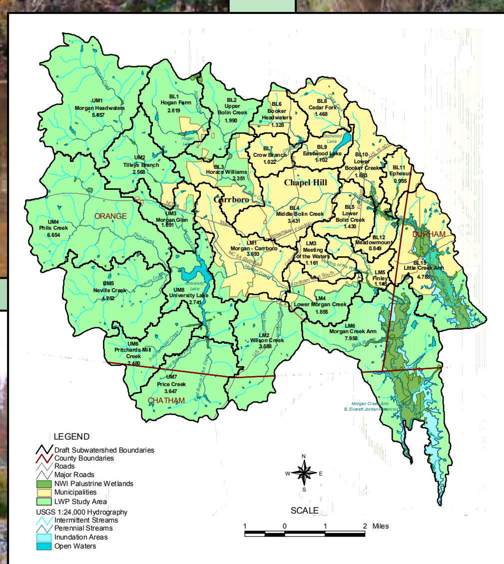
Morgan Creek Local Watershed Plan

Detailed Assessment Report

North Carolina Ecosystem Enhancement Program

Ecosystem Enhancement PROGRAM

July 2004



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Morgan Creek
Detailed Assessment Report
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1 Introduction

The North Carolina Ecosystem Enhancement Program (NCEEP) has recognized the importance of framing stream and wetland restoration efforts within a watershed context to maximize the functional benefits realized through these projects. The primary mechanism for realizing this objective is the development of a *Local Watershed Plan* that identifies the major causes and locations of degraded or threatened watershed functions, and cost-effective restoration or protection projects and Best Management Practices (BMPs) to address these needs.

In the initial phases of this local watershed planning (LWP) effort, all existing data and assessment information pertaining to the study area were analyzed and reviewed. This information, in conjunction with preliminary reconnaissance, was utilized to identify the primary threats, or stressors, to watershed functions within the study area. The three primary areas of watershed function addressed in this effort are: 1) Hydrology and Aquatic Habitat Functions, 2) Water Quality and Water Supply Functions, and 3) Terrestrial Habitat Functions. The conclusions of these initial phases are documented in the *Preliminary Findings Report* (Tetra Tech, 2004), which also includes a detailed description of the study area and additional characterization information. In addition to identifying the primary threats to watershed functions, the *Preliminary Findings Report* establishes the appropriate indicators necessary to measure conditions in the watershed in terms of those stressors, and describes the assessment tools and methods to evaluate the indicators. The reader is urged to review the *Preliminary Findings Report* (*PFR*) prior to reading this document; a summary of the *PFR* is presented in Section 1.1 below.

This *Detailed Assessment Report* describes the assessments of each of the indicators set forth in the *Preliminary Findings Report* and the conclusions resulting from them. In addition, this report applies a comprehensive assessment of all indicators to identify those portions of the study area having the greatest existing functional losses and the greatest risk for future degradation of watershed functions. Areas with the greatest existing functional losses will be targeted for stream and wetland restoration/enhancement, retrofitting of BMPs, and other management efforts to address those losses. Areas with the greatest risk of future degradation will be targeted for development of the appropriate management and protection measures to prevent those losses. In addition, this Detailed Assessment seeks to identify the most undisturbed portions of the riparian corridor within the study area with the highest quality terrestrial habitat and targets those areas for preservation efforts. By targeting preservation efforts in conjunction with restoration projects, the optimum benefits of each of these measures can be realized at the holistic watershed scale.

In the final phases of this local watershed enhancement planning effort, the management alternatives identified to address the targeted areas for restoration, protection, and preservation will be described in detail and prioritized on the basis of factors such as their feasibility and cost effectiveness.

1.1 Summary of Preliminary Findings Report

The final draft of the *Preliminary Findings Report* was submitted to NCEEP in January 2004. That document characterized existing watershed conditions based upon available information sources from previous assessment and characterization efforts within the study area. The report recommended indicators and assessment tools for evaluating watershed function to be used in the next phase of the planning process. For purposes of further discussion, a detailed map of the study area and its subwatersheds is presented in Figure 1-1.

Field reconnaissance efforts and assessments of existing data revealed a consistent pattern of watershed functional health across data types and data sources. The evidence consistently indicates that the primary watershed functions are fully or mostly intact in the rural headwater portions of both the Morgan and

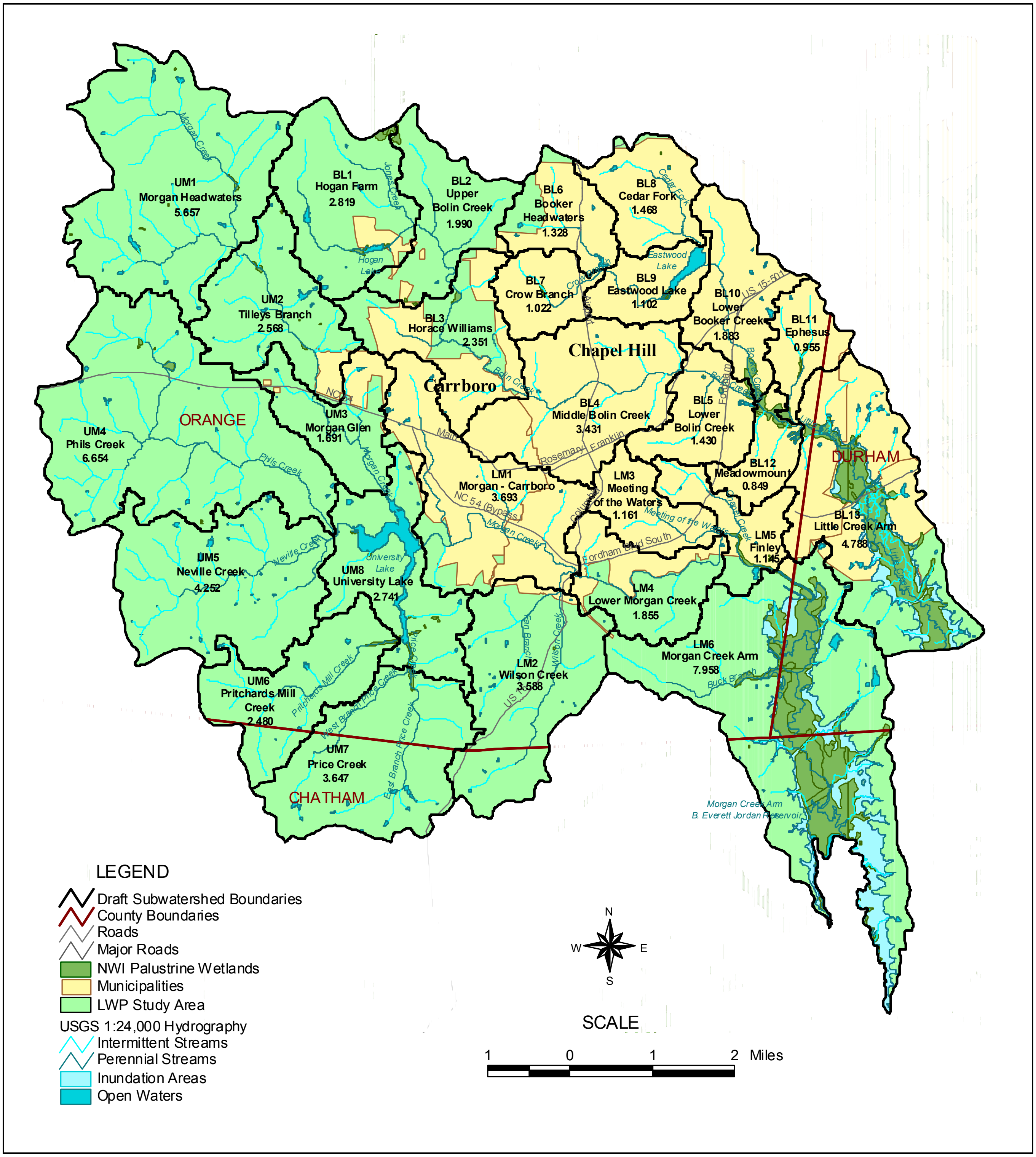

Figure 1-1. Local Watershed Plan Study Area and Delineated Subwatersheds

Key Terms

In the context of Local Watershed Planning the term **“stressor”** refers to forces within the watershed, usually resulting from human activities or alteration, which have the potential to degrade watershed functions. For instance, urban stormwater runoff is a common stressor with the potential to adversely impact aquatic habitat, water quality, and hydrologic functions within a watershed. Due to its diffuse nature, stormwater runoff cannot always be measured directly, but rather, is measured with indicators of its impacts. The term **“indicator”** is used to mean a quantifiable or subjectively rankable measure that provides a means of evaluating the health of watershed functions and that can be predicted in response to management options. Examples of indicators include water quality parameters (e.g., DO, temperature, nutrients, metals), percent imperviousness, percent disturbed buffer, sediment load, stream erosion/instability, and chlorophyll *a*. Linking management objectives to water quality and aquatic habitat impacts through the use of indicators provides decision-makers with meaningful information to support specific management decisions. That linkage is established through the use of assessment tools. The term **“assessment tool”** refers to the data collection, modeling and statistical analyses used to quantify the status of indicators and predict the outcome of management actions. In the course of watershed assessment, the level at which an indicator is said to show degradation of watershed functions is referred to as a **“targeting threshold.”** When a given indicator exceeds the targeting threshold, it means that management action is necessary to address the appropriate stressor in order to restore the affected watershed functions. Often, the goal of management actions is to reduce or eliminate the impact of the stressor to a sufficient degree to lower the predicted indicator value to a level at or below the targeting threshold.

Bolin/Little Creek watersheds. However, the evidence also indicates a progressive decline in the health of these functions moving downstream into the urbanized portions of each watershed.

A number of factors contribute to this downstream decline in functional health including increases in imperviousness, disturbance of overall forest cover, riparian buffer disturbance and encroachment into floodplain areas. These changes in land use/land cover conditions from upstream to downstream have resulted in degradation of watershed functions that is evident in the decreasing taxonomic diversity of the benthic community data, and in the increased proportion of water samples that failed to meet water quality criteria.

The distinction between rural upstream and urbanized downstream portions of the watersheds is also seen in channel geomorphic conditions as indicated by the visual stream assessments performed by Tetra Tech using the USDA (1998) Stream Visual Assessment Protocol (SVAP). With some exceptions, the SVAP stream morphology scores tend to be in the Good to Excellent range in the upstream segments, declining to Fair to Poor conditions in the downstream sections (refer to Figure 2-3). Similarly, a greater proportion of the sites selected by the stakeholder team to reflect “Good” watershed conditions were located in headwater areas and a greater proportion of those deemed to reflect “Bad” conditions were located in the downstream sections of each watershed.

The upstream to downstream pattern of degradation illustrated in the *Preliminary Findings Report* indicates that urbanization is the biggest overall threat to watershed functions. For this reason, the overall focus of the *Detailed Assessment* phase is to quantify the impacts of urbanization on watershed functions where it has already occurred or is predicted to occur in the future. As urbanization occurs, threats to watershed functions can include: increased stormwater discharges directly to streams, in terms of both volume and velocity; increased overland flow of stormwater; increased pollutant loading in stormwater due to build-up and wash-off, illicit connections, and dumping into storm sewers; increased stream temperature due to lack of shading and heated stormwater runoff from ponds and impervious areas; reduced groundwater recharge and baseflow due to increased imperviousness; and decreased number and diversity of plants and animals due to the lack—or poor quality—of habitat.

Subsections 1.1.1 through 1.1.3 summarize the specific objectives for detailed assessment of the three distinct groups of subwatersheds (defined here as the USGS 14-digit hydrologic units) within the study area.

1.1.1 Upper Morgan Creek Subwatersheds (UM1 through UM6)

The *Preliminary Findings Report* concluded that watershed functions are less threatened in the Upper Morgan Creek subwatersheds than in the other subwatersheds within this LWP study area. Due to development restrictions of a five-acre minimum lot size, imperviousness levels are relatively low, the majority of riparian buffers are intact, and nearly 60 percent of the watershed land area remains forested. **Despite the overall rural and undisturbed nature of Upper Morgan Creek, some localized threats to watershed functions do exist. One or more dairy farming operations in the Morgan Creek headwaters (UM1) require implementation of appropriate best management practices to protect stream corridors.** Future development across the entire area of the Upper Morgan Creek watershed has the potential to cause stream degradation. Despite the land use restriction holding new development to a five-acre minimum lot size, widespread low-density suburban development across the subwatershed will increase road infrastructure and convert forest land to buildings, driveways, and lawns, which could result in significant increases in stormwater runoff rates.

Objectives for Detailed Assessment:

- **Quantify the range and extent of adverse impacts stemming from those localized stressors associated with agricultural activities in Upper Morgan Creek.**
- **Identify the restoration and management opportunities associated with those localized stressors in Upper Morgan Creek.**
- **Estimate the potential for stream degradation as a result of low-density suburban development on a watershed scale within the Upper Morgan Creek watershed and identify those areas most at risk.**
- **Identify those areas with the highest quality of aquatic and terrestrial habitat and prioritize them for preservation.**

1.1.2 Lower Morgan Creek Subwatersheds (LM1 through LM6)

The health of Lower Morgan Creek varies significantly from subwatershed to subwatershed. University Lake and the storm flow control it provides has had a net beneficial effect on the mainstem of the creek resulting in relatively high benthic community ratings and good water quality at sites downstream of the lake.

In contrast, Meeting of the Waters (MOW) Creek drains a portion of the highly urbanized main campus of UNC-Chapel Hill resulting in high overall imperviousness within the subwatershed (LM3). Benthic community and water quality ratings in this subwatershed are among the lowest in the study area. The entire lengths of MOW Creek and Morgan Creek from the confluence with MOW downstream to Jordan Lake are listed as "impaired" on the NCDWQ 2002 303(d) List (2003a) and the list attributes the impairment to urban runoff and storm sewers. The other tributaries of the Lower Morgan Creek watershed vary significantly in their condition depending on the level and location of development within them. Several tributaries including Wilson Creek are experiencing active stream erosion and received relatively low SVAP scores in their lower reaches due to development. However, the upper portions of these tributaries often are relatively undeveloped and preliminary reconnaissance efforts indicate healthy conditions.

Some of the quality wildlife habitat areas identified by a Triangle Land Conservancy (TLC) study (Wiley et al., 1999) are located in the Lower Morgan Creek watershed. However, in the intervening period since the TLC study, some of these quality habitat areas within the watershed have been lost to or significantly degraded by development.

Objectives for Detailed Assessment:

- **Further quantify the impacts of urban stormwater runoff on MOW Creek and identify potential management and stormwater BMP retrofit opportunities to alleviate those impacts.**
- **Determine the need for stream restoration along MOW Creek and identify reaches where restoration would be feasible and beneficial.**
- **Identify those sections with the greatest existing levels of erosion and degradation and target those areas for restoration and management efforts to alleviate the losses of aquatic habitat and flood attenuation functions.**
- **Identify those segments where degradation has not yet occurred, but where future development is likely to result in damaging stormwater runoff and target those areas for the management efforts to prevent the associated functional losses.**
- **Identify those areas with the highest quality of aquatic and terrestrial habitat and prioritize them for preservation. (The highest priority will be given to those quality habitat areas at the greatest risk of being lost to development.)**

1.1.3 Bolin/Little Creek Subwatersheds (BL1 through BL13)

The upstream to downstream pattern of increasing urbanization and degradation of watershed functions is most evident in the Bolin/Little Creek watershed. LWP subwatersheds BL1 through BL3 remain nearly or better than 50 percent forested with relatively low levels of riparian buffer disturbance. Imperviousness is also low in these headwater subwatersheds. Benthic community and water quality ratings are relatively good at the headwater stations on Bolin Creek. However, this portion of the LWP study area is the most threatened by future development. The risk of stream erosion and degradation occurring as a result of new development and increased stormwater runoff is heightened by the fact that soils in the upper Bolin Creek watershed have elevated K-Factors (soil erodibility factors, which represent both susceptibility of soil to erosion and the rate of runoff) similar to those in Morgan Creek headwaters, indicating a high potential for soil and stream bank erosion.

In the middle Bolin Creek subwatersheds, BL4 and BL5, urbanization increases and the stream receives stormwater runoff from much of downtown Chapel Hill. A gradual downstream decline of the conditions of various watershed indicators is evident. The riparian area is compromised by a sewer line easement and various encroachments. Benthic community ratings decrease from Fair at upstream stations above Airport Rd. (Waterside Dr., Estes Dr, and Village Rd.) to Poor at stations below Airport Rd. (Bollinwood Dr. and E. Franklin St.), and water quality declines relative to the headwater stations. Preliminary reconnaissance revealed active stream erosion occurring in segments along the Chapel Hill greenway from Airport Rd. to the Chapel Hill Community

The Booker Creek watershed (LWP Subwatersheds BL6-BL10) is predominantly urban and suburban. Land cover analysis shows moderate to high levels of imperviousness, loss of the majority of the watershed's forest cover, and significant levels of disturbance of riparian buffers. All available benthic community data indicate that Booker Creek is in poor health throughout its length. Overall water quality ratings for Booker Creek stations indicate degradation relative to other stations. In terms of physical habitat, reconnaissance efforts have shown that the majority of Booker Creek appears to be stable with intact streambanks. Many areas of Booker Creek avoided becoming unstable by virtue of having substrates with high bedrock and large boulder content that provide grade control. High stormwater runoff volumes that have scoured out leaf packs and caused isolated areas of bank erosion resulted in some impairment of the biological community within this watershed (NCDWQ, 2003b).

There are some indications of chronic toxicity issues on Crow Branch (subwatersheds BL7 and BL9) and Little Creek in the vicinity of Pinehurst Drive (NCDWQ, 2003b). The assessment report notes that two UNC-CH hazardous waste landfills are located immediately adjacent to Crow Branch. However, no chemical pollutant monitoring was conducted in conjunction with the toxicity testing, so the specific pollutant(s) that may have caused the instream toxicity could not be identified with the available data. Benthic community monitoring for the NCDWQ assessment of the Little Creek watershed indicated "massive" deformities of *chironomid* larvae in the vicinity of Pinehurst Drive. The reported deformity rates and severity indicate that sediment or water column toxicity may be a problem in this vicinity, but sediment toxicity tests on sediment samples from this section of Little Creek were inconclusive.

Improvement of habitat conditions in Little Creek will require a comprehensive effort to address stream erosion and instability issues on a whole watershed scale. This comprehensive approach will need to include an effective stepwise strategy to restore morphological stability to streams within the Bolin/Little Creek watershed. This stability will only be achieved through a deliberately coordinated effort to mitigate the damaging storm flows entering the stream network while restoring the dimension, pattern, and profile that are appropriate for the new flow regime and associated sediment load. Measures such as stormwater retrofits and, where appropriate, construction/restoration of riparian wetlands are also likely to be integrated components of a successful restoration strategy for Bolin/Little Creek. The detailed assessment approach will be designed to identify the optimum locations for retrofits and other structural stormwater BMPs, and to compare potential implementation scenarios on the basis of benefit/cost ratios.

Objectives for Detailed Assessment:

- **Further quantify the impacts of urban stormwater runoff on Bolin, Booker and Little Creeks and their tributaries and identify potential management and stormwater BMP retrofit opportunities to alleviate those impacts.**
- **Identify the stream reaches along Bolin, Booker and Little Creeks and their tributaries where erosion and instability have resulted in degradation of functions, and target those areas for management and restoration efforts (where restoration is deemed to be feasible and cost effective) to alleviate that degradation and prevent any further loss of functions.**
- **Determine the need for stream restoration along Bolin, Booker and Little Creeks and their tributaries and identify reaches where restoration would be feasible and beneficial.**
- **Identify those segments of Bolin, Booker and Little Creeks and their tributaries where degradation has not yet occurred, but where future development is likely to result in damaging stormwater runoff and target those areas for the management efforts to prevent the associated functional losses.**
- **Develop recommendations for further monitoring and analysis to determine if sediment toxicity is a problem in Little Creek near Pinehurst Drive and identify sources if it is.**
- **Continue investigating potential sources of low dissolved oxygen (such as leaking sewer lines or organic loading from septic tanks).**
- **Continue evaluating any subsequently available chemical and biological data collected within the watershed to determine if conditions improve after recovery from the extended drought.**

- **Develop recommendations for further monitoring and analysis to identify sources of toxicity in Crow Branch and Booker Creek.**

1.1.4 Threats for the Entire LWP Study Area

Nutrient concentrations have not been identified as a significant threat to the health of flowing streams within the study area. However, nutrient loads generated from the study area are of concern for the lakes receiving this flow, especially Jordan Lake and University Lake. Within these lakes, excess nutrient loads can lead to algal blooms that are unsightly, degrade recreational opportunities, alter biological uses, and present problems for treatment for use as potable water supplies.

Fecal coliform bacteria counts exceed the water quality criterion more frequently than any other parameter analyzed in study area. While these levels are of concern, fecal coliform bacteria and other pathogens can originate from a wide variety of sources including, but not limited to buildup and wash-off from impervious surfaces, failing septic tanks, leaking or failing sewer lines and pet wastes in runoff from suburban communities. Before further efforts can be undertaken to address fecal coliform bacteria (and other pathogens), an analysis should be performed to identify the most likely sources within the study area.

Objectives for Detailed Assessment:

- **Perform analysis to determine the most likely sources of fecal coliform and other pathogen loading to streams within the LWP study area.**
- **Develop a detailed nutrient loading and reservoir response model for University Lake under contract to OWASA; use these models to evaluate areas with the greatest potential to deliver nutrients to University Lake and target them for restoration and management efforts to reduce these loads.**
- **Identify the subwatersheds with the greatest potential to deliver nutrients to Jordan Lake and target them for restoration and management efforts to reduce those loads.**

1.2 Purpose of Detailed Assessment

The primary objective of the *Detailed Assessment Report* is to evaluate magnitude and spatial pattern of functional stressors within the study area. This information will allow targeting of management in a cost effective manner. Associated with this objective are three major assessment goals:

- To confirm and quantify the linkages between stressors and indicators identified in the *Preliminary Findings Report* (Tetra Tech, 2004).
- To establish targeting thresholds for specific indicators.
- To identify and rank subwatersheds for relative management priority where indicators exceed targeting thresholds.

The development of management recommendations for the prioritized subwatersheds will occur in the forthcoming *Targeting of Management Report*. Selection of specific BMPs will occur through collaboration with NCEEP, local resource professionals, and through cost/benefit analysis of alternative BMPs to address specific stressors.

The objectives for this Local Watershed Planning initiative are consistent with the primary stated goals of the NCEEP, which are to:

- Protect and improve watershed functions by restoring wetland, stream, and riparian area functions and values lost through historic, current, and future impacts.

- Achieve a net increase in riparian zone acreage, functions, and values in all of North Carolina's major river basins.
- Promote a comprehensive approach for the protection of natural resources.

Because watershed functions are affected by processes occurring outside of the riparian zone, a comprehensive approach that includes assessment of upland [non-aquatic] and headwaters' stressors and recommendations for upland BMPs is important not only for improving function but for assuring the long-term success of stream and/or wetland restoration projects. Thus, the objectives of this project that are ultimately to be addressed in the *Local Watershed Plan* include:

- Comprehensive management of upland water quality stressors.
- Management of riparian zone functions and water quality stressors.
- Prioritization of riparian restoration and preservation sites (stream and/or wetland).

In addition to the results of the Detailed Assessment, final targeting of management will be based on input from local stakeholders, resource professionals, and cost/benefit analyses.

1.3 Organization of Detailed Assessment Report

This report is organized by the three primary areas of watershed function that were assessed at the subwatershed scale. An assessment of *Hydrologic and Aquatic Habitat Functions* (Section 2) is provided first, followed by assessment of *Water Quality and Water Supply Functions* (Section 3) and *Terrestrial Habitat Functions* (Section 4). Section 5 of the report provides a *Combined Assessment of All Data and Indicators* that produces a set of targeted watersheds for the central focus of future management efforts. Section 6 briefly summarizes the *Next Steps* in evaluating and selecting specific management measures that will lead to development of the overall watershed plan.

2 Assessment of Hydrology and Aquatic Habitat Functions

A summary of the key potential stressors to hydrology and aquatic habitat functions, along with a listing of the indicators used in their assessment and the tools used to perform those assessments is presented in Table 2-1. Details of the each assessment method and the corresponding results are discussed in Sections 2.1 through 2.5. Wherever possible, the results for each indicator are presented in the context of the Local Watershed Plan (LWP) subwatersheds shown in Figure 1-1.

Table 2-1. Summary of Indicators and Tools Used for Detailed Assessment of Hydrology and Aquatic Habitat Functions

Watershed Function	Potential Stressor	Indicator	Scale	Assessment Technique
Hydrologic & Aquatic Habitat Functions	Multiple	Overall Stream Condition	Subwatershed*/ Stream Reach	NRCS-SVAP**
	Stream Erosion and Instability	Erosion and Instability Potential	Subwatershed*/ Stream Reach	SVAP** Morphology Critical Velocity
	Urban/Suburban Development	Imperviousness	Subwatershed*	GIS Analysis
	Riparian Buffer Disturbance	Riparian Buffer Condition	Subwatershed*/ Stream Reach	GIS Analysis
	Floodplain Alteration	Floodplain Encroachment	Subwatershed*	GIS Analysis

*"Subwatershed" refers to smaller drainage areas within selected 14-digit hydrologic units delineated for the purposes of defining distinct management units within the context of Local Watershed Planning efforts, usually in the range of 1-10 square miles in area (refer to Figure 1-1).

**Stream Visual Assessment Protocol (USDA, 1998)

2.1 Comprehensive Visual Assessment of Stream Condition and Aquatic Habitat

The Stream Visual Assessment Protocol (SVAP) was developed by the Natural Resources Conservation Service (NRCS) to provide a basic evaluation of streams through consideration of physical, chemical, and biological parameters (USDA, 1998). The SVAP is a tool for preliminary characterizations of stream condition, as well as for identifying the need for more detailed assessment methods that focus on a particular aspect of the aquatic system. The overall SVAP assessment is presented here at the beginning of the Detailed Assessment Report because of its applicability in evaluating a full range of factors affecting aquatic habitat, stream morphology, and, to some extent, water quality. While the specific morphology components are broken out and analyzed separately in Section 2.2.1, the overall SVAP analysis is presented here because it includes evaluation of important micro-habitat parameters such as the presence of stream shading, leaf packs, and root masses, as well as evaluation of embeddedness of the critical interstitial spaces of riffle habitats with sediment.

2.1.1 Description of NRCS-SVAP Methods

Up to 15 parameters can be scored for a stream reach (not all parameters are appropriate for all reaches) by comparing visually observed conditions to descriptions provided in the protocol. A score of 1 indicates most impaired or degraded conditions; a score of 10 is indicative of conditions expected in a healthy stream. The overall assessment score for a reach is determined by averaging the scores of the assessed parameters.

Sampling reaches were selected to provide both general characterizations of stream conditions across the many streams in the study area as well as a verification of model output generated for the Stream Stability Assessment (refer to Section 2.2.2). The location of sampling reaches within LWP subwatersheds was selected such that conditions at the reach level could be extrapolated to the entire subwatershed. For subwatersheds where stream stability was evaluated using models, additional reaches were included for verification of model output.

2.1.1.1 Risk Threshold Definition

Stream conditions were evaluated at 54 reaches in 25 LWP subwatersheds across the study area using the NRCS SVAP. While up to 15 parameters are available in the protocol, no more than 12 were assessed at any study area reaches. The 12 parameters assessed in this effort and their descriptions are as follows:

1) Channel condition: measures the degree of physical alterations to the channel. Indicators include unnaturally straight sections, high banks, riprap, berms and spoil piles, headcuts, perched culverts, lack of regularly spaced depositional features, raw banks, and excessive bank erosion.

2) Hydrologic alteration: characterizes the regularity of overbank flows. Indicators include water stains on bridge abutments, sediment deposits in overbank areas, flow debris suspended in streamside vegetation, scars on the upstream side of bank vegetation, and accounts from neighboring property owners.

3) Riparian zone: measures the width of the natural vegetation zone from the bank of the active channel out onto the floodplain. Natural plant communities have species native to the site or introduced species that function similar to native species. Natural communities also include a diversity of structural elements (e.g., aquatic plants, groundcover, shrubs, understory, and canopy trees).

4) Bank stability: rates the existence of or potential for detachment of soil from the streambanks. Unvegetated or poorly vegetated reaches, exposed tree roots, undercut banks, scalloped banks, steep banks, and eroded bank material at the toe of the bank are all indicators of poor bank stability.

5) Water appearance: evaluates the turbidity, color, and other visual characteristics of the water. The clarity of the water, depth to which objects can no longer be seen, surface films, and odors are factored into the score for this parameter.

6) Nutrient enrichment: the types and quantity of aquatic vegetation often reflect nutrient enrichment. Excessive growth of algae and macrophytes on benthic substrates, algal blooms, and the intensity of the color green in the water indicate degraded water quality due to elevated nutrient loads.

7) Barriers to fish movement: characterizes the ability of aquatic organisms to move through a reach. Only barriers that block movement at all flows, not just low or high flows, were considered detrimental. Drop structures, dams, steep culverts, and waterfalls can be barriers.

8) Instream fish cover: measures the availability of physical habitat for fish. The availability of logs/large woody debris, deep pools, overhanging vegetation, boulders/cobbles, undercut banks, thick root mats, dense macrophyte beds, riffles, and backwater pools was evaluated.

9) Pools: characterizes the abundance and depth of pools in the reach. More abundant pools with a variety of depths support more aquatic communities and indicate fewer disturbances to the reach.

10) Insect/invertebrate habitat: measures the availability and abundance of physical structure for insects/invertebrate habitat. Evaluated structures include fine woody debris, submerged logs, leaf packs, undercut banks, cobbles, boulders, and coarse gravel.

11) Canopy cover: rates the proportion of the water surface in the reach that is shaded. The sun is assumed directly overhead during full leaf-out while scoring this parameter. Canopy cover provides shade to help regulate water temperature and serves as a source of organic material for instream communities.

12) Riffle embeddedness: measures the degree to which riffle substrates are surrounded by fine sediment. The score is based on the proportion of the substrate height surrounded by fines. The degree of embeddedness directly relates to the suitability of riffle substrate for use by macroinvertebrates, fish spawning, and egg incubation.

Comprehensive SVAP classes were generated according to the rating thresholds in Table 2-2, which are taken directly from the SVAP guidance document (USDA, 1998), for each reach using all the parameters evaluated in this study.

Table 2-2. SVAP Classes for Average Site/Parameter Scores

Average Score	SVAP Class
< 6.0	Poor
< 7.5	Fair
< 9.0	Good
> = 9.0	Excellent

2.1.1.2 Findings for Existing Conditions – Entire Study Area

The SVAP classes, sometimes referred to as ratings in this document, are mapped in Figure 2-1. In general the overall classes show the spatial pattern discussed in the summary of the *Preliminary Findings Report* in Section 1. The upstream, less developed, portions of the watersheds have higher scores reflecting better stream conditions with the exception of a few areas subject to localized impacts, whereas the downstream, urbanized portions have lower scores reflecting more widespread degradation.

The objective of applying the SVAP methodology to a variety of stream reaches throughout the study area was to broadly compare the condition of streams and to relatively identify the most influential stressors. Altered hydrology, both due to watershed development and channel modifications, and the effects of sediment were consistently identified in the study area as primary stressors. Frequently, limited instream habitat for both fish and invertebrates was identified as a contributing factor to stream degradation. Limited habitat is typically a function of the impacts from urban hydrology and sediment as habitat structure is washed out by storm flows or smothered by excessive instream deposition. Due to the patterns of development in the study area, subwatersheds receiving runoff from the more developed areas of Chapel Hill and Carrboro, as well as subwatersheds currently undergoing considerable development, were generally most degraded according to the SVAP methodology.

To facilitate the presentation of the SVAP findings, LWP subwatersheds were grouped into seven clusters reflecting similar stream types and conditions, as well as similar land use conditions. In Appendix B, the scores are discussed in detail by those clusters, called SVAP subbasins, with emphasis on the most important scoring parameters within those localized areas and the potential stressors that are likely to be linked to those parameters. The detailed scores for the 54 individual reaches evaluated using the SVAP are also provided in Appendix B.

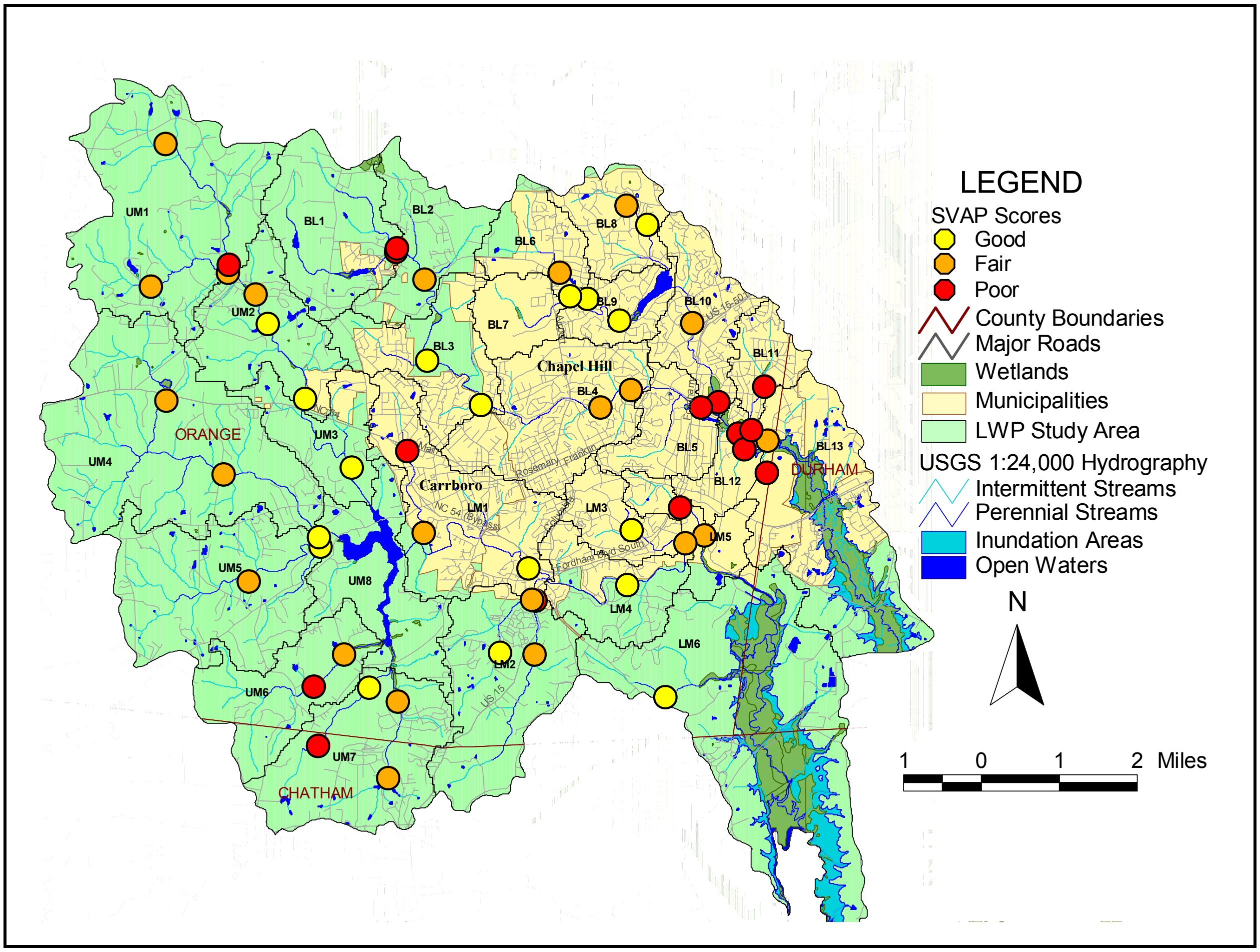

Figure 2-1. SVAP Classes for the 53 Individual Reaches Evaluated in this Study

2.1.1.3 LWP Subwatershed Summary of Stream Visual Assessment Results

To evaluate stream conditions at the LWP subwatershed scale and establish priority subwatersheds for further management effort at the end of this Detailed Assessment, the SVAP scores were aggregated for each LWP subwatershed. Cumulative numeric scores for all reaches (shown in Figure 2-1) were averaged within a given LWP subwatershed, which was then assigned to an SVAP class according to the breakpoints given in Table 2-2. The LWP subwatershed results are mapped in Figure 2-2.

The majority of the LWP subwatersheds fell into the Fair class with some headwater subwatersheds receiving a rating of Good, including those in upper Bolin Creek (BL3), upper Booker Creek (BL7 and BL9), and upper Morgan (UM3). Poor SVAP ratings resulting from localized stream degradation resulted in subwatershed-wide ratings of Poor in uppermost Bolin Creek (BL1) and in Pritchards Mill Creek (UM6). Widespread degradation as a result of the impacts of urbanization resulted in Poor subwatershed ratings for lower Bolin (BL5), Booker (BL10) and Little Creeks (BL11-BL13) and one subwatershed in lower Morgan Creek (LM5). These LWP subwatershed SVAP ratings were used to deter the Subwatershed Priority Scores described in Section 5.

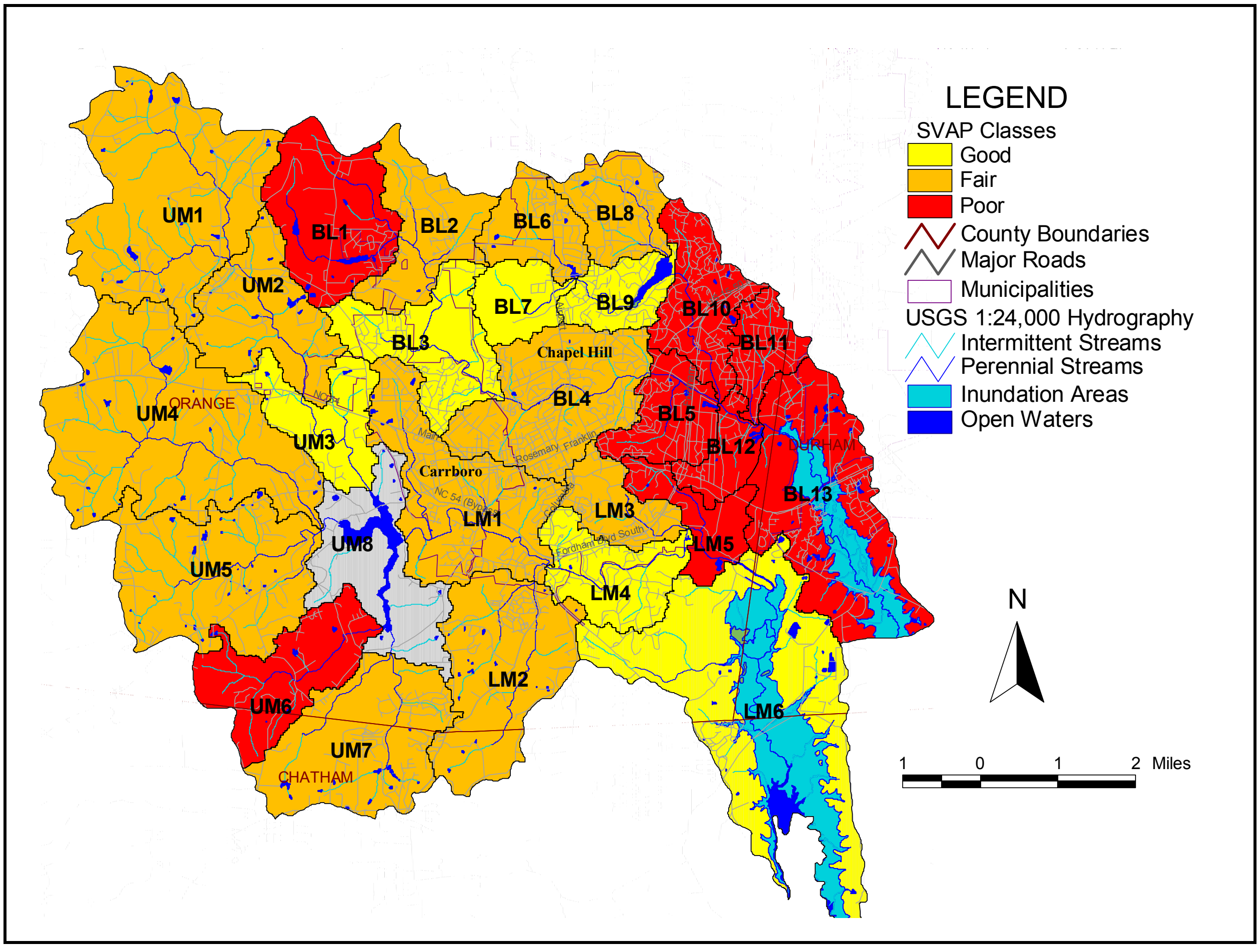

Figure 2-2. SVAP Classes by LWP Subwatershed

2.2 Overview of Stream Erosion and Instability Indicators

Conversion of forest or agricultural land to commercial and residential uses leads to a substantial increase in impervious surface in portions of the watershed where development occurs, or has already occurred, which in turn leads to increased frequency and magnitude of peak flow events instream. Increased stormwater velocities will cause greater shear stress resulting in increased rates of bank erosion and channel scour, potentially leading to unstable and eroded conditions in receiving streams. The resulting erosion and instability causes excessive sediment loading to downstream reaches and often eliminates the natural riffle/pool sequences that are essential to instream aquatic habitat.

Stream instability and erosion resulting from existing development and potential future development have been identified as primary threats to aquatic habitat functions in both the Morgan and Bolin/Little Creek watersheds. For purposes of this Detailed Assessment, two separate means of measuring the potential for such instability have been utilized:

- NRCS-SVAP Morphology Assessment
- Critical Velocity Analysis

The NRCS-SVAP Morphology Assessment represents a breakout of the three parameters within the SVAP assessment methodology that pertain to stream morphology, which are evaluated on site. The

Critical Velocity Analysis represents the application of established stream thresholds for erosion and instability to estimates of stream velocity generated with a hydrologic and hydraulic (H&H) modeling framework. The modeling analysis allows for a predictive tool to evaluate potential future conditions or existing conditions in areas not accessible for in-situ evaluations, whereas the SVAP Morphology Assessment provides a real-world verification of modeling predictions where the two analyses coincide spatially. Additionally the SVAP Morphology Assessment allows for evaluation of stream erosion and instability in areas where critical velocity criteria are inappropriate or of limited value. The following sections describe each of the two methods in detail.

2.2.1 NRCS-SVAP Stream Morphology Assessment

Excessive streambank erosion, channel widening, and steep, bare banks as a result of streambed incision are examples of active geomorphic processes that indicate morphologically unstable reaches. Dynamically adjusting reaches have an imbalance between their ability to transport sediment and the sediment loads within them that can lead to a variety of negative impacts on both instream aquatic habitat and the biological communities it supports.

The morphologic stability of the streambed and banks at each of the evaluated stream reaches in the study area was characterized using three of the SVAP parameters. The visual assessments of stability provide a consistent methodology for comparing reaches across the study area. Additionally, the SVAP allows for comparisons between modeled critical velocity predictions of stability and in-situ conditions. In this fashion, the SVAP serves as an external check on the model-generated results presented in Section 2.2.2. Agreement between the two methods provides validation for the model whereas disagreement indicates the potential need for additional model calibration. Validation is critical under the existing conditions so that the model results under the future scenario, which cannot be compared to in-situ assessments, can confidently be considered as representative.

2.2.1.1 Description of NRCS-SVAP Morphology Assessment Methods

One component of morphologic stability as it relates to the reaches in the study area is streambank stability, which was directly evaluated through the Bank Stability parameter in the SVAP. Bank height, surface vegetation, and erosional areas are factored into the score, which ranges from a low of 1 to a high of 10. The modeled predictions of stability are based on a threshold analysis that results in either a “low risk” or “at risk” classification depending on whether the threshold is exceeded. In order to compare the range of SVAP scores to the two distinct risk classes generated through modeling, the SVAP scores were segregated into two groups. As the general SVAP scoring equates scores of 6 and lower as Poor, scores of 1 through 6 were considered “at risk” of bank instabilities; scores of 7 through 10 were considered “low risk.”

Streambed stability is another component of morphologic stability investigated in the study area. The stability of the streambed was evaluated through the Hydrologic Alteration parameter in the SVAP. This parameter gages the regularity of out-of-bank flows, for example, every three to five years, every six to ten years, etc. Reaches that have unstable streambeds tend to either incise or aggrade. Incised channels have scoured beds that create deeper channels that limit the access of flood flows to the floodplain. Braided channels resulting from excessive instream sedimentation are typical of aggrading reaches. Since no braided channels were observed in the study area, bed instability was considered only if reaches were at risk of incision. Using the same logic that was applied to the bank stability characterization, the SVAP scores for the Hydrologic Alteration parameter were separated into two groups – scores between 1 and 6 for reaches “at risk” of incision and scores between 7 and 10 for “low risk” reaches.

The final SVAP parameter factored into the evaluation of morphologic stability is Channel Condition. Physical anthropogenic impacts on the channel, such as straightening, deepening, hardening, installing structures (e.g., drop structures, culverts, dams), and limiting floodplain access, affect the score for this parameter. Evidence such as unnaturally straight sections, overly high banks, berms or spoil piles, and riprap or concrete lining reduce the score for the Channel Condition parameter. As described for Bank Stability and Hydrologic Alteration, SVAP scores for Channel Condition between 1 and 6 were considered "at risk" while those between 7 and 10 were considered "low risk" for morphologic instabilities.

2.2.1.2 Stream Morphology Risk Threshold Definitions

In keeping with the NRCS-SVAP guidance the scores for each of the three parameters used in this morphological assessment were averaged for each of the 53 sites evaluated and those averaged morphology scores were assigned to classes, or ratings, reflecting Excellent, Good, Fair, or Poor morphological conditions at each site according to the scoring breakpoints given in Table 2-2. The resulting morphology ratings for all sites evaluated within the study area are shown on the map in Figure 2-3. Overall, the SVAP Morphology Assessment results continue to show the upstream to downstream pattern of adverse impacts associated with urbanization within the study area. Exceptions to this overall pattern are manifested in the poor ratings assigned to sights in the uppermost portions of Morgan Creek (UM1) where current and past practices at dairy cattle operations have resulted in significant stream erosion and instability. Recent suburban development has also resulted in morphological stream degradation in the upper sections of Bolin Creek (BL1 and BL2). The results are discussed in greater detail below.

2.2.1.3 Discussion of Findings for Existing Conditions

Of the two factors noticeably affecting the morphologic stability of the stream reaches surveyed throughout the study area, underlying geology potentially has the most profound influence. The weathering of underlying geologic formations produces surface soils, and strata that weather readily and produce copious amounts of soil, whereas, less soil is generated from more resistant formations. The reaches in the study area underlain by the Carolina Slate Belt, a metamorphic lithology generally more resistant to weathering, tend to have regular bedrock influence in the streambed as well as cobble and boulder substrates in both the streambed and streambanks. Gravels, sands, and fines, including cohesive clays and silts, dominate the channel boundary composition of the reaches running through the Triassic Basin, a sedimentary lithology formed from deposition in an ancient alluvial fan. As larger size substrates can better resist the erosive power of concentrated runoff as compared to sands and gravels, reaches in the

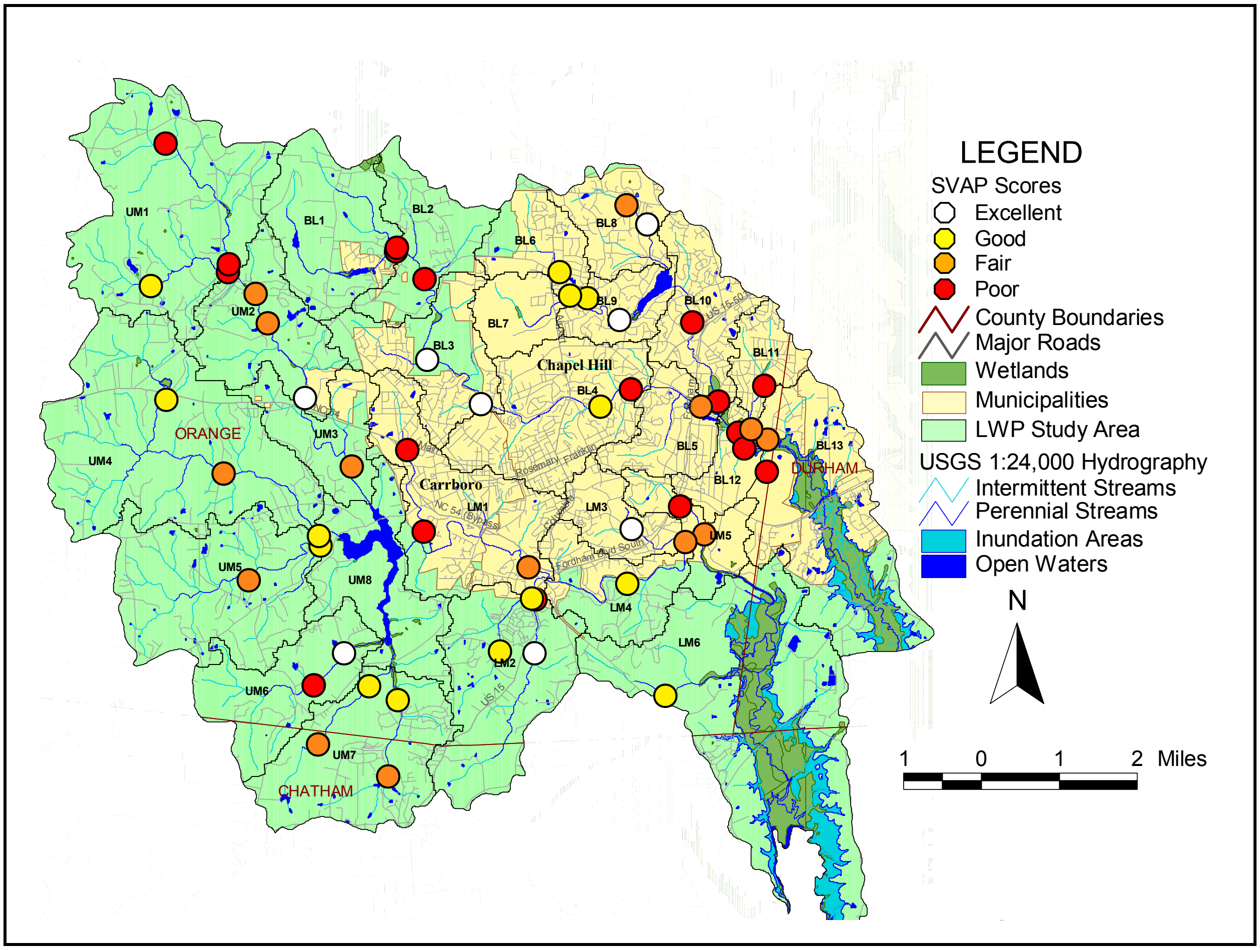

Figure 2-3. SVAP Morphology Ratings for the 53 Sites Evaluated within the LWP Study Area

Carolina Slate Belt tended to be less susceptible to morphologic instabilities than reaches in the Triassic Basin. The transition between the two geologic formations, illustrated in Figure 2-4, occurs near Eastwood Lake on Booker Creek, upstream of the Franklin Street crossing on Bolin Creek, and near the Botanical Gardens for Meeting of the Waters and Morgan Creek.

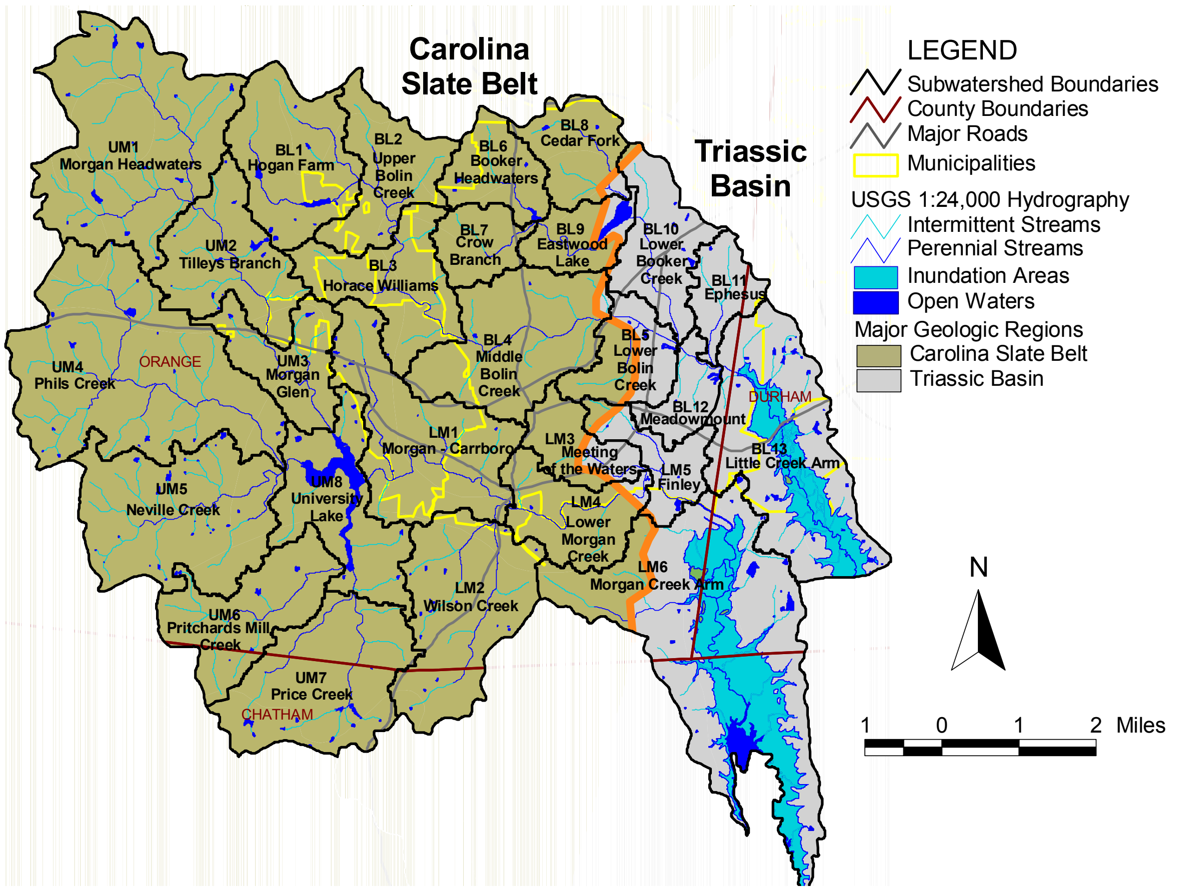

Figure 2-4. Major Geologic Regions within the LWP Study Area

The second major factor affecting the morphologic stability of streams within the study area is channelization, which can include widening, deepening, and straightening a channel. In watersheds with concentrated development, channelization primarily occurred to enhance surface drainage, increase flood conveyance, expand useable lands, and facilitate infrastructure (e.g., sanitary sewer lines, roadways, and rail lines). Consequences of channelization include increases in hydrologic forces applied to the channel boundary due to removal of natural resistance (e.g., bedforms, meanders, and woody debris), limited access to overbank areas due to deeper channels, and elevated instream sediment loads due to less frequent overbank deposition – all of which act together to increase morphologic instabilities. Evidence of channelization was noted in the lower reaches of Booker Creek and Bolin Creek, as well as sections of Little Creek, Toms Creek, and Chapel Creek.

The morphologic stability of the surveyed reaches varied considerably across the study area. The reaches draining to University Lake in the upper Morgan Creek watershed, excluding upper Morgan Creek, tend to be low risk for morphologic instabilities. The Carolina Slate Belt formation underlies all of these reaches and no evidence of large-scale channelization was observed. The morphology of the reaches in upper Morgan Creek was mostly impaired. Minor incision coupled with high vertical stream banks affected the majority of these reaches, except where localized occurrences of bedrock or coarse substrate serve as grade control (e.g., upstream of the Highway 54 crossing). In general, much of the channel boundary materials along upper Morgan Creek were composed more of sand and fines than other evaluated reaches in the Carolina Slate Belt.

Outside of Toms Creek, the surveyed reaches in the lower Morgan Creek watershed generally showed little evidence of morphologic instabilities. The high degree of development in the Toms Creek watershed yields elevated amounts of runoff that appear to be actively enlarging the channel. While Toms Creek is located in the Carolina Slate Belt, the boundary materials are more typical of Triassic Basin streams. These soils affect the stability of reaches of Chapel Creek (which also appeared to have been channelized) and Meeting of the Waters.

The morphologic stability of the analyzed reaches in the Booker Creek watershed was highly rated, particularly upstream of Eastwood Lake. The influence of the Carolina Slate Belt geology on the morphology of these reaches limits the potential for incision and widening. Downstream of Eastwood Lake, where Booker Creek enters the Triassic Basin, much of the creek appears subjected to historic channelization. These reaches, however, are considered low risk for morphologic instabilities due primarily to instream deposition subsequent to the channelization and the high water surface elevation relative to the bank height.

The lower reaches of Bolin Creek (approximately downstream of the Franklin Street crossing) and Little Creek are affected by the Triassic Basin soils and historic channelization similar to lower Booker Creek. The low stream gradient through the Triassic Basin limits hydrologic power, which reduces stresses applied to the channel boundary and encourages deposition to replace sediment scoured during high flows. The streambanks through these reaches are more susceptible to degradation than the streambed.

Coarse substrates and bedrock outcrops substantially reduce the potential for morphologic instabilities through the upper reaches of Bolin Creek. The surveyed reaches along upper Bolin Creek all rated either Good or Excellent for both of the parameters used to assess morphologic stability. However, Bolin Creek and Jones Creek near their confluence exhibit signs of both incision and bank erosion. These channel boundaries are composed of alluvial material more characteristic of the Triassic Basin, reducing its resistance to erosive flows. In conjunction with the recent development and increases in stormwater runoff from the Hogan Farms development, channel widening and incision are expected to continue.

The range of evidence of morphologic instabilities in the analyzed reaches in the study is considerable. A majority of the reach-to-reach variability can be explained by the underlying geology, historical channelization, and urbanization patterns of the contributing watershed. Due to the location of the Triassic Basin downstream of the Carolina Slate Belt, channelization in the downstream reaches, and a substantial amount of stormwater runoff entering the creeks in the downstream reaches due to the Chapel Hill and Carrboro town centers, the morphologic stability of the analyzed reaches tends to decrease in a downstream direction.

2.2.1.4 Subwatershed Summary of SVAP Morphology Assessment Results

In order to evaluate stream erosion and instability at the LWP subwatershed scale and establish priority subwatersheds for further management effort at the end of this Detailed Assessment, the SVAP Morphology Assessment scores were aggregated for each LWP subwatershed. The scores were aggregated by averaging the three-part numeric scores for all reaches (shown in Figure 2-3) within a given LWP subwatershed and assigning that average score to an SVAP class according to the breakpoints given Table 2-2. The LWP subwatershed results are mapped in Figure 2-5.

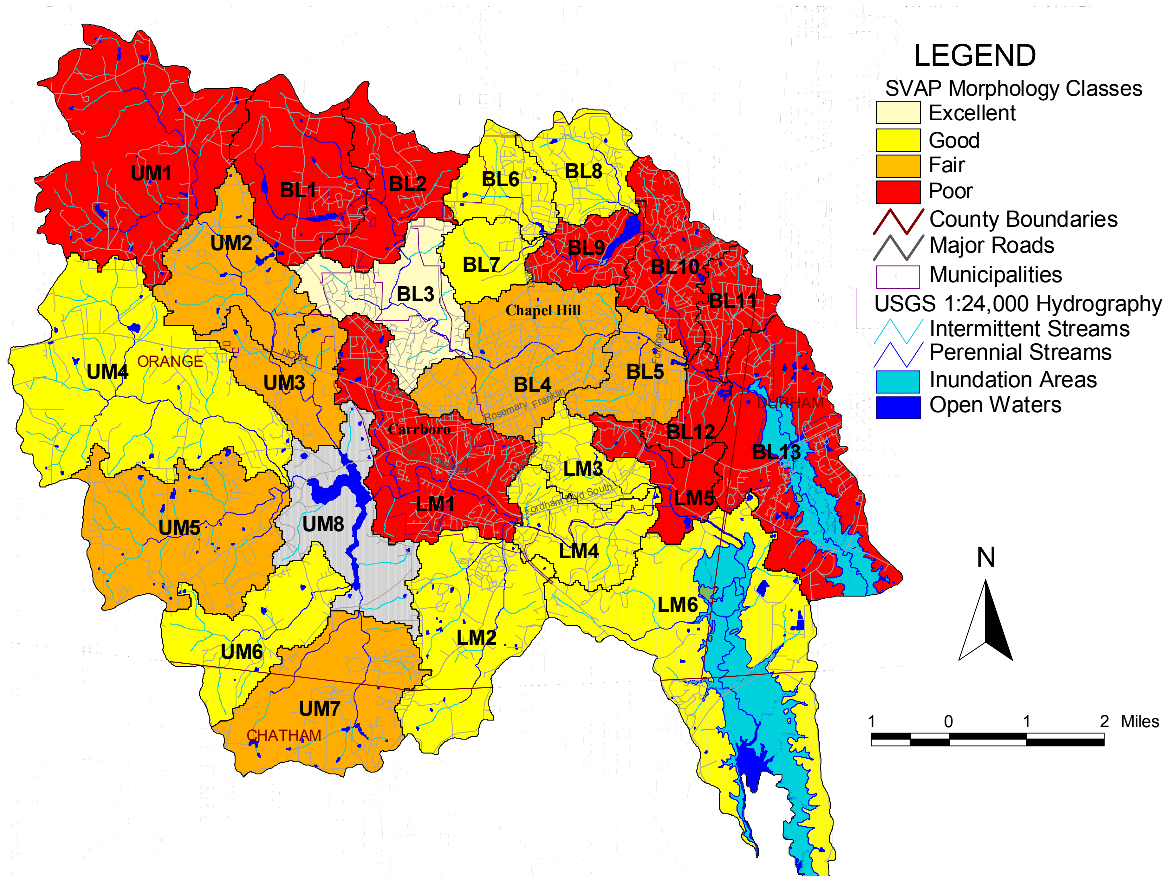

Figure 2-5. SVAP Classes by LWP Subwatershed

Based on subwatershed average morphology ratings, only one subwatershed (BL3) in upper Bolin Creek received a rating of Excellent. This particular subwatershed comprises the bulk of the Horace Williams Airport tract now slated for the development of the Carolina North extension of the UNC-Chapel Hill campus. In its current state, the subwatershed is mostly undeveloped especially along the riparian corridor and exemplifies some of the healthiest hydromorphological conditions observed in the entire study area. Several subwatersheds with significant levels of urbanization received Poor or Fair ratings, particularly those in the lower Bolin/Booker/Little Creek area. The Morgan Creek subwatershed immediately below University Lake (LM1) received a Poor rating, but the rating actually reflects the degraded conditions in the Toms Creek portion of the subwatershed, where the SVAP evaluations were performed. As a result of degradation from the aforementioned impacts of localized agricultural activities the uppermost subwatershed of Morgan Creek (UM1) received a Poor rating. It is possible that the incised streams within that upper portion of Morgan Creek are having an adverse effect on stream stability in segments immediately downstream, which may be resulting in the Fair morphological ratings in subwatersheds UM2 and UM3. Localized stream degradation from agriculture and areas of residential development have also resulted in Fair ratings for subwatersheds UM5 and UM7.

2.2.2 Critical Velocity Assessment of Stream Stability

The goals of the hydrologic and hydraulic modeling in the Morgan Creek and Bolin/Booker/Little Creek watersheds were: (1) to evaluate stream flows under existing and future development scenarios; and (2) to determine the stability of the channels at the channel forming flow. In this study, stream stability is defined through the condition of the stream banks as well as the streambed. Banks considered stable do not contribute significant amounts of sediment to the stream whereas those considered unstable are failing and eroding so that excessive sediment enters the stream. Unstable streambeds are evidenced by either incised channels or by excessive deposition of sediment. Hydrologic modeling was performed to develop flow-frequency data for selected streams in the study area so that an estimate of the channel forming flow could be quantified. Hydraulic modeling was implemented to assess channel stability for various flows associated with existing and future development, the channel forming flow in particular. The following sections discuss briefly how the selected hydrologic models were developed and applied to the Morgan Creek and Little Creek watersheds.

2.2.2.1 Development of Existing and Future Land Use Conditions

Modeling analyses, such as this stream stability assessment, rely on approximations of future land use to generate predictions of the future conditions of watershed functions. In order to form the basis for this Critical Velocity Assessment, as well as the other modeling analyses in this Detailed Assessment Report, GIS databases were developed to approximate existing land use conditions within the LWP study area and future “buildout” land use conditions, reflecting the maximum development capacity according to current zoning and land use plans. The following paragraphs describe how existing and buildout land use patterns were evaluated. More detailed discussion of methods and results of these analyses are presented in Appendix A and the University Lake Baseline Analysis Memo (Tetra Tech, 2003b)

To address the faults inherent to parcel database coverages, Tetra Tech chose to combine a parcel-based analysis with additional GIS data sources to generate the existing land use and disturbed area estimates for the project watersheds. Planimetric data of impervious surfaces were also used to refine the analysis.

Existing Land Use

To assess existing land use patterns within the study area, land use categories were assigned by parcel based on Orange County, Durham County and Chatham County tax parcel databases and corresponding GIS shapefiles. The general approach was to use parcel data to assign land use categories in areas where zoning information and/or building foot print information was available. In the remaining areas, land use categories where assigned using MRLC-NLCD (1997) coverages. Subwatershed level tabulations of non-urban land uses were adjusted to account for development that has occurred since the NLCD was developed. Slightly different procedures were used in the Upper Morgan Creek (University Lake) subwatersheds than in subwatersheds in the rest of the study area. Parcels in the majority of the study area were assigned to categories used in the Jordan Lake TMDL Watershed Model Development Project. These procedures also apply to the Upper Morgan Creek subwatersheds with a few exceptions largely related to the fewer number of land use categories applied to developed areas in the mostly rural Upper Morgan Creek subwatersheds versus the number of categories used in remainder of the study area (Tetra Tech, 2003b).

Buildout Land Use

The buildout land use scenario was used to assess the maximum development potential of the watershed under current zoning ordinances and development plans. Thus, all developable land (unprotected forest, agriculture, etc.) was assumed to develop to either residential or commercial land use. Lands currently in a protected status (parks, protected areas, conservation easements) were assumed to remain undeveloped and were modeled as forested land, with the exception of a few parcels in the University Lake watershed assumed to remain as active pasture. In general, parcels already developed under the existing land use scenario were assumed to remain in the same land use class, unless they were residential lots that were large enough to be subdivided. Commercial/Institutional parcels were assumed to develop to their full potential. In keeping with the zoning and watershed ordinances in place in Orange and Chatham counties, all buildout residential development was assumed to follow current zoning, taking ordinance limits on lot size into account.

The majority of the remaining undeveloped land at buildout was classified as forest and was by definition a combination of the protected/common/park parcels and forested land on 3+ or 5+ acre lots. Small areas of remaining undeveloped pasture comprise a combination of a few specific parcels on 5+ acre lots. Barren land use was assumed to disappear in the buildout scenario. Urban grass, wetland, and open water land uses were assumed to be retained in the Lower Morgan/Little subwatersheds. Much of the Durham County portion of the study area is made up of protected Army Corp lands surrounding Jordan Lake and was assumed to remain protected in the future.

2.2.2.2 Critical Velocity Analysis Methods

A watershed model was coupled with a channel hydraulics model to evaluate the impacts of stormwater runoff on the streams in the Morgan Creek LWP study area. A generally accepted conceptual model shown in Figure 2-6 illustrates the linkages between increases in impervious surfaces in a watershed due to development, increases in peak stream flows, and subsequent channel instabilities resulting in impaired aquatic habitat. In this conceptual model, increased peak stream flow represents the stressor whereas impairment of instream aquatic habitat represents the corresponding functional response of the watershed. Physical models are tools used to characterize the linkages presented in the conceptual model. For the Morgan Creek LWP study area, physical models were implemented to assess the influence of stormwater runoff and associated peak stream flows on the morphologic stability of stream reaches, which then relates to the condition of instream aquatic habitat.

For the Morgan Creek LWP study area, stormwater runoff associated with various precipitation storms was modeled using the TR-55 (NRCS, 1986) methodology in a HEC-HMS framework (USACE, 2002). The land cover in the study area under existing and buildout conditions was represented through the NRCS curve number and soil loss methodology. Total precipitation storm depths for the 2-year, 5-year, and 10-year 24-hour storm events were acquired from Technical Publication No. 40 (TP-40) (Herschfield, 1961) and converted to 24-hour storm durations using the NRCS Type II synthetic rainfall distribution. The USGS flow gage on Morgan Creek at the Highway 54 crossing (Gage #02097464) was used to calibrate the model for Morgan Creek, and regional regression equations were used to calibrate the models for the other streams in the study area (Robbins and Pope, 1996; Pope, Tasker, and Robbins, 2001).

The stream flows generated by the HEC-HMS model served as the input to a hydraulic model. The HEC-RAS water surface profile model (USACE, 2003) was used to calculate channel velocities throughout the stream reaches in the study area. Channel velocity was selected as an indicator of the force exerted by the stream flow on the channel boundary. Typical maximum permissible values for various natural channel boundary materials (e.g., clay, sand, and cobbles) were referenced from published literature (Fischenich, 2002) and set as thresholds for assessing risk of instability. For reaches where the streambed and channel banks were composed of different materials, separate thresholds were established. In cases where the modeled channel velocity exceeds the selected threshold value, the reach was considered “at risk” for morphologic degradation.

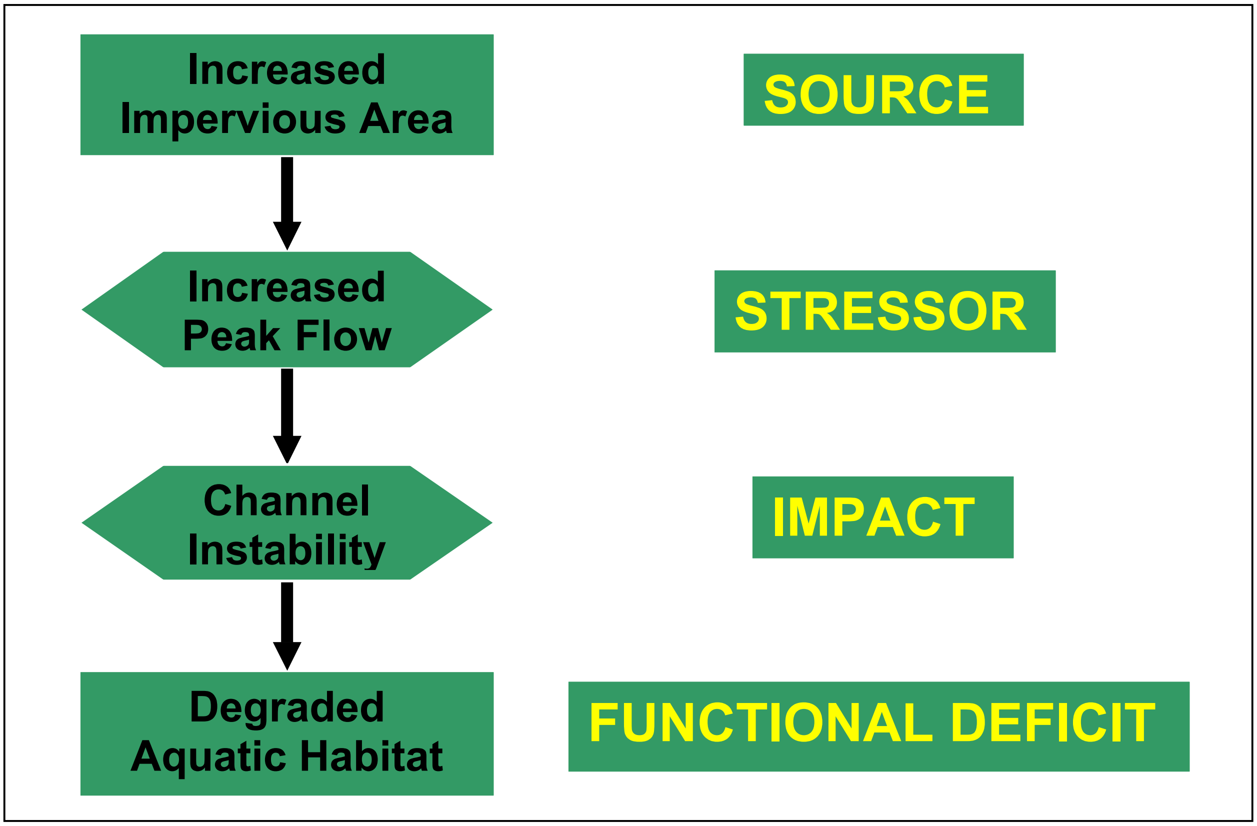

Figure 2-6. Conceptual Model Illustrating Degradation of Watershed Functions as a Result of Increased Imperviousness

The level of risk in a stream reach relates to whether the bed only, banks only, or bed and banks exceed the established thresholds. The HEC-RAS model also calculates the elevation of the water surface for a given flow rate. For channel cross sections that were considered morphologically stable based on visual inspections, the calculated elevation of the water surface can be compared to the elevation of the top of the channel banks. It was assumed for this study area that the channel forming flow (e.g., the representative flow that controls the morphology of the channel) corresponds to the flow that fills the active channel in a stable reach to the top of the banks. When the channel is filled to the top of the banks, additional flow volumes are primarily conveyed in the floodplain and channel velocities no longer appreciably increase as discharge increases. For selected stable reaches in the study area, the 2-year 24-hour flow tended to exceed the capacity of the channel. Therefore, more frequent recurrence interval flows were modeled until the flow filled the channel to the top of the banks. Overall, the 1.5-year recurrence interval flow best represented the channel forming flow for the modeled reaches in the Morgan Creek LWP study area. A 1.5-year recurrence interval is frequently cited in published literature as a reasonable temporally based approximation of channel forming flow (Williams, 1978; FISRWG, 1998).

For the 1.5-year recurrence interval flow, risk of channel instability was evaluated under existing land development conditions as well as expected buildout conditions. Since the buildout condition is based upon full development of the Morgan Creek LWP study area rather than a specific date (e.g., the 20-year plan for development), the buildout condition represents the maximum expected runoff. Therefore, unless the conditions and regulations governing buildout change, reaches projected as "low risk" under the buildout scenario are not anticipated to become "at risk" of morphologic degradation during future channel forming flows.

2.2.3 Comparison of Critical Velocity Assessments and SVAP Morphology Results for Existing Conditions

Visual assessments were performed on the in-situ conditions at representative reaches in the study area against which the calibrated model results were compared. Two out of approximately a dozen parameters (i.e., hydrologic alteration, and bank stability) in the Stream Visual Assessment Protocol (USDA, 1998) were used to categorize the existing stability of the streambed and channel banks. Use of this protocol allowed the modeled predictions of stability to be validated. The validation was critical for the existing conditions so that the modeled predictions under the buildout scenario, which cannot be compared to in-situ assessments, can be considered representative of actual conditions.

Under the existing land development conditions, the modeled predictions for risk of channel instability generally agree with the visual assessments. For the streambed, 22 of the 32 reaches that were modeled show agreement between the in-situ assessment and the model predictions as shown in Figure 2-7. Of the 10 reaches where the two methods disagree, six reaches have a visual assessment score within one point (out of 10) of the threshold set to differentiate between “at risk” and “low risk” reaches. This degree of variability can be expected when using a subjective visual assessment. While the visual assessments and model predictions agree in approximately 70 percent of the cases, the agreement may actually be closer to 90 percent when the subjectivity of the visual assessment technique is considered.

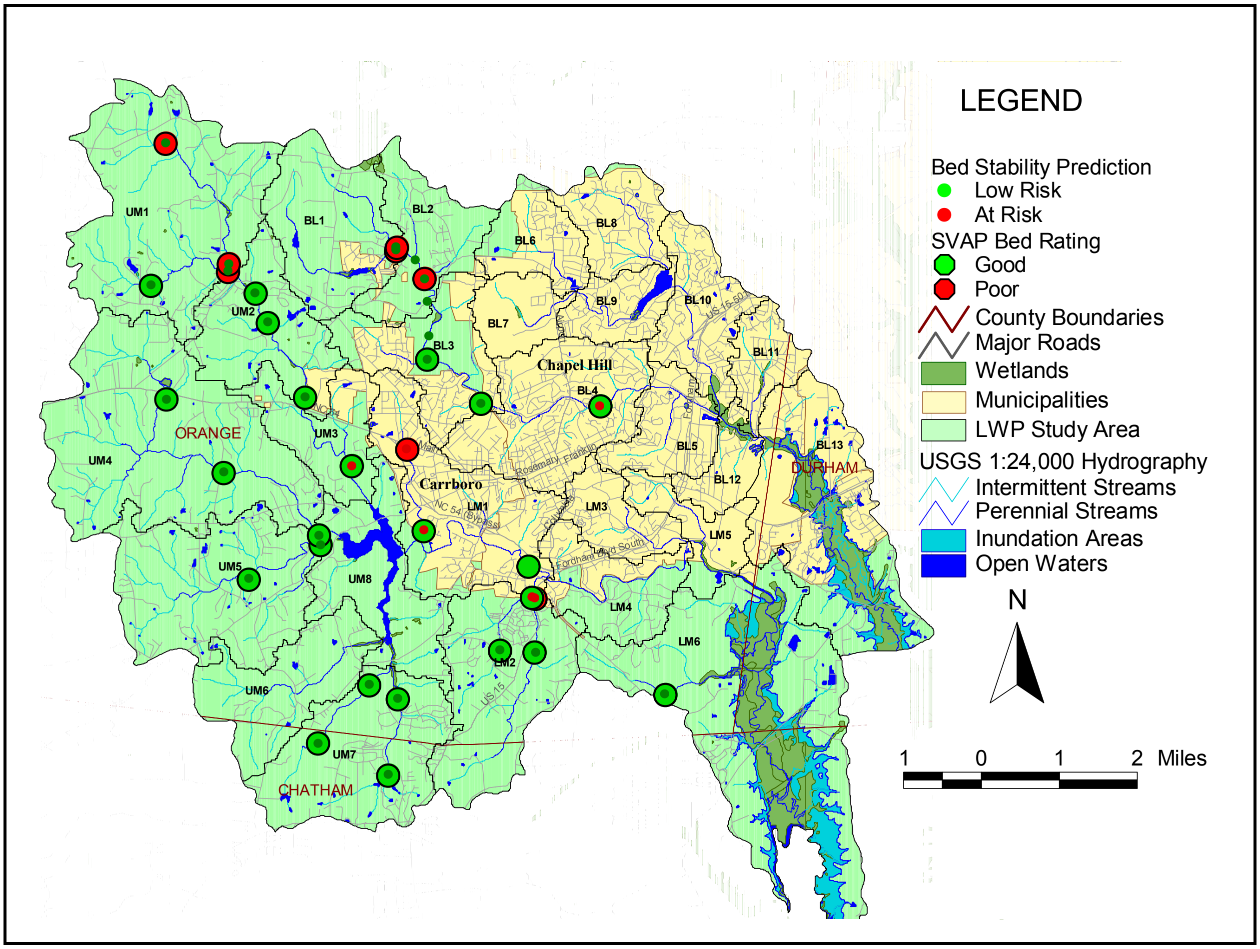

Figure 2-7. Verification of Streambed Stability Predictions with On-Site SVAP Measurements

Similar results were observed for comparison of streambank instability predictions. As shown in Figure 2-8, the modeled predictions and visual assessments of risk of bank instabilities agree in 22 of the 32 reaches. The two assessment methods produce similar levels of risk in approximately 70 percent of the reaches. When the subjectivity of the visual protocol is considered, three of the 10 reaches exhibiting disagreement have scores within 1 point of the threshold between “at risk” and “low risk.” When these three reaches are considered, the agreement between the methods approaches 80 percent.

For the stream reaches where the modeled predictions of risk level are different than the visual assessment, potential causes of the discrepancy were investigated. The most obvious cause of differing assessments stems from proximity of indicators to thresholds that were established. Another potential error source occurs because the curve number approach for quantifying development and stormwater runoff in a watershed does not explicitly address stormwater management controls. For recent developments, such as Southern Village on Fan Branch, where stormwater management facilities regulated through local ordinances were incorporated, the resolution of the watershed model is too coarse to capture the influence of these facilities, yet all of the impervious areas associated with the development are reflected in the calculated curve number. These situations can lead to model predictions overstating the risk of channel degradation when the visual assessment appears as “low risk.”

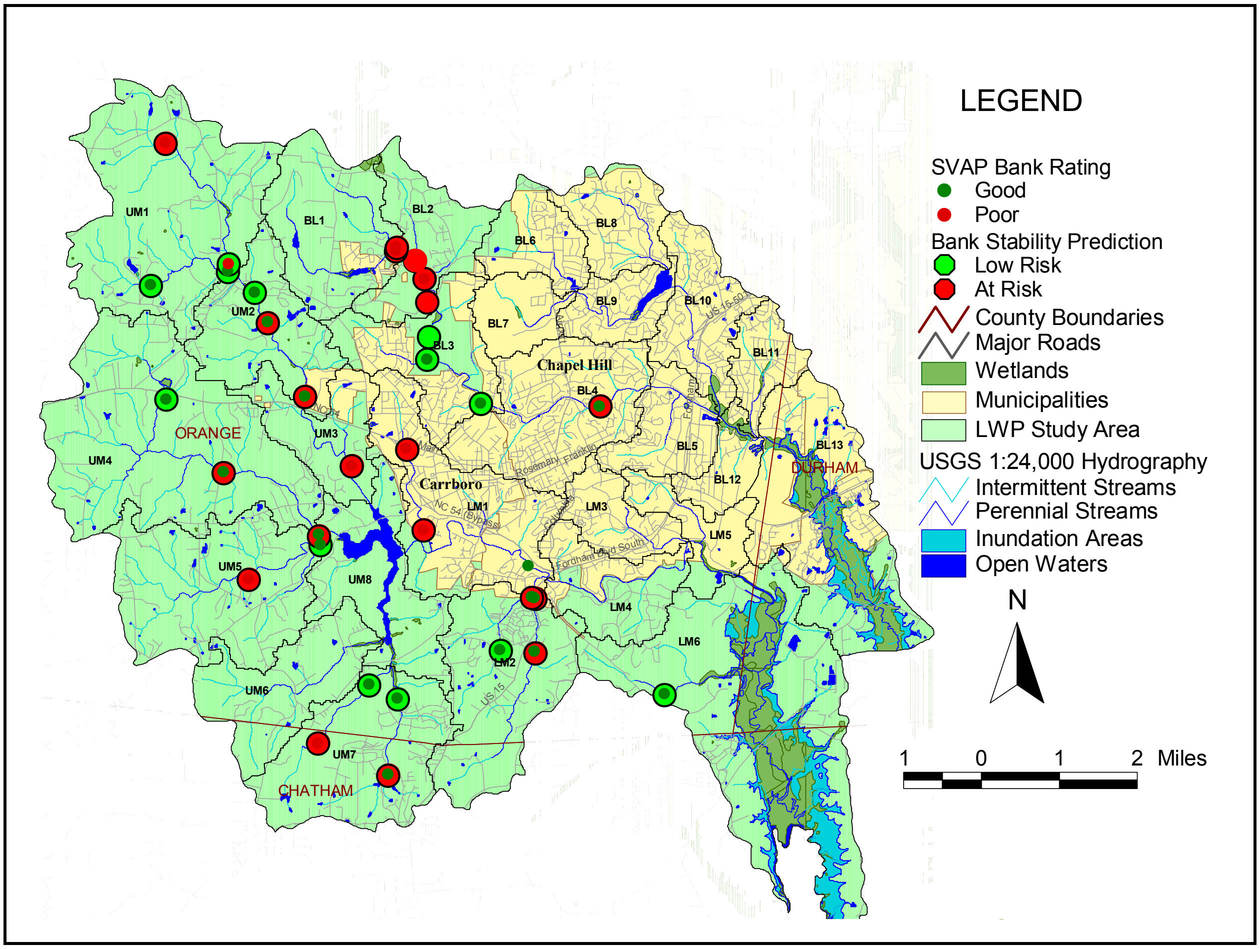

Figure 2-8. Verification of Streambank Stability Predictions with On-Site SVAP Measurements

2.2.4 Stream Erosion Risk Threshold Definitions

Given the high levels of correlation of risk levels between the model predictions and visual assessments under the existing development conditions, it is reasonable to expect that the modeled projections under the buildout condition are realistic and justifiable. A comparison of the results for the existing and buildout conditions is presented in Table 2-3. As is evidenced by the table contents, the risk of stream bank degradation is higher than bed degradation. This result is expected as the substrate in the streambed is typically coarser and more resistanct to erosive forces than the bank materials.

Table 2-3. Summary of Reaches "At Risk" of Degradation

Development Scenario	Streambed	Stream Banks
Existing Conditions	6 Reaches	20 Reaches
Buildout Conditions	8 Reaches	20 Reaches

To better identify LWP watersheds that are at risk of channel degradation and impairment of instream aquatic habitat due to stormwater runoff, the stability assessments of individual reaches are aggregated to the watershed scale. All of the evaluated reaches in a LWP watershed were given a score between one and three depending on whether the streambed only, channel banks only, or both stream bed and channel banks were at risk of degradation (Table 2-4).

Table 2-4. Reach Scores Based on Risk of Instability

Degree of Risk	Score
Both Streambed and Channel Banks	3
Either Streambed or Channel Banks	2
Neither Streambed nor Channel Banks	1

The scores for all reaches in a watershed were averaged to yield a composite score. Risk was assigned at the watershed scale based on the thresholds shown in Table 2-5.

Table 2-5. Thresholds for Degree of Risk at the Subwatershed Scale

Degree of Risk	Threshold
High	Average Score > 2.5
Medium	1.5 ≤ Average Score ≤ 2.5
Low	Average Score < 1.5

Figure 2-9 illustrates the composite risk of modeled channel degradation at the LWP subwatershed scale for the Morgan Creek study area under existing development conditions. Urbanization plays a primary role in two of the three subwatersheds categorized as high risk for morphologic instabilities. The watershed for Toms Creek, the tributary to Morgan Creek immediately downstream of University Lake, is highly impervious and the power associated with excessive quantities of stormwater runoff is greater than the resistance of the channel boundary materials. In the middle Bolin Creek subwatershed, approximately bounded by Franklin Street and Estes Drive extension, the stormwater runoff from portions of Carrboro and Chapel Hill enters the creek where it naturally transitions from the higher gradient Carolina Slate Belt geology to the lower gradient, depositional soils of the Triassic Basin. The higher flow velocities and increased runoff volumes act on less resistant bank materials of the Triassic Basin resulting in high risk of morphologic instabilities. The remaining subwatershed categorized as high risk is the lower third of upper Morgan Creek (immediately upstream of University Lake). The middle third of upper Morgan Creek is classified as medium risk, while the upper third is low risk. The cumulative effects of stormwater runoff delivered from the entire upper Morgan Creek watershed degrades the stability of the channel, exacerbating conditions in a downstream progression.

The upper Bolin Creek subwatersheds are considered medium risk for morphologic instabilities to the stream channel under existing development conditions due to the recent development of the Hogan Farms subdivision within the contributing watershed. As the municipalities of Carrboro and Chapel Hill expand in this portion of the study area, natural land covers are replaced with impervious surfaces that lead to altered stream hydrology to which the channels must adjust. The Phils Creek subwatershed is categorized as medium risk, which seems higher than expected, because, as part of the University Lake watershed, this subwatershed is predominantly low-density with extensive forested cover underlain by the Carolina Slate Belt formations. However, the main tributary to Phils Creek flowing south from Highway 54 has been subject to a substantial artificial increase in baseflow because it receives water transferred from Cane Creek Reservoir to University Lake for OWASA drinking water supply purposes. As a result of this modification of the hydrologic regime, the channel has become incised, which limits access of high flows to overbank areas and increases the forces applied on the streambanks resulting in active erosion.

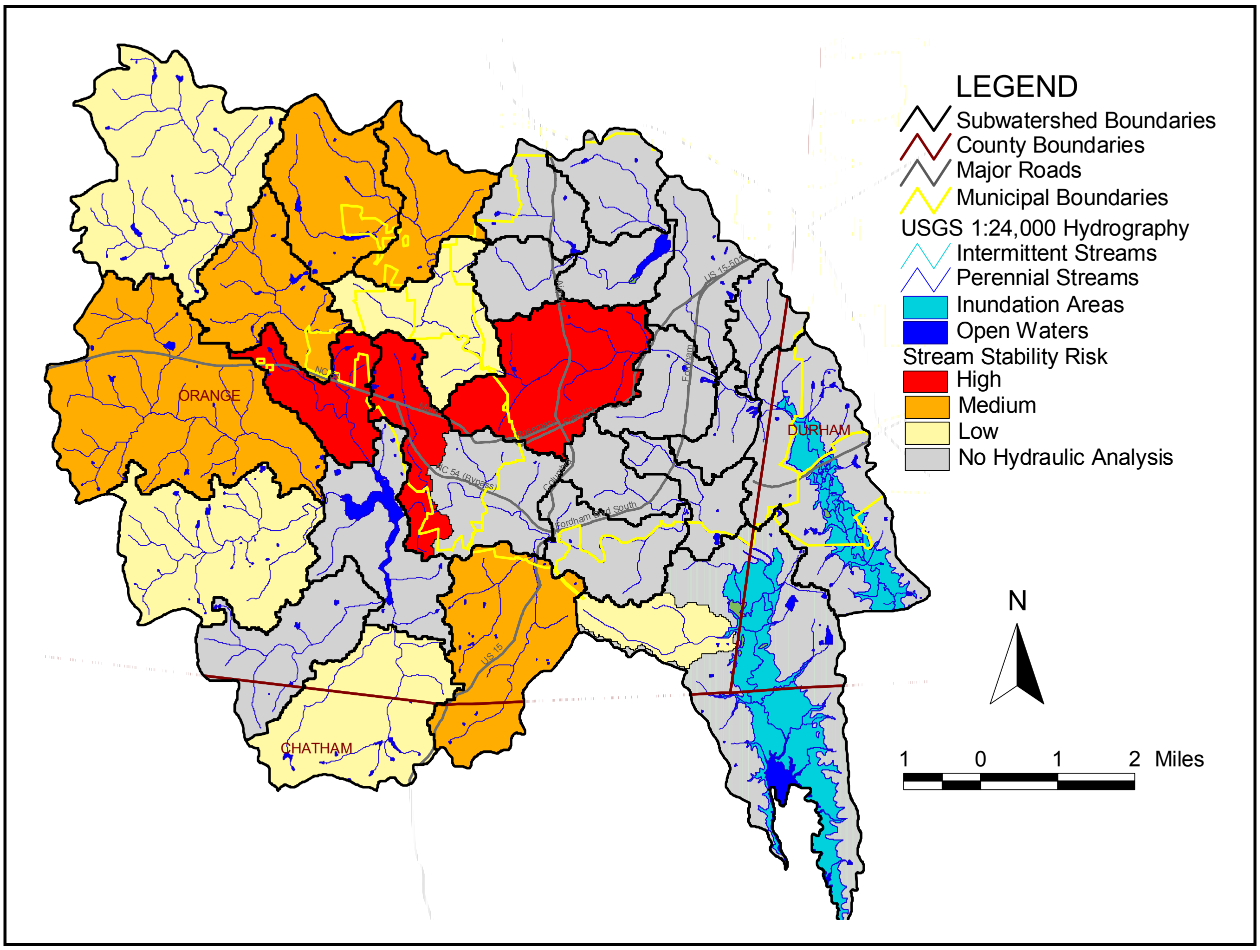

Figure 2-9. Stream Stability Risk Ratings for Existing Land Use Conditions

The medium risk classification of the Fan Branch and Wilson Creek subwatershed under existing conditions is a function of the early stages of urbanization. Development in the headwaters, located in Chatham County, increases stormwater runoff that progresses through the majority of the channel length before joining Morgan Creek. Therefore, increases in flow volumes in the headwaters affect all of the receiving downstream channels. Additionally, the widening of US-15 South both directly and indirectly affects channel stability. Directly, the road widening introduces additional impervious surface and stormwater conveyances in the subwatershed; indirectly the wider road enhances access to developable lands, which also increases the amount of impervious area. Throughout the study area, factors that lead to changes in stream hydrology consequently lead to changes in channel morphology, as supported by the results of the stream stability models.

Figure 2-10 illustrates the composite risk of modeled channel degradation at the LWP subwatershed scale for the Morgan Creek study area under existing development conditions. Examining both Figure 2-9 and Figure 2-10 reveals that the degree of risk is essentially the same under the buildout conditions as under existing development conditions. The only LWP watershed to change the degree of risk is the Fan Branch and Wilson Creek watershed. The degree of risk increases from medium to high due to significant development potential – especially in the headwaters in Chatham County where higher development densities are allowed and the predominant existing land cover is forest. While change in the degree of risk occurs for only one LWP watershed, this does not mean that risk at individual sites remains unchanged. There are slight changes in the degree of risk under buildout conditions; however, these changes are minor enough to not be reflected at the subwatershed scale.

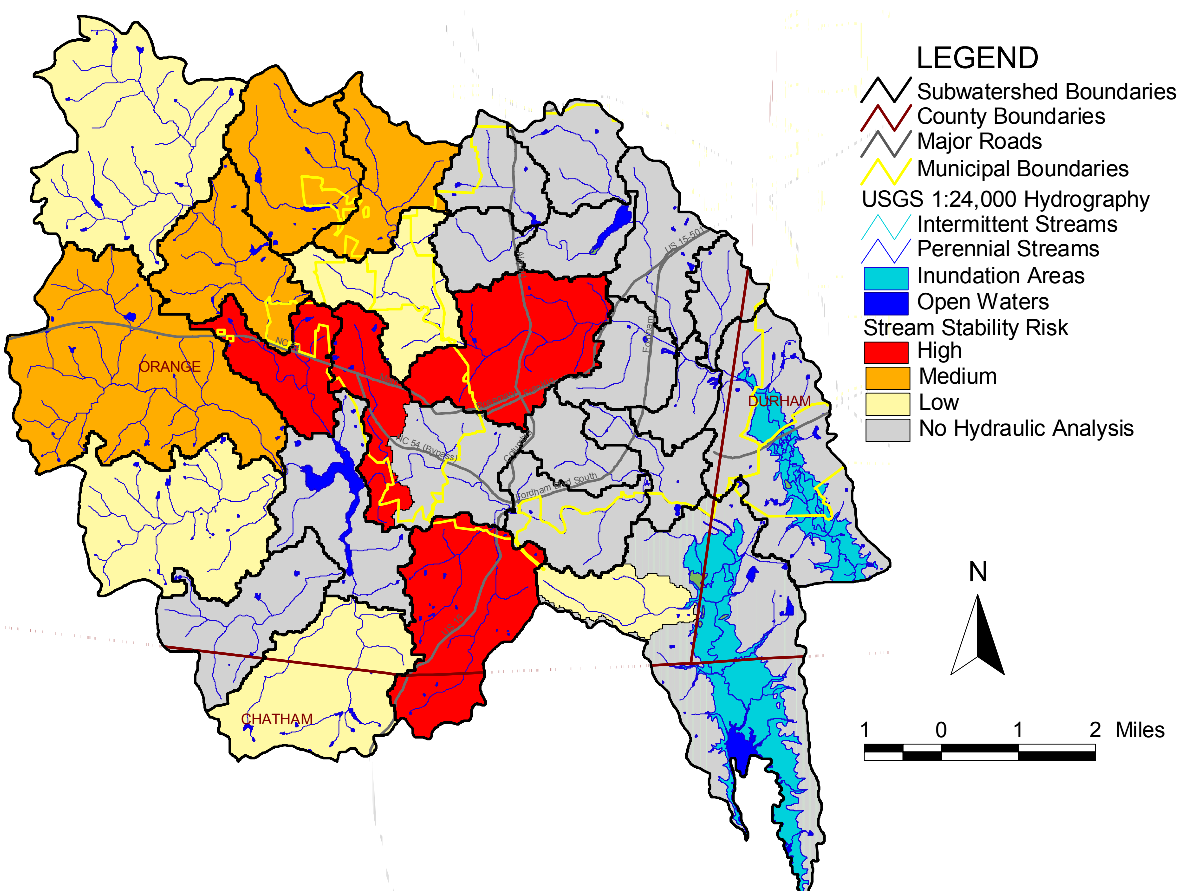

Figure 2-10. Stream Stability Risk Ratings for Buildout Land Use Conditions

Overall, the risk levels for streambed and bank degradation are unlikely to increase as the Morgan Creek LWP study area approaches a buildout condition. In general, stream reaches where the greatest risks of channel instabilities are projected to occur under buildout conditions are already at risk under existing conditions; reaches that are at low risk under existing conditions remain low risk at buildout. This trend is likely attributed to the relationships between existing development patterns, development regulations, and stormwater management ordinances. In the headwaters of the Morgan Creek watershed, where some development potential exists, it is expected that low-density residential developments will replace agricultural lands, which will actually reduce stormwater runoff due to the very low densities to which the local jurisdictions limit development. As mentioned previously the upper Morgan Creek watershed is the water supply watershed for University Lake, where Orange County enforces a 5-acre minimum lot size on new development and Chatham County maintains a 2-acre minimum. While these minimum lot sizes are intended to control pollutants entering University Lake, the regulations also appear to be an effective means of limiting the deleterious effects of stormwater runoff associated with increases in impervious surfaces. The stormwater management ordinance for Chapel Hill, which comprises a majority of the study area, limits the post-construction volume of runoff to the predevelopment volume for the 2-yr 24-hour event as well as limiting the post-construction runoff rate to the predevelopment rate for the 1-year, 2-year, and 25-year 24-hour storm events. In combination, these development patterns, development density regulations, and the stormwater management ordinances effectively limit the potential for increasing the risk of channel degradation under the buildout scenario.

Linkage Between Channel Degradation and Instream Aquatic Habitat Quality

Based on the results of the stability analyses for the streams in the Morgan Creek LWP study area, a probable linkage between channel degradation and impairment of instream aquatic habitat can be developed. As discussed in the previous sections, as a watershed develops and impervious surfaces are increased, stormwater runoff increases. However, if development densities are kept very low or if higher density development is allowed and effective stormwater management ordinances are implemented and enforced, the potential for destabilizing impacts on channel morphologies can be limited. In reaches where the streambed and banks are morphologically unstable, the quality of instream aquatic habitat is affected. When stream banks fail, sediment is introduced into the channel, embedding benthic substrate and clogging interstitial volumes and bank vegetation is lost. Trees providing canopy cover, input of organic material, and shading can fall into the channel, pools become filled with sediment, flow conditions become more homogeneous, and the available area for habitat is reduced. Many of these consequences also occur when streambeds are unstable.

As channel degradation becomes more prominent, the quality of the instream aquatic habitat decreases. In the Morgan Creek LWP study area, the results of the stability analyses show that the predominant areas of degradation under existing conditions remain degraded when the watershed is built out. The buildout condition is not so developed as to cause many additional reaches to destabilize due to increases in stormwater runoff; however, it is also not sufficient to allow existing degraded reaches the opportunity to stabilize themselves. Therefore, existing reaches at risk of channel degradation are prime candidates for restoration efforts. Focusing efforts in these reaches will provide the greatest opportunity for not only eliminating the cause of instream habitat impairment, but also enhancing the quality of instream habitat.

2.3 IMPERVIOUSNESS

The Center for Watershed Protection holds that, "Imperviousness is a very useful indicator with which to measure the impacts of land development on aquatic systems" (Shueler and Holland, 2000). As the amount of imperviousness in a watershed increases, the volume of rainwater that flows directly into the stream network increases, rather than infiltrating into groundwater. In order to accommodate the increased runoff volume, the cross-sectional area of the streams has to increase. This increase is achieved through widening of the stream banks, or downcutting of the streambed, or as is often the case, both.

Instability and erosion of this nature result in the loss of aquatic habitat functions within the affected streams through sediment loading and the disturbance of riffle-pool sequencing. In addition to increasing runoff volumes, impervious surfaces accumulate pollutants from vehicles and the atmosphere over time, which are subsequently washed into streams by storm events. Studies have also linked increases in imperviousness to excessive warming of water temperatures in aquatic systems (Shuler and Holland, 2000). The assessment of impervious surfaces in a watershed is a primary step in the detection of existing and potential threats to stream habitats.

2.3.1 Imperviousness Risk Threshold Definition

The most recent update of the Center for Watershed Protection's impervious cover model (ICM) indicates that streams are likely to be adversely impacted when impervious cover (IC) within their watershed reaches 10 percent or more, and that the level of degradation becomes significantly more likely and tends to be more severe at IC levels of 25 percent or more. In 2001, the Center completed a review of 225 research studies that measured a number of indicators of stream health relative to the amount of IC. The review reaffirmed that the IC range of 10-25 percent imperviousness was a strong predictor of stream degradation, and at levels of 25 percent or more, degradation was almost inevitable (Schueler, 2004).

2.3.2 Findings for Existing Conditions

To calculate the percent imperviousness for each subwatershed, a GIS union was created with building, road, parking lot, and driveway polygons from Carrboro, Chapel Hill, Durham, and Orange County governments. Where road polygons were not available, 24.4-foot buffers were created around street centerlines to approximate road surface. Impervious surface may be slightly underestimated in rural areas because driveway and parking lot footprints were not available outside of the Chapel Hill, Durham, and Carrboro road polygon extents.

The imperviousness of subwatersheds UM6, UM7, and LM2 may be underestimated because data on Chatham County buildings were incomplete. Data on roads and buildings were insufficient for subwatershed LM6. Despite these limitations, this analysis provides a reasonable comparison of imperviousness between subwatersheds. Figure 2-11 displays the total percent imperviousness for each subwatershed.

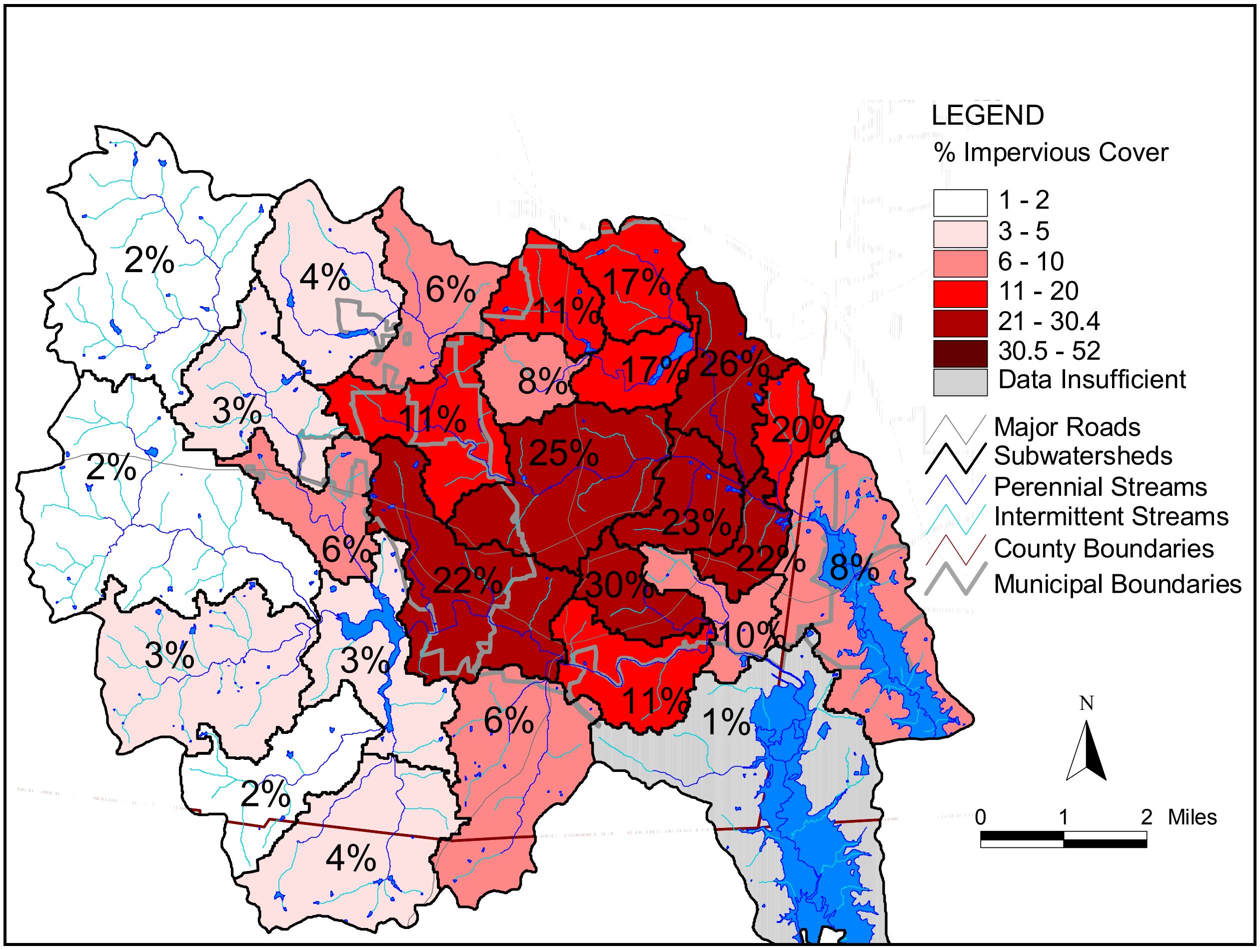

Figure 2-11. Existing Imperviousness by LWP Subwatershed

The planimetric data underestimate imperviousness in Southern Village and Meadowmont, two large, mixed-use developments in Chapel Hill. The planimetric data include about one-third of the total proposed construction for Southern Village, but may not include all of the recent construction. The planimetric data did not include any Meadowmont buildings. The existing impervious surface in Meadowmont was estimated with the development's impervious surface allocation and a visual assessment of the construction to date. Existing imperviousness in Meadowmont was estimated at 22 percent.

Overall, the Morgan Creek study area is about 8 percent impervious. Subwatersheds LM1, LM3, BL4, BL5, BL12, and BL10 have the highest levels of imperviousness, ranging from about 21 to 30 percent of subwatershed area. As in the forest cover analysis, these subwatersheds represent the most disturbed portions of the study area, and they contain the town centers of Carrboro and Chapel Hill as well as the 54 and 15-501 business corridors. In general, imperviousness decreases with distance away from the town centers. Percent imperviousness ranges from 3 to 20 percent in the subwatersheds outside of the town centers. The upper Morgan Creek subwatersheds represent the least developed, most rural areas in the study area, with subwatersheds UM1, UM4, and UM6 at less than 2 percent imperviousness. The most significant reason for this low level of imperviousness in the upper Morgan Creek subwatersheds (UM1 – UM7) is that this area is covered by the local governments' University Lake Watershed Protection Overlay Zone, 90 percent of which is restricted to 5-acre minimum residential lots and approximately 4 percent imperviousness.

2.3.3 Findings for Future Baseline Conditions

A GIS and database analysis was performed to estimate the amount of impervious cover by LWP subwatershed for the future land use conditions within the LWP study area by applying estimates of imperviousness to each of the land use categories in the buildout scenario developed for this study (as summarized in section 2.3.1 and described in detail in Appendix A). Levels of imperviousness were applied to each category according to the distribution shown in Table 2-6, which is derived from the levels of imperviousness given for each land use category in the NRCS TR-55 manual (NRCS, 1986). For land use categories in which development densities did not correspond exactly those indicated for the categories in the TR-55, interpolation between categories was utilized to project levels of imperviousness. Using the GIS, the land uses were divided by LWP subwatersheds to calculate the imperviousness for each subwatershed.

Table 2-6. Percent Imperviousness for Land Use Categories

Land Use Name	GWLF Code	% Impervious
Residential – Very Low Density (2+ acres per d.u.)	RVL	8
Residential – Low Density (1.5-2 acres per d.u.)	RLL	14
Residential – Medium Low Density (1-1.5 acres per d.u.)	RML	18
Residential – Medium High Density (0.5-1 acres per d.u.)	RMH	23
Residential – High Density (0.25-0.5 acres per d.u.)	RHH	29
Residential – Multifamily/Very High Density (< 0.25 acres per d.u.)	RVH	50
Office/Light Industrial	OFF	70
Commercial/Heavy Industrial	CIT	85
Urban Greenspace	UGR	0
Pasture	PAS	0
Row Crop	ROW	0
Forest	FOR	0
Wetlands	WET	0
Barren	BAR	0
Water	WAT	NA

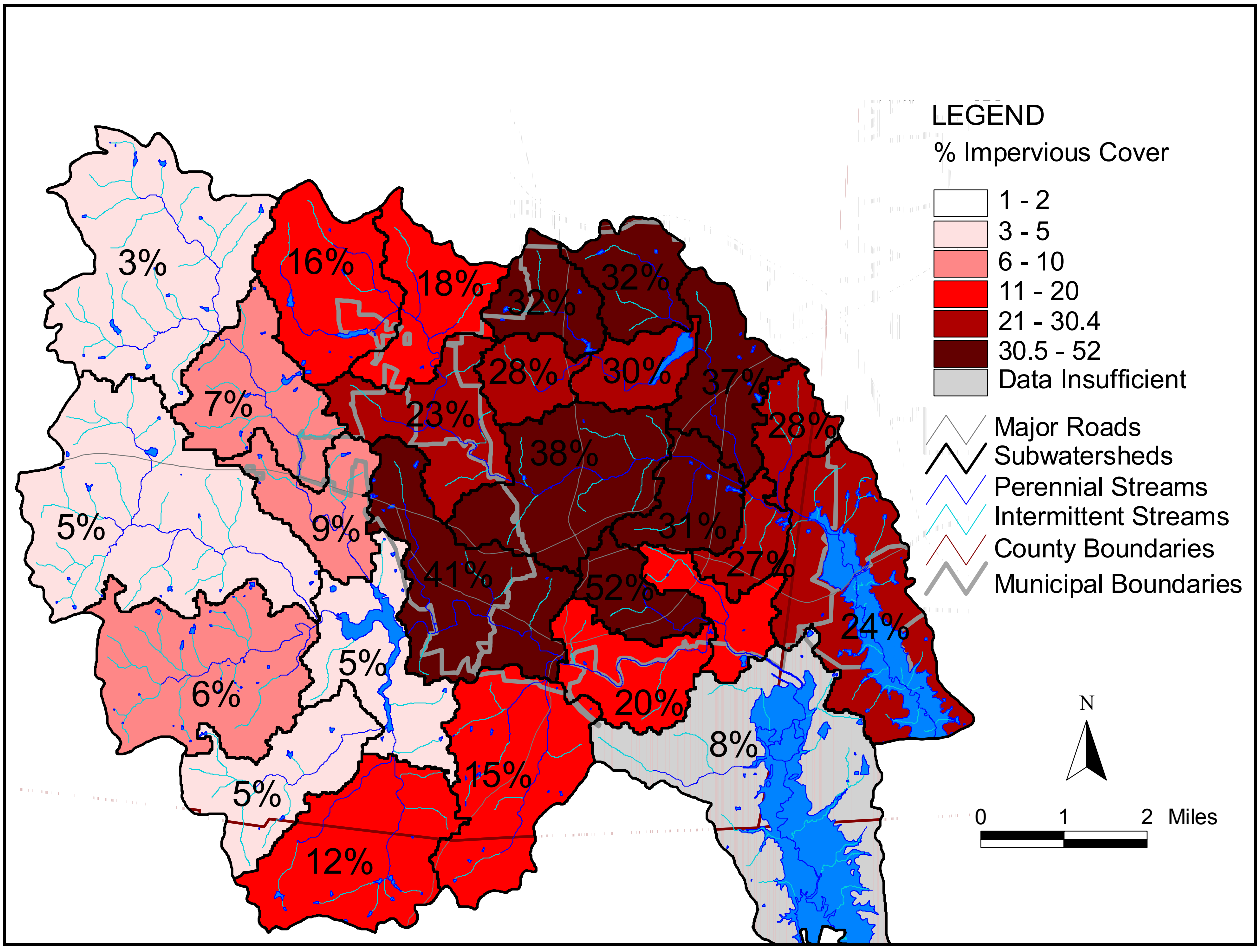

Figure 2-12. Estimated Future Imperviousness for Buildout Scenario by LWP Subwatershed

Collectively, most of the University Lake watershed will remain under the 10 percent imperviousness threshold even under buildout conditions as a result of the 5-acre minimum lot size restriction within the watershed. The exception is the southernmost LWP subwatershed, which drains a portion of northern Chatham County, where lots as small as two acres may be developed resulting in a predicted level of 12 percent imperviousness. Downstream of University Lake, urban areas within Chapel Hill and Carrboro municipal limits are expected to achieve levels of imperviousness in the range of 30 to 50 percent.

In terms of identifying those portions of the study area most at risk for future degradation, it is useful to evaluate the incremental increase in imperviousness from existing to buildout land use conditions. That incremental increase is shown by LWP subwatershed in Figure 2-13. As would be expected, the smallest increases, at five percent or less, occur in the University lake subwatersheds with a slightly larger increase expected in the Chatham County portion. With continued development of the UNC-Chapel Hill main campus, a large increase in imperviousness of more than 20 percent is predicted for the Meeting of the Waters subwatershed. Large increases are also expected in the Durham County portion of the Little Creek watershed and in the uppermost subwatershed of Booker Creek (BL6 and BL7).

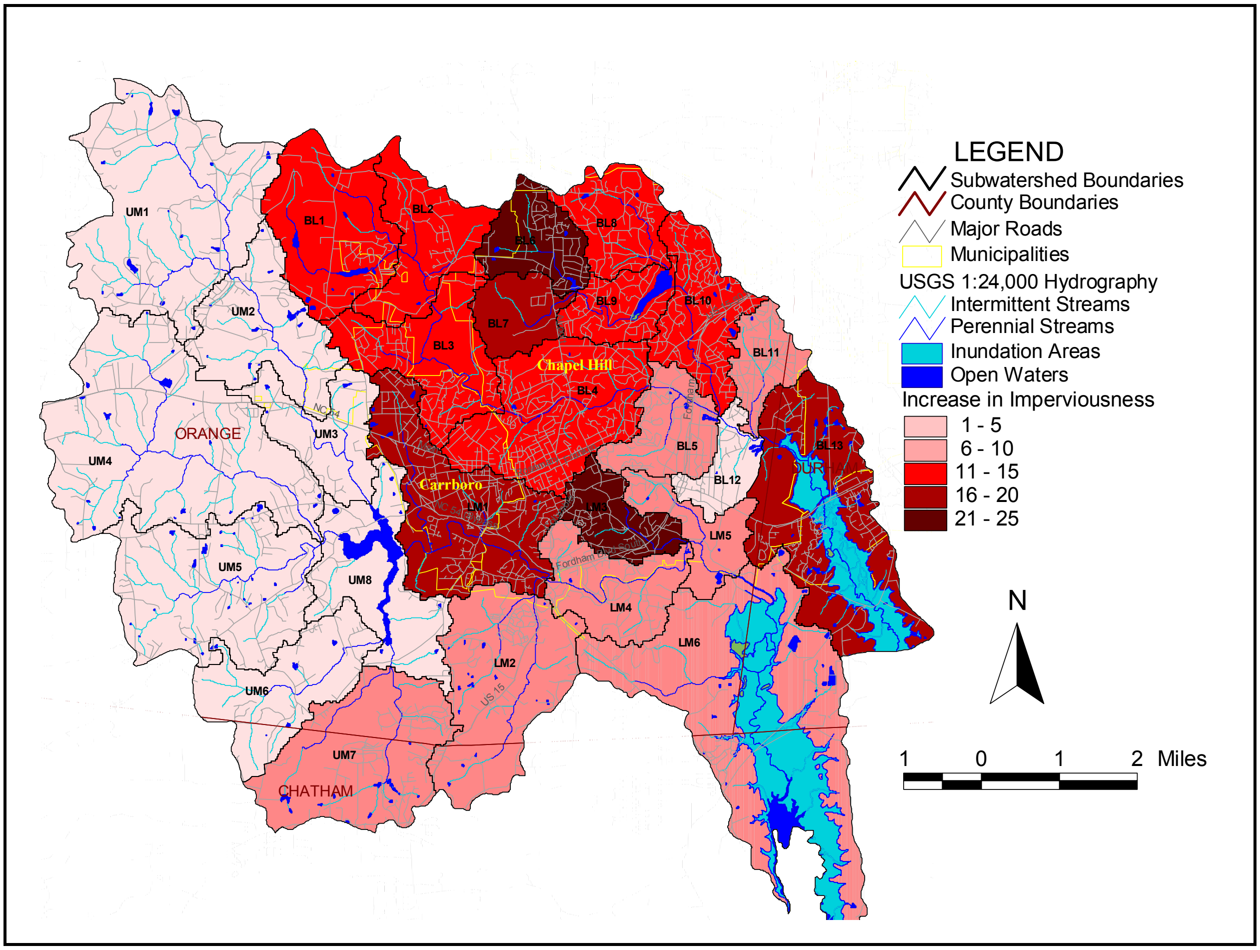

Figure 2-13. Incremental Increase in Imperviousness from Existing to Buildout Land Use

2.4 RIPARIAN BUFFERS

2.4.1 Vegetative Status Assessment Methods

GIS buffer polygons were used to tabulate land cover around all 1:24,000 scale stream reaches at a distance of 100 feet on each side of the stream. Lakes and ponds were excluded from the buffer polygons. For the purposes of this analysis, "disturbed" land is defined as those areas that have been converted from natural areas (forest/wetland) to other land uses (agricultural/residential/commercial) to a sufficient degree as to be detectable at the resolution of the land cover data. The ArcView Spatial Analyst extension was used to analyze the 1999 land cover data within the defined buffer area. The level of resolution within the land cover data is 30 x 30 meter pixels, and each pixel is assigned a land cover category based on the cover type occupying the majority of the pixel.

2.4.2 Findings for Existing Conditions

Results of the buffer analysis for the Morgan Creek study area are presented in Table 2-7 and Figure 2-14 Within the study area, 37 percent of the total buffer area is disturbed. The three 14-digit hydrologic units within the study area range from about 40 percent buffer disturbance for Little Creek to 27 percent buffer disturbance for Upper Morgan, with Lower Morgan at a median of 36 percent.

Table 2-7. Degree of Disturbance of Riparian Buffer Vegetation by LWP Subwatershed

Subwatershed	Area (ac)	Area (sq mi)	% Urban	% Suburban	% Field	% Forest	% Emergent Wetlands	% Water	% Disturbance
Little Creek									
Hogan Farm	113	0.2	2.8	8.8	18.1	66.8	2.2	1.4	29.7
Upper Bolin Creek	82	0.1	1.6	11.8	9.4	76.9	0.3	0.0	22.8
Horace Williams	130	0.2	2.8	17.9	10.3	68.4	0.5	0.0	31.0
Middle Bolin Creek	154	0.2	6.8	31.1	15.2	46.2	0.7	0.0	53.1
Lower Bolin Creek	57	0.1	10.3	25.3	7.9	56.1	0.4	0.0	43.5
Booker Headwaters	48	0.1	30.9	17.1	11.5	40.1	0.0	0.5	59.4
Crow Branch	39	0.1	8.8	19.9	7.0	60.8	0.6	2.9	35.7
Cedar Fork	75	0.1	6.7	32.7	9.4	48.5	1.8	0.9	48.8
Eastwood Lake	35	0.1	1.2	24.8	9.3	62.7	0.0	1.9	35.4
Lower Booker Creek	69	0.1	12.9	21.9	10.3	54.5	0.3	0.0	45.2
Ephesus	58	0.1	2.7	35.6	7.2	53.4	0.0	1.1	45.5
Meadowmont	46	0.1	3.4	31.3	13.5	48.1	3.8	0.0	48.1
Little Creek Arm	273	0.4	2.8	17.9	13.1	62.7	3.2	0.2	33.8
Upper Morgan									
Morgan Headwaters	393	0.6	1.3	10.3	19.9	67.6	0.8	0.1	31.5
Tilleys Branch	168	0.3	0.1	8.9	10.9	80.1	0.0	0.0	19.9
Morgan Glen	100	0.2	1.6	13.2	11.0	74.0	0.2	0.0	25.7
Phils Creek	468	0.7	3.6	8.4	9.7	77.4	0.8	0.1	21.7
Neville Creek	296	0.5	1.1	12.9	20.8	64.0	1.0	0.1	34.9
Pritchards Mill Creek	149	0.2	2.1	8.1	11.5	76.9	0.9	0.6	21.6
Price Creek	177	0.3	1.3	13.6	15.6	67.2	1.9	0.4	30.5
University Lake	96	0.1	2.3	16.8	13.8	63.4	0.7	3.0	32.9
Lower Morgan									
Morgan-Carrboro	203	0.3	14.9	29.4	12.6	42.0	1.1	0.0	56.9
Wilson Creek	172	0.3	6.1	15.7	15.1	62.9	0.3	0.0	36.9
Meeting of the Waters	42	0.1	16.4	17.9	7.7	57.4	0.5	0.0	42.1
Lower Morgan Creek	101	0.2	2.4	15.5	11.9	69.8	0.4	0.0	29.7
Finley	71	0.1	11.4	26.2	24.3	36.9	1.3	0.0	61.8
Morgan Creek Arm	395	0.6	0.8	9.9	9.7	78.2	1.4	0.1	20.3
Total	**3,027**	**4.7**	**4.1**	**15.4**	**13.4**	**65.8**	**1.0**	**0.3**	**32.9**

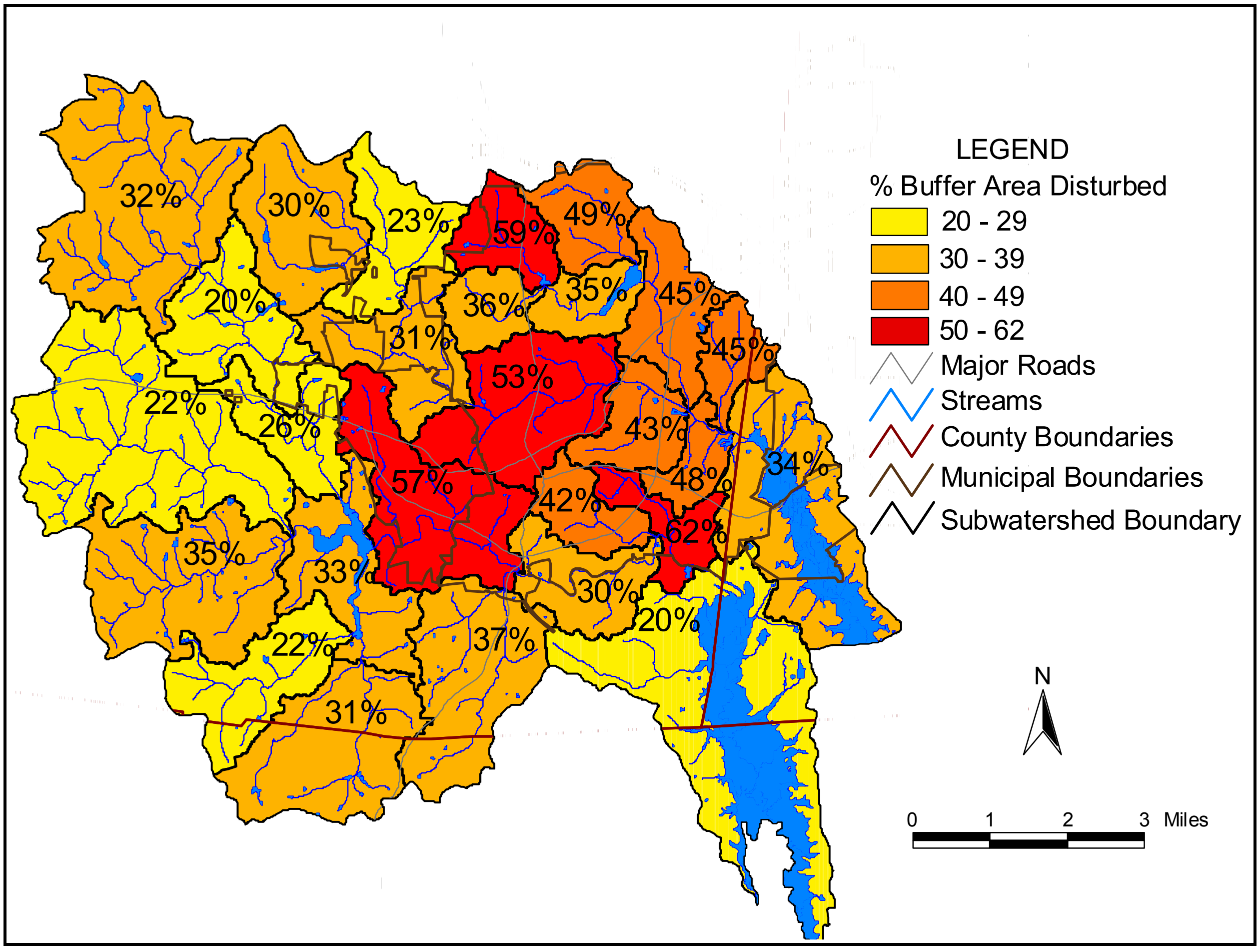

Figure 2-14. Degree of Disturbance of Riparian Buffer Vegetation by LWP Subwatershed

This analysis suggests that stream buffers are most protected in Upper Morgan. Therefore, the Lower Morgan and Little Creek watersheds are likely to require more intensive buffer management strategies than Upper Morgan. Management strategies will also differ for the more disturbed watersheds because suburban land uses cause most of the buffer disturbance in the Lower Morgan and Little Creek watersheds, while Upper Morgan is disturbed primarily by field.

At the subwatershed level, over half of the stream buffer is disturbed in 4 of the 27 subwatersheds (LM2, LM5, BL2, BL6). Buffers in LM3, BL5, and BL12 are slightly less disturbed overall. Subwatersheds with between 40 and 50 percent buffer disturbance overall include BL8, BL10, and BL11. Nine subwatersheds have between 30 and 40 percent buffer disturbance overall. The subwatersheds with the least buffer disturbance (less than 30 percent) are UM2, UM3, UM4, UM6, and BL2. BM6 is unique in that its stream buffer is 20 percent disturbed overall, and this difference is caused by the large amount of protected public land surrounding Jordan Lake.

It is important to note that much of the riparian buffer disturbance reflects development prior to 1980. In the 1980s and 90s, local jurisdictions in the Morgan Creek LWP study area adopted stringent stream buffer requirements, resulting in buffers greater than 100 feet in much of the watershed development in the last 15 to 20 years. Future development must also comply with these stream buffer requirements.

2.4.3 Buffer Disturbance Risk Ratings

No established risk threshold is available to link the degree of buffer disturbance to the likelihood of stream degradation. However, it is widely accepted that as naturally vegetated riparian buffers are encroached upon by anthropogenic land uses, the likelihood of stream degradation increases as a result of increased stormwater runoff and pollutant loading. Reduction in shade cover also results in degradation of aquatic habitat. In order to be able to factor the disturbance of natural buffer vegetation into the final ranking of subwatersheds in Section 5, based on best professional judgment and the distribution of buffer disturbance rates for subwatersheds across the study area, risk ratings for buffer disturbance were assigned according to the ranges of disturbance given in Table 2-8.

Table 2-8. Risk Rating for Degree of Riparian Buffer Disturbance

Degree of Risk	Threshold
Very High	Disturbance > 50%
Medium	Disturbance = 40 - 50%
High	Disturbance = 30 - 40%
Low	Disturbance < 30%

2.5 FLOODPLAIN ENCROACHMENT

A wide, vegetated floodplain that can be accessed by a stream during high flow events decreases stream velocity and protects downstream areas from more pronounced flooding. When development occurs in a floodplain, construction is likely to decrease floodplain area and increase floodplain slope; vegetation is removed, and low areas are elevated with fill soil. Confinement or incision of the channel can reduce the ability of a stream to access the flood plain. Such alternations increase flood velocity, reduce flood retention, and lead to more severe flooding downstream.

2.5.1 Assessment Approach

The existence of buildings in the floodplain is one indicator of floodplain alteration in the Morgan Creek study area. GIS analysis was used to tabulate the area of building footprints in the 500-year floodplain (FEMA Q3) per subwatershed. While the 100-year floodplain is most often the legal standard utilized for siting of structures, the 500-year floodplain was used in this analysis because the location of buildings and other structures within the 500-year floodplain area can result in grading and alteration of the 100-year floodplain immediately adjacent to streams. The FEMA Q3 polygons for Orange and Durham counties were intersected with the study area subwatershed boundaries, and the aggregate area of buildings in the floodplain was tabulated on the basis of the GIS coverage of building footprints obtained from the Orange County GIS Department. GIS data were incomplete for subwatersheds UM6, UM7, LM6, and BL13.

2.5.2 Target and Risk Threshold Definition

No established risk threshold is available to link the degree of floodplain encroachment to the loss of riparian floodplain function. However, as construction activities occur within floodplains, the associated filling and regrading often diminishes the storage capacity in the immediate area, leading to increasing potential for downstream flooding. In order to be able to factor the encroachment of construction on floodplains into the final ranking of subwatersheds in Chapter 5, based on best professional judgment and the distribution of encroachment rates for subwatersheds across the study area, risk ratings for floodplain encroachment were assigned according to the ranges of encroachment given in Table 2-8. The thresholds were set on the basis of best professional judgment and the distribution of data from this analysis for all subwatersheds evaluated.

Table 2-9. Risk Rating for Degree of Floodplain Encroachment

Degree of Risk	Encroachment Threshold
Very High	6-8%
Medium	4-6%
High	2-4%
Low	0-2%

2.5.3 Findings – Floodplain Encroachment

The percent of the floodplain in buildings is displayed in Figure 2-15. Subwatersheds BL5, BL10, LM1, and LM3 contain the most floodplain development in the study area. Building in the floodplain has been concentrated in the Little Creek watershed, especially in subwatersheds BL5 and BL10 (7.9 and 6.6 percent of the floodplain respectively). Floodplain encroachment tends to be commercial in these subwatersheds. Very little floodplain building has occurred in the Upper Morgan watershed. In Lower Morgan, the subwatersheds with the most floodplain building are LM1 and LM3 (3.6 and 3.1 percent of the floodplain respectively). Floodplain building in LM1 appears to be mostly residential, while buildings in the LM3 floodplain are part of UNC. Other important alterations to the floodplain include roads, sewer lines, and other utilities.

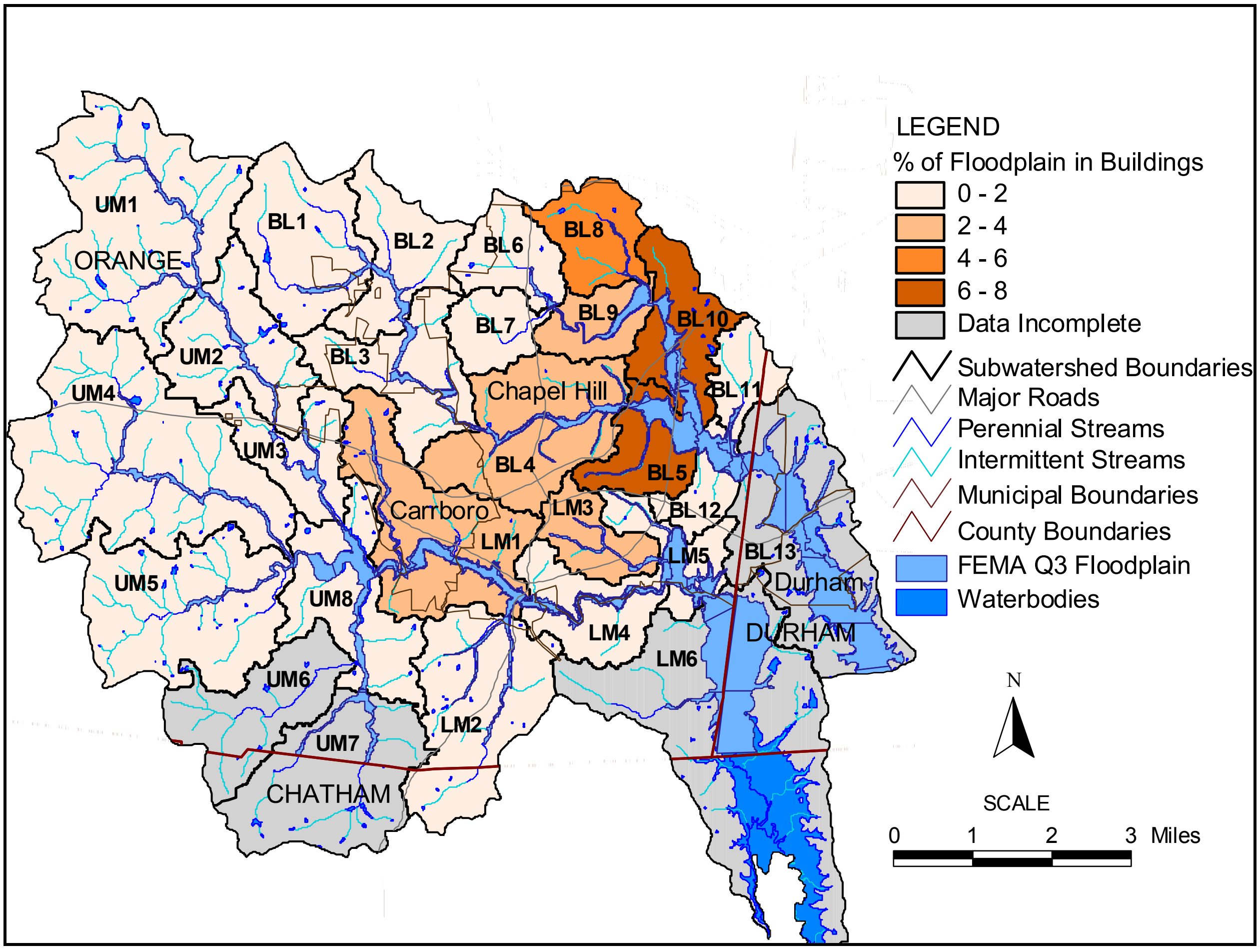

Figure 2-15. Degree of Floodplain Encroachment by LWP Subwatershed

3 Assessment of Water Quality/Water Supply Functions

A summary of the key potential stressors to water quality and water supply functions, along with a listing of the indicators used in their assessment and the tools used to perform those assessments is presented in Table 3-1. Details of the each assessment method and the corresponding results are discussed in Sections 3.1 through 3.3. Wherever possible, the results for each indicator are presented in the context of the Local Watershed Plan (LWP) subwatersheds shown in Figure 1-1.

Table 3-1. Summary of Indicators and Tools Used for Detailed Assessment of Water Quality and Water Supply Functions

Watershed Function	Potential Stressor	Indicator	Scale	Assessment Technique
Water Quality & Water Supply Functions	Jordan Lake Eutrophication	Nutrient Loading Rates	Watershed	GWLF*** Derived Export Rates Fate & Transport Modeling (SPARROW)
	University Lake Eutrophication	Nutrient Loads Eutrophic Response	Watershed	GWLF** Loading Model BATHTUB*** Response Model
	Fecal Coliform Loads	Water Quality Criteria Excursions	Subwatershed*	Statistical Analysis of Monitoring Data

*"Subwatershed" refers to smaller drainage areas within selected 14-digit hydrologic units delineated for the purposes of defining distinct management units within the context of Local Watershed Planning efforts, usually in the range of 1-10 square miles in area (refer to Figure 1-1).

**Generalized Watershed Loading Function (Haith and Shoemaker, 1987)

***Walker BATHTUB Model (Walker, 1987)

It should be noted that, while an extensive review and analysis of ambient water quality monitoring data from various sources is present in the *Preliminary Findings Report*, no such analysis is presented here. Given that the primary purpose of this *Detailed Assessment Report* is to compare, rank and prioritize LWP subwatersheds for further management in the final phase of this local watershed planning effort, and that ambient water quality monitoring sites are not distributed evenly across LWP subwatersheds, there was no practical way to use the data in a fair and comparable fashion in this subwatershed-level analysis. However, water quality monitoring data will be relied on again in the final phase to inform the development of restoration and management strategies for LWP subwatersheds.

3.1 Assessment Of Nutrient Delivery to Jordan Lake

NCDWQ has listed the Upper New Hope Creek and Morgan Creek arms of Jordan Lake as impaired and is undertaking efforts to develop a TMDL to address nutrient loads and eutrophication in these segments of the lake. Tetra Tech (2002 and 2003a) has developed a watershed nutrient delivery model and a lake nutrient response model to evaluate nutrient management scenarios on behalf of NCDWQ and a partnership of NPDES permitees. The nutrient management scenarios address both point and nonpoint sources, and nitrogen as well as phosphorus, because the nutrient response model and other assessments have indicated that co-limitation is occurring in the New Hope Creek arm. NCDWQ will use the modeling results to determine the necessary load reductions from each source and how to distribute the required reductions between sources and throughout the watershed.

The NC Environmental Management Commission's Water Quality Committee approved schedule for Jordan Lake TMDL development dictates that NCDWQ is to develop a nutrient management strategy for incorporation into the TMDL to be released as a public notice draft in late 2004. The TMDL is likely to call for some form of reduction in existing nonpoint source nutrient loads. For these reasons, the *Preliminary Findings Report* set forth as a primary objective for this effort to identify those areas within the LWP study area having the greatest potential to deliver nutrients to Jordan Lake, and to target those areas for management efforts to reduce nutrient loads.

Tetra Tech (2003b) also developed a modeling framework for OWASA to assess eutrophication potential in University Lake, and serve as a guide for management efforts in the watershed. Analysis tools created as part of this effort include an in-lake nutrient response model and a calibrated watershed model for upper Morgan Creek. The most recent conclusions from the University Lake analysis are summarized in Section 3.2.

Since these projects and the Morgan Creek LWP effort were conducted during the same general time frame and across common spatial boundaries, there was considerable overlap in data and methodologies between the projects. The primary differences in these analyses were related directly to the varying scales at which they were conducted, and those differences are discussed below.

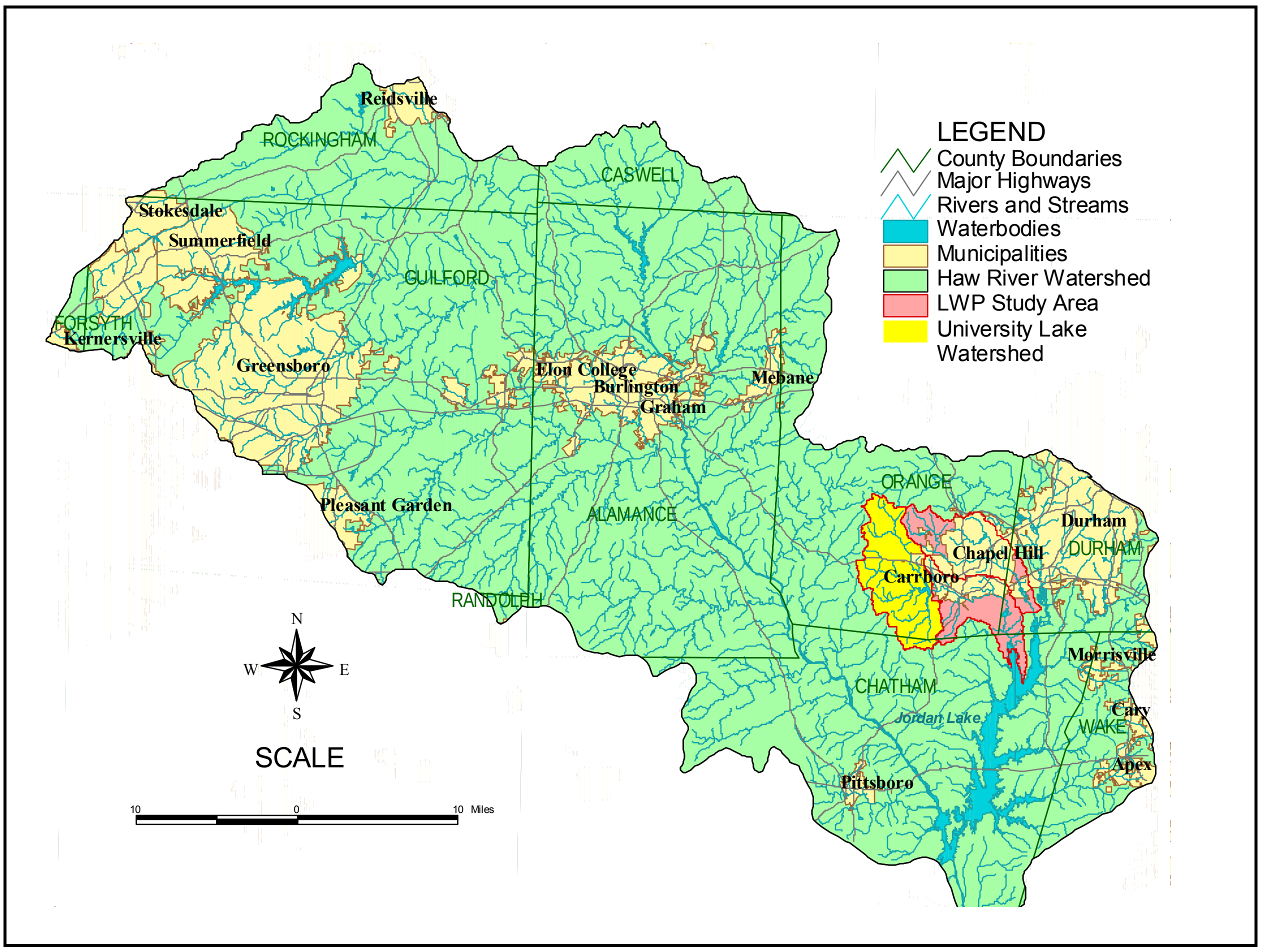

Figure 3-1. Jordan Lake Watershed with Morgan Creek LWP Study Area and University Lake Watershed

3.1.1 Assessment Methods

Tetra Tech drew on the recent projects outlined above to estimate nutrient loading in the study area for both existing land use and projected buildout land use. The existing and future land use scenarios utilized in this analysis are the same as those used in the Critical Velocity Analysis of Stream Stability (refer to Section 2.3.1), and the development of those scenarios for this project is discussed in detail in Appendix A. Work from the University Lake Planning Model Project conducted for OWASA (Tetra Tech, 2003b) was utilized to estimate nutrient loads in the Upper Morgan Creek subwatersheds. For the Lower Morgan Creek and Little Creek subwatersheds, work from the large-scale Jordan Lake TMDL Watershed Model (Tetra Tech, 2003a) was used as a starting point, but the methodology was refined down to the tax parcel scale to estimate nutrient loads from each LWP subwatershed.

The next step in the analysis was to take the subwatershed loads and estimate the portion of each load delivered to Jordan Lake. The stream transport component of the USGS SPARROW model (Smith et al., 1997) was utilized for this task. SPARROW refers to spatially referenced regressions of contaminant transport on watershed attributes, and was developed based on nationwide USGS monitoring of 414 ambient water quality monitoring stations. The model empirically estimates the origin and fate of contaminants in streams. The SPARROW tool actually contains two portions, one to generate upland loads and one to account for mass transport through stream reaches. This approach used only the portion of the SPARROW model that estimates transport. Nutrient trapping in University Lake was also taken into accounted.

Finally, delivered loads were calibrated using an adjustment factor to match the watershed total nonpoint source loads estimated for the Jordan Lake Project. The loads from the Jordan Lake Project were calibrated to match observed instream nutrient loads from the four primary tributaries to the lake.

The subwatershed nutrient loading model and the SPARROW fate and transport modeling are described in detail in Appendix A.

3.1.2 Results

For each LWP subwatershed the SPARROW fate and transport analysis was used to predict the proportion of nutrients delivered downstream to Jordan Lake under existing and buildout land use conditions. The resulting delivery ratios are given as percentages for existing and buildout land use scenarios in Table 3-2. The spatial distribution of delivery ratios for total nitrogen under existing and future buildout scenarios is shown in Figure 3-2. Total phosphorus delivery ratios follow spatial patterns identical to those exhibited by total nitrogen and are therefore not shown here. Note that watersheds near the lake had higher deliveries than hydrologically distant watersheds. As an example, BL11 had an overall TN delivery of 0.835 through BL13, while BL8 had an overall TN delivery of 0.716 through BL10, BL12, and BL13.

Delivery ratios alone are not sufficient to assess the risk of nutrient loading from a given subwatershed. Delivered loads also fall short of showing the relative contribution to Jordan Lake nutrient loads for each of the subwatersheds because they can exaggerate the impact of a large subwatershed simply by virtue of its size. To generate a meaningful comparison of nutrient loading potential across LWP subwatersheds, delivered loads were combined with subwatershed area to produce exerted loading rates expressed in pounds per acre per year. Loading rates for existing and buildout land use for each subwatershed are shown in Table 3-3 and graphically in Figure 3-3 through Figure 3-6. The total nitrogen loading rates for loads exerted on Jordan Lake from LWP subwatersheds for existing and buildout land use conditions are shown in Figure 3-3 and Figure 3-4, respectively, and the exerted total phosphorus loading rates for existing and buildout conditions are shown in Figure 3-5 and Figure 3-6.

When evaluating the distribution of subwatershed load rates in Figure 3-3 through Figure 3-6, note that the colors of the subwatersheds indicating their individual exerted loading rate are broken down by quintiles in each scenario. When comparing the existing and future scenarios, it is important to notice the numeric increase in loading rates associated with each quintile. For instance, the exerted total nitrogen (TN) loading rate for the top quintile of subwatershed increases from a range of about 6-7 lbs/ac/yr for existing conditions to 8.5-10.5 lbs/ac/yr under buildout conditions. Similarly, exerted total phosphorus (TP) loading rates for the top quintile increase from a range of 0.9-1.2 lbs/ac/yr to a range of 1.2-1.6 lbs/ac/year.

Despite the fact that higher delivery ratios occur in subwatersheds closer to the Jordan Lake, the exerted loading rate figures show that the heavily developed subwatersheds in the urban centers of both Chapel Hill and Carrboro contribute the highest loads.

Table 3-2. Existing and Buildout Delivery Ratios

	Existing Deliv. Ratios		Buildout Deliv. Ratios	
	TN	TP	TN	TP
BL1	0.5169	0.5167	0.5448	0.5367
BL2	0.5583	0.5464	0.5841	0.5644
BL3	0.6260	0.5935	0.6475	0.6082
BL4	0.6785	0.6292	0.6965	0.6412
BL5	0.7121	0.6516	0.7277	0.6619
BL6	0.5661	0.5520	0.5915	0.5697
BL7	0.5661	0.5520	0.5915	0.5697
BL8	0.6300	0.5963	0.6513	0.6108
BL9	0.6300	0.5963	0.6513	0.6108
BL10	0.7121	0.6516	0.7277	0.6619
BL11	0.7348	0.6666	0.7486	0.6757
BL12	0.7348	0.6666	0.7486	0.6757
BL13	0.8800	0.7600	0.8800	0.7600
LM1	0.6430	0.6447	0.6519	0.6511
LM2	0.6430	0.6447	0.6519	0.6511
LM3	0.6931	0.6808	0.7008	0.6863
LM4	0.6931	0.6808	0.7008	0.6863
LM5	0.7181	0.6986	0.7249	0.7034
LM6	0.8650	0.8000	0.8650	0.8000
UM1	0.4896	0.2809	0.4720	0.2854
UM2	0.4896	0.2809	0.4720	0.2854
UM3	0.4896	0.2809	0.4720	0.2854
UM4	0.4896	0.2809	0.4720	0.2854
UM5	0.4896	0.2809	0.4720	0.2854
UM6	0.4896	0.2809	0.4720	0.2854
UM7	0.4896	0.2809	0.4720	0.2854
UM8	0.4896	0.2809	0.4720	0.2854

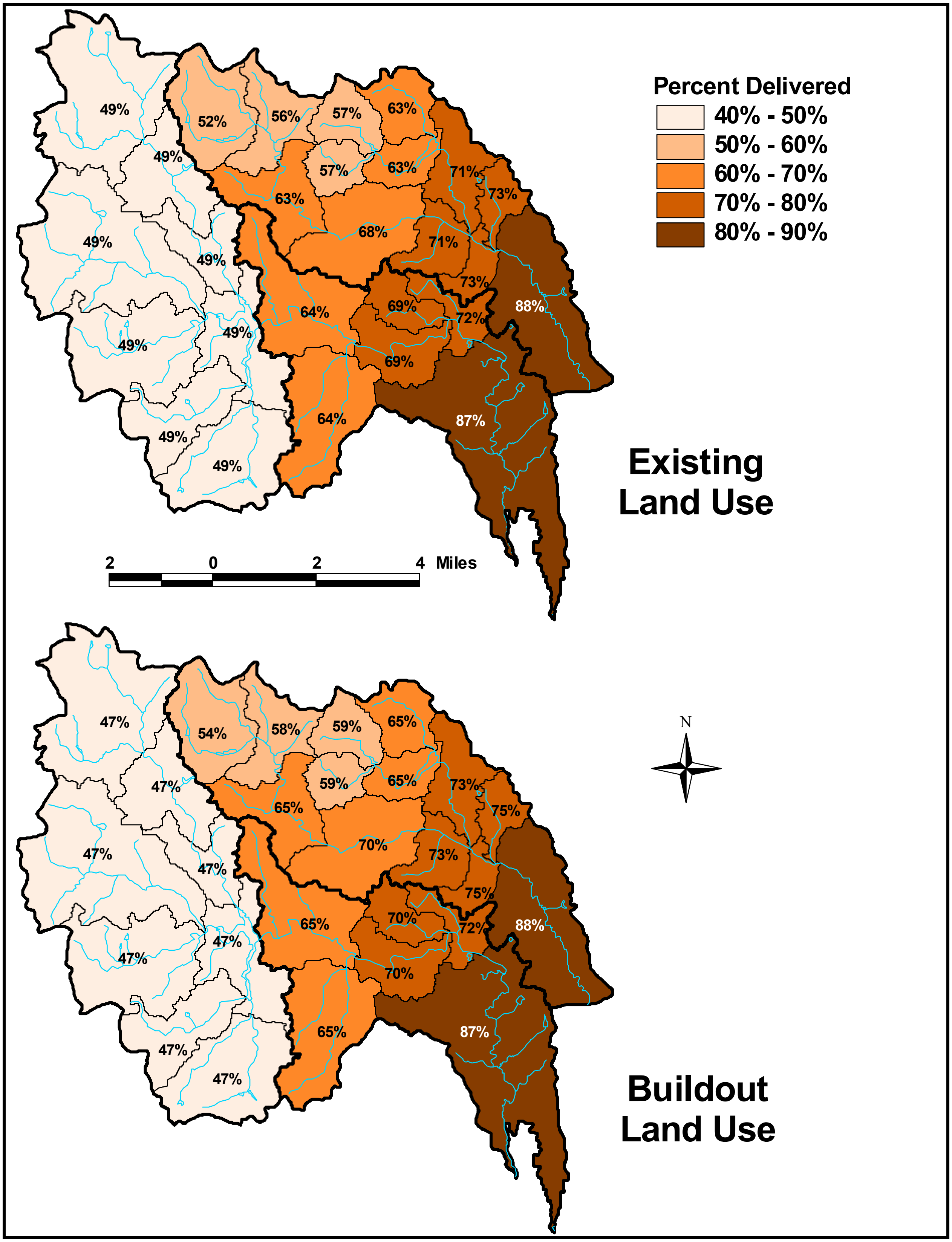

Figure 3-2. TN Delivery Ratios for Existing and Buildout Land Use

Table 3-3. Existing and Buildout Nutrient Loading Rates to Jordan Lake

	Existing Loading Rates (lb/ac/yr)		Buildout Loading Rates (lb/ac/yr)	
	TN	TP	TN	TP
BL1	3.08	0.573	4.96	0.803
BL2	4.59	0.529	5.37	0.853
BL3	4.05	0.799	6.07	0.901
BL4	6.84	1.119	9.60	1.414
BL5	6.51	0.988	8.47	1.246
BL6	4.69	0.713	6.71	1.050
BL7	3.01	0.726	5.58	0.871
BL8	6.11	0.955	8.08	1.225
BL9	5.92	0.881	7.14	1.101
BL10	6.79	1.153	9.49	1.383
BL11	6.34	0.994	8.45	1.232
BL12	4.85	0.738	7.97	1.163
BL13	4.35	0.866	10.60	1.212
LM1	6.23	1.098	9.11	1.450
LM2	5.26	0.657	5.93	0.769
LM3	6.32	0.963	10.06	1.570
LM4	6.31	0.782	6.60	1.065
LM5	2.99	0.490	5.24	0.820
LM6	2.82	0.381	8.07	0.604
UM1	1.69	0.129	2.31	0.112
UM2	2.44	0.155	3.24	0.160
UM3	2.82	0.178	3.52	0.169
UM4	2.09	0.135	3.00	0.115
UM5	2.26	0.130	2.98	0.118
UM6	1.64	0.095	2.83	0.112
UM7	3.28	0.182	4.76	0.204
UM8	2.05	0.170	2.40	0.134

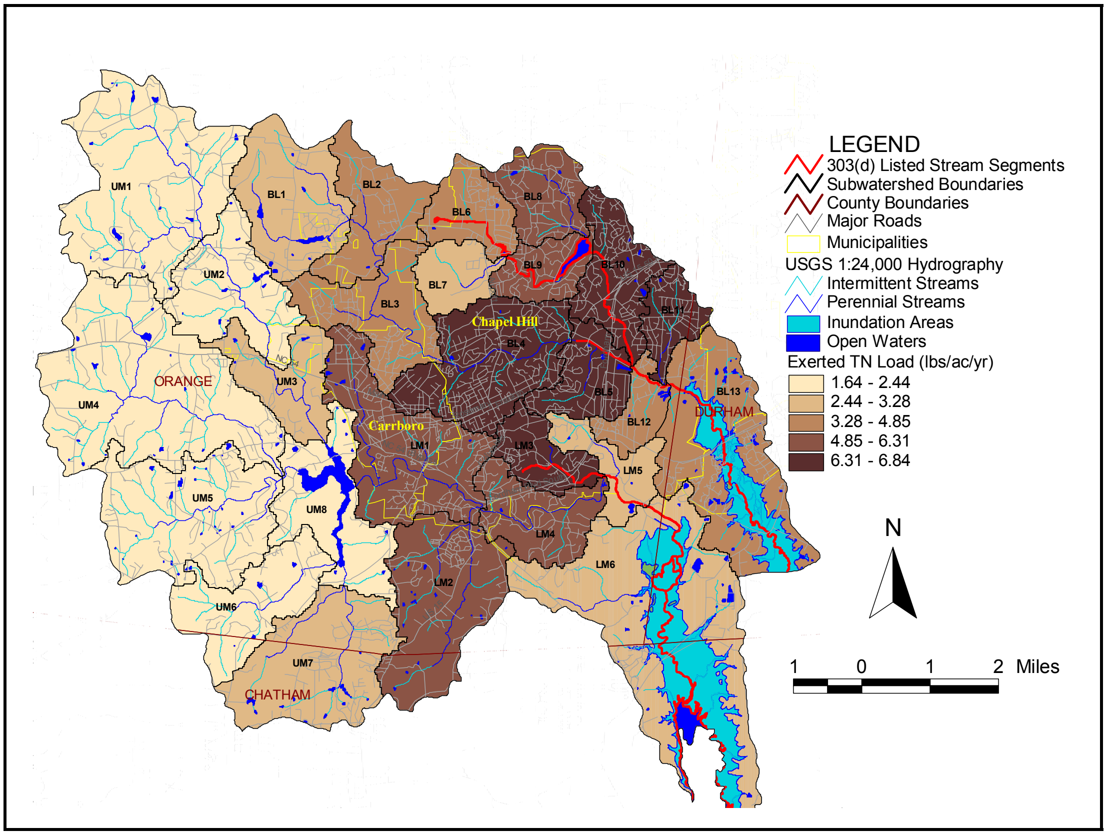

Figure 3-3. TN Loading Rates (lbs/ac/yr) – Existing Land Use

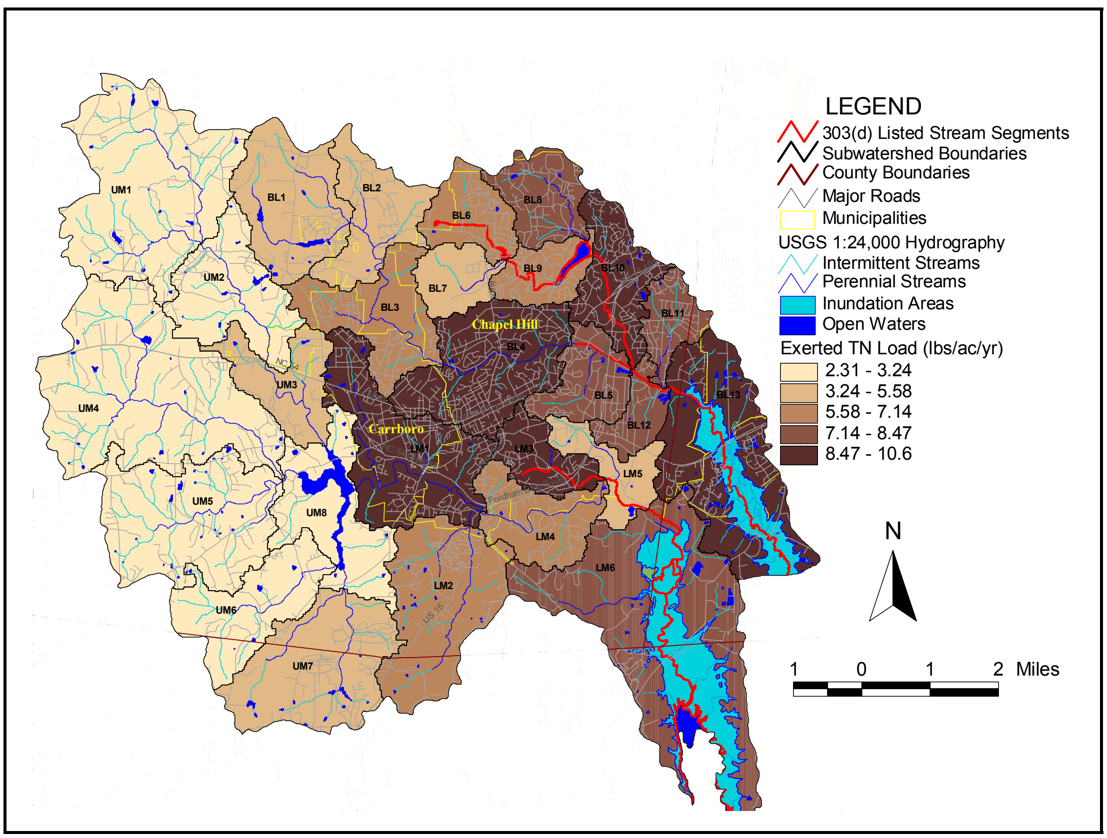

Figure 3-4. TN Loading Rates (lbs/ac/yr) – Buildout Land Use

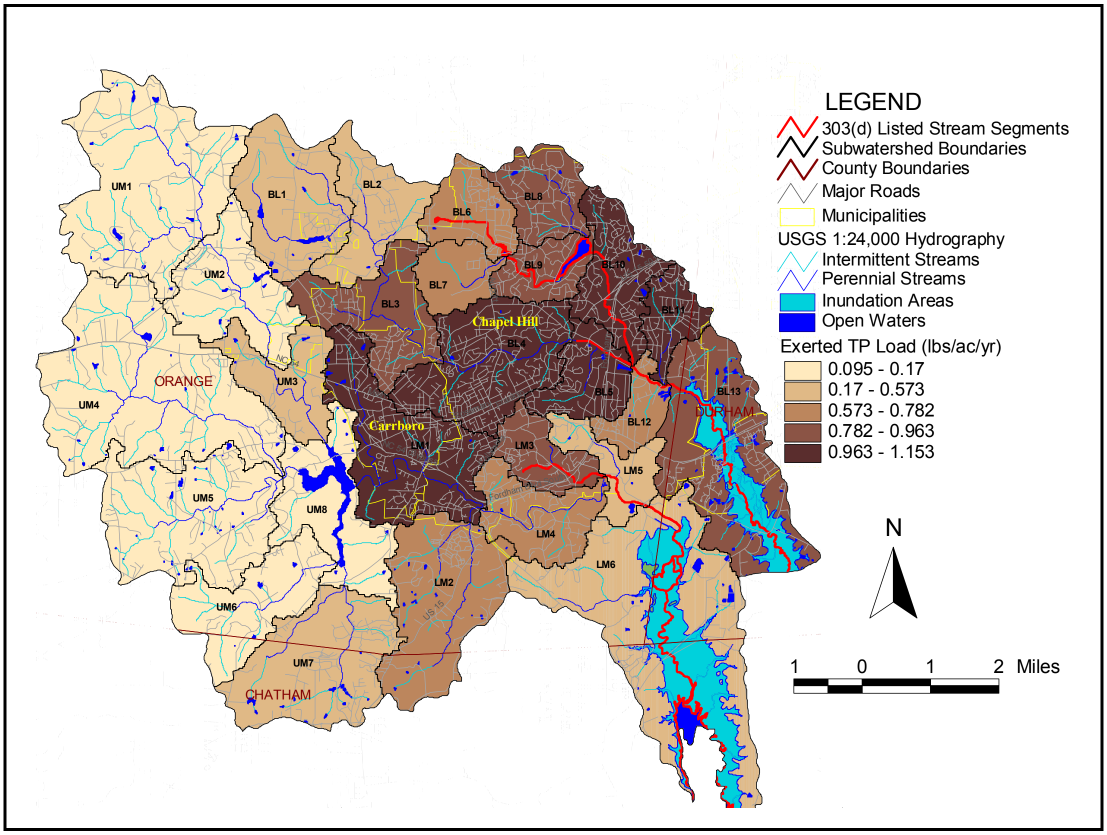

Figure 3-5. TP Loading Rates (lbs/ac/yr) – Existing Land Use

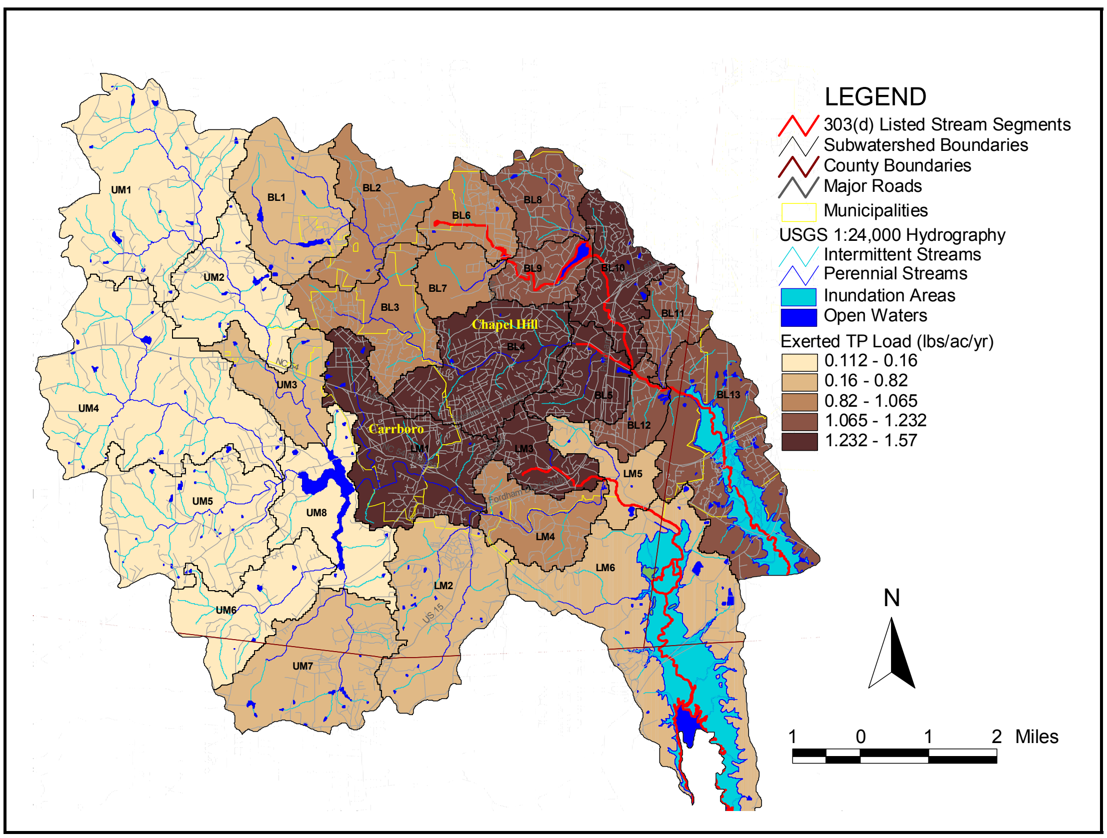

Figure 3-6. TP Loading Rates (lbs/ac/yr) – Buildout Land Use

3.1.3 Nutrient Loading Target and Risk Threshold Definition

Section 3.5.4 of the *Preliminary Findings Report* presents a scoping level analysis of the relative magnitude of the various point and nonpoint source nutrient loads to Jordan Lake. The analysis illustrates that the nonpoint source nutrient loads from the LWP study area do not constitute a sufficiently large enough portion of the overall nutrient budget for the lake to allow for evaluation of prospective changes in those loads due to management actions within the study area by using the Jordan lake nutrient response model. In addition, while it is expected that the Jordan Lake TMDL will require reductions in point and nonpoint source nutrient load, no firm numeric targets have been established to date. For these reasons, it is impractical to attempt to define firm numeric risk thresholds or management goals for nutrient loading in this document.

However, in order to prioritize subwatersheds for further management, it was necessary to establish a means of relative comparison between subwatersheds. For purposes of ranking the subwatersheds in Section 5 of this *Detailed Assessment Report*, based on best professional judgment and the observed distribution of subwatershed loading rates, it was deemed appropriate to rank subwatersheds based on the loading rate quintile in which they fall. In other words, those subwatersheds in the highest quintile in terms of their exerted nitrogen and phosphorus loads under existing land use conditions would be ranked highest in priority for management efforts to reduce those loads.

In terms of establishing priority subwatersheds for efforts to prevent future nutrient loads, the most efficient use of limited management resources would be achieved by focusing efforts on those subwatersheds where the greatest incremental increase in nutrient loading would be expected relative to existing conditions. The comprehensive ranking and prioritization of subwatersheds presented in Section 5 relies on the predicted incremental increase in future loads to rank subwatersheds. The incremental increases in subwatershed nitrogen and phosphorus loading rates from existing to buildout land use conditions are shown in Figure 3-7 and Figure 3-8, respectively. Due to the low-density development restrictions, the majority of subwatersheds in the University Lake watershed experience no, or only very slight, increases in loads for both TN and TP. For both TN and TP, the largest future increases in loading rates are predicted to stem from the Morgan Creek subwatershed immediately below University Lake (UM1), which includes the urban center of Carrboro, Meeting of the Waters (UM3), where significant growth is planned for the main campus of UNC, and the Bolin Creek subwatershed that contains most of Meadowmont (BL12). The subwatersheds nearest to Jordan Lake (BL13 and UM6), most of which are located with Chatham and Durham County jurisdictions, are also expected to experience large increases in nutrient loading rates. With regard to the future increase in TP loads, the upper Booker Creek subwatershed (BL6) is expected to experience a large increase in loading. Significant future increases in TN loading rates are expected to occur on a broad scale basis throughout the Bolin/Booker/Little Creek watershed.

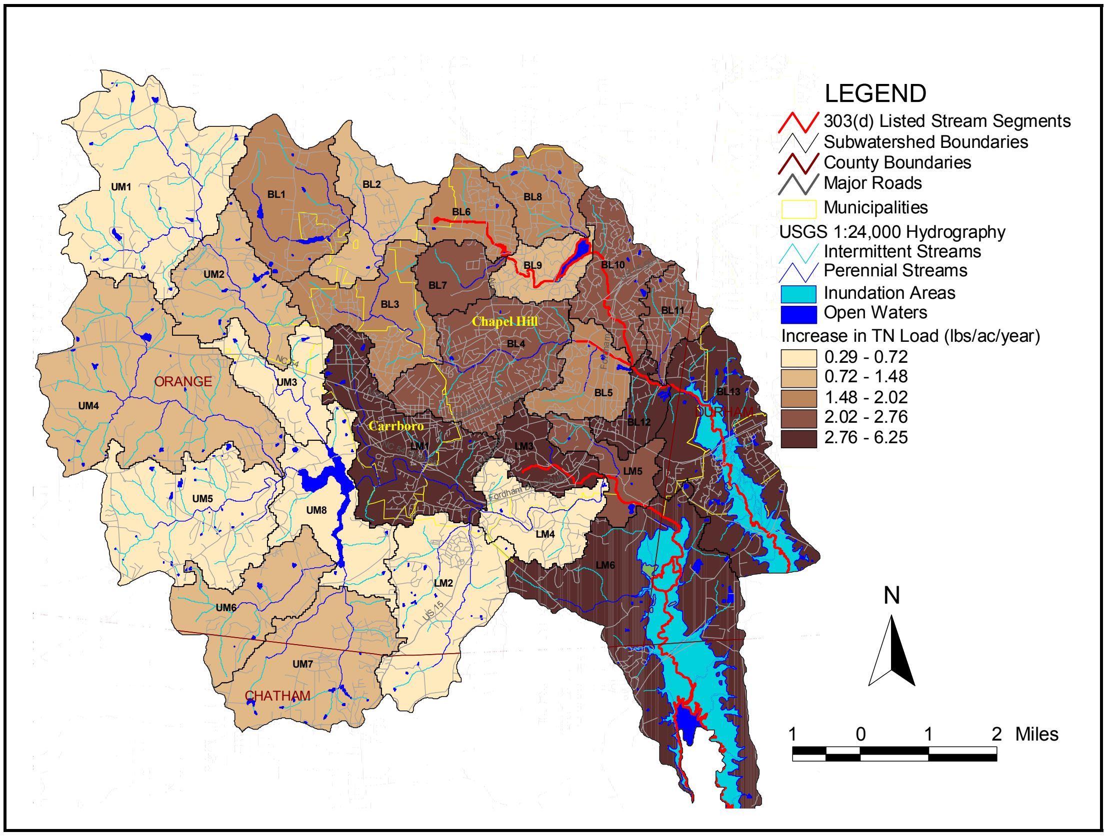

Figure 3-7. Increase in TN Loads (lbs/ac/yr) from Existing to Buildout Land Use Conditions

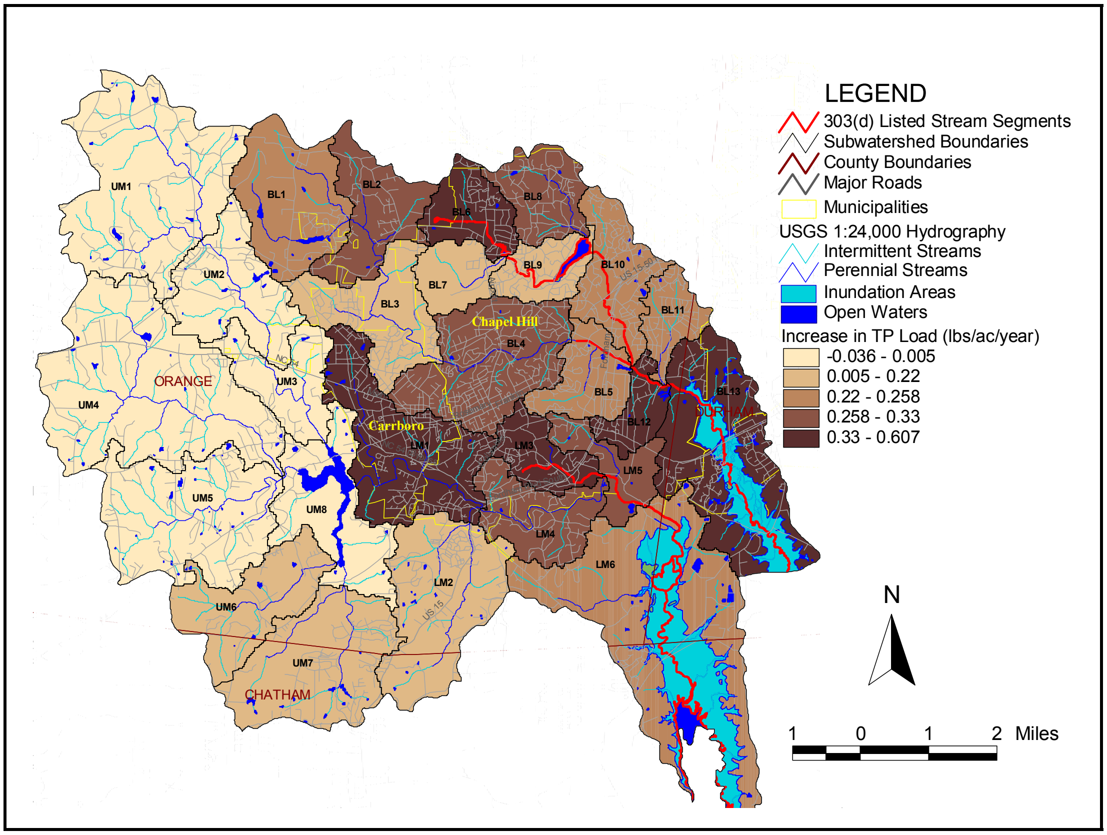

Figure 3-8. Increase in TP Loads (lbs/ac/yr) from Existing to Buildout Land Use Conditions

3.2 Summary of University Lake Nutrient Loading and Eutrophication Analysis

Tetra Tech staff completed a watershed study for the Cane Creek Reservoir in 1996 and provided ongoing planning services to help OWASA develop management strategies and target land acquisition for protection of their water supply. In November 2001, Tetra Tech submitted *Summary of Findings for Evaluating Water Quality at University Lake and Cane Creek Reservoir*. This report investigated observed problems in raw water quality in the lakes, and led to recommendations for potential in-lake management strategies. An important finding of this report is that elevated algal and total organic carbon concentrations in University Lake are primarily due to external loading and exacerbated by occasional wind-mixing events. Following that study, OWASA indicated interest in developing a set of planning tools for the University Lake watershed similar to those created for Cane Creek Reservoir.

To evaluate the need and potential for development of the planning model, Tetra Tech undertook a scoping analysis (now referred to as Phase 1 of the University Lake Planning Model project) in February 2002. Results of the Phase 1 scoping analysis were transmitted to OWASA on May 12, 2002. The analysis showed that there is still a considerable amount of land that is developable within the University Lake water supply watershed. Thus, even with existing development restrictions enforced by Carrboro and Orange County, the anticipated increases in nutrient loads from future development may subject University Lake to unacceptable levels of water quality degradation. Based on these findings, OWASA decided to proceed with a second phase of the project to develop a technically-based planning tool to support further management studies.

The first two tasks under Phase 2 involved setup and calibration of a watershed nutrient loading model and a lake water quality response model. To assess the contribution of upland sediment and nutrient loads from various areas in the watershed, Tetra Tech selected the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992). Watershed loads to University Lake are simulated with the GWLF model, using the Windows interface version known as BasinSim (Dai et al., 1999). GWLF provides a mechanistic, but simplified simulation of precipitation-driven runoff and sediment and nutrient delivery, yet is intended to be applicable without calibration.

Three land use scenarios were chosen to assess the impacts of future development in the University Lake watershed. The first is the "existing" land use scenario, which serves as the baseline to which the other two scenarios will be compared. The second is a "buildout" scenario, which represents the maximum development that can occur based on the zoning ordinances in place in the watershed. The third is the "partial-buildout" scenario which assumes that 50 percent of buildout may likely occur in the next 20 or so years. Thus "partial-buildout" is a more realistic scenario than "buildout." The existing and buildout land use scenarios are identical to the land use scenarios utilized in this LWP effort.

3.2.1 Eutrophication Response

Figure 3-9 shows the expected frequency of chlorophyll *a* concentrations greater than 40 µg/L during the summer months. The value of 40 µg/L is the state water quality standard for chlorophyll *a*, and is also used as an approximate indicator of significant algal blooms. However, it should be noted that water quality goals for water supply intake areas are frequently lower than the general standard. Raschke (1993) recommends a mean growing season concentration of 15 µg/L for small southeastern water supply impoundments, and 25 µg/L for protection of other uses. Nonetheless, the frequency of exceedances of 40 µg/L provides a relative indicator of nuisance algae bloom conditions. Under existing conditions, the frequency of exceedance of 40 µg/L was less than 10 percent for each modeling year, except for 1998. Under buildout conditions, only two years have exceedances less than 10 percent of the time. The summer of 1996 has very low predicted frequencies (less than 0.1 percent) regardless of land use scenario.

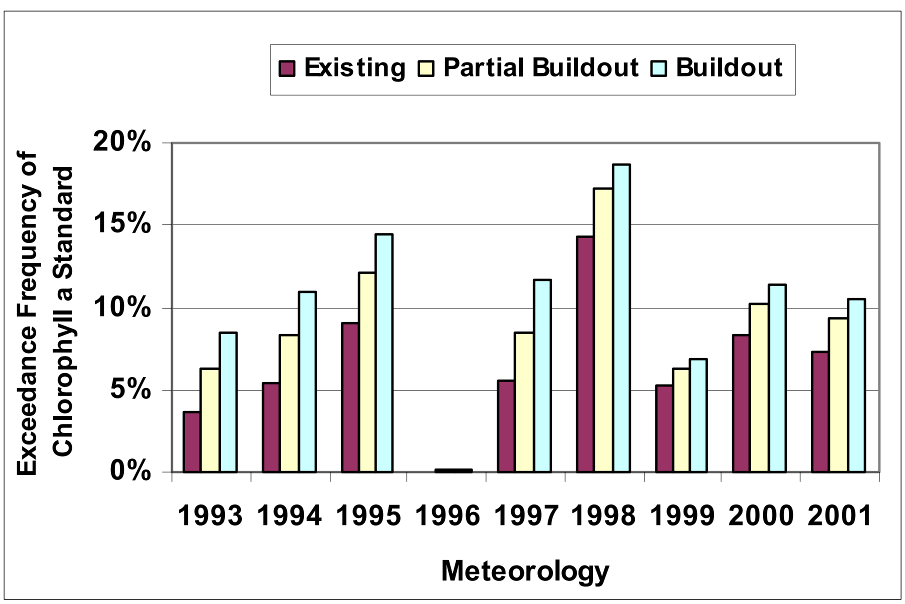

Figure 3-9. Summer Frequency of Chlorophyll *a* Concentrations Exceeding 40 µg/L

Under existing land use conditions with 1993 to 2001 meteorological data, University Lake is expected to exceed the 40 µg/L water quality standard 7 percent of the time. Under buildout conditions, the frequency increases to 10 percent across the modeling years. The summer of 1998 had the highest predicted frequencies: 14 percent under existing conditions and 19 percent under buildout conditions.

To test the sensitivity of the eutrophication model to watershed nutrient load reductions, Tetra Tech performed sensitivity analyses under a built out land use scenario with 25 percent reductions in nitrogen, phosphorus, and both nitrogen and phosphorus.

Figure 3-10 compares the frequencies of exceedance for each buildout scenario to existing conditions. In four of nine modeling years, reducing either nitrogen or phosphorus by 25 percent results in a lower frequency of exceedance compared to existing conditions. When both nutrient loads are reduced by 25 percent, the frequency of exceeding the chlorophyll *a* standard is lower than existing conditions in all nine modeling years.

It appears from the sensitivity analysis that OWASA may either maintain or improve water quality in University Lake by reducing future loads of nitrogen and/or phosphorus from the watershed. The fact that future conditions are sensitive to phosphorus controls is important, as phosphorus loading is typically more amenable to reduction with management measures and improved site design.

Thus, development and growth in the University Lake Watershed will likely impact water quality in the lake. Runoff volumes will increase slightly with additional impervious surfaces, and annual total nitrogen loads will increase by 33 to 74 percent depending on atmospheric conditions. Sediment loads are predicted to decrease due to conversion of agriculture, and annual total phosphorus loads are predicted to decrease as well. However, growing season phosphorus loads are predicted to increase in some of the lower flow years that have the greatest potential risk of algal blooms. The net result is a small but consistent increase in predicted chlorophyll *a* concentrations.

The additional eutrophication expected in University Lake is considered to be minimal. Standard management practices will probably be capable of maintaining the existing algal response and preventing degradation of the raw water supply. Total nitrogen loads increase steadily as development occurs. Variations in phosphorus loads balance out year to year. However, sediment control is vital to maintaining low phosphorus concentrations in the lake. Construction sites that are left disturbed for extended periods with no erosion control practices could significantly alter the predicted phosphorus balance in this watershed.

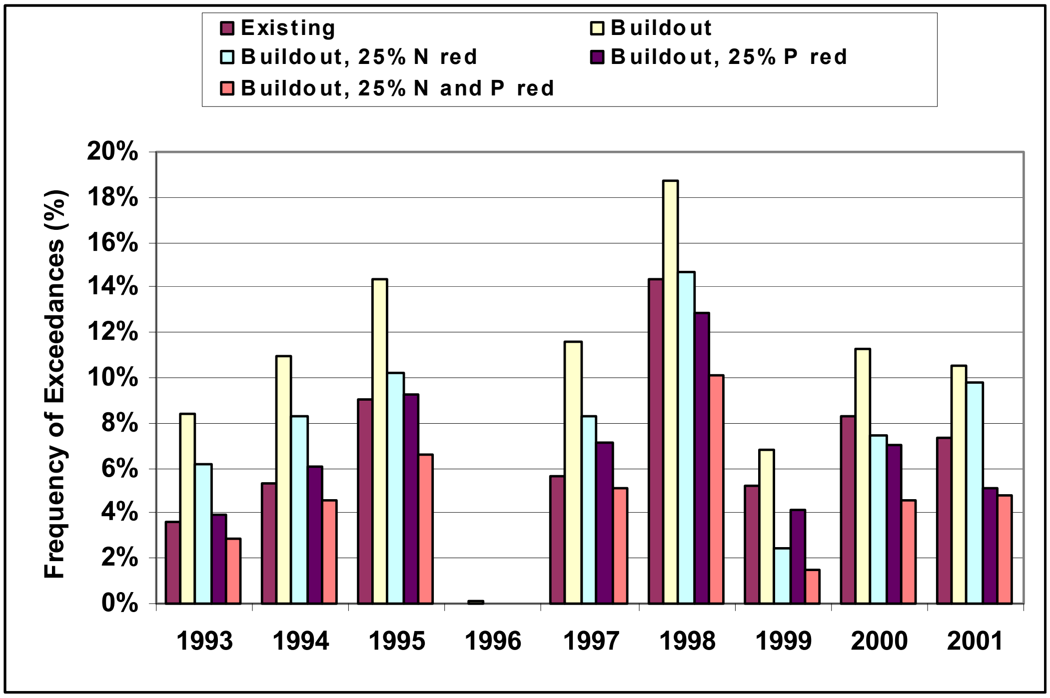

Figure 3-10. Impacts of Nutrient Reduction on Predicted Summer Frequencies of Algal Blooms greater than 40 µg/L Chlorophyll *a*

3.3 Analysis of Potential Fecal Coliform Sources

The *Preliminary Findings Report* identified fecal coliform loading as one of the primary indicators of water quality stressors within the Morgan Creek LWP study area. The Water Quality Stressor Index (refer to Section 3.3 of the *Preliminary Findings Report*) indicated that fecal coliform was the parameter that most often violated the water quality criterion against which it was evaluated (200 counts/100 mL). The analysis found that fecal coliform levels exceeded the criterion over 30 percent of the time at ambient monitoring stations across the study area and as much as 65 percent of the time at the four worst stations. It should be noted that the ambient water quality data used in the development of the Water Quality Stressor Index and in this analysis reflect almost entirely baseflow conditions.

In the interest of investigating potential sources of fecal coliform loads to streams within the study area, Tetra Tech performed a correlation and regression tree (CART) analysis on the fecal coliform data to identify which potential subwatershed-scale sources most strongly correlated with elevated fecal coliform levels. The CART analysis of fecal coliform data is presented in detail in Appendix A.

Essentially the CART analysis looked at those subwatersheds contributing flow to ambient monitoring stations with high frequencies of exceedance of fecal coliform criteria and compared them to subwatersheds contributing flow to ambient monitoring stations with low frequencies of exceedance. The analysis compared the subwatersheds on the basis of several potential explanatory variables relating to possible coliform sources. The objective of the analysis was to identify those explanatory variables that most closely correlated with the exceedances, showing them to be potential sources of fecal coliform loading.

This analysis classified fecal coliform criterion excursions with a number of explanatory variables. The explanatory variables were based on common sources of fecal coliform including the presence of agricultural animals, household pets, sewer pipe defects, septic tanks, and land cover within each subwatershed. All variables were weighted by subwatershed area. The sewer pipe type and defects variables were acquired from a closed circuit television inspection performed for OWASA by Brown & Caldwell and CH2MHILL. Structural pipe defects included pipe corrosion, cracks, and other indications of leaks. Service pipe defects included root intrusion, grease buildup, and pipe sags. Structural defects cause exchange of water in and out of the sewer pipes, while service defects restrict the movement of water and cause sewer overflows (Brown & Caldwell and CH2MHILL, 2002).

Several classification tree iterations were performed varying explanatory variables by spatial scale and testing different groupings of explanatory variables. Sewer pipe service defects and pipe type consistently appeared at the top of the classification trees indicating that these explanatory variables correlated most closely with fecal coliform levels. The most important pipe types were ductile iron pipe (DIP) and cast iron pipe (CIP). High fecal coliform was classified with high proportions of cast iron pipe, while low fecal coliform was classified with high proportions of ductile iron pipe. This classification makes sense because the closed circuit television inspection documented a large number of service defects for cast iron sewer pipe, at 580 per mile, while ductile iron pipe had very few service defects, at 15 per mile (Brown & Caldwell and CH2MHILL, 2002). Ductile iron is a material used in newer sewer line construction, whereas, cast iron lines tend to be older and in worse condition simply by function of age.

The results suggest that further investigation into potential fecal coliform sources should be targeted toward subwatersheds with high sewer pipe service defects, high proportions of cast iron sewer pipe, and low proportions of ductile iron sewer pipe. A GIS analysis was performed to identify the subwatersheds meeting those specific criteria as shown in Figure 3-11.

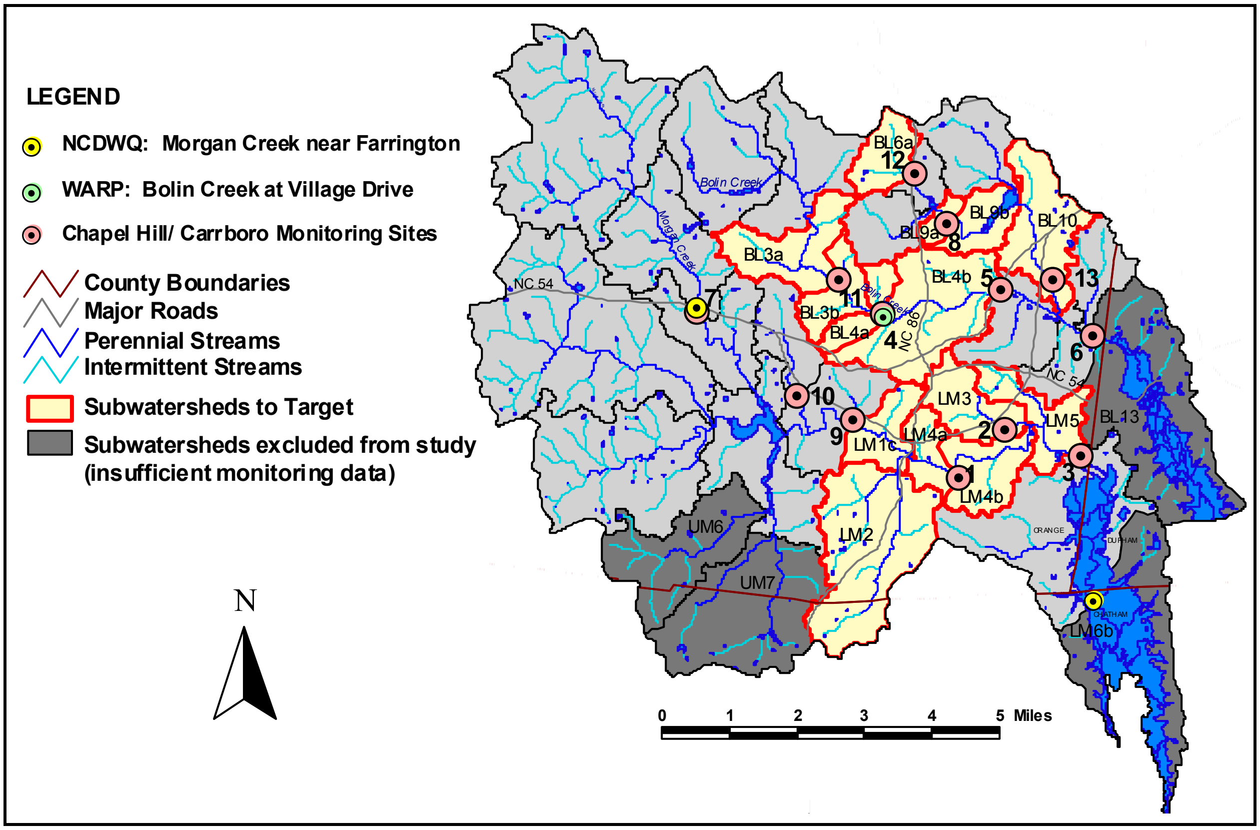

Figure 3-11. Subwatersheds Indicated as Targets by the Fecal Coliform CART Analysis

When evaluating the results of this analysis, it is important to note that a CART analysis shows correlative relationships, but does not necessarily indicate causality. Other source variables may contribute to fecal coliform loads, confounding the results of the analysis. For example, areas with older cast iron sewer pipes may have dense populations of both humans and pets. These areas may also be impacted by higher levels of imperviousness and less forest cover.

For additional reasons, firm conclusions regarding sources of fecal coliform cannot be drawn from this analysis. As mentioned above, the fecal coliform data used in this analysis are almost entirely reflective of only baseflow conditions. A similar analysis of fecal coliform data collected during storm flow might show entirely different correlations. Also, the closed circuit television inspection performed for OWASA by Brown & Caldwell and CH2MHILL only examined a very small portion of their large wastewater collection system, and a larger sample may yield significantly different defect rates.

Given the inconclusiveness of this analysis, the results were not utilized in the ranking and prioritization of LWP subwatersheds in Section 5 of this Detailed Assessment Report. At this time, it is recommended that no further action be taken until further analysis can be performed on fecal coliform data collected during stormflow conditions. Ongoing storm event monitoring by NCDWQ and the Town of Chapel Hill may result in the accumulation of sufficient data to support such an analysis by the end of this LWP study.

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4 Assessment of Terrestrial Habitat Functions and Preservation Potential

A summary of the key values used to assess terrestrial functions and preservation potential, along with a listing of the indicators used in their assessment and the tools used to perform those assessments is presented in Table 2-1. Details of each assessment method and the corresponding results are discussed in Sections 4.1 through 4.4. Wherever possible, the results for each indicator are presented in the context of the Local Watershed Plan (LWP) subwatersheds shown in Figure 1-1.

Table 4-1. Summary of Indicators and Tools Used for Detailed Assessment of Terrestrial Habitat Functions and Preservation Potential

Watershed Function	Potential Value	Indicator	Scale	Assessment Technique
Terrestrial Habitat Functions	Forest Habitat Contiguousness	Forest Cover Disturbance	Subwatershed*	GIS Analysis
	High Quality Habitat	Forest Age/ Habitat Composition	Subwatershed*	1) GIS Analysis of GAP 2) Natural Heritage Inventory 3) Local Habitat Studies
	Wetland Distribution	National Wetland Inventory (NWI)	Subwatershed*	GIS Analysis of NWI
	Species and Habitats of Special Concern	Natural Heritage Element Occurrences	Subwatershed*	GIS Analysis

*"Subwatershed" refers to smaller drainage areas within selected 14-digit hydrologic units delineated for the purposes of defining distinct management units within the context of Local Watershed Planning efforts, usually in the range of 1-10 square miles in area (refer to Figure 1-1).

4.1 Purpose of Habitat and Preservation Potential Assessment

While the other chapters of this document have focused on indicators of existing degradation of watershed functions and the risk of future degradation, this chapter will focus on indicators of high value areas of the Morgan and Bolin/Booker/Little Creek watersheds where functions are healthy and fully intact (or at least relatively unimpaired). Obviously, it is important to identify areas where aquatic habitat, water quality, hydrology and other such watershed functions have been degraded or lost, and determine the management and restoration measures necessary to recover those functions. It is also equally important to identify those portions of the watershed that have very high quality habitat, or very pristine water quality, or have flood storage capacity that is integral to the well being of downstream segments.

In addition to the authority to effect stream and wetland restoration for mitigation purposes, within its programmatic mission, NCEEP has the authority to direct funding to the preservation of riparian corridors (and possibly extending to some upland areas) that exhibit high quality habitat and/or high watershed functional value in terms of the contribution to hydrology or water quality. The purpose of the assessment set forth in this chapter is to best identify those riparian corridors that have the highest functional value in order to target such areas for preservation efforts

The following sections describe each of these indicators in detail.

4.2 HABITAT ASSESSMENT METRICS

In specific, six habitat metrics were used to measure the relative habitat value of each LWP subwatershed. The metrics are listed and the various data and information sources utilized to develop these metrics are described below.

1) Percent forest cover in each subwatershed.
2) Percent high priority habitats defined by the NC Gap Analysis Project (GAP) (NCGAP, 2003) vegetation species alliances (including dry mesic oak and hardwood forests, oak bottomland forest, all bottomland hardwood and swamp forest, submerged aquatic vegetation, and emergent wetland vegetation) within the riparian corridor of each subwatershed.
3) Percent National Wetlands Inventory (NWI) (USFWS, 1994) wetlands in the floodplain or riparian buffer of each subwatershed.
4) Presence of valuable habitat and rare species as defined by the Significant Natural Heritage Areas delineated by the NC Natural Heritage Program.
5) Presence of valuable habitat and rare species as defined by the Natural Heritage Element Occurrences enumerated by the NC Natural Heritage Program.
6) Presence of valuable habitat as defined by the Triangle Land Conservancy Prime Forest Assessment (Wiley et al., 1999).

North Carolina GAP Project Habitat Data

The vegetation land cover data from NCGAP was used to determine the percent of forest and high priority habitat in each subwatershed. NCGAP developed the vegetation data by extracting forested areas from the 1992-1993 National Land Cover Data. Then aerial videos of the forested areas were recorded across the state. The NCGAP staff visited selected sites that corresponded to the aerial footage and identified the common species at those sites. Using the species data as well as NWI and NRCS soils data, they developed decision rules to classify the satellite imagery (NCGAP, 2003). The NCGAP data for the Morgan Creek LWP study area is shown in Figure 4-1.

The percentage forest cover for each subwatershed was determined by tabulating the area of deciduous, evergreen, mixed, and woody wetlands (excluding shrublands) in the NCGAP vegetation data and dividing by subwatershed area. The percent of forest by subwatershed ranged from about 30 to 90 percent, with a mean of about 70 percent.

To determine the high priority habitats, representatives of wildlife habitat and natural resource agencies advised NCEEP and Tetra Tech on the prioritization of the GAP vegetation data. Agencies and organizations represented in this effort included the NC Wildlife Resources Commission, the NC Natural Heritage Program, The NC Gap Analysis Project, the US Fish and Wildlife Service, and the Triangle Land Conservancy. The vegetation species alliances given the highest priority by the advising resource professionals included dry mesic oak and hardwood forests, oak bottomland forest, all bottomland hardwood and swamp forest, submerged aquatic vegetation, and emergent wetland vegetation.

The percentage of the riparian corridor within each subwatershed occupied by high priority habitat was determined by tabulating the area of the prioritized NCGAP vegetation types for each subwatershed and dividing by subwatershed area. The percent of high priority habitat by subwatershed ranged from about 10 to 40 percent, with a mean of about 20 percent.

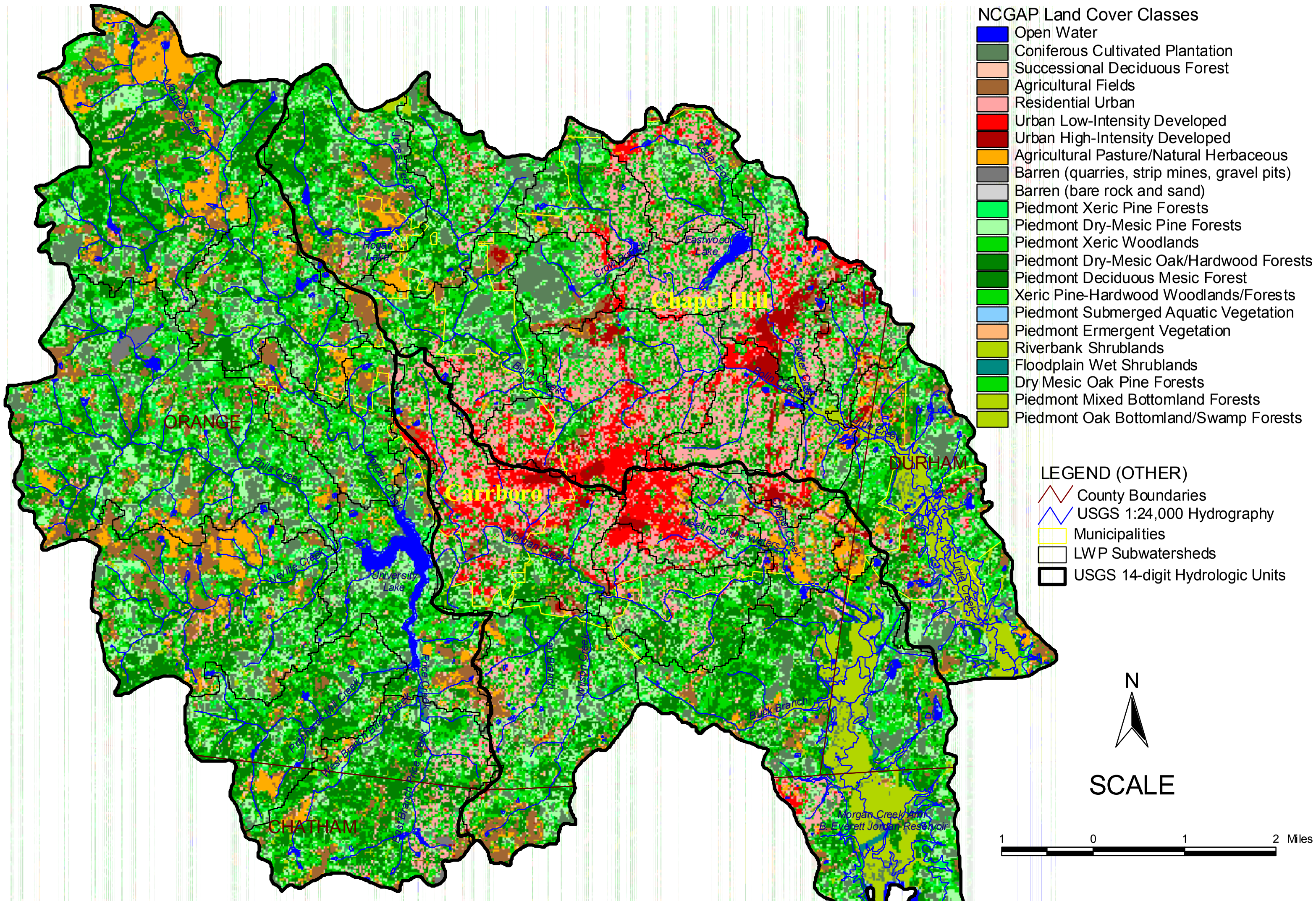

Figure 4-1. NCGAP Vegetation Alliance Data for Morgan Creek LWP Study Area

National Wetlands Inventory Data

The extent of potential wetland preservation sites in the riparian buffer was determined with the NWI. NWI wetlands that contain emergent, forested, or scrub-shrub vegetation were considered. GIS polygons of the floodplain were created for each subwatershed, and, in accordance with NCEEP preservation guidelines, the polygons included the digitized 100-year FEMA floodplain and a 300-foot buffer around perennial streams where FEMA maps were not available. The percent of vegetated NWI wetlands in the floodplain, or riparian buffer, ranged from 0 to 66 percent, with a mean of 10 percent. A detailed analysis of the distribution of wetlands and hydric soils within the LWP study area is presented in Section 3.5.5 of the *Preliminary Findings Report*.

Prime Forests Assessment

Triangle Land Conservancy (TLC) used 1988 aerial photographs to identify prime forests in Orange County. TLC identified prime forest as deciduous tracts greater than 10 acres and mixed or evergreen tracts greater than 40 acres. As a priority metric, the presence of unprotected TLC prime forest tract was recorded for each subwatershed. A detailed summary of the TLC Prime Forests Assessment is presented in Section 3.5.6 of the *Preliminary Findings Report*.

North Carolina Natural Heritage Program Data and Information

Within the Morgan Creek study area the North Carolina Natural Heritage program has designated 20 sites as significant natural heritage areas (SNHAs) and 57 natural heritage element occurrences (NHEOs). The SNHAs are GIS polygons of ecologically significant natural communities, and the NHEOs are GIS points where rare species or natural communities have been observed. As indicated by Steve Hall and Linda Pearsall (2004) of North Carolina's Natural Heritage Program, a habitat prioritization needs to include the SNHA and NHEO sites because many of these sites fall within common, non-priority species alliances in the GAP data. As a priority metric, the presence of SNHAs and NHEOs were recorded for each subwatershed. The NHEOs for birds and butterflies were excluded because these animals can easily travel between subwatersheds. NHEOs classified as historic or destroyed were also excluded from the analysis.

A detailed description of each of the SNHAs within the LWP study area is provided in Section 3.5.6.1 of the *Preliminary Findings Report* and the SNHAs and NHEOs are shown in Figure 4-2.

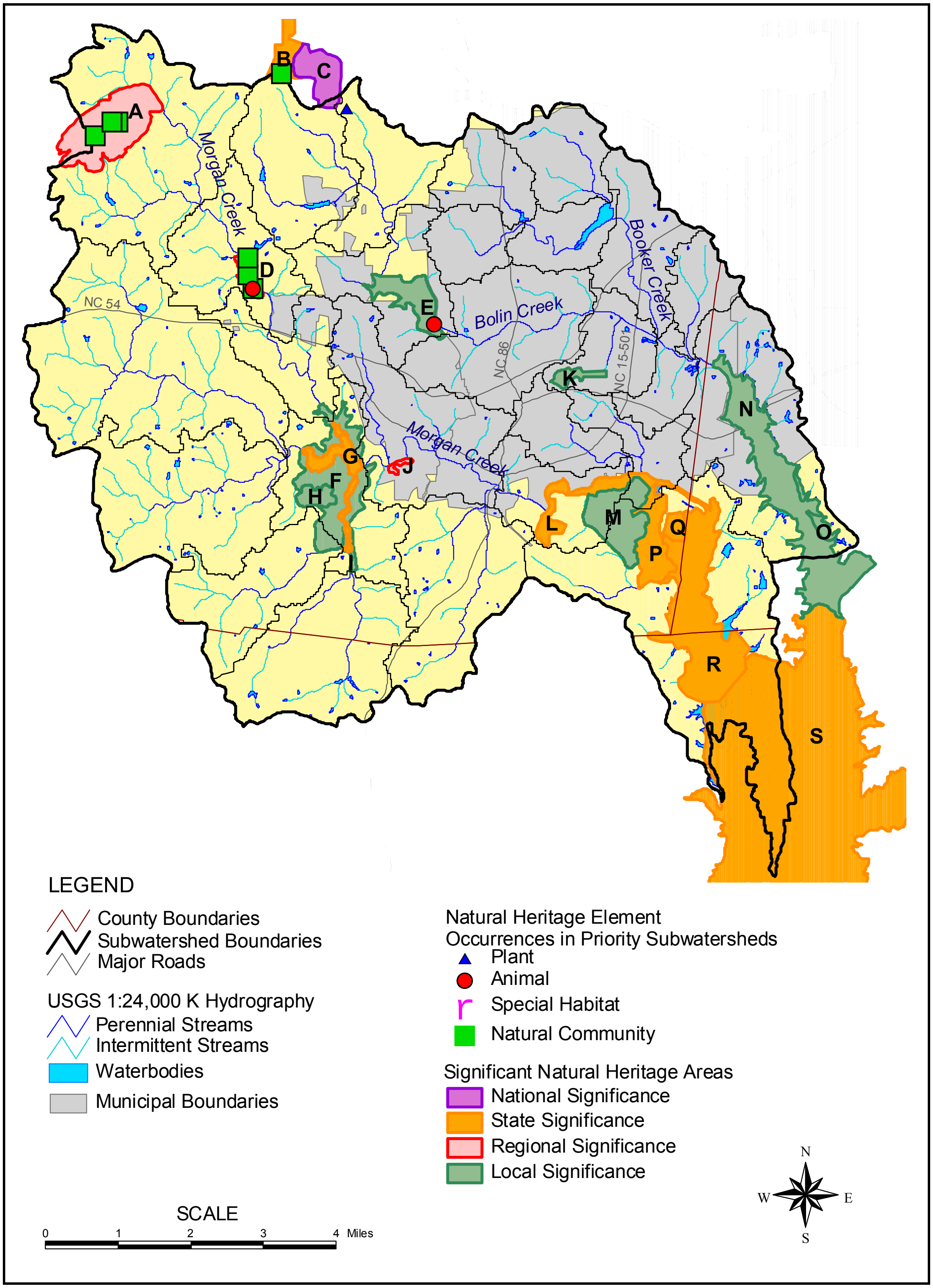

Figure 4-2. Significant Natural Heritage Areas and Natural Heritage Element Occurrences

4.3 HABITAT SCORING METHODS

The six metrics listed at the beginning of section 4.2 were used to calculate habitat value/preservation potential scores according to the scoring system in Table 4-2 below. For the first three metrics, the percent vegetation cover calculations were divided into quartiles and ranked from lowest to highest percent area. Points were awarded based on the quartiles of each cover category (e.g., four points were awarded to habitat polygons in the top quartile for percent forest). In addition to the quartile scores, points were awarded for the presence of TLC prime forest tracts, SNHAs, and NHEOs in each subwatershed, as shown in Table 4-2.

Table 4-2. Scoring System for Preservation Potential

Criteria	Score
First Quartile (Highest Scores) (% subwatershed forested, % high priority habitat, NWI wetlands)	4
Second Quartile (% subwatershed forested, % high priority habitat, NWI wetlands)	3
Third Quartile (% subwatershed forested, % high priority habitat, NWI wetlands)	2
Fourth Quartile (Lowest Scores) (% subwatershed forested, % high priority habitat, NWI wetlands)	1
Contains one or more TLC Prime Forest Tracts	2
Contains one or more Significant Natural Heritage Areas	4
Contains one or more Natural Heritage Element Occurrences	4

4.4 RESULTS OF TERRESTRIAL HABITAT ASSESSMENT AND TARGETING OF PRESERVATION EFFORTS

Habitat percentages and scores for each subwatershed are listed in Table 4-3 and Table 4-4, respectively, and habitat scores are displayed spatially in Table 4-3. The subwatersheds immediately upstream of Jordan Lake and those in the headwaters of Morgan and Bolin Creeks received a score of 22, the highest total score for quality of terrestrial habitat and potential for preservation sites. Since a majority of the land in the Jordan Lake subwatersheds (BL13 and LM6) is already either protected as state park or US Army Corps of Engineers property, the results of this analysis would suggest that preservation efforts should be focused on lands in the headwaters of Morgan and Bolin Creeks. Large areas of mature forest still remain in this part of the study area, and many of these areas are not protected and are under pressure from development, especially those in the Bolin Creek headwaters.

With a priority score of 21, Tilleys Branch subwatershed (UM2) should also be a high priority target for preservation efforts. The Tilley's branch subwatershed contains a 66-acre significant natural heritage area with 0.7 miles of riparian buffer along Morgan Creek. Three natural communities and the four-toed salamander have been observed in the Tilley's Branch subwatershed.

Preservation efforts should also be focused in the Horace Williams subwatershed (BL3). Although it received an average priority score of 15, the habitat within this subwatershed is severely threatened by development. The Horace Williams subwatershed contains a 243-acre significant natural heritage area that includes 1.4 miles of riparian buffer along Bolin Creek.

Table 4-3. Terrestrial Habitat Metrics for the Morgan Creek LWP Subwatersheds

Subwatershed	% Forest in Subwatershed	% Top Priority Habitat	% NWI Wetlands in Buffer
Hogan Farm	80	25	3
Upper Bolin Creek	85	22	0
Horace Williams	74	18	4
Middle Bolin Creek	44	13	0
Lower Bolin Creek	38	13	6
Booker Headwaters	73	20	0
Crow Branch	78	10	0
Cedar Fork	63	18	0
Eastwood Lake	48	12	6
Lower Booker Creek	49	13	18
Ephesus	63	15	34
Meadowmont	54	17	33
Little Creek Arm	80	33	66
Morgan Headwaters	74	27	3
Tilleys Branch	85	23	6
Morgan Glen	79	18	0
Phils Creek	84	19	0
Neville Creek	74	21	0
Pritchards Mill Creek	90	31	6
Price Creek	82	29	5
University Lake	71	16	4
Morgan - Carrboro	50	15	0
Wilson Creek	81	22	0
Meeting of the Waters	32	9	0
Lower Morgan Creek	76	24	0
Finley	58	16	9
Morgan Creek Arm	90	36	55

Table 4-4. Terrestrial Habitat Priority Scores for the Morgan Creek LWP Subwatersheds

Subwatershed	% Forest	% Top Priority Habitat	% NWI wetlands in Buffer	Presence of TLC Prime Forest Tracts	Presence of SNHA in Sub-watershed	Presence of NHEO in Sub-watershed	Total Score
Little Creek Arm	4	4	4	2	4	4	22
Morgan Creek Arm	4	4	4	2	4	4	22
Tilleys Branch	4	4	3	2	4	4	21
Hogan Farm	4	4	2	2	4	4	20
Upper Bolin Creek	4	4	1	2	4	4	19
Morgan Headwaters	3	4	2	2	4	4	19
Lower Morgan Creek	3	4	1	2	4	4	18
Pritchards Mill Creek	4	4	3	2	4	0	17
University Lake	3	2	2	2	4	4	17
Finley	2	2	3	2	4	4	17
Horace Williams	3	3	3	2	4	0	15
Morgan - Carrboro	2	2	1	2	4	4	15
Lower Bolin Creek	1	2	3	0	4	4	14
Lower Booker Creek	2	2	4	2	0	4	14
Morgan Glen	4	3	1	2	4	0	14
Price Creek	4	4	3	2	0	0	13
Meadowmont	2	3	4	2	0	0	11
Wilson Creek	4	4	1	2	0	0	11
Booker Headwaters	3	4	1	2	0	0	10
Phils Creek	4	3	1	2	0	0	10
Neville Creek	3	4	1	2	0	0	10
Cedar Fork	3	3	1	2	0	0	9
Ephesus	2	2	4	0	0	0	8
Middle Bolin Creek	1	1	1	0	4	0	7
Crow Branch	4	1	1	0	0	0	6
Eastwood Lake	1	1	3	0	0	0	5
Meeting of the Waters	1	1	1	0	0	0	3

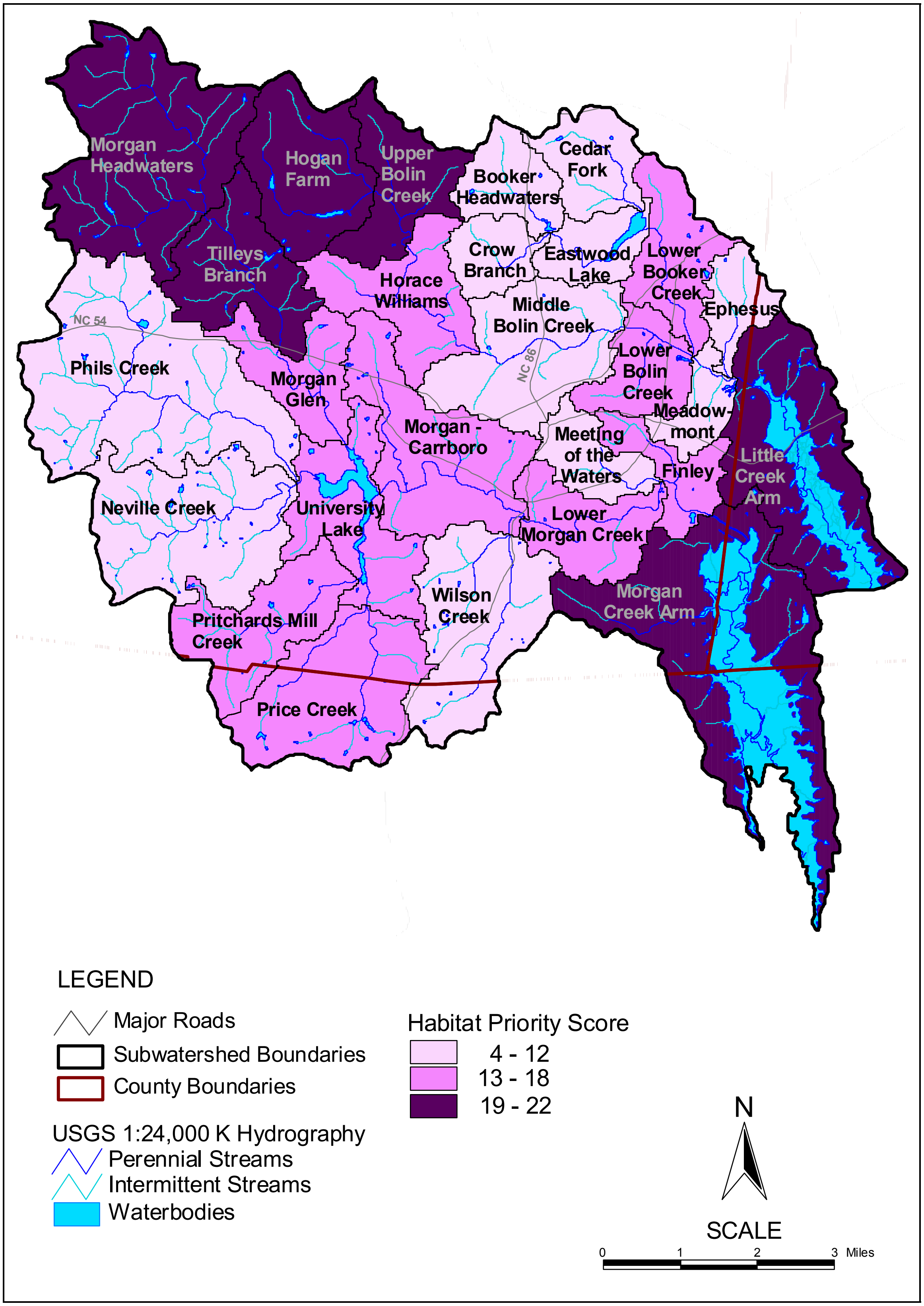

Figure 4-3. Habitat Priority Scores for Morgan Creek LWP Subwatersheds

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5 Combined Assessment of All Data and Indicators

5.1 Methods for Prioritization of Subwatersheds

In conjunction with this local watershed planning effort, representatives of the Cape Fear River Assembly have facilitated the involvement of a team of local stakeholders consisting of planning and stormwater management staff from local municipalities, local resource agency staff, UNC planning and utility staff, representatives from OWASA, and representatives of local conservation and environmental advocacy groups. The purposes of stakeholder involvement are to obtain local insight into the functional health of the targeted watershed(s) in terms of where the most degraded or most pristine areas are located, to obtain local input into the management, restoration, and preservation priorities established within the local watershed planning effort, and to build local support or "buy-in" for the recommendations contained in the final Local Watershed Plan.

One of the primary purposes of the Detailed Assessment is to target selected LWP subwatersheds for restoration, preservation, or management efforts with the input of the stakeholder team. **Based on the results of this functional assessment, a ranking system was developed to assess each of the LWP subwatersheds for three targeting categories: 1) the presence of, or potential for, existing degradation to watershed functions, 2) the risk for future degradation, and 3) the preservation value of the subwatershed. The ranking system involves numeric scoring for each subwatershed for the key assessment indicators within the context of the three primary ranking categories. The scoring system is shown in Table 5-1.**

Two numeric scores are generated for each subwatershed, one for existing risk and the other for future risk. The subwatershed ranking for Habitat Quality/Preservation Priority (refer to Section 4) is folded into Score 1 – Existing Risk/Priority for Management. Score 1 is partly referred to as "Priority for Management" because, while most of the indicators included reflect levels of degradation, the Habitat Quality/Preservation Priority rankings reflect need for action of management to protect high value and healthy functions rather than those that are degraded.

For the indicators that reflect degradation or risk for degradation, as that degradation/risk goes up, the point score increases, reflecting the increasing need for restoration and management to address or prevent functional losses. Conversely with the Habitat Quality/Preservation Potential indicator, as habitat functions and value increase (implying less degradation) the score increases, reflecting the need for preservation and management to protect those high value functions. The Habitat Quality/Preservation Priority rankings were folded in with the indicators for existing degradation in order to prioritize further management efforts on those subwatersheds where system-level functional benefits could be realized by performing restoration in conjunction with preservation efforts. It is easy to understand that affecting stream restoration at or upstream of an area of high quality riparian habitat would only enhance the value of that habitat, or help to protect it for the future. By the same token, preservation of the riparian habitat at or upstream of an area where stream (and/or) wetland restoration has been done would obviously act to protect the restoration investment and enhance its overall value.

The intent of the ranking system is for those subwatersheds with the highest risk points reflecting existing degradation and/or high riparian habitat quality/preservation potential to be targeted for restoration, management and preservation efforts to restore degraded functions and protect healthy functions on a watershed scale. The intent is also to target those subwatersheds with the highest risk points reflecting the potential for future degradation to be targeted for management efforts to prevent future loss or degradation of watershed functions. Fewer indicators are used to evaluate the potential for future degradation because the assessment tools utilized in this watershed planning effort allowed for prediction of future conditions for only two indicators: stream stability and imperviousness.

Table 5-1. Scoring System Used to Rank Subwatersheds According to Status of Indicators

SCORE 1	RISK LEVEL/PRIORITY POINTS				
Existing Risk/Priority for Management	Low	Med	High	Very High	Extreme
Stream Stability (Rural Subs Only) *Score stems from modeling analysis*	0	1	2		
	Excellent	Good	Fair	Poor	
Stream Visual Assessment Protocol *Score based on SVAP Class*	0	1	2	3	
SVAP Morphology Assessment *Score based on SVAP Class*	0	1	2	3	
Riparian Buffer Disturbance *Low Risk = buffer disturbance less than 30%* *Medium Risk = buffer disturbance 30-40%* *High Risk = buffer disturbance 40-50%* *Very High = buffer disturbance greater than 50%*	0	1	2	3	
Imperviousness *High Risk = 10% impervious or more* *Very High Risk = 25% impervious or more*	0		2	4	
Nitrogen Loading Potential *Subwatersheds sorted and rated by quintile lbs/ac/yr*	0	1	2	3	4
Phosphorus Loading Potential *Subwatersheds sorted and rated by quintile lbs/ac/yr*	0	1	2	3	4
Floodplain Encroachment *Low Risk = 0-2% Encroachment* *Medium Risk = 2-4% Encroachment* *High Risk = 4-6% Encroachment* *Very High Risk = 6-8% Encroachment*	1	2	3	4	
Habitat Quality/Preservation Potential	*3 -7*	*8-11*	*12-17*	*18-22*	
Score stems from Habitat Assessment Scores	0	2	4	6	
SCORE 2	**RISK POINTS**				
Future Risk/Priority for Prevention	Low Risk	Med Risk	High Risk	Very High	Extreme
Stream Stability (Rural Subs Only) *Score stems from modeling analysis*	0	1	2		
Increase in Imperviousness *Low Risk = 0-5% increase in imperviousness* *Medium Risk = 6-10% increase in imperviousness* *High Risk = 11-15% increase in imperviousness* *Very High Risk = 16-20% increase in imperviousness* *Extreme Risk = 21-25% increase in imperviousness*	0	1	2	3	4
Increase in Phosphorus Load *Subwatersheds sorted and rated by quintile lbs/ac/yr*	0	1	2	3	4
Increase in Nitrogen Load *Subwatersheds sorted and rated by quintile lbs/ac/yr*	0	1	2	3	4

It should be noted that for Score 2 – Future Risk/Priority for Prevention, with the exception of Stream Stability, all of the indicators are scored on the basis of the predicted incremental increase from existing land use conditions to the buildout scenario. The intent of this means of ranking subwatersheds is to direct attention and resources aimed at preventing future degradation of watershed functions to those areas where the greatest increase in imperviousness and nutrient and other pollutant loading are expected to occur.

It should also be noted that in the course of organizing and evaluating the array of indicators used in this analysis, it became very apparent that a clear distinction existed between LWP subwatersheds that are predominantly rural in nature and those that are predominantly urban. The distinction is apparent in the stressors that tend to affect watershed functions and the degree to which functions are affected within the two groups of subwatersheds. In the rural subwatersheds existing degradation is often a function of existing or past agricultural practices and these areas tend to be at risk for degradation from future development, whereas in urban subwatersheds the impacts of existing development with loss of forest cover, increased imperviousness, and the associated increases in stormwater runoff and nonpoint source pollutant loads tend to drive the degradation of watershed functions. Based on professional judgment and the endorsement of stakeholders, the decision was made to compare urban and rural/developing subwatersheds separately for ranking and prioritization purposes, rather than comparing urban to rural. The split between urban and rural subwatersheds is illustrated in Figure 5-1.

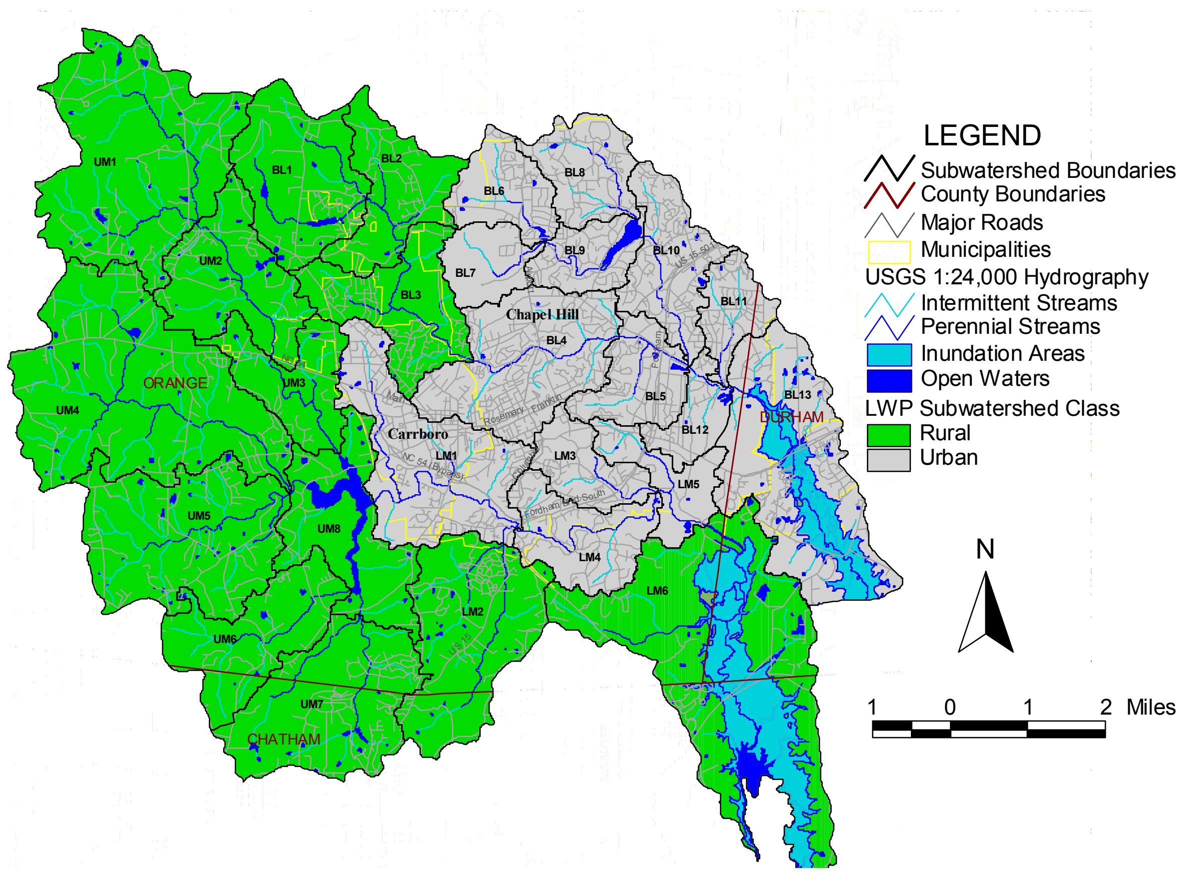

Figure 5-1. Urban vs. Rural and Developing LWP Subwatersheds

5.2 SUBWATERSHED RANKINGS BASED ON EXISTING RISK/PRIORITY FOR MANAGEMENT

The combined scores for indicators showing the priority for restoration, management and preservation efforts based on existing conditions are presented for rural and urban subwatersheds in Table 5-2 and are illustrated spatially in Figure 5-2. When examining Figure 5-2 it is important to note that the subwatersheds are grouped by color according to their final scores, with rural subwatersheds spectrally grouped from pink to purple and urban subwatersheds spectrally grouped from beige to brown. In addition, each subwatershed is labeled with the final score and letters for each indicator that ranked high or very high risk/priority in that subwatershed. As a result, higher scoring subwatersheds are reflected in darker colors and the indicator letters provide insight into the potential stressors resulting in the rank/priority of those subwatersheds.

Scrutiny of the numeric indicator scores in Table 5-2 shows that scores for the Critical Velocity Assessment of Stream Stability are not available for urban subwatersheds. This indicator was not generated in the urban areas because these subwatersheds, which are located largely in the Triassic Basin and the transition areas approaching it (refer to Section 2.2.1), often contain streams with substrates dominated by bedrock and large rocks. In addition any of the streams within the urban subwatersheds were found to already be incised and eroding, and located in already developed areas with limited potential for significant land use change in the future. For these reasons, an involved modeling analysis to generate future predictions of stream stability was either inappropriate or of limited use in the urban subwatersheds.

Figure 5-2 shows that upper Bolin Creek subwatersheds (BL1-BL3) score highest among rural subwatersheds in terms of their priority for restoration and preservation, and that a high scoring cluster of subwatersheds is also present in the Morgan Creek headwaters (UM1-UM3). These two sets offer a strong opportunity to pursue an integrated effort to implement stream restoration to address areas of localized morphological degradation from agricultural and suburban development impacts along with preservation of high value riparian and upland terrestrial habitats. Figure 5-2 also shows a vein of high priority urban subwatersheds along the Bolin Creek mainstem (BL4 –BL5) and up into lower Booker Creek below Eastwood Lake. Collectively, this Detailed Assessment has shown that this area, in addition to the Morgan Creek subwatershed immediately downstream of University Lake (LM1), has experienced the highest level of degradation as a result of the impacts of urbanization.

5.3 SUBWATERSHED RANKINGS BASED ON FUTURE RISK/PRIORITY FOR PREVENTION

The combined scores for indicators showing the priority for efforts to prevent future degradation, based on the predictions of indicator conditions corresponding to the buildout land use scenario, are presented for rural and urban subwatersheds in Table 5-3 and are illustrated spatially in Figure 5-3.

Figure 5-3 shows that upper Bolin Creek subwatersheds (BL1-BL3) score high among rural subwatersheds in terms of their priority for efforts to prevent future degradation. The risk in these subwatersheds is driven by the fact that this area comprises the 10 and 20-year urban transition zones in the Orange County Comprehensive Plan (Orange County, 2003) where substantial levels of urban and suburban development will be directed in the future. Predictions of conditions for indicators of watershed health in this assessment have consistently shown that these levels of development will result in degradation of watershed functions unless preventative actions are taken.

The upper Bolin Creek watershed also encompasses a major portion of the Horace William Airport tract, which is slated for development of the Carolina North expansion of UNC. The manner in which this project is developed will have significant and lasting effects on the future health of the Bolin Creek watershed. It should be noted that the Habitat Quality/Preservation Priority Assessment (refer to Section 4) has shown that the LWP subwatershed that includes the Horace Williams Airport tract also contains some of the most valuable and undisturbed terrestrial habitat in the entire Bolin Creek watershed. Additionally, the indicators of stream morphology and aquatic habitat demonstrate that the portion of Bolin Creek within the Horace Williams tract exhibits some of the healthiest stream conditions in the entire LWP study area.

Among urban watersheds, Figure 5-3 shows that the Morgan Creek subwatershed immediately downstream of University Lake (LM1) exhibits high risk for degradation from future development as does the Meeting of the Waters subwatershed (LM4). The risk in the Meeting of the Waters watershed stems from the potential for substantial levels of new development associated with the main UNC campus. However, the university is currently developing a plan to reduce and control nonpoint source pollutant loads and stormwater impacts in a portion of this subwatershed.

Significant risk for future degradation is also present in the headwater areas of Booker Creek (BL6) resulting from the presence of a large area of developable land within that subwatershed. High risk is also indicated in the Little Creek subwatershed immediately upstream of Jordan Lake (BL13) due to the potential for future urban and suburban development within the Durham County and City of Durham portions of the LWP study area. Predicted impacts from potential development in the Durham and Chatham County portions of the study area also account for high risk of future degradation in the lower Morgan Creek subwatershed immediately upstream of Jordan Lake (UM6).

Table 5-2. Score 1 – Existing Risk/Priority for Management for Rural and Urban LWP Subwatersheds

RURAL Name	Number	Imperv-iousness	Stream Stability	SVAP Morphology	SVAP Overall	Exerted TN Load	Exerted TP Load	Buffer Disturbance	Floodplain Encroachment	Habitat/ Preservation	Total Score
Hogan Farm	BL1	0	1	3	3	1	1	1	1	6	17
Upper Bolin Creek	BL2	0	1	3	2	2	1	0	1	6	16
Wilson Creek	LM2	2	1	1	2	3	2	1	1	2	15
Horace Williams	BL3	2	0	0	1	2	3	1	1	4	14
Morgan Headwaters	UM1	0	0	3	2	0	0	1	1	6	13
Morgan Glen	UM3	0	2	2	1	1	1	0	1	4	12
Tilleys Branch	UM2	0	1	1.5	1.5	0	0	0	1	6	11
Price Creek	UM7	0	0	1.5	2	1	1	1	0	4	10.5
Morgan Creek Arm	LM6	0	0	1	1	1	1	0	0	6	10
Pritchards Mill Creek	UM6	0	0	1	2.5	0	0	0	0	4	7.5
Neville Creek	UM5	0	0	1.5	1.5	0	0	1	1	2	7
Phils Creek	UM4	0	1	1	2	0	0	0	1	2	7
University Lake	UM8	0				0	0	1	1	4	6
URBAN Name	**Number**	**Imperv-iousness**	**Stream Stability**	**SVAP Morphology**	**SVAP Overall**	**Exerted TN Load**	**Exerted TP Load**	**Buffer Disturbance**	**Floodplain Encroachment**	**Habitat/ Preservation**	**Total Score**
Lower Booker Creek	BL10	4		3	2.5	4	4	2	4	4	27.5
Lower Bolin Creek	BL5	2		2	3	4	4	2	4	4	25
Morgan - Carrboro	LM1	2		3	2	3	4	3	2	4	23
Ephesus	BL11	2		2.5	3	4	4	2	1	2	20.5
Middle Bolin Creek	BL4	2		2	2	4	4	3	2	0	19
Little Creek Arm	BL13	2		2.5	2.5	2	3	1	0	6	19
Meeting of the Waters	LM3	4		1	1.5	4	3	2	2	0	17.5
Lower Morgan Creek	LM4	2		1	1	3	2	1	1	6	17
Cedar Fork	BL8	2		0.5	1.5	3	3	2	3	2	17
Meadowmount	BL12	2		3	3	2	2	2	1	2	17
Finley	LM5	0		2.5	2.5	1	1	3	1	4	15
Eastwood Lake	BL9	2		3	1	3	3	1	2	0	15
Booker Headwaters	BL6	2		1	2	2	2	3	1	2	15
Crow Branch	BL7	0		1	1	1	2	1	1	0	7

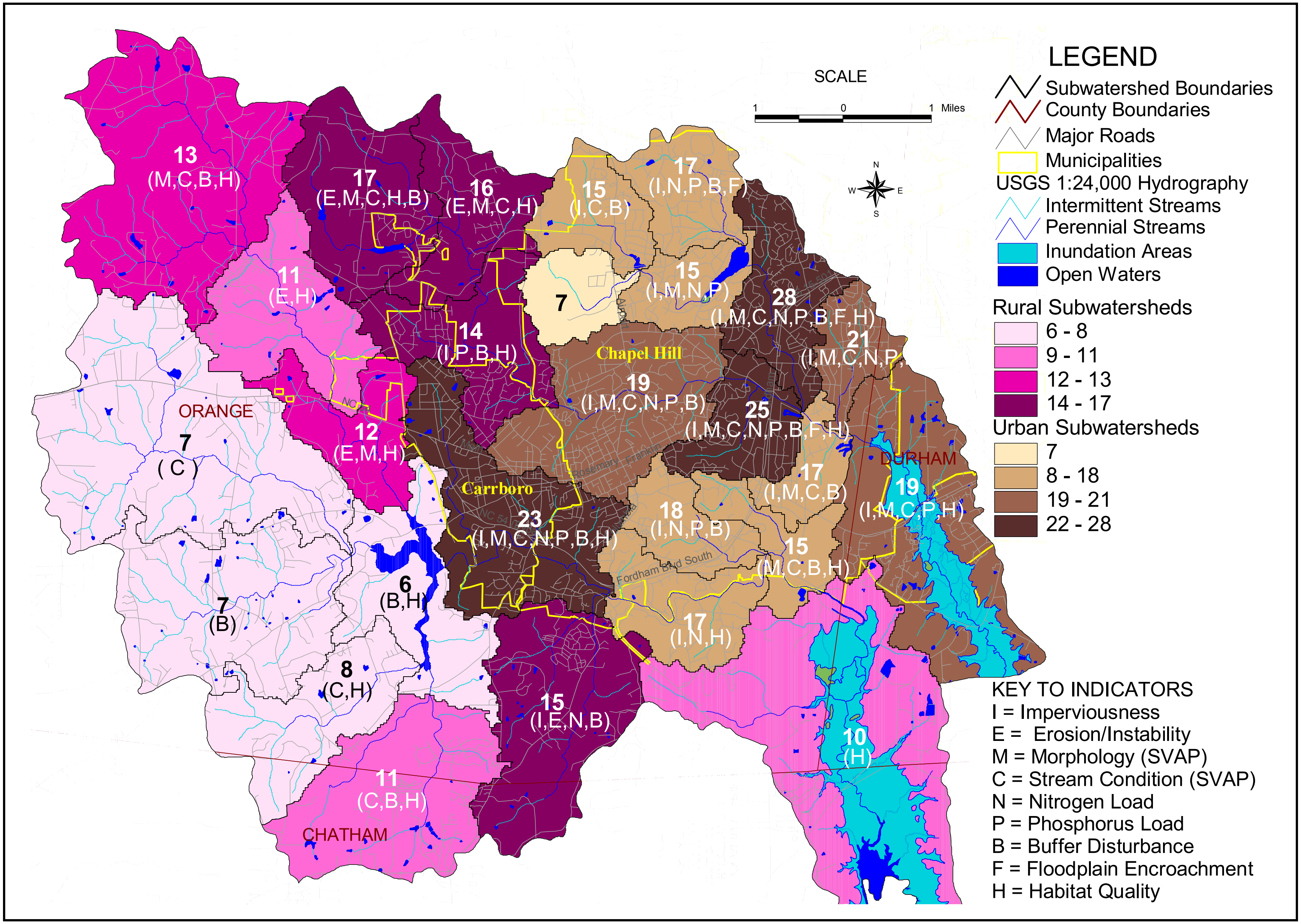

Figure 5-2. Score 1 – Existing Risk/Priority for Management for Rural and Urban LWP Subwatersheds

Table 5-3. Score 2 – Future Risk/Priority for Prevention for Rural and Urban LWP Subwatersheds

RURAL Name	Number	Imperv-iousness	Stream Stability	TN Load Increase	TP Load Increase	Total Score
Morgan Creek Arm	LM6	1	0	4	2	7
Upper Bolin Creek	BL2	2	1	1	3	7
Hogan Farm	BL1	2	1	2	2	7
Horace Williams	BL3	2	0	2	1	5
Wilson Creek	LM2	1	2	0	1	4
Price Creek	UM7	1	0	1	1	3
Pritchards Mill Creek	UM6	0	0	1	1	2
Phils Creek	UM4	0	1	1	0	2
Morgan Glen	UM3	0	2	0	0	2
Tilleys Branch	UM2	0	1	1	0	2
University Lake	UM8	0	0	0	0	0
Neville Creek	UM5	0	0	0	0	0
Morgan Headwaters	UM1	0	0	0	0	0
URBAN Name	**Number**	**Imperv-iousness**	**Stream Stability**	**TN Load Increase**	**TP Load Increase**	**Total Score**
Meeting of the Waters	LM3	4		4	4	12
Morgan - Carrboro	LM1	3		4	4	11
Little Creek Arm	BL13	3		4	4	11
Booker Headwaters	BL6	4		2	4	10
Middle Bolin Creek	BL4	2		3	3	8
Meadowmount	BL12	0		4	4	8
Finley	LM5	1		3	3	7
Cedar Fork	BL8	2		2	3	7
Crow Branch	BL7	3		3	1	7
Lower Booker Creek	BL10	2		3	2	7
Ephesus	BL11	1		3	2	6
Lower Bolin Creek	BL5	1		2	2	5
Lower Morgan Creek	LM4	1		0	3	4
Eastwood Lake	BL9	2		1	1	4

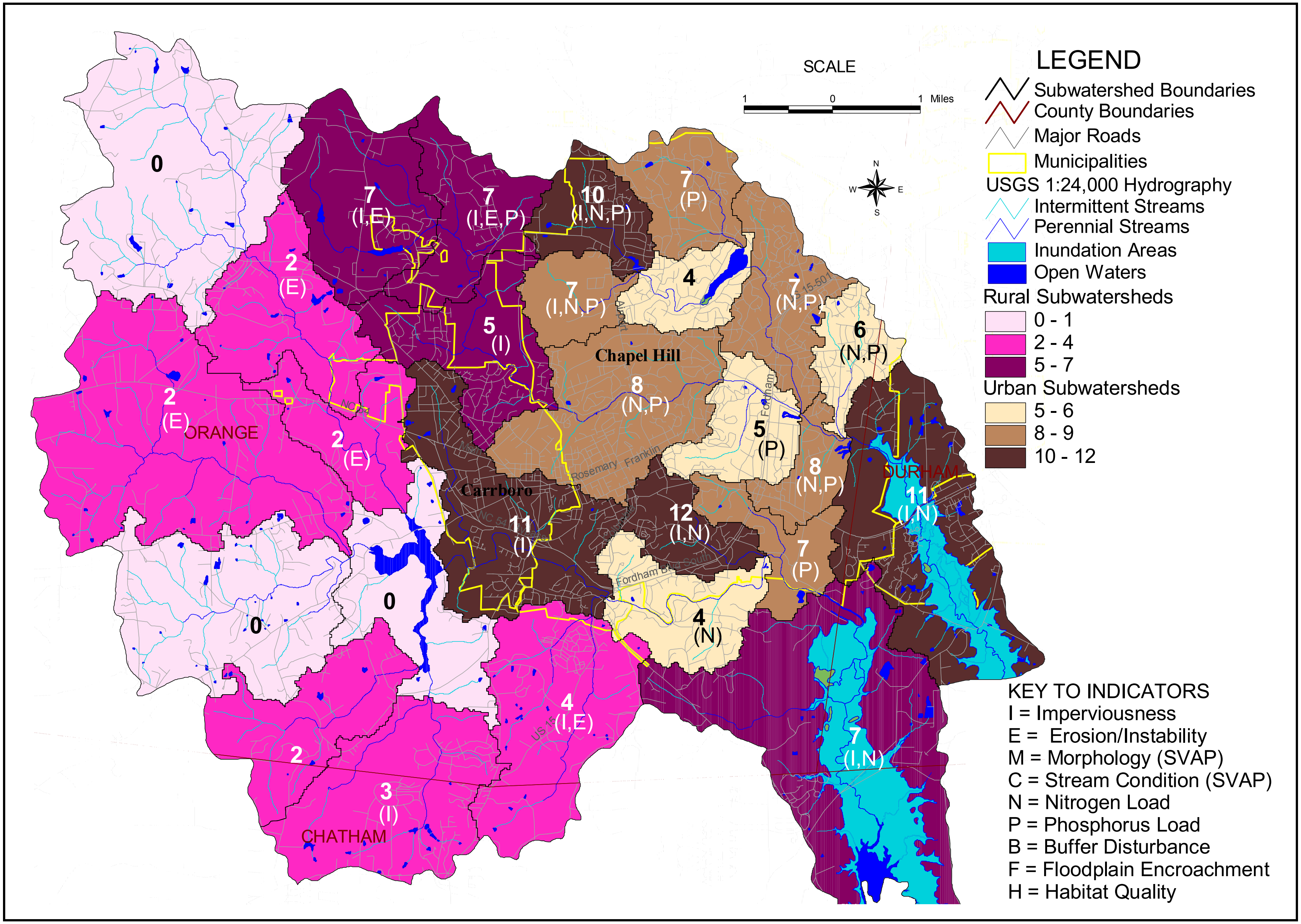

Figure 5-3. Score 2 – Future Risk/Priority for Prevention for Rural and Urban LWP Subwatersheds

5.4 SUBWATERSHEDS RECOMMENDED FOR TARGETING OF RESTORATION, PRESERVATION AND PREVENTION OF FUTURE DEGRADATION

Based on the scores presented in Table 5-1 and Table 5-3 and shown in Figure 5-2 and Figure 5-3, **it is recommended that the first tier of subwatersheds in which to focus further restoration, preservation and prevention efforts for the remainder of project resources in the local watershed planning study consist of the Bolin Creek subwatersheds BL1-BL5, lower Booker Creek (BL10), and the upper Morgan Creek subwatersheds UM1-UM3. It is recommended that the second tier of subwatersheds consist of the headwater portions of Booker Creek, subwatersheds BL6-BL9, the Little Creek subwatersheds BL11 and BL12, and the lower Morgan Creek subwatersheds LM1 and LM3-LM5, which include Meeting of the Waters and Chapel Creek.** The two recommended tiers of subwatersheds are illustrated in Figure 5-4.

The individual subwatershed scores in Figure 5-2 and Figure 5-3 did not indicate a great degree of overlap between high priority subwatersheds for efforts related to existing conditions and those with high priority for effort to prevent future degradation. However, the two tiers recommended here represent the intent to identify contiguous blocks of subwatersheds where the mutually enhancing benefits of efforts to restore and protect watershed functions under existing conditions and measures to prevent future functional losses could be realized at the integrated system level.

It should be noted that while the Morgan Creek and Little Creek subwatershed immediately upstream of Jordan Lake exhibited fairly high priority levels, especially in regard to their risk for future degradation, they were not recommended for inclusion in Tier 1 or Tier 2. The reason for this exclusion is that, with the exception of very recent participation by a representative of Durham County, the jurisdictions affecting these subwatersheds have not participated in the stakeholder process.

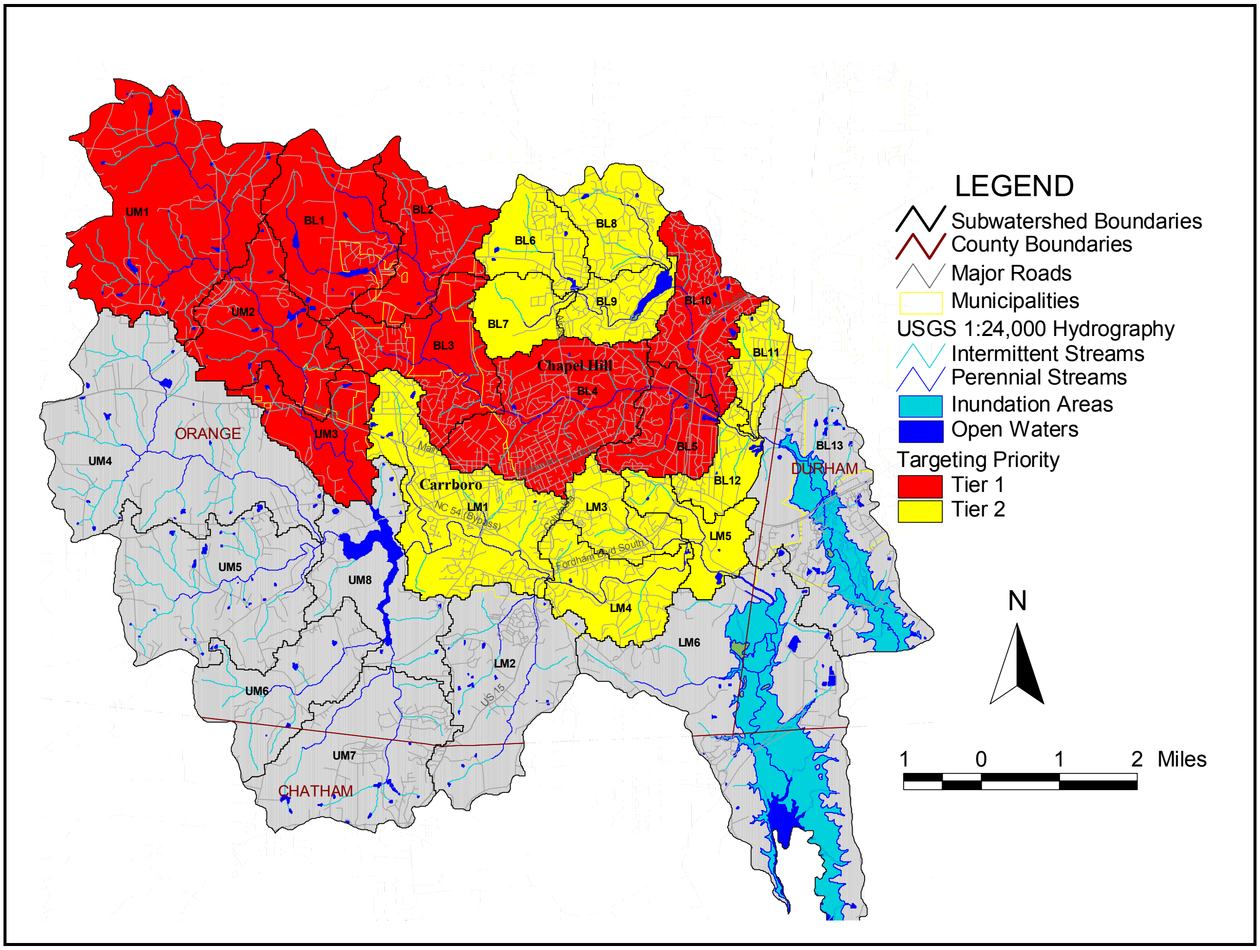

Figure 5-4. Recommended Tier 1 and Tier 2 Subwatersheds

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6 Next Steps

In the final phases of this local watershed planning effort, Tetra Tech's project team will develop a *Targeting of Management Report* identifying and evaluating the most promising opportunities for restoration, BMP implementation and preservation in the subwatersheds targeted in Chapter 5. The report will include benefits to the targeted subwatersheds for several alternative management measures along with estimates of implementation costs for these measures. To arrive at cost-effective solutions that will maximize improvements in watershed function, cost effectiveness analysis will be used to rank the efficiency of various management options. NCEEP and the various stakeholders will then be able to use this information to guide implementation efforts.

The primary criterion for targeting of management efforts in the Tier 1, and potentially Tier 2, subwatersheds of the Morgan Creek LWP study area will be an assessment of net benefit of various management efforts to watershed functions. This approach recognizes that there are several major factors that regulate aquatic ecosystem system functions at both local and watershed scales. These include:

- Local physical habitat structure (channel form, substrate distribution, and riparian vegetation)
- Physical water quality factors (including temperature)
- Flow regime (adequate baseflow, peak stormflow)
- Energy load from the watershed (sediments, nutrients, toxicants)

Generally, restoration efforts address only the first of these factors. The remaining factors which can collectively be termed as "stressors" require local watershed planning efforts at the watershed scale and should be thought of as "risk factors" that can be as important in determining the long-term success of restoration efforts. In terms of net benefit to watershed function, it is desirable to develop local watershed plans that increase the amount of high quality local habitat, decrease current stressor loads, and prevent future increases in stressor loading. The next phase will use planning methods that address each of these areas.

6.1 Identification of Restoration Opportunities

One of the primary stressors resulting in existing degradation of watershed functions within this study area has been identified as stream erosion and instability. The measures evaluated in the final phases of this local watershed planning effort to address this existing degradation will include BMP retrofitting to reduce the adverse impacts of stormwater runoff. Retrofitting options and alternatives will be evaluated in conjunction with the use of natural channel design and bioengineering methods to restore aquatic habitat and hydrologic functions to stream channels within targeted subwatersheds.

Beginning with the first tier of LWP subwatersheds identified in Section 5.4, a detailed assessment of restoration feasibility will be performed to identify the optimum restoration approach for the principle stream reaches within the targeted subwatersheds. The prioritization of restoration methods will generally follow the priority levels set forth by Rosgen, which are illustrated in Figure 6-1 (dashed lines represent existing channel and floodplain) and summarized as follows (Rosgen, 1996):

Priority 1: Construct a new channel with an accessible floodplain at the stream's previous elevation adjacent to degraded and incised existing channel. Abandon and fill degraded channel.

Priority 2: Establish an accessible floodplain at the channel's existing elevation or higher, but not at original height.

Priority 3: Convert the stream (or reach) to a new stream type without an active floodplain but containing a flood prone area (typically involves construction of a step-pool stream type).

Priority 4: Stabilize the channel in place.

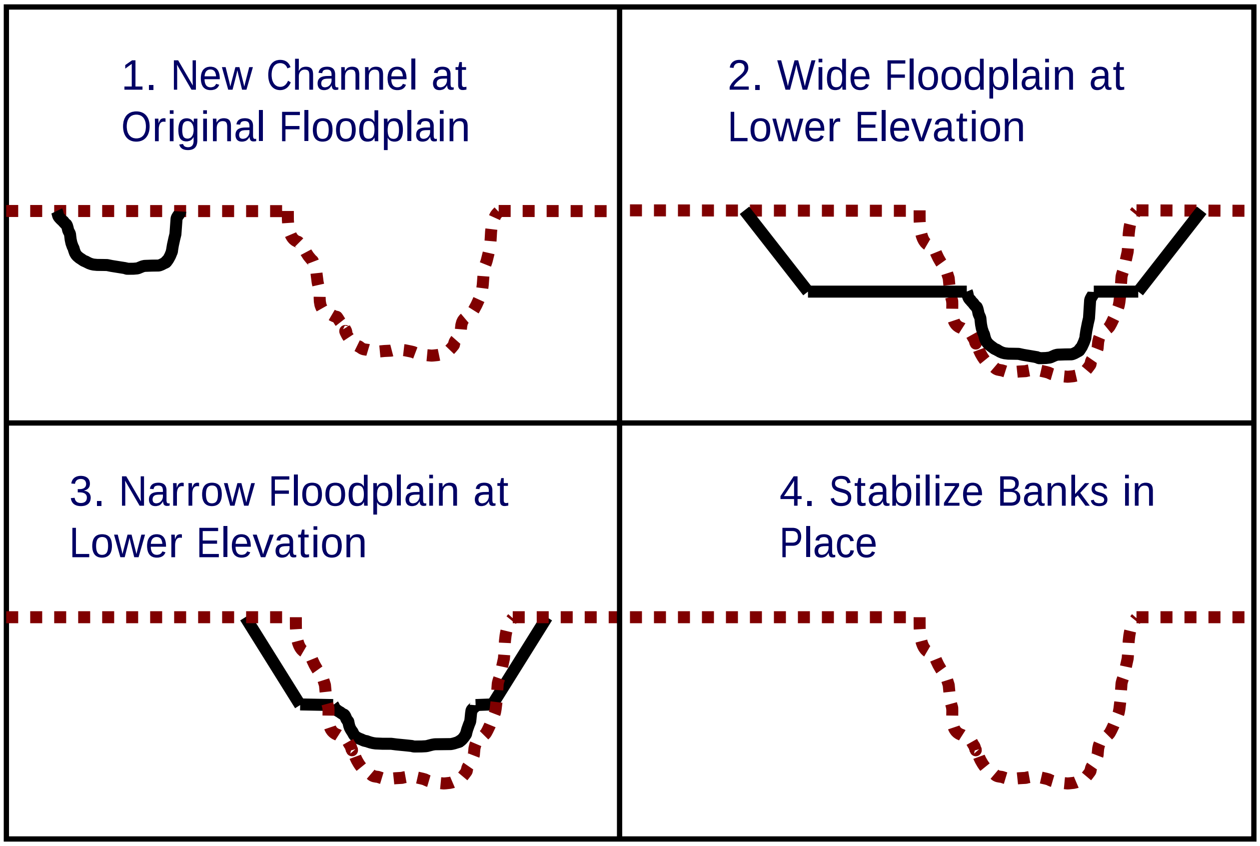

Figure 6-1. Four Priorities of Stream Restoration Methods (Rosgen, 1996)

Each of the methods outlined above has different advantages, disadvantages and constraints associated with it, and costs can vary significantly from method to method. For instance, Priority 1 restoration will not be feasible in many of the urbanized portions of the Bolin Creek and Booker Creek watersheds because that approach requires significant available land area adjacent to the existing degraded channel. In most areas of middle and lower Bolin Creek watershed, and in almost all of the Booker Creek watershed, water and sewer lines, roadways, and other infrastructure features are located immediately adjacent to stream channels precluding establishment of the necessary stream meander associated with Priority 1 restoration. In the urbanized areas of the Bolin and Booker Creek watersheds it is likely that Priority 2 and Priority 3 restoration will be more appropriate, but these approaches often have higher costs than Priority 1 due to increased excavation and construction requirements. It should be noted that Priority 4 restoration, which involves the use of riprap, gabions, or other stream hardening methods to fix an eroding channel in place, would only be considered as a last resort, and only for relatively short reaches of streams integrated into larger restoration projects. Priority 4 restorations only temporarily suspend the process of bank erosion and prevent the excess sediment transport downstream, but they do not contribute to restoration of the aquatic habitat functions of the stream channel. While it is not possible to estimate exact cost without a detailed engineering analysis of restoration plans for a given reach, to the extent possible the project team will utilize *conceptual design* level costs to generate cost estimates for the optimum restoration approaches within the targeted subwatersheds.

For stream reaches where excessive costs or logistical constraints imposed by existing topography or infrastructure prohibit stream restoration, riparian buffer restoration projects may be recommended. Riparian buffer restoration consists of re-establishing a native streamside vegetative community in areas where is has been removed or substantially degraded. Buffer restoration can improve watershed functions by slowing stormwater runoff, increasing pollutant removal rates within the buffer, and improving riparian wildlife habitat. Where appropriate, restoration opportunities of this nature will be identified in the *Targeting of Management Report*.

The *Preliminary Findings Report* and this *Detailed Assessment Report* have identified excess nutrient loading and stream erosion and instability as primary stressors to watershed functions in the Morgan Creek LWP study area. Fecal coliform loads and instream toxicity have also been identified as concerns. All of these stressors can be attributed to the adverse impacts of urban stormwater runoff. Reduction of these stressors offers a strong opportunity to realize multiple benefits through the retrofitting of stormwater BMPs, primarily stormwater wetlands and detention ponds, which can reduce peak stormflow and nutrient and other pollutant loads. For those LWP subwatersheds identified as high risk for nutrient loading and stream erosion and instability by the Detailed Assessment, the project team will perform a GIS analysis using information such as digital elevation data, high-resolution aerial photography, and tax parcel data to identify potential BMP retrofit sites. The suitability of potential retrofit sites will be further evaluated through field reconnaissance and/or the input of local planners and stormwater managers from the stakeholder team.

To the extent that project resources allow, opportunities for site-scale stormwater BMPs such as bio-retention cells (also known as rain gardens), will be identified within targeted subwatersheds. “Site-scale stormwater BMPs” refers to BMPs that are effective in storing or treating runoff from small areas such as individual home sites or parking lots. Due to the scale of application, which is typically to watersheds of only 5 acres or less, project resources prohibit the evaluation of this type of BMP on a watershed, or even subwatershed scale. To the extent that project resources allow, sites may be identified for demonstration projects using site-scale BMPs.

6.2 Opportunities to Prevent ***Future*** Degradation

Conversion of existing areas with agricultural and forested land cover to suburban and urban land uses has been determined to be a major cause of risk for future degradation. The upper Bolin Creek watershed has been identified as an area where such growth is likely to occur, and is already beginning to occur in pockets. **Whether this development results in significant degradation of watershed functions will be decided by the rules and regulations set forth by local jurisdictions which can influence where development occurs, how it’s designed, and the degree to which controls or management measures are required.**

Tetra Tech will review the existing stormwater management requirements of all three jurisdictions affecting Tier 1 and Tier 2 subwatersheds (Chapel Hill, Carrboro, and Orange County). In addition, Tetra Tech will review each of the three jurisdictions’ Phase II NPDES stormwater permit applications submitted in 2003. Once these applications are approved by NCDENR, the jurisdictions have one year to begin implementation. To the extent possible, Tetra Tech will also review and summarize the work currently being conducted by NCDENR toward development of a TMDL for nitrogen and phosphorus for the upper New Hope and Morgan Creek arms of Jordan Lake, which will encompass the Morgan Creek LWP study area. Finally, Tetra Tech will review the results of the Center for Watershed Protection Low Impact Design Survey completed by the local jurisdictions during the stakeholder process for this LWP effort. Through the review of the existing and pending regulatory structure, Tetra Tech will identify gaps, as well as opportunities for strengthening stormwater management and enhancing protection of watershed functions.

Enhanced protection/management measures such as these can be applied across entire watersheds or within smaller areas to affect increased protection within targeted subwatersheds where growth is more likely to occur. Where appropriate, the review and recommendations will include spatially explicit measures to address targeted subwatersheds with high risk for future degradation.

In targeted subwatersheds where the modeling analysis has predicted a high future risk for stream erosion and instability and/or high future risk for nutrient loading, examples of appropriate stormwater BMPs will be developed. Given that the subwatersheds predicted to be at risk for future degradation as a result of stream erosion and instability are a function of where the high-density development is located, and no concrete means are available at this time to determine where such development may occur, these potential BMP scenarios will be largely hypothetical in nature. To the extent that project resources allow, these hypothetical BMP scenarios will be tested within the modeling framework to evaluate their predicted impact on peak instream flow conditions and stream erosion predictions.

6.3 PRIORITIZATION OF RESTORATION OPPORTUNITIES

Proposed stream restoration projects, BMP retrofits, and where possible, other management measures recommended in the *Targeting of Management Report*, will be evaluated and prioritized in terms of their cost-effectiveness. For each recommended restoration project or management measure, conceptual design-level costs will be estimated and used in conjunction with estimates of the amount of stressor reduction to generate approximations of cost-effectiveness for use in prioritizing opportunities. Estimates of the degree of stressor reduction or functional improvement for the various opportunities identified will be generated using the assessment tools already developed in this LWP effort. For instance, the GWLF-derived nutrient-loading model developed for the Detailed Assessment can be used to generate the predicted nutrient loads to any given stormwater BMP or stream restoration project, which can be used in conjunction with published nutrient removal rates to estimate and compare cost-effectiveness and prioritize opportunities.

6.4 PRIORITIZATION OF PRESERVATION EFFORTS

Based on remote sensed data and the input of representatives of wildlife habitat and natural resource agencies subwatersheds have been identified within the study area that have riparian corridors with high wildlife habitat value. The upper portions of the Bolin Creek and Morgan Creek watersheds have been found to possess substantial areas of high value habitat, and in addition the upper Bolin Creek watershed is heavily threatened with wildlife habitat loss due to future development. Tetra Tech will perform a GIS analysis of property ownership within both of these areas. Detailed maps of targeted subwatersheds will be produced showing all parcels that include some portion of the riparian corridor, and parcels will be prioritized for preservation based on factors such as the length of riparian corridor they encompass, the quality of habitat within those corridors and whether or not they are contiguous with valuable upland forest habitat.

6.5 SUMMARY

This *Detailed Assessment Report* has identified those portions of the Morgan Creek LWP study with the greatest levels of functional degradation under existing conditions, as well as those areas at the greatest risk for future degradation. Additionally, those portions of the study area with the highest preservation potential have been identified. Based on these factors, clusters of subwatersheds have been targeted for further restoration, management, and preservation efforts in the interest of achieving the highest level of mutually enhancing benefits from all of these actions at the watershed scale. The opportunities identified and supporting information provided in the Targeting of Management Report will provide NCEEP and the LWP stakeholder with the tools necessary to optimize the use of finite resources in the process of implementing the recommended projects and actions.

7 References

Brown & Caldwell and CH2MHILL. 2002. Technical Memorandum 8.4 Wastewater Collection, Pumping, and Conveyance Facilities. Prepared for Orange Water and Sewer Authority. Carrboro, NC.

Dai, T., R. L. Wetzel, I. C. Anderson, and L. W. Haas. 1999. BasinSim 1.0: A Windows-Based Watershed Modeling Package. Developed at the Virginia Institute of Marine Science, College of William and Mary. Funded by a NOAA Coastal Zone Management grant through the Virginia Coastal Resources Management Program.

FISWRG. 1998. Stream Corridor Restoration: Principles, Processes, and Practices. Federal Interagency Stream Restoration Working Group.

Fischenich, C., 2001. Stability Thresholds for Stream Restoration Materials. Engineer Research and Development Center (ERDC) Technical Note EMRRP-SR-29. Ecosystem Management and Restoration Research Program (EMRRP). Vicksburg, Mississippi.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF, Generalized Watershed Loading Functions, Version 2.0: User's Manual. Department of Agricultural and Biological Engineering, Cornell University, Ithaca, NY.

Hall, S., and Pearsall, L. NC Natural Heritage Program. Personal Communication. Meeting to Coordinate and Obtain Input from Representatives of Wildlife Habitat and Natural Resource Agencies. Offices of NC Ecosystem Enhancement Program, January, 2004.

Hershfield, David M, 1961. Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. U.S. Department of Commerce, Weather Bureau Technical Paper No. 40. Washington, D.C.

Hunter, Kathleen. 2003. The Chapel Hill News. "Carolina North raises concerns". November 16, 2003. Vol. 80, No. 75. p A1,A4.

MRLC. 1997 National Land Cover Database developed by the Multi-Resolution Land Characterization Consortium. Metadata available online at: http://landcover.usgs.gov/natllandcover.html.

NC Gap Analysis Project, 2003. Vegetation Data. [Online] Available: http://www.ncgap.ncsu.edu/

NCDWQ. 2003a. North Carolina Water Quality Assessment and Impaired Waters List (2002 Integrated 305(b) and 303(d) Report). North Carolina Department of Environment and Natural Resources, Division of Water Quality.

NCDWQ. 2003b. Assessment Report: Biological Impairment in the Little Creek Watershed. North Carolina Department of Environment and Natural Resources, Division of Water Quality, April, 2003.

NWI. 1994. National Wetlands Inventory. U.S. Fish & Wildlife Service. United States Department of the Interior, Washington , D.C. http://www.nwi.fws.gov/index.html

National Resources Conservation Service (NRCS), 1986. Technical Release 55, Urban Hydrology for Small Watersheds, Second Edition. United States Department of Agriculture, Washington, D.C.

Orange County, 2003. Map of Orange County Master Plan. Available for download at http://www.co.orange.nc.us/planning/index.htm . Prepared by the Orange County Planning Department, Hillsborough, NC. January 2003.

Pope, B.F., Tasker, G.D., and J.C. Robbins, 2001. Estimating the Magnitude and Frequency of Floods in Rural Basins of North Carolina – Revised. United States Geologic Survey, Water Resources Investigations Report 01-4207.

Raschke, R. 1993. Guidelines for Assessing and Predicting Eutrophication Status of Small Southeastern Piedmont Impoundments. Prepared for USEPA Region IV, Atlanta GA.

Robbins, J.C., and B.F. Pope, 1996. *Estimation of Flood-Frequency Characteristics of Small Urban Streams in North Carolina*. United States Geologic Survey, Water Resources Investigations Report 96-4084.

Rosgen, D.R., 1996. *Applied River Morphology*. Wildland Hydrology, Pagosa Springs, CO.

Schueler & Holland. August, 2000. The Importance of Imperviousness. The Practice of Watershed Protection. Retrieved August, 2002. http://www.stormwatercenter.net/. Center for Watershed Protection, 2000.

Schueler,T. 2004. Urban Subwatershed Restoration Manual No. 1: An Integrated Framework to Restore Small Urban Watersheds version 1.0. Prepared for the Office of Water Management, USEPA, Washington, DC. Center for Watershed Protection, Ellicot, MD.

Smith, R.A., G.E. Schwarz, and R.B. Alexander. 1997. Regional interpretation of water-quality monitoring data. *Water Resources Research*, 33(12): 2781-2798.

Tetra Tech. 2002. Jordan Lake Nutrient Response Model. Prepared for Jordan lake Project Partners. Tetra Tech, Inc., Research Triangle Park, NC.

Tetra Tech. 2003a. B. Everett Jordan Lake TMDL Watershed Model Development. Prepared for N.C. Division of Water Quality. Tetra Tech, Inc., Research Triangle Park, NC.

Tetra Tech. 2003b. University Lake Baseline Analysis Memo. Prepared for Orange Water and Sewer Authority. Carrboro, NC. Tetra Tech, Inc., Research Triangle Park, NC.

Tetra Tech. 2004. Morgan Creek LWP – Preliminary Findings Report. Prepared for N.C. Ecosystem Enhancement Program. Tetra Tech, Inc., Research Triangle Park, NC. January 2004

USDA. 1998. Stream Visual Assessment Protocol. United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS). National Water and Climate Center Technical Note 99-1. Washington, D.C.

United States Army Corps of Engineers (USACE), 2002. HEC-HMS Hydrologic Modeling System, Version 2.1.3. Hydrologic Engineering Center, California.

United States Army Corps of Engineers (USACE), 2003. HEC-RAS River Analysis Software, Version 3.0.1. Hydrologic Engineering Center, California.

Walker W.W., Jr. 1987. Empirical Methods for Predicting Eutrophication in Impoundments. Report 4-Phase III: Applications Manual. U.S. Army Corps of Engineers Technical Report E-B1-9.Waterways Experiment Station, Vicksburg, MS.

Wiley, Haven, Ludington, Livy, Hall, Steve. 1999. Rating Land in Orange County by its Wildlife Value. Triangle Land Conservancy, Research Triangle Park

Williams, G.P., 1978. Bank-Full Discharge of Rivers. Water Resources Research, 14(6): 1141-1154.

Appendix A. Development of Modeling Tools

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1 Development of Existing and Future Land Use Conditions

1.1 INTRODUCTION

Modeling analyses, such as the stream stability assessment and nutrient loading analyses presented in this *Detailed Assessment Report*, rely on approximations of future land use to generate predictions of the future conditions of watershed functions. GIS databases were developed to approximate existing land use conditions within the LWP study area and future “buildout” landuse conditions, reflecting the maximum development capacity according to current zoning and land use plans. The following setions describe how existing and buildout land use patterns where evaluated.

1.2 METHODS

GIS tax-parcel data provide a good starting point for existing land use classification, but there are disadvantages to relying solely on parcel data. For instance, a 100-acre rural parcel may be classified as residential, when in reality the parcel may contain one house and a maintained yard a few acres in size; the rest of the lot may be forested or agricultural. Therefore, it would not be appropriate to apply a residential pollutant-loading rate to the entire parcel.

Land cover data based on satellite imagery provide a good way to distinguish some types of land cover without the constraints of a single land use assignment within a parcel boundary. However, it is difficult to distinguish residential land use of varying densities from satellite-based land cover. Residential lands generally show a pattern of random residential land use pixels dispersed within forest cover. This may even occur in dense urban areas with a well-developed tree canopy. A second problem with satellite imagery is that the latest available interpreted coverage for the watershed is over 10 years old and does not reflect recent development in the watershed.

To address the faults inherent to parcel database coverages, Tetra Tech chose to combine a parcel-based analysis with additional GIS data sources to generate the existing land use and disturbed area estimates for the project watersheds. Parcel data for each of the counties in the project area were obtained (current through July 2002 to March 2003, depending on the source). The interpretation of the parcel data was further refined through targeted orthophoto analysis. Planimetric data of impervious surfaces were also used to refine the analysis. The National Land Cover Database (NLCD) from the Multi-Resolution Land Characterization (MRLC) Consortium was used for the satellite land cover data. The NLCD is based on interpretation of Landsat satellite thematic mapper imagery, and is available for this area based on images recorded between 1992 and 1994 (Figure 1-1).

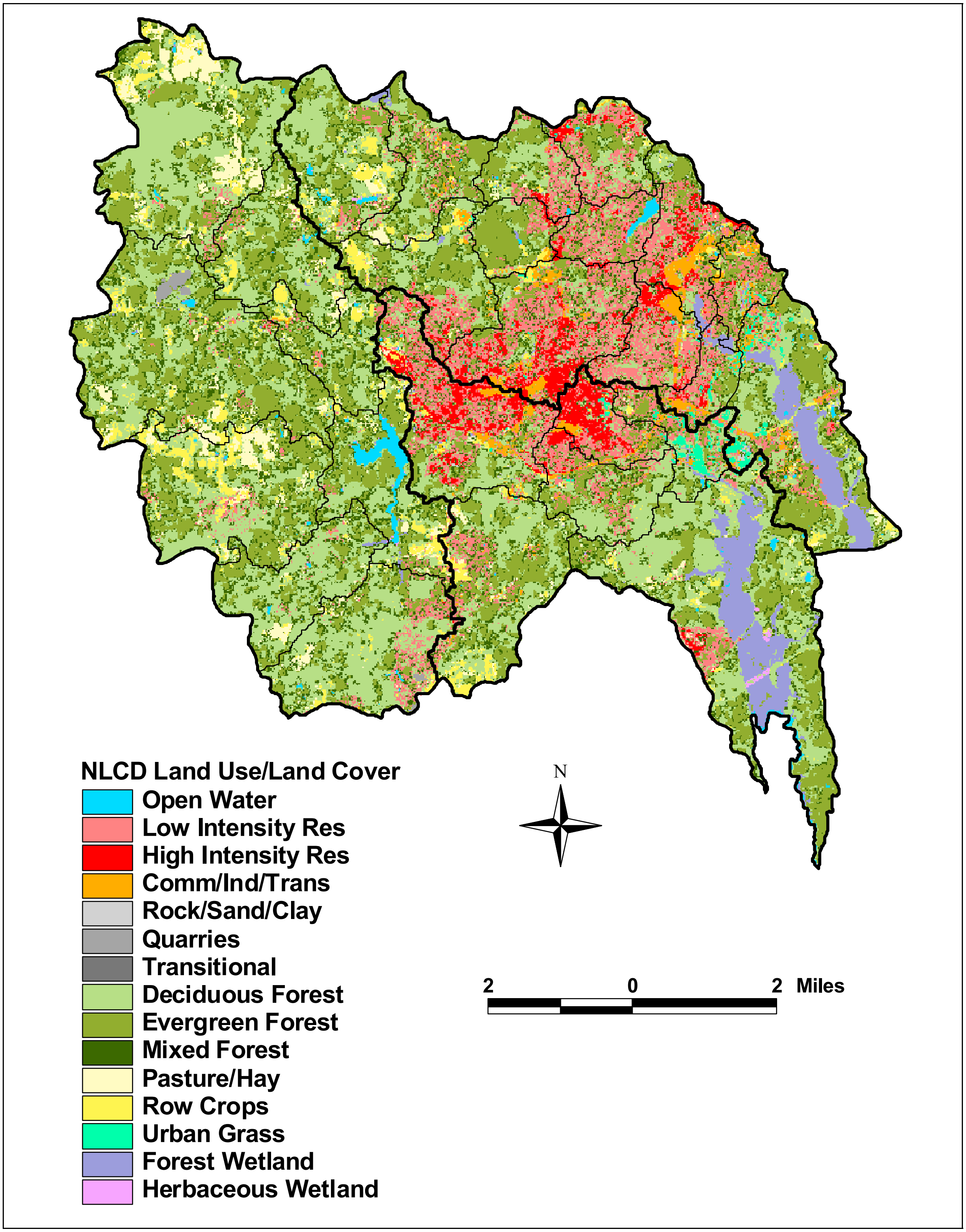

Figure 1-1. NLCD Land Cover

When the hydrography coverage and the NLCD grid data were displayed together, it became apparent that the two coverages were not aligning properly. The source of the error is unknown but is likely due to the original projection used by the NLCD, which is optimized for the entire lower 48 states and is not specific to North Carolina. The NLCD data were spatially shifted about 12 meters south and 75 meters west to achieve an optimal visual alignment between the hydrography coverage and the NLCD grid.

1.3 EXISTING LAND USE

Land use categories were assigned by parcel based on Orange County, Durham County and Chatham County tax parcel databases and corresponding GIS shapefiles. A combination of information was used, depending on availability and jurisdiction, including land use information, zoning, building use information, building count on a parcel basis, building value, and parcel size. Parks and protected areas were located using GIS shapefiles provided by Orange County Environment and Resources Conservation Department and NC Center for Geographic Information and Analysis. Parcels in the University Lake watershed were assigned to categories used in the University Lake Planning Model Project, while parcels in the remaining portion of the project area were assigned to categories used in the Jordan Lake TMDL Watershed Model Development Project. The University Lake Baseline Analysis Memo (Tetra Tech, 2003b) discusses the parcel-based classification in detail. The methods discussed in that report also apply to the Lower Morgan Creek and Little Creek subwatersheds, but with a few differences:

- There was a finer division of residential classes in the Lower Morgan/Little subwatersheds based on land use classes used in the Jordan Lake TMDL Watershed Model Development Project. Parcels were assigned to residential classes based on parcel size. Parcels containing apartments, condos, and town homes were also assigned to the highest density residential category.
- Non-residential developed lands were assigned to two categories – commercial and institutional (versus commercial only for University Lake subwatersheds). There were many large parcels that were only partially developed, so a shapefile of building footprints and other impervious surfaces was used to find the “effective developed area” of commercial/institutional land use in each parcel (defined as the impervious area plus a portion of the pervious area). The remaining area was assumed to be vacant land use.
- The cap on residential lot size beyond which the remainder of a lot was considered undeveloped was three acres (versus five acres in the University Lake subwatersheds).

As discussed previously, parcel data provide a better picture of developed land use, but are not usually adequate for characterizing minimally disturbed or agricultural areas. The NLCD data were used to “fill in the gaps” for chosen areas in the parcel analysis – vacant parcels, agricultural and forested parcels, parks and protected areas, and the vacant areas in larger commercial/institutional parcels. Large rural residential parcels provided an additional challenge – there are many lots classified as residential that are much larger than three or five acres (some are in excess of 100 acres) and likely contain a mixture of residential, agricultural, and forested land use. To account for this, a portion of each of these parcels was classified as residential capped at the maximum lot size, and the remaining portion was classified as undeveloped. For example, a 10-acre lot would be classified as having five acres of residential land and five acres of vacant land in the University Lake subwatersheds, while a 10-acre lot in the other subwatersheds would be classified as having three acres of residential land and seven acres of vacant land. While the two methods produce a different land use distribution, each is appropriate to its destination nutrient model.

All of the unclassified areas – vacant parcels, parks, the vacant portion of large commercial/institutional parcels, and the vacant portion of large rural residential parcels – were summed within each model subwatershed. NLCD data were then used to assign the remaining land use classes.

NLCD land uses were totaled in each model subwatershed. Some of the land uses were assumed to be accurate on a subwatershed scale, and to have not changed substantially during the 10 years following the time frame of the NLCD development. In the University Lake subwatersheds, barren lands (chiefly quarries) fell into this category. In the remaining subwatersheds, the following land uses were taken directly from the NLCD totals: barren lands, open water, urban grass, and wetlands. The additional land use classes were appropriate for these subwatersheds, since they are present in larger proportions than in the University Lake subwatersheds.

After these land uses were subtracted out, the remaining area was assigned to forest, pasture, or row crop agriculture based on the relative proportions of these land uses within each subwatershed according to the NLCD classification. The assumption is that, while the absolute area of forest and agriculture reported by NLCD is not accurate under current conditions (due to development occurring within the last 10 years and problems classifying urban land use), the proportions are reasonable on a subwatershed scale. There is an underlying assumption that development in the last 10 years is occurring proportionately on forest and agricultural lands, i.e., one of those land uses is not being selected preferentially for development.

Septic system loading is calculated differently in each of the models. In the University Lake Model, loading is determined by the number of households using onsite septic systems. In the Jordan Lake Model, residential land uses are divided into septic and sewered classes, and the septic residential land use classes have higher loading rates. As a result, the Lower Morgan/Little Creek land uses have separate septic and sewered residential classes. In both models, the area served by sewer was determined from information provided by OWASA. All residential parcels not on sewer were assumed to use onsite septic systems.

Areas of existing land use are summarized in Table 1-1 and Table 1-2. Figure 1-2 and Figure 1-3 show the parcel-based land use. Note that several of parcel classes contribute area to the "vacant" category, which becomes reassigned to NLCD land use as discussed previously.

Table 1-1. Existing Land Use (ac) for University Lake Subwatersheds

Land Use	UM1	UM2	UM3	UM4	UM5	UM6	UM7	UM8	Total	Percent
Forest	2,276.5	1,005.2	527.6	2,813.8	1,466.0	988.7	1,307.6	1,137.9	11,523.3	60.5%
Pasture	403.7	58.7	31.6	140.4	165.4	37.1	39.5	74.9	951.3	5.0%
Row Crops	157.5	42.3	48.0	153.3	187.6	12.2	37.8	104.0	742.8	3.9%
5 ac Residential Lots	336.1	225.8	145.4	348.7	333.5	240.8	143.3	112.0	1,885.6	9.9%
2-5 ac Residential Lots	288.1	119.1	173.0	248.2	382.9	244.1	219.9	195.0	1,870.1	9.8%
1-2 ac Residential Lots	91.4	117.5	49.7	205.8	110.9	25.9	217.6	37.8	856.6	4.5%
< 1 ac Residential Lots	19.0	29.3	38.8	94.5	23.7	2.1	281.8	22.6	511.7	2.7%
Commercial and Heavy Industrial	0.8	2.6	14.1	0.7	1.5	2.2	5.6	6.3	33.5	0.2%
Barren Land (includes quarries)	1.8	0.4	3.3	77.8	4.5	0.2	18.5	3.8	110.3	0.6%
Road Right-of-Way	68.8	67.7	51.8	129.6	98.3	34.4	62.6	60.9	574.0	3.0%
Total	3,643.6	1,668.5	1,083.4	4,212.8	2,774.2	1,587.7	2,334.0	1,755.1	19,059.3	100.0%

Table 1-2. Existing Land Use (ac) for Lower Morgan Creek and Little Creek Subwatersheds

	Residential, Onsite Septic				Residential, Sewered														
	2.0 - 3.0 acre lot	1.5 - 2.0 acre lot	1.0 - 1.5 acre lot	0.5 - 1.0 acre lot	2.0 - 3.0 acre lot	1.5 - 2.0 acre lot	1.0 - 1.5 acre lot	0.5 - 1.0 acre lot	0.25 - 0.5 acre lot	< 0.25 acre lot	Office/Institutional	Commercial/Industrial	Urban Grass	Pasture	Row Crop	Forest	Wetlands	Barren Land	Open Water
BL1	217.7	29.5	28.7	26.5	0.7	0.0	0.0	26.2	35.6	11.5	0.0	0.9	0.2	68.9	99.8	1,218.1	20.5	3.8	24.2
BL2	123.6	28.3	61.1	67.4	25.1	3.1	7.6	57.1	64.4	7.6	0.0	0.2	0.9	27.9	21.0	767.4	9.3	0.2	1.1
BL3	23.1	5.2	5.9	8.7	33.1	3.5	19.3	70.6	226.9	66.9	30.0	0.6	3.6	23.3	75.5	892.8	4.9	2.4	0.4
BL4	2.6	1.8	2.2	6.1	62.4	50.2	91.1	282.8	310.5	385.6	80.4	126.7	20.3	1.6	23.6	742.7	1.3	5.6	0.4
BL5	12.4	1.7	7.1	3.5	32.0	17.4	66.2	121.7	80.9	77.7	33.3	68.5	9.9	2.3	5.0	361.1	6.0	0.7	2.7
BL6	19.6	5.0	6.8	24.4	17.1	8.5	50.9	35.0	97.3	109.7	18.8	1.4	0.4	11.5	8.2	433.2	1.8	0.9	5.6
BL7	0.0	0.0	0.0	0.0	10.0	0.0	1.6	18.3	22.6	33.0	0.0	31.8	1.6	1.7	29.2	491.6	3.6	3.3	1.8
BL8	11.3	8.2	11.8	12.0	38.2	31.8	73.8	158.2	68.4	145.5	10.6	23.6	2.7	5.4	8.1	323.9	0.7	1.6	2.0
BL9	3.6	5.1	10.5	7.8	11.6	9.5	49.4	268.5	66.1	32.8	9.4	1.2	0.9	0.4	0.4	183.9	2.0	0.2	42.5
BL10	0.0	0.0	1.0	1.6	9.6	7.6	38.5	179.9	155.3	140.9	34.0	95.2	0.2	3.9	20.6	475.6	36.3	4.4	3.8
BL11	0.0	0.0	0.0	0.0	6.3	7.9	34.4	72.4	213.3	36.5	5.6	2.6	11.1	0.3	4.8	194.1	17.8	0.4	0.4
BL12	0.0	0.0	0.1	1.7	8.3	2.9	24.3	65.5	44.2	28.8	5.2	23.5	35.6	0.0	0.0	270.3	33.6	0.0	0.4
BL13	40.6	7.0	9.4	7.0	42.7	17.3	31.6	114.2	138.5	76.5	7.5	57.1	99.2	32.2	75.3	1,681.4	597.4	16.9	15.6
LM1	32.6	6.6	7.2	8.0	75.5	17.3	35.5	180.0	287.2	349.7	39.5	217.9	6.0	18.3	55.4	1,006.4	7.8	12.7	2.9
LM2	309.0	63.4	62.4	102.1	0.8	0.0	0.0	3.0	65.0	108.9	13.1	3.3	1.3	56.9	113.7	1,391.1	2.0	3.1	0.9
LM3	2.2	2.4	4.1	8.5	6.2	15.8	26.0	39.7	4.4	0.4	234.6	0.0	165.9	0.0	3.4	228.2	0.0	0.4	0.0
LM4	31.9	17.6	49.3	56.1	53.2	39.4	107.3	136.5	34.6	29.6	27.8	1.4	26.7	2.6	4.5	567.1	0.7	1.6	0.0
LM5	0.0	0.6	4.5	1.7	18.4	10.0	16.6	29.6	4.0	0.8	21.1	12.0	98.3	3.5	5.1	486.5	14.2	0.4	3.1
LM6	194.9	26.8	54.8	39.6	12.7	8.3	0.2	0.0	0.0	0.9	0.0	6.7	4.9	65.8	75.2	3,524.9	992.1	0.9	87.2

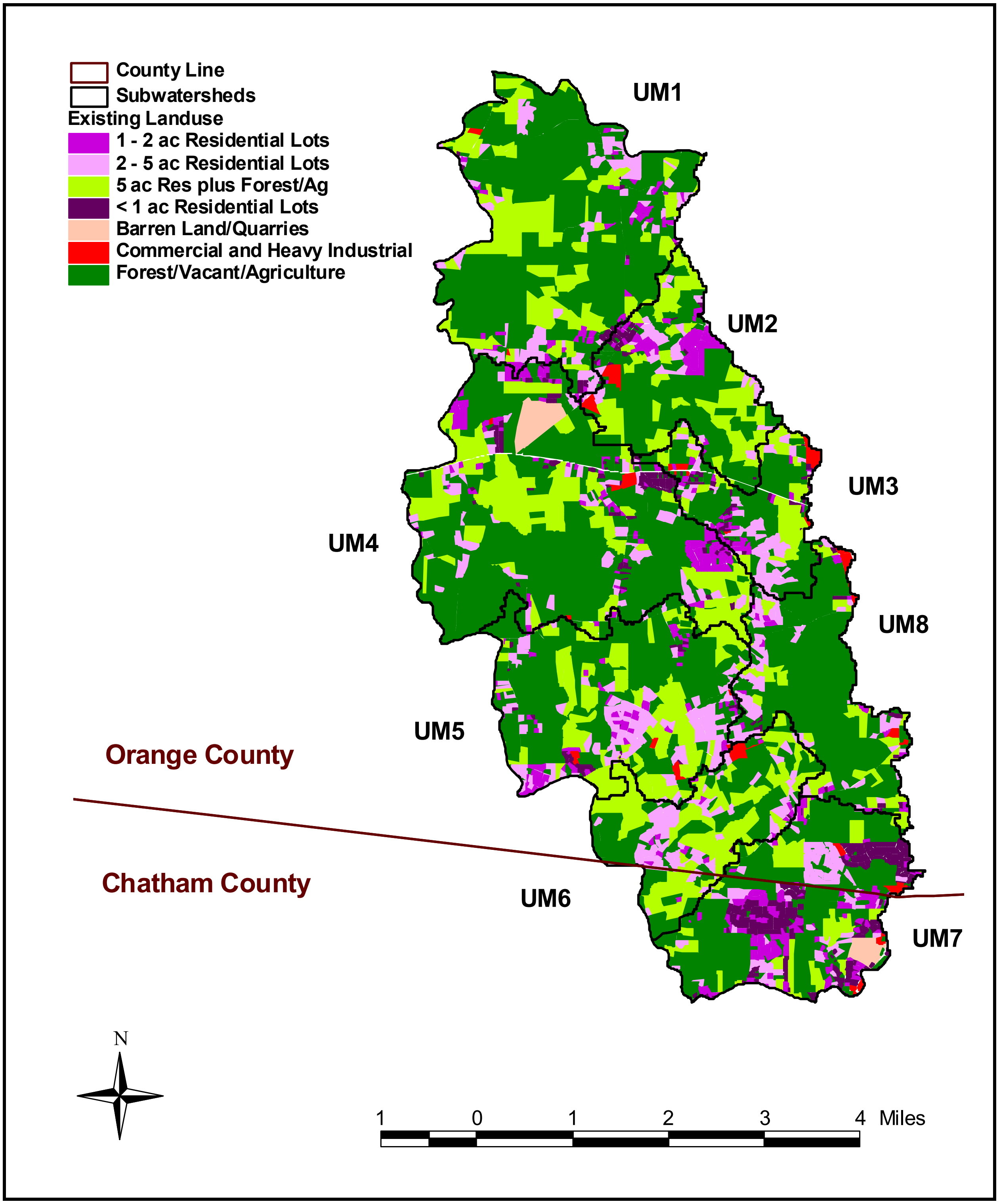

Figure 1-2. Parcel Based Land Use for Existing Conditions in the Upper Morgan Creek Subwatersheds

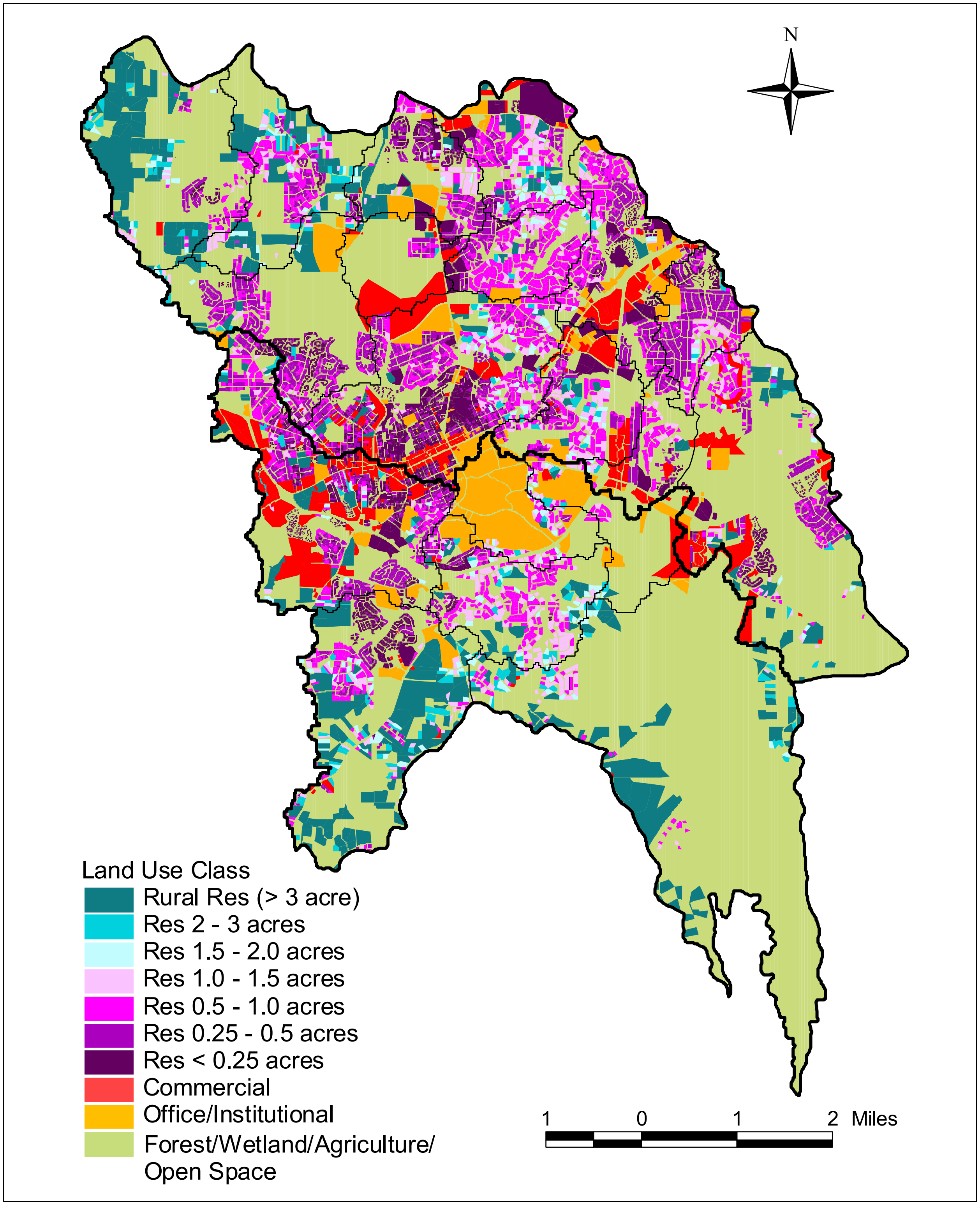

Figure 1-3. Parcel Based Land Use for Existing Conditions in the Lower Morgan Creek and Little Creek Subwatersheds

1.4 BUILDOUT LAND USE

The land use classification system using parcel data was used as the starting point for the buildout analysis, as for the existing land use analysis. While NLCD data were utilized for the buildout scenario as well, the parcel data were used to a much greater extent. The following paragraphs discuss the assessment of future development, the assignment of nonresidential land uses, and the use of NLCD data.

The buildout land use scenario was used to assess the maximum development potential of the watershed under current zoning ordinances and development plans. Thus, all developable land (unprotected forest, agriculture, etc.) was assumed to develop to either residential or commercial land use. Lands currently in a protected status (parks, protected areas, conservation easements) were assumed to remain undeveloped and were modeled as forested land, with the exception of a few parcels in the University Lake watershed assumed to remain as active pasture.

The Durham County parcel database included a projected future land use field, which was used to assign buildout land use classes. Much of the Durham County portion of the study area is made up of protected Army Corp lands surrounding Jordan Lake and was assumed to remain protected in the future. Buildout land use assignment was more involved for Orange and Chatham Counties. A summary of methods follows; a more detailed discussion is available in the University Lake Baseline Analysis Memo (Tetra Tech, 2003b).

In general, parcels already developed under the existing land use scenario were assumed to remain in the same land use class, unless they were residential lots that were large enough to be subdivided. Commercial/Institutional parcels were assumed to develop to their full potential.

In keeping with the zoning and watershed ordinances in place in Orange and Chatham counties, all buildout residential development was assumed to follow current zoning, taking ordinance limits on lot size into account. For Orange County, the ordinance sets a minimum lot size of 5 acres per dwelling unit in the University Lake watershed, except for lots on record as existing before October 2, 1989. These "grandfathered" lots may contain up to five lots with a minimum size of 2 acres per dwelling unit; the 5-acre restriction then applies to the remaining portion of the lot. For the Chatham County portion of the study area, there is a 90,000-ft^2 minimum lot size (about 2 acres) for future residential development.

At buildout, residential lots were assumed to develop at their allowed density without consideration of limitations that might be imposed by lack of sewer service or soils unsuitable for septic tanks. In this sense, the analysis represents a conservative upper boundary. However, the assumptions that new lots must fit within existing parcel boundaries results in a realized average lot size that is greater than the minimum and provides additional area for suitable onsite wastewater disposal.

Parcels in Orange and Chatham counties were assessed to determine their development potential. Parcels were assigned to "developable" or "not developable" categories depending on the type of existing development, lot size, jurisdiction, and zoning. Developable parcels that are large enough to be subdivided within ordinance and zoning limits were given a "may be subdivided" designation. Calculations were performed to determine the projected number of future lots and effective density for each of the parcels that could be subdivided, taking ordinance limitations and grandfathering into account.

In the existing land use analysis, the assumption for rural residential lots greater than a set threshold was that the portion of a lot in excess of the threshold would be either forested or agricultural. The same assumption was made for the buildout scenario. Note that for the most part, this would apply primarily to lots in the University Lake watershed between 5 and 15 acres in size due to the assumptions listed above. In the University Lake subwatersheds, the portion of a residential lot in excess of five acres was assumed forest or agriculture according to NLCD proportions of those land uses in each model subwatershed. However, no substantial row crop land use was assumed to occur due to the small lot size, so all future buildout agricultural land use was assumed pasture. In the Lower Morgan/Little subwatersheds, the portion of a residential lot in excess of three acres was assumed to be forested only.

As a result of the analysis methods, the forest class at buildout was made up of a combination of the protected/common/park parcels and forested land on 3+ or 5+ acre lots, and the pasture class was made up of a combination of a few specific parcels assigned to pasture and agricultural land on 5+ acre lots. Barren land use was assumed to disappear in the buildout scenario. Urban grass, wetland, and open water land uses were assumed to be retained in the Lower Morgan/Little subwatersheds.

No additional sewer service is expected in the University Lake Watershed in the future, in either Orange County or Chatham County. In the remaining portions of study area, sewer service is expected to extend to 20-year urban transition zones. All future residential areas not already on public sewer were assumed to use septic systems for waste treatment. The count of septic systems in each subwatershed was found by assuming one septic system for each residential parcel, including one septic system for each future lot in the subdivided parcels.

The Horrace Williams tract of the University of North Carolina located in the Little Creek subwatersheds was given special consideration. It was assumed to develop according to a draft plan released by the university during November 2003 (Hunter, 2003). The plan proposes that 240 acres will be developed in the eastern portion of the tract, and about 700 acres will be undeveloped. The future use of this parcel is certain to be debated, contested, and probably refined as the university and area stakeholders work through discussions and negotiations. However, this information was the most recent available at the time of this writing.

Areas of buildout land use are summarized in Table 1-3 and Table 1-4. Figure 1-4 and Figure 1-5 show the parcel-based land use. Note that much of the 5-acre class in the Upper Morgan subwatersheds and the Rural Residential class in the Lower Morgan and Little Creek subwatersheds is assigned to forest and other NLCD land uses, as discussed previously.

Table 1-3. Buildout Land Use (ac) for University Lake Subwatersheds

Land Use	UM1	UM2	UM3	UM4	UM5	UM6	UM7	UM8	Total	Percent
Forest	677.8	155.0	123.7	386.2	220.1	117.7	160.5	661.7	2,502.7	13.1%
Pasture	157.0	19.4	8.0	19.6	53.1	4.6	3.9	18.3	283.8	1.5%
Row Crops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
5 ac Residential Lots	2,188.5	1,034.3	507.3	2,791.5	1,669.6	803.9	421.9	653.0	10,070.1	52.8%
2 - 5 ac Residential Lots	410.9	206.1	259.8	556.6	558.4	550.6	1,022.1	260.9	3,825.5	20.1%
1 - 2 ac Residential Lots	113.2	122.1	53.5	212.3	125.0	50.7	298.2	42.9	1,017.9	5.3%
< 1 ac Residential Lots	21.4	29.6	41.9	96.3	30.2	4.8	287.0	36.0	547.0	2.9%
Commercial and Heavy Industrial	5.9	34.3	37.5	20.5	19.5	21.0	24.5	21.4	184.5	1.0%
Barren Land (includes quarries)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0%
Road Right-of-Way	68.8	67.7	51.8	129.6	98.3	34.4	115.9	60.9	627.3	3.3%
Total	3,643.5	1,668.5	1,083.4	4,212.7	2,774.1	1,587.7	2,334.0	1,755.0	19,058.8	100.0%

Table 1-4. Buildout Land Use (ac) for Lower Morgan Creek and Little Creek Subwatersheds

	Residential, Onsite Septic				Residential, Sewered														
	2.0 - 3.0 acre lot	1.5 - 2.0 acre lot	1.0 - 1.5 acre lot	0.5 - 1.0 acre lot	2.0 - 3.0 acre lot	1.5 - 2.0 acre lot	1.0 - 1.5 acre lot	0.5 - 1.0 acre lot	0.25 - 0.5 acre lot	< 0.25 acre lot	Office/Institutional	Commercial/Industrial	Urban Grass	Pasture	Row Crop	Forest	Wetlands	Barren Land	Open Water
BL1	217.7	29.5	28.7	26.5	0.7	0.0	0.0	26.2	35.6	11.5	0.0	0.9	0.2	68.9	99.8	1,218.1	20.5	3.8	24.2
BL2	123.6	28.3	61.1	67.4	25.1	3.1	7.6	57.1	64.4	7.6	0.0	0.2	0.9	27.9	21.0	767.4	9.3	0.2	1.1
BL3	23.1	5.2	5.9	8.7	33.1	3.5	19.3	70.6	226.9	66.9	30.0	0.6	3.6	23.3	75.5	892.8	4.9	2.4	0.4
BL4	2.6	1.8	2.2	6.1	62.4	50.2	91.1	282.8	310.5	385.6	80.4	126.7	20.3	1.6	23.6	742.7	1.3	5.6	0.4
BL5	12.4	1.7	7.1	3.5	32.0	17.4	66.2	121.7	80.9	77.7	33.3	68.5	9.9	2.3	5.0	361.1	6.0	0.7	2.7
BL6	19.6	5.0	6.8	24.4	17.1	8.5	50.9	35.0	97.3	109.7	18.8	1.4	0.4	11.5	8.2	433.2	1.8	0.9	5.6
BL7	0.0	0.0	0.0	0.0	10.0	0.0	1.6	18.3	22.6	33.0	0.0	31.8	1.6	1.7	29.2	491.6	3.6	3.3	1.8
BL8	11.3	8.2	11.8	12.0	38.2	31.8	73.8	158.2	68.4	145.5	10.6	23.6	2.7	5.4	8.1	323.9	0.7	1.6	2.0
BL9	3.6	5.1	10.5	7.8	11.6	9.5	49.4	268.5	66.1	32.8	9.4	1.2	0.9	0.4	0.4	183.9	2.0	0.2	42.5
BL10	0.0	0.0	1.0	1.6	9.6	7.6	38.5	179.9	155.3	140.9	34.0	95.2	0.2	3.9	20.6	475.6	36.3	4.4	3.8
BL11	0.0	0.0	0.0	0.0	6.3	7.9	34.4	72.4	213.3	36.5	5.6	2.6	11.1	0.3	4.8	194.1	17.8	0.4	0.4
BL12	0.0	0.0	0.1	1.7	8.3	2.9	24.3	65.5	44.2	28.8	5.2	23.5	35.6	0.0	0.0	270.3	33.6	0.0	0.4
BL13	40.6	7.0	9.4	7.0	42.7	17.3	31.6	114.2	138.5	76.5	7.5	57.1	99.2	32.2	75.3	1,681.4	597.4	16.9	15.6
LM1	32.6	6.6	7.2	8.0	75.5	17.3	35.5	180.0	287.2	349.7	39.5	217.9	6.0	18.3	55.4	1,006.4	7.8	12.7	2.9
LM2	309.0	63.4	62.4	102.1	0.8	0.0	0.0	3.0	65.0	108.9	13.1	3.3	1.3	56.9	113.7	1,391.1	2.0	3.1	0.9
LM3	2.2	2.4	4.1	8.5	6.2	15.8	26.0	39.7	4.4	0.4	234.6	0.0	165.9	0.0	3.4	228.2	0.0	0.4	0.0
LM4	31.9	17.6	49.3	56.1	53.2	39.4	107.3	136.5	34.6	29.6	27.8	1.4	26.7	2.6	4.5	567.1	0.7	1.6	0.0
LM5	0.0	0.6	4.5	1.7	18.4	10.0	16.6	29.6	4.0	0.8	21.1	12.0	98.3	3.5	5.1	486.5	14.2	0.4	3.1
LM6	194.9	26.8	54.8	39.6	12.7	8.3	0.2	0.0	0.0	0.9	0.0	6.7	4.9	65.8	75.2	3,524.9	992.1	0.9	87.2

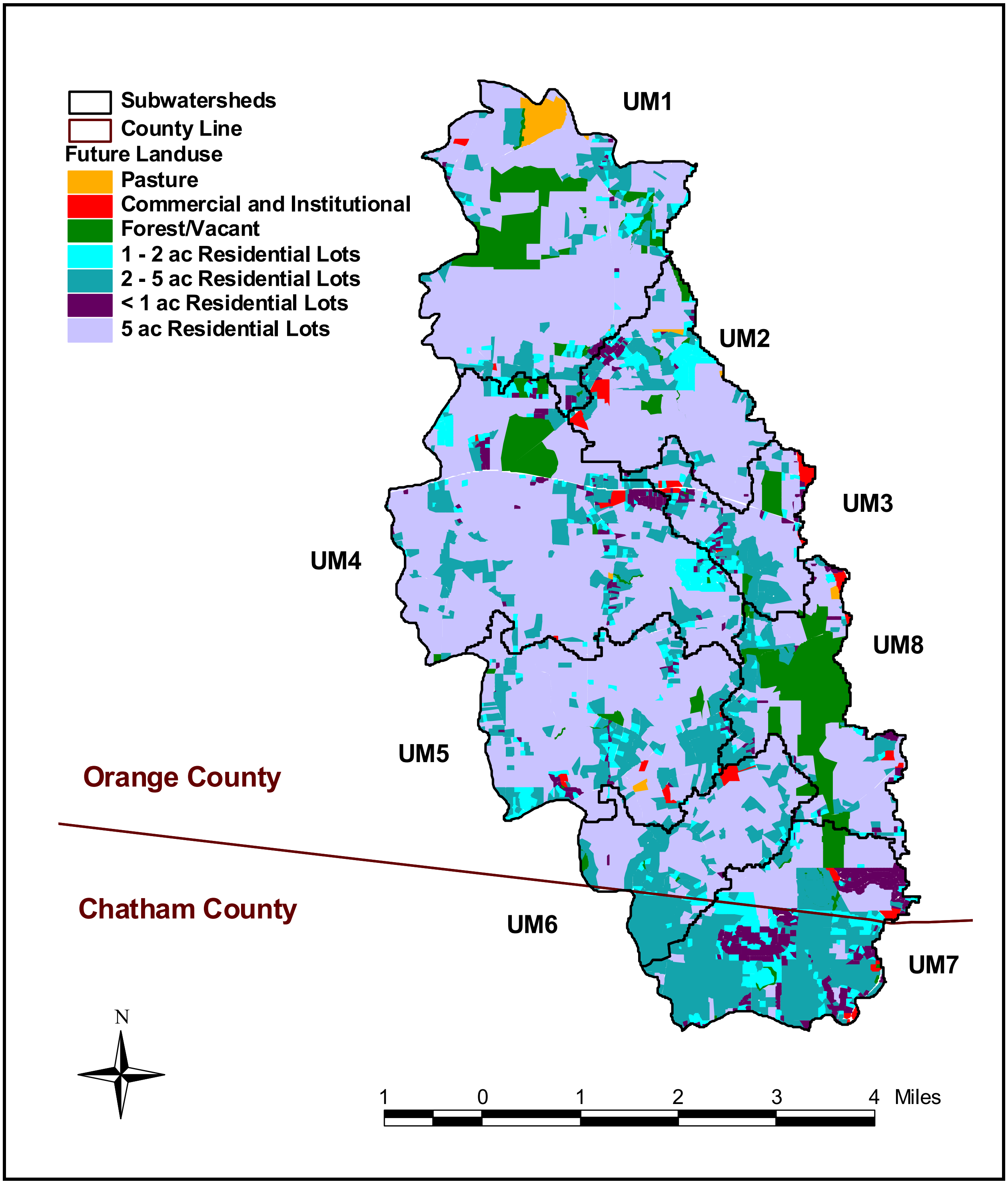

Figure 1-4. Parcel Based Land Use for Buildout Conditions in the Upper Morgan Creek Subwatersheds

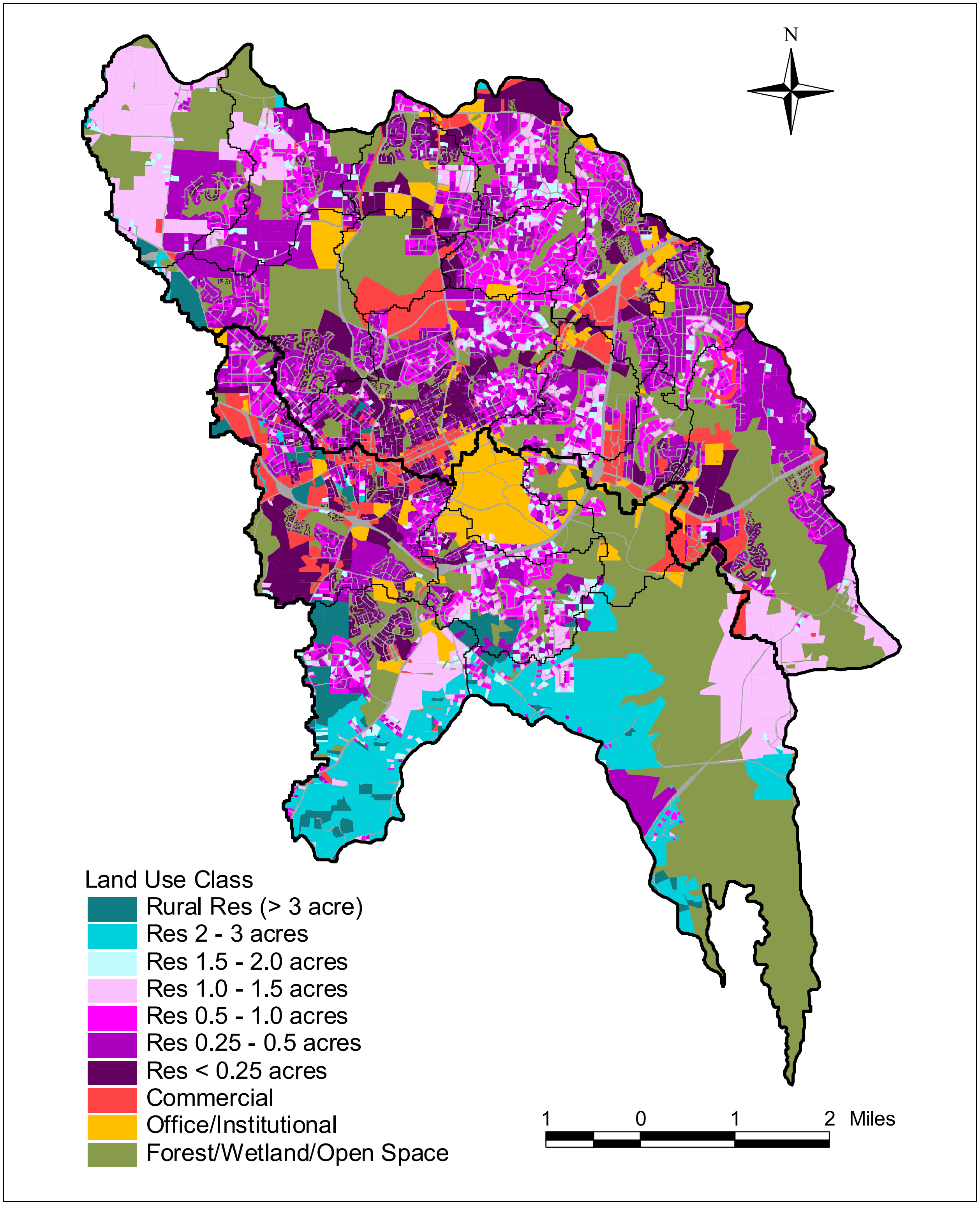

Figure 1-5. Parcel Based Land Use for Buildout Conditions in the Lower Morgan Creek and Little Creek Subwatersheds

2 Hydrologic Modeling

A hydrologic model is a mathematical representation of the physical response of a watershed to rainfall. Hydrologic models are tools widely used to predict runoff from a watershed under conditions other than those experienced historically or in cases where no historical monitoring data exist. Theoretical or design rainstorms, conversion of land cover due to urban development, channel modifications, and stormwater management facilities can all be evaluated using models.

The US Army Corps of Engineers hydrologic modeling system HEC-HMS (USACE, 2003a) was selected to model the hydrology of the study area watersheds. This model offers various methodologies for converting rainfall to runoff, as well as capabilities to generate, combine, and route hydrographs through channels, storage facilities, drainage structures, and conveyances. The HEC-HMS model allows the relative frequency and magnitude of certain stream flows to be characterized for the existing and future land cover scenarios.

2.1.1 Drainage Basin Delineation

The Morgan Creek study area is approximately 75 square miles and is comprised of three 14-digit hydrologic units: Little Creek (including Bolin and Booker Creeks), Upper Morgan, and Lower Morgan. For purposes of this Local Watershed Planning (LWP) process, the study area was divided into 27 separate subwatersheds, ranging in size from one to eight square miles. The National Elevation Dataset (NED) 30-meter digital elevation model (DEM) of the study area was used in a GIS for the preliminary delineations. Initially, 41 subwatersheds were identified, one for each perennial tributary to either Morgan Creek or Little Creek proper, and one for each segment of stream between tributaries. Subwatersheds with similar geology, soils, and landuse distributions were aggregated to arrive at the final 27 subwatersheds.

For hydrologic modeling purposes, the 27 final LWP subwatersheds were further subdivided where additional resolution was required. LWP subwatersheds where local stormwater management ordinances require future stormwater runoff patterns to match existing conditions were excluded from hydrologic modeling because further watershed development is not expected to negatively impact stream hydrology. Therefore, a visual assessment of existing conditions was taken as representative of both existing and future conditions. In the 12 LWP subwatersheds where modeling was carried out, 36 modeling subwatersheds were delineated ranging in size from 0.25 to 3.5 square miles. The average subwatershed size was 1.1 square miles. These smaller subwatersheds were delineated using 2-foot and 5-foot interval topographic contour lines in a GIS.

2.1.2 Runoff Curve Numbers, Soils, and Land Cover Data

One of the principle components of rainfall runoff models is the conversion of precipitation to runoff. To represent this process in the studied watersheds, the Soil Conservation Service's (SCS) curve number and soil loss methodologies were implemented. These methods have been used extensively in similar studies and are well documented in numerous publications including Technical Release 55 (NRCS, 1986) and the National Engineering Handbook (NRCS, 1972). The main parameters affecting the curve number index are land cover, soil type, and antecedent moisture condition. Using this index to determine the amount of available soil storage and subsequent precipitation excess in a drainage basin is a standard hydrologic analysis technique.

A GIS was used to calculate curve numbers for each of the modeling subbasins. Digital renderings of the soil survey for Orange, Durham, and Chatham counties were used to characterize the hydrologic group of each soil type present in the study area. The 1992 National Land Cover Database (NLCD) developed by the USGS and USEPA represents the existing land cover. In the GIS, the land cover and soil data are overlaid. The GIS creates a new data layer for each unique combination of land cover and hydrologic soil type. A curve number is assigned to each of these polygons based on a lookup table. The subwatershed boundaries are overlaid on these polygons and a composite curve number is calculated for each modeling subwatershed by area weighting the polygon curve numbers within its boundary. The future land cover scenarios were developed as described in Section 1.4 of this appendix.

The antecedent moisture condition (AMC) has a direct effect on the magnitude of the curve number. AMC describes the amount of moisture present in the soil prior to a storm event. A greater AMC means the ground is more saturated, reducing the potential for infiltration, and consequently increasing the runoff volume. For this study, the average soil moisture condition (AMC II) was selected to represent conditions that are neither excessively wet nor excessively dry prior to a precipitation event.

2.1.3 Time of Concentration and Lag Time

The HEC-HMS hydrologic model selected for this study offers a variety of methodologies to represent the conversion of rainfall to runoff. The SCS unit hydrograph methodology was selected since it only requires one input parameter, the lagtime for each subbasin. The lagtime is defined as the lag (time) between the center of mass of the rainfall excess and the peak of the unit hydrograph. The lag is a function of subbasin topography and land cover as well as channel geometry and roughness.

The lag for each subwatershed was calculated using the SCS curve number method developed from research watershed data (NRCS, 1972). The curve number method relates basin lag to the hydraulic length of the watershed, average channel slope, and watershed curve number as shown in the equation below.

$$L = \frac{\ell^{0.8}\left(\left(\frac{1000}{CN}\right) - 9\right)^{0.7}}{1900Y^{0.5}}$$

Where

L	=	basin lag (hours);
ℓ	=	hydraulic length (feet);
CN	=	basin curve number; and,
Y	=	average channel slope (percent).

2.1.4 Computation Interval

The computation interval is the length of time that passes between successive model iterations. In the HEC-HMS model, the computation interval can be set to a minimum of 1 minute and a maximum of 24 hours. In general, the computation interval, or time step, should be short enough to display sufficient detail around the peak of the hydrograph associated with the smallest subbasin. Additionally, it should be set such that no oscillations occur in the hydrographs generated at storage routing locations. The HEC-HMS user's guide (USACE, 2001) states that the model time step should not exceed 0.29 times the shortest lag time for the subbasins in the model. Based on the size of the subbasins in this study and the associated lag times, the model time step was set to 1 minute, which offered more than the minimum required resolution for the rising limb of the runoff hydrographs.

2.1.5 Rainfall

For the study area in Orange and Chatham counties in North Carolina, a Type II 24-Hour SCS synthetic rainfall storm distribution is appropriate. In regions with Type II storm distributions, the peak storm intensity occurs at the center of the storm, after approximately 12 hours. For Type II storms, the largest 6-minute rainfall depth is assumed to occur at about the middle of the 24-hour period, the second largest 6-minute incremental depth during the next 6 minutes, and the third largest in the 6-minute interval preceding the maximum depth. This process continues in order of decreasing magnitude so that the minimum incremental storm depths occur at the beginning and end of the storm. In this fashion, the maximum 6-minute depth is contained within the maximum 1-hour depth, the maximum 1-hour depth within the maximum 4-hour depth, and so on. This approach is called the balanced storm because the rainfall distribution is balanced to simulate the appropriate rainfall intensity for any storm duration.

The rainfall depth data for various return interval storms for a 24-hour duration are available from the National Weather Service Technical Paper No. 40, Rainfall Frequency Atlas of the United States (Hershfield, 1961).

The average rainfall depth over a watershed for a given frequency decreases with increasing drainage area. Areal reduction of point rainfall is necessary to reduce rainfall depths applied to a watershed by the HEC-HMS model. The error introduced by not reducing point rainfall increases with drainage area. The error is generally considered insignificant for drainage areas less than 10 square miles. Since the modeled streams in the study area have drainage areas less than this threshold, the error introduced by not accounting for the areal reduction factor is insignificant, so no factor was used.

2.1.6 Base Flow

The HEC-HMS hydrologic model offers a few options for modeling base flow throughout a watershed. However, for moderate and extreme storm events over relatively urbanized basins, base flow contributions are generally insignificant and direct runoff will completely dominate the peak of the storm hydrograph. For these reasons, base flow was not simulated in the HEC-HMS model nor is it likely to significantly affect model output.

2.1.7 Hydrologic Routing

Hydrologic routing represents the dynamic movement of a flood hydrograph through conveyances. The routing techniques used in HEC-HMS models are standard methods widely used in hydrologic modeling. Hydrologic channel routing on all channel reaches was performed using the Muskingum-Cunge method. This routing technique is a finite-difference scheme based on physical channel properties and the inflow hydrograph opposed to the somewhat arbitrary, empirical approach used for estimating parameters in the Muskingum method. The Muskingum-Cunge method is a widely used routing technique because of its applicability to a wide range of channel and hydrograph conditions.

To route hydrographs using the Muskingum-Cunge method, the HEC-HMS model requires reach length, slope, Manning's "n" value, and a few general dimension of cross section shape. Reach length and slope were taken from measurements from the topographic maps in a GIS. Manning's roughness values were determined from channel characteristics. The cross section shape parameters were taken from the channel surveys.

2.1.8 Calibration

Typically a hydrologic model is calibrated by comparing computed peak flows and their timing at key locations in a watershed with gage data collected at these same locations. When gage data are not available, an alternate calibration technique is to compare flows from the hydrologic model to predictions from regional regression equations.

Morgan Creek is the only modeled stream in the study area upon which a flow gage is operated. The USGS maintains the gage at the crossing of NC Highway 54 (gage number 02097464) that has been in operation since 1989. Therefore, the gage record was used to determine various recurrence interval discharges using the procedures outlined in Bulletin 17B (HSIAC, 1981). Since no flow gages are managed by either the USGS or the United States Department of Agriculture's (USDA) Agriculture Research Service (ARS) on the remaining modeled streams, these HEC-HMS models could not be calibrated to actual flow data. The most recent regional regression equations were employed to provide general comparisons at selected locations. For the bankfull flow, regional regression equations for rural watersheds (Harman et al., 1999) and urban watersheds (Doll et al., 2002) have been developed for the Piedmont Region of North Carolina. For larger return frequency storms (e.g., 2-year and 5-year), Pope, Tasker, and Robbins (2001) developed equations for rural basins and Robbins and Pope (1996) developed equations for urbanized basins across the Piedmont.

The HEC-HMS model for Morgan Creek was calibrated differently than the remainder of the modeled streams since gage data was available. For Morgan Creek, a stable reach located just upstream of the NC-54 crossing was used to characterize the channel forming flow. As the reach was not incised, it was assumed that the power exerted by flood flows on the channel boundary do not increase considerably as flows exceed the channel capacity and access the overbank areas. Therefore, total precipitation storm depths were decreased in the model from the 2-year 24-hour amount of 3.6 inches until the flow just filled the channel to the top of the banks. When the total storm depth was reduced to 3.2 inches, the discharge at the reach of interest filled the channel just to the top of the banks. Based on the USGS gauging record for Morgan Creek, it was determined that the 3.2 inch rainfall event correlated with the 1.5 year recurrence interval flow. This value fits in the 1 – 2 year range for bankfull flows identified by Williams (1978) and matches well with Dunne and Leopold's (1978) value of 1.5 years based on a nationwide analysis of streams. Without sediment monitoring data for Morgan Creek, the 1.5-year recurrence interval flow simulated the bankfull flow, which was assumed to represent the channel forming flow. The stability modeling was performed at the channel forming flow as it is considered to perform the most work, where work is measured in terms of sediment transport, on the channel over an extended period. Thus, the channel forming flow is taken to have the most influence of whether the channel is incising, aggrading, widening, etc., which directly affects the quality of instream habitat and the abundance and diversity of biological communities.

The HEC-HMS models for the remaining modeled streams were calibrated to the bankfull regional regression equation estimates using the 3.2-inch precipitation event determined for Morgan Creek. The research by both Harman et al. (1999) and Doll et al. (2002) for North Carolina Piedmont watersheds placed the bankfull flow return interval at about 1.4 years, which closely matches the value determined for Morgan Creek. Conditions within the modeled subwatersheds were consistent with the constraints outlined in each of the regional regression papers with regard to subbasin area and percent impervious area. The rural equations were developed for watersheds with less than 20 percent impervious cover and the urban equations are suitable for basins with impervious cover between 17 and 80 percent of the subbasin area. The regression equations have an approximate range of ± 40 percent for the standard error of prediction. While the regression methodology is not exact, if the HEC-HMS predicted discharge was within 20 percent of the regression estimate (approximately half of the allowable error), the model was considered calibrated. If the HEC-HMS model did not generate a discharge that fell within the ± 20 percent, potential adjustments were considered and evaluated.

As an additional check, the top of the channel banks was identified at each cross section surveyed during field visits. Using the calibrated watershed models, the resulting discharges could be modeled hydraulically to predict water surface elevations. The hydraulic model serves as a check of the to ensure that the predicted water surface elevation agreed with the field observed indicators of the top of the channel banks.

After calibrating the hydrologic models for the existing landuse, the landuse scenarios was changed to reflect future scenarios. The working assumption for the future landuse scenarios is that the discharge magnitudes are representative of future conditions since the model was calibrated for existing conditions. This allows the hydrologic impacts associated with future land cover conversions to be compared to each other and to the existing conditions.

2.2 HYDRAULIC MODELING

The study reaches selected for stability analyses were limited to those that had available cross section geometry. The US Army Corps of Engineers River Analysis System HEC-RAS (USACE, 2003b) was selected to perform the hydraulic modeling. The foundations of the hydraulic models for both creeks were taken from the HEC-2 framework established as part of the Federal Emergency Management Agency's (FEMA) Flood Insurance Study (FIS) for Bolin Creek, Jones Creek, Morgan Creek, Phils Creek, Neville Creek, and the East and West Branches of Price Creek. HEC-RAS is intended for use in analyzing one-dimensional, steady, gradually varied flow conditions and it is frequently used for open channel stream hydraulic analyses.

The stream hydraulic models were used to predict channel velocity, boundary shear stress, specific stream power, and other hydraulic parameters to evaluate channel stability and develop water surface profiles throughout the study reaches. The flow rates calculated by the HEC-HMS model for the channel forming event were input to the HEC-RAS model to calculate stream stability indicators at each cross section.

The following sections discuss briefly how the HEC-RAS models and associated modeling parameters were developed and applied in the Little Troublesome Creek watershed.

2.2.1 Cross Section Data

Stream cross section data were obtained from field surveys performed by Tetra Tech, Inc. and S&EC, Inc. in the spring of 2003. The cross section data from the surveys provided a detailed summary of the active channel while the floodplain data were supplemented from the Flood Insurance Studies. Only monitoring sites of interest in this study were surveyed, the FIS surveyed cross sections were used to describe the channel between monitoring sites.

2.2.2 Flow Change Locations

The location of flow change points within the hydraulic models directly influence computed water surface elevations. Discharges were generated in the HEC-HMS hydrologic model at each subbasin outlet, at each flow junction, and the outlet of each reach. Flow change points are accordingly placed in the hydraulic model.

2.2.3 Roughness Factors

Manning's "n" values, which are composite roughness descriptors combining components of both form and grain roughness, were taken from the FIS HEC-2 models. The values determined for that study were acceptable for the stream stability modeling.

2.2.4 Boundary Conditions

There are several options for establishing a downstream starting water surface elevation in the HEC-RAS model. Since the flow through the reach is subcritical, a downstream control is required. FEMA specifies hydraulic models used for flood insurance purposes have starting water surface elevations set to normal depth as determined by the slope area method. For this study, the specified downstream control was also set to normal depth. The flow in the lower reaches of the creeks was assumed to be steady and uniform so that the slope for normal depth could be taken as the bed slope of the channel.

2.2.5 Expansion and Contraction

Contraction or expansion of flow due to changes in channel cross section geometry is a common contribution to energy losses within a reach. The coefficients for contraction and expansion are multiplied by the absolute difference in velocity head between cross sections to yield the energy loss caused by the transition. Due to flow separation mechanics, the expansion coefficient is higher than the contraction coefficient. For this study the expansion coefficient was set to 0.4 and the contraction coefficient to 0.2.

2.2.6 Bridges and Culverts

The dimensions of the many bridges and culvert crossing were not surveyed as part of this study; however, they were surveyed as part of the FIS program, so they were included in the HEC-RAS models. The dimensions were checked to ensure no gross errors were apparent and the channel dimensions were updated where survey data indicated an update was prudent.

2.2.7 Calibration

Hydraulic model calibration in the Morgan Creek study area was performed by comparing water surface elevations at channel forming flows to the elevation of the top of the channel banks in stable reaches. If any gross discrepancies were observed between the modeled water surface elevation and the surveyed bank height, the HEC-RAS models were adjusted such that the proper water surface elevation was represented.

3 Nutrient Delivery Model

3.1 Background Information

NCDWQ has listed the Upper New Hope Creek and Morgan Creek arms of Jordan Lake as impaired and is undertaking efforts to develop a TMDL to address nutrient loads and eutrophication in these segments of the lake. Tetra Tech (Tetra Tech, 2003a and b) has developed the Jordan Lake Nutrient Response Model and the Jordan Lake TMDL Watershed Model to evaluate nutrient management scenarios on behalf of NCDWQ and a partnership of NPDES permitees. The nutrient management scenarios address both point and nonpoint sources, and nitrogen as well as phosphorus because the nutrient response model and other assessments have indicated that co-limitation is occurring in the New Hope Creek arm. NCDWQ will use the modeling results to determine the necessary load reductions from each source and how to distribute the required reductions between sources and throughout the watershed.

The NC Environmental Management Commission's Water Quality Committee approved schedule for Jordan Lake TMDL development dictates that NCDWQ is to develop a nutrient management strategy for incorporation into the TMDL to be released as a public notice draft in late 2004. The TMDL is likely to call for some form of reduction in existing non-point source nutrient loads. For these reasons, the *Preliminary Findings Report* set forth as a primary objective for this effort to identify those areas within the LWP study area having the greatest potential to deliver nutrients to Jordan Lake, and to target those areas for management efforts to reduce nutrient loads.

Tetra Tech (2003c) also developed a modeling framework for OWASA to assess eutrophication potential in University Lake, and serve as a guide for management efforts in the watershed. Analysis tools created as part of this effort include an in-lake nutrient response model and a calibrated watershed model for upper Morgan Creek. The most recent conclusions from the University Lake analysis are summarized in Section 3.2 of the main body of the *Detailed Assessment Report*.

3.2 Technical Approach

Tetra Tech drew on recent projects to estimate nutrient loading in the study area for both existing land use and projected buildout land use. Work from the University Lake Planning Model Project conducted for OWASA (Tetra Tech, 2003b) was utilized to estimate nutrient loads in the Upper Morgan Creek subwatersheds. For the Lower Morgan Creek and Little Creek subwatersheds, work from the large-scale Jordan Lake TMDL Watershed Model (Tetra Tech, 2003a) was used as a starting point and refined for the project subwatersheds.

Since all three projects were conducted during the same general time frame, there was considerable overlap in data and methodologies between the projects. However, there were also differences mostly related to spatial scale, which are discussed below. More detailed explanations of modeling assumptions and land use classifications are available in the project reports.

The next step in the analysis was to take the subwatershed loads and estimate the portion of each load delivered to Jordan Lake. The stream transport component of the USGS SPARROW model (Smith et al., 1997) was utilized for this task. SPARROW refers to spatially referenced regressions of contaminant transport on watershed attributes, and was developed based on nationwide USGS NASQAN monitoring of 414 stations. The model empirically estimates the origin and fate of contaminants in streams. The SPARROW tool actually contains two portions, one to generate upland loads and one to account for mass transport through stream reaches. This approach used only the portion of the SPARROW model that estimates transport. Nutrient trapping in University Lake was accounted for separately.

Finally, delivered loads were calibrated using an adjustment factor to match the watershed total nonpoint source loads estimated for the Jordan Lake Project. The loads from the Jordan Lake Project were calibrated to match observed loads estimated using a FLUX analysis.

3.3 Nutrient Loading Model

Nonpoint loading of water and nutrients was simulated using the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) in both the University Lake Project and the Jordan Lake Project. The complexity of this loading function model falls between that of detailed simulation models, which attempt a mechanistic, time-dependent representation of pollutant load generation and transport, and simple export coefficient models, which do not represent temporal variability. GWLF provides a mechanistic, simplified simulation of precipitation-driven runoff and sediment delivery, yet is intended to be applicable as an assessment tool with or without formal calibration. Solids load, runoff, and groundwater seepage can then be used to estimate particulate and dissolved-phase nutrient delivery to a stream, based on concentrations in soil, runoff, and groundwater.

While both projects used GWLF to simulate nutrient loading, they were implemented in a fundamentally different fashion. The University Lake watershed GWLF model was configured and calibrated as a complete watershed model, with delivered loads to University Lake computed and summed on an annual basis. For the Jordan Lake Project, separate GWLF models were developed to simulate unit loads at the field scale for each of the 19 model land uses. Variations in meteorology, soil and geological properties, and other factors were determined for the entire Jordan Lake watershed and compiled into 14 nutrient response zones. Altogether 19 times 14, or 266 models were used. Seasonal and annual TN and TP loading rates for each land use in each nutrient response zone were calculated from model output. The product of these loading rates and land use areas produced total TN and TP loads for each subwatershed which were then coupled to a SPARROW analysis of instream transport to estimate delivered loads (see Section 3.4).

The pollutant loads predicted by the calibrated University Lake GWLF model were used for the Upper Morgan Creek subwatersheds in this project. The subwatersheds were identical between the projects. Simulated loads were averaged on an annual basis for each subwatershed for model years 1991-1999, which corresponded most closely with the model time frame used in the Jordan Lake Project.

The Jordan Lake Project used larger subwatersheds corresponding to 14 digit HUCs, two of which compose the Lower Morgan Creek and Little Creek subwatersheds. The loading rates differ between the two HUCs due to physiographic variations. Jordan Lake Model loading rates were applied to the land use totals in this project to arrive at total TN and TP loads for each subwatershed. TN and TP loads for each model subwatershed under existing and buildout conditions are shown in Table 3-1.

Table 3-1. TN and TP loads for Existing and Buildout Land Use

	Existing Load (lb/yr)		Buildout Load (lb/yr)	
	TN	TP	TN	TP
BL1	10,757	2,001	16,440	2,698
BL2	10,471	1,233	11,720	1,925
BL3	9,723	2,026	14,102	2,230
BL4	22,121	3,907	30,273	4,843
BL5	8,364	1,387	10,650	1,723
BL6	7,042	1,097	9,643	1,566
BL7	3,476	860	6,167	1,000
BL8	9,114	1,504	11,658	1,884
BL9	6,628	1,042	7,731	1,272
BL10	11,497	2,132	15,719	2,519
BL11	5,277	911	6,899	1,115
BL12	3,584	601	5,787	936
BL13	15,149	3,492	36,915	4,889
LM1	22,906	4,027	33,025	5,264
LM2	18,779	2,339	20,886	2,712
LM3	6,769	1,051	10,665	1,699
LM4	10,816	1,364	11,175	1,843
LM5	3,052	513	5,291	854
LM6	16,626	2,429	47,530	3,843
UM1	12,528	1,666	17,739	1,416
UM2	8,194	905	11,271	924
UM3	6,241	687	8,074	640
UM4	18,185	2,039	27,104	1,716
UM5	12,581	1,260	17,203	1,127
UM6	5,304	535	9,531	624
UM7	15,631	1,511	23,531	1,670
UM8	7,361	1,062	8,905	826

Note: Loads for UM1 through UM8 are expressed as load delivered to University Lake. Loads for the other subwatersheds are estimates at the local subwatershed scale, prior to reduction during stream transport.

3.4 NUTRIENT DELIVERY MODEL

The stream transport component of the USGS SPARROW model (Smith et al., 1997) was used to estimate nutrient delivery to Jordan Lake. In SPARROW, nutrient mass reduction during transport is calculated using first order decay equations that are a function of time-of-travel:

$$C_t = C_o \cdot e^{-\delta t}$$

where:

C_o = pollutant mass present at the upstream end of a reach

C_t = pollutant mass present at the downstream end of a reach following travel time *t*

δ = decay rate (1/day)

t = time of travel (days)

Estimates of instream losses during transport were calculated using a modification of the USGS SPARROW methodology. Specification of δ was based on SPARROW national numbers (Smith et al., 1997) with a modification developed by RTI for the Jordan Lake Project to address the observed phenomenon of greater losses in smaller streams, as shown in Table 3-2. The modified approach retains the central tendency of the loss rate for flows below 1000 cfs reported by Smith et al. This method is discussed further in the Jordan Lake TMDL Watershed Model Development Project Report (Tetra Tech, 2003a).

Table 3-2. Default SPARROW and Modified Loss Rates (δ, per day)

Flow Regime	SPARROW (Smith et al., 1997)		Modified	
	Total N	Total P	Total N	Total P
< 1000 cfs	0.3842 (bootstrap) 0.3758 (parametric)	0.2680 (bootstrap) 0.2584 (parametric)	=-0.082·LN(flow) + 0.843	=-.058·LN(flow) + 0.607

SPARROW losses depend on time of travel, which can be calculated from distance and velocity. NCDEM (1984) conducted a study based on 125 velocity studies, and reported a velocity equation with the following form:

$$U\ (ft/s) = 0.124\ Q_{avg}^{\ 0.4}\ S_0^{\ 0.29}$$

where Q_{avg} is the average flow of the segment (cfs) and S_0 is slope in ft/mi. Given the average travel distance and velocity, average travel time can be calculated. The fraction of N and P transmitted is then estimated using the standard SPARROW equations for small streams.

Slopes were estimated by finding the change in elevation across each stream reach length. Stream lengths were found using an RF3 shapefile. Elevations were taken from high resolution GIS contour shapefiles (2 ft or 5 ft contour interval, depending on location), with the exception of a few elevations located near Jordan Lake taken from the 10 m resolution National Elevation Dataset. Flow was estimated using the Jordan Lake Project GWLF model output of unit flows for each land use, summed within each subwatershed. Flows were accumulated additively for connecting subwatersheds to arrive at a final estimate of flow within each subwatershed.

Spillage from University Lake is not gaged, and its use as a water supply further complicates estimating flow. Lower Morgan Creek has a USGS gaging station at the outlet of LM5 with about two decades of data. Average annual flow at the gage was used for the flow in LM5 (44.12 cfs), and flows in the other Lower Morgan subwatersheds were back-calculated using the GWLF flow estimates.

The estimation of flow depends on land use, and buildout land use has a greater proportion of land uses with higher runoff. As a result, buildout delivery ratios differ from existing delivery ratios. Estimated discharge from University Lake under buildout conditions is not known, so we assumed that buildout discharge would be the same as existing discharge (gains in runoff are offset by increases in water consumption). Accumulated flows in the Lower Morgan subwatersheds were forward calculated from the existing flow from UM8 (which was originally back-calculated from the observed flow at LM5).

SPARROW calculations within the Upper Morgan subwatersheds were not performed since the University Lake GWLF model provided *delivered* nutrient loads into University Lake. However, loads delivered through University Lake were reduced by an in-lake delivery ratio, estimated by Tetra Tech using a BATHTUB model (discussed in the University Lake Baseline Analysis Memo). The University Lake delivery ratios (Table 3-3) reflected average delivery for model years 1993-1999. Loads leaving University Lake were then subject to further reductions along the Lower Morgan mainstem using the SPARROW analysis.

Table 3-3. Delivery Ratios to University Lake Outlet Used for University Lake Overflow

	Existing Conditions	Buildout Conditions
TN	0.8261	0.7839
TP	0.4623	0.4644

SPARROW calculations were performed only for mainstem segments (Figure 3-1). Determining an "average" flow path length and slope in headwater subwatersheds would have been arbitrary; there are multiple flow paths, and the point where perennial stream flow begins would vary seasonally. SPARROW parameters and calculated decay rates are shown in Table 3-4 and 0.

Table 3-4. SPARROW Parameters

	Segment Length (mi)	Beg. Elev (ft)	Ending Elev (ft)	Accum. Flow (cfs), Existing Land Use	Accum. Flow (cfs), Buildout Land Use
BL2	1.10	458	436	6.07	7.42
BL3	2.44	436	345	9.27	11.29
BL4	2.27	345	256	15.13	18.26
BL5	0.99	256	246	17.45	20.90
BL9	2.01	412	272	5.08	6.22
BL10	2.05	272	246	10.57	12.76
BL12	0.71	246	242	29.25	35.18
BL13	4.60	242	218	37.22	45.34
LM1	2.91	348	288	33.29	34.80
LM4	2.74	288	246	40.61	43.43
LM5	0.94	246	242	44.12	47.99
LM6	5.62	242	216	53.86	59.14

Table 3-5. Decay Rates

	Existing Land Use Decay Rates		Buildout Land Use Decay Rates	
	TN	TP	TN	TP
BL2	0.695	0.502	0.679	0.491
BL3	0.660	0.478	0.644	0.466
BL4	0.620	0.449	0.605	0.439
BL5	0.609	0.441	0.594	0.431
BL9	0.710	0.513	0.693	0.501
BL10	0.650	0.470	0.634	0.459
BL12	0.566	0.411	0.551	0.400
BL13	0.546	0.397	0.530	0.386
LM1	0.556	0.404	0.552	0.401
LM4	0.539	0.392	0.534	0.388
LM5	0.532	0.387	0.526	0.382
LM6	0.516	0.376	0.508	0.370

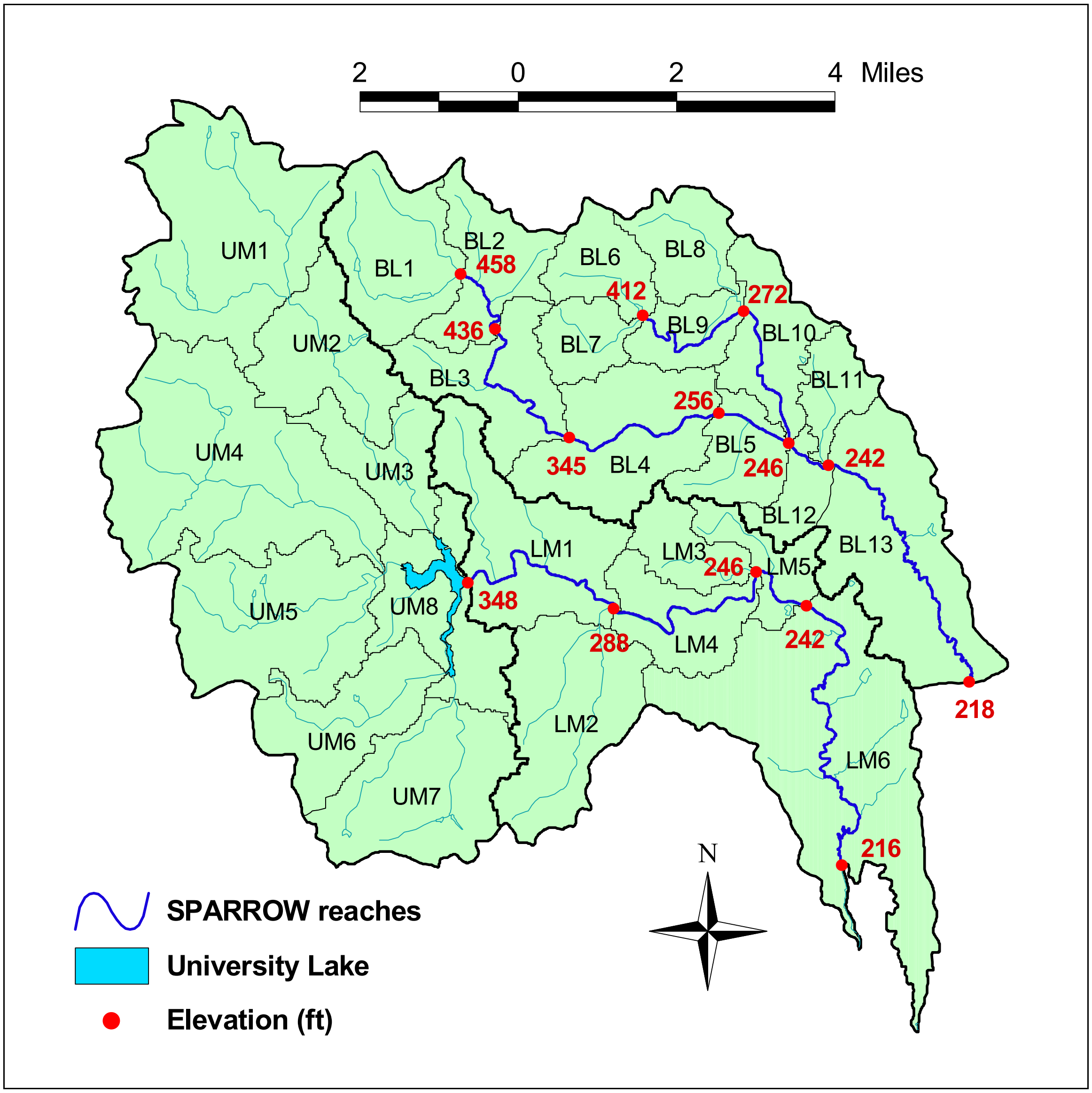

Figure 3-1. SPARROW Reaches

3.5 Results

Nutrient delivery was calculated on a cumulative basis for each subwatershed. Watersheds near the lake had higher deliveries than hydrologically distant watersheds. As an example, BL11 had an overall TN delivery of 0.835 through BL13, while BL8 had an overall TN delivery of 0.716 through BL10, BL12, and BL13. Delivered nutrient loads for each subwatershed were then calculated using the cumulative delivery ratios for both existing land use and buildout land use conditions.

Existing land use condition loads delivered to Jordan Lake were summed across subwatersheds for Little Creek and Morgan Creek. Delivered loads were compared to nonpoint source loads found in the Jordan Lake Project. The Jordan Lake Project loads were calibrated to match observed loads found from a FLUX analysis of loads in the Triangle area. The Jordan Lake Project FLUX analysis concluded that delivered loads from Triangle area creeks were somewhat lower than those calculated from a SPARROW analysis using the modified delivery ratios, so an additional reduction was determined. The reason for the additional nutrient removal is unknown, but one of the most likely reasons is significant retention in the wooded meandering backwater reaches near Jordan Lake.

Not surprisingly, this analysis also estimated higher delivered loads than those found in the Jordan Lake Project. An adjustment factor was used to reduce delivery ratios and thus reduce delivered loads to match the Jordan Lake Project nonpoint loads. Separate factors were used for the Little Creek subwatershed and the Upper/Lower Morgan Creek subwatersheds. In each case the factor was applied equally to each of the subwatersheds. Applying the reduction in this fashion assumes there is some process acting on each of the subwatersheds equally (such as additional reduction in the final reach). The same adjustment factors were then applied to the buildout delivered loads. Final delivery ratios are shown in Table 3-6. Subwatersheds that are more hydrologically distant from Jordan Lake have better nutrient trapping, as shown in Figure 3-2 and Figure 3-3.

Delivery ratios alone are not sufficient to assess the risk of nutrient loading. Delivered loads also do not show the relative contribution to nutrient loading for each of the subwatersheds. However, delivered loads can be combined with subwatershed area to produce loading rates. Loading rates for existing and buildout land use for each subwatershed are shown in Table 3-7 and graphically in Figure 3-4 through Figure 3-7.

Table 3-6. Existing and Buildout Delivery Ratios

	Existing Deliv. Ratios		Buildout Deliv. Ratios	
	TN	TP	TN	TP
BL1	0.5169	0.5167	0.5448	0.5367
BL2	0.5583	0.5464	0.5841	0.5644
BL3	0.6260	0.5935	0.6475	0.6082
BL4	0.6785	0.6292	0.6965	0.6412
BL5	0.7121	0.6516	0.7277	0.6619
BL6	0.5661	0.5520	0.5915	0.5697
BL7	0.5661	0.5520	0.5915	0.5697
BL8	0.6300	0.5963	0.6513	0.6108
BL9	0.6300	0.5963	0.6513	0.6108
BL10	0.7121	0.6516	0.7277	0.6619
BL11	0.7348	0.6666	0.7486	0.6757
BL12	0.7348	0.6666	0.7486	0.6757
BL13	0.8800	0.7600	0.8800	0.7600
LM1	0.6430	0.6447	0.6519	0.6511
LM2	0.6430	0.6447	0.6519	0.6511
LM3	0.6931	0.6808	0.7008	0.6863
LM4	0.6931	0.6808	0.7008	0.6863
LM5	0.7181	0.6986	0.7249	0.7034
LM6	0.8650	0.8000	0.8650	0.8000
UM1	0.4896	0.2809	0.4720	0.2854
UM2	0.4896	0.2809	0.4720	0.2854
UM3	0.4896	0.2809	0.4720	0.2854
UM4	0.4896	0.2809	0.4720	0.2854
UM5	0.4896	0.2809	0.4720	0.2854
UM6	0.4896	0.2809	0.4720	0.2854
UM7	0.4896	0.2809	0.4720	0.2854
UM8	0.4896	0.2809	0.4720	0.2854

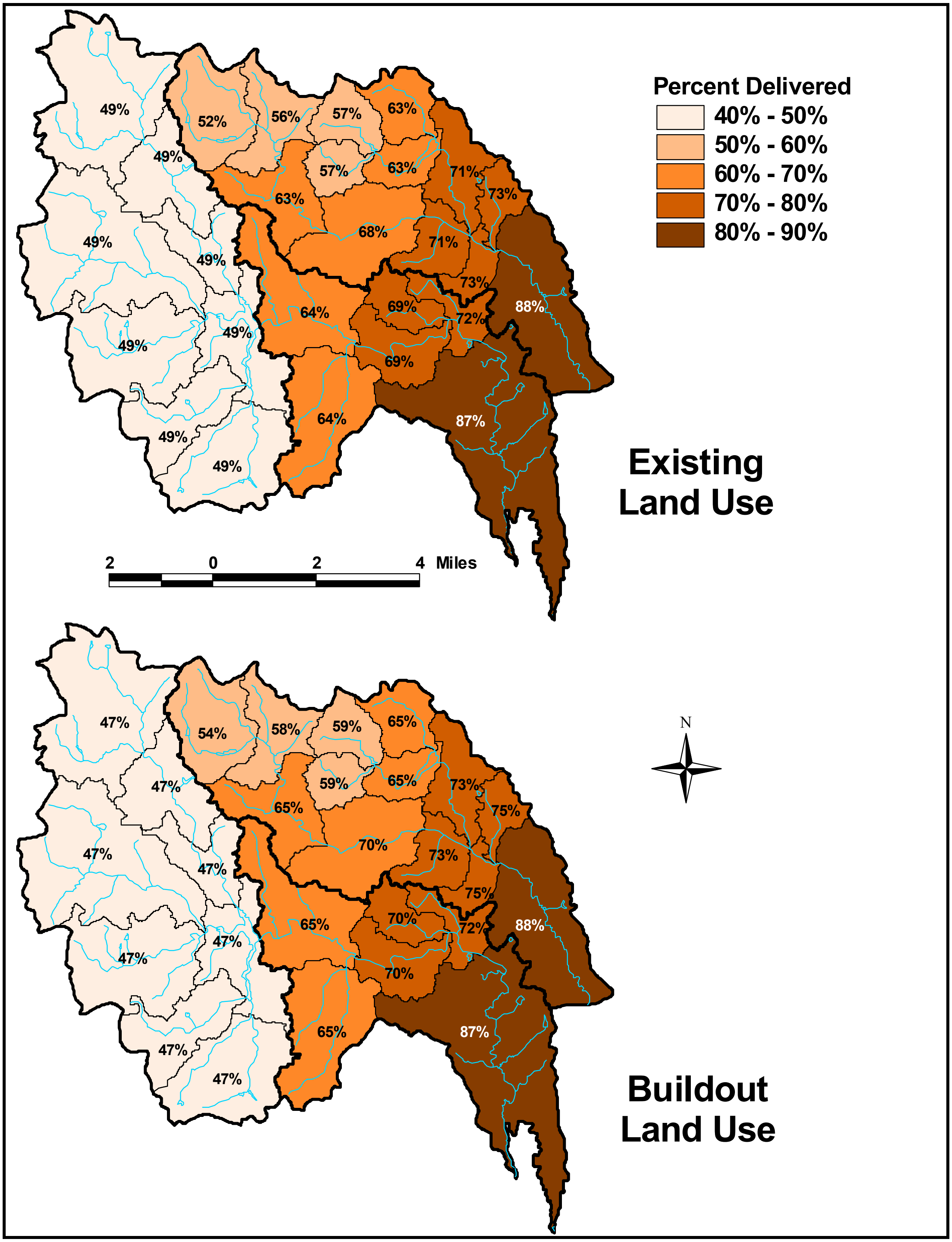

Figure 3-2. TN Delivery Ratios for Existing and Buildout Land Use

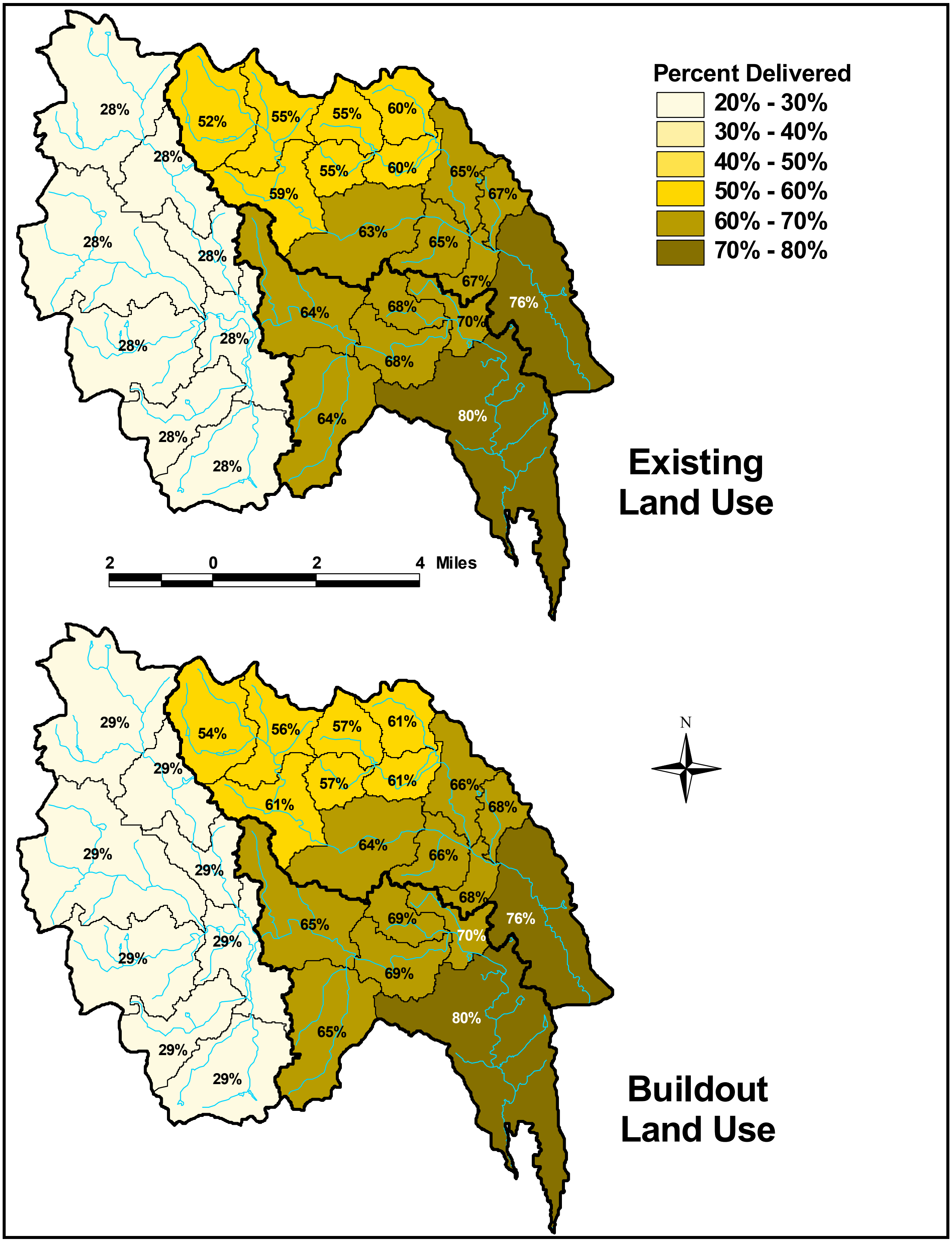

Figure 3-3. TP Delivery Ratios for Existing and Buildout Land Use

Table 3-7. Existing and Buildout Loading Rates

	Existing Loading Rates (lb/ac/yr)		Buildout Loading Rates (lb/ac/yr)	
	TN	TP	TN	TP
BL1	3.08	0.573	4.96	0.803
BL2	4.59	0.529	5.37	0.853
BL3	4.05	0.799	6.07	0.901
BL4	6.84	1.119	9.60	1.414
BL5	6.51	0.988	8.47	1.246
BL6	4.69	0.713	6.71	1.050
BL7	3.01	0.726	5.58	0.871
BL8	6.11	0.955	8.08	1.225
BL9	5.92	0.881	7.14	1.101
BL10	6.79	1.153	9.49	1.383
BL11	6.34	0.994	8.45	1.232
BL12	4.85	0.738	7.97	1.163
BL13	4.35	0.866	10.60	1.212
LM1	6.23	1.098	9.11	1.450
LM2	5.26	0.657	5.93	0.769
LM3	6.32	0.963	10.06	1.570
LM4	6.31	0.782	6.60	1.065
LM5	2.99	0.490	5.24	0.820
LM6	2.82	0.381	8.07	0.604
UM1	1.69	0.129	2.31	0.112
UM2	2.44	0.155	3.24	0.160
UM3	2.82	0.178	3.52	0.169
UM4	2.09	0.135	3.00	0.115
UM5	2.26	0.130	2.98	0.118
UM6	1.64	0.095	2.83	0.112
UM7	3.28	0.182	4.76	0.204
UM8	2.05	0.170	2.40	0.134

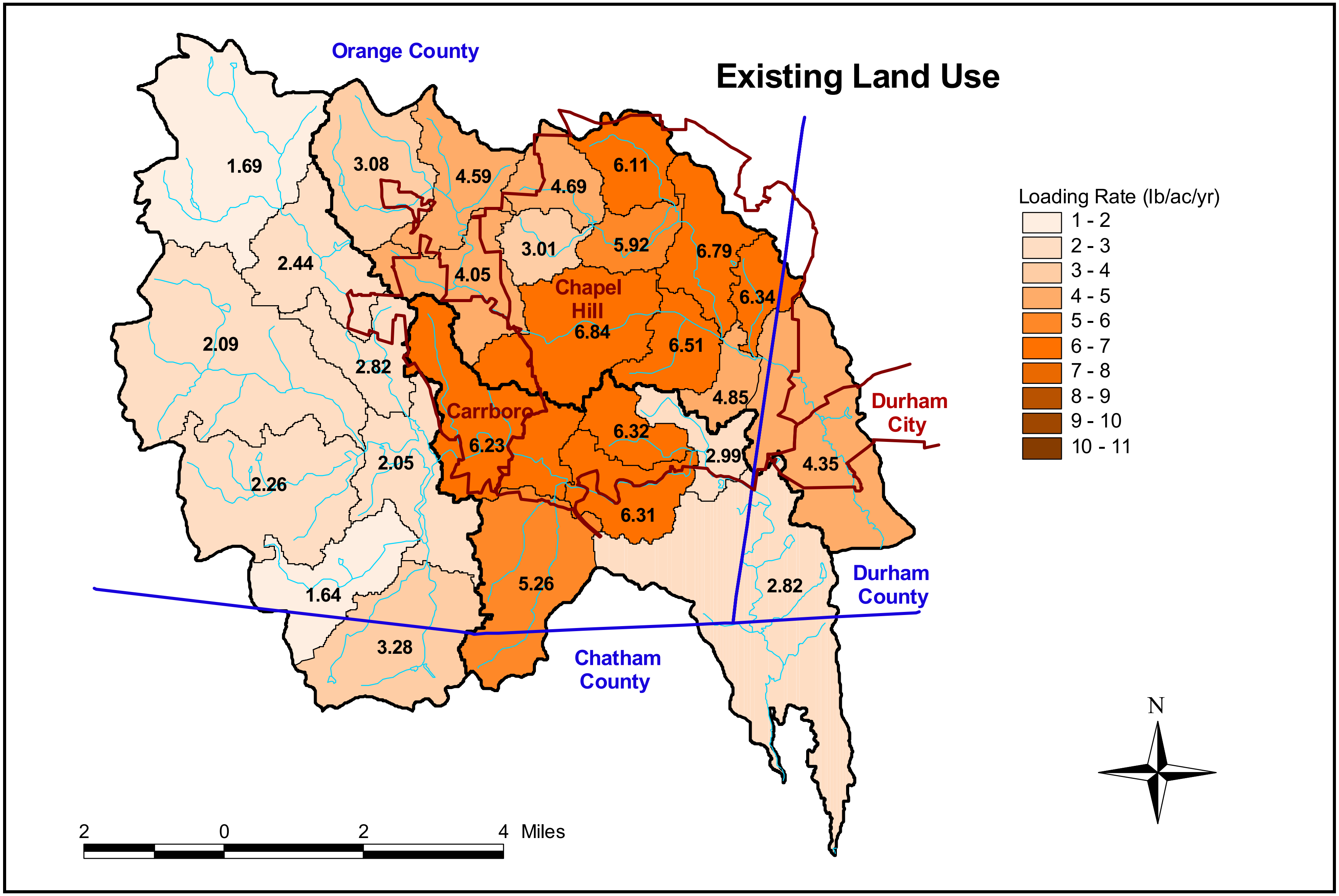

Figure 3-4. TN Exerted Subwatershed Loading Rates for Existing Land Use

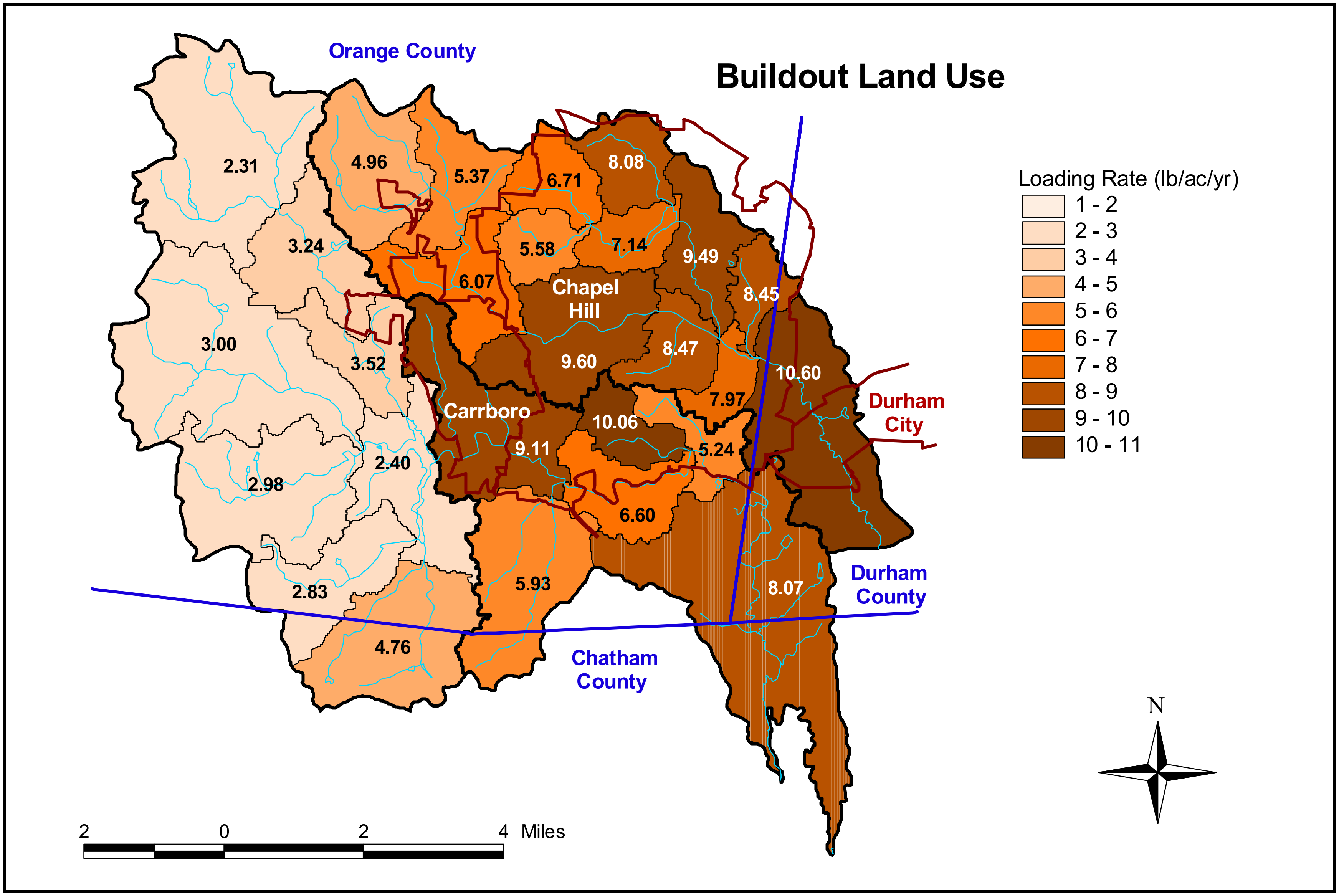

Figure 3-5. TN Exerted Subwatershed Loading Rates for Buildout Land Use

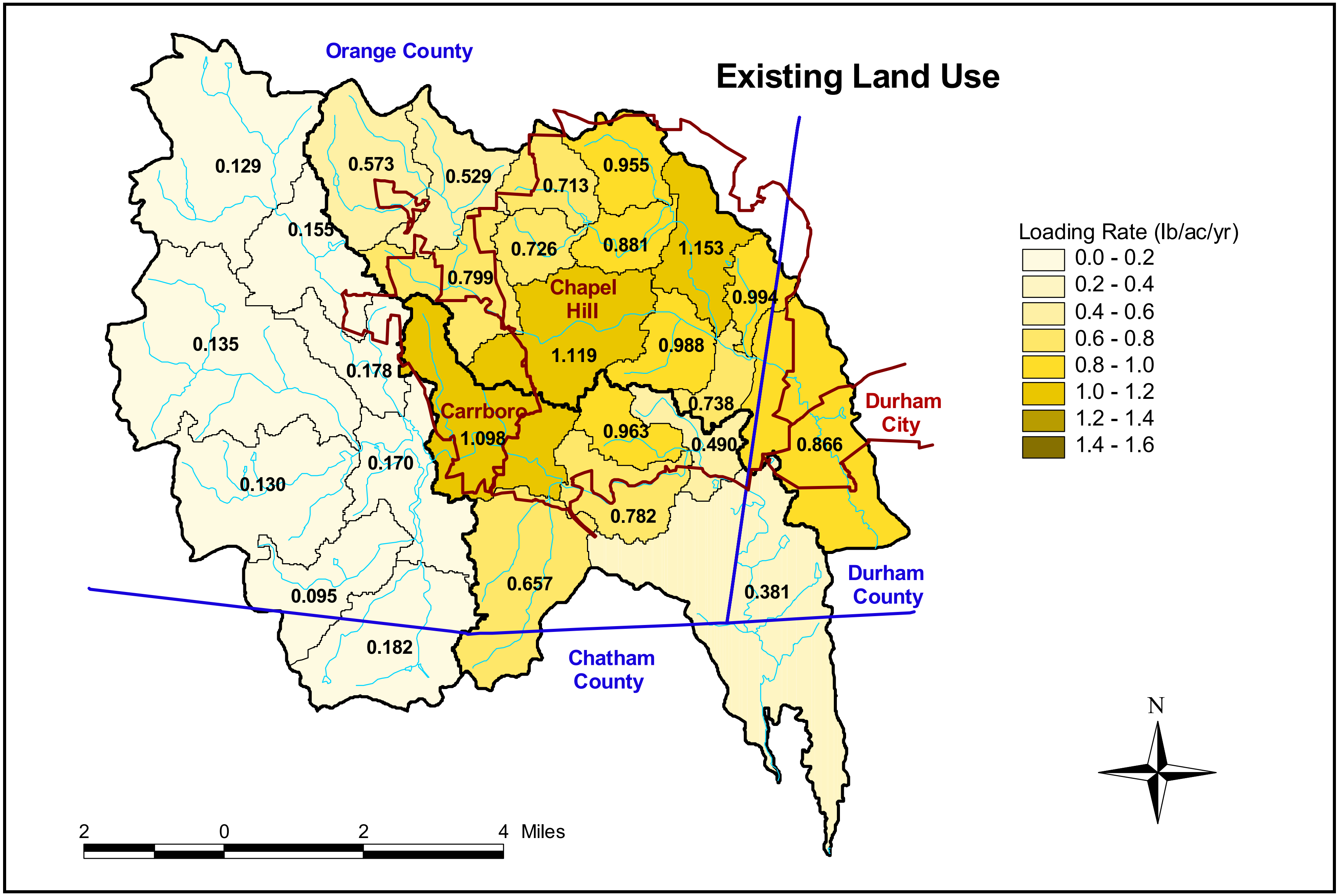

Figure 3-6. TP Exerted Subwatershed Loading Rates for Existing Land Use

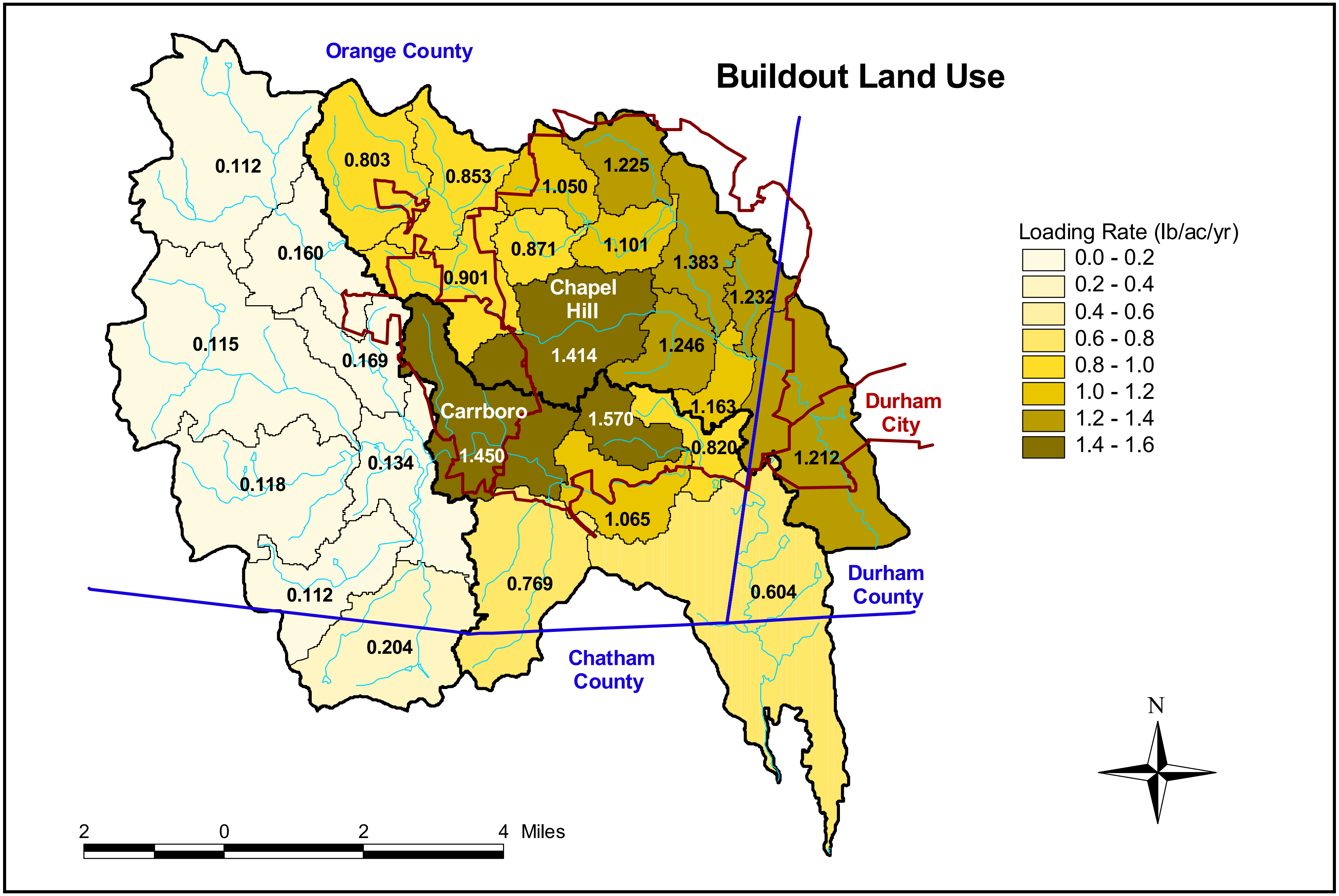

Figure 3-7. TP Exerted Subwatershed Loading Rates for Buildout Land Use

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4 Analysis of Fecal Coliform Sources

4.1 INTRODUCTION

Fecal coliform bacteria are indicators of the presence of disease causing bacteria. These bacteria can enter streams through point sources like wastewater discharges or through non-point sources like runoff from pasture. A variety of sources may contribute to high fecal coliform occurrences in the Morgan Creek study area. Urban sources include household pets, leaking sewer pipes, and sewer overflows, and rural sources include agricultural animals, wildlife, and septic systems. A classification tree analysis indicated that sewer pipe service defects and pipe type were most informative in classifying fecal coliform occurrences. These variables are, however, strongly correlated with watershed imperviousness. The results suggest that ten subwatersheds should be prioritized for more extensive monitoring and assessment.

Fecal coliform is a water quality indicator of concern in the Morgan Creek Study Area. In the Preliminary Findings Report, fecal coliform was the water quality indicator to most frequently exceed its criterion (200 counts/ 100 mL) and, therefore, received the highest score in the Water Quality Stressor Index (Figure 1). The percent of excursions by station and agency are shown in Figure 2, and the numbers in parentheses refer to the locations in Figure 3. Locations 2, 3, 5 and 10 exhibited the highest percentage of excursions (over 65 percent). This data was measured, for the most part, during base flow periods. Fecal Coliform counts may vary greatly during storm flow periods.

Although fecal coliform bacteria are not a direct cause of watershed degradation, the management of fecal coliform could improve the overall health of the Morgan Creek and Little River ecosystems. Not only do high counts of fecal coliform indicate that the public is at risk for infectious diseases, but the major sources of fecal coliform also contribute runoff, sediment, and nutrients to the watershed. The efforts to restore streams or manage pollution may one day coincide with the management of fecal coliform.

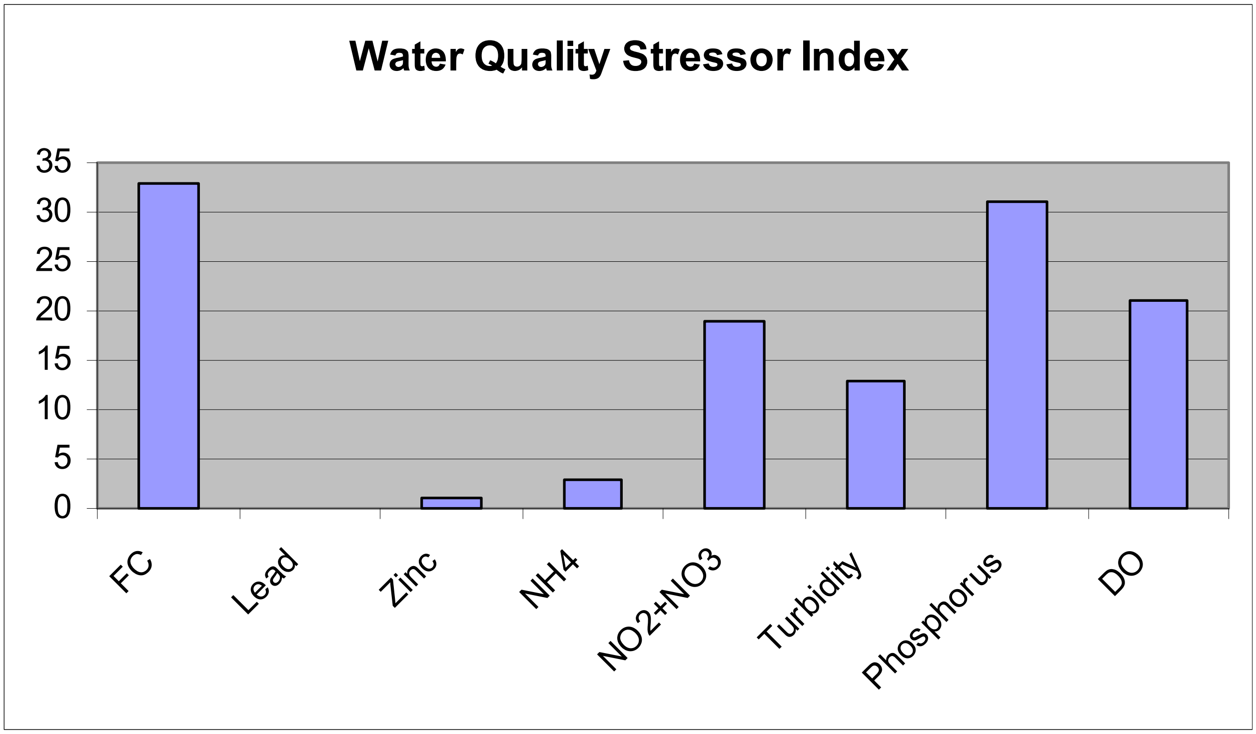

Figure 1. Summary of Scores Relative to Indicators for Water Quality Stressors

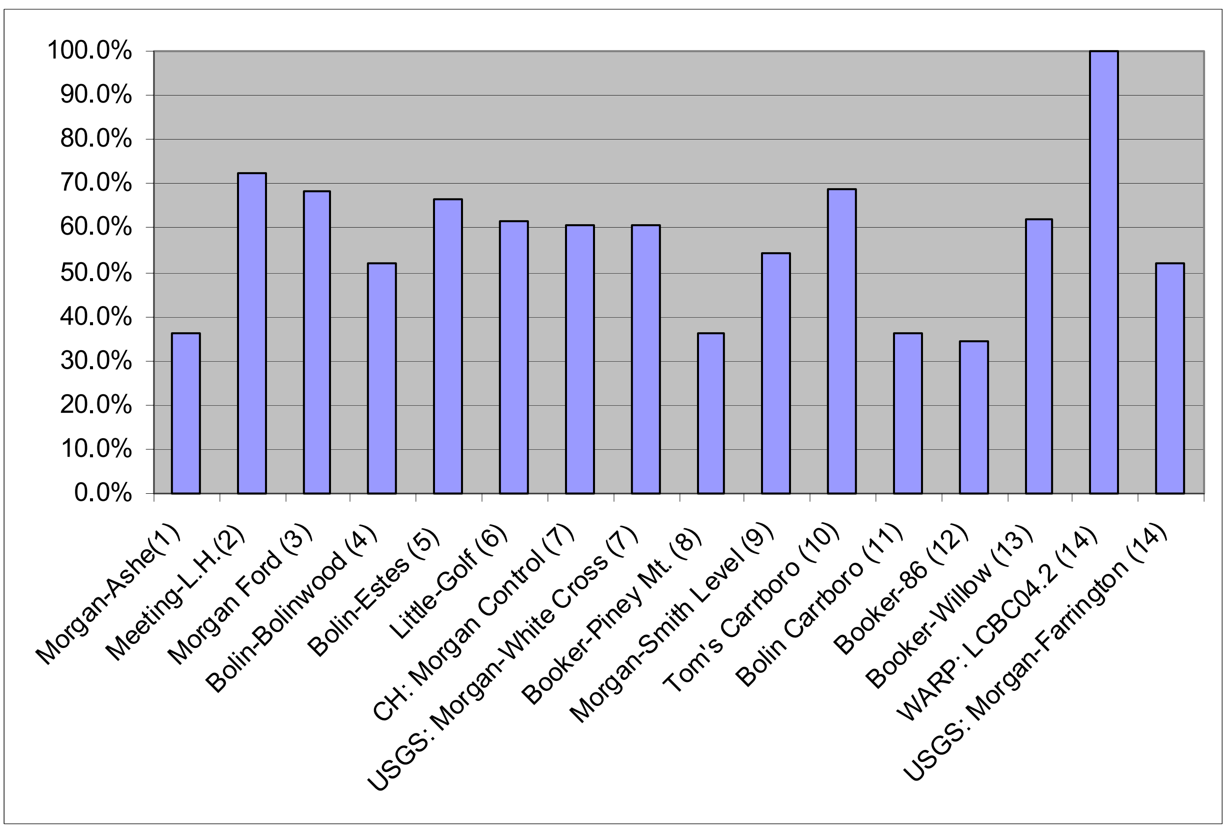

Figure 2. Fecal Coliform Excursions by Station and Agency: % >200 CFU/100ml

4.2 Methods

This analysis classified fecal coliform criterion excursions with a number of explanatory variables. The explanatory variables were based on common sources of fecal coliform including agricultural animals, household pets, sewer pipe defects, septic tanks, and land cover. Table 1 provides a brief description of each variable and organizes the variables by source type. All variables were weighted by subwatershed area. The sewer pipe type and defects variables were acquired from a closed circuit television inspection performed by Brown & Caldwell and CH2MHILL. Structural pipe defects included pipe corrosion, cracks, and other indications of leaks. Service pipe defects included root intrusion, grease buildup, and pipe sags. Structural defects cause exchange of water in and out of the sewer pipes, while service defects restrict the movement of water and cause sewer overflows (Brown & Caldwell and CH2MHILL, 2002).

Fecal Coliform data were available for 14 locations in the Morgan Creek Study area (Figure 3). The data were measured by NCDENR, USGS, and the Town of Chapel Hill. Seven study area subwatersheds were divided so that each station location corresponded approximately to a watershed outlet.

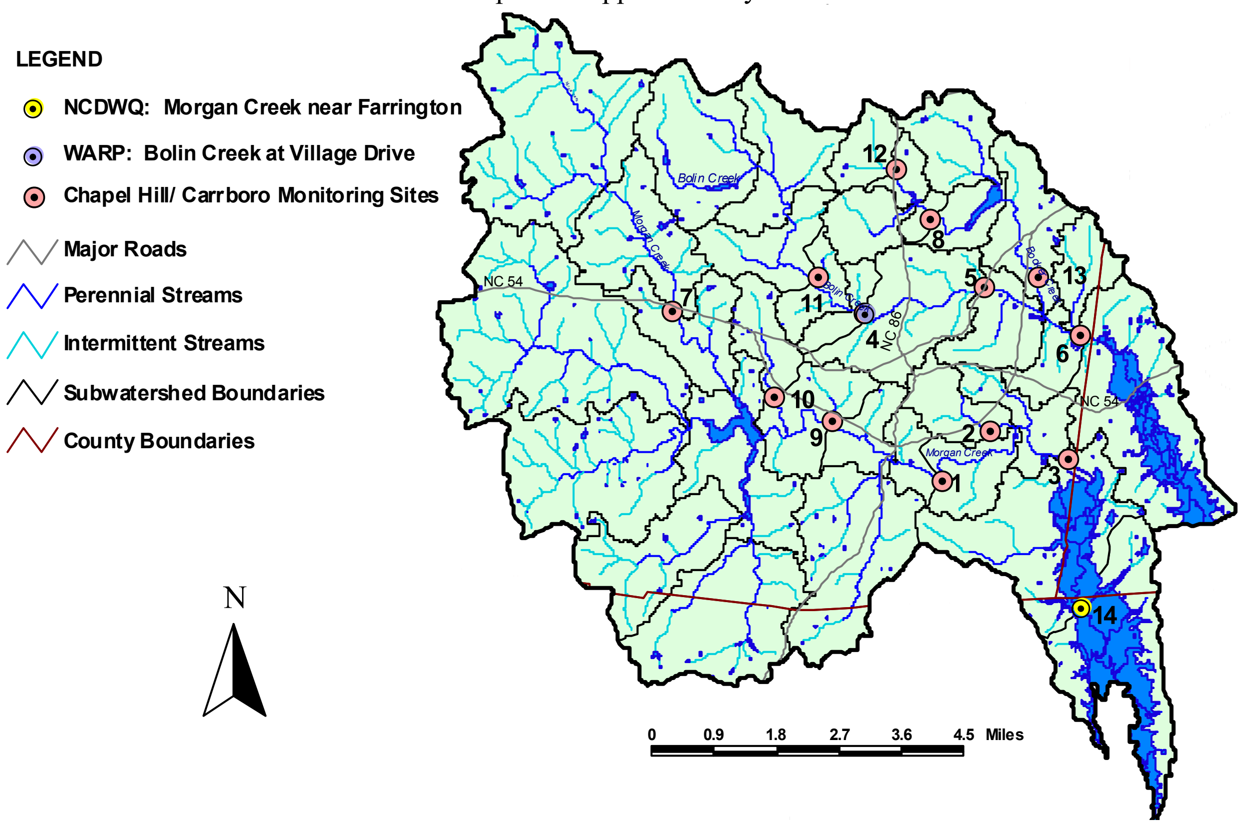

Figure 3. Fecal Coliform monitoring stations in the Morgan Creek Study Area

Table 1. Descriptions of Fecal Coliform Predictor Variables

Variable	Description
Pet Feces	
Households (Hshld)*	Number of non-vacant parcels per acre in residential zoning
Agricultural Animals	
Pasture (MRLC_Pst)*	Percent area in pasture
Land use and disturbance	
LS_Dist*	Percent area disturbed (in field, suburban, or urban landuses)
LS_Buff_Dist	Percent of 100-ft stream buffer area disturbed (in field, suburban, or urban landuses)
LS_Urban	Percent of land in urban landuses
LS_Suburb	Percent of land in suburban landuses
LS_Field	Percent of land in field
LS_Forest	Percent of land in forest
Impervious	Percent area in impervious surfaces
Buildings in the Floodplain	
Build_Q3*	Percent of the floodplain occupied by buildings
Unsewered Parcels	
Unswrd*	Number of non-vacant unsewered parcels per acre
Sewer Pipe Defects	
TPD	Estimated total sewer pipe defects per acre
STPD*	Estimated sewer pipe structural defects per acre
SVPD*	Estimated sewer pipe service defects per acre
DIP*	Miles per acre of Ductile Iron Pipe
Plastic*	Miles per acre of Plastic Pipe (PVC, ESVC, ABS)
VC*	Miles per acre of Clay and Vitrified Clay Pipe
Unknown	Miles per acre of Unknown Pipe Material
Concrete*	Miles per acre of Concrete Pipe
Cast_Iron*	Miles per acre of Cast Iron Pipe

*These variables were used in the final classification trees.

Three watershed scales were used to calculate the explanatory variables. In the first watershed level, the subwatershed values immediately upstream were used. In the second level, the second nearest upstream subwatershed values were aggregated with the first level values. This process was repeated for the third level. If two subwatersheds had nearby outlets, both were included on the same level (Figure 4).

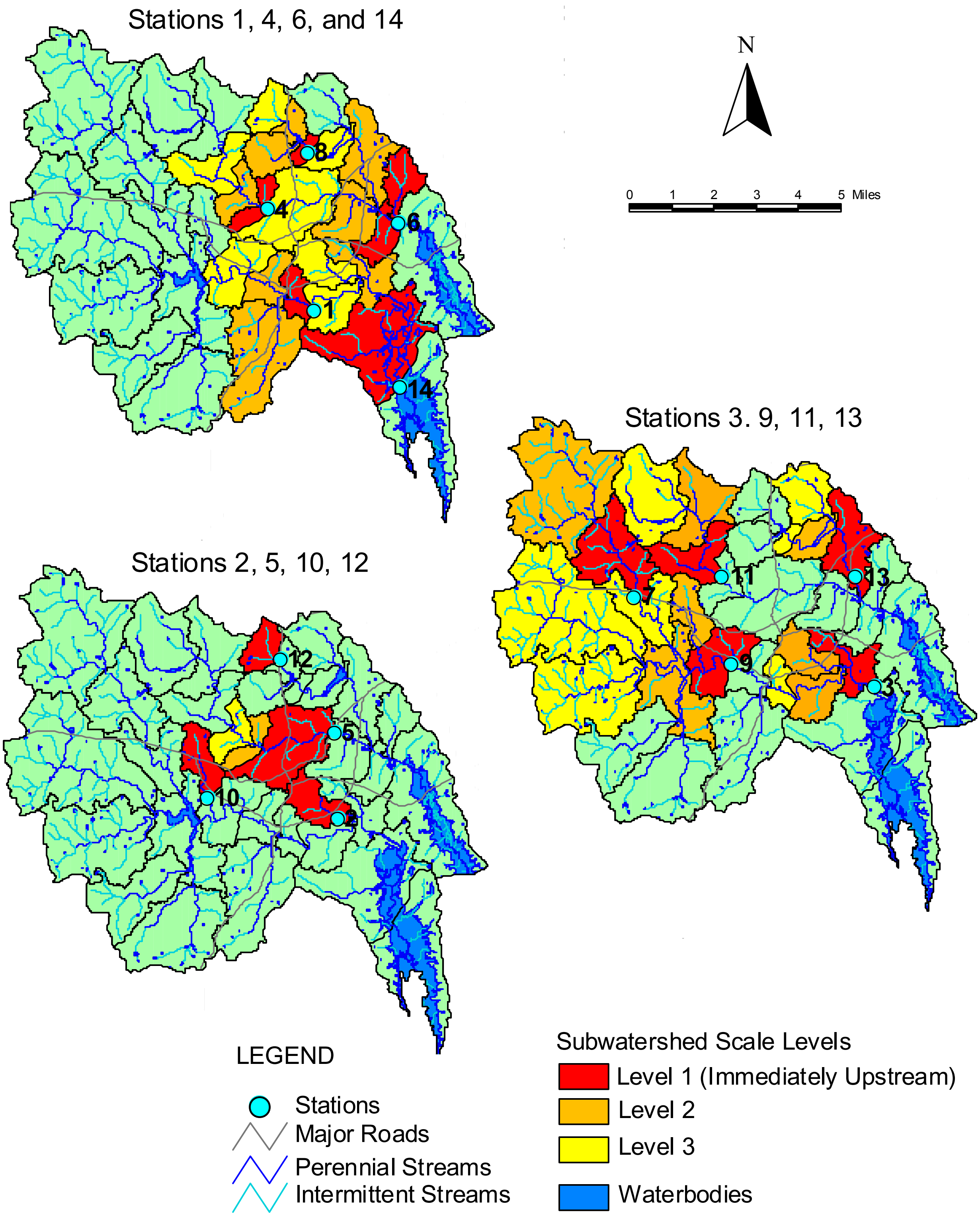

Figure 4. Subwatershed Scale Levels for Fecal Coliform Explanatory Variables

The precision of the classification model may be decreased if correlated variables are entered together. Therefore, a preliminary tree was performed with all of the variables, and then the most important variables within each source type were entered in separate classification trees. In Table 1, asterisks indicate the chosen variables from each source category. Although pipe defects and pipe types represent the same source, these variables were the most successful at classifying excursions in the preliminary analysis. To assess which variable is more successful, final classification trees were performed separately for pipe defects and pipe type.

Variables were also removed if they were highly correlated (r >0.90) with another explanatory variable. For example, impervious surface was highly correlated with pipe defects (r = 0.94). In the preliminary classification tree, pipe defects were most successful at classifying fecal coliform excursions while impervious surface was one of the least successful variables. Pipe defects were retained because they were much more successful than impervious surface in the preliminary classification tree. Disturbed land was less correlated with pipe defects than impervious surface and was chosen to represent landuse as a source of fecal coliform loading.

Two final sets of classification trees were performed, with one tree for each watershed level within a set. One set classified fecal coliform by pipe service defects, pipe structural defects, number of households, area disturbed, floodplain occupied by buildings, and unsewered parcels. The same variables were used in the second set except that the pipe defect variables were replaced with the pipe type variables.

Using FACT-style direct stopping, node splitting was stopped when the number of cases was less than 5% of the total cases or when a perfect classification was reached (meaning no misclassified cases). The classification was based on discriminant, univariate splits for categorical and ordered predictors. Since this method required a categorical dependent variable, the fecal coliform samples were classified into two groups: (1) greater than 200 counts/100mL and (2) less than or equal to 200 counts/100mL. The North Carolina criterion for fecal coliform is a geometric monthly mean of 200 counts/100mL; although geometric means were not used in this analysis, the criterion provides a rough classification of compliance and non-compliance (NCDWQ, 2000).

4.3 Results

Figure 6 and Figure 7 display the final classification trees for the first watershed level (see Legend in Figure 5). The success of a classification tree can be measured by the misclassification cost, which is the percent of cases that were classified incorrectly. The classification trees across the three subwatershed levels had misclassification costs of about 0.37 (Table 2). The misclassification costs indicate that at least 60 percent of the cases were classified correctly. Since the success of the classification did not change appreciably between watershed levels, all watershed levels should be considered as informative.

Table 2. Misclassification Costs for Fecal Coliform Classification Trees

Watershed Level	Pipe Defects	Pipe Type
1	0.365	0.369
2	0.365	0.369
3	0.371	0.371

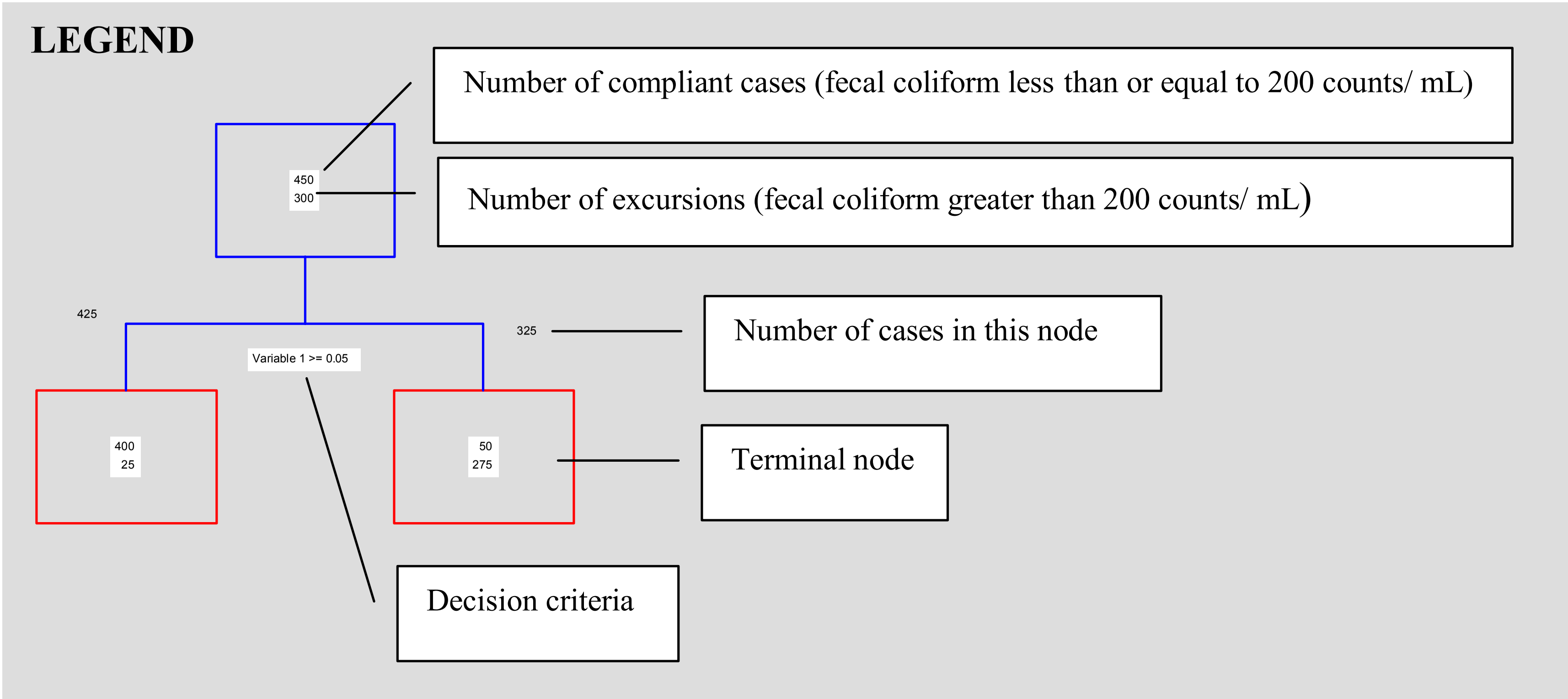

Figure 5. Legend for the Classification Tree Diagrams

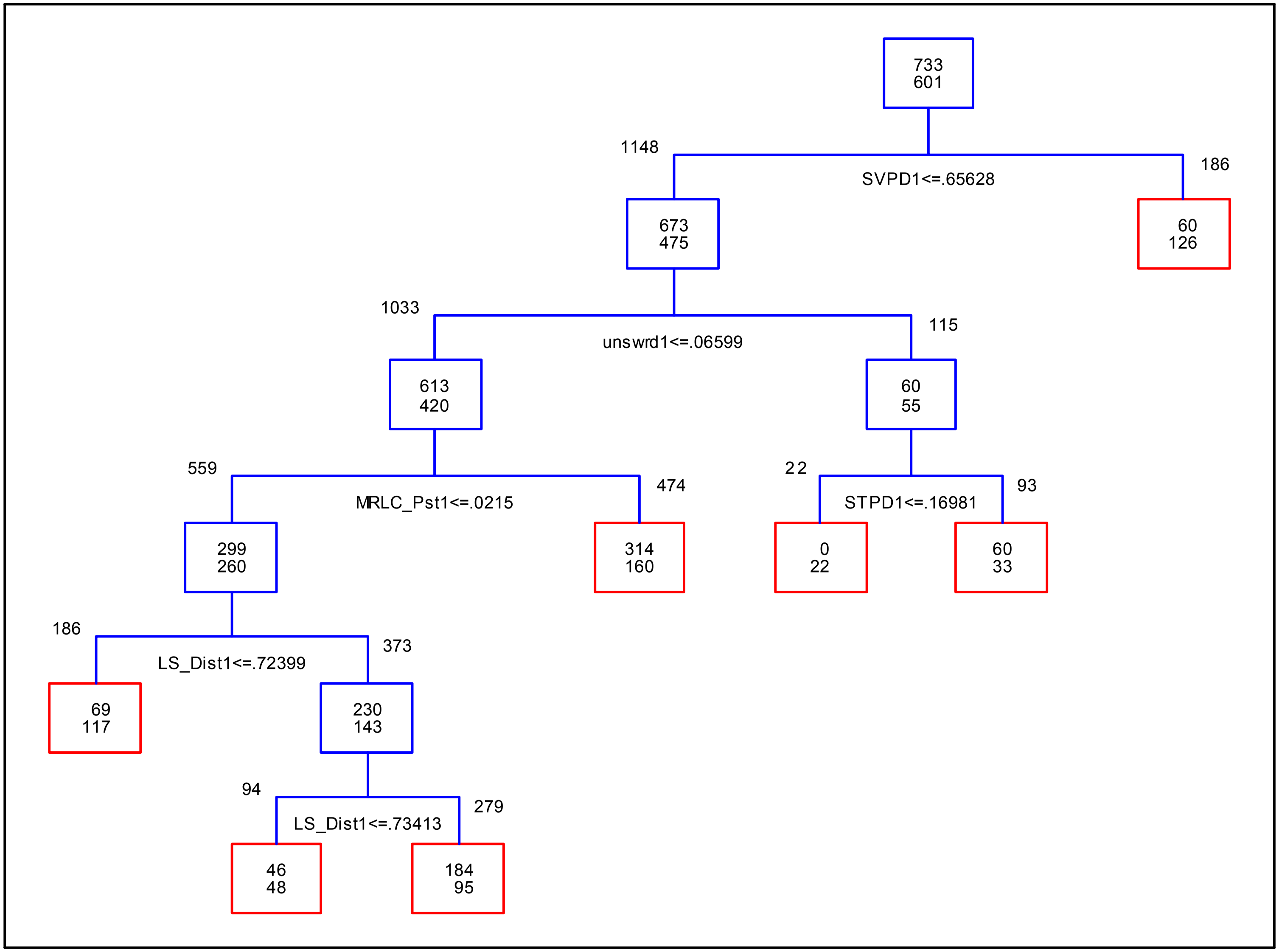

Figure 6. Classification Tree Diagram for the Pipe Defects set and Watershed Level 1

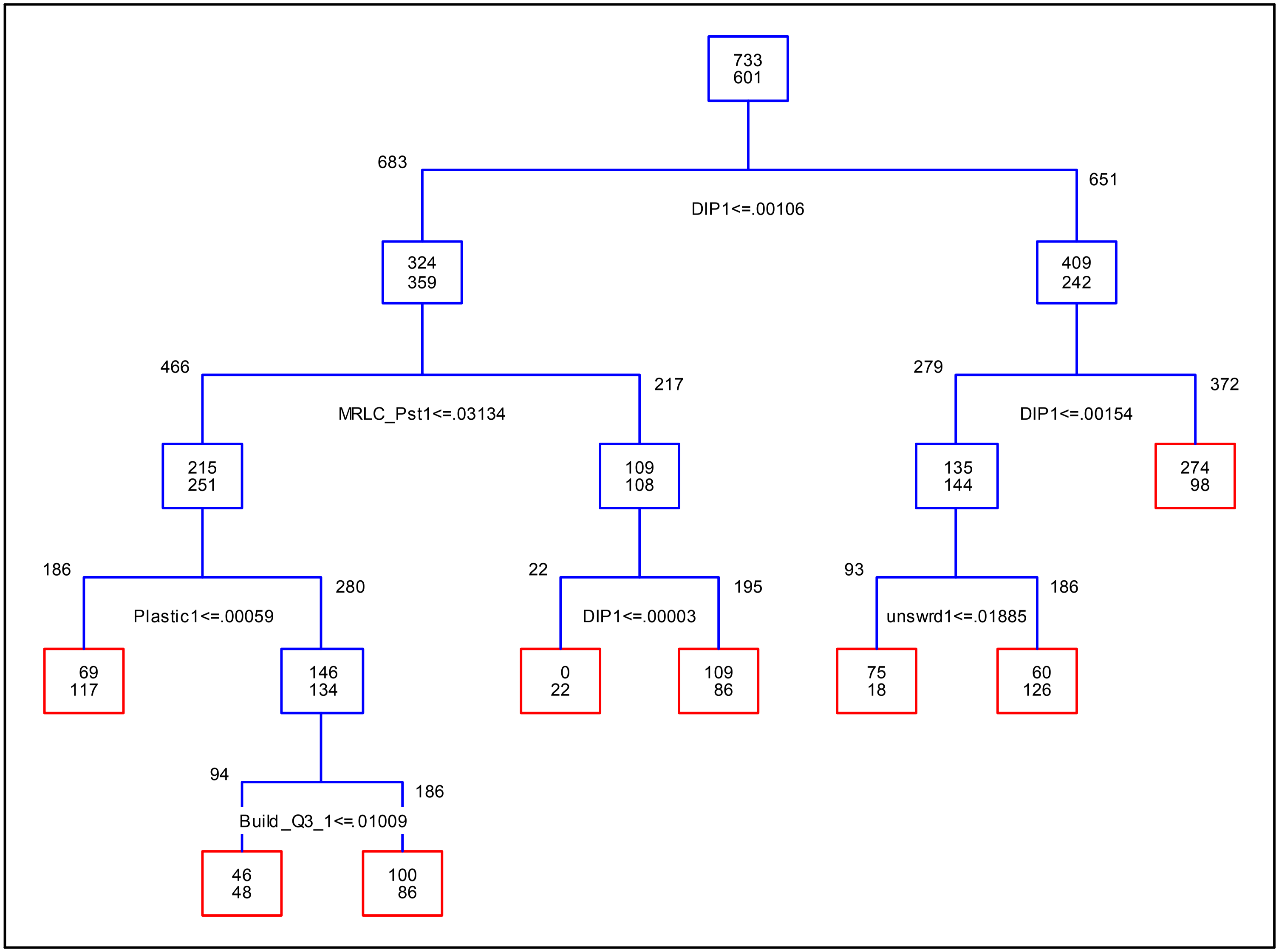

Figure 7. Classification Tree Diagram for the Pipe Type set and Watershed Level 1

The higher a variable is on the classification trees, the more successful it is in classifying fecal coliform criterion excursions. Sewer pipe service defects and pipe type consistently appeared at the top of the classification trees. The most important pipe types were ductile iron pipe (DIP) and cast iron pipe (CIP). High fecal coliform was classified with high proportions of cast iron pipe, while low fecal coliform was classified with high proportions of ductile iron pipe. This classification makes sense because cast iron pipe had a large number of service defects (580 per mile) while ductile iron pipe had very few service defects (15 per mile; Brown & Caldwell and CH2MHILL, 2002). Unsewered parcels, percent pasture, and buildings in the floodplain appeared at least once on the second tiers of the classification trees. Land disturbance, number of households, and structural pipe defects were least important in classifying fecal coliform occurrences.

Classification trees do not demonstrate a causal relationship but do suggest which variables are most strongly associated with high concentrations of fecal coliform. This analysis should be used to target potential sources for more extensive monitoring. According to the results, further study should target subwatersheds with high sewer pipe service defects, high proportions of cast iron sewer pipe, and low proportions of ductile iron sewer pipe. Figure 8 displays the subwatersheds that were prioritized by the classification trees. Further monitoring will be required to assess the source likelihood in subwatersheds with insufficient monitoring data.

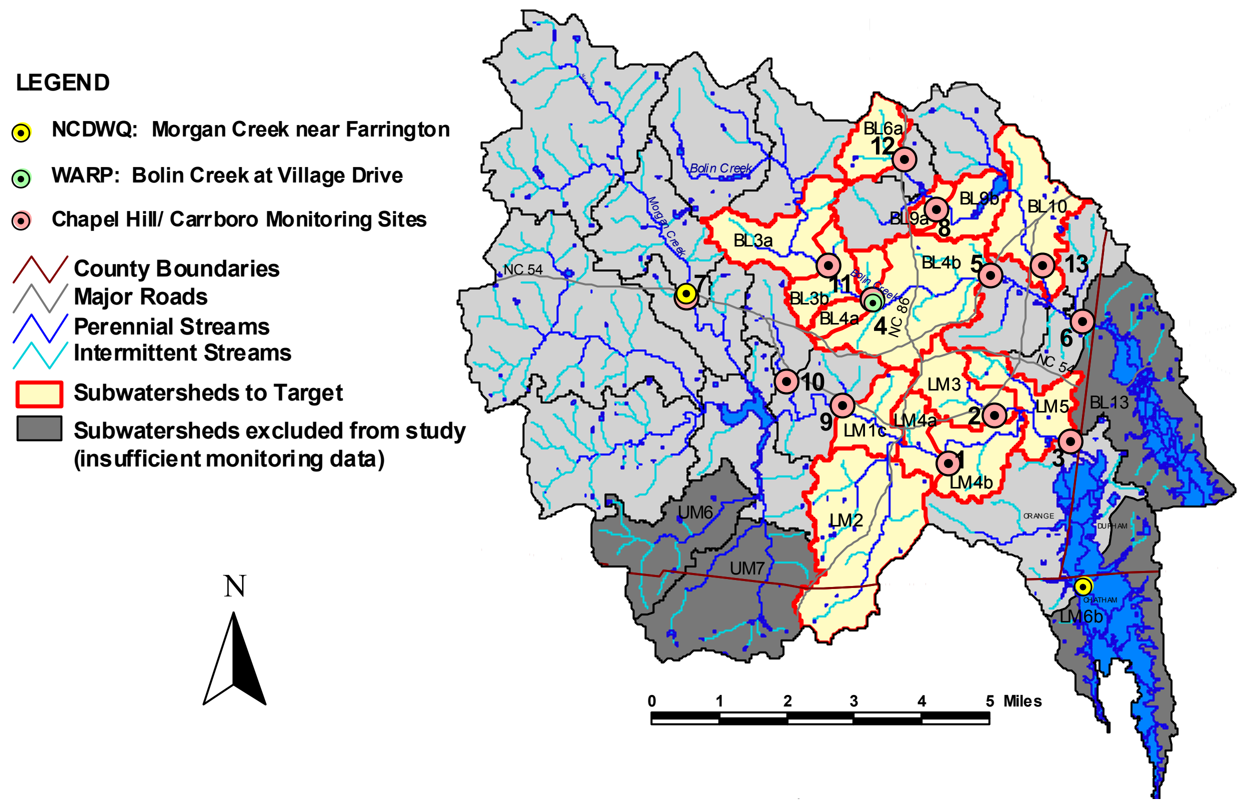

Figure 8. Subwatersheds Indicated as Targets by Fecal Coliform Classification Trees

5 Visual Assessment of Stream Conditions

A preliminary review of the Morgan Creek study area revealed that hydrologic modeling would not be prudent for all streams. For portions of Chapel Hill and Carrboro where stormwater management ordinances are in place that limit the volume and rate of stormwater runoff from post-construction conditions to pre-development conditions, stream hydrology under the built-out scenario was assumed to be similar to existing hydrology. Therefore, modeling to predict future conditions was deemed unnecessary and was instead replaced with visual assessments of in-situ conditions. Additionally, these visual assessments could be used to calibrate the hydrologic and hydraulic models under existing conditions. The stream visual assessment protocol (SVAP) developed by the US Department of Agriculture (USDA, 1998) was selected to provide a consistent framework for the visual reach assessments.

An example SVAP field data sheet and a condensed list of the parameters evaluated with the protocol are presented in Attachment A. The list of evaluated parameters is condensed form the full SVAP guidance document, which can be found at:

http://www.nrcs.usda.gov/technical/ECS/aquatic/svapfnl.pdf

The scores for the individual parameters evaluated at each site in the Morgan creek LWP study area are listed in Table B-1. Parameters without a score were not evaluated at a particular site because they were not appropriate. The SVAP Ranking column is calculated as the average of the evaluated parameters and the SVAP Class is determined based on the ranking as stipulated in the SVAP guidance.

Table B-1. Composite SVAP Scores for Surveyed Sites in the Morgan Creek Study Area

Stream	Approximate Location	Date Surveyed	Crew	Channel Condition	Hydrologic Alteration	Riparian Zone	Bank Stability	Water Appear	Nutrient Enrich	Fish Cover	Pools	Invert. Habitat	Canopy Cover	Riffle Embedd	Total Score	SVAP Ranking	SVAP Class
Cedar Fork	Silo Road	10/14/03	JB/RB	8	7	5	6	7	7	6	7	7	6	8	74	6.73	Fair
Cedar Fork	Kenmore Rd	10/14/03	JB/RB	9	9	9	9	8	7	8	3	8	8	9	87	7.91	Good
Crow Branch	Near Booker Ck	09/04/03	JB/RB	9	9	7	8	9	8	6	7	7	7	8	85	7.73	Good
Booker Creek	Dixie Drive	10/14/03	JB/RB	7	9	5	9	8	6	7	7	7	5	8	78	7.09	Fair
Booker Creek	Piney Mountain	09/04/03	JB/RB	9	9	9	8	7	8	7	8	8	8	8	89	8.09	Good
Booker Creek	Concordia Court	09/04/03	JB/RB	9	9	7	9	7	8	6	7	8	7	8	85	7.73	Good
Booker Creek	US Franklin St	09/04/03	JB/RB	5	7	7	5	8	7	5	7	6	6	6	69	6.27	Fair
Booker Creek	Longleaf Drive	10/14/03	JB/RB	3	7	5	5	8	8	3	3	4	6		52	5.20	Poor
Jones Creek	US Bolin Ck	01/13/04	JD/DP	2	5	9	2	7	8	2	2	7	5	2	51	4.64	Poor
Bolin Creek	US Jones Ck	01/13/04	JD/DP	5	5	9	3	5	7	3	3	8	6	2	56	5.09	Poor
Bolin Creek	Camden Lane	01/13/04	JD/DP	7	5	9	5	8	9	5	4	10	9	9	80	7.27	Fair
Bolin Creek	DS CHHS	01/13/04	JD/DP	9	10	10	9	7	7	7	6	9	10	7	91	8.27	Good
Bolin Creek	Railroad	01/13/04	JD/DP	10	10	9	10	7	7	8	7	10	7	10	95	8.64	Good
Bolin Creek	Greenway	01/13/04	JD/DP	8	9	9	8	7	6	5	6	8	7	8	81	7.36	Fair
Bolin Creek	Village Green	01/13/04	JD/DP	2	5	9	3	7	7	10	9	10	7	5	74	6.73	Fair
Bolin Creek	Cleland Road	01/13/04	JD/DP	1	9	7	8	3	3	5	5	5	7		53	5.30	Poor
UT Little Ck	Pinehurst Dr	10/14/03	JB/RB	2	2	4	10	5	8	3	1	2	2		39	3.90	Poor
UT Little Ck	Lancaster Rd	10/14/03	JB/RB	4	8	6	9	4		5	6	4	6		52	5.78	Poor
Little Creek	Pinehurst Dr	10/14/03	JB/RB	6	6	4	5	9	6	6	7	5	3		57	5.70	Poor
Little Creek	DS Golf Course	10/14/03	JB/RB	8	8	8	6	6	7	7	8	5	5		68	6.80	Fair

Stream	Approximate Location	Date Surveyed	Crew	Channel Condition	Hydrologic Alteration	Riparian Zone	Bank Stability	Water Appear	Nutrient Enrich	Fish Cover	Pools	Invert. Habitat	Canopy Cover	Riffle Embedd	Total Score	SVAP Ranking	SVAP Class
UT Little Ck	Simerville Road	10/14/03	JB/RB	7	6	6	4	4		6	4	5	6		48	5.33	Poor
UT Little Ck	Burning Tree	10/14/03	JB/RB	2	6	6	6	7	7	2	1	2	8		47	4.70	Poor
Chapel Creek	Fordham Rd	09/04/03	ALL	5	7	4	5	9	8	5	5	7	2		57	5.70	Poor
Chapel Creek	Old Mason Farm	09/04/03	ALL	7	9	5	6	7	9	5	7	5			60	6.67	Fair
MOTW	Eringhaus Dorm	11/05/03	JD/DP	10	10	10	10	8	9	5	5	9	9	5	90	8.18	Good
MOTW	Bot. Gardens	11/05/03	JD/DP	8	6	8	6	9	9	6	9	10	8	3	82	7.45	Fair
Morgan Creek	Ashe Place	11/05/03	JD/DP	10	6	8	10	10	9	5	10	10	7	9	94	8.55	Good
Buck Branch	Aqueduct Ctr.	09/04/03	PS/JD	8	8	4	8	9	8	8	7	9	6		75	7.50	Good
Wilson Creek	DS Wave Road	09/05/03	DP/LT	8	9	8	10	7	7	5	8	6	1		69	6.90	Fair
Wilson Creek	US Fan Branch	09/04/03	DP/LT	4	3	1	8	8	9	3	8	4	7		55	5.50	Poor
Fan Branch	US Elem School	09/05/03	DP/LT	9	8	9	7	8	9	8	8	9	8		83	8.30	Good
Fan Branch	US Wilson Ck	09/04/03	DP/LT	9	9	10	8	8	7	7	6	9	4	4	81	7.36	Fair
Morgan Creek	Braswell Road	11/05/03	JD/DP	8	6	7	8	8	9	6	8	10	6	8	84	7.64	Good
Toms Creek	Main Street	09/05/03	PS/JD	2	3	4	3	6	7	3	3	3	4		38	3.80	Poor
Toms Creek	OWASA	09/05/03	PS/JD	4	6	7	3	7	7	9	9	7	6	5	70	6.36	Fair
E Price Mill	Rosswood Ct	11/05/03	JD/DP	7	7	8	6	8	8	4	4	7	9	3	71	6.45	Fair
E Price Mill	Brandywine Ct	11/05/03	JD/DP	9	8	10	8	9	8	2	2	6	6	1	69	6.27	Fair
W Price Mill	Hubbell Court	11/05/03	JD/DP	7	7	5	5	8	7	2	3	3	3	1	51	4.64	Poor
W Price Mill	Lovingood Lane	11/05/03	JD/DP	9	8	9	8	10	10	6	8	10	5	5	88	8.00	Good
Pritchards Mill	Preston Springs	11/05/03	JD/DP	1	1	8	2	9	10	2	2	5	9	1	50	4.55	Poor
Pritchards Mill	Old School Rd	11/05/03	JD/DP	10	9	9	9	8	8	5	5	7	8	1	79	7.18	Fair
Neville Creek	Stansbury Rd	09/17/03	DP/LT	8	7	5	5	5	8	8	7	8	7	8	76	6.91	Fair

Stream	Approximate Location	Date Surveyed	Crew	Channel Condition	Hydrologic Alteration	Riparian Zone	Bank Stability	Water Appear	Nutrient Enrich	Fish Cover	Pools	Invert. Habitat	Canopy Cover	Riffle Embedd	Total Score	SVAP Ranking	SVAP Class
Neville Creek	US Phils Creek	09/05/03	DP/LT	9	8	9	6	8	7	9	9	9	5	10	89	8.09	Good
Phils Creek	NC-54	09/17/03	DP/LT	9	9	9	8	8	5	8	6	5	9	6	82	7.45	Fair
Phils Creek	Neville Rd	09/17/03	DP/LT	8	8	9	6	8	8	8	9	9	7	2	82	7.45	Fair
Phils Creek	US Neville Creek	09/05/03	DP/LT	9	9	9	8	7	8	6	9	8	8		81	8.10	Good
Morgan Creek	Turkey Trail	11/05/03	JD/DP	8	6	10	5	8	6	8	10	10	8	8	87	7.91	Good
Morgan Creek	NC-54	09/05/03	PS/JD	9	10	9	9	8	8	10	8	10	7	10	98	8.91	Good
Morgan Creek	Laurel Springs	09/05/03	PS/JD	8	7	10	7	9	8	10	9	1	10	10	89	8.09	Good
Morgan Creek	Dairyland Rd	09/17/03	JC/JD	7	8	10	7	9	7	5	4	7	10	8	82	7.45	Fair
Morgan Creek	Dairyland Rd	09/17/03	JC/JD	5	4	8	5	6	5	5	4	10	7	4	63	5.73	Poor
Morgan Creek	Maple View	09/17/03	JC/JD	5	5	9	4	7	7	6	8	10	9	4	74	6.73	Fair
UT Morgan Ck	Little Creek Farm	09/17/03	DP/LT	9	9	9	7	5	8	7	5	8	6	8	81	7.36	Fair
UT Morgan Ck	US Morgan Ck	09/17/03	JC/JD	5	4	9	6	9	8	6	4	10	8	9	78	7.09	Fair

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To facilitate the presentation of the SVAP findings, evaluated reaches were grouped by LWP subwatershed into seven subbasins as defined in Table B-2 and illustrated in Figure B-1. To the extent possible, the SVAP subbasins are comprised of groups of LWP subwatersheds reflecting similar stream types and conditions, as well as similar land use conditions. Between five and nine assessment reaches are included in each SVAP subbasin. The Upper Morgan Creek SVAP subbasin contains the portion of Morgan Creek and its tributaries upstream of University Lake. Phils Creek, Neville Creek, and Pritchards Mill Creek are grouped into the University Lake SVAP subbasin. The East and West branches of Price Mill Creek, Fan Branch, and Wilson Creek comprise the Chatham County SVAP subbasin. Toms Creek, Chapel Creek, Buck Creek, Meeting of the Waters, and Morgan Creek downstream of University Lake make up the Lower Morgan Creek SVAP subbasin. Jones Creek and Bolin Creek upstream of the Estes Drive extension crossing constitute the Upper Bolin Creek SVAP subbasin. Crow Branch, Cedar Fork Creek, and Booker Creek are included in the Booker Creek SVAP subbasin. The Lower Bolin Creek SVAP subbasin contains Bolin Creek downstream of the Estes Drive extension crossing, Little Creek, and their tributaries.

Table B-2. SVAP Subwatersheds by LWP Subbasins

Subwatershed	Included LWP Subbasins
Upper Morgan Creek	UM1, UM2, UM3
University Lake	UM4, UM5, UM6
Chatham County	UM7, LM2
Lower Morgan Creek	LM1, LM3, LM4, LM5, LM6
Upper Bolin Creek	BL1, BL2, BL3
Booker Creek	BL6, BL7, BL8, BL9, BL10
Lower Bolin Creek	BL4, BL5, B11, BL12, BL13

Basic statistics (mean, median, and standard deviation) were calculated for the each of the 12 parameters evaluated within each SVAP subbasin. [Note: scores for the Barriers to Fish Movement parameter were scored as a 10 at 53 of the 54 reaches; therefore, this parameter was not considered in further analyses due to its limited discriminatory power.] The statistics were used to categorize each parameter into classes based on the criteria established in the SVAP protocol as shown in Table B-3. The basic statistics were also calculated at the SVAP subbasin scale on all of the values within a given subbasin for a particular parameter. The mean values were used for a relative comparison of parameters within SVAP subbasins. For example, of the 11 parameters evaluated across the 8 reaches in the Upper Morgan Creek subbasin, the parameter with the lowest average value was taken to indicative of the greatest stressor.

Table B-3. SVAP Classes for Average Site/Parameter Scores

Average Score	SVAP Class
< 6.0	Poor
< 7.5	Fair
< 9.0	Good
> = 9.0	Excellent

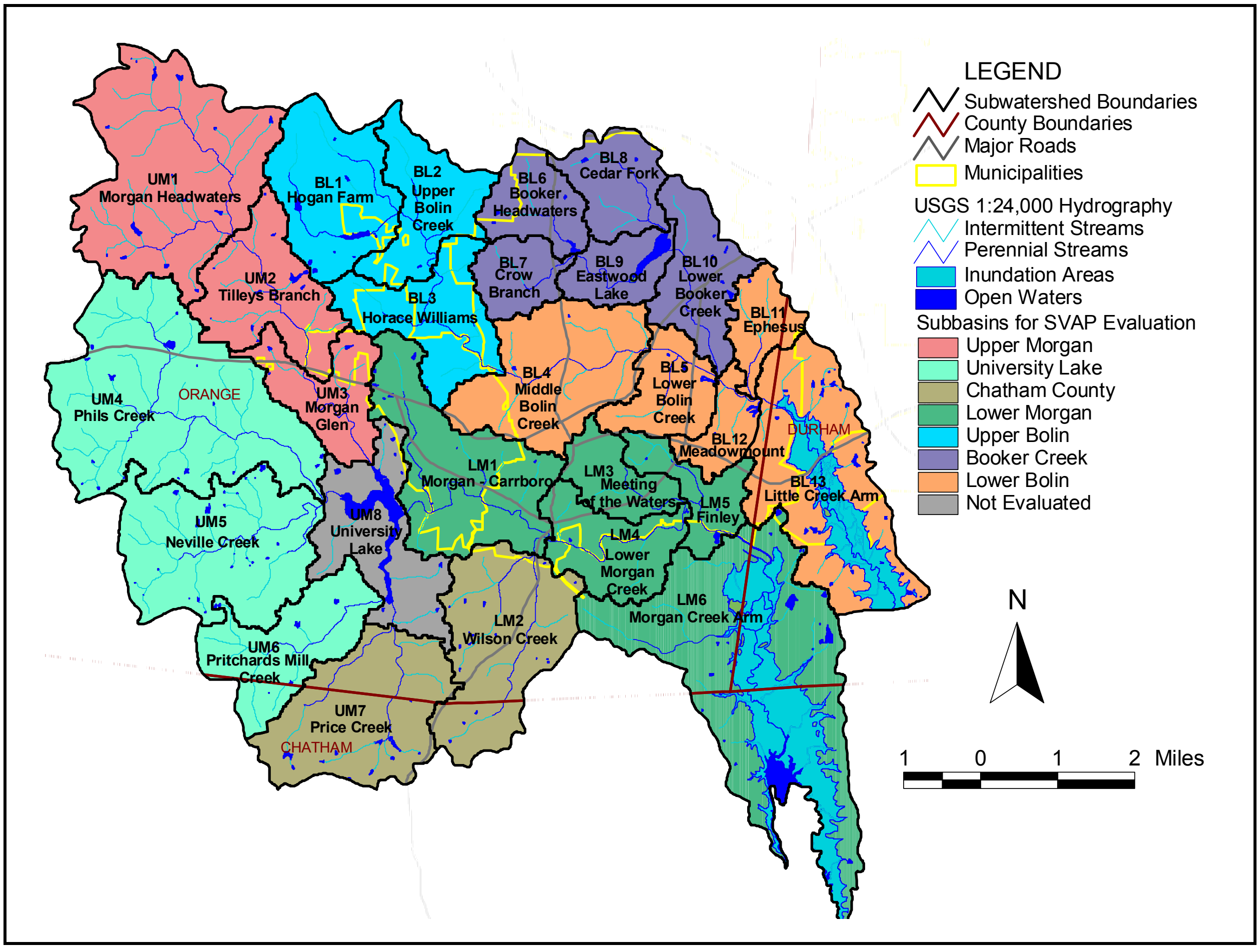

Figure B-1. Subbasins Used for SVAP Evaluation

Findings for Existing Conditions – Entire Study Area

For the scores averaged across all 54 sampled reaches, limited fish cover was identified as the primary stressor as it was the only parameter classified as Poor; the condition of the riparian zone scored highest with a classification of Good, and all other parameters were classified as Fair. At the study area scale, none of the mean values for any parameter classified as Excellent. Relative to the other scored SVAP parameters, limited fish cover, reduced pool abundance and depth diversity, and embedded riffles most negatively impacted stream condition. Conversely, the riparian zone condition, water appearance, and visually observed nutrient enrichment received the highest score. A probable interpretation of these results on a study area wide basis is that impaired fish and macroinvertebrate communities are more impacted by degraded instream habitat conditions than by impaired water quality; however, as the SVAP is only a preliminary characterization of stream condition, more detailed survey methods would be required to validate this interpretation.

For general comparisons, an average score for all parameters evaluated at all reaches within the seven SVAP subwatersheds was calculated. This score is intended to provide an indication of the condition of the streams within each subwatershed. The results are presented in Table B-4. Despite the classification of all seven subwatersheds into either the Fair or Poor classes, the score allows for relative comparisons across the study area. The Upper Morgan Creek and University Lake subwatersheds are relatively least impaired, potentially due to the limited development of their watersheds. The higher ranking of the Booker Creek watershed probably results from the influence of the Carolina Slate Belt geology on the stream morphology. The effects of development, both ongoing (e.g., within Chatham County and in the headwaters of Bolin and Booker Creeks) and historic (e.g., Chapel Hill and Carrboro) combined with erodible Triassic Basin soils lead to the relatively lower scores in the remaining subwatersheds.

Table B-4. Average SVAP Score by SVAP Subbasin

SVAP Subbasin	SVAP Score	SVAP Class	Rank[1]
Upper Morgan Creek	7.41	Fair	1
University Lake	7.09	Fair	3
Chatham County	6.67	Fair	6
Lower Morgan Creek	6.91	Fair	4
Upper Bolin Creek	6.78	Fair	5
Booker Creek	7.11	Fair	2
Lower Bolin Creek	5.77	Poor	7

[1] Ranked from least impaired (1) to most impaired (7).

Subbasin Specific SVAP Findings

Eight reaches were evaluated within the Upper Morgan Creek subbasin. None of the averaged scores for any SVAP parameter rated as Poor, but the condition of the riparian zone rated Excellent. Poor bank stability, reduced pool abundance and depth diversity, and hydrologic alterations to the stream channels had the greatest relative negative impact on stream condition. The condition of the riparian zone, the quality of invertebrate habitat, and an established canopy cover provided the greatest relative benefit to the stream condition. Within the Upper Morgan Creek subbasin, the SVAP results indicate that sediment generated from both hydrologic alterations and livestock operations not only fills pools, but also embeds riffles and smothers fish and invertebrate habitat.

Seven reaches were evaluated in the three LWP subwatersheds forming the University Lake subbasin. The average score for riffle embeddedness ranked as Poor and was identified as the primary stressor of stream condition. Half of the remaining parameters were classified as Fair; half were classified as Good. Riffle embeddedness, poor bank stability, and limited fish cover scored relatively lowest; whereas, the condition of the riparian zone, channel condition, and minimal visible nutrient enrichment scored relatively highest. As the condition of the reaches in the University Lake subbasin is relatively high, the results of the SVAP indicate that degraded instream habitat structure due to excess watershed-based sediment is a predominant threat to biological functions in these streams.

The higher allowable development densities in Chatham County predominantly affect two LWP subwatersheds in the study area; therefore, the eight reaches in these two subwatersheds were evaluated as the Chatham County subbasin. The mean values for riffle embeddedness, fish cover, canopy cover, and pools resulted in classifications as Poor. However, Good classifications were assigned to five parameters: water appearance, nutrient enrichment, channel condition, riparian zone condition, and bank stability. While bank stability is good in this subbasin, embedded riffles and limited abundance and depth diversity of pools are identified as potential stressors, overland sources of sediment (e.g., US 15-501 widening and residential and commercial developments) are the primary candidates for the instream impairment.

Nine reaches were evaluated in the Lower Morgan Creek subbasin. The condition of fish cover was classified as Poor and no parameter rated as Excellent. The limited fish cover, riffle embeddedness, and canopy cover had the greatest negative impact on stream condition. While visually assessed nutrient enrichment and water appearance were both classified as Good, previous water quality samplings in this subbasin have revealed considerable water quality impacts. Throughout the Lower Morgan Creek subbasin, the SVAP results indicate that limited habitat structure due to storm flows and instream sedimentation are primary threats instream aquatic biological communities.

In the three LWP subwatersheds encompassing the headwater areas of Bolin Creek, five reaches were evaluated. Within this SVAP subbasin, none of the averaged scores classified as either Excellent or Good; the parameters were about evenly distributed between the Fair and Poor classes. However, the three reaches in and immediately downstream of the Hogan Farm development scored considerably lower than the two reaches between Homestead Road and Estes Drive extension. Due to the wide discrepancy between conditions at these reaches, it is not meaningful to discuss the subbasin-averaged findings. Thus, for the three reaches near the Hogan Farm development, only one parameter was classified as Excellent but over half were classified as Poor. As pool abundance and depth diversity, fish cover, bank stability, riffle embeddedness, channel condition, and hydrologic alterations were identified as stressors, the impacts of increased stormwater and sediment runoff due to recent residential development are probably responsible. For the two reaches between Homestead Road and Estes Drive extension, no parameters were classified as Poor but three-quarters were classified as Good or Excellent. Pool abundance and depth diversity, water appearance, and visually assessed nutrient enrichment were the only identified stressors, indicating that washoff from the headwaters reaches is likely to be impacting these reaches as well as the upstream segments. Therefore, addressing stormwater and erosion control issues in the headwaters would not only improve the quality of the headwater reaches, but also alleviate the identified stressors in these downstream reaches.

The Booker Creek subbasin includes eight reaches that were evaluated. None of the SVAP parameters was classified as either Poor or Excellent. Hydrologic alteration, riffle embeddedness, and water appearance were classified as Good while the remaining eight parameters rated Fair. Six of the eight sites evaluated were located upstream of Eastwood Lake in the Carolina Slate Belt geologic formation. Therefore, these streams have higher gradients, coarser substrates (including boulders and bedrock), and more erosion resistant stream banks. The heterogeneity of instream habitat types in the Booker Creek subbasin as a result of these factors results in the relatively less impaired stream conditions.

Nine stream reaches were sampled in the Lower Bolin Creek subbasin. Across these reaches, none of the averaged parameter scores was classified as Good or Excellent. In comparison to the rest of the study area, the stream condition in the Lower Bolin Creek subbasin was most impaired. Over half of the parameters were in a Poor condition, with channel condition, invertebrate habitat, and pool abundance and depth diversity identified as the primary stressors. The sampled reaches are affected most heavily by the urban development in Chapel Hill and Carrboro. Efforts to achieve flood control and locate sanitary sewer lines, roadway bridges and culverts require channel modifications that result in debris removal, channel realignment, and homogenization of instream conditions. All of these historical channel modifications have contributed to the degraded conditions observed within this SVAP subbasin.

Additionally, fluvially transported sediment from upstream areas of the watershed tends to be deposited through the stream reaches in this subbasin due to their lower gradient and reduced stream power.

The objective of applying the SVAP methodology to a variety of stream reaches throughout the study area was to broadly compare the condition of streams grouped by subbasin and to relatively identify the most influential stressors. Altered hydrology, both due to watershed development and channel modifications, and the effects of sediment were consistently identified in the study area as primary stressors. Frequently, limited instream habitat for both fish and invertebrates was identified as a contributing factor to stream degradation. Limited habitat is typically a function of the impacts from urban hydrology and sediment as habitat structure is washed out by storm flows or smothered by excessive instream deposition. Due to the patterns of development in the study area, subbasins receiving runoff from the more developed areas of Chapel Hill and Carrboro, as well as watershed currently undergoing considerable development, were generally most impaired according to the SVAP methodology.

Attachment A

Example SVAP Field Data Sheet

List of Parameters Evaluated for SVAP

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References for Appendices

Brown & Caldwell and CH2MHILL. 2001. Technical Memorandum 8.4 Wastewater Collection, Pumping, and Conveyance Facilities.

Doll, B.A., Wise-Frederick, D.E., Buckner, C.M., Wilkerson, S.D., Harman, W.A., and R.E. Smith, 2002. Hydraulic Geometry Relationships for Urban Streams throughout the Piedmont of North Carolina. Journal of the American Water Resources Association, 38(3): 641-651.

Dunne, T. and L.B. Leopold, 1978. Water in Environmental Planning. W.H. Freeman, San Francisco, CA.

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF, Generalized Watershed Loading Functions, Version 2.0: User's Manual. Department of Agricultural and Biological Engineering, Cornell University, Ithaca, NY.

Harmon, W.A., G.D. Jennings, J.M. Patterson, D.R. Clinton, L.O. Slate, A.G. Jessup, J.R. Everhart, and R.E. Smith, 1999. Bankfull Hydraulic Geometry Relationships for North Carolina Streams. In: AWRA Wildland Hydrology Proceedings. D.S. Olsen and J.P. Potyondy, editors. AWRA Summer Symposium. Bozeman, Montana. p. 401-408.

Hershfield, David M, 1961. Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. U.S. Department of Commerce, Weather Bureau Technical Paper No. 40. Washington, D.C.

Hunter, Kathleen. 2003. The Chapel Hill News. "Carolina North raises concerns." November 16, 2003. Vol. 80, No. 75. p A1,A4.

Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (HSIAC), 1982. Guidelines for Determining Flood Flow Frequency: U.S. Geological Survey Bulletin 17B. Office of Water Data Coordination. Reston, Virginia.

NCDWQ. 2000. Cape Fear River Basinwide Water Quality Plan. North Carolina Division of Water Quality. [Online] Available: http://h2o.enr.state.nc.us/basinwide/Capefear/capefearindex.htm

National Resources Conservation Service (NRCS), 1986. Technical Release 55, Urban Hydrology for Small Watersheds, Second Edition. United States Department of Agriculture, Washington, D.C.

National Resources Conservation Service (NRCS), 1997. National Engineering Handbook, Part 630 Hydrology, Chapter 10. United States Department of Agriculture, Washington, D.C. p. 15-1 – 15-9.

Pope, B.F., Tasker, G.D., and J.C. Robbins, 2001. Estimating the Magnitude and Frequency of Floods in Rural Basins of North Carolina – Revised. United States Geologic Survey, Water Resources Investigations Report 01-4207.

Robbins, J.C., and B.F. Pope, 1996. Estimation of Flood-Frequency Characteristics of Small Urban Streams in North Carolina. United States Geologic Survey, Water Resources Investigations Report 96-4084.

Smith, R.A., G.E. Schwarz, and R.B. Alexander. 1997. Regional interpretation of water-quality monitoring data. *Water Resources Research*, 33(12): 2781-2798.

Tetra Tech. 2003a. B. Everett Jordan Lake TMDL Watershed Model Development. Prepared for N.C. Division of Water Quality. Tetra Tech, Inc., Research Triangle Park, NC.

Tetra Tech. 2003b. University Lake Baseline Analysis Memo. Prepared for Orange Water and Sewer Authority. Carrboro, NC. Tetra Tech, Inc., Research Triangle Park, NC.

USDA. 1998. Stream Visual Assessment Protocol. United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS). National Water and Climate Center Technical Note 99-1. Washington, D.C.

United States Army Corps of Engineers (USACE), 2001. Hydrologic Modeling System HEC-HMS User's Manual, Version 2.1. Hydrologic Engineering Center, California.

United States Army Corps of Engineers (USACE), 2003a. HEC-HMS Hydrologic Modeling System, Version 2.2.2. Hydrologic Engineering Center, California.

United States Army Corps of Engineers (USACE), 2003b. HEC-RAS River Analysis Software, Version 3.1.1. Hydrologic Engineering Center, California.

Williams, G.P., 1978. Bank-Full Discharge of Rivers. Water Resources Research, 14(6): 1141-1154.