream of the upper station that reduced downstream storm impacts.
- Baseflow nitrogen and phosphorus levels were elevated compared to unimpacted streams (Caldwell, 1992). Nutrient concentrations prior to relocation of the discharge were significantly higher than current ambient data. Total nitrogen concentrations were 1½ times higher prior to the relocation and phosphorus concentrations were twice as high.

The geometric mean of five fecal coliform samples collected during baseflow conditions over an approximately 30-day period in August and September 2000 exceeded the North Carolina standard for these waters (Table 5.3). High fecal coliform levels do not appear to be due to sewage spills (see Section 2). Additional fecal coliform sampling conducted by DWQ staff in 2001 as part of a TMDL evaluation also found that levels exceeded the North Carolina standard at a number of other locations in the watershed (NCDWQ, 2002). These data indicated that the

highest fecal coliform levels in the watershed occurred in the tributary draining downtown Reidsville and in the Little Troublesome Creek headwaters near Scales Street.

Table 5.3 Fecal Coliform Monitoring Results, Little Troublesome Creek at SR 2600 (LTLT01)

Date (all 2000)	(colonies/100ml)
August 8	680
August 17	210
August 22	110
September 11	190
September 12	250
Geometric Mean	**237**
NC Standard	**200**

5.3 Stressor and Source Identification

Given the complexities of land use within the urban areas of Reidsville, a wide range of toxicants could potentially affect surface water quality in the study area. Pesticides from agricultural areas are potential toxicants in the downstream portion of the watershed. Benthic macroinvertebrate data (Section 4) suggest toxic impacts at LTLT03 and at the benthic sampling location at LTLT07, just upstream of LTLT06.

Evaluation of water column toxicity was carried out primarily at LTLT01 and LTLT03 and included: bioassays (acute and chronic), chemical pollutant monitoring (metals, pesticides and other organic compounds), and deployment of SPMDs to sample organic contaminants. Results of this sampling are discussed in Section 5.3.1. Bed sediment at LTLT03 was also studied for the presence of toxic conditions. Sediment toxicity assessment work included: 42-day toxicity bioassays and chemical analyses for metals, semi-volatile organic compounds, PAHs, TPHs and pesticides. Bed sediment results are presented in 5.3.2.

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

Five ambient chronic bioassays were conducted on baseflow samples collected at each of two locations, LTLT01 and LTLT03. Five acute bioassays were conducted on storm samples collected at LTLT03 and two on storm samples collected at LTLT01. Greater emphasis was placed on toxicity analyses at LTLT03 because benthic macroinvertebrate data indicated likely toxicity at this location.

Table 5.4 Chronic and Acute Bioassays—Water Column

Date (all 2001)	Little Troublesome Creek at SR 2600 (LTLT01)		Little Troublesome Creek at NC 87 (LTLT03)	
	Chronic Bioassay	Acute Bioassay	Chronic Bioassay	Acute Bioassay
April 10	pass	-	pass	-
May 1	pass	-	pass	-
June 7	-	pass	-	pass
July 25	-	pass	-	pass
August 7	pass	-	pass	-
September 9	-	-	-	pass
September 10	-	-	-	pass
September 18	fail	-	invalid*	-
September 24	-	-		pass
October 2	pass	-	pass	-

Additional test data in Appendix B.
* Laboratory control failure.

All bioassays conducted at the NC 87 location (LTLT03) passed (Table 5.4) except for a chronic test conducted on September 18 (2001). This test passed based on treatment reproduction but is considered invalid due to inadequate control reproduction (see Appendix B). These tests provided no indication of water column toxicity at LTLT03 on the dates sampled.

Downstream at SR 2600 (LTLT01), all tests passed except the chronic bioassay conducted on the September 18 sample. This test failed on the basis of acute mortality effects. Chronic effects may also have been present (see Appendix B). The reasons for this test failure are not apparent. Organic contaminants and surfactants (MBAS) were not detected. Pesticide analyses were not conducted on this sample; however, and thus, pesticides cannot be ruled out as a potential cause of toxicity. Metals concentrations (see Table 5.7) were similar to other baseflow monitoring events at this location, with elevated aluminum, iron and manganese concentrations but no other metals exceeded chronic aquatic life screening levels. Due to the ability of toxicity tests to integrate effects from all chemical stressors present, observed effects may be due to combinations of chemicals that do not exceed levels observed to cause toxicity as a single compound. Toxicity may also be due to compounds not analyzed.

b. Pesticides and Organic Compounds

Grab samples. Organic chemical analyses (TPHs , MTBE, volatile and semi-volatile organic compounds, MBAS, phenols and PAHs) conducted on baseflow samples collected at LTLT01 and LTLT03 resulted in no values above detection limits (see Appendix B for details). No volatile and semi-volatile compounds were detected at LTLT05 during a single baseflow sampling event conducted in October 2000.

No organic compounds (see Section 5.1.1 for list) were detected during storm samples from LTLT01 and LTLT03 except for three current use pesticides (Table 5.5). Metolachlor, simazine and atrazine were detected in one of four storm samples analyzed at LTLT01 and one of eight samples analyzed at LTLT03. These three chemicals are herbicides used for pre- and post-emergent control of grasses and weeds in agriculture and turf management.

Acute bioassay samples collected at the time these pesticides were detected passed. Observed 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. There are no published fresh water ecological screening benchmarks associated with simazine or metolachlor, but concentrations observed in Little Troublesome Creek are several orders of magnitude below effects levels reported in the literature (see discussion in Appendix B).

Table 5.5 Current Use Pesticides Detected in Grab Samples from Little Troublesome Creek (µg/L)

Pesticide	June 7, 2001		July 25, 2001	
	LTLT01	LTLT03	LTLT01	LTLT03
Simazine	0.61	0.25	-	-
Metolachlor	-	-	0.37	0.49
Atrazine	-	-	0.106	0.084

A dash (-) indicates concentrations were below the detection limit of 0.005 µg/L.

SPMDs. Semi-permeable membrane devices deployed during two 21-day periods in October and November 2001 collected more than 60 different organic contaminants, including: ten chlorinated pesticides, eight polychlorinated biphenyls (PCBs), 44 polycyclic aromatic hydrocarbons (PAHs) and the current use pesticides metolachlor and chlorpyrifos. SPMD concentrations 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. They do not provide information regarding pulse events such as storms. There was one 0.3-inch rain event during the second deployment period. Since the deployment occurred during the fall, pollutants that may be associated with the spring and summer growing seasons (e.g. some pesticides) may have been missed or may be present at lower concentrations than during other times of the year.

Table 5.6 presents selected results illustrating that estimated average concentrations are well below benchmark values (see Appendix B for complete results). Of the chlorinated pesticides detected, heptachlor and dieldrin were the closest to their respective screening values, but still well below likely toxic levels (Table 5.6). Total PCBs were also well below benchmark concentrations. The PAHs listed in Table 5.6 illustrate the wide gap typically observed between concentrations of individual PAHs and screening values.

Current use pesticides captured by SPMDs included metolachlor and chlorpyrifos. Metolachlor, which was also detected in grab samples, was detected only during the first deployment period

and concentrations were twice as high at the upper station (LTLT03) when compared to the lower station (LTLT01). Chlorpyrifos is an insecticide used in agriculture and domestic applications. It is commercially available and is an ingredient in a product called Dursban. It was captured at average concentrations well below chronic screening levels during both monitoring periods (Table 5.6).

Table 5.6 Selected SPMD Pollutants Captured (ng/L)

Pollutants		Little Troublesome Creek at NC 87 LTLT03		Little Troublesome Creek at SR 2600 LTLT01		Chronic Screening Value (ng/L)	Acute Screening Value (ng/L)
		1st Deploy.[1]	**2nd Deploy.[2]**	**1st Deploy.[1]**	**2nd Deploy.[2]**		
Chlorinated Pesticides	Dieldrin	0.17	0.22	0.13	0.32	56	240
	Heptachlor	0.47	0.55	0.38	0.45	3.8	520
	Sum of DDTs	0.26	0.24	0.56	0.41	-	-
PAHs	Fluoranthrene	8.83	10.46	7.91	5.98	6160	33600
	Pyrene	6.18	7.11	8.84	8.47	-	-
	Acenapthene	0.42	0.49	0.17	0.17	23000	80000
	Sum of PAHs	39.63	46.69	45.95	40.32	-	-
PCBs	Sum of PCBs	0.43	0.43	0.45	0.37	14	-
Current Use Pesticides	Metolachlor	0.19	<0.025	0.08	<0.025	-	-
	Chlorpyrifos	0.10	0.06	0.08	0.10	41	83

Screening values are NAWQC (USEPA, 1999), except for acenapthene and fluoranthrene. These latter values are Final Acute Values and Final Chronic Values calculated by EPA for use in deriving sediment quality criteria (see Suter and Tsao (1996)).

[1] First deployment period was October 17 through November 7, 2001.

[2] Second deployment period was November 7 through November 28, 2001 and included a rain event of 0.3 inches.

c. Metals

Trace metals were commonly found at LTLT01 and LTLT03. Baseflow and stormflow data for these sites are shown in Tables 5.7 and 5.8, respectively, for all metals for which exceedances of water quality benchmarks occurred or for which no benchmarks are available. Baseflow concentrations of iron, aluminum and manganese commonly exceeded screening values at both sites. This is not unusual for North Carolina streams. Lead and silver values occasionally exceeded NAWQC. As discussed above, chronic bioassays associated with baseflow sampling events did not indicate toxicity, with the exception of the September 18 (2001) sample at LTLT01. Metal concentrations on this date were not atypical for this location. No bioassay was conducted on the January 29 (2001) sample, which had the highest baseflow metals concentrations observed at site LTLT01. The available toxicity test data do not assess the potential toxicity of these metals concentrations, which may be representative of regularly occurring intermittent concentrations.

Storm conditions at LTLT01 resulted in no exceedances of NAWQC (Table 5.5). Aluminum, copper, lead and zinc concentrations exceeded acute screening levels during four of five storm

events sampled at LTLT03. Acute bioassays associated with each of these storm events did not indicate toxicity.

Since total rather than dissolved concentrations were measured, metals bioavailability is difficult to fully assess. Adjusting benchmarks for hardness only partially addresses this issue. Metals such as aluminum, iron, manganese, copper and zinc are widespread in North Carolina's waters. Potential effects on benthic macroinvertebrates are uncertain since organisms in a given locality may be adapted to local concentrations. The fact that almost all bioassays conducted on samples collected at the same time (within minutes) of chemical samples provided no evidence of toxicity is a fairly strong indication that the concentrations of metals in the stream were not problematic on these occasions.

d. Other Toxicants

MBAS (anionic surfactants) were detected in one baseflow sample at LTLT03 (0.126 mg/L) and two samples at LTLT01 (0.144 mg/L and 0.104 mg/L). Bioassays conducted on samples collected at the same time as MBAS samples did not indicate toxicity.

Table 5.7 Selected Total Metals Concentrations in Baseflows and NAWQC Chronic Values (μg/L)*

a. Little Troublesome Creek at SR 2600 (LTLT01)

Parameter	1/29/2001	NAWQC	4/10/2001	NAWQC	5/1/2001	NAWQC	8/7/2001	NAWQC	9/18/2001	NAWQC	10/2/2001	NAWQC
Aluminum	**3450**	87	**167**	87	**113**	87	**231**	87	**173**	87	**317**	87
Cadmium	0.2	1.3	-	1.2	0.1	1.4	0.8	1.4	-	1.4	-	1.3
Iron	**2820**	1000	**1480**	1000	**1360**	1000	**1520**	1000	**1100**	1000	**1080**	1000
Lead	**5**	1.1	**3**	1.1	-	1.3	-	1.2	-	1.3	-	1.2
Manganese	**271**	120	**155**	120	**160**	120	**206**	120	**214**	120	118	120
Silver	**1.8**	0.36	-	0.36	-	0.36	-	0.36	-	0.36	-	0.36
Hardness (mg/L)	42.7	--	42.0	--	49.5	--	48.0	--	48.5	--	46.0	--

b. Little Troublesome Creek at NC 87 (LTLT03)

Parameter	8/7/2001	NAWQC	8/31/2001	NAWQC	9/18/2001	NAWQC	10/2/2001	NAWQC
Aluminum	**132**	87	**110**	87	**136**	87	**133**	87
Cadmium	0.2	1.5	-	1.4	-	1.3	-	1.4
Iron	**1700**	1000	**1310**	1000	**1550**	1000	**1210**	1000
Lead	**2**	1.4	-	1.3	-	1.2	-	1.3
Manganese	**361**	120	**260**	120	**261**	120	**155**	120
Silver	**0.9**	0.36	-	0.36	-	0.36	-	0.36
Hardness (mg/L)	52.0	--	49.3	--	46.5	--	49.3	--

* Metals for which all values were below chronic benchmarks are not included (arsenic, chromium, copper, mercury, nickel, zinc).
Values in bold type exceed the applicable screening benchmark. Silver and manganese screening values are Tier II (USEPA, 1995), all others are NAWQC (USEPA, 1999).
See Appendix B for discussion. Screening values were adjusted for hardness where appropriate. Mean hardness value used for August comparisons.
A dash (-) denotes concentrations below detection limit. Detection limits were less than or equal to screening values except for silver. See Appendix B for detection limits.

Table 5.8 Selected Total Metals Concentrations in Stormflows and NAWQC Acute Values (µg/L)*

a. Little Troublesome Creek at SR 2600 (LTLT01)

Parameter	3/15/2001	NAWQC Levels	6/7/2001	NAWQC Levels	7/25/2001	NAWQC Levels
Aluminum	167	750	447	750	313	750
Copper	2	6.5	5	5.3	4	7.1
Iron	1420	N/A	2010	N/A	1510	N/A
Lead	-	29	3	22	-	33
Zinc	4.1	60	6.4	50	4.9	65
Hardness (mg/L)	44.0	--	35.8	--	49.0	--

b. Little Troublesome Creek at NC 87 (LTLT03)

Parameter	7/25/2001	NAWQC Levels	9/9/2001	NAWQC Levels	9/10/2001	NAWQC Levels	9/22/2001	NAWQC Levels	9/24/2001	NAWQC Levels
Aluminum	**1120**	750	**1520**	750	123	750	**1930**	750	**788**	750
Copper	**19**	4.4	**21**	4.1	2	4.1	**17**	4.1	**8**	3.9
Iron	2820	N/A	11300	N/A	5760	N/A	10600	N/A	2950	N/A
Lead	**34**	17	**56**	16	-	16	**47**	16	**18**	14
Zinc	**178**	42	**105.3**	40	11.7	40	**105.0**	40	**48.9**	38
Hardness (mg/L)	29.0	--	27.3	--	27.3	--	27.3	--	25.5	--

* Metals for which all values were below acute benchmarks are not included (arsenic, cadmium, chromium, manganese, mercury, nickel, silver).
Values in bold type exceed the applicable NAWQC (USEPA, 1999). Acute screening value not available for iron. See Appendix B for discussion.
Screening values are adjusted for hardness where appropriate. Hardness not available for September 9, 10 and 22. Mean hardness value used for these dates.
A dash (-) denotes metal concentrations below detection limit. Detection limits were less than or equal to screening values except for silver. See Appendix B for detection limits.

5.3.2 Bed Sediment Toxicity

a. Bioassays

Bed sediment toxicity and chemistry were evaluated at Little Troublesome Creek at NC 87 (LTLT03) because benthic community composition and *Chironomus* deformities at this location indicated potential toxic impacts (Section 4). Sediments were collected in August 2001 and tested for toxicity using *Hyallela azteca.* None of the test endpoints (28-day survival, 28-day growth, 35-day survival, 42-day growth, 42-day survival, and reproduction at 42 days) met statistical criteria for test failure, but reproduction in the depositional sediment at LTLT03 appears to be considerably lower than for the control sample. See Appendix B for additional details.

b. Pesticides and Organic Compounds

Chemical analyses conducted with these same sediments detected ten organic compounds. The chlorinated pesticide 4,4' DDE (a DDT degradation product) and five PCBs were detected at levels well below screening values (Table 5.9). No current use pesticides were detected.

Pyrene, the only polycyclic aromatic hydrocarbon (PAH) detected in sediment, was present at 1814 µg/Kg. Pyrene is a by-product of incomplete fossil fuel combustion (e.g., gas and diesel engine exhaust) and is ubiquitous in the environment. This concentration is above the conservative benchmark range and falls within the lower portion of the non-conservative benchmark range (Table 5.9). It is therefore possible, though not probable, that pyrene contributes to some degree of toxicity.

Total petroleum hydrocarbons as diesel fuel (TPH-DRO) were detected at 31.7 mg/Kg. There are no published screening levels for TPH in surface waters. This concentration approaches the NC Groundwater Section's Action Level (40 ppm) for contaminated soils.

Table 5.9 Organic Pollutants Detected in Depositional Sediment, Little Troublesome Creek at NC 87 (LTLT03)

Analyte (µg/Kg dry weight)	Concentration	**Benchmark Values (µg/Kg)**		
		Conservative	Non-Conservative	EPA Region 4
4,4'-DDE	0.35	1.42 to 5	6.75 to 374	2.07
Total DDTs	0.35	1.58 to 7	46.1 to 4450	1.58
Sum PCBs	2.48	10 to 70	180 to 6996	21.6
Pyrene	**1814**[1]	44.27 to 665	875 to 11220	330
TPH DRO (mg/Kg)	31.7[2]	No published benchmark value		

Benchmark values are adjusted for TOC where appropriate. See Appendix B.

[1] Pyrene was detected at 1814 µg/Kg using EPA Method 8100 (PAHs) and 1063 µg/Kg using EPA Method 8270 (semi-volatile compounds).

[2] Total Petroleum Fuel Hydrocarbons using SW-846, 3550 California GC-FID method Diesel fuel.

Value in bold type exceeded one or more benchmark values.

c. Metals

Eight metals (Table 5.10) fell within the range of conservative benchmarks, and aluminum was just below the conservative benchmark level. Aluminum, iron and manganese are common constituents of soil clays in this region, most likely accounting for their abundance in the stream sediments. While the cumulative effect of these metals could be a potential concern, the chronic bioassay conducted on this sediment did not provide evidence of toxicity.

Table 5.10 Metals Detected in Depositional Sediment, Little Troublesome Creek at NC 87 (LTLT03)*

Metals (mg/Kg dry weight)	Concentration	Benchmark Values (mg/Kg)**		
		Conservative	Non-Conservative	EPA Region 4
Aluminum	24700	25500	58030 to 73160	--
Beryllium	1.01	--	--	--
Cadmium	**2.11**	0.583 to 1.2	3 to 41.1	0.676
Chromium	**57**	26 to 81	90 to 370	52.3
Copper	**24**	16 to 35.7	54.8 to 270	18.7
Iron	**27000**	20000 to 188400	40000	--
Lead	**47**	30 to 46.7	68.7 to 396	30.2
Manganese	**519**	460 to 1673	819 to 11000	--
Mercury	0.08	0.13 to 0.2	0.486 to 2	0.13
Nickel	**26**	15.9 to 39.6	35.9 to 75	15.9
Thallium	5.4	--	--	--
Zinc	**153**	98 to 159	271 to 1532	124

* Includes all metals detected in depositional sediment. Antimony, arsenic, selenium and silver were not detected. Benchmarks not available for beryllium and thallium. Values in bold type exceed one or more benchmark values.

** Conservative ranges ('no 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. See Appendix B.

5.3.3 Dissolved Oxygen and Nutrients

Dissolved oxygen (DO) was evaluated using several approaches. DO was measured when samples were collected for laboratory analysis. Additionally, DO was measured on many occasions during watershed reconnaissance and stream survey activities. Finally, data sondes--multiparameter probes with a data logging capability—provided data on daily DO cycles at several locations in the watershed. Nutrients were sampled primarily at LTLT01 and LTLT03.

The lowest DO levels observed at SR 2600 and NC 87 (5.3 and 5.0 mg/L, respectively) were measured during biological sampling in July 2001. Results from data sonde deployments indicated a typical daily DO cycle with minimum levels occurring overnight. The lowest observed DO during these deployments was 4.9 mg/L at LTLT02 (see Appendix B). Following

a storm in September 2001, a DO reading of 4.0 mg/L was recorded in Little Troublesome Creek at NC 87, downstream from the location where a floodplain area, flooded by a beaver impoundment, was draining back into the main channel. DO measurements under 3 mg/L were recorded in several small tributaries.

As noted earlier, nitrogen and phosphorus levels were elevated at LTLT01 (SR 2600). Though the number of samples is too small to be conclusive, available data (Table 5.11) suggest that stormflow nutrient concentrations may be higher in the upper (LTLT05) and middle (LTLT03) portions of the watershed than downstream at LTLT03.

Table 5.11 Median Nutrient Concentrations in Little Troublesome Creek (mg/L)*

	Sampling Location					
	LTLT05		LTLT03		LTLT01	
	Baseflow	Stormflow	Baseflow	Stormflow	Baseflow	Stormflow
Total Phosphorus	-	0.30 (1)	0.04 (3)	0.13 (2)	0.10 (6)	0.11 (3)
Ammonia Nitrogen	-	0.2 (1)	0.1 (3)	0.1 (2)	0.1 (6)	0.1 (3)
TKN	-	1.5 (1)	0.7 (3)	2.3 (2)	0.7 (6)	1.4 (3)
Nitrate + Nitrite Nitrogen	-	0.73 (1)	0.50 (3)	0.70 (2)	0.36 (6)	0.44 (3)
Total Nitrogen	-	2.2 (1)	1.2 (3)	3.0 (2)	1.1 (6)	1.9 (3)

* Number of samples in parentheses.

5.3.4 Source Area Assessments

Substantial monitoring work was devoted to investigating potential stressor sources throughout the watershed. Industrial activities within the headwater areas of Reidsville were a concern as well as the impact of beaver impoundments and associated backwater discharges. Details of these investigations are provided in Appendix B.

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 Troublesome Creek watershed. However, a perspective limited to a small number of locations in a watershed may not provide an accurate picture of overall channel conditions, nor result in the identification of pollutant sources and specific problem areas. This study therefore undertook a broader characterization of stream condition by examining large sections of the Little Troublesome 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 virtually the entire mainstem of Little Troublesome Creek from Richardson Drive in Reidsville to SR 2600 (Mizpah Church Road), a total of over 6.5 miles, plus 0.6 miles of the major tributary draining portions of downtown Reidsville (Figure 2.1). Reconnaissance activities were conducted at numerous other mainstem and minor tributary locations. Some areas were surveyed on numerous occasions.

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. A more detailed description of existing conditions is included in Appendix D, along with additional photographs.

6.1 Summary of Existing Conditions

6.1.1 Overall Channel and Riparian Condition

Channel Conditions. Little Troublesome Creek and its tributaries are highly incised. Stream banks are steep and often poorly vegetated. Areas of bank erosion are common (Exhibit 6.1). As noted in Section 2, large portions of Little Troublesome Creek were channelized at various times. The channelized areas extend from the mouth of the creek to about 0.3 miles below SR 2598 (approximately 3 miles) and from about one half mile above NC 87 to Richardson Drive in Reidsville (a distance of over 2.5 miles). Because of the direct and indirect impacts of this channelization, much of Little Troublesome Creek today has high, steep banks and very little meander, except where sinuosity has begun to develop within the incised channel.

This description does not apply to the middle, apparently unchannelized portion of the stream (approximately 2.3 miles in length) that flows through lower gradient, sometimes swampy areas. The stream in these reaches (see Appendix D) does not exhibit the straight channel or the high, steep banks observed in other reaches (Exhibit 6.2). Braided or multiple channels (Rosgen D stream type) occur in some places. Floodplains in these low gradient areas are often extensive, with stream corridors up to 0.25 miles wide. A headcut approximately two feet high is located 0.3 miles below SR 2598, at the transition between the lower channelized portion of the creek

and the middle swampy area. A headcut or knickpoint is an abrupt change in slope representing a zone of headward erosion within the stream channel.

Exhibit 6.1 Bank erosion near SR 2600

Exhibit 6.2 Low gradient area above SR 2598

Beaver impoundments have recently become prevalent in these reaches, but are periodically destroyed by natural and/or human actions. Water levels are dependent on the current condition and height of beaver dams. Some areas of bottomland forest are experiencing extensive tree mortality due to the higher water levels.

Historic channelization aside, streams have been moved or piped in places, most notably in Reidsville. The use of culverts and riprap is extensive in the upper part of the study area. The headwater reaches drain highly impervious areas served by storm sewer systems and they are thus subject to considerable hydraulic stress. There are few if any intact areas in the headwaters from which macroinvertebrate recolonization could occur following disturbance.

Even non-channelized tributaries are often incised. In many areas this is likely due in large part to downcutting that occurred following the lowering of local base level with the channelization of the mainstem. The more recent effects of urbanization are apparent in the headwaters. Other contributing factors may include floodplain accretion during past periods of high agricultural activity and poor management practices.

Riparian Conditions. Trees line the banks of most stretches of Little Troublesome Creek and many of its tributaries, although this tree line is often only a few yards wide, giving way to mowed utility right-of-way, pasture, golf course or pavement. Stormwater culverts generally bypass existing riparian buffers and discharge directly to the stream. In the lower half of the watershed, extensive former floodplains (present day terraces) border the mainstem just below upland areas but above the present day floodplains. Several such areas are used as pasture.

Aquatic Habitat. Habitat for aquatic organisms is highly degraded. The bottom substrate at most locations is largely mobile sand, often several feet deep, which provides an unstable habitat for aquatic macroinvertebrates and fish. This sand is mobilized during storms, and channel bars commonly shift location. The abrasive, scouring action of the moving sand is also detrimental to organisms which are using submerged tree trunks, roots and other available stable habitats in the stream. Riffles are generally absent except in the headwaters. Most pool habitats are temporary, associated with woody debris that moves frequently during storms. The majority of the channelized stream consists of shallow sandy runs with extensive sand deposits which scour the bottom as they move downstream during high flow events. Bank habitat is often sparse due to bank failure and erosion, or inaccessible due to incision. Organic microhabitat is limited in many locations.

NCSU Geomorphic Assessments. As a part of this study, DWQ contracted with the Stream Restoration Institute at NCSU to conduct a morphological evaluation and restoration feasibility study of three reaches (Figure 6.1):

- Little Troublesome Creek at SR 2600. This reach, located at the downstream end of the study area, is typical of much of the channelized lower portion of the Little Troublesome Creek mainstem.
- Little Troublesome Creek downstream of SR 2598. This area, described in Appendix D, contains a low gradient swampy area and the headcut noted above (Exhibit 6.3).
- Little Troublesome Creek upstream of Scales Street in Reidsville. This reach is typical of the mainstem channel in the urban upper portion of the study area.

These evaluations included a visual assessment of stream morphology, pebble counts, longitudinal and cross-sectional surveys, and other field activities. Bank pins and permanent cross-sections were installed so that future changes in channel morphology can be monitored. These evaluations are documented in three reports by NCSU (2001a, 2001b, 2002). Table 6.1

summarizes basic geomorphic parameters for the three reaches. The restoration implications of this work are addressed in Section 8.

The assessments indicated that the SR 2600 reach and the portion of the SR 2598 reach below the headcut, with conditions typifying the channelized parts of the lower mainstem, are incised, low width/depth ratio, E type channels (Rosgen, 1996). The NCSU evaluations concluded that these reaches are laterally unstable and likely to widen further in the future (NCSU, 2001b and 2002). The NCSU survey of the reach of Little Troublesome Creek below SR 2598 indicated ongoing lateral erosion as well as the vertical instability associated with upstream migration of the headcut. A braided channel (Rosgen D) exists above the headcut. The Scales Street reach reflects more recent channelization and was typed as F5. This reach is also considered unstable both laterally and vertically (aggradation) (NCSU, 2001a).

Table 6.1 Selected Geomorphic Characteristics of Three Reaches Evaluated by NCSU

	Little Troublesome Ck. above SR 2600	**Little Troublesome Ck. below SR 2598**	**Little Troublesome Ck. above Scales Street**
Width/Depth Ratio [1]	7.1	5.5	14.2
Entrenchment Ratio [2]	>2.2	>2.2	1.6
D_{50} (mm) [3]	0.4 (sand)	< 0.062 (silt/clay)	0.4 (sand)
Slope (%)	0.04	0.46	0.46
Sinuosity [4]	1.0	1.1	1.03
Rosgen Stream Type [5]	E5	E6	F5
Bank Height Ratio [6] (range)	1.8-2.0	1.5-2.0	1.0-4.2

Source: NCSU 2001a, 2001b and 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

Exhibit 6.3 Headcut downstream of SR 2598

6.1.2 Channelization and Hydrologic Impacts

For much of its length, Little Troublesome Creek is a highly modified, uniform channel system. The channelization of the early 20th Century (see Section 2), which itself followed extensive agricultural sediment inputs, resulted in a stream which was largely straight and devoid of material coarser than sand. Coarse substrate suitable for riffles has either been removed during dredging or remains buried under the sand that dominates the stream bed. The straightening, deepening and widening of the stream resulted in a channel system with little habitat diversity.

The direct impacts of channelization have since been eclipsed by other forces, including channelization's indirect effects, which have persisted for decades. With the modification of sinuosity and slope and creation of high stream banks, channelization often sets in motion an extended period of systemic instability characterized by channel incision and subsequent widening (Schumm et al., 1984; Brookes, 1988; Darby and Simon, 1999). These channel adjustments affect the stability of both the channelized areas themselves as well as unchannelized tributaries, which incise in response to changes in their base level, potentially resulting in the 'rejuvenation' of the entire drainage network (Schumm et al., 1984). These long-term processes generate large amounts of sediment due to bed and bank erosion, resulting in highly unstable stream habitat, and increase the vulnerability of the stream to changes in watershed hydrology (e.g., due to subsequent urbanization).

These processes have been at work in Little Troublesome Creek for decades and can be observed today. The complicating impacts of urban hydrologic changes are particularly likely in the upper half of the watershed. The middle portion of the creek, beginning above NC 87 and extending most of the way to SR 2598, is not highly incised and has access to a broad floodplain, serving to mitigate some of the hydrologic impacts of urban stormflows.

6.1.3 Beaver Impacts

The ongoing expansion of beavers (*Castor canadensis*) throughout the watershed is also altering aquatic habitat. Observations during the two years of this study are confirmed by conversations with local residents: beaver dams are appearing in many more places than in recent memory. Among the physical and chemical effects of these impoundment are the following (also see McDowell and Naiman, 1986; Hackney and Adams, 1992; Margolis et al., 2001a and 2001b):

- changing shallow flowing waters into deeper, slow pools or runs, with an increase in habitat for certain aquatic organisms (and waterfowl) and a decrease in habitat for others;
- allowing suspended solids to settle, along with any attached contaminants, resulting in lower turbidity downstream of the beaver dam;
- flooding bottomland forests in low gradient areas, resulting in some tree mortality and the flourishing of sedges and other vegetation tolerant of permanent standing water;
- generally lower dissolved oxygen concentrations in the ponds and immediately downstream of the dams due to high rates of microbial respiration in bottom muds and limited opportunity for reaeration;
- dampening the surge of stormflows from upstream, resulting in less severe bank erosion downstream of the dam;
- reduction of coarse woody debris and organic microhabitat below the dams;
- periodic release of pulses of fine inorganic sediments and organic material when dams are breached.

While some impact on downstream macroinvertebrate populations seems likely, evaluating the precise nature and extent of these impacts in Little Troublesome Creek is beyond the scope of the present study.

6.2 Future Changes

Little Troublesome Creek is currently evolving in response to multiple disturbances—most notably the lingering systemic response to channelization and the response to more recent changes in watershed hydrology associated with urbanization. Incision has previously occurred in much of the channel system. For most of its length, Little Troublesome Creek is in a stage of channel widening. 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). There is little doubt that this scenario is being played out in Little Troublesome Creek.

Particularly in the upper watershed, this recovery process has been complicated by the increase in stormwater volumes and velocities associated with increasing levels of watershed imperviousness. Sediment from construction activities may also have contributed to channel instability and habitat degradation, though the area has been growing relatively slowly and only limited construction was observed during the course of the study. Without intervention, natural processes will continue to widen the incised portion of Little Troublesome Creek until a stable morphology is reached. This process will likely take decades. Further incision may occur,

depending upon the extent and intensity of future development and the nature of associated stormwater management practices. This incision would likely result in even further channel widening and delay the process of recovery.

The headcut between SR 2598 and SR 2600 will continue to move upstream. This will generate sediment that will continue to contribute to downstream habitat degradation. Much of the area immediately upstream of the headcut is not incised. This area will incise as the headcut progresses, causing the destabilization and subsequent widening of this area.

Section 7
Analysis and Conclusions: Causes and Sources of Impairment

This section analyzes the likely causes of impairment in the Little Troublesome Creek watershed, drawing upon the information presented earlier in this report. The sources or origins 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 causes 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 candidate causes of impairment evaluated were:

- Habitat degradation due to sediment deposition and substrate instability.
- Organic and nutrient enrichment (nutrient and low dissolved oxygen impacts).
- Toxicity due to nonpoint source inputs.

7.1.3 Review of Evidence

The Little Troublesome Creek mainstem is impaired for its entire length within the study area. Biological conditions in the lower half of the stream appear to have improved from past surveys, consistent with removal of the Reidsville WWTP discharge in 1998, but the stream remains impaired throughout its length (see Section 4).

<u>Organic and nutrient enrichment</u>. Enrichment was considered as a candidate cause of impairment due to the existence of possible sources of nutrients and organic inputs, the low gradient of the stream in some areas and stagnation due to beaver ponds. Two lines of evidence are relevant here: benthic community data and water quality monitoring data.

While an initial review of available benthic macroinvertebrate data did not clearly indicate impacts from enrichment, further data collection and evaluation showed that benthic community composition at the mid- and lower-mainstem locations (NC 87 and SR 2600) and in the tributary draining downtown Reidsville were indicative of organic enrichment/low dissolved oxygen

conditions (Section 4 and Appendix A). At the two upper mainstem locations, benthic indicators showed impairment, but did not specifically point toward organic enrichment/low dissolved oxygen.

Monitoring of dissolved oxygen levels in Little Troublesome Creek and its tributaries, at a variety of times and locations, provided evidence of sporadic and localized low DO levels (Section 5), mostly associated with very small tributaries and/or beaver dams. Levels of dissolved oxygen that would be expected to have a negative impact on benthos were not observed in the mainstem of Little Troublesome Creek. However, given that periodic monitoring documented DO levels of approximately 5 mg/L at a number of mainstem locations, it is likely that lower DO levels occur on at least an occasional basis.

The fact that streamflows were lower than normal for most of the study period (Section 2) could contribute to DO levels that are atypically low for Little Troublesome Creek. DO levels may be adequate during years of normal streamflow, and perhaps stress from organic enrichment would not be evident under such conditions.

While low streamflows and widespread beaver activity make it difficult to draw conclusions regarding the role of organic enrichment, current benthic data clearly indicate that exposure to low DO conditions must be frequent or intense enough to affect community composition at present. At least during the current low flow period, this important stressor plays a secondary role in existing biological impairment.

Habitat degradation due to sediment deposition and substrate instability. Initial reconnaissance indicated that habitat in the mainstem of Little Troublesome Creek and its tributaries appeared to be substantially degraded. This factor clearly warranted consideration as a contributor to biological impairment. Relevant lines of evidence include benthic macroinvertebate community data, habitat and geomorphic evaluation, and watershed history and characteristics.

The watershed has a long history of activities that can impact habitat on a broad scale. These include: 1) substantial inputs of sediment during past periods of intense agricultural activity; 2) dredging and direct channel modification (straightening, relocation) at various times and locations; 3) channel degradation and widening (including tributaries) in response to channelization; and 4) channel erosion and substrate instability in response to modified watershed hydrology accompanying development. Sediment inputs from construction activities may have been a factor, though in recent decades growth has been slow in the area. Increasingly, beaver activity affects habitat in the area, replacing free-flowing stream habitat with pond and backwater environments.

As described in Sections 4 and 6, habitat in Little Troublesome Creek is highly degraded. Bottom substrate at most locations consists of deep deposits of unstable sand. Riffles and pools are infrequent, and bank habitat and organic microhabitats are minimal at many locations. Macroinvertebrate sampling at all mainstem and tributary locations showed impairment (Section 4). Habitat at the reference stream (Rock House Creek), though sandy, was more stable than sites on Little Troublesome Creek. Riffles were more frequent and organic microhabitat was abundant. It appears that significant recovery has occurred since Rock House Creek last experienced major habitat degradation (probably agricultural sediment inputs from the first half

of the 20th century). A degree of recovery has occurred and Rock House Creek now supports a reasonably diverse benthic community.

Due to the presence of riffle habitat unusual for Little Troublesome Creek, the sampling location above Scales Street in Reidsville has greater habitat and substrate diversity than any other location sampled in the stream, yet supported only a highly degraded benthic community. Broader scale factors are not favorable here, however. Large areas immediately upstream and downstream are dominated by unstable sand that likely periodically affects the sample reach. The site drains a 3.0 square mile watershed that is highly developed with residential and commercial areas and a golf course. Stream biota are likely subjected to extensive scour during storms. Further, Little Troublesome Creek above this site is a small sandy stream with no intact tributaries that can provide a ready source of recolonization following disturbance (see background note on the Stress-Recovery Cycle). This factor may be an important constraint on the biological potential of this site.

The benthic community in the channelized portions of the stream is consistent with habitat impacts, although there were also indications of factors such as organic enrichment and toxicity. Comparison with historic data indicates only a modest degree of improvement in the benthos at the mid- to lower-watershed locations despite substantial water quality improvement due to relocation of the Reidsville WWTP discharge (Section 5). Further improvement in all parts of the stream is likely limited by poor habitat. Habitat degradation is considered a primary cause of impairment.

Toxicity due to nonpoint source inputs. Toxicity was evaluated as a potential contributor to impairment due to the diverse range of land uses and source activities in the watershed and the recent presence (1998) of a major wastewater discharge. Four lines of evidence are relevant: water quality monitoring data collected during the course of the study; in-stream bioassay data; sediment chemistry and bioassay data; and benthic community data.

Benthic community composition indicated likely toxic impacts in the tributary draining downtown Reidsville and at the mid-watershed location at NC 87 (Section 4). Midge deformity analysis also indicated some toxicity at NC 87 (this analysis could not be conducted at the other sampling locations). Benthos did not specifically indicate toxic impacts at other locations, although the macroinvertebrate community was dominated by tolerant taxa at these sites.

One of seven water column bioassays conducted at NC 2600 indicated toxicity (Section 5), providing evidence that toxic conditions occur at least occasionally (this was a chronic test that failed due to test organism mortality). None of the water column bioassays at NC 87 (5 baseflow, 5 stormflow) showed toxicity. At SR 2600 and NC 87, water column metals (lead, copper, zinc, manganese, silver, iron and aluminum) exceeded NAWQC on occasion (Section 5), although only total metals concentrations were analyzed and bioavailability could not be evaluated analytically. No toxicity test was conducted during the baseflow sampling event exhibiting the highest metals concentrations.

Various pesticides and organic compounds were detected in the water column of Little Troublesome Creek (Section 5). In general, comparison of the observed concentrations with screening values did not indicate likely toxicity in water samples. The number of samples was

limited; however, and it is likely that higher concentrations of pollutants periodically occur. Additionally, NAWQC and other screening values are not available for many current use pesticides. For more than 20 other organic compounds, screening values were lower than laboratory detection limits (Appendix B). Whether these analytes were present in concentrations likely to be toxic is thus unknown.

At NC 87, bed sediment concentrations of pyrene were in the non-conservative benchmark range, and concentrations of numerous metals were in the conservative benchmark range. A chronic bioassay conducted on sediments collected at the NC 87 location did not meet the statistical criteria for test failure, but reproduction in depositional sediment at 42 days appeared to be considerably lower than for the control sample, indicating the possibility of some toxicity.

As discussed previously, reach scale habitat at the sampling location above Scales Street on Little Troublesome Creek was good, though broader scale (regional) habitat issues are a concern. This site is probably subject to significant hydraulic stress due to the considerable upstream imperviousness and possesses few, if any, upstream areas to serve as recolonization sources (Section 6). Toxicity may, along with these broader habitat concerns, contribute to impairment at this location.

In the tributary draining downtown Reidsville both reach scale and regional habitat was unfavorable, and benthic community analysis suggests toxic impacts. A limited amount of sampling was done in this small tributary, and toxicity tests were not performed. Lead concentrations in stormwater along with high conductance readings during baseflow suggest that toxicity might be evident if habitat were to improve (see Appendix B).

It is unlikely that the limited number of samples collected during the study captured the full variability in pollutant concentrations, and higher levels of contaminants probably periodically occur. Additionally, NAWQC and other screening values are not available for many current use pesticides. For more than 20 other 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 very episodic and difficult to identify clearly. Even though water column toxicity analyses were performed on numerous occasions and toxic conditions (test failures) were not documented by these tests, one cannot rule out toxicity at other times 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 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

Evidence bearing on potential toxicity is diverse and difficult to synthesize clearly. However, benthic community composition and midge deformities strongly suggest that toxic stressors impact macroinvertebrates at several locations. The bioassay failure at SR 2600 provides further evidence that toxic conditions periodically occur. Toxicity is considered a secondary cause of impairment in Little Troublesome Creek.

Other factors. It is likely that the intensive beaver activity in this watershed has some effect on stream biota. Sufficient information is not available, however, to evaluate the specific nature of beaver impacts on Little Troublesome Creek. Given this uncertainty, beaver activity must be considered a potential contributor to impairment, although DWQ staff have sampled other streams below beaver impoundments without observing the types of impacts seen in Little Troublesome Creek.

Limited recolonization potential from within the watershed is a concern. With its narrow drainage area, Little Troublesome Creek is joined by few tributaries, and many of these lack perennial flow. The headwaters of Little Troublesome Creek and its major tributary drain highly developed portions of Reidsville. This likely makes it more difficult for downstream areas to recover from disturbances.

7.1.4 Conclusion

Multiple lines of evidence support the conclusion that habitat degradation is pervasive and a primary cause of impairment in Little Troublesome Creek. Organic enrichment and toxicity from nonpoint sources are also important stressors to the benthic community at a number of locations and are considered secondary causes of impairment. The impacts of organic enrichment were probably exacerbated by the low streamflows prevalent during the study period. Beaver impoundments likely impact aquatic biota to some degree, although information on specific impacts is lacking. Beaver are considered a potential contributor to impairment.

7.2 Sources of Impairment

Habitat degradation. Habitat degradation in Little troublesome Creek stems primarily from hydromodification. EPA defines hydromodification (source category 7000) as the alteration of the hydrologic characteristics of surface waters resulting in degradation of resource conditions (USEPA, 1997). Two types of hydromodification are the primary reasons for habitat degradation in the study watershed: (1) channelization (alteration of channel morphology, dredging); (2) in the upper portion of the watershed, increased stormflows due to the increase in impervious surfaces associated with development.

The historic channelization of the stream, discussed earlier, had both direct negative impacts on channel conditions and aquatic habitat and enduring indirect effects on bank stability. Considerable bank erosion occurred over a period of decades as Little Troublesome Creek incised and then widened. With the incision of Little Troublesome Creek, tributary streams that had not been channelized incised due to a lowering of local base level, degrading habitat in those streams and providing an additional source of sediment to Little Troublesome Creek. These processes of channelization and incision, which resulted in high steep banks with inadequate

vegetative protection, also made Little Troublesome Creek and its tributaries more vulnerable to future disturbances. Trees continue to be undercut and topple into the stream, and the associated soil becomes stream sediment.

Impervious areas associated with rooftops, roads and parking areas have greatly altered the hydrologic characteristics of the study area, especially in the upstream portion. 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 it to major streams. The resulting increase in stormflows can often be sufficient in itself to cause bank erosion and/or incision. Indeed this is occurring in the headwaters of Little Troublesome Creek. Where banks are already in poor condition due to past activities, as is the case in much of the watershed, severe bank erosion is all but certain. The hydrologic impacts of urban development likely have only a limited impact on the lower reaches of Little Troublesome Creek (e.g., SR 2600) at present. The lack of incision in much of the middle portion of the stream and ready access to a broad floodplain, in conjunction with widespread beaver activity, act to mitigate stormflows and velocities.

The headcut on Little Troublesome Creek in the area below SR 2598 is also a continuing source of sediment (see Section 6). The gully at the headcut provides mass wasting inputs to the channel, which are then gradually carried off by the stream. If the headcut is allowed to gradually work its way upstream, it will deepen the channel and cause additional bank instability.

While most sediment observed in the stream likely has its origins within the channel system, inputs of sediment from eroding upland areas have been a factor historically. As discussed in Sections 2 and 6, agriculture was an important source of past sediment, but has not been significant recently in the study area and is not likely an important contributor to impairment. Given the level of construction activity in the US 29 and 29A corridor areas over the past 20 years, it is likely that sediment inputs from those activities occurred. Whether substantial quantities of this material remains in the channel network is not clear. Current upland sources of sediment are relatively limited, but include road building and other construction activities concentrated along US 29A and NC 87 corridors in Reidsville, along with erosion at stormwater outlets.

Toxicity. The particular pollutants responsible for toxic impacts to Little Troublesome Creek (and their sources) have not been identified. Several metals were often present at elevated concentrations, but their potential role in causing toxic impacts remains unclear. There are many potential sources in upper half of the watershed, which is characterized by diverse urban activities. Inputs likely enter the stream with storm runoff, though periodic spills or unpermitted connections to the storm sewer system are also possibilities. The presence of pollutants in stormwater samples could also be due at least in part to mobilization of fine sediment and attached contaminants already in the stream from past inputs. Specific conductance was highest in the tributary draining a portion of downtown (Appendix B) and in the developed headwaters of Little Troublesome Creek above the confluence, indicating that these areas merit further investigation.

Organic enrichment. The primary reasons for organic enrichment are not clear. Nutrient levels are elevated. Available data appear to indicate that nutrient concentrations during storms are

higher in the more developed upper watershed, but the extent to which loading is driven by storm inputs versus baseflow sources such as infiltration from sanitary sewers is unknown. Agricultural activities are not likely to be a primary source, given the limited agriculture remaining in the watershed and its location in the lower portion of the drainage area. Biochemical oxygen demand (BOD) was not evaluated, but 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 levels in runoff from medium density residential areas was almost twice as high as BOD 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 event concentrations ranging from 11 to 17 mg/L. Given the age of the sanitary sewer system in the older portions of Reidsville, leaky sanitary sewers or illegal connections to the storm sewer system must be considered potential sources. This possibility is supported by the fact that the tributary draining the older part of Reidsville had the highest fecal coliform levels of all areas sampled during the recent TMDL investigation (NCDWQ, 2002). This small stream also appeared to have perennial flow during the study, despite rainfall levels well below average (Appendix D). Instances of organic inputs and low dissolved oxygen were observed near industrial areas (Appendix B). The low gradient of middle and lower portions of the stream, as well as beaver activity, may also contribute to the problem.

7.3 Other Issues of Concern

Though we lack current data on fish communities in Little Troublesome Creek, habitat for fish is very poor, due in large part to sedimentation. Riffle areas, important for many stream species, are largely lacking. Pools are transitory and primarily small. Bank cover is uncommon.

The sediment and nutrients transported by Little Troublesome Creek continue to have negative resource impacts after they leave the study area. Sediment is transported to the Haw River and eventually to B. Everett Jordan Reservoir, where it contributes to habitat degradation and reduces reservoir capacity. Though at under 13 square miles, the Little Troublesome Creek watershed constitutes only a small portion of the Jordan Reservoir drainage, nutrient inputs from this and other small watersheds cumulatively impact the lake.

☞ 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 Troublesome Creek: Recommended Strategies

As discussed in the previous section, the primary causes of impairment in Little Troublesome Creek are: habitat degradation caused by hydromodification; organic enrichment; and toxicity due to unidentified sources. Future development may also pose a threat to streams in the Little Troublesome Creek 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 diverse and functional biological community in Little Troublesome Creek. Over the past century Little Troublesome Creek has experienced major physical disturbance. Because channel instability and degraded aquatic habitat are so widespread, bringing about substantial improvement in physical conditions will be a challenge. Yet the watershed has not been so highly modified as to preclude significant improvements in stream integrity. Watershed imperviousness in the more developed Reidsville portion of the study area is approximately 20%--high enough to cause hydrologic impacts but not to preclude substantial restoration opportunities. Vegetated riparian areas remain along a significant portion of major stream corridors. A return to the relatively unimpacted conditions that probably existed prior to widespread agriculture is unlikely, but Little Troublesome Creek can potentially support a healthier community than it does today. The exact extent of biological improvement that will occur as habitat and water quality is restored is difficult to predict.

8.1.1 Habitat Degradation--Sedimentation and Substrate Instability

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

a. Background

Habitat deterioration in Little Troublesome Creek is driven by hydromodification of two types—long-term adjustments to past channelization, and the hydrologic impacts of recent and ongoing development in the upper watershed. The impacts of these disturbances have been cumulative and (in the upper watershed) are difficult to differentiate. In the absence of further management actions, substantial channel adjustment--with resulting poor habitat for fish and macroinvertebrates--will likely continue until the stream has had an adequate time to develop a channel morphology in equilibrium with hydrologic conditions in the watershed. Continually changing hydrology associated with ongoing development will prolong this period of adjustment.

Given the significant hydrologic alteration of the headwaters and the downtown tributary, greatly improved aquatic habitat may not follow stream stability, especially in the upper portion of the study area. 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. Sedimentation would likely be less significant once the channel stabilizes. However, the altered hydrologic conditions associated with increased development, if not at least partially mitigated, are likely to result in conditions which would make it extremely difficult to sustain substantial improvements in aquatic communities.

b. Improving Aquatic Habitat— A General Approach

Both stream channel restoration and stormwater retrofits to control stormwater volume and velocity are necessary to address the poor habitat conditions in Little Troublesome Creek. Specifically:

1. The entire mainstem of Little Troublesome Creek below Richardson Drive should eventually be restored to a stable morphology.
2. Stormwater BMPs to reduce post-construction runoff volume and partially restore watershed hydrology should be implemented in the existing developed areas of the Little Troublesome Creek headwaters, the tributary draining downtown Reidsville and industrial parks above NC 87.
3. Channel restoration and stormwater BMPs must be implemented in an integrated fashion so that both channel morphology and watershed hydrology problems are addressed using a coordinated approach in each subwatershed. Given the scope of the problem, it will be necessary to implement restoration efforts incrementally over an extended period of time. Ongoing planning will be a necessity.
4. The headcut below SR 2598 should be stabilized as soon as practical to prevent further incision and channel destabilization.

<u>Stream channel restoration</u>. Significant improvements in aquatic habitat are unlikely as long as the channel network remains grossly unstable. Over a period of decades the channel will develop a stable form on its own. The alternative to waiting for this to occur is a large-scale stream channel restoration effort to create a stable channel morphology. It is not likely that smaller scale habitat improvement efforts would be adequate to reverse the widespread decline in aquatic habitat. Even if effective in improving habitat in localized areas, such areas would be largely isolated from one another and would not function well ecologically. Further, such an approach would do nothing to address the large sediment loads that Little Troublesome Creek contributes to the Haw River, or the loss of streamside property caused by bank erosion.

Since overall channel morphology is unstable, simple bank stabilization will not be effective. Stream channel restoration is necessary to reestablish a stable channel dimension (cross-sectional dimension), pattern (sinuosity and planform) and longitudinal profile (slope). While other options exist (see NCSU, 2001a and 2001b), the most feasible approach to the restoration of the incised channels in this watershed is probably to construct appropriate floodplain area and channel form within the existing incised 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, 2001a and 2001b; Rosgen, 1997).

Stormwater retrofits. Relying on channel stabilization and restoration alone to substantially improve aquatic habitat and biological conditions in the upper portion of the watershed does not have a high probability of success. Although channels can be designed to remain stable under existing hydrologic conditions, stress on aquatic organisms from frequent periods of high velocity and scour will be considerable, and is likely to limit the resulting biotic diversity. Partial restoration of watershed hydrology--the mitigation of some of the hydrologic impacts of existing development--is often a prerequisite for the improvement of urban stream habitat.

Stormwater retrofits are structural stormwater measures (best management practices or BMPs) for urban watersheds that are 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 specific local needs and conditions. These issues will be discussed later. Many practices installed to reduce hydrologic impacts will also remove pollutants, though this is highly variable by pollutant and by BMP.

Timing and scope. Improving habitat conditions throughout the mainstem of Little Troublesome Creek is a long-term objective, but restoration of Little Troublesome Creek below NC 87 should not be undertaken in the short run. The middle and lower mainstem will be difficult if not impossible to restore as long as sediment loads (primarily from upstream bank erosion) and uncontrolled stormwater flows from tributary and headwaters areas continue unabated. Short-term goals must therefore focus on the restoration of these smaller subwatersheds. Restoration of the middle and lower mainstem of Little Troublesome Creek should be approached after upstream sediment sources have been controlled and upstream hydrologic conditions have been mitigated to the extent feasible.

Given the size of the watershed, restoration will be a task of substantial proportions. Specific projects must be designed and implemented incrementally over an extended period of time. Improvement in stream condition is also likely to be incremental. Individual subwatersheds should be the operational unit for planning and implementation (Caraco et al., 1998). Considering the scope of activities, logistical complexities and scientific uncertainties it is not possible to anticipate all necessary actions in advance. Restoring Little Troublesome Creek, and urban streams generally, requires an iterative process in which sequential efforts are implemented over time in conjunction with an effort to monitor changes in stream condition and plan subsequent actions.

While all steps cannot be outlined in advance, it is possible to chart an initial direction for restoration. The following section proposes a set of restoration activities for Little Troublesome Creek above NC 87 as the first priority area to be addressed. Organizational and planning issues are discussed further in Section 8.3.

Watershed restoration of the type necessary to significantly improve Little Troublesome Creek 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); Montgomery County, Maryland (Montgomery County DEP, 2001); and Michigan's Rouge River watershed (Cave and Bryson, 2001; Rouge River Project, 2002).

c. Developing a Subwatershed Strategy for Little Troublesome Creek above NC 87

For the reasons discussed above, the upper Little Troublesome Creek watershed is proposed as the initial focus for restoration activities. This area can serve as an early basis for both technical work and the formation of an organizational framework for watershed restoration and intergovernmental cooperation. The initial practices implemented would serve as pilot projects to help familiarize stakeholders with both the processes and practices of stream channel restoration and stormwater retrofitting. With appropriate monitoring, these efforts would also provide important information regarding the extent and pace of biological improvement that can be expected. Much of the stream is bordered by a vegetated riparian area. The upper watershed is entirely within the City of Reidsville, simplifying governmental jurisdiction issues. The length of the mainstem above NC 87 is about four miles, with tributary channels (based on 1:24000 scale topographic maps) of about the same length. Impervious areas covered an estimated 20% of the eight square mile watershed in 1993.

Restoration efforts within this subwatershed should include the following measures:

1. Appropriate stormwater retrofit opportunities should be identified and implemented to reduce stormwater volumes and velocities. Management should focus on three discrete areas: a) the downtown tributary watershed, where the most concentrated commercial (and some industrial) activity is located; b) the Little Troublesome Creek headwaters above the tributary confluence, which is also extensively developed; and c) the area between the tributary confluence and NC 87, which drains industrial areas on the south side of Reidsville. Appropriate retrofit opportunities should be carried out in each of these three catchments.
2. The mainstem of Little Troublesome Creek above NC 87 should be restored at least from Richardson Drive to the confluence with the downtown tributary, a distance of approximately two miles. Restoration opportunities above Richardson Drive and on the tributary draining the downtown section of Reidsville should also be evaluated. The evaluation conducted by NCSU as a part of this study (NCSU, 2001a) documents current morphology of one reach in this area and discusses restoration options.
3. Restoration opportunities on small tributaries in the upper watershed should also be identified.
4. Stream condition and the necessity for restoration of the creek from the tributary confluence down to NC 87 should be evaluated. Much of this section, though still undergoing morphological adjustment, has progressed further towards a stable state than the other channelized portions of the stream. Potentially, much of this section could be left to stabilize naturally without imposing a substantial sediment load on downstream reaches.
5. Stormwater BMPs should be in place prior to restoration of the mainstem channel above NC 87.

6. Forested buffers should be restored in areas in which they do not exist. Property owners should be encouraged to replant native riparian vegetation along tributary channels from which such vegetation has been removed.

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) and detailed in state BMP manuals (e.g., NCDWQ, 1999; Maryland Department of the Environment, 2000). Some of these include:

- detention ponds;
- retention (wet) ponds;
- stormwater wetlands;
- 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);
- education to promote hydrologic awareness; and
- changes in design/construction standards.

Determining which BMPs (or which combination of practices) will be most feasible and effective for a particular catchment depends on numerous site specific and jurisdictional specific issues, including: drainage patterns; size of potential BMP locations; treatment volume needed (considering catchment size and imperviousness); soils; location of existing infrastructure; 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). A key design challenge is to maximize hydrologic mitigation and/or pollution removal potential while limiting impacts to infrastructure and existing structures.

Recommendations for specific stormwater retrofit projects are beyond the scope of this investigation. Specific projects should be identified as part of the development of more detailed restoration plans for individual subwatersheds. These plans should be developed with the input of a broad-based stakeholder group and should consider water quality goals, other water resource concerns (e.g., flooding) and local infrastructure issues.

DWQ encourages the consideration of a wide range of practices and approaches. Ponds of various types are probably the practice most familiar to many engineers and can indeed be versatile and cost-effective. Detention alone does not reduce stormwater volume; however, though the rate and timing of discharge are controlled. It is important to carefully examine infiltration practices (both structures and 'behavioral' changes such as redirecting downspouts to pervious areas) and design approaches that reduce the volume of runoff. 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. Some retrofit methods may have negative side effects that must be carefully considered. For example, regional wet detention facilities may disrupt recolonization, alter the food/energy source available to downstream biota and, depending upon design and operation, reduce downstream baseflows (Maxted and Shaver, 1999; Schueler, 2000a).

d. Beaver Impacts

Beavers are common in the creek. This activity has both negative and positive aspects. Though obviously part of the natural environment, it is often difficult for beaver impoundments and stream channel restoration projects to coexist. Beaver impoundments can alter the sediment transport capacity of a stream and can cause bank blowouts. A strategy for limiting or mitigating beaver impacts should be developed in conjunction with restoration planning. One option is to allow beaver activity to continue in areas where the stream is not highly incised and channel restoration is not essential. Active management over the long-term will probably be needed.

e. Other Issues/recommendations

The gully and head cut on the mainstem of Little Troublesome Creek 0.3 miles downstream of SR 2598 must be stabilized. Although this is located toward the lower end of the watershed, it is important that temporary stabilization occur as soon as possible. Restoration of the channelized lower portion of the creek, downstream of this reach, is probably not appropriate until upstream issues have been addressed. This may take some time to accomplish, however. Meanwhile, the headcut will continue its gradual migration upstream, making eventual restoration more costly and serving as a continuing source of sediment.

An engineered solution is required to stabilize the headcut and allow the stream to dissipate the energy of the large drop in grade (NCSU, 2002a). Given the unique characteristics of the site, an engineering study will be necessary to determine specific options. Cost cannot be estimated with available information.

Another active gully, on a small tributary downstream of Equity Drive, also should be stabilized. Stormwater runoff from adjacent industrial facilities needs to be controlled to limit future sediment input to the creek.

f. Costs and Constraints

The restoration of channel stability and aquatic habitat in Little Troublesome Creek will be a major undertaking in terms of technical planning, project implementation, finances and organizational coordination. Costs will be considerable. Rough cost estimates for channel restoration and stormwater retrofitting for the upper watershed are provided below.

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 should be expected for the restoration of urban stream channels. The restoration of 2.5 miles of mainstem channel and two miles of tributary channel (21,120 feet) in the upper watershed above NC 87 would likely cost on the order of $4.7 million or more.

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 $10,000 per impervious acre treated for projects treating 10 impervious acres, but $5,000 per impervious acre

treated for projects covering 100 impervious acres. Little Troublesome Creek above NC 87 has approximately 1024 impervious acres (8 square miles, or 5120 acres, times an imperviousness of 20%). Retrofitting of all impervious areas will be neither necessary nor feasible. Claytor (1999) suggests that a minimum of 50% of a watershed be retrofitted. Assuming a cost of $7,500 per impervious acre (typical treated area size between 10 and 100 acres), it would cost approximately $3.75 million to retrofit 500 impervious acres. These estimates are based on data that are several years old and are subject to many uncertainties, but a minimum of $1 million per square mile of watershed can be used as a gross approximation of the costs of a large-scale watershed restoration.

Costs could be reduced to some extent if restoration is planned and implemented in conjunction with capital improvements and infrastructure enhancements (e.g., bridge or sewer line replacement) anticipated by local governments. 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). Cost-effective restoration opportunities are also likely as portions of the watershed are redeveloped incrementally over a period of decades (Ferguson et al., 1999).

Restoring the miles of unstable stream channel in the entire Little Troublesome Creek watershed will necessitate working cooperatively with many (potentially one to several hundred) property owners. 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 the Little Troublesome mainstem will be an advantage in terms of access but a constraint in terms of restoration options.

8.1.2 Organic enrichment/low dissolved oxygen

As described in Section 7, the major sources of nutrients and oxygen demand have not been specifically identified, but likely reside primarily in the developed upper portion of the watershed. Both stormwater sources and the sanitary sewer system are likely to be important contributors. Actions recommended above or planned to address other problems or regulatory requirements should at least partially address organic loading and constitute an important first step in addressing the issue: 1) stormwater retrofit activities intended to control stormwater volumes will likely reduce nutrients to some extent; 2) activities undertaken to address fecal coliform sources under the recently developed TMDL are likely to result in further identification of organic loading sources and some reduction in inputs; 3) Reidsville's actions (under the new collection systems permit) to assess the condition of its sanitary sewer system will also assist with source identification. Some types of problems, e.g., replacing leaking sanitary sewer lines, may take years to fully address. Periodic biological monitoring would also serve to document whether the benthic community continues to indicate stress from organic enrichment/low dissolved oxygen after streamflows return to normal and initial management actions have been taken to address sources.

8.1.3 Toxicity

Biological data indicate that toxic impacts are likely in the tributary draining downtown Reidsville. Impacts appear to extend at least as far downstream as NC 87. 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. However, the problem will be difficult to address directly with the existing level of information. Implementing structural BMPs to remove toxicants of unknown origin or characteristics could be extremely inefficient and potentially ineffective. Results of additional monitoring 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. Various source control activities would be relatively easy to implement, and should be an important component of a toxics strategy. Some of these include: education of residents and property managers regarding proper use of storm drains; education of residents, maintenance personnel and commercial applicators regarding appropriate pesticide use; enhanced pollution prevention practices in industrial facilities and municipal operations facilities.

Stormwater retrofit measures in the headwaters area, carried out as part of the overall Little Troublesome Creek restoration strategy, will also result in some pollutant removal and may result in the attenuation of toxicity. The additional scrutiny given to stormwater and sanitary sewer issues as part of the fecal coliform TMDL and Reidsville's collection system review may result in the identification of some specific sources. Additional data should be obtained to more narrowly define the nature and sources of the toxicants involved. Periodic biological monitoring should be carried out in the headwaters to determine if the benthic community improves as the result of these activities.

8.2 Addressing Future Threats

Portions of the watershed are relatively undeveloped at the present time, particularly in the lower half of the study area. Considerable development is likely in these areas over the next several decades. Without an effort to mitigate the hydrologic impacts of this development or improve sediment and erosion control practices for construction, continued stream degradation in Little Troublesome Creek is likely. Addressing these future threats is essential, or improvements resulting from efforts to control current sources of impairment may be short-lived or may never materialize.

8.2.1 Sediment from New Construction

Significant future sediment inputs would prolong habitat instability even if existing sources of sediment (primarily bank erosion) were addressed. Construction activity during the study period was relatively limited and rainfall was below average. Significant upland sediment inputs were not observed. It is clear from experience elsewhere, however, that sediment inputs from

construction activities can be substantial, particularly in the case of large projects, and that existing practices often do not protect streams from sediment impacts.

Effective enforcement of sediment and erosion control regulations on the part of the Division of Land Resources will be essential to the prevention of additional sediment inputs from construction activities. While a complete evaluation of current sediment and erosion control practices is beyond the scope of this study, development of improved erosion and sediment control practices may be beneficial. The CWMTF could consider working cooperatively with regulatory agencies and willing developers to install and monitor innovative approaches that could supplement or serve as alternatives to current practices and requirements.

8.2.2 Hydromodification Due to Increased Stormflows

As new development occurs in the Little Troublesome Creek watershed, it is likely that stormflows will increase with the expansion of associated impervious areas. Both peak discharges as well as the frequency and duration of high velocity flows can be expected to increase and to 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, stream banks throughout the watershed are in poor condition and prone to erosion. Streams in the study area are likely to be highly sensitive to increases in stormflow. Given these conditions, increased bank erosion and/or incision is likely if significant hydrologic change occurs in the watershed.

New development in the study area is currently subject to the City of Reidsville's stormwater ordinance, which applies to new development that adds at least 10,000 square feet of impervious area (Section 2). While the city's stormwater and drainage requirements may result in some water quality benefits, their primary impact is probably to limit downstream flood peaks. It is unlikely that these regulations, which require control of the 10-year storm, will protect stream channels from the hydrologic impacts of development. Smaller, more frequent storms, 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).

While Reidsville is not automatically designated by EPA for coverage under the Phase II stormwater program currently being implemented, it may potentially be regulated if designated by the state (see Section 2).

Whether accomplished through Phase II requirements or voluntary local action, it is important that comprehensive practices for the management of post-construction runoff be implemented. The sensitive channels in this watershed are most likely to be protected from the hydrologic impacts of new development if post construction stormwater requirements include:

1. Extended detention of the 1-year 24-hour storm or alternative criteria to address geomorphically relevant flows (see Brown and Caraco, 2001; Maryland Department of the Environment, 2000).
2. Active promotion of infiltration practices and other approaches to limit stormwater volume (examples include grassed swales and bioretention areas; see Prince Georges County DER, 2000.

3. Application of these requirements to all new development.

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 and intermittent streams.

8.2.4 Other Concerns

Many water quality impacts can result from the incremental and cumulative impacts of land management decisions made by individual residents and property owners throughout the watershed. Educational efforts directed at homeowners and managers of commercial and industrial areas in the watershed would be useful to promote improved riparian zone management and the appropriate use of pesticides and fertilizers.

8.3 A Framework for Improving and Protecting Stream Integrity

Restoration projects of this scale require an iterative process of 'adaptive management' (Reckhow, 1997; USEPA, 2001). An initial round of management actions should 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. An organizational framework for ongoing watershed management is essential in order 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 (Rockingham County and Reidsville), as well as a broad range of other stakeholders, will be critical if conditions in Little Troublesome Creek 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 a patient approach to planning and implementing projects to move toward that vision.

The planning framework being developed as part of the local watershed planning process initiated by the NC Wetlands Restoration Program in the Troublesome Creek and Little Troublesome Creek watersheds (see Section 2) could serve as the basis for this effort.

8.4 Summary of Watershed Strategies for Little Troublesome Creek

The most important factors leading to impairment in the study area are systemic in nature. Addressing these problems will require actions that are similarly broad in scope. Mitigating the

potential impacts of future watershed development on watershed hydrology is also critical, or improvements resulting from efforts to control current sources of impairment may be short lived.

The following actions are necessary to address current sources of impairment in Little Troublesome Creek and to prevent future degradation. The intent of these recommendations is to describe the types of actions necessary to improve conditions in Little Troublesome Creek, not to specify particular administrative or institutional mechanisms for implementing remedial practices. Actions one through six are all essential to the restoration of aquatic communities throughout the Little Troublesome Creek study area. Actions seven through nine are important in order to protect streams in the watershed from the impacts of new development. The remaining actions would also be useful to improve water quality but will result in limited improvement unless the first six are also accomplished.

1. **Over the long run, extensive stream channel restoration activities and stormwater retrofit BMPs should be implemented in much of the watershed in order to improve aquatic habitat**. This will involve a substantial effort that would likely take several decades to fully implement:
   a) Much of Little Troublesome Creek, as well as a few tributary channels, should be restored to a stable morphology.
   b) BMPs to reduce stormwater runoff volume and partially restore watershed hydrology should be implemented in the existing developed areas of the Little Troublesome headwaters, the tributary draining portions of downtown Reidsville, and other areas of dense development, such as the existing industrial park.
2. **These activities should be implemented deliberately and incrementally over time**.
   a) Work should be carried out first in tributary and headwaters subwatersheds. Restoration of the mainstem of Little Troublesome Creek should be approached later when upstream sediment sources have been reduced and upstream hydrologic conditions have been mitigated to the extent practical.
   b) Channel restoration and stormwater BMPs must be implemented in an integrated fashion so that both channel morphology and watershed hydrology problems are addressed using a coordinated approach in each subwatershed.
   c) Local governments and other stakeholders must develop the cooperative organizational framework necessary to carry out the watershed planning, project design, implementation and monitoring activities that will be necessary to sustain this effort over time.
   d) Since it is difficult for restored stream channels to maintain stability and proper sediment transport in the presence of active beaver impoundments, a strategy for managing beaver impacts should be developed in conjunction with detailed restoration plans.
3. **The eight square mile subwatershed consisting of Little Troublesome Creek above NC 87 should serve as the focus for initial planning and project activities**. Costs are likely to exceed $1 Million per square mile of watershed. Activities should include:
   a) Developing specific plans for three distinct subareas: the downtown tributary watershed, where the most concentrated commercial land use is located; the Little Troublesome Creek headwaters above the tributary confluence; and the area between the tributary confluence and NC 87, which drains industrial areas on the south side of Reidsville.
   b) Implementing appropriate retrofit opportunities to control runoff volume and velocities flows from existing developed areas in each of these three catchments. The selection of

specific BMP types and locations will require additional planning and site specific engineering evaluations.

c) Restoring the mainstem of the creek to a stable morphology from Richardson Drive to the confluence with the downtown tributary.
d) Further evaluating the necessity for restoration of the creek from the tributary confluence down to NC 87. Much of this section has progressed further towards a stable state than the other channelized portions of the stream and can potentially be left to stabilize naturally without imposing a substantial sediment load on downstream reaches.
e) Evaluating and implementing channel restoration opportunities on tributaries.
f) Encouraging property owners along all streams to replant native riparian vegetation.

4. **The headcut in Little Troublesome Creek downstream of SR 2598 should be stabilized as soon as practicable**. Although restoration of the stream channel in this area is probably not appropriate until upstream issues have been addressed, stabilization of the headcut is advisable in the short run to prevent its continued migration upstream. Further migration of the headcut would serve as a continuing source of sediment and make eventual restoration more costly.
5. **Actions recommended above and activities already planned to address other problems or regulatory requirements are likely to reduce organic and nutrient loading** to some extent, perhaps substantially. These include: stormwater retrofits intended to control stormwater volumes and velocities; activities undertaken to address fecal coliform sources under the recently developed TMDL; Reidsville's actions under the new collection systems permit to assess the condition of its sanitary sewer system. **Local and state agencies should be encouraged to give these activities a high priority**. Periodic biological monitoring should be undertaken to evaluate whether indicators of organic enrichment decline and whether further action is necessary.
6. **Additional data should be obtained to more narrowly define the nature and source of toxicants impacting Little Troublesome Creek and the downtown tributary**. Planned or recommended activities (e.g., BMPs intended to control stormwater volumes or fecal coliform TMDL implementation efforts) may reduce toxicant inputs to some degree. Additional pollution control efforts may well be necessary. Some source control measures (such as enhanced practices at industrial facilities and municipal operations facilities) would be relatively easy to implement in the short-term and should be an important component of a toxics strategy. Other BMPs (such as structural stormwater treatment practices) will be difficult to plan or implement efficiently without further information. Periodic monitoring should be carried out to determine if ongoing activities lead to improvements in the benthic community.
7. Post-construction stormwater management should be required for all new development in the watershed in order to prevent further channel erosion and continued habitat degradation due to additional uncontrolled stormwater inputs. These requirements are more likely to be effective if they include the active promotion of infiltration practices and other approaches to limit stormwater volume, and extended detention of the 1-year 24-hour storm, or alternative criteria to address geomorphically relevant flows.
8. Whether accomplished through incentives or regulatory means it is important that existing riparian buffers be protected.
9. Effective enforcement of sediment and erosion control regulations on the part of the Division of Land Resources will be essential to the prevention of additional sediment inputs from

construction activities. Development of improved erosion and sediment control practices may be beneficial.

10. An area of active channel erosion in the tributary draining the Equity Drive area on the east side of Reidsville should be stabilized. Controlling industrial stormwater runoff is a necessary first step in this process.
11. A watershed education program should be developed and implemented with the goal of targeting homeowners and managers of commercial and industrial facilities in order to reduce current stream damage and prevent future degradation. At a minimum the program should include elements to address the following issues:
    a) redirecting downspouts to pervious areas rather than routing these flows to driveways or gutters;
    b) protecting existing wooded riparian areas on ephemeral streams;
    c) replanting native riparian vegetation on perennial, intermittent and ephemeral channels where such vegetation is absent; and
    d) reducing and properly managing pesticide and fertilizer use.

Section 9
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