

Assessment Report: Biological Impairment in the Upper Swift Creek Watershed

**Neuse River Basin
Wake County, N.C.**

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Executive Summary

Introduction

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

Study Area and Stream Description

Swift Creek is a tributary of the Neuse River located in Wake and Johnston Counties (see map in Section 1) in DWQ subbasin 03-04-02. The 20.8 square mile area under current study is the headwaters portion of the watershed upstream of Holly Springs Road, above Lake Wheeler. About 70 percent of the highly developed study area lies within the Cary town limits, while 11 percent lies within Apex near the eastern boundary of Cary. Streams in the watershed are classified as WS-III NSW (nutrient sensitive waters). There are no permitted discharges of domestic or industrial wastewater in the study area. Approximately 20% of the study area is impervious. Extensive development occurred during the 1980s and 1990s. The watershed is described further in Section 2.

North Carolina's 303(d) list designates Swift Creek as impaired for its entire length in the study area. Williams Creek, the major tributary, is also impaired for its entire length. Impairment has been apparent since 1989. Though comparisons are difficult due to differences in sampling techniques, it appears that these streams were not impaired when first sampled in 1980. Most of the major tributaries of upper Swift Creek are impounded near their mouths. In-stream habitat is highly variable.

Approach

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

Conclusions

Aquatic organisms in upper Swift Creek are heavily impacted by multiple stressors associated with the high levels of development in the watershed. Multiple stressors are characteristic of most developed watersheds, although sometimes a single stressor can be identified as being of primary importance in causing impairment. In upper Swift Creek, however, the relative contribution of these stressors cannot be clearly differentiated based on the available data. Toxic impacts, scour, habitat degradation, hydromodification due to dams and organic/nutrient

enrichment are all considered to be stressors that cumulatively cause impairment. Scour is probably the most pervasive stressor and several lines of evidence point to toxic impacts in the mainstem, while the impacts of organic enrichment and severe habitat degradation are more localized. The limited opportunity for macroinvertebrate recolonization from within the watershed, due to the blockage of drift by impoundments and to the highly impacted condition of tributary streams, is also a concern. Sedimentation contributes to habitat degradation but there is little evidence that sedimentation per se is severe enough to be considered a cause of impairment above Holly Springs Road, except in several specific locations—in Williams Creek between Gregson Drive and US-1, and in Swift Creek in the Lochmere Golf Club. Sediment transport to Lake Wheeler appears to be considerable, however.

Management Strategies

The objective of efforts to improve stream integrity is to restore water quality and habitat conditions to support a more diverse and functional biological community in Swift Creek. Because of the widespread nature of biological degradation and the highly developed character of the watershed, bringing about substantial water quality improvement will be a tremendous challenge. While a return to the relatively unimpacted conditions that existed prior to widespread agriculture and urbanization is unlikely, Swift Creek can potentially support a healthier biological community than it does today. Additionally, the quantities of sediment and other pollutants transported to Lake Wheeler, which will be used as a drinking water supply reservoir by Raleigh in the near future, can be reduced. Swift Creek flows through the Swift Creek Bluffs and Hemlock Bluffs Nature Preserves. Improvements in the biological condition of Swift Creek would enhance the overall ecological integrity of these important natural areas.

Because of uncertainties regarding how individual remedial actions cumulatively impact stream conditions and in how aquatic organisms will respond to improvements, the intensity of management effort necessary to bring about a particular degree of biological improvement cannot be established in advance. The types of actions needed to improve biological conditions in Swift Creek can be identified, but the mix of activities that will be necessary – and the extent of improvement that will be attainable – will only become apparent over time as an adaptive management approach is implemented. Management actions are suggested below to address individual problems, but many of these actions are interrelated.

The following actions are necessary to address current sources of impairment in Swift Creek, and to prevent future degradation (see Section 8 for additional details). The intent of these recommendations is to describe the types of actions necessary to improve conditions in the Swift Creek watershed, not to specify particular administrative or institutional mechanisms for implementing remedial practices. Actions one through five are important to restoring and sustaining aquatic communities in the watershed, with the first three recommendations being the most important.

1. **Feasible and cost-effective stormwater retrofit projects should be implemented throughout the watershed to mitigate the hydrologic effects of development** (increased stormwater volumes and increased frequency and duration of erosive and scouring flows). This should be viewed as a long-term process. Although there are many uncertainties, costs of \$1 million or more per square mile of watershed can probably be anticipated.
 - a) Over the short-term, currently feasible retrofit projects should be identified and implemented.

- b) In the longer term, additional retrofit opportunities should be sought out in conjunction with infrastructure improvements and redevelopment of existing developed areas.
 - c) Specific priorities should include evaluating whether existing in-stream impoundments could be retrofitted to improve water quantity control, retrofitting areas draining directly to the Swift Creek mainstem and retrofitting Apex Branch, the major tributary to Williams Creek and the largest unimpounded tributary in the study area.
2. **A strategy to address toxic inputs should be developed and implemented, including a variety of source reduction and stormwater treatment methods.** As an initial framework for planning toxicity reduction efforts, the following general approach is proposed:
 - a) Implementation of available BMP opportunities for control of stormwater volume and velocities. Recommended above to improve aquatic habitat potential, these BMPs will also remove toxicants from the stormwater system.
 - b) Development of a stormwater and dry weather sampling strategy in order to facilitate the targeting of pollutant removal and source reduction practices.
 - c) Implementation of stormwater treatment BMPs, aimed primarily at pollutant removal, at appropriate locations.
 - d) Development and implementation of a broad set of source reduction activities focused on: reducing nonstorm inputs of toxicants; reducing pollutants available for washoff during storms; and managing water to reduce storm runoff. Suggestions for potential source reduction practices are provided.
 3. **The technical, economic and regulatory feasibility of implementing minimum releases from Summit Lake, MacGregor Downs Lake, Loch Lomond and Lake Lochmere should be explored.** These releases would help to restore baseflow levels in Swift Creek.
 4. **Stream channel restoration activities should be implemented in targeted areas, in conjunction with stormwater retrofit BMPs, in order to improve aquatic habitat.** Priority areas include Williams Creek from Gregson Drive to US 1 (approx. 3400 feet), and the portion of Swift Creek flowing through Lochmere Golf Club (approx. one mile). Apex Branch between Parliament Place in Apex and MacKenan Drive in Cary (approx. 4000 feet) also has numerous unstable areas and should be evaluated for restoration. Costs of at least \$1 million per mile of channel should be anticipated.
 5. **Actions recommended above (e.g., stormwater quantity and quality retrofit BMPs) are likely to reduce nutrient and organic loading to some extent, although additional efforts may be necessary.** Nutrient reduction activities currently underway as part of the Neuse River basin efforts could also have an impact. Activities recommended to address organic loading include the identification and elimination of illicit discharges; education of homeowners, commercial applicators, and others regarding proper fertilizer use; street sweeping; catch basin clean-out practices; and the installation of additional BMPs targeting BOD and nutrient removal at appropriate sites.
 6. Prevention of further channel erosion and habitat degradation will require effective post-construction stormwater management for all new development in the study area. The Phase II stormwater program and the Neuse stormwater and buffer rules must be effectively implemented. Implementing post-construction stormwater requirements comparable to those in the Neuse stormwater rules throughout the study area would increase the likelihood that channels will be adequately protected.
 7. Effective enforcement of sediment and erosion control regulations on the part of Apex, Cary and Wake County will be essential to the prevention of additional sediment inputs from construction activities. Development of improved erosion and sediment control practices may be beneficial.

8. The watershed education programs currently implemented by local governments should be continued and enhanced, with the goal of reducing current stream damage and prevent future degradation. At a minimum the program should include elements to address the following issues:
 - a) Redirecting downspouts to pervious areas rather than routing these flows to driveways or gutters.
 - b) Protecting existing wooded riparian areas on ephemeral streams.
 - c) Replanting native riparian vegetation on perennial, intermittent and ephemeral channels where such vegetation is absent.
 - d) Reducing and properly managing pesticide and fertilizer use.

Section 1

Introduction

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

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

1.1 Study Area Description

Swift Creek is located in Wake and Johnston Counties, in the Neuse River basin (Figure 1.1). The stream's headwaters are within the towns of Apex and Cary in southwestern Wake County. The creek flows southeast before joining the Neuse River outside of Smithfield, draining a 155 square mile watershed. The 20.8 square mile (33.3 sq. km) area under current study is the portion of the watershed upstream of Holly Springs Road, near the eastern boundary of Cary. There are no permitted point sources of domestic or industrial wastewater in the study area. The watershed is largely developed and is primarily within the town limits of Cary and Apex. North Carolina's 303(d) list designates Swift Creek as impaired for its entire length in the study area. Williams Creek, the major tributary, is also impaired for its entire length. Streams in the watershed are classified as WS-III NSW (nutrient sensitive waters). Swift Creek lies within DWQ subbasin 03-04-02.

1.2 Study Purpose

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

1. Identifying the most likely *causes* of biological impairment (such as degraded habitat or specific pollutants).
2. Identifying the major watershed activities and *sources* of pollution contributing to those causes (such as stream bank erosion or stormwater runoff from particular urban or rural areas).

3. Outlining a watershed *strategy* that recommends restoration activities and best management practices (BMPs) to address the identified problems and improve the biological condition of the impaired streams.

This investigation focused primarily on aquatic life use support issues. It was intended to assess the major issues related to biological impairment as comprehensively as possible within the time frame of the study. While not designed to address other important issues in the upper Swift Creek watershed, such as bacterial contamination or flooding, the report discusses those concerns where existing information allows.

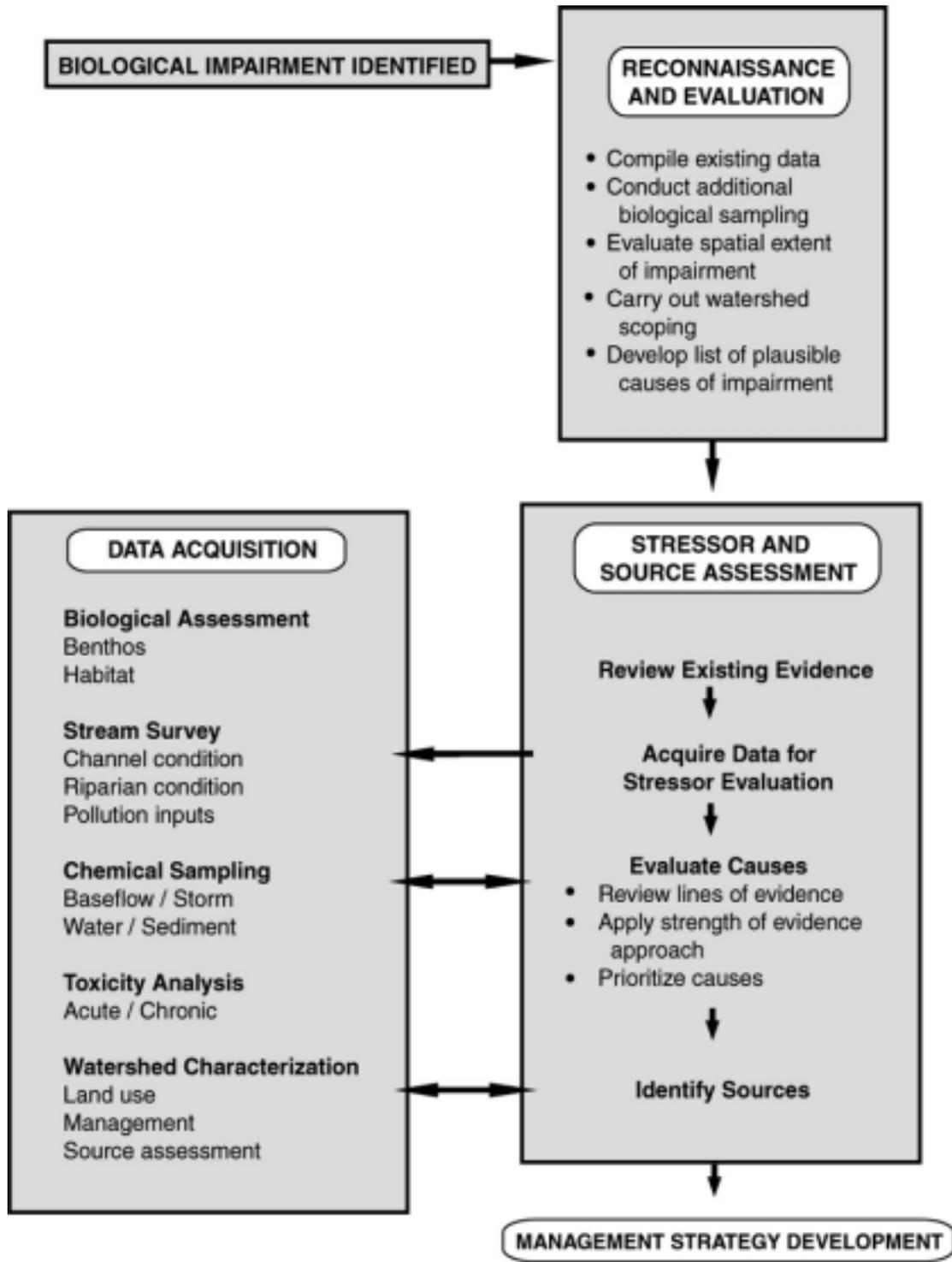
Table 1.1 Study Areas Included in the Watershed Assessment and Restoration Project

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

1.3 Study Approach and Scope

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

Figure 1.2 Overview of Study Activities



Background Note: Identifying Causes of Impairment

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

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

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

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

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

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

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

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

1.3.1 Study Approach

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

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

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

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

1.3.2 Approach to Management Recommendations

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

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

It is not the objective of this study to specify particular administrative or institutional mechanisms for implementing remedial practices, but only to describe the types of actions that must occur to place Swift Creek on the road to improvement. It is DWQ's hope that local governments and other stakeholders in the Swift Creek watershed will work cooperatively with each other and with state agencies to implement these measures in cost-effective ways.

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

1.3.3 Data Acquisition

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

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

Section 2

Description of the Upper Swift Creek Watershed

2.1 Introduction

The 2000 303(d) list describes Swift Creek as impaired for its entire length within the study area. Williams Creek, a major tributary, is also impaired for its entire length. Streams in the watershed are classified as WS-III NSW. Just below the study area, the mainstem of Swift Creek has been dammed to create Lake Wheeler and, a short distance downstream, Lake Benson, which is a former water supply for Raleigh and planned future water supply. Downstream of Lake Benson, Swift Creek still supports populations of rare, threatened and endangered mussels. About 70 percent of the study area lies within the Cary town limits, while 11 percent lies within Apex and the remainder is in unincorporated areas of Wake County. The US 1 and US 64 corridors cut through the watershed. This section summarizes watershed hydrography and topography, describes current and historical land use, and discusses potential pollutant sources.

2.2 Streams and Hydrology

Swift Creek is formed by the confluence of Williams Creek, which drains the eastern side of Apex, and an unnamed tributary draining part of downtown Cary and including MacGregor Downs Lake. In the present document this latter stream will be referred to as Cary Branch. Local usage varies. (Figure 2.1). Other significant tributaries to Swift Creek (Figure 2.1 and Table 2.1) include Long Branch, Lynn Branch, Speight Branch, and the unnamed tributary draining Regency Park Lake (referred to in this report as Regency Branch). Williams Creek has one major tributary (officially unnamed), referred to in this report as Apex Branch (Figure 2.1). Apex Branch was considered to be the headwaters of Swift Creek in some previous DWQ studies (e.g., Lenat, 1989).

While the mainstem of Swift Creek is not impounded within the study area all significant tributaries other than Speight Branch are impounded (Table 2.1). Summit Lake, on Williams Creek, was constructed as a water supply reservoir for Apex, although it is no longer used for that purpose. The other impoundments were constructed as amenities and several are associated with golf course communities (Exhibit 2.1). With the exception of Williams Creek, all of these impoundments are located near the mouth of the tributary. In total, streamflows from 13 square miles (63% of the drainage area above Holy Springs Road) are controlled by these impoundments (Table 2.1). An additional impoundment, Kildaire Farm Lake (Lake Kildaire), located on Cary Branch upstream of MacGregor Downs Lake, covers 40 acres and was built in the 1980s as part of the Kildaire Farm development. Only Regency Park Lake is required to make a minimum release (Table 2.1). The largest unimpounded stream in the study area is Apex Branch, the tributary of Williams Creek draining portions of downtown Apex.

Precipitation at Raleigh-Durham International Airport (approximately 8.5 miles north of the center of the study area) averages 42.1 inches (1074 millimeters) per year (1948-2001 period of record), with a fairly even distribution among months. Precipitation at the airport during 2000 and 2001, when most field work for this study was conducted, was 93% and 83% of the annual

mean, respectively. Precipitation at the weather station operated by North Carolina State University (NCSU) on Lake Wheeler Road (just outside the northeast corner of the study area), however, was slightly above average for both years, totaling 47.1 and 47.3 inches for 2000 and 2001, respectively (data provided by State Climate Office at NCSU).

The USGS operated a partial record station on Swift Creek at Holly Springs Road several decades ago, and has operated a continuous record stream gage (no. 0208758850) on Swift Creek just downstream of SR 1375, below Lake Wheeler, since 1987 (drainage area of 36 square miles.) Average daily discharge at this gage was 83% of average in 2000 and 1% above average in 2001. Swift Creek was not gaged above Lake Wheeler during the field study period, although the gage site at Holly Springs Road (no. 02087580) was reactivated as a continuous record gage in March 2002.

USGS regional low flow equations for this area (Giese and Mason, 1991) predict a 7Q10 flow of approximately 2.1 cubic feet per second (cfs) at Holly Springs Road, although this does not account for the potential impact of upstream impoundments. Typical mean annual flows in this part of the state are approximately 1.1 cfs/square mile (Giese and Mason, 1991).

Table 2.1 Major Tributaries and Impoundments, Upper Swift Creek

Tributary		Major Impoundment			
Name	Drainage Area (sq. miles)	Name	Drainage Area (sq. miles)	Date of Construction*	Minimum Release (cfs)**
Williams Creek	5.3	Summit L.	2.2	1921	0
Cary Branch	4.8	MacGregor Downs L.	4.5	1968	0
Regency Branch	1.6	Regency Park L.	1.5	1981	0.25
Long Branch	1.5	Loch Lomond	1.4	1984	0
Lynn Branch	3.6	Lake Lochmere	3.4	1985	0
Speight Branch	1.5	--none--	--	--	--

* Source: Haven, 2000.

** Required minimum release under the Dam Safety Law of 1967. Source: NC Division of Land Resources.



Exhibit 2.1 Lake Lochmere

2.3 Topography and Geology

Elevations in the headwaters areas, near downtown Cary and downtown Apex, are approximately 500 feet above mean sea level. The stream drops to approximately 340 feet just below US 1, and then flows at a more gentle gradient, losing only an additional 50 feet in elevation before entering Lake Wheeler. Swift Creek has a wide historic floodplain below Regency Parkway, sometimes flanked by steep bluffs on the south side.

Upland soils of the watershed consist of a variety of soil associations (Cawthorn, 1970), corresponding to the three major geologic belts running in a north-south direction through the study area. The western edge of the study area (encompassing the headwaters of Williams Creek, above Summit Lake, and the headwaters of Apex Branch) is in a Triassic basin (Figure 2.1). Soils of the Mayodan-Granville-Creedmore association predominate. The middle portion of the upper Swift Creek watershed, from the head of Summit Lake to approximately the Kildaire Farm Road area, is in the Carolina Slate Belt. Approximately 55% of the study area consists of Slate Belt soils, which are primarily of the Herndon-Georgeville association. The Raleigh Belt includes the eastern third of the watershed. Predominate soils are of the Appling and Cecil-Appling associations, derived primarily from crystalline materials (mostly granite, gneiss and shist) and mudstone.

Soils along Swift Creek between Holly Springs Road and Lake Wheeler are largely of the Wehadkee series. These are nearly level poorly drained soils formed in sandy alluvium and are common along streams in Wake County. Upstream of this area, soils along Swift Creek are largely of the Chewacla series. These soils are also common on floodplains in Wake County, forming in deposits of fine loamy materials. Both Wehadkee and Chewacla soils are common along the lower portions of tributary streams.

2.4 Natural Areas and Rare Aquatic Species

Two major nature preserves lie along the mainstem of Swift Creek within the study area. Cary's Hemlock Bluffs Nature Preserve is located upstream of Kildaire Farm Road, while the Triangle Land Conservancy's Swift Creek Bluffs Nature Preserve is located upstream of Holly Springs Road.

The portion of Swift Creek below Lake Benson supports 11 species of rare, threatened or endangered aquatic animals: one fish and ten mussel species, including the federally endangered dwarf wedgemussel (*Alasmidonta heterodon*). None of these species are currently known to exist within the study area, although this portion of Swift Creek was likely within their historic range. Limited survey work has been carried out in the study area due to the developed nature of the watershed.

2.5 Land Cover in the Watershed

The study area is highly developed and residential subdivisions cover much of the watershed. The upper portion of the watershed includes part of downtown Cary and Apex and a number of older residential neighborhoods. The US 1 and US 64 corridors include numerous office parks and extensive commercial areas (shopping centers, automobile dealerships, etc). Similar areas exist in portions of Apex, along Walnut Street and Kildaire Farm Road in Cary and scattered throughout other parts of the watershed.

The distribution of land cover in the watershed is shown in Figure 2.2 and Table 2.2. This information, based on satellite imagery from 1998 and 1999, was taken from a data base developed by the US Environmental Protection Agency as part of a landscape characterization study of the Neuse River Basin (see Appendix C for additional information). Forested areas covered approximately one third of the watershed, many of them located in floodplains and natural areas. Almost 2/3 of the land cover is characterized as developed, with 26% of the study area in high and medium density uses with imperviousness exceeding 36%, and 37% in lower density uses with imperviousness between 10 and 35%. While agriculture was once widespread in this part of Wake County, farming currently has only a minimal presence in the watershed (<1% of area). These are generally areas in which horses are pastured, located primarily on the outskirts of Apex.

Impervious surfaces (areas such as rooftops, roads and parking lots that prevent infiltration of precipitation into the soil) cover approximately 20% of the study area (see Appendix C). Significant impacts to stream biota can generally be expected with this degree of impervious cover (Schueler, 1994).

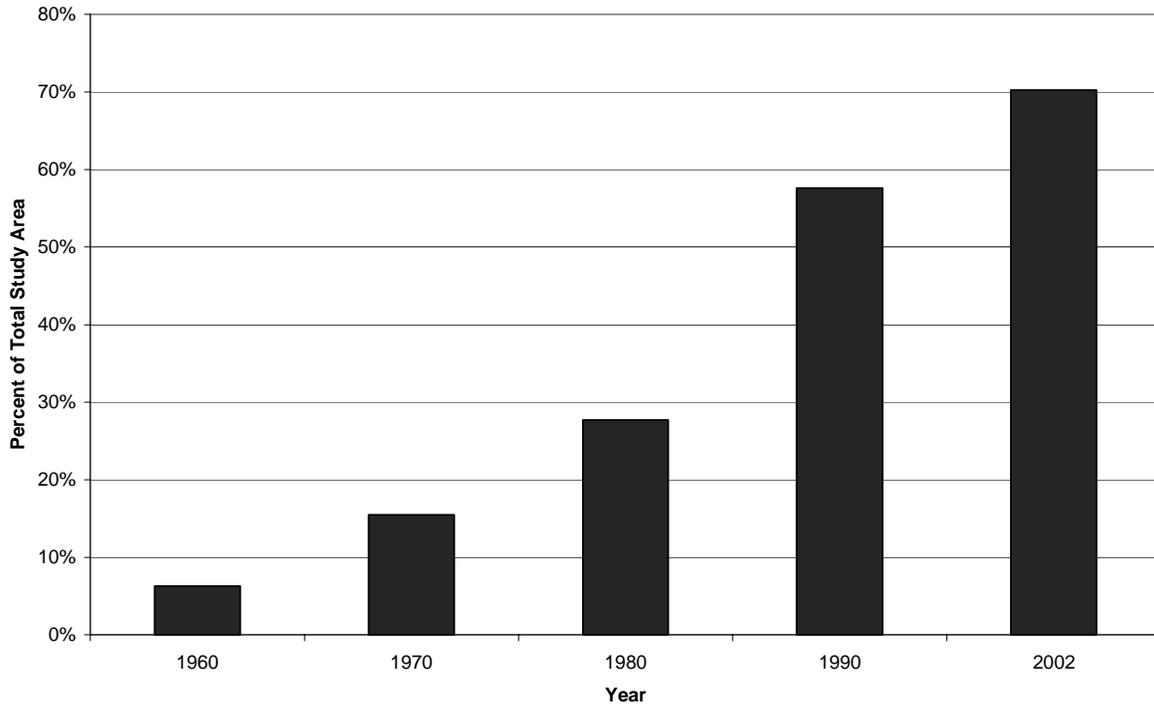
Table 2.2 Current Land Cover, Swift Creek Watershed above Holly Springs Road

Category	Acres	Percent of Watershed
High Density Developed (>71% impervious)	806.7	6.1
Medium Density Developed (36-50% imperv.)	2660.6	20.0
Low Density Developed (10-35% imperv.)	4903.2	36.9
Row Crops	31.6	0.2
Other Agricultural (hay, pasture, fallow)	61.8	0.5
Wooded	4428.5	33.3
Wetlands	168.3	1.3
Water	203.9	1.5
Other (barren land, unclassified)	26.0	0.2
<i>Total</i>	<i>13, 290.6</i>	<i>100.0</i>
Source: Land Use/Land Cover data developed by USEPA for Neuse River Basin. Based upon 1998-99 Spot 4 and Landsat 7 satellite imagery. See Appendix C.		

While data are not available to evaluate land cover changes in the watershed quantitatively, it is clear from aerial photography that land use and cover have changed significantly over the past quarter century. Prior to the 1960s, development (other than rural residences) in the study area was limited primarily to areas immediately adjacent to downtown Cary and Apex. Development began to expand outwards in the 1960s as construction began on the MacGregor Downs development. The town limits of Cary and Apex have expanded substantially over the past 40 years.

The expansion of Cary into the upper Swift Creek drainage has been particularly notable (Figure 2.3), as rural land was gradually annexed and developed. Cary town staff indicated that land has generally not been annexed far in advance of development. Development activities are most often initiated soon after annexation. The expansion between 1980 and 1990 was particularly significant—the portion of Cary within the study area increased from 5.8 to 12.0 square miles during the decade. The Kildaire Farms, Regency Park, Lochmere and MacGregor Office Park developments, among others, were all approved in the early to mid 1980s and built out over the next decade or so. Parcels on which building occurred during the 1980s are shown in Figure 2.4.

Figure 2.3 Percentage of Upper Swift Creek Study Area within Cary Town Limits, 1960-2002



Source: Calculated from jurisdictional boundary GIS data provided by the Town of Cary

2.6 Sources of Pollution

2.6.1 Permitted Discharges

The study area contains no NPDES (National Pollutant Discharge Elimination System) wastewater discharges or permitted animal operations. There is one facility with an NPDES stormwater permit in the study area. Apex Lumber has a permit (NCG210234) to discharge stormwater to Williams Creek upstream of Summit Lake.

2.6.2 Nonpoint Source Inputs

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

a. Historic Issues

This area, like much of Wake County, has a long agricultural history. High levels of agricultural activity existed earlier in the 20th century. While changes in active cropland in the watershed have not been quantified, a review of aerial photographs as far back as the 1940s showed

considerable land under cultivation in the study area, a situation that persisted as late as the 1970s. Agricultural use was likely even higher earlier in the 20th century. Farm acreage in Wake County declined by almost 75% from 1945 to 1997, with about half of this decline occurring prior to 1964 (US Bureau of Census data provided by Wake Soil and Water Conservation District).

While it has probably been some time since active erosion from cultivated land has been a problem, it is likely that pervasive sediment inputs from historic agricultural activities once occurred in this watershed. For additional background on historical land use changes and their impact on stream condition, see the Background Note "Landscape History and Channel Alteration in the Piedmont Region".

As far as could be ascertained, large scale channel modification has not occurred in the study area, at least during the 20th century. Some channelization (moving, straightening and dredging of streams) likely occurred earlier in order to facilitate cultivation of the land, and channelization of some stream reaches has occurred over the past several decades to facilitate development and infrastructure work.

Studies of sedimentation in Lake Wheeler (Haven, 2000) indicate significant sediment inputs from the watershed since the lake was built in 1954. Other impoundments in the study area are also accumulating substantial sediment (see discussion below), and several (Lake Kildaire and Loch Lomond) were dredged during the course of the present study to remove deposited material. Clearly a substantial sediment load has been carried by Swift Creek in the recent past, possibly continuing in the present.

b. Existing Developed Areas

Residential development. Most of the land in the study area is zoned for residential uses, and most has been developed (Exhibits 2.2 and 2.3). While housing density varies, much of the study area within the planning jurisdictions of Cary and Apex is developed at residential densities averaging 2.5 dwelling units per acre (Wake County Land Use Plan, Section V. Water Supply Watershed Protection Policies, online at <http://www.co.wake.nc.us/planning>.) Most of these areas use traditional curb and gutter drainage. Stormwater BMPs are largely absent.

Commercial and industrial development. Commercial and industrial activity in the watershed is considerable. Nineteen percent of the study area (Figure 2.5) is zoned for business, commercial, industrial, or institutional uses (based upon analysis of March 2001 Wake County parcel data). Major commercial and industrial areas include: downtown Cary; along Kildaire Farm Road (e.g., Shoppes of Kildaire); the Tryon Road corridor (Wake Medical Center, Wal-Mart, Waverly Place); the Regency Park area; MacGregor Village; and the auto park area off of US 64 (Exhibits 2.4 and 2.5).

Though much of this development is fairly recent, it largely predates stormwater control requirements, and BMPs (e.g., onsite detention ponds) for the control of post-construction stormwater are generally found only in very recent projects.



Exhibit 2.2 Apartment complex near the headwaters of Cary Branch



Exhibit 2.3 Typical single family homes in the study area



Exhibit 2.4 The Shoppes of Kildaire on Kildaire Farm Road



Exhibit 2.5 Waverly Place on Tryon Road

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

Paved areas have increased dramatically in the upper Swift Creek watershed in recent decades. Vehicular traffic has increased due both to the increased population in the watershed and to increased traffic on US 1 and US 64 from development west and south of the watershed (Table 2.3).

Table 2.3 Annual Average Traffic Counts (Average Number of Vehicles per Day) at Selected Locations in the Upper Swift Creek Watershed, 1980 and 1998

Location	Year	
	1980	1998
US 1-64, west of Kildaire Farm Rd.	13,900	56,000
Kildaire Farm Rd., north of US 1-64	4,400	26,000
Kildaire Farm Rd., near Lochmere Rd.	2,000	20,000
US 64, west of US 1 split	7,700	38,000

Source: NC Department of Transportation

Golf courses. The MacGregor Downs County Club (Exhibit 2.6), founded in the 1960s, borders MacGregor Downs Lake and Cary Branch north of US 1 (Figure 2.5). East of Kildaire Farm Road, Swift Creek flows through the Lochmere Golf Club (Exhibit 2.7), constructed during the 1980s, for approximately 1.25 miles. The lower portion of Long Branch and Lynn Branch (below Loch Lomond and Lake Lochmere, respectively) also flow through the course, which uses a pond on Lynn Branch for irrigation. Turf management activities such as fertilization and pesticide application are potential sources of chemical inputs to streams, especially after storms, depending upon the management practices used.

c. Construction

Construction has slowed somewhat in recent years as much of the area has been built out. Scattered residential construction was observed in the watershed during the study period, as well as commercial, office and institutional construction in a number of areas, including: the Regency Park area; the Tryon Road corridor; in headwaters of Apex Branch near downtown Apex; and along Crescent Green Drive off of Kildaire Farm Road.



Exhibit 2.6 MacGregor Downs County Club, lake in background



Exhibit 2.7 Pond in Lochmere Golf Club

Sediment inputs associated with past development have likely been considerable. Based upon extensive field investigations, Haven (2000) estimated sediment accumulation in many of the major impoundments in the upper Swift Creek watershed (see Table 2.4). Haven (2000) noted an increase in the rate of growth of the Lake Wheeler delta (sediment accumulation where Swift Creek enters the head of the reservoir) after 1973, corresponding to the period of increased development in the watershed. Floodplain deposits were not observed along tributary streams, indicating that sediment transported by these streams was routed to Swift Creek or to intervening impoundments. Haven estimated levee deposits on the floodplain of the Swift Creek mainstem above Lake Wheeler at about 9,000 m³ (average floodplain width = 0.7 km, or 0.4 miles).

Table 2.4 Sediment Accumulation in Impoundments in the Upper Swift Creek Watershed

Impoundment	Size (acres)	Approximate Date of Construction	Total Sediment Accumulation (m ³)	Average Annual Accumulation (m ³)
Summit L.	47	1921	41,700	535
MacGregor Downs L.	60	1968	51,400	1658
Regency Park L.	22	1981	10,200	567
Loch Lomond	19	1984	19,400	1293
Lake Lochmere	79	1985	52,800	3771
Lake Wheeler	610	1954	252,600	5613

Source: Haven, 2000.

d. Sanitary Sewer Lines

The vast majority of the study area is served by water and sewer from Cary and Apex. Cary's sanitary sewer lines run near the entire Swift Creek mainstem in the study area, then turn south to the wastewater treatment plant that discharges to Middle Creek (Figure 2.5). Sewer lines also parallel much of Williams Creek, Cary Branch, Long Branch, Lynn Branch and Speight Branch.

From January 2000 through May 2002, 13 spills of untreated sewage reaching surface waters were reported to DWQ by Cary and Apex (Table 2.5), many of them to tributaries of Lake Kildaire and MacGregor Downs Lake.

Table 2.5 Spills of Sewage to Upper Swift Creek and Tributaries January 2000 through May 2002

	Date	Volume (gallons)	Receiving Stream	Cause
Apex	1/31/00	3	UT to Williams Creek	broken force main
	1/15/01	600	UT to Williams Creek	grease
Cary	6/9/00	588	UT to MacGregor Downs Lake	roots
	6/12/00	1,412	UT to MacGregor Downs Lake	roots
	10/20/00	2,011	UT to Lake Kildaire	grease
	1/27/01	10,098	Speight Branch	vandalism
	4/18/01	1,200	UT to Lake Lochmere	rags
	12/1/01	857	UT to Lake Kildaire	paper
	1/26/02	945	UT to MacGregor Downs Lake	roots
	2/17/02	1,713	UT to Lake Kildaire	vandalism
	3/25/02	800	UT to Lake Kildaire	grease
	4/9/02	770	UT to Lochmere Highlands Ponds	grease
	5/2/02	980	UT to Swift Creek	grease

UT = unnamed tributary.

Background Note: Landscape History and Channel Alteration in the Piedmont Region

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

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

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

Many of these watersheds have since undergone, or are currently experiencing, significant development as the Piedmont continues to grow. The major hydrologic changes that accompany development and the resulting physical and biological deterioration of stream channels are well known. The impact of urbanization is often made worse, however, by the persistent effects of historical practices. Many streams are already incised and subject to ongoing bank erosion and sedimentation due to prior impacts from agricultural erosion and channel modification, leaving them extremely vulnerable to the altered hydrology brought on by urban and suburban growth. In highly impacted watersheds, the relative effects of these various disturbances can be difficult if not impossible to distinguish. It is clear, however, that the legacy of past land use practices is still with us, and that we cannot understand the current condition of many impaired streams without understanding the history of their watersheds.

2.7 Trends in Land Use and Development

The population of Cary has increased dramatically over the past thirty years, from 7,640 in 1970 to over 96,000 in 2000 (Town of Cary, 2000), as areas surrounding the historic core of the town were annexed and developed. Apex has also expanded rapidly, its population increasing three-fold since 1980 to the current level of over 20,000 (based on US Census figures. See <http://www.apexnc.org>).

Most of the study area has been built out over the last 20 years. Although about one third of the area is wooded (Table 2.2), much of the existing forest lies in nature preserves or other undevelopable areas. Pockets of developable land remain, but construction is likely in many of these areas in the near future. Of the 19 percent of the watershed in unincorporated areas, the vast majority is in the extraterritorial jurisdiction (ETJ) of Apex or Cary, with small areas along Penny Road and Holly Springs Road outside of Cary's ETJ but within its short-term urban service area. Given the limited amount of developable land in the study area, future development activity will probably have relatively modest water quality impacts compared to the large scale activity of the past several decades.

2.8 Regulatory Issues and Local Water Quality Activities

A mosaic of state and local regulatory programs impact development and water quality protection in the upper Swift Creek watershed. The most important of these are briefly described below.

Water supply watershed regulations. Water supply protection efforts have evolved rapidly over the past several decades in response to state mandates and local needs. Wake County first adopted regulations to protect water supply watersheds in 1984, and Cary adopted its first watershed ordinance in the late 1980s. The Environmental Management Commission (EMC) and the DWQ initiated a voluntary Water Supply Protection Program in 1986. The program became mandatory for local governments with the passage of the Water Supply Watershed Protection Act (General Statutes 143-214.5 and 143-214.6) in 1989 and the subsequent approval of regulations outlining minimum statewide water supply protection standards by the EMC in 1992.

A Swift Creek Land Management Plan for the entire Wake County portion of the watershed (not including Johnston County) was developed cooperatively by the relevant local governments (Wake County, Apex, Cary, Raleigh and Garner) and adopted in 1990. The purpose of the plan was to protect the future viability of the creek as a water supply source while still allowing for the extension of urban development. The plan includes impervious surface limits and vegetative buffer requirements. With some changes, this plan remains in effect (see the section of the Wake County Land Use plan entitled "Water Supply Watershed Protection Policies", available online at <http://www.co.wake.nc.us/planning>). Since most of the current study area is currently developed (much of it was developed or platted at the time the plan was adopted), the strategy primarily affects the less developed portions of the Swift Creek watershed downstream of Holly Springs Road.

Cary and Apex developed water supply watershed regulations under the state program in the early 1990s. Existing Planned Unit Developments (PUDs), such as Lochmere, that had been approved but not yet built out, were exempt from on-site stormwater requirements. The impoundments constructed as a part of these developments (e.g., Regency Lake, Kildaire Farms Lake, Lake Lochmere and Loch Lomond) were considered to provide some mitigation from stormwater impacts, although these impoundments were designed as amenities and not for specific stormwater control objectives.

Riparian Buffers. The riparian buffer requirements of North Carolina's water supply watershed regulations and the Neuse River basin rules both apply to the study area, although Cary and Apex have ordinances providing more stringent protection of buffers. The state water supply protection rules require a 30-foot vegetated riparian buffer. The buffer rules adopted by the state for the Neuse River basin, requiring the preservation of existing buffers, apply to intermittent and perennial waterbodies shown on the most recent county soil survey maps or USGS 1:24,000 scale topographic maps. A minimum 50-foot (15 m) vegetated buffer is required on each side of a waterbody, the first 30 feet (9 m) of which must remain essentially undisturbed. Exemptions are allowed for various activities. The establishment of new buffers is not required unless existing land use changes. Stormwater flows cannot be routed through the buffer in channelized form, but must be converted to sheet flow to provide an opportunity for infiltration and pollutant removal.

Both Apex and Cary have instituted buffer protection measures that exceed state requirements on many streams. Apex currently requires 100-foot buffers on perennial streams in water supply watersheds, while Cary requires 100-foot buffers on both perennial and intermittent streams. Much of the existing development in the upper Swift Creek watershed occurred prior to the implementation of the Neuse River buffer rules or the current stringent local requirements.

Neuse stormwater rules. Portions of the study area under the planning jurisdiction of Cary and Wake County are also subject to the Neuse River Basin Stormwater Rules, which became effective in 1998. Nitrogen loading from new development must be held to 3.6 pounds/acre per year, and no net increase in peak flows leaving the site from predevelopment conditions is allowed for the 1-year 24-hour storm. Among the other requirements of this rule are: implementation of public education programs, identification and removal of illegal discharges to the stormwater system, and identification of suitable locations for potential stormwater retrofits. Cary and Wake County have developed locally run programs to address these requirements. Land under the planning jurisdiction of Apex is not subject to the Neuse stormwater requirements. The vast majority of development in the study area predates these requirements.

Phase II stormwater. EPA has developed a Phase II stormwater program, mandating that small communities not previously subject to federal stormwater requirements apply for permit coverage. Communities in urbanized areas designated by the US Bureau of the Census must apply for stormwater permit coverage by March 2003. Apex, Cary and Wake County have all been so designated. The federal regulations discuss development and implementation of comprehensive stormwater management programs including six minimum measures: 1) public education and outreach on stormwater impacts; 2) public involvement/participation; 3) illicit discharge detection and elimination; 4) construction site stormwater runoff control; 5) post-construction stormwater management for new development and redevelopment; and 6) pollution prevention/good housekeeping for municipal operations. In October 2002, the NC

Environmental Management Commission passed a temporary rule governing the implementation of the Phase II program in the state.

Other regulations. Apex, Cary and Wake County all have delegated local programs under North Carolina's Sedimentation Pollution Control Act and regulate erosion and sediment from construction in their respective jurisdictional areas. The Cary, Apex and Wake County floodplain ordinances are applicable in the study area.

Wake County Watershed Plan. In the fall of 2000, the Wake County Commissioners initiated a process for the development of a watershed management plan for the County. A Watershed Management Task Force, consisting of local elected officials and others appointed by the Commissioners, was established to oversee the process. The plan development process included an assessment of current stream and watershed conditions and an evaluation of options and strategies to protect and restore water quality. The consulting firm CH2M Hill was hired by the county to develop the plan, working closely with the Task Force and local government staff. The plan, completed in January 2003, includes the Task Force's recommendations to the Wake County Commissioners and local governments regarding actions to further water quality protection and restoration (WCWMPTF, 2003). For purposes of the plan, the County was divided into 81 watersheds, one of which is the upper Swift Creek study area.

Citizen activities. There has been a substantial concern expressed by local residents about water quality issues. Residents in the less developed portions of the Swift Creek watershed have been attempting to incorporate in an effort to prevent denser development from moving into additional portions of the watershed.

Section 3

Potential Causes of Biological Impairment

The study identified those factors that were plausible causes of biological impairment in the upper Swift Creek watershed using both biological assessment and watershed-based approaches. An evaluation of benthic community data and other biological and habitat indicators can point toward general types of impacts that may likely impact aquatic biota. These stressors were flagged for further investigation. Land uses and activities in the Swift Creek watershed were also examined to identify potential stressors for further evaluation.

3.1 Key Stressors Evaluated in the Swift Creek Watershed

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

1. *Habitat degradation--sedimentation.* Sedimentation impacts habitat through the loss of pools, burial or embedding of riffles, and in many cases, high levels of substrate instability. Excess sedimentation was historically listed as a problem parameter for upper Swift Creek on the 303(d) list, and thus, merited further evaluation.

2. *Habitat degradation-- lack of key microhabitat.* Preliminary watershed investigations indicated that while habitat conditions are quite variable in Swift Creek and its tributaries, important microhabitats for benthic macroinvertebrates -- such as woody debris, leaf packs and root mats -- may be present in only limited amounts in some areas. The degree of, reasons for, and biological implications of habitat degradation needed further evaluation.

3. *Hydromodification--scour due to stormflows.* Highly developed watersheds, such as the upper Swift Creek drainage, often experience rapid changes in streamflows during storms and increased velocities. Increased levels of impervious cover increase the volume and energy of stormflows, which can dislodge aquatic macroinvertebrates and some microhabitats from the stream.

4. *Hydromodification--dams.* In-stream impoundments that do not release water during dry periods can contribute to habitat loss and potentially exacerbate low dissolved oxygen levels. Given the large number of tributary impoundments in the watershed, the presence and management of dams merited investigation.

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

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

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

An initial review of the benthic community data for Swift Creek indicated potential impacts from organic loading in some portions of the stream (see Section 4).

Section 4

Biological Conditions and Stream Habitat

Biological assessment (bioassessment) involves the collection of stream organisms and the evaluation of community diversity and composition to assess water quality and ecological conditions. Evaluation of habitat conditions at sampling locations is an important component of bioassessment.

Prior to this study, DWQ's Biological Assessment Unit collected benthic macroinvertebrate samples from various sites in the upper Swift Creek watershed in 1980, 1989, 1991 and 1995. The stream was rated Fair at Holly Springs Road in 1989 and 1995, and most tributaries sampled were rated Fair or Poor. Available data indicate that the benthic community was more diverse in 1980.

DWQ has sampled fish at Holly Springs Road on a number of occasions between 1995 and 2000. The fish community was rated Poor in 1995 and has fluctuated between Fair and Good-Fair in more recent sampling years. Species diversity at this site is low (NCDWQ, 2001b) and an altered trophic structure is evident, with common omnivorous species (e.g., bluehead chub) largely absent.

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

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

This section describes the approach to bioassessment used during the study and summarizes the results of this work. Benthic macroinvertebrate sampling and habitat assessments conducted by CH2M Hill as a part of Wake County's watershed management plan development (see Section 2) are also summarized. A more detailed analysis of the condition of aquatic macroinvertebrate communities in the Swift Creek watershed may be found in Appendix A.

4.1 Approach to Biological and Habitat Assessment

Benthic macroinvertebrate community samples were collected during the study at six sites in the watershed (Figure 4.1) and one location on a reference stream outside of the study area. Sites are described in Section 4.2. The reference stream does not represent undisturbed conditions, but serves as a comparison site in a less impacted watershed within the same ecoregion and general geology as Swift Creek. Sampling took place in April, May and July 2000, and in April and June 2001.

4.1.1 *Benthic Community Sampling and Rating Methods*

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

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

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

Historical sampling sometimes used methods other than those described above. At some sites, a modified Qual 4 (termed EPT method) was used in which Qual 4 sampling procedures were used but only EPT taxa were identified. Samples collected in 1980 used kick-net samples only. Since only a single habitat type (riffles) was sampled, this method will produce lower taxa richness than the methods used subsequently.

The use of *Chironomus mentum* (mouth structure) deformities is a good tool for toxicity screening (Lenat, 1993). At least 20-25 *Chironomus* are evaluated for deformities and a "toxic score" is computed for each site. DWQ data have shown the percent deformities for sites rated Excellent, Good, and Good-Fair averaged about 5%, with a mean toxic score of about 7. Sites with Fair and Poor bioclassifications with stressors considered nontoxic were combined into a polluted/nontoxic group, with a deformity rate of 12% and a mean toxic score of 18. "Nontoxic" conditions for this group includes solely organic inputs and natural organic loading (swamps). Finally, sites affected by a toxic stressor had higher deformity rates. A Fair/Toxic group had a 25% deformity rate and a mean toxic score of 52. A further significant increase was seen for the Poor/Toxic group: mean deformity rate = 45%, mean toxic score = 100. In the Swift Creek

watershed, sufficient numbers of *Chironomus* for the deformity analysis were only collected at one location and date—at Hemlock Bluffs in May 2000.

4.1.2 *Habitat Assessment Methods*

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

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

4.2 **Results and Discussion**

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

Williams Creek and Tributaries

Williams Creek at US. 64. This site, located approximately one-half mile below Summit Lake, was the most upstream station on Williams Creek. The in-stream habitat for this site consisted primarily of rocks, with few sticks, leaf packs, root mats or other microhabitat. The bottom substrate was mostly gravel and sand. The banks were unstable and sparsely vegetated. Although not rated because of its width, the benthic community was highly degraded, with only 6 EPT taxa and a Biotic Index among the highest found during the study. Frequent low flows due to the impoundment just upstream may contribute to benthic community impacts.

Williams Creek at MacGregor Center. This site is located in the MacGregor Center office park on Edinburgh Drive, downstream of Gregson Drive (Exhibit 4.1). The riparian zone is managed turf. Shading is minimal, and parking lots a few meters from the stream provide immediate hydrologic and pollutant inputs. Banks are highly unstable. Instream habitat was poor, consisting primarily of undercut banks and rocks. Riffle substrate consisted of rocks that were used to stabilize banks. This site was sampled three times during the study and the benthic community was highly degraded on all occasions. Impacts from low water conditions may occur during the summer, but these effects can be difficult to separate from other factors.

Williams Creek at US 1. This site, located approximately one-quarter mile downstream of the MacGregor Center site, was not sampled during the study, but was sampled on four occasions historically, and is comparable to the MacGregor Center location. The decline in larger substrates such as gravel and rubble since 1980 and the increase in silt and sand during that period are notable. This station, like the other sampling sites in the Williams Creek drainage, is located in the Carolina Slate Belt. Cobble and large gravel substrate are generally abundant in Slate Belt streams if not buried by deposited sediment or removed during channelization. Overall, data from this site and the adjacent MacGregor Center site suggest that benthic community conditions have not changed significantly over the last 12 years, but that conditions have declined since 1980. The 1980 collection was based only on kick samples, yet yielded considerably higher EPT taxa richness than for any subsequent sampling. Review of 1980 data suggests that a Good-Fair rating would have been assigned to this and the other stations sampled at that time (Lenat, 1989).

UT Williams Creek (Apex Branch) at McKenan Drive. This tributary, which enters Williams Creek between the US 64 and MacGregor center sites, is the largest unimpounded tributary in the study area (Exhibit 4.2). It was sampled downstream of MacKenan Drive, just above the confluence with Williams Creek. A sewer line parallels the right bank, but both banks have a forested buffer. In-stream habitat consisted of rocks, macrophytes, some leaf packs and sticks, and some undercut banks. Many habitats were inaccessible during baseflow (undercut banks and root mats were above the water surface). It appears that the tributaries in the headwaters of Williams and Swift Creeks frequently experience low flow conditions. Only seven EPT species were collected. Taxa tolerant of low dissolved oxygen (DO) were found. Dissolved oxygen levels at the time of benthic sampling (5 mg/L) were considered low for the time of year (May).

Swift Creek and Speight Branch

Swift Creek at Hemlock Bluffs Nature Preserve. This station, the most upstream location sampled on the mainstem of Swift Creek (Exhibit 4.3), is a few hundred meters upstream (west) of SR 1300 (Kildaire Farm Road). The site was also sampled in 1989 and a location just upstream was sampled in 1980. During the current study, the site was accessed from Cary's Ritter Park, which is across the creek from Hemlock Bluffs Nature Preserve. A paved greenway and sewer right of way run along the north bank. Coarse substrate was common; the local geology (Raleigh Belt) and topography (bluffs) provide a ready source of this material. In 2000 and 2001, there were few leaf packs present and a noticeable lack of snags and logs. Overall, reach habitat was better here than at other sites sampled in the study area. Only nine EPA taxa were collected on each of the sampling occasions during the study, which yielded bioclassifications of Fair and Poor. In the May 2000 sample (bioclassification of Poor), there was an abundance of taxa often indicative of organic loading (e.g., *Chironomus* spp.). A midge deformity analysis resulted in a score of 40, indicating the presence of some toxicity. The June 2001 sample (bioclassification of Fair) did not include sufficient *Chironomus* to repeat the midge deformity analysis. Indicators of organic enrichment were absent in this second sample and few toxic indicator taxa were present.

Swift Creek at Holly Springs Road. This is the most downstream site in the survey and is located below Lochmere Golf Club and just upstream of the confluence with Speight Branch (Exhibit 4.4). The southern bank contains Swift Creek Bluffs Nature Preserve (Triangle Land Conservancy property). Although both banks have a forested buffer, they are undergoing

moderate to severe erosion. The habitat was better than at most other sites, and debris jams (downed trees) were common. Sand and gravel make up the majority of the substrate. The midge assemblage in the spring 2000 sample indicates possible toxic effects, although the number of *Chironomus* spp. was insufficient to conduct a midge deformity analysis. The spring 2001 sample did not contain a midge assemblage indicative of toxicity. All surveys at this site (during the current study and in 1995 and 1989) yielded a Fair bioclassification. When comparing spring sampling data from 1989, 2000 and 2001 and allowing for sample type, there is no apparent change in community composition indicating changes in water quality over the past dozen years. Review of 1980 data suggests that a Good-Fair rating would have been assigned to this station at that time (Lenat, 1989).

Speight Branch at SR 1385 (Lilly Atkins Road). This small tributary enters Swift Creek just upstream from Holly Springs Road, and immediately downstream of the Swift Creek sampling location. The surrounding catchment consists of suburban residences, but the stream flows through a forested zone and along a sewer line right-of-way. The habitat was good and the specific conductance (82 $\mu\text{mhos/cm}$) was lower than any other site in the watershed. Though not rated due to its width, the benthic community was degraded at this site.

Reference

Upper Barton Creek at NC 50 (Creedmoor Road). This stream (not shown on Figure 4.1), located on the outskirts of North Raleigh, was selected as a comparison site for Swift Creek. The sampled reach and most of the watershed are located in the Raleigh Belt, with a portion of the headwaters lying in the Carolina Slate Belt. The benthic community was classified as Good during the early 1990s (Appendix A), though it was rated Good-Fair on both occasions sampled during the present study. When last sampled in 2001, there was a good mix of substrates, with numerous pools and riffles despite a significant amount of sand (25% of substrate). Benthic habitat was diverse -- sticks and leaf packs were common, as were undercut banks. This site is similar in width to Swift Creek from Hemlock Bluffs down to the Holly Springs Road site. EPT taxa richness values are higher and Biotic Index values are lower than any of the sites sampled in the Swift Creek watershed during the study. Both metrics have declined since 1991, as residential development has expanded into this watershed. Noticeable habitat changes from previous years included an increase in riffle embeddedness.

4.3 Wake County Data

As a part of the development of the Wake County Watershed Management Plan, CH2M Hill sampled benthic macroinvertebrates at Holly Springs Road in 2001. The site received a Fair rating, comparable to DWQ sampling results. Eight EPT taxa were collected and the BI was 6.06.

CH2M Hill also evaluated stream habitat at numerous locations in the County, including 11 sites in the study area and in Upper Barton Creek (Table 4.2) using a protocol developed for Mecklenburg County based on EPA's rapid bioassessment habitat method. Procedures are described in CH2M Hill (2001). Habitat condition was rated as optimal, sub-optimal, marginal or poor. Most sites in the study area received a rating of marginal, with the best habitat (sub-optimal) found in several tributaries (Apex Branch and Regency Branch).

4.4 Summary of Conditions and Nature of Impairment

Benthic community data collected during the study indicate that Swift Creek is impaired for its entire length within the study area and that Williams Creek is also impaired below Summit Lake. While comparison of data from different time periods is difficult due to changes in sampling methods, it appears that streams in the study area, though degraded, were not impaired when benthos were first sampled in 1980. When the watershed was next sampled in 1989, impairment was widespread in the mainstem of Swift and Williams Creeks, a situation that remains today. Upper sites, where the creeks are smaller, may be subject to stresses associated with low streamflows. Pollution tolerant taxa are common at all sampling locations, and there is evidence of at least intermittent toxicity in the mainstem of Swift Creek at Hemlock Bluffs and Holly Springs Road.

Reach habitat is quite variable, with some sites having wide forested riparian zones and good riffle habitats and other exhibiting less favorable characteristics. Some sediment deposition is evident in the stream, although massive deposits are present only in localized areas, most notably in Williams Creek in the MacGregor Center area. Root mats and other microhabitat were often unavailable to macroinvertebrates during baseflow due to the incised nature of stream channels in the watershed.

In contrast, a comparison stream (Upper Barton Creek), which drains a developing, though much less intensely modified watershed than Swift Creek, supports a more diverse and less stressed benthic fauna and better in-stream habitat.



Exhibit 4.1 Williams Creek in MacGregor Center Office Park



Exhibit 4.2 Apex Branch at MacKenan Drive



Exhibit 4.3 Swift Creek at Hemlock Bluffs



Exhibit 4.4 Swift Creek at Holly Springs Road

Table 4.1 Selected Benthic Community and Habitat Characteristics¹, Upper Swift Creek Study Sites

Location	Date	Stream Width (m) ²	Substrate: % sand and silt ³	Habitat Score (max. of 100) ⁴	In-stream Structure Score (max. of 20) ⁵	Embed -edness (max. of 15) ⁷	EPT ⁶ Taxa Richness	EPT ⁶ Biotic Index	Biotic Index ⁶	Bioclassification ⁶
Williams Creek at US 64	5/19/00	2	60	54	11	2	6	6.69	7.30	Not Rated*
UT Williams Creek (Apex Branch) at MacKenan Dr.	5/19/00	3	10	67	13	14	7	6.59	6.62	Not Rated*
Williams Creek at MacGregor Center	4/10/01	3	60	59	11	14	7	6.88	7.14	Not Rated*
	7/5/00	2	43	50	14	6	5	6.72	--	Not Rated**
	5/10/00	3	40	46	10	6	8	6.78	7.00	Not Rated*
Williams Creek at US 1	7/24/95	5	90	--	--	--	4	7.42	--	Poor**
	7/9/91	2	40	--	--	--	10	6.28	--	Not Rated**
	3/2/89	6	70	--	--	--	9	6.34	--	Fair**
	3/80	5	20	--	--	--	14	NA	NA	NA
Swift Creek at Hemlock Bluffs	6/21/01	5	65	70	16	14	9	6.62	6.87	Fair
	5/3/00	7	20	76	14	12	9	6.33	7.37	Poor
	3/2/89	7	60	--	--	--	14	6.18	--	Good-Fair**
	3/80	8	20	--	--	--	10	NA	NA	NA
Swift Creek at Holly Springs Road	4/9/01	4	50	77	16	10	10	6.44	6.83	Fair
	7/5/00	7	50	61	12	6	9	6.81	--	Fair**
	4/24/00	9	25	73	16	6	12	6.41	6.84	Fair
	7/24/95	4	60	--	--	---	7	6.35	--	Fair**
	3/6/89	8	45	--	---	--	9	6.17	--	Fair**
Speight Branch at SR 1385	5/2/00	3	50	80	15	8	6	5.51	6.76	Not Rated
Upper Barton Creek at NC 50	4/10/01	4	25	87	16	15	18	4.68	5.48	Good-Fair
	8/10/00	5	50	83	20	6	14	5.44	--	Good-Fair**

1. Habitat data available for 2000 and 2001 samples only.

2. Wetted channel width at time of sampling.

3. Based on visual estimate of substrate size distribution.

4. See text for list of component factors.

* Qual 4 method.

** Qual 4 method used but only EPT species evaluated. BI was not calculated.

NA Not applicable. Based on kick sample only. See text for discussion.

5. Visual estimate of in-stream habitat variety and area available for colonization.

6. See text for description.

7. Extent to which rocks (gravel, cobble and boulder) are covered by finer sediments.

Table 4.2 Habitat Data Collected by CH2M Hill in Upper Swift Creek and Upper Barton Creek, 2001

Wake County ID Code	Stream	Site Location	Habitat Score**	Habitat Condition
HA-27	Williams Ck.	Old Raleigh Rd.	76.0	Marginal
HA-28	Apex Branch	W Sterlington Pl and Mellonsbury Dr.	106.5	Marginal/Sub-optimal
HA-26	Apex Branch*	MacKenan Dr.	128.0	Sub-optimal
HA-25	Williams Ck.*	MacGregor Village Shopping Center	79.0	Marginal
HA-19	Regency Branch	Above Regency Park at Glade Park Rd.	135.0	Sub-optimal
HA-18	UT Swift Ck. (southern fork)	Ave. of the Estates	86.0	Marginal
HA-20	UT Swift Ck. (northern fork)	Ave. of the Estates	84.5	Marginal
HA-23	Swift Ck.	Greenway between Regency Pkwy. and SR 1300	91.5	Marginal
HA-21	Swift Ck.	Kildaire Farm Rd. (SR 1300)	106.5	Marginal/Sub-optimal
STA-16	Swift Ck*.	Holly Springs Rd. (SR 1152)	85.0	Marginal
HA-15	Speight Branch*	Lilly Atkins Rd. (SR 1385)	82.5	Marginal
HA-79	Upper Barton Ck.*	NC 50	113.5	Sub-optimal

Source: CH2M Hill

* Site was also a DWQ benthic sampling location during 2000-2001.

** Maximum score of 200.

Section 5

Chemical and Toxicological Conditions

Water quality assessment provides information to evaluate whether chemical and physical conditions negatively affect benthic communities. Two broad purposes of this monitoring are:

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

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

DWQ has an ambient station below Lake Benson, but data from this location are unlikely to provide useful information about water quality in the upper watershed due to the impacts of Lakes Benson and Wheeler. From 1988-94 the USGS conducted water quality sampling at Holly Springs Road as part of the Triangle Water Supply Monitoring Project (Garrett et al., 1994; Childress and Treece, 1996). The Lower Neuse Basin Association (LNBA), a coalition of municipalities and industries discharging wastewater below the Falls of the Neuse Reservoir, has been conducting ambient monitoring on Swift Creek at Holly Springs Road since the late 1990s.

5.1 Approach to Chemical, Physical and Toxicity Sampling

5.1.1 General Approach

General Water Quality Characterization. One station at the downstream end of the study area (Swift Creek at Holly Springs Road) was sampled on a near monthly basis to characterize water quality conditions (see Section 5.2). A standard set of parameters similar to those evaluated at DWQ ambient stations was utilized (see Appendix B). Grab samples were collected during both baseflow and storm conditions. Baseflow periods were defined as those in which no measurable rain fell in the watershed during the 48-hour period preceding sampling. Storm samples were collected on the rising stage of the hydrograph. Fecal coliform samples were collected under baseflow conditions on five occasions between August 19 and September 18, 2001.

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

Sampling focused primarily on those physical and chemical parameters that preliminary investigations indicated merited investigation as plausible causes of biological impairment. As discussed in Section 3, these included low dissolved oxygen, nutrients and toxicity from a variety

of potential sources. Because of the diverse land use in the upper Swift Creek watershed and the wide variety of activities that could potentially result in toxicity, storm event sampling included a wide range of pollutants, including:

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

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

Field measurements (pH, dissolved oxygen, specific conductance standardized to 25 degrees C and temperature) were made on numerous occasions throughout the watershed to further characterize water quality conditions. Data sondes--multiparameter probes with a data logging capability--were deployed at six locations in the watershed at various times during 2000 and 2001 (a total of twelve individual deployments). Field parameters were recorded every 15 minutes during these deployment periods.

Extended in-stream monitoring to evaluate long-term exposure to pollutants was conducted using semi-permeable membrane devices (SPMDs). These are passive sampling devices that accumulate hydrophobic organic pollutants to which the devices are exposed during deployment (see Appendix B for additional details). SPMDs were deployed at three locations (SWSC01, SWSC03 and SWAP01) for one seven-day period during December 2001. The SPMDs were analyzed for PAHs, PCBs, organochlorine pesticides and selected current use pesticides.

Bed sediment was collected from the Swift Creek mainstem at Holly Springs Road and at Hemlock Bluffs, as well as from Upper Barton Creek. The Upper Barton Creek samples were collected for reference purposes. Sediments were analyzed for pesticides, metals, PAHs, PCBs, semi-volatile organic pollutants and chronic toxicity. A forty-two day chronic toxicity bioassay was performed using *Hyallela azteca* as described in ASTM (2000) and USEPA (2000b).

Water and Sediment Benchmarks. To help evaluate whether observed concentrations are likely to have a negative impact on aquatic life, water column concentrations were compared to EPA's National Ambient Water Quality Criteria (NAWQC) for freshwater (USEPA, 1999) and Tier II benchmarks (USEPA, 1995). Metals benchmarks were adjusted for hardness where recommended (USEPA, 1999). For chromium, the NAWQC for Cr VI was used. The use of NAWQC and other benchmarks is discussed in more detail in Appendix B.

Sediment data were compared to a set of sediment benchmarks used by the DWQ Aquatic Toxicology Unit (Appendix B). These were grouped into conservative and non-conservative ranges in the manner of MacDonald et al. (2000). Conservative ranges ('no or low effects' benchmarks) are sets of threshold values, below which there is low probability of toxicity. Region 4 USEPA values are included in the set of conservative values, but they are also presented by themselves because the DWQ Aquatic Toxicology Unit uses these as initial screening benchmarks. Non-conservative ranges ('probable effects' benchmarks) are sets of values above which there is a high probability of toxicity. If a measured value falls between the low value of the conservative range and the high value of the non-conservative range, it is possible that it is toxic, with higher concentrations indicating an increased probability of toxicity.

Benchmarks were used for initial screening of potential impacts. All lines of evidence available, including toxicity bioassays, benthic macroinvertebrate data, in addition to data on analyte concentrations, were utilized to make the final evaluation of the likely potential for pollutants to negatively impact aquatic biota.

5.1.2 Site Selection

Primary chemical and toxicological sampling stations (Figure 5.1 and Table 5.1) are listed below. Some were also sampled for benthic macroinvertebrates and described in Section 4.

- *Swift Creek at Holly Springs Road (SWSC01).* This site was located at the downstream end of the study area and served as the integrator station where overall water quality conditions were documented. This site was also a LNBA monitoring site and a biological monitoring location. Because the concurrent macroinvertebrate sampling suggested ongoing water quality problems, stressor identification and toxicity sampling were also conducted at this location.
- *Speight Branch at Lilly Atkins Road (SWSP01).* This site was located on a relatively small unimpounded tributary of Swift Creek that enters the mainstem just below the integrator station. This site was also a biological monitoring station.
- *Long Branch at Lochmere Golf Club (SWLG01).* This site was located immediately upstream of the confluence of Long Branch with Swift Creek. It was sampled to identify pollutant inputs from Long Branch and the golf course.
- *Swift Creek at Kildaire Farm Road (SWSC02).* This site was located just upstream of Lochmere Golf Club. Stressor identification and toxicity testing were done here as an upstream comparison for SWSC01.

- *Swift Creek at Hemlock Bluffs (SWSC02.2)*. This site is located adjacent to where the trail from Ritter Park enters the greenway along Swift Creek opposite Hemlock Bluffs Nature Preserve. Biological, sediment and data sonde sampling were done here.
- *Swift Creek at Regency Parkway (SWSC03)*. This site is located upstream of the bridge crossing Swift Creek, just downstream from the confluence of Williams Creek and Cary Branch. Toxicity and stressor identification sampling was done here to document conditions in the upper watershed.
- *Williams Creek at MacGregor Center Office Park (SWWM01)*. This site was located adjacent to the parking lot serving the MacGregor Center. Biological, toxicity and chemical sampling were conducted at this site.
- *Apex Branch at McKenan Drive (SWAP01)*. This site was located near the mouth of a major unimpounded tributary. Benthos were also collected at this location.
- *Upper Barton Creek at Creedmoor Road (UBUB01)*. This site (not shown on Figure 5.1) served as a comparison site for the Swift Creek mainstem because of its better habitat and biological condition. This watershed is much less developed than the watershed of Swift Creek. Bed sediment samples were collected here.

Table 5.1 Summary of Monitoring Approaches Used at Primary Sampling Sites

STATION			MONITORING APPROACH				
Code	Location	Benthos	Water Quality ¹	Toxicity (water)	Bed Sediment	SPMD ²	Data Sonde
Swift Creek	SWSC01	Swift Creek at Holly Springs Road ³	X	X	X	X	X
	SWSP01	Speight Branch at Lilly Atkins Road	X				X
	SWLG01	Mouth of Long Branch at Golf Course		X			
	SWSC02	Swift Creek at Kildaire Farm Road		X	X		X
	SWSC02.2	Swift Creek at Hemlock Bluffs	X			X	X
	SWSC03	Swift Creek at Regency Parkway		X	X		X
	SWWM01	Williams Creek at MacGregor Office Park	X	X			X
	SWWM02	Williams Creek at US 64	X				
	SWAP01	Apex Branch at McKenan Drive	X	X	X		X
Ref	UBUB01	Upper Barton Creek at Creedmoor Road	X	X		X	

¹ Grab samples and/or repeated field measurements

² SPMD--semipermeable membrane device

³ Integrator Station

5.2 Water Quality Characterization

During the period between February and September 2001, eight baseflow and four storm samples were collected at Swift Creek at Holly Springs Road (SWSC01) in order to characterize chemical and physical conditions in the study area. Selected results are shown in Table 5.2 (also see Appendix B). LNBA data for 2000 and 2001 are presented for comparison purposes.

Table 5.2 Mean Values of Selected Parameters for DWQ and Lower Neuse Basin Association Data, Swift Creek at Holly Springs Road

PARAMETER	BASEFLOW			STORMFLOW			LNBA DATA (2000-2001)		
	N	MEAN	RANGE	N	MEAN	RANGE	N	MEAN	RANGE
DO (mg/L)	9	7.2	4.5 - 11.5	4	6.8	5.7 - 8.7	33	6.6	4.7 - 10.5
pH (Standard Units)	8	6.8	6.3 - 7.4	4	7.1	7.0 - 7.2	33	6.8	6.0 - 7.8
Specific Conductance (µS/cm)	8	86	67 - 101	4	77	57 - 102	33	102	55 - 143
Turbidity (NTU)	8	7.0	2.8 - 11.1	4	240.8	92.5 - 432	23	11.2	3.2 - 38
Ammonia Nitrogen (mg/L)	8	0.09	0.05 - 0.10	4	0.50	0.10 - 0.80	23	0.07	0.01 - 0.35
Total Kjeldahl Nitrogen (mg/L)	8	0.9	0.6 - 1.4	4	1.7	1.0 - 2.2	21	0.4	0.1 - 1.0
Nitrate+Nitrite Nitrogen (mg/L)	8	0.16	0.02 - 0.30	4	0.37	0.32 - 0.49	23	0.10	0.01 - 0.29
Total Nitrogen (mg/L)	8	1.0	0.8 - 1.6	4	2.1	1.3 - 2.7	21	0.5	0.1 - 1.2
Total Phosphorus (mg/L)	8	0.06	0.03 - 0.11	4	0.19	0.09 - 0.32	22	0.08	0.01 - 0.66

- Dissolved oxygen levels at Holly Springs Road were generally adequate during both storm and baseflow conditions, though values under 5 mg/L were recorded by both DWQ and the LNBA.
- Turbidity levels were elevated during storms (mean = 240 NTU). These values are somewhat higher than at sites further upstream.
- Nitrogen and phosphorus concentrations were elevated compared to unimpacted streams (Caldwell, 1992), especially during storms. Nitrogen concentrations in LNBA samples were generally lower than in DWQ samples.
- Fecal coliform bacteria were measured five times in a 30-day period in August and September 2001. The geometric mean for the five samples was 68 colonies per 100 ml (Table 5.3), well below the North Carolina standard of 200 col/100 ml. LNBA data indicate a somewhat higher fecal coliform level (geometric mean of 184 for all samples from 2000-2001).

Table 5.3 Fecal Coliform Monitoring Results at Holly Springs Road (SWSC01)

DATE (2001)	COLONIES (per 100 mL)
August 19	69
August 23	82
August 29	78
September 13	45
September 18	72
GEOMETRIC MEAN	68
NC STANDARD	200

5.3 Stressor and Source Identification

Given the complexities of land use and management in this developed watershed, a wide range of chemical stressors could potentially impact water quality in Swift Creek. Pesticides, herbicides and commercial fertilizers are used by the two golf courses, landscaping companies and by homeowners throughout the watershed. Benthic macroinvertebrate community assessment and midge deformity analysis suggest toxicity and /or organic enrichment at sites SWSC03 and SWSC01.

Water column sampling bearing on toxic impacts (conducted primarily at SWSC03 and SWSC01) included: laboratory bioassays (primarily acute), chemical pollutant monitoring (grab samples analyzed for metals, pesticides and other organic compounds), and deployment of SPMDs to sample a broad array of organic contaminants. Results of this sampling are discussed below. Bed sediments at SWSC01 and SWSC02.2 were studied for the presence of toxic conditions. Sediment toxicity assessment work (presented in 5.3.2) included: 42-day toxicity bioassays and chemical analyses for metals, semi-volatile organic compounds, PAHs, TPHs and pesticides.

5.3.1 Water Column Toxicity

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

a. Bioassays

A total of 12 acute bioassays were conducted on storm samples collected at three locations between March and July 2001 (Table 5.4). Two chronic bioassays were performed on baseflow samples from SWSC01 during August and September 2001.

There was no indication of toxicity in the acute bioassays except for the 6/01/01 event at Holly Springs Road. This test failed with a LC₅₀ of 61% (mortality of 50% of test organisms when sample was diluted to an estimated 61% of ambient concentration). One hundred percent mortality occurred for test organisms at ≥75% ambient sample concentration. A concurrent toxicity analysis upstream at Regency Parkway (SWSC03) passed with no mortality.

High metals concentrations (see discussion below) provide one plausible explanation for the toxic event at Holly Springs Road although this is not conclusive. Pesticide analyses were not conducted during this storm. Diethylphthalate and butylbenzylphthalate were detected in the SWSC03 sample and diethylphthalate was detected at SWSC01. Phthalates are common laboratory chemicals and their presence may be the result of sampling or laboratory contamination. The concentration of diethylphthalate in the SWSC01 sample (15 µg/L) was well below Tier II acute and chronic screening values for aquatic life (1800 µg/L and 210 µg/L, respectively).

Two chronic toxicity tests were also conducted with samples collected at SWSC01 (Table 5.4). Both passed with regard to reproduction, although the 8/23/01 sample had approximately a 9% reduction in reproduction as compared to the control. This level of reduction is at the borderline of test sensitivity and may or may not indicate an actual toxic effect. Neither organic compounds

nor metals were detected in this sample at levels at which toxic impacts would be clearly expected.

Table 5.4 Chronic and Acute Bioassays—Water Column

Date (all 2001)	SWSC01		SWSC03	SWWM01
	Chronic Bioassay	Acute Bioassay	Acute Bioassay	Acute Bioassay
March 15	-	pass	pass	-
April 25	-	pass	pass	-
June 1	-	fail*	pass	-
June 13	-	pass	pass	pass
July 26	-	pass	pass	pass
August 23	pass**	-	-	-
September 14	pass	-	-	-

* LC₅₀ = 61.2%.

- Indicates no test.

** Sample reproduction = 91.3% of control.

Additional test data in Appendix B

b. Pesticides and Other Organic Compounds

Grab samples. Organic chemical analyses (TPHs, MTBE, semi-volatile organic compounds, MBAS, phenols and PAHs) were conducted on baseflow samples collected at SWSC01, SWSC02, SWSC03 and SWWM01. Other than pesticides and MBAS, diethylphthalate and butylbenzylphthalate (discussed above) were the only organic contaminants detected.

Five current-use pesticides were detected in the watershed: carbaryl, chlorothalonil, chlorpyrifos, diazinon and simazine (Table 5.5). Simazine was reported in nearly all samples and diazinon was detected on seven occasions. Diazinon is an organophosphate insecticide sold under trade names such as Spectracide and Gardentox. Simazine is a triazine herbicide used for preemergent control of broad leaf weeds and sold under trade names such as Princep. Both are among pesticides commonly used by homeowners and frequently found in urban and suburban streams in North Carolina (Oblinger and Treece, 1996; Bales et al., 1999) and throughout the nation (Schueler, 1995; Hoffman et al., 2000).

During the storm event of 7/26/01, diazinon exceeded the Tier II acute screening value (USEPA, 1995) of 0.017 µg/L at SWSC02 and SWWM01. An acute toxicity test conducted at SWWM01 passed, while no test was conducted at SWSW02. Diazinon exceeded the Tier II chronic benchmark of 0.043 µg/L in one baseflow sample (9/18/01). No toxicity test was conducted. All chlorpyrifos concentrations were below NAWQC (0.041 µg/L chronic and 0.083 µg/L acute). The remaining three pesticides detected do not have published ecological screening benchmarks, but the concentrations observed are below reported effects concentrations from the literature. See Appendix B for additional discussion. Simazine concentrations above 1 µg/L were found in Williams Creek, Long Branch and throughout Swift Creek suggesting widespread usage in the watershed. Most other pesticides were also detected in more than one stream.

Five pesticides were detected in samples collected by the USGS from 1989-1992 at Holly Springs Road as part of the Triangle Water Supply Monitoring Project (Table 5.6). Diazinon was present at levels exceeding the Tier II chronic screening value.

Table 5.5 Current-Use Pesticide Concentrations in Water Samples (µg/L)

SITE CODE	DATE	FLOW CONDITION	PESTICIDE				
			carbaryl	chlorothalonil	chlorpyrifos	diazinon	simazine
SWSC01	03/15/01	Storm	-	-	-	-	-
	04/25/01	Storm	-	-	0.014	-	3.16
	06/13/01	Storm	3.62	-	-	-	0.68
	07/26/01	Storm	-	-	-	-	-
	08/23/01	Baseflow	-	-	-	-	-
	09/13/01	Baseflow	-	0.023	-	0.018	0.008
	09/18/01	Baseflow	-	0.04	-	0.056	0.017
SWLG01	04/25/01	Storm	-	-	0.019	-	0.84
SWSC02	04/25/01	Storm	-	-	-	-	1.97
	07/26/01	Storm	-	-	-	0.24	0.47
	09/24/01	Storm	-	0.007	-	0.036	0.005
SWSC03	03/15/01	Storm	-	-	-	-	5.87
	04/25/01	Storm	-	-	0.009	-	0.059
	06/13/01	Storm	-	-	-	-	0.37
	07/26/01	Storm	-	-	-	-	0.71
	09/24/01	Storm	-	0.032	-	0.019	0.009
SWWM01	06/13/01	Storm	0.78	-	-	-	0.68
	07/26/01	Storm	-	-	-	0.28	2.6
	09/24/01	Storm	-	-	-	0.007	0.041

- Indicates analyte concentration was below the 0.005 µg/L detection limit

Table 5.6 Organic Compounds Detected by the USGS, Swift Creek at Holly Springs Road (1989-1992)

Analyte (µg/L)	N	# DETECTS	MEDIAN	MINIMUM	MAXIMUM	BENCHMARKS ¹	
						CHRONIC	ACUTE
chlorpyrifos	5	3	0.01	< 0.01	0.01	0.041	0.083
lindane	9	4	0.001	< 0.001	0.001	0.08	0.95
dieldrin	9	2	< 0.001	< 0.001	0.003	0.056	0.24
heptachlor epoxide	9	1	< 0.001	< 0.001	0.002	0.0038	0.52
diazinon	7	6	0.02	< 0.01	0.09	0.043	0.17
MBAS	14	14	35	0.01	60	--	--

¹ NAWQC except diazinon (Tier II) and lindane (gamma-BHC) chronic benchmark, which is EPA Region IV chronic surface water screening benchmark. No benchmarks are available for MBAS.

Anionic surfactants (MBAS) were detected in three stormflow samples, two on 7/26/01 at sites SWSC02 (0.029 mg/L) and SWSC03 (0.188 mg/L), and one on 9/24/01 at SWWM01 (0.122 mg/L). None were detected downstream at Holly Springs Road (SWSC01). Notably higher concentrations occurred at the upstream sites. One potential source could be the surfactants used in car washing. The upstream sites (SWSC03 and SWWM01) are nearest to major auto dealers.

An acute bioassay conducted at SWSC03 at 7/26/01 passed. No aquatic life screening benchmark is available for MBAS. The toxicity of specific surfactants varies, and the laboratory test for MBAS does not identify which anionic surfactants are present or their individual concentrations. The common anionic surfactant linear alkylbenzene sulfonate (LAS) can be toxic at concentrations as low as 0.025 mg/L (Kimerle, 1989). The lack of toxic effect at the MBAS concentrations observed in Swift Creek may be explained by the nature of the specific surfactants present (e.g., predominant substances may be less toxic than LAS) by the loss of surfactants during laboratory bioassay procedures or by analytical interferences. In the early 1990s, sampling conducted by the USGS at Holly Springs Road found MBAS levels as high as 0.060 mg/L.

SPMDs. Semi-permeable membrane devices deployed during one eight-day period in December 2001 collected more than 50 different organic compounds including: five organochlorine pesticides, one polychlorinated biphenyl (PCB), 42 polycyclic aromatic hydrocarbons (PAHs), and the current-use pesticides chlorpyrifos and pendimethalin (selected data in Table 5.7; additional results in Appendix B). Other organic compounds detected included benzothiazole, squalene and caryophyllene. SPMD concentrations represent an average concentration over the entire deployment period and are an excellent indication of the hydrophobic organic contaminants to which the sampling site was exposed. These devices do not provide information regarding pulse events such as storms although increased levels during storms can increase the average concentration for the deployment period. There was a one-inch rain event during the deployment. Observed concentrations were generally well below benchmark values. Of the PAHs, fluoranthrene and pyrene were present at the highest concentrations.

Table 5.7 Selected Pollutants Captured by Passive Sampling Devices (ng/L)*

POLLUTANTS (ng/L)		STATION CODE			CHRONIC SCREENING VALUE (ng/L)	ACUTE SCREENING VALUE (ng/L)
		SWSC01	SWSC03	SWAP01		
Current-Use Pesticides	chlorpyrifos	0.57	-	-	41	83
	pendimethalin	-	0.92	3.03	-	-
Miscellaneous Organics	benzothiazole	0.044	-	0.022	-	-
	squalene	-	0.22	-	-	-
	caryophyllene	0.13	-	-	-	-
Chlorinated Pesticides	hexachlorobenzene	-	0.028	0.056	-	-
	alpha chlordane	0.10	0.11	0.11	4.3	2,400
	gamma chlordane	0.065	0.077	0.109	4.3	2,400
	trans-nonachlor	0.044	0.036	0.050	-	-
	4,4'-DDE	-	0.011	0.017	-	-
PCBs (1 total)	PCB 101	0.014	0.015	0.014	14	-
PAHs (42 total)	Sum of PAHs	73	116	92	-	-

* Screening benchmarks are NAWQC. Value for total chlordane is used for alpha and gamma chlordane.

c. Metals

Trace metals were commonly found at all sites that were sampled. Ubiquitous metals include aluminum, iron, manganese and zinc. Table 5.8 presents metals concentrations at Holly Springs Road compared to the hardness-adjusted aquatic life criteria. Baseflow aluminum concentrations are chronically above the benchmark. During stormflows, both aluminum and copper levels tend to exceed acute benchmarks.

Since total rather than dissolved concentrations were measured, metals bioavailability is difficult to fully assess. Adjusting benchmarks for hardness only partially addresses this issue. Metals such as aluminum, iron, manganese, copper and zinc are widespread in North Carolina's waters. Potential effects on benthic macroinvertebrates are uncertain since organisms in a given locality may be adapted to local concentrations.

Two chronic toxicity tests (8/23/01 and 9/13/01) conducted on baseflow samples passed, indicating that observed concentrations of metals in the stream were not sufficient to cause short-term toxic impacts. However, no bioassay was conducted at the time of the 2/29/01 sample, which had the highest aluminum concentrations; or at the time of the 9/18/01 sample, which had extremely high zinc and copper levels and the largest number of metals exceeding screening values during baseflow. The available toxicity test data do not assess the potential toxicity of the metals concentrations occurring on these dates, which may be representative of regularly occurring intermittent concentrations.

As discussed above, an acute toxicity test conducted on at SWSC01 6/1/01, the date of the highest stormflow metals concentrations observed, failed with an LC₅₀ of 61.2%. Particularly of note was the elevated copper level which exceeds the acute NAWQC for aquatic life by a factor of five. Aluminum, cadmium, lead and zinc also exceeded hardness-adjusted acute screening values. While other explanations (including unsampled pollutants) cannot be ruled out, the high concentrations of these five metals provide a plausible explanation for the observed toxicity failure.

Table 5.8 Swift Creek at Holly Springs Road: Total Metals Concentrations and NAWQC Values

METAL (µg/L)	CHRONIC BENCHMARK ¹	BASEFLOW								ACUTE BENCHMARK ¹	STORMFLOW			
		2/9/01	3/12/01	4/11/01	5/31/01	6/29/01	8/23/01	9/13/01	9/18/01		3/15/01	6/1/01	6/13/01	7/26/01
Aluminum	87	350	291	255	149	105	152	192	189	750	253	3200	965	1070
Cadmium	0.9	-	-	-	-	-	-	-	0.4	0.9	0.1	1.3	-	0.3
Chromium	N/A	-	-	-	-	-	-	-	-	16	-	9	-	1
Copper	3.2	-	4	1	-	2	1	1	15	3.6	3	19	4	5
Iron	1000	1030	547	995	752	980	1010	1060	1220	N/A	1320	6380	1510	2060
Lead	0.7	-	-	-	-	-	-	-	3.0	13	2	20	7	4
Manganese	120 ²	83	89	140	89	126	112	86	96	2300	167	1660	217	355
Nickel	18	1	-	1	-	-	-	-	-	140	-	27	-	4
Silver	0.36	-	-	-	-	-	-	-	0.6	N/A	-	-	-	-
Zinc	42	6	6	7	7	15	1	-	234	36	8	98	18	26

¹ Benchmark values are adjusted according to average hardness except for aluminum, iron and manganese for which no conversions were available.

² Tier II benchmark value; NAWQC value not available.

- Metal concentration was below detection limit. Detection limits are found in Appendix B.

5.3.2 *Bed Sediment Toxicity*

a. Bioassays

Bed sediment toxicity and chemistry were evaluated in the mainstem of Swift Creek at Holly Springs Road (SWSC01) and Hemlock Bluffs (SWSC02.2) because benthic community composition and *Chironomus ssp.* deformities indicated potential toxic impacts (Section 4). Upper Barton Creek at Creedmoor Road (UBUB01), outside of the watershed, was sampled as a reference site. Sediments were collected in July 2001 at SWSC01 and UBUB01 and in August 2001 at SWSC02.2. Samples were tested for toxicity using *Hyallela azteca*. None of the test endpoints (28-day survival, 28-day growth, 35-day survival, 42-day survival, 42-day growth, and reproduction at 42 days) met statistical criteria for test failure, but reproduction in the sediments from Hemlock Bluffs appeared to be considerably lower than for the control sample. Conversely, reproduction in sediments from Upper Barton Creek appeared to be considerably higher than for the control sample. See Appendix B for additional details.

b. Pesticides and Organic Compounds

Chemical analyses conducted with these same sediments detected a number of organic compounds (Table 5.9). The current use pesticides chlorpyrifos and simazine were detected at both Swift Creek sampling sites. Additionally, carbaryl and chlorothalonil were present in depositional sediments of SWSC01 and SWSC02.2, respectively. Only atrazine, a pesticide with wide agricultural use, was detected in Upper Barton Creek sediments. Observed concentrations were well below benchmark levels for chlorpyrifos (NYDEC, 1999), the only one of these pesticides for which a screening benchmark is available. A number of organochlorine pesticides that are no longer registered for sale were present in the depositional sediments at all three sites. The presence of these analytes is presumably from past use (e.g., due to erosion of soils to which these pesticides had been applied in the past). Total DDTs, 4,4'-DDE and gamma chlordane were present at both Swift Creek sites at levels that fell in or near the conservative benchmark range, indicating concentrations that may be toxic but for which the probability of toxicity is low. Levels of these particular analytes was actually somewhat higher in Upper Barton Creek, where Total DDTs exceeded the upper end of the conservative range and 4,4'-DDE fell at the lower end of the non-conservative benchmark range. PAHs and base/neutral and acid organics were not detected.

c. Metals

Nine metals were present in the depositional sediments, most of them at all three locations (Table 5.10). Concentrations were generally below the level of screening benchmarks, although at Hemlock Bluffs cadmium was present in the conservative benchmark range, and manganese levels were just below the conservative range. Aluminum, iron and manganese are common constituents of soil clays in this region, most likely accounting for their abundance in stream sediments. While the cumulative effect of these metals could be a potential concern, the chronic bioassay conducted on this sediment did not provide evidence of toxicity.

Table 5.9 Organic Pollutants Detected in Depositional Sediment, Swift Creek and Upper Barton Creek (µg/Kg dry weight)*

ANALYTE (µg/Kg dry weight)		STATION CODE			BENCHMARK VALUES (µg/Kg)		
		SWSC01	SWSC02.2	UBUB01	Conservative	Non-Conservative	EPA Region 4
CURRENT-USE PESTICIDES	atrazine	bdl	bdl	6.10	-	-	-
	carbaryl	3.60	bdl	bdl	-	-	-
	chlorothalonil	bdl	5.00	bdl	-	-	-
	chlorpyrifos	12.00	2.90	bdl	-	-	-
	simazine	2.40	4.60	bdl	-	-	-
ORGANO-CHLORINE PESTICIDES	hexachlorobenzene	0.35	bdl	1.65	10	6 to 240	NA
	alpha chlordane	0.23	0.42	0.60	0.5 to 7	4.79 to 60	0.5
	gamma chlordane	0.67	0.86	1.12	0.5 to 7	4.79 to 60	0.5
	trans-nonachlor	bdl	0.15	0.37	-	-	-
	dieldrin	bdl	bdl	0.39	0.02 to 2.9	4.3 to 1265	0.02
	4,4'-DDT	0.27	bdl	0.14	1.19	4.77 to 25	1.19
	4,4'-DDD	1.15	bdl	0.87	1.2 to 8	7.81 to 60	1.2
	4,4'-DDE	4.21	1.26	6.84	1.42 to 5	6.75 to 374	2.07
Sum of DDTs	5.63	1.26	7.85	1.58 to 7	25 to 4450	1.58	
PCBs	Sum of PCBs	5.85	1.01	6.26	10 to 70	180 to 5300	21.6

*Values in bold type exceed one or more benchmark values. Benchmarks adjusted for total organic carbon where applicable.

Conservative ranges ('no effects' benchmarks) are threshold values below which there is low probability of toxicity. Non-conservative ranges ('probable effects' benchmarks) are sets of values above which there is a high probability of toxicity. See Appendix B.

Table 5.10 Metals Detected in Depositional Sediment, Swift Creek and Upper Barton Creek (mg/Kg dry weight)*

METALS (mg/Kg dry wt.)	STATION CODE			BENCHMARK VALUES (mg/Kg)		
	SWSC01	SWSC02.2	UBUB01	Conservative	Non-Conservative	EPA Region IV
Aluminum	2600	7710	5770	25500	58030 to 73160	-
Cadmium		0.78	0.57	0.58 to 1.2	3 to 41.1	0.68
Chromium	4.3	8.3	15.4	26 to 81	90 to 370	52
Copper	2.5	8.1	7.0	16 to 36	55 to 270	19
Iron	5080	11700	10100	20000 to 188400	40000	-
Lead	4.7	9.2	3.9	30 to 47	69 to 396	30
Manganese	145	457	290	460 to 1673	819 to 11000	-
Nickel			5.9	16 to 40	36 to 75	16
Zinc	19	46	28	98 to 159	271 to 1532	124

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

Conservative ranges ('no or low effects' benchmarks) are threshold values below which there is low probability of toxicity. Non-conservative ranges ('probable effects' benchmarks) are sets of values above which there is a high probability of toxicity. See Appendix B.

5.3.3 Organic Enrichment, Nutrients and Dissolved Oxygen

Dissolved oxygen (DO) was evaluated using several approaches. DO was measured when samples were collected for laboratory analysis. Also, data sondes—multiparameter probes with data logging capability—provided data on daily DO cycles at several locations in the watershed. Nutrients were sampled at SWSC01, SWSC02 and SWSC03 on the mainstem and at SWWM01 on Williams Creek.

The lowest DO levels observed during chemical sampling on the main stem occurred in the afternoon at Holly Springs Road in September 2001 (4.5 mg/L). During field sampling, DO levels tended to be higher at the more upstream sites on the same dates. Results from data sonde deployments indicated a typical daily DO cycle with minimum levels occurring overnight. During data sonde deployments, DO concentrations dropped as low as 3.1 mg/L at Hemlock Bluffs, 4.0 mg/L at Holly Springs Road, and 4.5 mg/L in Williams Creek at MacGregor Center (see Appendix B).

Nutrient concentrations during storm events (Table 5.11) were elevated throughout the watershed. (Baseflow nutrient data were collected only at SWSC01. See Table 5.2). Clear upstream-downstream patterns are not evident from the available data.

Table 5.11 Nutrient Concentrations in the Upper Swift Creek Watershed (mg/L)

PARAMETER	SWSC01			SWSC02			SWSC03			SWWM01		
	N	MEAN	RANGE	N	MEAN	RANGE	N	MEAN	RANGE	N	MEAN	RANGE
Ammonia Nitrogen	4	0.5	0.1 - 0.8	2	0.2	0.1 - 0.2	4	0.3	0.1 - 0.7	3	0.3	0.1 - 0.8
Total Kjeldahl Nitrogen	4	1.7	1.0 - 2.2	2	1.4	1.1 - 1.7	4	1.7	0.9 - 2.5	3	1.8	1.0 - 2.5
Nitrate+Nitrite Nitrogen	4	0.4	0.3 - 0.5	2	0.2	0.2 - 0.2	4	0.3	0.1 - 0.5	3	0.3	0.1 - 0.6
Total Nitrogen	4	2.1	1.3 - 2.7	2	1.6	1.3 - 1.9	4	2.0	1.1 - 2.6	3	2.2	1.2 - 2.6
Total Phosphorus	4	0.19	0.09 - 0.32	2	0.15	0.09 - 0.20	4	0.24	0.1 - .62	3	0.13	0.10 - 0.15

Section 6

Channel and Riparian Conditions

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

Project staff walked the entire mainstem of Swift Creek from its source (confluence of Williams Creek and Cary Branch) to Holly Springs Road, a distance of approximately 2.5 miles, and most of the Williams Creek mainstem from Summit Lake to its mouth, a distance of about two miles. Portions of Apex Branch, Long Branch, Lynn Branch and other tributaries were also surveyed. Some areas were surveyed on numerous occasions. This section summarizes channel and riparian conditions and discusses likely future changes in stream channels. A more detailed description of existing conditions is included in Appendix D.

6.1 Summary of Existing Conditions

6.1.1 Overall Channel and Riparian Condition

Channel Conditions. Swift Creek and its tributaries are moderately to highly incised. The history of this incision is not clear, and some if not much of it likely predates the development of the last quarter century. Bank erosion is common (Exhibit 6.1), although the severity of erosion varies greatly. Many areas have little bank protection but may be eroding only slowly due to the cohesive soils often comprising the lower banks and the stabilizing influence of roots associated with the mature woody vegetation that is frequently present. Although mass failure is occurring at some locations, and the stream is clearly evolving in response to the alteration of watershed hydrology by development, the channel network as a whole is not grossly unstable. The mainstem of Swift Creek appears to maintain its natural sinuosity in many areas, although some reaches have been channelized, as discussed below.

Riparian Conditions. The mainstem of Swift Creek in the study area is protected by a wooded riparian buffer for most of its length. The stream is paralleled by a Cary greenway trail from Regency Parkway to Kildaire Farm Road (Exhibit 6.2). The trail runs within a few yards of the creek in places, but lies more than 50 feet from the stream in most areas. Mature woody vegetation is common. Examination of aerial photographs dating back to the 1940s indicates that the immediate riparian areas along the mainstem have been relatively undisturbed during this period.

The major exception is the area below Kildaire Farm Road, where the stream runs through the Lochmere Golf Club. Here wooded riparian vegetation is sparse and managed turf often borders the stream (Exhibit 6.3). Bank erosion and in-channel sediment deposition are widespread in this area.

Property along the mainstem above Kildaire Farm Road is largely in public ownership. Land downstream of Kildaire Farm Road is primarily in private ownership, much of it in the Lochmere Golf Club. Between the golf course and Holly Springs Road, much of the land is owned by either the Triangle Land Conservancy or the NC Department of Transportation (NCDOT). The NCDOT property, which borders both Swift Creek and Speight Branch, was purchased as part of a stream restoration project on the lower portion of Speight Branch.

Most stormwater inputs discharge to streams via culverts routed through the riparian zone.

Aquatic Habitat. In-stream habitat in the Swift Creek mainstem is variable. Cobble riffles were present in the two benthic sampling reaches, but were absent from many areas. It was not unusual for riffles to be very widely spaced, often several hundred yards apart. Other habitat types were generally present, though seldom in abundance. Bank habitat was often inaccessible due to channel incision. Sediment deposition in the channel of Swift Creek is readily observable but does not appear to be a major contributor to channel degradation in most areas. Riffles are generally not highly embedded and, with the exception of the Lochmere Golf Club and a few smaller areas, substantial accumulation in the channel was not evident.

Tributary habitat is also highly variable. Portions of Williams Creek and Apex Branch have good riffle habitat. Though some organic microhabitat and bank habitat often exist, they are not generally present in substantial quantities or are unavailable due to incision or low flows. Major sediment deposition on Williams Creek is evident primarily in the area between Gregson Drive and US 1.

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

- Williams Creek in MacGregor Office Park, off Edinburgh Drive, an area of high instability.
- Swift Creek upstream of Holly Springs Road (from Holly Springs Road upstream to the Lochmere Golf Club, a distance of approximately 2300 feet). This reach, located at the downstream end of the study area, is typical of much of the Swift Creek mainstem.

These evaluations included a visual assessment of stream morphology, pebble counts, longitudinal and cross-sectional surveys, and other field activities. Bank pins and permanent cross-sections were installed so that future changes in channel morphology can be monitored. These evaluations are documented in two reports by NCSU (2001, 2002). Table 6.1 summarizes basic geomorphic parameters for the three reaches. The restoration implications of this work are addressed in Section 8.

The assessments indicated that the Swift Creek reach is an incised F type channel (Rosgen, 1996) that is laterally unstable (see Appendix E for description of channel types). The downstream portion of this reach is highly sinuous and is experiencing significant bank erosion on the outside

of meander bends. The upstream portion of the reach is straight and of fairly uniform morphology, indicating that it may have been channelized many years ago. Erosion is evident on both banks. Bank height ratios (bank height/bankfull height) in the reach varied from 1.6 to 2.3 (NCSU, 2001), indicating a high degree of incision. The stream is in the process of widening, probably in response to the urbanization of the watershed.

The Williams Creek Reach is an unstable E channel (Rosgen, 1996), flowing through an office park environment (NCSU, 2002). Managed turf extends down to the stream banks, providing limited bank protection. The banks are highly unstable in this reach and mass failure is evident in numerous areas.

Table 6.1 Selected Geomorphic Characteristics of Two Reaches Evaluated by NCSU

	Swift Creek above Holly Springs Road	Williams Creek off Edinburgh Drive
Width/Depth Ratio ¹	10.7	8.6
Entrenchment Ratio ²	>1.3	>2.2
D ₅₀ (mm) ³	10.0 (gravel)	10.6 (gravel)
Slope (%)	0.13	0.14
Sinuosity ⁴	1.03	1.06
Rosgen Stream Type ⁵	F4	E4
Bank Height Ratio ⁶ (range)	1.6-2.3	1.0-1.4

Source: NCSU 2001 and 2002.

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

CH2M Hill Assessments. As a part of data collection phase in the development of the Wake County Watershed Management Plan, CH2M Hill carried out geomorphic assessments at 11 sites in the study area. Most sites (see Appendix D) were found to have low (<8) width/depth ratios and were classified as Rosgen E type channels.

6.1.2 Channelization and Hydrologic Impacts

Field evaluations and examination of aerial photography since the 1940s provide no evidence of systemic channelization (straightening or dredging of the stream) during this period, although individual sections of stream have been modified. Notable examples include:

- rerouting of Swift Creek, Williams Creek and Cary Branch near their confluence in association with the construction of Regency Parkway and adjacent office/industrial parks;
- straightening of approximately 1000 feet of Swift Creek where it is crossed by Kildaire Farm Road (Exhibit 6.4); and
- rerouting of Williams Creek through the auto park area downstream of US 64.

Additionally, about 1200 feet of Swift Creek running through a wooded area below the Lochmere Golf Club is unusually straight and may have been modified in the past. Based on the age of the riparian vegetation, this straightening is likely at least 100 years old. Numerous

reaches of tributary streams have been straightened or moved as part of various development projects over the past 20 years.

While channelization of portions of a stream can often lead to systemic readjustment due in part to changes in stream slope (Schumm et al., 1984; Darby and Simon, 1999), such systemic changes have not occurred in Swift Creek, probably due to periodic bedrock outcrops that serve as grade control.

Tributary flows rise rapidly during storms, as do flows in the Swift Creek mainstem despite the presence of numerous tributary impoundments (Exhibit 6.5). Large volume stormwater inputs occur throughout the watershed and substrate scouring is evident. Despite substantial sediment transported by the stream, most cobble riffles in the mainstem have only moderate embeddedness, as discussed earlier. While sandy substrate exists in some portions of the stream, frequent observations before and after storms indicate that this material was not accumulating during the study period but moved through the channel system in pulses. On occasion this material accumulated temporarily after smaller storms and was subsequently flushed out after larger (near bankfull) events.

Many tributary impoundments (including MacGregor Downs Lake, Summit Lake, Regency Park Lake, Lake Lochmere and Loch Lomond) released water only intermittently during the summers of 2000 and 2001. Similar situations occurred during early fall and late spring. Water levels in these impoundments were below the level of the principal spillway for much of the summer except during the periods immediately following precipitation sufficient to fill the lakes (Exhibits 6.6 and 6.7). At these times flow in the stream below the dam was generally nonexistent or was limited to small amounts of leakage through the dam. During these periods, unimpounded tributaries of comparable watershed size (Speight Branch, Apex Branch) generally continued to flow at moderate rates, providing baseflow to Swift Creek. Habitat contraction in Swift Creek was readily observable. As streamflows decline, the riffle area available to benthic organisms declines and the accessibility of bank habitat decreases.

6.2 Future Changes

Swift Creek and its tributaries are still responding to the altered hydrologic conditions brought about by the substantial development of the past several decades. This channel instability will likely continue for several decades until the channel has attained a morphology in equilibrium with the new hydrologic conditions. Additional incision may occur in some areas, but this will be limited by bedrock outcrops. Signs of active incision were not evident in the mainstem of Swift Creek during the project, although rapid incision was ongoing in the unnamed tributary to Swift Creek draining the Crescent Business Park area (see Exhibit 6.8 and Appendix D). Further stream widening is the most likely scenario, although the rate of widening in much of the mainstem will likely continue to be slowed to some degree by good bank vegetation and cohesive lower bank material. Incised streams that have begun widening generally continue to do so until the channel width is sufficient to allow for the stabilization of slumped banks and a new geomorphic floodplain develops within the incised channel (Schumm et al., 1984; Simon 1989; Simon and Darby, 1999). As widening occurs, bank habitat will remain unavailable to benthic organisms in many areas. Baseflow water depths will become more shallow, potentially resulting in increased temperatures and lower dissolved oxygen levels.



Exhibit 6.1 Bank erosion on Swift Creek upstream of Holly Springs Road



Exhibit 6.2 Swift Creek Greenway



Exhibit 6.3 Swift Creek through Lochmere Golf Club



Exhibit 6.4 Channelized portion of Swift Creek below Kildaire Farm Road



Exhibit 6.5 Williams Creek at MacGregor Center Office Park during overbank storm event



Exhibit 6.6 Common summer conditions at the MacGregor Downs Lake spillway



Exhibit 6.7 Dry streambed in Cary Branch, below MacGregor Downs Lake



Exhibit 6.8 Active incision, unnamed tributary to Swift Creek near Crescent Business Park

Section 7

Analysis and Conclusions - Causes and Sources of Impairment

This section analyzes the likely causes of impairment in the upper Swift Creek watershed, drawing upon the information presented earlier in this report. The sources or origin of these key stressors are also discussed.

7.1 Analyzing Causes of Impairment

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

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

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

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

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

- **Secondary cause of impairment.** A stressor that is having an impact sufficient to cause biological impairment but that is not the most critical or limiting cause. Impairment is likely to continue if the stressor is not addressed.
- **Cumulative cause of impairment.** A stressor that is not sufficient to cause impairment acting singly, but that is one of several stressors that cumulatively cause impairment. A primary cause of impairment generally will not exist. Impairment is likely to continue if the various cumulative stressors are not addressed. Impairment may potentially be addressed by mitigating some but not all of the cumulative stressors. Since this cannot be determined in advance, addressing each of the stressors is recommended initially. The actual extent to which each cause should be mitigated must be determined in the course of an adaptive management process.
- **Contributing stressor.** A stressor that contributes to biological degradation and may exacerbate impairment but is not itself a cause of impairment. Mitigating contributing stressors is not necessary to address impairment, but should result in further improvements in aquatic communities if accomplished in conjunction with addressing causes of impairment.
- **Potential cause or contributor.** A stressor that has been documented to be present or is likely to be present, but for which existing information is inadequate to characterize its potential contribution to impairment.
- **Unlikely cause or contributor.** A stressor that is likely not present at a level sufficient to make a notable contribution to impairment. Such stressors are likely to impact stream biota in some fashion but are not important enough to be considered causes of or contributors to impairment.

7.1.2 *Candidate Stressors*

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

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

7.1.3 *Review of Evidence*

Swift Creek is impaired for its entire length in the study area, a condition that has been evident since 1989. Williams Creek and Apex Branch are also considered impaired (Section 4), although some sites were too small to receive a formal bioclassification. Though comparison of results is difficult because of changes in sampling techniques, available biological data indicate that the creek, though degraded, was probably not impaired as recently as 1980.

Habitat degradation--sedimentation. Sedimentation was listed as a problem parameter for Swift Creek on the 303(d) list, and thus, merited further evaluation. Relevant lines of evidence include benthic macroinvertebrate community data, habitat and geomorphic evaluation, and watershed history and characteristics.

Visual estimates of substrate composition at benthic macroinvertebrate sampling locations indicate that sand and silt have become more prevalent since 1980 (Section 4). However, stream surveys and habitat assessments conducted in conjunction with biological sampling indicated that substantial sediment accumulation and resulting habitat degradation is not evident in most of the mainstem of Swift Creek and many tributaries. Many riffles are not highly embedded. The most significant area of sediment impact on the mainstem occurs in the Lochmere Golf Club, where woody riparian vegetation is often limited and bank erosion is common. Sediment deposition does cause substantial habitat degradation in Williams Creek between Gregson Drive and US 1, where channel instability has resulted in deep sediment deposits in portions of the reach.

While sedimentation contributes to habitat degradation to some degree, there is little evidence that sedimentation per se is severe enough to be considered a cause of impairment, except in the reaches noted above. It is evident from observation, from the condition of channel bars and stream banks and from historical analyses (Haven, 2000) that Swift Creek carries a substantial sediment load. For the most part, however, the creek appears to have the transport capacity to carry this load without resulting in widespread severe depositional problems above Holly Springs Road. This sediment is deposited in Lake Wheeler, reducing reservoir capacity.

Habitat degradation--lack of microhabitat. The contribution of habitat degradation to biological impairment was further evaluated because initial observations revealed highly variable conditions in Swift Creek and its tributaries, with poor conditions evident in some areas. Relevant lines of evidence include benthic macroinvertebrate community data, habitat and geomorphic evaluation, and watershed history and characteristics.

As noted above, historic sampling at a number of locations indicates a decline in biological condition between 1980 and 1989. Considerable development occurred in the watershed at this time. While this may certainly have led to habitat degradation, it could also have contributed to increased levels of other stressors. Changes in stream habitat during this period cannot be evaluated (aside from substrate, noted above) since habitat evaluation data are not available for the earlier sampling events.

Benthos are impaired throughout the watershed, despite variability in reach scale habitat, implying that factors other than or in addition to habitat condition are likely impacting the benthic community. Yet in-stream habitat is clearly degraded, even at the better sites, where relatively high habitat scores in part reflect good riparian zones and lack of channelization. The Hemlock Bluffs and Holly Springs Road sampling locations, for example, exhibit better habitat than many (unsampled) mainstem reaches, many of which lack riffles, have been channelized, or have limited bedform diversity. Even at these sampling sites, however, some habitat types were limited. Little organic microhabitat was observed at Hemlock Bluffs during the study period, despite the presence of a wide riparian zone with dense mature woody vegetation at the site and for some distance upstream. Similarly, organic microhabitat was not abundant downstream near Holly Springs Road, aside from log/debris jams associated with trees entering the stream from collapsed stream banks.

While systemic channel modification is not evident, a number of sections of Swift and Williams Creek have been channelized (see Section 6). Habitat is poor in these areas, which generally have deep uniform channels, little habitat diversity, no riffles and very low baseflow velocities.

Benthic macroinvertebrate sampling was not conducted in any of these sections due to low velocities.

The local geology supplies cobble and gravel material for riffles, some of it from eroding bluffs, but riffles are usually very widely spaced. While woody riparian vegetation borders the stream in many areas, root mat habitat and habitat created by undercut banks is often inaccessible to aquatic organisms at normal water levels due to channel incision. Areas of relatively good in-stream habitat are often separated by long stretches of more degraded stream.

Habitat in most areas is degraded, but is probably not a primary limiting factor for benthos. Especially in the mainstem of Swift Creek, the available reach habitat should be able to support somewhat more diverse benthic communities than are currently present. However, reach habitat is poor throughout Williams Creek and likely plays a more significant role in impairment. Rocks are abundant in Williams Creek at US 64, but other habitat types are limited. Below US 64, through the Auto Park area, the stream is largely a uniform reconstructed channel with little habitat value. Downstream in MacGregor Office Park, sedimentation is one important dimension of habitat degradation, as discussed earlier, but organic microhabitat is also rather limited. Reach habitat is considerably better at most other benthic monitoring locations in the study area, although organic microhabitat is not as prevalent as would be expected given riparian zone characteristics, and some root mat/bank habitat is inaccessible under normal baseflow conditions.

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

Virtually all benthic macroinvertebrate samples collected from Swift Creek and its tributaries during the study period exhibit high BI or EPT BI values, indicating the prevalence of organisms tolerant of a variety of stressors. For one of the three samples collected at Holly Springs Road, community composition (midge assemblage) indicated potential toxic impacts (Section 4). At Hemlock Bluffs (Ritter Park), a mentum deformity analysis score of 40, indicating moderate toxicity, was found during the single sampling event yielding sufficient *Chironomus* to conduct the test. Benthos were impaired at these locations despite reach habitat that, though degraded, was adequate to support a more diverse benthic assemblage.

Watershed characteristics (high level of development and high traffic volumes) suggest the potential for loading of many pollutants. The level of development increased substantially during the period when biological condition declined, indicating the likelihood of increased pollutant inputs.

Water column bioassays indicated the presence of toxicity during one of five storm events evaluated at Holly Springs Road (Section 5). The cause of this toxicity cannot be determined with certainty, although elevated metals are one plausible explanation. Five metals exceeded acute screening values during this event, which exhibited the highest metals concentrations of any storm sampled during the study. Pesticides were not analyzed during this event. Bioassays

conducted during several baseflow periods did not indicate the presence of toxicity, although these tests were not conducted on several of the samples having the highest baseflow metals concentrations.

Grab samples and passive sampling devices detected a wide range of toxicants in the water column, many at relatively low concentrations. Eight different metals exceeded NAWQC on occasion (Section 5). In some cases (e.g., aluminum and copper), exceedences of NAWQC were commonplace. Only total metals concentrations were analyzed and bioavailability could not be evaluated analytically. Six current use pesticides were detected during the study. Simazine was ubiquitous, though not at concentrations exceeding screening values. Diazinon exceeded Tier II screening values on several occasions, though toxicity failure was not observed. USGS sampling in the early 1990s also found high levels of diazinon, indicating that its presence in Swift Creek may be longstanding. Elevated MBAS levels were observed, especially in the upper watershed.

It is unlikely that the limited number of samples collected during the study captured the full variability in pollutant concentrations, and higher levels of contaminants probably periodically occur. Additionally, NAWQC and other screening values are not available for many current use pesticides. For more than 20 other organic compounds analyzed, screening values were lower than laboratory detection limits (Appendix B). Whether these analytes were present in concentrations likely to be toxic is thus unknown.

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

Sediment chemistry analyses and bioassays were performed on samples at Holly Springs Road and Hemlock Bluffs. Chemical analyses identified several current use pesticides. A number of metals and several organochlorine pesticides had concentrations at or near the conservative benchmark range, indicating that toxicity is possible but not probable. Long-term bioassay tests of these sediments did not indicate toxicity.

Evidence bearing on potential toxicity is diverse and difficult to synthesize. However, benthic community composition, midge deformities and one acute bioassay failure during a storm strongly suggest that toxic conditions occur at least periodically in Swift Creek. The specific pollutants responsible for this toxicity cannot be identified with certainty and may be variable. Various metals have been documented at levels that could potentially cause toxic effects, but other toxicants may be important (e.g., the pesticide diazinon) on other occasions. The relative importance of these pollutants – or contaminants not identified by current sampling – cannot be determined with the available data.

Organic and nutrient enrichment. Enrichment was considered a candidate cause of impairment because initial review of the benthic community data indicated potential impacts from organic/nutrient loading in some portions of the stream. Two lines of evidence are relevant here: benthic community data and water quality monitoring data.

Benthic community data indicated the presence of organic and nutrient enrichment in one of the two samples collected from Swift Creek at Hemlock Bluffs (Section 4). At other locations, benthic indicators showed impairment, but did not specifically point toward organic enrichment/low dissolved oxygen.

Monitoring of dissolved oxygen levels in Swift Creek and its tributaries, at a variety of times and locations, provided evidence of sporadic and localized low DO levels (Section 5). Levels of dissolved oxygen that would be expected to have a severe negative impact on benthos were not observed in the mainstem of Swift Creek (Section 5). However, given that periodic monitoring documented DO levels of between 4 and 5 mg/L at a number of mainstem locations, it is likely that lower DO levels occur on at least an occasional basis.

Nitrogen and phosphorus levels are elevated, although the biological response of free-flowing streams to nutrient loading is highly variable, and depends upon shading, stream velocity and other factors. It is thus difficult to use in-stream nutrient concentrations to determine whether nutrients are a cause of benthic impairment.

It is difficult to differentiate the impacts of enrichment from DO impacts due to lower baseflows resulting from urbanization of the watershed and limited summer releases from upstream impoundments. It seems likely, however, that at least intermittent and localized impacts of enrichment occur in the watershed. Conditions in 2000 may have been exacerbated by lower than normal stream discharge. While the study area was not gaged at the time of the investigation, flows at the USGS gage below Lake Wheeler were below average during 2000 but not 2001 (Section 2).

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

Observation during storms indicated that water levels and velocities of both Swift Creek and its tributaries changed rapidly during the onset of storm events, and that exposure of the stream to high velocity flows was commonplace, with substantial movement of bed substrate and microhabitat. Due to the incised nature of the channel, the energy of the stream is confined within the banks except during large storms. At locations such as Holly Springs Road, thin layers of sand are deposited and then removed in subsequent storms. It is evident that the stream has substantial sediment transport capacity, as most reaches do not appear to be experiencing long-term accumulation despite significant sediment supply from eroding banks and other sources. The large suspended sediment load could exacerbate the direct scouring effect on stream biota by contributing to the dislodging of benthic organisms. Dislodging of organisms can be expected with increased frequency and severity compared to Upper Barton Creek, which likely experiences less frequent and intense periods of scouring flows.

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

The watershed is largely developed, with impervious surfaces covering about 20% of the area. Many pervious areas have been highly modified and have lost some infiltration capacity. Most development predates current stormwater control requirements. Significant hydrologic impacts can generally be expected under these conditions.

Taken as a whole, these observations strongly suggest scouring of substrate occurs frequently, and likely contributes to both habitat degradation and dislodging of organisms. While difficult to isolate from other factors associated with a developed watershed, this is very likely an important and pervasive stressor that contributes to impairment of the macroinvertebrate community.

Hydromodification due to dams. The presence of a significant impoundment on five tributaries in the study area was evident upon initial reconnaissance. Dams can impact downstream aquatic communities in a number of ways.

1. Prevention of downstream colonization of aquatic populations. Invertebrate and fish communities depend on upstream-downstream movement for colonization. Downstream drift is a key mechanism for aquatic invertebrate community maintenance (Waters, 1972; Williams and Hynes, 1976). Macroinvertebrate recolonization after disturbance occurs through a number of mechanisms, with drift considered the most important method (Smock, 1996).

In-stream impoundments serve as a barrier to downstream drift. Drifting invertebrates encounter a much different environment in a pond and will generally not survive passage through the impoundment. If downstream benthic communities in these streams are severely impacted due to scour from storms, toxicity or other events, then recolonization depends on mechanisms other than downstream drift, such as aerial dispersal by adult insects, which can take a long period of time.

2. Lower water levels below dams. Many small impoundments release no water downstream when water levels are below the level of the main spillway. A dry stream bed is obviously problematic for aquatic invertebrates and fish. Many studies have demonstrated substantial changes in benthic community composition due to the lower water levels of drought (e.g., Canton et al., 1984; Cowx et al., 1984). Reduced flows can stress aquatic invertebrate communities by shrinking aquatic habitat and changing energy dynamics (velocities).

3. Change in temperature and dissolved oxygen. An increase in water temperature below impoundments has been associated with benthic community shifts (e.g., Fraley, 1979).

4. Change in food type. Change in food type available to biological communities is often another important impact from the dams. Numerous studies have documented a distinct change in the benthic community to dominance by organisms that feed on small particulate organic matter and algae below dams (e.g., Ward and Stanford, 1979). Dams hold back coarse particulate organic matter (leaves, sticks, large wood), an important food source for benthic

invertebrates. Impoundments produce planktonic algae, which serve as a very different food type for downstream benthic invertebrates.

Impoundments also alter sediment transport. If trapping of sediment is too efficient, the stream, lacking a natural sediment supply, will have an excess of stream power and may entrain bank and bed material below the dam.

At its source (mouth of Williams Creek), 6.7 of 10.1 square miles of the Swift Creek drainage area (66%) lie behind major tributary impoundments. The situation does not improve significantly further downstream. At Holly Springs Road, 63% of the drainage area (13.0 of 20.8 square miles) is impounded. Only one of the five impoundments has a minimum release requirement. The most important impact of these impoundments in the study area is probably the exacerbation of low flow conditions and resultant impacts on habitat availability and dissolved oxygen. Lack of flow over most dams was a common occurrence during the summers of 2000 and 2001. Dam leakage generally was not apparent or was minimal. Swift Creek itself was always flowing at these times (as were unimpounded tributaries in most cases), but flows were likely lower than would otherwise have been the case, resulting in reduced habitat area and inaccessibility of some habitat types (partial dewatering of riffles and decreased accessibility of root mats). Impacts on macroinvertebrate drift likely occur, but the effect of this on Swift Creek is probably limited by the fact that many of the areas above the dams (e.g., on Cary Branch, Long Branch and Lynn Branch) are among the most densely developed portions of the watershed and streams in these areas likely support impoverished benthic communities (no benthic community sampling was conducted above the dams). Downstream erosion is most likely due to urbanization impacts--incision and ongoing bank erosion are evident even in tributaries that are not impounded (e.g., Apex Branch).

While these impacts cannot be readily differentiated from those of lower urban baseflows and organic enrichment, it is likely that lowered water levels below dams are an important stressor to biological communities in Swift Creek. As discussed in Section 4 (also see NCDWQ, 2001b), the fish community in Swift Creek at Holly Springs Road is characterized by low species diversity and contains few omnivorous taxa. It is likely that fish recolonization in Swift Creek is limited by both tributary impoundments and the presence of Lake Wheeler immediately downstream.

7.1.4 Conclusion

Aquatic organisms in upper Swift Creek are heavily impacted by multiple stressors associated with the high levels of development in the watershed. Multiple stressors are characteristic of most developed watersheds, although sometimes a single stressor can be identified as being of primary importance in causing impairment. In upper Swift Creek, however, the relative contribution of these stressors cannot be clearly differentiated based on the available data. Toxic impacts, scour, habitat degradation due to limited microhabitat, hydromodification due to impoundments, and organic/nutrient enrichment are all considered to be stressors that cumulatively cause impairment. Toxicity and scour may be the most important factors. Scour is probably the most pervasive stressor and several lines of evidence point to toxic impacts in the mainstem, while the impacts of organic enrichment and severe habitat degradation are more localized. Yet all of these stressors must be viewed as significant. Lack of macroinvertebrate

recolonization due to dams and to the highly impacted condition of tributaries is also a concern (see Section 7.3). Sediment deposition is an important contributor to habitat degradation in several reaches, but is not a widespread cause of impairment.

This evaluation is confined to the causes of impairment in Swift and Williams Creeks. Impairment in the other smaller streams in the study area was not specifically evaluated, though these waterbodies are subject to many of the same stressors evident in Swift Creek and Williams Creek. Low summer baseflows due to the small catchment size, exacerbated by the high levels of development in the watershed, are likely more significant in many of these small creeks than in Swift Creek.

7.2 Sources of Impairment

Toxicants. It is likely that a variety of toxicants impact the stream at various times and that the cumulative impact of these contaminants is a significant issue. Metals are likely important, but various organic contaminants (e.g., diazinon) may also be a factor. Diverse source areas exist throughout this highly developed watershed (residential, commercial and industrial areas, golf courses, vehicular sources). Contaminants likely enter the stream via a variety of pathways, including storm runoff, seepage from groundwater, periodic spills or unpermitted discharges to the storm sewer system.

Vehicles can be major source of metals and hydrocarbons. Characteristics of the upper Swift Creek watershed indicate that it likely has significant vehicular inputs: major commercial areas with parking; fairly dense residential areas and street networks; major highway arteries with high traffic volumes.

Scour and habitat degradation. EPA defines hydromodification (source category 7000) as the alteration of the hydrologic characteristics of surface waters resulting in degradation of resource conditions (USEPA, 1997). While channelization (alteration of channel morphology, dredging) has impacted some reaches in the study area, the type of hydromodification of primary importance is the alteration of watershed hydrology by increased impervious area and the installation of a storm drainage system associated with development of the watershed. Much rainfall that previously infiltrated into the soil or gradually flowed into streams through feeder channels now falls on impervious areas and is collected by storm sewers which efficiently route runoff to major streams. The resulting increase in stormwater volumes and the frequency and duration of erosive flows is the major factor causing scouring and habitat degradation. The historic condition of the channel is not known, but it is likely that some incision occurred prior to development, increasing the sensitivity of streams to subsequent hydrologic changes.

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

Hydromodification due to dams. Hydromodification results from the dams located on Williams Creek, Cary Branch, Regency Branch, Long Branch and Lynn Branch. In particular, the lack of releases from these structures during dry periods when unimpounded tributaries continue to flow is problematic.

Organic and organic enrichment/low dissolved oxygen. It was not possible to distinguish clearly between the impacts of organic/nutrient loading and the effects of impoundments on dissolved oxygen. Urban hydrologic impacts are an additional factor, contributing to lower DO levels due to lower baseflows and wider baseflow channels that contribute to lower velocities and result in lower water levels that are more easily subject to heating. Potential sources of BOD and nutrients are ubiquitous in a developed watershed such as this one and include leaking sewer lines, illegal connections to the storm drain system, fertilizer inputs from managed turf areas, atmospheric nitrogen sources, and a variety of organic debris (both trash and natural material). Specific contributors of organic inputs were not evaluated, and it is likely that loadings to Swift Creek are the result of a multitude of smaller sources rather than large isolated inputs. Fecal coliform levels (Section 2) were relatively modest for a developed area, indicating that perhaps sewer lines (or other sources of enrichment that also contain high fecal bacteria concentrations) may not be a major factor. On a number of occasions (see Appendix D) careless application of lawn chemicals in commercial areas was observed (e.g., broadcast of granules directly into a stream).

7.3 Other Issues of Concern

Limited recolonization potential from within the watershed is a concern. Downstream drift of benthic organisms is a very important mechanism for the maintenance of benthic macroinvertebrate populations, allowing for more rapid recovery from disturbance than other mechanisms such as aerial recolonization (Waters, 1972; Williams and Hynes, 1976). The lack of quality upstream sources of colonization, thus, contributes to biological degradation in Swift Creek by altering the balance between disturbance and recovery (see the Background Note "The Stress-Recovery Cycle"). Impoundments and development have seriously compromised this ecological function, and virtually all tributaries draining to Swift Creek within the study area have been significantly impacted. Substantial sediment inputs have occurred, the streams have been straightened or ripped in some areas, and these channels now receive concentrated flow from curb and gutter drainage systems and a wide range of pollutants. The loss of these refugia will likely limit the recovery potential of upper Swift Creek.

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

Swift Creek flows through the Swift Creek Bluffs and Hemlock Bluffs Nature Preserves, and its condition affects the overall ecological condition of these two important natural areas. The terrestrial portions of these two preserves are already recognized for their ecological value. Improvements in the ability of Swift Creek to support native biological communities would enhance the ecological integrity of the two preserves.

Sediment, nutrients and toxicants from Swift Creek are transported to Lake Wheeler (and to some extent downstream to lower Swift Creek and the Neuse River) where they can have negative resource impacts. Sediment, whether its origin lies within the channel or in eroding uplands, continues to degrade habitat and reduce reservoir capacity.

Background Note: The Stress-Recovery Cycle

Even in relatively pristine streams, aquatic organisms are exposed to periods of stress. Natural stresses due to high flows during storms, low flows during hot dry summer periods or episodic large sediment inputs (e.g., from slope failures in mountain areas or breaching of beaver dams) can have significant impacts on stream communities.

Although aquatic communities in high quality streams may be impacted by such disturbances, and some species may be temporarily lost from particular sites, populations are able to reestablish themselves--often very quickly--by recolonization from less impacted areas or refugia (see Yount and Niemi, 1990; Niemi et al., 1990). This process can involve recolonization from backwater areas, interstitial zones (spaces between the cobble and gravel substrate), the hyporheic zone (underground habitats just below the stream bed surface layer) or other available microhabitats. Repopulation from headwaters or tributary streams not impacted by the disturbance can also occur. For insects, aerial recolonization is important as well.

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

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

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

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

Efforts to restore better functioning aquatic communities in degraded streams must consider strategies to both reduce the stresses affecting stream biota and to protect and restore potential refugia and other sources of colonizing organisms. Under some conditions, the lack of adequate recolonization sources may delay or impede recovery. Protecting existing refugia and those relatively healthy areas that remain in impacted watersheds should be an important component of watershed restoration efforts (McGurrin and Forsgren, 1997; Frissell, 1997).

Section 8

Improving Stream Integrity in Upper Swift Creek: Recommended Strategies

As discussed in the previous section, Swift Creek is impaired by the cumulative impacts of toxicity, scour, habitat degradation, hydromodification due to impoundments and organic/nutrient enrichment. This section discusses how these problems can be addressed. A summary of recommendations is included at the end of the section. Since most of the study area is already developed, the potential impacts of future development, though important, are not as significant a concern as in less developed watersheds.

8.1 Addressing Current Causes of Impairment

The objective of efforts to improve stream integrity is to restore water quality and habitat conditions to support a more diverse and functional biological community in Swift Creek. Because of the widespread nature of biological degradation and the highly developed character of the watershed, bringing about substantial water quality improvement will be a tremendous challenge. Yet the watershed has not been so highly modified as to preclude improvements in stream integrity. A return to the relatively unimpacted conditions that existed prior to widespread agriculture and urbanization is unlikely, but Swift Creek can potentially support a healthier biological community than it does today. Additionally, the quantities of sediment and other pollutants transported to Lake Wheeler, a future drinking water supply reservoir, can be reduced.

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

8.1.1 *Hydromodification Due to Scour*

Frequent periods of high-velocity storm flow dislodge benthic organisms and contribute to habitat degradation by removing organic microhabitat and causing bank instability. This will continue unless some of the hydrologic impacts of existing development can be abated. Existing stormwater BMPs serve to mitigate the problem to a limited extent. The vast majority of development occurred prior to any BMP requirements. Most structures implemented under water supply protection rules (designed to control the first inch of runoff) were intended

primarily to address pollutant removal, not hydrologic impacts. Additional stormwater controls are necessary to partially restore watershed hydrology by reducing runoff volume and reducing the frequency and duration of erosive flows.

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

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

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

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

DWQ encourages the consideration of a wide range of practices and approaches. Ponds of various types are probably the practice most familiar to engineers and can indeed be versatile and cost-effective. Detention alone does not reduce stormwater volume; however, though the rate and timing of discharge can be controlled. It is important to carefully examine infiltration practices, including both structures and ‘behavioral’ changes, such as redirecting downspouts to pervious areas. While there are clearly limits to the usefulness of infiltration, based on soils, water table levels and other factors (Livingston, 2000), these practices are often underused. Design approaches to minimize runoff volume are also important tools (Caraco et al., 1998; Prince George’s County DEP, 2000). Some retrofit methods may have negative side effects that must be carefully considered. For example, regional wet detention facilities, though they may remain a viable alternative in some situations, can disrupt recolonization, alter the food/energy source available to downstream biota, and, depending upon design and operation, reduce or eliminate downstream baseflows (Maxted and Shaver, 1999; Schueler, 2000a).

Recommendation. What is feasible or cost-effective in the way of retrofitting a developed watershed like Swift Creek is constrained by existing conditions. Conditions change, however, and a long-term commitment to partially restoring watershed hydrology will be necessary to create opportunities and take advantage of the available options. In order to have a biologically meaningful impact on watershed hydrology, cost-effective projects will likely have to be sought out and implemented over an extended time frame.

1. Short-term. Over the next decade, the towns of Cary and Apex can investigate retrofit possibilities and implement those that are feasible, given current infrastructure and financial constraints.
2. Mid-term. Road realignment, sewer line and bridge replacement, and other infrastructure projects will likely make feasible other retrofit opportunities over the next 10-20 years. Such projects can be pursued, and the search for retrofit opportunities can be integrated into the capital improvement planning process.
3. Long-term. Over a more extended period, cost-effective restoration opportunities are likely as portions of the watershed are redeveloped incrementally (Ferguson et al., 1999). An ongoing awareness of retrofit needs and changes in development regulations may be necessary to help create and take advantage of these opportunities.

Existing in-stream impoundments should be evaluated to determine their retrofit potential. Areas draining directly to the Swift Creek mainstem or unimpounded tributaries (e.g., MacGregor Office Park Area, Regency Parkway area below Regency Park Lake) should be priority areas for retrofit consideration. Apex Branch is the largest unimpounded tributary in the study area. If at least partially restored, it could provide a base for biological improvement efforts and a source of macroinvertebrate recolonization for downstream areas. Priority should be given to retrofits in this subwatershed. Williams Creek downstream of its confluence with Apex Branch must also be targeted if biological improvements in Apex Branch are to have an impact in Swift Creek.

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

Only gross estimates of total costs are possible. Claytor (1999) suggests that a minimum of 50% of a watershed be retrofitted. Thus, for example, a two-square mile watershed that is 25% impervious has approximately 320 impervious acres (2 square miles, or 1280 acres, times an imperviousness of 25%). Assuming a typical cost of \$10,000 per impervious acre, it would take approximately \$1.6 million to retrofit 160 impervious acres. This approaches \$1 million per square mile of watershed area, assuming that retrofitting relies primarily on ponds. This estimate, based on data that are now almost a decade old, should be used only as a general indication of the likely scale of effort that may be necessary, assuming a sufficient number of viable retrofit projects can be identified. Actual total costs may be higher or lower depending on many factors, including the types of BMPs used and the scale of each project. Some cost reduction may be possible if retrofits are planned and implemented in conjunction with anticipated capital improvements and infrastructure enhancements. The potential connection

between watershed restoration and infrastructure issues has been increasingly recognized by local governments (e.g., City of Austin, 2001; Montgomery County DEP, 2001).

8.1.2 Toxic Impacts

While high levels of some contaminants have been found, the particular pollutants or mix of pollutants of primary concern remains unclear. Long-term impacts of repeated exposures may be important, and the most critical toxicants may vary with time, associated with specific events. Source areas likely lie throughout the watershed.

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

1. Implementation of available BMP opportunities for control of stormwater volume and velocities. Recommended earlier in order to reduce scour impacts and improve aquatic habitat potential, these BMPs will also remove toxicants from the stormwater system (the extent of removal will vary depending upon the specific structures and pollutants involved).
2. Development of a stormwater and dry weather sampling strategy for the watershed. A wide range of conventional BMPs can be used to remove pollutants from stormwater runoff (see ASCE, 2001). For example constructed wetlands, vegetated swales and various types of ponds can remove a substantial percentage of metals. Selection of particular BMPs can proceed more efficiently, however, if better information on specific target pollutants and source areas is available. Such information would also aid in the targeting of source reduction efforts (discussed below). To address these needs, a monitoring strategy should be developed based upon further watershed reconnaissance.
3. Implementation of stormwater treatment BMPs, aimed primarily at pollutant removal, at appropriate locations. Results of additional monitoring will be important in targeting these BMPs, although some likely "hot spots" (areas of intense activity or high risk) could be identified without water quality sampling. Proprietary treatment systems can be considered where adequate space is not available for conventional stormwater BMPs.
4. Development and implementation of a broad set of source reduction activities. Since removing pollutants from stormwater can be difficult and expensive, pollution prevention activities are crucial. Among activities that should be considered for inclusion in a pollution prevention efforts are the following:
 - Reducing nonstorm inputs of toxicants by:
 - a) identification and elimination of illicit connections (actions required under the Neuse Stormwater Rule and the new phase II stormwater program);

- b) review of existing information on groundwater contamination and implementation of appropriate remediation measures if warranted;
 - c) verification that industrial and commercial floor drains empty to the sanitary sewer system or appropriate treatment facilities; and
 - d) education of industrial and commercial operation and maintenance staff regarding proper use of storm drains and the implications of dumping.
- Reducing pollutants available for washoff during storms by:
 - a) education of homeowners, grounds staff, and commercial applicators regarding appropriate pesticide use;
 - b) provision of technical assistance to golf course staff regarding appropriate pesticide usage.
 - c) outreach and technical assistance to industrial and commercial facilities regarding materials storage practices; spill prevention procedures; and spill control and cleanup procedures.
 - Managing water to reduce storm runoff by:
 - a) routing roof drains and pavement to available pervious areas where feasible (may require some regrading); and
 - b) proper maintenance of existing BMPs.

The condition of residential lawns and commercial grounds in this watershed strongly suggests that turf chemicals are likely applied in substantial quantities. Education for property owners, maintenance staff of commercial facilities, and commercial applicators regarding pesticide use should be a priority. While clear pesticide impacts associated with golf courses were not documented during the study, the location of these facilities along waterways increases the risk of periodic impacts if proper procedures are not followed. A review of chemical handling and application practices would be appropriate. Educational efforts now underway to reduce nitrogen loading may have some impact. Such efforts may need to be expanded to include pesticides.

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

Development of a specific pollution prevention strategy is beyond the scope of this study. Some elements of a strategy could probably be implemented by enhancing or redirecting existing program activities. In other cases, new initiatives may be necessary. While state agencies such as DWQ and the Division of Pollution Prevention and Environmental Assistance (DPPEA) can play a role, planning and implementation of a strategy are likely to be more effective if carried out by local government, agencies and stakeholders.

8.1.3 *Hydromodification Due to Dams*

As far as baseflow impacts are concerned (impacts on organism movement, low flows, dissolved oxygen), removal of the dams would be the best option for restoring biological integrity. However, this is not likely to be an economically viable alternative given the amenity value of

the impoundments and, in many cases, the recency of their construction. The dams are also serving to treat stormwater pollutants to some degree, and their removal would necessitate finding a way to replace this removal capacity in a watershed in which still greater stormwater treatment and control are needed. Without removal of the dams, some types of impacts (e.g., interference with macroinvertebrate drift and fish migration) could likely not be mitigated. However, the lack of discharge from these structures is probably the most important impact in the present situation. The Division of Land Resources regulates dam construction and maintenance under the Dam Safety Law of 1967, and minimum release requirements can be established to protect aquatic life. Dams built before 1967 are not exempt from this law. Only Regency Park Lake currently has a minimum release requirement (Section 2). The technical, economic and regulatory feasibility of implementing minimum releases from the other impoundments should be explored. Voluntary release agreements may also be an option. The Lochmere development is already releasing water from Lake Lochmere through an underdrain to provide irrigation water for the Lochmere Golf Club.

8.1.4 Habitat Degradation

Habitat in the study area is limited by dams, erosive scouring stormflows due to the hydrologic impacts of recent and ongoing development, and (in some locations) by sedimentation. The impacts of dams on microhabitat cannot be addressed except by dam removal (see above). The remaining factors can be addressed by a combination of stormwater quantity retrofits and stream channel restoration.

Stormwater quantity retrofits, discussed earlier, can partially mitigate existing hydrologic impacts. This will reduce sediment inputs, allow for more rapid healing of unstable areas, and facilitate the development of better in-stream habitat. Such healing is likely to take many years, since the stream is still in the process of adjusting to recent hydrologic alteration of the watershed.

Stream channel restoration techniques could be used to speed the recovery process. On the mainstem of Swift Creek, however, much of the riparian zone consists of areas of healthy forested vegetation, some of which lie in protected natural areas. The process of channel reconstruction could have negative impacts in these areas, and from a long-term perspective, it may be more prudent to confine channel restoration activities to areas where problems are particularly severe.

Specific recommendations are as follows:

1. The channel of Williams Creek should be restored from Gregson Drive to US 1 (approx. 3400 feet). Much of this section has been evaluated by the NCSU Stream Restoration Institute, as discussed in Section 6 (NCSU, 2002).
2. The channel of Apex Branch between Parliament Place in Apex and MacKenan Drive in Cary (approx. 4000 feet) has numerous unstable areas and should be evaluated for restoration.
3. Channel restoration should be carried out in conjunction with stormwater retrofits at these locations or habitat potential will continue to be limited by stormflows even after a stable channel develops.

4. The portion of Swift Creek flowing through Lochmere Golf Club, approximately one mile in length, is highly unstable and serves as a major source of sediment. Channel restoration here is recommended.

Stream channel restoration involves reestablishing a stable channel dimension (cross-section), pattern (sinuosity and planform) and longitudinal profile (slope). While other options exist (see NCSU, 2001 and 2002), the most feasible approach to the restoration of most channels in this watershed is probably to construct appropriate floodplain area and channel form within the existing incised channel (Rosgen priority 2 or priority 3 approach). The specific restoration strategy selected will depend upon the stream corridor width available (belt width), among other factors (NCSU, 2001 and 2002; Rosgen, 1997). Based on the recent experience of the North Carolina Wetlands Restoration Program (Haupt et al., 2002) and a number of Maryland counties that have active restoration programs (Weinkam et al., 2001), costs of at least \$200 per linear foot (over \$1 million per mile) should be expected for the restoration of urban stream channels.

Staff of the NC Wildlife Resources Commission's Nongame and Endangered Wildlife Program (Judith A. Ratcliffe, personal communication) indicated that surveys for freshwater mussels were recommended prior to conducting channel restoration work in the study area, since it is within the historical range of a number of threatened and endangered species (see Section 2).

8.1.5 Organic and Nutrient Enrichment

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

Nutrient and organic loading can be addressed in a variety of ways, including stormwater treatment. Additional BMPs constructed to address other problems (see above) are likely to reduce nutrient and BOD inputs. BMPs targeted at these pollutants may be warranted at high loading areas identified during subsequent investigation. Organic and nutrient loading can also be reduced via established practices such as: the identification and elimination of illicit discharges; education of homeowners, commercial applicators and others regarding proper fertilizer use; street sweeping; and catch basin clean-out practices. Activities currently underway or planned by local governments to reduce nutrient inputs to comply with Neuse River basin rules could reduce nutrient levels significantly if effectively implemented. The identification and elimination of illicit connections is required under the Neuse Stormwater Rule and the Phase II stormwater program.

8.1.6 Other Concerns

Many water quality impacts can result from the incremental and cumulative impacts of land management decisions made by individual residents and property owners throughout the watershed. Educational efforts directed at homeowners and managers of commercial and

industrial areas in the watershed would be useful to promote improved riparian zone management and the appropriate use of pesticides and fertilizers.

8.2 Addressing Future Threats

Since the study area is largely developed, potential threats from construction-related sediment inputs and hydromodification from post-construction stormwater are likely to be less substantial than in less built-out watersheds. It is nonetheless important that effective enforcement of existing sediment and erosion control regulations occur on the part of Apex, Cary and Wake County.

New development will be subject to a number of recently implemented regulatory requirements. Portions of the study area under the planning jurisdiction of Cary and Wake County are subject to the Neuse River Basin Stormwater Rule, which requires that nitrogen loading from new development be held to 3.6 pounds/acre/year, and that there be no net increase (from predevelopment conditions) in peak flows leaving the site for the 1-year 24-hour storm. The flow control provision applies only to new development with imperviousness levels of at least 15%. Those parts of the watershed under the Apex planning jurisdiction are not currently subject to the Neuse stormwater requirements. Cary, Apex and Wake County are also among the communities automatically designated (based on US Bureau of the Census data) for coverage under the Phase II stormwater program. The post-construction stormwater provisions of the Phase II program require control of the 1-year 24-hour storm for development with imperviousness of 24% or greater.

To avoid additional channel erosion, it is critical that effective post-construction stormwater management occurs throughout the study area. Effective implementation of the Phase II stormwater program and the Neuse stormwater and buffer rules must be an important part of this effort. The Neuse rules should provide better channel protection than the Phase II requirements due to the lower threshold for the use of stormwater controls (15% imperviousness vs. 24%). Channels in the watershed are most likely to be protected from the hydrologic impacts of new development if stormwater controls comparable to the Neuse rules are implemented throughout the study area.

8.3 A Framework for Improving and Protecting Stream Integrity

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

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

An organizational framework for ongoing watershed management is essential in order to provide oversight over project implementation, to evaluate how current restoration and protection strategies are working, and to plan for the future. While state agencies can play an important role in this undertaking, planning is often more effectively initiated and managed at the local level. A coordinated planning effort involving local governments in the watershed (Apex, Cary, Wake County), as well as a broad range of other stakeholders, will be critical if conditions in upper Swift Creek are to be improved. This effort must include the development of a long-term vision for protecting and restoring the watershed, as well as the specific work that will be necessary to support a patient approach to planning and implementing projects to move toward that vision.

Wake County has recently completed a watershed management plan (WCWMPTF, 2003; available online at <http://projects.ch2m.com/WakeCounty>). The ongoing planning structure that emerges from this process may provide a suitable organizational home for water quality improvement and protection in the Swift Creek watershed. The Wake County Watershed Management Plan designated the Swift Creek watershed (including the study area) as one that should be given a high priority for restoration, in part because of its water supply status. Developing specific restoration strategies for Swift Creek or other priority watersheds was beyond the scope of the County’s planning effort.

8.4 Summary of Watershed Strategies for Swift Creek

The following actions are necessary to address current sources of impairment in Swift Creek and to prevent future degradation. Actions one through five are important to restoring and sustaining aquatic communities in the watershed, with the first three recommendations being the most important.

1. **Feasible and cost-effective stormwater retrofit projects should be implemented throughout the watershed to mitigate the hydrologic effects of development** (increased stormwater volumes and increased frequency and duration of erosive and scouring flows). This should be viewed as a long-term process. Although there are many uncertainties, costs of \$1 million or more per square mile of watershed can probably be anticipated.
 - a) Over the short-term, currently feasible retrofit projects should be identified and implemented.
 - b) In the longer term, additional retrofit opportunities should be sought out in conjunction with infrastructure improvements and redevelopment of existing developed areas.
 - c) Specific priorities should include evaluating whether existing in-stream impoundments could be retrofitted to improve water quantity control, retrofitting areas draining directly

to the Swift Creek mainstem and retrofitting Apex Branch, the largest unimpounded tributary.

2. **A strategy to address toxic inputs should be developed and implemented, including a variety of source reduction and stormwater treatment methods.** As an initial framework for planning toxicity reduction efforts, the following general approach is proposed:
 - a) Implementation of available BMP opportunities for control of stormwater volume and velocities. Recommended above to improve aquatic habitat potential, these BMPs will also remove toxicants from the stormwater system.
 - b) Development of a stormwater and dry weather sampling strategy in order to facilitate the targeting of pollutant removal and source reduction practices.
 - c) Implementation of stormwater treatment BMPs, aimed primarily at pollutant removal, at appropriate locations.
 - d) Development and implementation of a broad set of source reduction activities focused on: reducing nonstorm inputs of toxicants; reducing pollutants available for washoff during storms; and managing water to reduce storm runoff. Suggestions for potential source reduction practices are provided.
3. **The technical, economic and regulatory feasibility of implementing minimum releases from Summit Lake, MacGregor Downs Lake, Loch Lomond and Lake Lochmere should be explored.** These releases would help to restore baseflow levels in Swift Creek.
4. **Stream channel restoration activities should be implemented in targeted areas, in conjunction with stormwater retrofit BMPs, in order to improve aquatic habitat.** Priority areas include Williams Creek from Gregson Drive to US 1 (approx. 3400 feet), and the portion of Swift Creek flowing through Lochmere Golf Club (approx. one mile). Apex Branch between Parliament Place in Apex and MacKenan Drive in Cary (approx. 4000 feet) also has numerous unstable areas and should be evaluated for restoration. Costs of at least \$1 million per mile of channel should be anticipated.
5. **Actions recommended above (e.g., stormwater quantity and quality retrofit BMPs) are likely to reduce organic and nutrient loading to some extent, although additional efforts may be necessary.** Nutrient reduction activities currently underway as part of the Neuse River basin efforts could also have an impact. Activities recommended to address organic loading include the identification and elimination of illicit discharges; education of homeowners, commercial applicators and others regarding proper fertilizer use; street sweeping; catch basin clean-out practices; and the installation of additional BMPs targeting BOD and nutrient removal at appropriate sites.
6. Prevention of further channel erosion and habitat degradation will require effective post-construction stormwater management for all new development in the study area. The Phase II stormwater program and the Neuse stormwater and buffer rules must be effectively implemented. Implementing post-construction stormwater requirements comparable to those in the Neuse stormwater rules throughout the study area would increase the likelihood that channels will be adequately protected.
7. Effective enforcement of sediment and erosion control regulations on the part of Apex, Cary and Wake County will be essential to the prevention of additional sediment inputs from construction activities. Development of improved erosion and sediment control practices may be beneficial.
8. The watershed education programs currently implemented by local governments should be continued and enhanced, with the goal of reducing current stream damage and prevent future degradation. At a minimum, the program should include elements to address the following issues:

- a) Redirecting downspouts to pervious areas rather than routing these flows to driveways or gutters.
- b) Protecting existing wooded riparian areas on ephemeral streams.
- c) Replanting native riparian vegetation on perennial, intermittent and ephemeral channels where such vegetation is absent.
- d) Reducing and properly managing pesticide and fertilizer use.

Section 9

References Cited

- Anacostia Restoration Team. 1991. *A Commitment to Restore Our Home River: A Six-Point Action Plan to Restore the Anacostia River*. Metropolitan Washington Council of Governments.
- ASCE. 2001. *Guide for Best Management Practice (BMP) Selection in Urban Developed Areas*. Urban Water Infrastructure Management Committee's Task Committee for Evaluating Best Management Practices. American Society of Civil Engineers. Reston, Virginia.
- American Society for Testing and Materials (ASTM). 2000. *Standard Test Methods for Measuring the Toxicity of Sediment-Associated Contaminants with Freshwater Invertebrates (ASTM E1706-00)*. ASTM Annual Book of Standards Volume 11.05. West Conshohocken, PA.
- Bales, J.D., J.C. Weaver and J.B. Robinson. 1999. *Relation of Land Use to Streamflow and Water Quality at Selected Sites in the City of Charlotte and Mecklenburg County, North Carolina, 1993-98*. USGS Water-Resources Investigations Report 99-4180. Raleigh, NC.
- Bannerman, R., D. Owens, R.Dodds and N. Hornewer. 1993. *Sources of Pollutants in Wisconsin Stormwater*. Water Science and Technology. 28:241-259.
- Bledsoe, B.P. and C.C. Watson. 2001. *Effects of Urbanization on Channel Instability*. JAWRA. 37:255-270.
- Brown, T. and D. Caraco. 2001. *Channel Protection*. Water Resources IMPACT. 3:6:16-19. November.
- Burton, G.A. and R.E. Pitt. 2001. *Stormwater Effects Handbook: A Toolbox for Watershed Managers, Scientists and Engineers*. Lewis Publishers. Boca Raton.
- Caldwell, W.S. 1992. *Selected Water-Quality and Biological Characteristics of Streams in Some Forested Basins of North Carolina, 1985-88*. USGS Water-Resources Investigations Report 92-4129. Raleigh.
- Canton, S.P., L.D. Cline, R.A. Short and J.V. Ward. 1984. *The Macroinvertebrates and Fish of a Colorado Stream During a Period of Fluctuating Discharge*. Freshwater Biology 14: 311-316.
- Cappiella, K. and K. Brown. 2001. *Land Use and Impervious Cover in the Chesapeake Bay Region*. Watershed Protection Techniques. 3:4: 835-840. December.
- Caraco, D. et al. 1998. *Rapid Watershed Planning Handbook: A Comprehensive Guide for Managing Urban Watersheds*. Center for Watershed Protection. October. Ellicott City, MD.
- Cawthorn, J.W. 1970. *Soil Survey of Wake County North Carolina*. USDA Soil Conservation Service.
- CH2M HILL. 1998. *East Watersheds Impacts Assessment*. Metro Atlanta Urban Watersheds Initiative. Prepared for Atlanta Department of Public Works. CH2M HILL. Atlanta.

- CH2M HILL. 2001. *Wake County Watershed Assessments—Station and Basin Selection and Sampling Approach*. Technical Memorandum No. 3. Report prepared for the Wake County Watershed Management Plan Task Force. June.
- Childress, C.J.O and M.W. Treece. 1996. *Water and Bed-Material Quality of Selected Streams and Reservoirs in the Research Triangle Area of North Carolina, 1988-94*. Water-Resources Investigations Report 95-4282. United States Geological Survey. Raleigh.
- City of Austin. 2001. *Watershed Protection Master Plan. Phase 1 Watersheds Report*. Executive Summary. Available on line at <http://www.ci.austin.tx.us/watershed/masterplan.htm>.
- Claytor, R.A. 1999. *An Eight-Step Approach to Implementing Stormwater Retrofitting*. Pp. 212-218 in *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*. Proceedings of Conference held February 9-12, 1998 in Chicago IL. EPA/625/R-99/002.
- Cowx, I.G., W.O. Young and J.M. Hellawell. 1984. *The Influence of Drought on the Fish and Invertebrate Populations of an Upland Stream in Wales*. *Freshwater Biology* 14: 165-177.
- Darby, S.E. and A. Simon (eds). 1999. *Incised River Channels: Processes, Forms, Engineering and Management*. John Wiley & Sons. Chichester, UK.
- Ferguson, B.K. 1997. *The Alluvial Progress of Piedmont Streams*. Pp. 132-143 in L.A. Roesner (ed) *Effects of Watershed Development and Management on Aquatic Ecosystems*. ASCE. New York.
- Ferguson, B., R. Pinkham and T. Collins. 1999. *Re-Evaluating Stormwater: The Nine Mile Run Model for Restorative Redevelopment*. Rocky Mountain Institute. Snowmass, CO.
- Foran, J.A. and S.A. Ferenc. 1999. *Multiple Stressors in Ecological Risk and Impact Assessment*. SETAC Press. Society for Ecological Toxicology and Chemistry. Pensacola.
- Fox, G.A. 1991. *Practical Causal Inference for Ecoepidemiologists*. *J Toxicol Environ Health*. 33:359-373.
- Fralely, J.J. 1979. *Effects of Elevated Stream Temperatures Below a Shallow Reservoir on a Cold Water Macroinvertebrate Fauna*. Pp. 257-272 in J.V. Ward and J.A. Stanford (eds) *The Ecology of Regulated Streams*. Plenum Press. New York, NY.
- Frissell, C.A. 1997. *Ecological Principles*. Pp. 96-115 in J.E. Williams, C.A. Wood and M.P. Dombeck (eds) *Watershed Restoration: Principles and Practices*. American Fisheries Society. Bethesda, MD.
- Galli, J. 1999. *Monitoring the Effectiveness of Urban Retrofit BMPs and Stream Restoration*. Pp. 48-53 in *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*. Proceedings of Conference held February 9-12, 1998 in Chicago IL. EPA/625/R-99/002.
- Garrett, R.G., J.E. Taylor and T.L. Middleton. 1994. *Water-Quality Data for Selected North Carolina Streams and Reservoirs in the Triangle Area Water Supply Monitoring Project, 1988-92*. Open-File Report 94-379. United States Geological Survey. Raleigh.

- Giese, G.L. and R.R. Mason. 1991. *Low-Flow Characteristics of Streams in North Carolina*. USGS Open-File Report 90-399. United States Geological Survey. Raleigh.
- Haupt, M., J. Jurek, L. Hobbs, J. Guidry, C. Smith and R. Ferrell. 2002. *A Preliminary Analysis of Stream Restoration Costs in the North Carolina Wetlands Restoration Program*. Paper presented at the conference *Setting the Agenda for Water Resources Research*. April 9, 2002. Raleigh, NC.
- Haven, W.T. 2000. *Reservoir Sedimentation in the North Carolina Piedmont*. Masters Thesis. North Carolina State University. Department of Marine, Earth and Atmospheric Sciences. Raleigh.
- Healy, R.G. 1985. *Competition for Land in the American South*. Conservation Foundation. Washington, DC.
- Heaney, J.P., R. Pitt and R. Field. 1999. *Innovative Urban Wet-Weather Flow Management Systems*. EPA/600/R-99/029. USEPA Office of Research and Development. Cincinnati, OH.
- Herricks, E.E. 2002. *Observed Stream Responses to Changes in Runoff Quality*. Pp. 145-157 in B.R. Urbonas (ed) *Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation*. Proceeding of an Engineering Foundation Conference. Snowmass Village, Colorado. August 19-24, 2001. American Society of Civil Engineers. Reston, VA.
- Hoffman, R.S., P.D. Capel and S.J. Larson. 2000. *Comparison of Pesticides in Eight US Urban Streams*. *Environ Tox and Chem*. 19:2249-2258.
- Horner, R.R., J.J. Skupien, E.H. Livingston and H.E. Shaver. 1994. *Fundamentals of Urban Runoff Management: Technical and Institutional Issues*. Terrene Institute. Washington DC.
- Jacobson, R.B. and D.J. Coleman. 1986. *Stratigraphy and Recent Evolution of Maryland Piedmont Flood Plains*. *American J of Science*. 286:617-637.
- Kimerle, R.A. 1989. *Aquatic and Terrestrial Ecotoxicology of Linear Alkylbenzene Sulfonate: Tenside, Surfactants, Detergents*. v. 26, pp. 169-176 as cited in Meade, R.H., editor. 1995. *Contaminants in the Mississippi River*. US Geological Survey Circular 1133. Reston, Virginia. <http://water.usgs.gov/pubs/circ/circ1133/organic.html>.
- Lenat, D.R. 1989. *Survey of Swift Creek Catchment Above Lake Wheeler*. North Carolina Division of Environmental Management. Memorandum.
- Lenat, D.R. 1993. *Using Mentum Deformities of Chironomus Larvae to Evaluate the Effects of Toxicity and Organic Loading in Streams*. *J. N. Am. Benthol. Soc.* 12(3):265-269.
- Livingston, E.H. 2000. *Lessons Learned about Successfully Using Infiltration Practices*. Pp. 81-96 in *National Conference on Tools for Urban Water Resource Management and Protection*. Proceedings of Conference held February 7-10, 2000 in Chicago, IL. EPA/625/R-00/001.
- Lopes, T.J. and S.G. Dionne. 1998. *A Review of Semivolatile and Volatile Organic Compounds in Highway Runoff and Urban Stormwater*. USGS Open-File Report 98-409.
- MacDonald, D.D., C.G. Ingersoll and T.A. Berger. 2000. *Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems*. *Archives of Environmental Contamination and Toxicology* 39: 20-31.

- MacRae, C.R. 1997. *Experience from Morphological Research in Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection?* Pp. 144-162 in Roesner, L.A. (ed) *Effects of Watershed Development and Management on Aquatic Ecosystems*. ASCE. New York.
- Maryland Department of the Environment. 2000. *2000 Maryland Stormwater Design Manual, Volumes I and II*.
- Maxted, J.R. and E. Shaver. 1999. *The Use of Retention Basins to Mitigate Stormwater Impacts to Aquatic Life*. Pp. 6-15 in *National Conference on Retrofit Opportunities for Water Resource Protection in Urban Environments*. Proceedings of Conference held February 9-12, 1998 in Chicago IL. EPA/625/R-99/002.
- McGurrin, J. and H. Forsgren. 1997. *What Works, What Doesn't, and Why*. Pp. 459-471 in J.E. Williams, C.A. Wood and M.P. Dombeck (eds) *Watershed Restoration: Principles and Practices*. American Fisheries Society. Bethesda, MD.
- Meade, R.H. 1982. *Sources, Sinks and Storage of River Sediment in the Atlantic Drainage of the United States*. J of Geology. 90:235-252.
- Meade, R.H. and S.W. Trimble. 1974. *Changes in Sediment Loads in Rivers of the Atlantic Drainage on the United States Since 1900*. Pp. 99-104. International Assoc of Hydrological Sciences Publ. No. 113.
- Metropolitan Washington Council of Governments. 1998. *Anacostia Watershed Restoration Progress and Conditions Report, 1990-1997*. May.
- Montgomery County Department of Environmental Protection. 2001. *Countywide Stream Protection Strategy*. Available online at <http://www.co.mo.md.us/dep/Watersheds/csps/csps.html>.
- NCDWQ. 1998. *North Carolina Ceriodaphnia Chronic Effluent Toxicity Procedure*. December 1985. Revised February 1998.
- NCDWQ. 1999. *Stormwater Best Management Practices*. Water Quality Section. April.
- NCDWQ. 2000. *A Citizen's Guide to Water Quality Management in North Carolina*. First Edition. Planning Branch.
- NCDWQ. 2001a. *Standard Operating Procedures—Biological Monitoring*. Biological Assessment Unit.
- NCDWQ. 2001b. *Basinwide Assessment Report-Neuse River Basin*. Environmental Sciences Branch. November.
- NCSU. 2001. *Morphological Evaluation and Restoration Feasibility Assessment Swift Creek near Cary, NC*. NC Stream Restoration Institute. November.
- NCSU. 2002. *Morphological Evaluation and Restoration Feasibility Assessment Williams Creek off of Edinburgh Drive in Cary, NC*. NC Stream Restoration Institute. March.
- New York Department of Environmental Conservation (NYDEC). 1999. *Technical Guidance for Screening Contaminated Sediments*. At <http://www.dec.state.ny.us/website/locator/fwmr.html>.

- Niemi, G.J., P. DeVore, N. Detenbeck et al. 1990. *Overview of Case Studies on Recovery of Aquatic Systems from Disturbance*. Environmental Management. 14:571-587.
- Northern Virginia Planning District Commission (NVPDC). 1996. *Nonstructural Urban BMP Handbook*. Annandale, VA. December.
- Oblinger, C.J. and M.W. Treece. 1996. *Water and Bed-Material Quality of Selected Streams and Reservoirs in the Research Triangle Area of North Carolina, 1988-94*. USGS Water-Resources Investigations Report 95-4282. Raleigh.
- Prince George's County Department of Environmental Resources. 2000. *Low Impact Development Design Strategies: An Integrated Design Approach*. USEPA. EPA 841/B-00/003. January.
- Reckhow, K.H. 1997. *Adaptive Management: Responding to a Dynamic Environment*. WRI News. Number 307. September/October. Pp. 2-3. Water Resources Research Institute of the University of North Carolina.
- Richter, D.D., K. Korfmacher and R. Nau. 1995. *Decreases in Yadkin River Basin Sedimentation: Statistical and Geographic Time-Trend Analyses, 1951 to 1990*. Report No. 297. Water Resources Research Institute of the University of North Carolina. Raleigh. November.
- Rosgen, D. 1996. *Applied River Morphology*. Wildland Hydrology. Pagosa Springs, CO.
- Rosgen, D. 1997. *A Geomorphological Approach to Restoration of Incised Rivers*. Pp. 12-22 in S.S.Y. Wang et al. (eds) *Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision*. Univ of Mississippi.
- Ryck, F., Jr. 1975. *The Effect of Scouring Floods on the Benthos of Big Buffalo Creek, Missouri*. Proceedings of the 29th Annual Conference of the Southeastern Association of Game and Fish Commissioners.
- Schueler, T. 1994. *The Importance of Imperviousness*. Watershed Protection Techniques. 1:3:100-111.
- Schueler, T. 1995. *Urban Pesticides: From the Lawn to the Stream*. Watershed Protection Techniques. 2:1:247-253.
- Schueler, T.R. 2000a. *The Environmental Impact of Stormwater Ponds*. Pp. 443-452 in T.R. Schueler and H.K. Holland (eds) *The Practice of Watershed Protection*. Center for Watershed Protection. Ellicott City, MD.
- Schueler, T.R. 2000b. *The Economics of Stormwater Treatment: An Update*. Pp. 61-65 in T.R. Schueler and H.K. Holland (eds) *The Practice of Watershed Protection*. Center for Watershed Protection. Ellicott City, MD.
- Schueler, T.R. and H.K. Holland. 2000. *Sligo Creek: Comprehensive Stream Restoration*. Pp. 716-721 in T.R. Schueler and H.K. Holland (eds) *The Practice of Watershed Protection*. Center for Watershed Protection. Ellicott City, MD.
- Schueler, T.R., J. Galli, L. Herson, P. Kumble and D. Shepp. 1991. *Developing Effective BMP Systems for Urban Watersheds*. Pp. 33-63 in Anacostia Restoration Team (ed) *Watershed Restoration Sourcebook*. Metropolitan Washington Council of Governments.

- Schumm, S.A., M.D. Harvey and C.C. Watson. 1984. *Incised Channels: Morphology, Dynamics and Control*. Water Resources Publications. Littleton, CO.
- Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford and C.P.Hawkins. 1990. *Role of Refugia in Recovery from Disturbances: Modern Fragmented and Disconnected River Systems*. *Environmental Management*. 14:711-724.
- Shields, F.D., A. Brookes A and J. Haltiner. 1999. *Geomorphological Approaches to Incised Stream Channel Restoration in the United States and Europe*. Pp. 371-394 in S. Darby and A. Simon (eds) *Incised River Channels: Processes, Forms, Engineering and Management*. John Wiley & Sons. Chichester, UK.
- Simon, A. 1989. *A Model of Channel Response in Disturbed Alluvial Streams*. *Earth Surface Processes and Landforms*. 14:11-26.
- Simon, A. and S. Darby. 1999. *The Nature and Significance of Incised River Channels*. Pp. 3-18 in S. Darby and A. Simon (eds) *Incised River Channels: Processes, Forms, Engineering and Management*. John Wiley & Sons. Chichester, UK.
- Simmons, C.E. 1993. *Sediment Characteristics of North Carolina Streams, 1970-79*. USGS Water-Supply Paper 2364 [Originally published in 1987 as Open-File Report 87-701].
- Smock, L.A. 1996. *Macroinvertebrate Movements: Drift, Colonization, and Emergence*. In F.R. Hauer and G.A. Lamberti (eds) *Methods in Stream Ecology*. Academic Press. San Diego, CA.
- Suter, G.W. and C.L. Tsao. 1996. *Toxicological Benchmarks for Screening of Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision*. Report ES/ER/TM-96/R2. US Department of Energy. Oak Ridge National Laboratory. Oak Ridge, TN.
- Town of Cary. 2000. *Population Report: June 2000*. Department of Development Services.
- Trimble, S.W. 1974. *Man-Induced Soil Erosion on the Southern Piedmont 1700-1970*. Ankeny, IA. Soil and Water Conservation Society of America.
- USEPA. 1993. *Methods for Measuring the Acute Toxicity of Effluents to Freshwater and Marine Organisms*. Fourth Edition. EPA/600/4-90/027F.
- USEPA. 1995. *Final Water Quality Guidance for the Great Lakes System*. 40 CFR Parts 9, 122, 123, 131, 132. Federal Register. 60:56:15365-15425. March 23.
- USEPA. 1997. *Guidelines for Preparation of the Comprehensive State Water Quality Assessments [305(b) Reports] and Electronic Updates: Supplement*. EPA 841-B-97-002B. September.
- USEPA. 1998. *Guidelines for Ecological Risk Assessment*. EPA 630-R-95-002F.
- USEPA. 1999. *National Recommended Water Quality Criteria--Correction*. EPA 822-Z-99-001.
- USEPA. 2000. *Stressor Identification Guidance Document*. EPA 822-B-00-025. December.
- USEPA. 2000b . *Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates*, Second Edition. EPA 823-B-99-007. Duluth, MN and Washington, DC.

- USEPA. 2001. *Protecting and Restoring America's Watersheds: Status, Trends, and Initiatives in Watershed Management*. EPA 840-R-00-001. June.
- USEPA. 2002. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas—Draft*. EPA 842-B-02-003. July.
- van Metre, P.C., B.J.Mahler and E.T. Furlong. 2000. *Urban Sprawl Leaves Its PAH Signature*. *Environmental Science and Technology*. 34:4064-4070.
- Wake County Watershed Management Plan Task Force (WCWMPTF). 2003. *Wake County Watershed Management Plan*. Report submitted to the Wake County Commissioners. Raleigh, NC. January. Available online at <http://projects.ch2m.com/WakeCounty>.
- Ward, J.V. and J.A. Stanford (eds). 1979. *The Ecology of Regulated Streams*. Plenum Press. New York, NY.
- Waters, T.F. 1972. *The Drift of Stream Insects*. *Annual Review of Entomology* 17: 253-272.
- Weinkam, C., R. Shea, C. Shea, C. Lein and D. Harper. 2001. *Urban Stream Restoration Programs of Two Counties in the Baltimore-Washington D.C. Area*. Paper Presented at the *Fourth Annual North Carolina Stream Restoration Conference, Stream Repair and Restoration: A Focus on the Urban Environment*. October 16-19, 2001. Raleigh, NC.
- Williams, D.D. and H.B. Hynes. 1976. *The Recolonization Mechanisms of Stream Benthos*. *Oikos* 27: 265-272.
- Wilson, M.P. 1983. *Erosion of Banks Along Piedmont Urban Streams*. Water Resources Research Institute of the University of NC. Raleigh. Report No. 189.
- Yoder, C.O. and E.T Rankin. 1995. *Biological Response Signatures and the Area of Degradation Value: New Tools for Interpreting Multimetric Data*. Pp. 263-286 in W.S. Davis and T.P. Simon (eds) *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Boca Raton, FL. Lewis Publishers.
- Young, G.K, S. Stein, P. Cole, T. Kammer, F.Graziano and F. Bank. 1996. *Evaluation and Management of Highway Runoff Water Quality*. US Department of Transportation. Federal Highway Administration. Publication No. FHWA-PD-96-032. Washington, DC. June.
- Yount, J.D. and G.J. Niemi. 1990. *Recovery of Lotic Communities and Ecosystems from Disturbance—A Narrative Review of Case Studies*. *Environmental Management*. 14:547-569.
- Urbonas, B.R. 2002. *Linking Stormwater BMP Designs and Performance to Receiving Water Impact Mitigation*. Proceeding of an Engineering Foundation Conference. Snowmass Village, Colorado. August 19-24, 2001. American Society of Civil Engineers. Reston, VA.