DWARF WEDGEMUSSEL VIABILITY STUDY

Complete 540
Triangle Expressway Southeast Extension

Wake and Johnston Counties

STIP Project Nos. R-2721, R-2828, and R-2829
State Project Nos. 6.401078, 6.401079, and 6.401080
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Prepared for:

North Carolina Department of Transportation
North Carolina Turnpike Authority

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Executive Summary

Swift Creek, a major tributary of the Neuse River Basin located in Wake and Johnston Counties, North Carolina, supports the federally Endangered Dwarf Wedgemussel (DWM), and several other rare aquatic species. The Swift Creek DWM population has been identified as essential for the recovery of the species by the US Fish & Wildlife Service (USFWS).

The NC Department of Transportation (NCDOT) proposes transportation improvements from the NC 55 Bypass in Apex to the US 64/US 264 Bypass in Knightdale. These improvements, known as the Complete 540 - Triangle Expressway Southeast Extension project, would extend the existing Triangle Expressway, effectively completing the 540 Outer Loop around Raleigh. Inevitably, this proposed project would require at least one crossing of Swift Creek.

Before assessing potential project related impacts to the Swift Creek DWM population, a comprehensive update to the environmental baseline of the Swift Creek population was completed as part of a study on the projected population and habitat viability. The purpose of this study is threefold:

- characterize existing conditions of the Swift Creek Watershed (SCW)
- summarize conservation measures that have been implemented to protect DWM in the SCW
- assess historic trends and future viability of the DWM population and habitat conditions.

Population viability attributes that were considered include range of occupied habitat, relative abundance, and evidence of reproduction and recruitment. Habitat viability attributes include general channel stability and micro-habitat characteristics like stream bank conditions and substrate composition.

A number of past studies assessed various aspects of the SCW. This report draws from these studies in order to develop a clearer and more concise picture of the current and projected future conditions of the watershed, with regard to land use and water quality. Data gaps in the watershed baseline information are also identified.

The second part of this study provides an accounting of various conservation measures that have been implemented in the SCW to protect the stream, and more specifically the DWM. A Local Watershed Management Plan was developed for the upper part of the SCW, and various recommendations from that plan have been adopted by participant municipalities. Additionally, recent highway and water treatment projects in the watershed incorporated various conservation measures to offset identified impacts to the species and the watershed. Conservation measures that have been adopted range from development restrictions, and Best Management Practices

(BMPs) that avoid/minimize future impacts, to various measures such as guaranteed low flow releases that were developed to offset impacts from particular projects.

Population trends of the DWM and other freshwater mussel species in Swift Creek were examined to compare current population conditions to the past. The trend analysis measures include relative abundance, age class distribution, and detection probability. Trends of in-stream habitat conditions, flow, channel stability, and substrate composition were also analyzed. Historic hydrograph data was analyzed to assess how often aquatic life is exposed to extreme low flows. Aerial photography was used to illustrate the condition of the stream channel and its movement, or lack thereof, across the landscape, and geomorphology attributes were compared between sites that currently support the DWM and sites that do not.

The results of this study demonstrate that there are numerous stressors to aquatic communities in the SCW, particularly the DWM population. Many of these stressors are directly and indirectly related to the urbanization of the watershed since the early 1990s. It appears that mussel populations have declined in conjunction with these recent changes in the watershed. The declines seem to have leveled off, and there is some indication that mussel recruitment has increased within the last few years. The geomorphology component of the study identified that the heterogeneous distribution of substrate size within a site is important for the DWM.

Based on this analysis, it is apparent that the long term viability of the DWM population in Swift Creek is threatened; however, it can be concluded with some level of uncertainty that there is a chance for this species to persist into the future. This chance of persistence is very tenuous, especially without active management and increased habitat protection. Management recommendations that would help ensure a sustainable DWM population include in-stream habitat monitoring, population augmentation using captive propagation techniques, continued targeted water quality monitoring, and establishing a DWM focused stakeholder group in the Lower SCW.

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1.0 INTRODUCTION

The North Carolina Turnpike Authority (NCTA) of the North Carolina Department of Transportation (NCDOT) proposes construction of a new road corridor from NC-55 (Apex) East to US-64 Bypass (Knightdale); thus completing the I-540 outer loop around the City of Raleigh (Figure 1). The Dwarf Wedgemussel (*Alasmidonta heterodon,* DWM), which is listed by the US Fish and Wildlife Service (USFWS) as a federally endangered species, occurs in Swift Creek within the proposed action area of the project. It was first documented to occur in Swift Creek in 1991 (Alderman 1991).

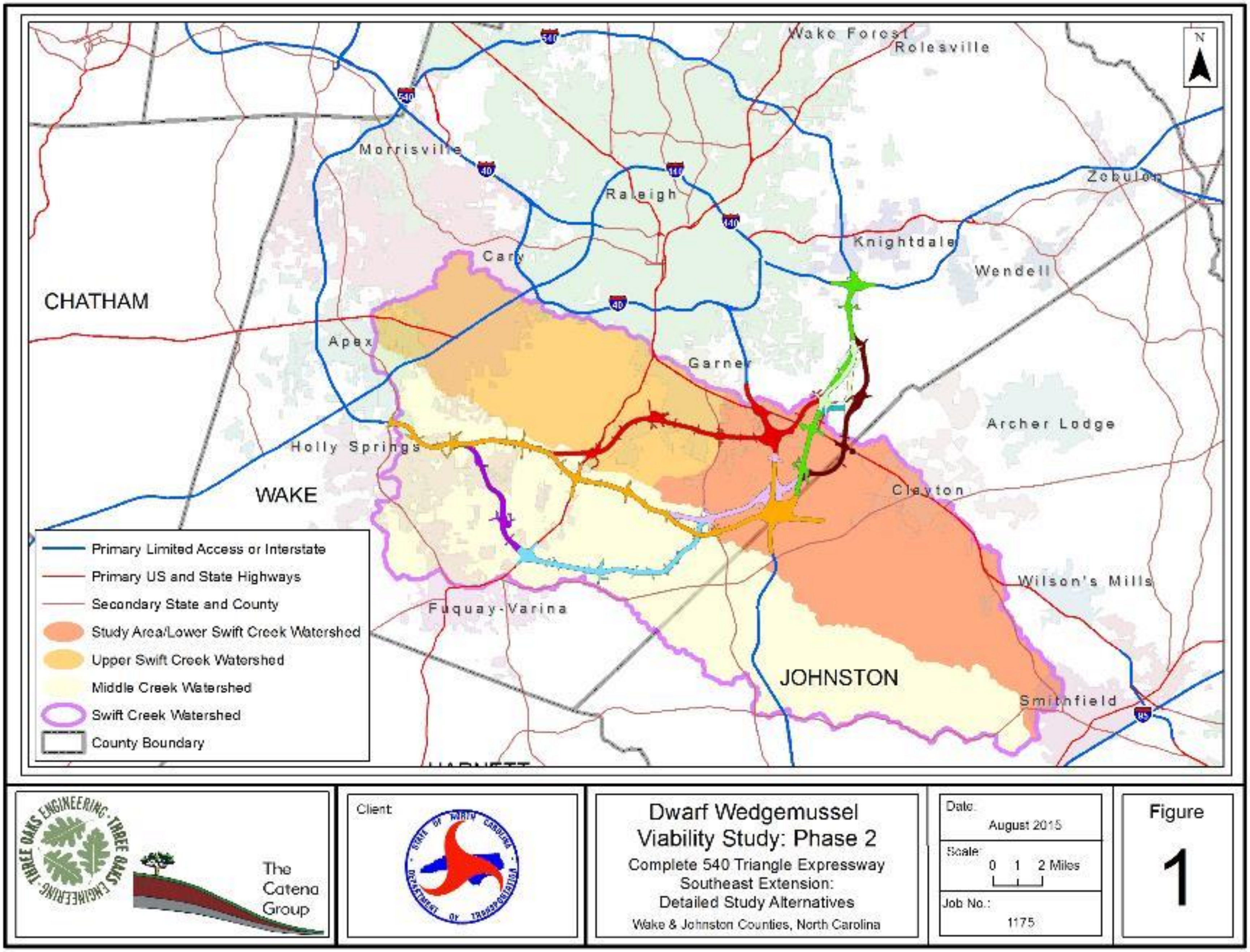
The North Carolina Wildlife Resources Commission (NCWRC) identified the Swift Creek Watershed (SCW) as one of 25 areas in North Carolina considered essential for the continued survival of endangered or threatened aquatic wildlife species (Alderman et al. 1993), as it supports several rare aquatic species (Table 1), including the DWM.

Table 1. Rare Aquatic Species in Swift Creek

Scientific Name	Common Name	NCWRC Status*	Nature Serve Status**	Federal Status
Alasmidonta heterodon	Dwarf Wedgemussel	E	S1	E
Alasmidonta undulata	Triangle Floater	T	S2	~
Anguilla rostrata	American Eel	~	S4	~
Elliptio lanceolata	Yellow Lance	E	S1	~
Elliptio roanokensis	Roanoke Slabshell	T	S1	~
Fusconaia masoni	Atlantic Pigtoe	E	S1	~
Lampsilis radiata	Eastern Lampmussel	T	S1S2	~
Lasmigona subviridis	Green Floater	E	S1	~
Lythrurus matutinus	Pinewoods Shiner	~	S3	~
Necturus lewisi	Neuse River Waterdog	SC	S2	~
Noturus furiosus	Carolina Madtom	T	S2	~
Strophitus undulatus	Creeper	T	S2	~
Villosa constricta	Notched Rainbow	SC	S3	~

*E, T, and SC denote Endangered, Threatened, and Special Concern respectively.
**S-ranks, referring to NC State ranks, range from S1 (imperiled) to S5 (secure), with S1S2 indicating some uncertainty in the appropriate rank.

As required by the Nature Preserves Act (NCGS 113A-164 of Article 9), the North Carolina Natural Heritage Program (NCNHP) compiles the North Carolina Department of Environment and Natural Resources (NCDENR) priority list of "Significant Natural Heritage Areas" (SNHAs). These sites are inventoried and evaluated on the basis of rare plant and animal species, rare or high quality natural communities, and special animal habitats, collectively termed the "Elements" of natural diversity. The sites are rated with regard to national and state significance, and nearly 250 acres of lower Swift Creek are rated as "High", which is the third highest rating, following "Exceptional" and "Very High", then followed by "Moderate", and


Wake Forest
Rolesville
Morrisville
Raleigh
Knightdale
Wendell
Zebulon
Cary
CHATHAM
Apex
Garner
Archer Lodge
Holly Springs
WAKE
Clayton
Fuquay-Varina
Wilson's Mills
JOHNSTON
Smithfield
N
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
Middle Creek Watershed
Swift Creek Watershed
County Boundary
The Catena Group
Client
Dwarf Wedgemussel Viability Study: Phase 2
Complete 540 Triangle Expressway Southeast Extension: Detailed Study Alternatives
Wake & Johnston Counties, North Carolina
Date: August 2015
Scale: 0 1 2 Miles
Job No.: 1175
Figure 1

“General”. It is noted that sites on the list should be given priority for protection; however, it does not imply that all of the areas currently receive protection (NCNHP 2015).

The Swift Creek population of the DWM was identified in the USFWS 1993 Recovery Plan as essential for the recovery of the species. Since the DWM is within the proposed action area, potential direct, indirect, and cumulative impacts to this species will need to be fully assessed and disclosed as required by Section 7 of the Endangered Species Act of 1973, as amended. This will be accomplished during the planning and environmental studies for the Complete 540 project.

In a letter to NCDOT dated February 17, 2011, the USFWS indicated that an updated Environmental Baseline of the DWM population in Swift Creek will be needed to determine if the proposed action has the potential to jeopardize the continued existence of this species. The USFWS proposed a three-tiered study to be implemented by NCDOT to develop this updated Environmental Baseline:

1. Provide an accounting (compliance/ implementation) of conservation measures that have been implemented in Swift Creek to protect DWM
2. Assess the effectiveness of existing conservation measures and environmental protections in Swift Creek with regard to habitat and population stability
3. Assess historic trends, and current viability of DWM population and habitat conditions in Swift Creek

In response to the correspondence and in coordination with NCDOT and USFWS, this study was initiated in March 2011, beginning with an intensive mussel survey effort that continued at various times of the year through October 2012. However, mussel surveys were also conducted in 2010 within Swift Creek as well as other waterbodies (Middle Creek, Neuse River etc.) within the project study corridors as part of the NEPA studies for the project. These data were gathered as a component of the mussel population viability portion of the third tier of this study. A Phase 1 report of this study was completed March 21, 2014, that compared the results of these surveys with all previous survey data. The other major tasks carried out in Phase 1 included assessing and comparing current and previous watershed and habitat conditions, as well as a gathering of information to provide an account of conservation measures, and what protective measures are in place within the SCW. The DWM Viability Study: Phase 1 Draft Report (Appendix A) served as an interim evaluation of baseline information for the watershed and the Swift Creek DWM population.

After review of the Phase 1 Draft Report by the USFWS and NCDOT, additional analysis was recommended for a second phase of the study (Phase 2) to develop a more complete baseline and meet the objectives of the study. The combined results of the two phases of this study are presented in this report.

1.1.Summary of Phase I Report

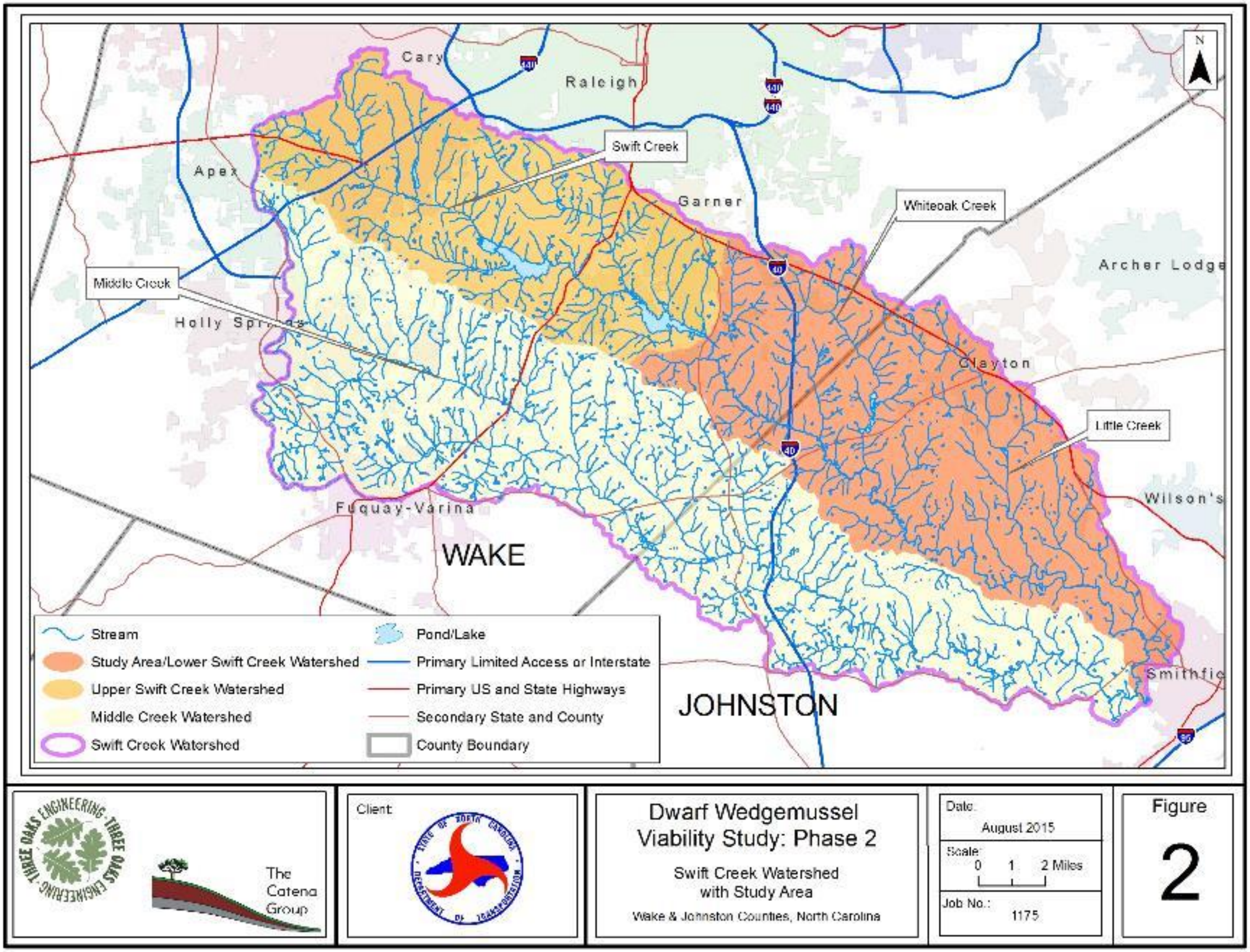
The preliminary results of Phase 1 demonstrated that there are numerous stressors to aquatic communities, particularly the DWM population, in the SCW. Many of these stressors are directly and indirectly related to the rapid urbanization of the watershed since the early 1990s. A number of conservation measures that had been developed and implemented within the SCW were identified in Phase 1. These measures consisted largely of establishing minimum buffer requirements, limiting the amount of imperviousness and nutrient inputs, and providing stormwater and erosion control measures. Additionally, measures associated with the Dempsey Benton Water Treatment Plant provide for maintenance of minimum flows in the Lower SCW. The Phase 1 report concluded that the effectiveness of these measures in providing sufficient protection to the DWM population was unclear. This was due mainly to the short period of time that these measures were in place, the difficulty in evaluating the effectiveness of a particular measure given the number of stressors that occur within the SCW, and the uncertainty of whether or not the measures were implemented to the level they were intended.

It appears that mussel populations have declined in conjunction with these recent changes. The declines seem to have leveled off, and there is some indication that mussel recruitment has increased within the last few years. The geomorphology component of the study identified that the heterogeneous distribution of substrate size within a site may be important for the DWM.

Phase 1 analysis indicated that the long term viability of the DWM population in SCW is threatened, but there was not sufficient information to predict the likelihood the species would continue to persist in Swift Creek into the future. Population augmentation using captive propagation of individuals was identified as a management tool that could enhance the viability of the population.

1.2.Study Area

SCW is located in Wake and Johnston Counties in Central North Carolina and is part of the Neuse River Basin (Figure 2). The watershed is contained entirely within the Piedmont Physiographic Province. The headwaters of Swift Creek are in the towns of Apex and Cary, Wake County; from there, the stream flows southeast for approximately 38 miles until joining the Neuse River near Smithfield in Johnston County. The system includes two major reservoirs, Lake Wheeler and Lake Benson, which serve as water sources for the Triangle Area. The drainage area of SCW is approximately 289 square miles, with a major tributary, Middle Creek accounting for 45% of the drainage area. SCW encompasses several municipalities, including portions of Raleigh, residential areas, forested areas, and agricultural fields. From the headwaters to and including Lake Benson is considered the Upper SCW; below Lake Benson to the convergence with the Neuse River (32 stream miles) is considered the Lower SCW (Figure 2). The DWM population occurs within the Lower SCW, thus it is where the majority of this


Cary
Raleigh
Apex
Garner
Swift Creek
Whiteoak Creek
Archer Lodge
Middle Creek
Holly Springs
Clayton
Little Creek
Wilson's
Fuquay-Varina
WAKE
JOHNSTON
Smithfie
Stream
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
Middle Creek Watershed
Swift Creek Watershed
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
County Boundary
The Catena Group
Client
Dwarf Wedgemussel Viability Study: Phase 2
Swift Creek Watershed with Study Area
Wake & Johnston Counties, North Carolina
Date: August 2015
Scale: 0 1 2 Miles
Job No.: 1175
Figure 2

study is focused, and is defined as the Study Area. However, conditions in the Upper SCW have some influence on the Lower SCW, therefore relevant data from the upper part of the watershed is provided and discussed in this report.

2.0 SPECIES DESCRIPTION

Alasmidonta heterodon (Dwarf Wedgemussel)

Federal Status: Endangered
Family: Unionidae
Listed: March 14, 1990

2.1.Characteristics

DWM was originally described as *Unio heterodon* (Lea 1829). Simpson (1914) subsequently placed it in the genus *Alasmidonta*. Ortman (1919) placed it in a monotypic subgenus *Prolasmidonta,* based on the unique soft-tissue anatomy and conchology. Fuller (1977) believed the characteristics of *Prolasmidonta* warranted elevation to full generic rank and renamed the species *Prolasmidonta heterodon*. Clarke (1981) retained the genus name *Alasmidonta* and considered *Prolasmidonta* to be a subjective synonym of the subgenus *Pressodonta* (Simpson 1900).

The specific epithet *heterodon* refers to the chief distinguishing characteristic of this species, which is the only North American freshwater mussel that consistently has two lateral teeth on the right valve and only one on the left (Fuller 1977). All other laterally dentate freshwater mussels in North America normally have two lateral teeth on the left valve and one on the right. DWM is generally small, with a shell length ranging between 25 mm and 38 mm. The largest specimen reported by Clarke (1981) was 56.5 mm long, taken from the Ashuelot River in New Hampshire. The periostracum is generally olive green to dark and nacre bluish to silvery white, turning to cream or salmon colored towards the umbonal cavities. Sexual dimorphism occurs in DWM, with the females having a swollen region on the posterior slope, and the males are generally flattened. Clarke (1981) provides a detailed description of the species.

Nearly all freshwater mussel species have similar reproductive strategies; a larval stage (glochidium) becomes a temporary obligatory parasite on a fish. This species is considered to be a long-term brooder, with gravid females reportedly observed in the fall months. Like other freshwater mussels, this species' eggs are fertilized in the female as sperm are taken in through their siphons as they respire. The eggs develop within the female's gills into larvae (glochidia). The females later release the glochidia, which then attaches to the gills or fins of a specific host fish species. Based on anecdotal evidence, such as dates when gravid females are present or absent, it appears that release of glochidia occurs primarily in April in North Carolina (Michaelson and Neves 1995). Recent research has confirmed at least three potential fish host species for DWM to be the Tessellated darter (*Etheostoma olmstedi*), Johnny Darter (*E. nigrum*), and Mottled Sculpin (*Cottus bairdii*) (Michaelson 1993). McMahon and Bogan (2001) and Pennak (1989) should be consulted for a general overview of freshwater mussel reproductive biology.

2.2.Distribution and Habitat Requirements

The historic range of DWM was confined to Atlantic slope drainages from the Peticodiac River in New Brunswick, Canada, south to the Neuse River, North Carolina. Occurrence records exist from at least 70 locations, encompassing 15 major drainages, in 11 states, and 1 Canadian Province (USFWS 1993). When the recovery plan for this species was written, DWM was believed to have been extirpated from all but 36 localities, 14 of them in North Carolina (USFWS 1993). The most recent assessment (2013 5-Year Review) indicates that DWM is currently found in 16 major drainages, comprising approximately 75 “sites” (one site may have multiple occurrences) (USFWS 2013). At least 45 of these sites are based on less than five individuals or solely on relict shells. It appears that the populations in North Carolina, Virginia, and Maryland are declining as evidenced by low densities, lack of reproduction, or inability to relocate any individuals in follow-up surveys. Populations in New Hampshire, Massachusetts, and Connecticut appear to be stable, while the status of populations in the Delaware River watershed affected by the floods of 2005 are still being studied. At a recent USFWS meeting, it was noted that one of the Farmington River populations has been extirpated, possibly lowering the number of occupied “sites” (Sarah McRae USFWS, personal communication).

Strayer et al. (1996) conducted range-wide assessments of remaining DWM populations and assigned a population status to each of the populations. The status rating is based on range size, number of individuals, and evidence of reproduction. Seven of the 20 populations assessed were considered “poor”, and two others were considered “poor to fair” and “fair to poor”, respectively. In North Carolina, populations are found in portions of the Neuse and Tar River basins; however, it is believed to have been extirpated from the main-stem of the Neuse River.

DWM inhabits creeks and rivers of varying sizes (down to approximately two meters [6 ft] wide), with slow to moderate flow. A variety of preferred substrates have been described that range from coarse sand, to firm muddy sand to gravel (USFWS 1993). In North Carolina, DWM often occurs within submerged root mats along stable streambanks (USFWS 2007). Two general in-stream habitat types, Shallow Fast Coarse (SFC) or Deep Stream Margin Roots (DSMR) habitats were identified as primarily supporting this species in Swift Creek (Entrix 2005). The wide range of substrate types used by this species suggests that the stability of the substrate is likely as important as the composition.

2.3.Threats, Particularly the Swift Creek Population

The cumulative effects of several factors, including sedimentation, point and non-point discharge, and stream modifications (impoundments, channelization, etc.) have contributed to the decline of this species throughout its range. With the exception of the Neversink River population in New York, which has an estimated population of over 80,000 DWM individuals, all of the other populations are generally small in numbers and restricted to short reaches of isolated streams. The low numbers of individuals and the restricted range of most of the surviving populations make them extremely vulnerable to extirpations from a single catastrophic event or activity (Strayer et al. 1996). Catastrophic events may consist of natural events such as flooding or drought, as well as human influenced events such as toxic spills associated with highways, railroads, or industrial-municipal complexes. Based on expert opinion of a North Carolina DWM (NC DWM) Work Group assembled by the USFWS Raleigh field office in 2012, the "Allee effect", defined as a high risk of demographic extirpation due to low population abundance and lack of dispersal, was identified as the second highest threat behind "unsuitable physical habitat" to the Swift Creek population (Smith et al. 2014).

2.3.1. *Sedimentation*

Siltation resulting from substandard land-use practices associated with activities such as agriculture, forestry, and land development has been recognized as a major contributing factor to degradation of mussel populations (USFWS 1996). Siltation has been documented to be extremely detrimental to mussel populations by degrading substrate and water quality, increasing potential exposure to other pollutants, and by direct smothering of mussels (Ellis 1936; Markings and Bills 1979). Sediment accumulations of less than 25 mm (one inch) have been shown to cause high mortality in most mussel species (Ellis 1936). In Massachusetts, a bridge construction project decimated a population of the DWM because of accelerated sedimentation and erosion (Smith 1981).

2.3.2. *Habitat Alteration*

The impact of impoundments on freshwater mussels has been well documented (USFWS 1992a; Neves 1993). Construction of dams transforms lotic habitats into lentic habitats, which results in changes in aquatic community composition. The changes associated with inundation adversely affect both adult and juvenile mussels as well as fish community structure, which could eliminate possible fish hosts for upstream transport of glochidia. Muscle Shoals on the Tennessee River in northern Alabama, once the richest site for naiads (mussels) in the world, is now at the bottom of Wilson Reservoir and covered with 5.79 meters (19 feet) of muck (USFWS 1992b). Large portions of all of the river basins within the DWM range have been impounded and this is believed to be a major factor contributing to the decline of the species (Master 1986; USFWS 1993).

2.3.3. *Toxic Contaminants*

The presence of toxic contaminants has been shown to contribute to widespread declines of freshwater mussel populations (Havlik and Marking 1987; Bogan 1993; Neves et al. 1997; Richter et al. 1997; Strayer et al. 2004). Toxic contaminants can produce lethal or sub-lethal responses to freshwater mussels. The NC DWM Work Group identified "low water quality due to contaminants" as the third most important threat to the Swift Creek population (Smith et al. 2014). The sensitivities of freshwater mussels to toxic contaminants is variable based on species, life stage (glochidium, juvenile, or adult), and environmental conditions, as well as concentration and exposure route (water column, sediments, etc.), frequency, and duration. Several studies have indicated that early life stages of freshwater mussels are among the most sensitive aquatic organisms to various inorganic toxicants such as copper (Jacobson et al. 1993; Jacobson et al. 1997; Milam et al. 2005; Wang et al. 2007a; Wang et al. 2007b) and ammonia (NH3) (Wade 1992; Augsperger et al. 2003; Bartsch et al. 2003; Newton et al. 2003; Wang et al. 2007a; Wang et al. 2007b; Grabarkiewicz and Davis 2008).

Anthropogenic sources of ammonia and copper in surface waters include sewage treatment effluent, industrial wastewater effluent, and runoff and ground water contamination from agriculture, lawn/turf management, livestock operations, roadways, and faulty septic systems. Sewage treatment effluent has been documented to significantly affect the diversity and abundance of mussel fauna (Goudreau et al. 1988). Goudreau et al. (1988) found that recovery of mussel populations might not occur for up to two miles below discharges of chlorinated sewage effluent.

Recent studies indicated that previous federal water quality criteria for many pollutants commonly found in wastewater discharges and stormwater runoff were likely not protective of freshwater mussels; nationwide regulations controlling the discharge or runoff of these pollutants are also not protective (Augspurger et al. 2003). The previous (1999) U.S. Environmental Protection Agency (EPA) recommended 'freshwater ammonia aquatic life ambient water quality' criteria were based on the most sensitive endpoints known at the time: the acute criterion was based primarily on effects on salmonids (where present) or other fish, and the chronic criterion was based primarily on reproductive effects on the benthic invertebrate *Hyalella* or on survival and growth of fish early life stages (when present) (USEPA 2009). Research demonstrated that these standards were not protective of freshwater mussel species, which are some of the most sensitive aquatic organisms to ammonia. As a result, the EPA recently revised the freshwater ammonia aquatic life ambient water quality criteria (acute and chronic standards) to reflect freshwater mussel species sensitivity thresholds (USEPA 2013).

Ward et al. (2007) sampled for ammonia, copper and chlorine at five locations within, or draining to, the portion of Swift Creek occupied by DWM, and found that ammonia and chlorine levels rarely exceeded ecological screening values; however, copper levels exceeded ecological screening values for both acute and chronic exposure at all sites. Further discussion of this study, and results of water quality sampling targeting these compounds that were conducted as part of the Phase 2 of this study are discussed in Section 3.5, and in further detail in the Lower Swift Creek Water Quality Report (Three Oaks Engineering/ The Catena Group 2015a), which is included in Appendix B

When publishing the five-year review for the Carolina Heelsplitter (*Lasmigona decorata*), another federally Endangered freshwater mussel species that occurs in North Carolina, the USFWS stated that there were "currently no water quality standards, or monitoring requirements for ammonia, copper and phosphorus in North Carolina" (USFWS 2012).

The Goose Creek Site Specific Management Plan (NCDENR 2009), which was developed to provide protection for the Carolina Heelsplitter, requires that any direct or indirect discharge that may cause ammonia toxicity to the Carolina Heelsplitter implement measures to reduce ammonia inputs to achieve 0.5 milligrams per liter or less of total ammonia based on chronic toxicity defined in 15A NCAC 02B .0202 (NCAC 1998). This level of total ammonia is based on ambient water temperature equal to or greater than 25 degrees Celsius (NCDENR 2009).

While there are still no adopted standards or monitoring requirements for ammonia, and phosphorus in North Carolina, standards have recently been developed for copper, as updated in the Triennial Review of Standards (North Carolina Register 2014). EPA water quality criteria and North Carolina water quality standards are discussed further in Section 3.3.

In addition, studies indicate other toxicants present in wastewater effluent such as pharmaceuticals and personal care products (fluoxitine, estrogenic compounds, opiate derivatives etc.) cause a wide array of neurotoxicological (Gagné et al 2007a), reproductive (Bringolf et al. 2007; Gagné et al 2007b) and behavioral (Hazelton et al. 2013, Heltsley et al. 2006) impacts to freshwater mussels.

Other sources of toxic contaminants in surface waters arise from highway and urban runoff. Numerous pollutants have been identified in highway runoff, including various metals (lead, zinc, iron, copper, etc.), sediment, pesticides, deicing salts, nutrients (nitrogen, phosphorus), and petroleum hydrocarbons (Gupta et al. 1981; Yousef et al. 1985). The sources of these runoff constituents range from construction and maintenance activities to daily vehicular use. Hoffman et al. (1984) concluded that highway runoff can contribute up to 80 percent of the total pollutant loadings to receiving water bodies; identifying, among others, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, lead, and zinc.

The toxicity of highway runoff to aquatic ecosystems is poorly understood. A major reason for this poor understanding is the low number of studies focusing solely on highway runoff. Potential impacts of highway runoff have often been inferred from studies conducted on urban runoff; however, the relative loadings of pollutants are often much greater in urban runoff, because of a larger drainage area and lower receiving water dilution ratios (Dupuis et al. 1985). The negative effects of urban runoff inputs on benthic macroinvertebrate communities have been well documented (Garie and McIntosh 1986; Jones and Clark 1987; Field and Pitt 1990). Lieb (1998) found the macroinvertebrate community of a headwater stream in Pennsylvania to be highly degraded by urban runoff via a detention pond. Improvements were observed at continual distances downstream from the discharge point; however, all sites examined were still impaired compared to a reference community.

The few studies that examined actual highway runoff show that some species demonstrate little sensitivity to highway runoff exposure, while others are much more sensitive (Dupuis et al. 1985). Maltby et al. (1995) found elevated levels of hydrocarbons and metals in both stream sediments and the water column below a heavily traveled British motorway. They demonstrated that the benthic amphipod (*Gammarus pulex*) experienced a decrease in survival when exposed to sediments contaminated with roadway runoff. However, this species showed no increase in mortality when exposed to water contaminated with roadway runoff. Most of these studies only measured acute toxicity to runoff and did not examine long-term effects.

The effects of highway runoff on freshwater bivalves have not been studied extensively. Augspurger (1992) compared sediment samples and soft tissues of three Eastern Elliptio (*Elliptio complanata*), a relatively common species upstream and downstream of the I-95 crossing of Swift Creek of the Tar River Basin in Nash County, North Carolina. The sediment samples as well as the mussels exhibited higher levels of aliphatic hydrocarbons, arsenic, lead, zinc, and other heavy metal contaminants in the downstream samples. Because of the small sample size, the effect on the health of these mussels was not studied. In another study, contaminant analysis of stream sediments showed an increase of polycyclic aromatic hydrocarbons and some metals downstream of road crossings, although there was no direct correlation found between increasing contaminant levels and decreasing mussel abundance at these crossings (Levine et al. 2005). The Eastern Elliptio was the only mussel species that was found in large enough numbers for statistically valid comparisons. The Eastern Elliptio is generally considered more tolerant of water quality degradation than many other mussel species. Further research is needed before the effects of highway runoff on sensitive mussel species such as the DWM can be determined.

In addition, contamination of surface water from toxic spills along roadways is known to have significant impacts to aquatic communities. A toxic spill resulting from a tanker truck accident that was carrying Octocure 554 (a chemical liquid used in the rubber making process) killed several miles of mussel populations in the Clinch River near Cedar Bluff, Virginia (Richmond Times Dispatch 1998). The spill killed thousands of fish and mussels, including three federally protected species. The Clinch River contains one of the most diverse mussel faunas in the United States. The stretch of the river affected by the spill was one of the few remaining areas that contained a reproducing population of the endangered Tan Riffleshell (*Epioblasma florentina walkeri*), which has not been found in the river since.

2.3.4. *Urbanization/Impervious Surface*

The Swift Creek watershed has experienced urbanization in recent years, which is discussed in detail in Section 3.0. The correlation of increasing development within a watershed and decreasing water quality is well documented (Lenat et al. 1979; Garie and McIntosh 1986; Crawford and Lenat 1989; Lieb 1998), and is largely associated with increases in impervious surface area. These increases in impervious surface area can affect water quality in a variety of ways, particularly with regard to changes to stream flow, water temperature, total suspended sediment, and pollutant loadings.

Multiple studies have demonstrated that water quality and stream ecosystem degradation begins to occur in watersheds that have approximately ten percent coverage by impervious surfaces (Schueler 1994; Arnold and Gibbons 1996; Stewart et al. 2000). NCWRC recommendations for management of protected aquatic species watersheds are to limit imperviousness to six percent of the watershed (NCWRC 2002). The amount of impervious surface has increased in the SCW, constituting about 11% of the SCW land area within Wake County (the more developed of the two counties). As a result, Wake County as a whole contributes about 4.29 inches/year of runoff (CDM 2003, Table 3-5). Of all the rainfall that falls onto these impervious surfaces, an estimated 95 percent becomes runoff. Johnston County is less developed than Wake County. As of 2011, the county was approximately 3.6 percent urban development, while the portion in the SCW was approximately 8.6 percent. This is based on the National Land Cover Dataset (NLCD, Homer et al. 2014), and assuming all development is captured in the Low, Medium, and High Intensity Developed categories. The 2009 NCDWQ Neuse River Basinwide Plan indicates the entire SCW is 29.5 percent urbanized, with much of the growth occurring in the last 20 years. Increases in impervious surface area within a watershed can result in extremes (either high or low) in peak discharge, runoff volume, and base flow conditions.

2.3.4.1. Peak Discharge

Peak discharge is the maximum rate of stormwater flow expected from a storm event, measured in cubic feet per second (cfs). Peak discharge is often one metric used in analyzing impacts from development. Peak discharge affects channel stability (or instability), which is one of the identified constituent elements of Critical Habitat for the DWM. Increases in peak discharge equates to higher velocity, which in turn increases the scouring effect (surface erodibility) of the runoff. Accordingly, sedimentation will increase as erosion rates increase. Increases of peak discharge rates, coupled with deforestation, have been shown to result in stream narrowing and incision and subsequent loss of ecosystem function (Sweeney et al. 2004). Increased runoff volume and peak discharge (from typical and atypical storm events) destabilize the stream channel.

2.3.4.2. Runoff Volume

Runoff volume is the amount of stormwater expected from a storm event, measured in acre-feet. Like peak discharge, runoff volume is another metric often used in determining impacts of development, especially on the aquatic environment. For example, increases in the amount of runoff normally equates to increased sediment. While the two indicators are related, when analyzed separately, both are useful in assessing impacts to aquatic systems.

In a stable system, an increase in the velocity may have little impact if volume does not change, provided that measures to slow the increased velocity have been implemented. However, the increased runoff volume may have enough sediment to cause detrimental impacts. Regardless, it is important to consider both the rate (peak discharge) and the amount (runoff volume) when assessing impacts to aquatic systems. Again, sufficient stormwater controls accompanying future development activities in any given watershed are essential for conservation of sensitive aquatic species such as DWM.

2.3.4.3. Decreased Base Flow

Increases of impervious surface lead to decreases in infiltration and base flow (groundwater flow) within adjacent streams. This can result in the following:

- Less water to cover the stream bottom during periods of reduced base flow.
- Increases in water evaporation and temperature in widened streams as a result of reduced overhanging tree cover and increased exposure to sunlight, especially in areas with shallower water.
- Extension of the waste water treatment plant (WWTP) effluent "plume" further downstream, if base flow is reduced and WWTP discharge remains constant or increases, as it takes longer for the stream to dilute the nutrients and other toxins in the effluent.

Permitted and un-permitted water withdrawals for crop and turf/lawn irrigation further exacerbate this effect. In North Carolina, permits are required for water withdrawals of one million gallons or greater. Withdrawals less than this are not regulated, and are often unknown. Numerous small withdrawal operations have been observed in the Lower SCW (Catena personal observations). During summer months withdrawals of up to 188 gallons per minute (gpm), or 0.42 cfs can significantly affect the available dilution for downstream dischargers (Belnick 2001).

In general, soils in the Piedmont portion of the Neuse River Basin are highly erodible and are underlain by fractured rock formations that have limited water storage capacity resulting in the streams that flow through them being naturally susceptible to periods of very low or even interrupted flow. Streams in this area tend to have low summer flows and limited ability to assimilate oxygen-consuming wastes (NCWRC 2005). In addition, the Upper SCW is close to the transitional area between the poorly drained soils of the Triassic basin and the moderately drained soils weathered from granitic rocks underlying the Lower SCW. As such, Swift Creek is even more susceptible to periods of interrupted flow, particularly in the upper reaches, which have almost no potential for sustained 7Q10 low flow discharge; 7Q10 is defined as the minimum average discharge for a consecutive seven day period occurring, on average, once in ten years (Weaver 1998). The natural susceptibility of these watersheds to periods of very low to interrupted flow is further compounded by anthropogenic factors such as water withdrawals and urbanization.

Prolonged periods of drought have been shown to adversely impact mussel species (Johnson et al. 2001; Golladay et al. 2005; USFWS 2012), as mussels may face increased water temperatures and reduced dissolved oxygen (DO) concentrations (hypoxia, or eventually anoxia), increased predation, and emersion or stranding (Johnson et al. 2001). Thin-shelled species like DWM may be inherently more prone to the consequences of drought than thicker shelled species like *Elliptio* mussels. Prolonged drought has been identified as a major threat to the endangered Carolina Heelsplitter (USFWS 2012). Similarly, based on expert opinion of a NC DWM Work Group assembled by the USFWS Raleigh field office, drought ("unsuitable flow") was identified as one of the top three threats in all of the populations in the Tar River Basin (Smith et al. 2015).

While drought is recognized as a major threat for many mussel species, the actual low flow requirements of mussels is poorly understood. Johnson et al. (2001) and Golladay et al. (2005) assessed drought impacts on mussel assemblages in a number of streams in the Flint River Basin of southwestern Georgia. Flow rate, water temperature, water depth, and DO were monitored throughout the study and sites were classified as flowing or non-flowing during the drought period. Sites that ceased flowing during the drought had significant declines in the abundance of all mussel species, some of which are endangered, as well as declines in species richness. However, sites that maintained some flow during the drought had increases in stable species of mussels and no change in special concern or endangered species through the drought. Mortality of mussels at sites that ceased flowing was attributed to reductions in DO concentration, which was highly correlated with water velocity.

As part of the Section 7 Consultation for the Dempsey E. Benton Water Treatment Plant, a 60-year synthesized hydrologic time series was developed for Swift Creek using a ratio of the drainage area from the nearby, unregulated Middle Creek. The analysis concluded that Swift Creek historically experienced near zero and zero flow conditions (Entrix 2005). Minimum flow releases are now guaranteed as a result of conservation measures developed for the project (see Section 4.2.5).

2.3.4.4. Thermal Pollution

Concerns over effects of thermal pollution from urban runoff on aquatic systems have increased in recent years. Elevation of stream temperature can raise Biochemical Oxygen Demand (BOD), lower DO, and alter faunal composition (Poole et al. 2001, Roa-Espinosa et al. 2003). Typically, runoff from a developed impervious area will have a temperature similar to the temperature of the impervious area. During the hot summer months, this could potentially make the stormwater runoff reach temperatures up to and above 90°F, which could be detrimental to the aquatic life. Traditional structural stormwater controls, such as open storm-water detention ponds/basins that do not allow for infiltration, do not protect receiving water bodies against adverse temperature effects. Various stormwater Best Management Practices (BMPs) have been shown to be effective in ameliorating temperature effects (NC State Cooperative Extension 2006a). For example, bioretention devices were shown to reduce runoff temperature by 5-10°F in Greensboro, NC (NC State Cooperative Extension 2006b). The loss of riparian buffers as well as peak discharge related channel widening can also contribute to stream temperature increases, by increasing sunlight exposure and decreasing water depth.

2.3.5. *Invasive Species*

The introduction of exotic species such as the Asian Clam (*Corbicula fluminea*) and Zebra Mussel (*Dreissena polymorpha*) has also been shown to pose significant threats to native freshwater mussels. The Asian Clam is now established in most of the major river systems in the United States (Fuller and Powell 1973), including those streams still supporting surviving populations of the DWM. Concern has been raised over competitive interactions for space, food, and oxygen with this species and native mussels, possibly at the juvenile stages (Neves and Widlak 1987; Alderman 1995). The Zebra Mussel, native to the drainage basins of the Black, Caspian, and Aral Seas, is an exotic freshwater mussel that was introduced into the Great Lakes in the 1980s and has rapidly expanded its range into the surrounding river basins, including those of the South Atlantic slope (O'Neill and MacNeill 1991). This species competes for food resources and space with native mussels and is expected to contribute to the extinction of at least 20 freshwater mussel species if it becomes established throughout most of the eastern United States (USFWS 1992b). The zebra mussel is not currently known from any river supporting DWM populations.

2.3.6. *Loss of Riparian Buffers*

Loss of riparian buffers can lead to degradation of adjacent aquatic habitats. The role of forested riparian buffers in protecting aquatic habitats is well documented (NCWRC 2002). Riparian buffers provide many functions including pollutant reduction and filtration, a primary source of carbon for aquatic food webs, stream channel stability, and maintenance of water and air temperatures. Numerous studies have recommended a range of buffer widths needed to maintain these functions. Recommended widths vary greatly depending on the parameter or function evaluated. Wide contiguous buffers of 100-300 feet are recommended to adequately perform all functions (NCWRC 2002). The NCWRC recommends a minimum 200-foot native, forested buffer on perennial streams and a 100-foot forested buffer on intermittent streams in watersheds that support federally endangered and threatened aquatic species (NCWRC 2002). Although not officially adopted, the USFWS uses the NCWRC recommendations as guidance when addressing federally protected aquatic species in North Carolina.

2.3.7. *Degradation Caused by All-terrain Vehicle Use*

Another human-related factor adversely impacting habitat of the DWM is recreational all-terrain vehicle (ATV) use. ATV tracks have been noted crossing streams as well as traveling stream channels throughout the Swift Creek watershed. In addition to directly running over mussels, ATVs destabilize stream banks and floodplains, causing sedimentation and buffer degradation. While there is no quantitative data available on ATV use, locally, this can have significant impacts. This was identified as a threat to the DWM population in Swift Creek (Smith et al. 2015)

Photo 1. ATV Trails in Swift Creek Channel

3.0 WATERSHED CONDITIONS

An overall assessment of current and past conditions of the watershed is crucial to understanding mussel population viability. Various GIS layers, aerial photography, and publications were consulted to characterize the past and current conditions within the SCW.

GIS data layers utilized include the National Land Cover Database (NLCD) and the National Pollution Discharge Elimination System (NPDES) database. The land cover shapefile is available from the United States Department of Agriculture/Natural Resources Conservation Service GeoSpatial Data Gateway (USDA 2015). The nationwide comprehensive land cover data layer was created through a cooperative project conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium using data through 2011. The NPDES shapefile is available online from NC OneMap as updated by the NCDWQ in 2006 (NC OneMap 2006). The file identifies outfall locations and type of individual NPDES permitted wastewater discharges. The NC Division of Water Resources (NCDWR, formerly the NC Division of Water Quality (NCDWQ)) also keeps a more updated list of active NPDES permits. The list, updated September 4, 2015, was used along with the shapefile to locate active permitted dischargers (NCDWR 2013a). **Please note: References to NCDWQ indicate information that was published prior to the agency name change.**

3.1. Land Use and Population Growth

In the last half century, the development within the SCW is concentrated in the towns of Cary and Apex, and along highway corridors (AMEC 2004). Cary's population grew from 7,640 to over 135,000 between 1970 and 2010 (NCDWQ 2003a; US Census 2015). As of 2014, according to the latest US Census Bureau estimates, Cary's population is estimated to be over 155,000 (US Census 2015). Apex's population grew from 2,192 to over 37,000 between 1970 and 2010 (NCDWQ 2003a; US Census 2015). Apex's population is estimated to be nearly 44,000 as of 2014 (US Census 2015). The upper portion of SCW has mostly been built out over the last 20 years, with the remaining forested areas lying almost completely in nature preserves or floodplains (see Section 3.1.1 below). Further development will likely not affect the water quality within the Upper SCW, given the large majority of development that has already taken place (NCDWQ 2003a). However, development is likely to happen in the Lower SCW where more parcels available for development remain.

The trend of development in recent years has occurred throughout much of the Neuse River Basin. Land cover information from the National Resources Inventory (NRI), which is published by the Natural Resource Conservation Service (NRCS), was collected several times between 1982 and 1997 and was presented in the 2009 Neuse River Basinwide Water Quality Plan, Chapter 16 – Community Changes and Challenges (NCDWQ 2009). While the data is outdated and presented at a larger scale than the project study area (the entire Neuse River Basin versus SCW), it demonstrates the development of the Neuse River Basin during the 15-year period for which data is available (Table 2). The most important change with regard to aquatic species is the conversion of agricultural land cover (-17%) and forest cover (-7.2%) to urban and developed land (+89.8%).

Table 2. Land Cover in the Neuse River Basin: 1982 vs. 1997 (NCDWQ, 2009)

Land Cover	1982 % of Total	1997 % of Total	% Change since 1982
Cultivated crop	28.8	23.9	-17.0
Uncultivated crop	0.4	1.5	275
Pasture	3.2	3.7	16.7
Forest	48.4	44.9	-7.2
Urban & built-up	6.9	13.1	89.9
Federal	2.1	2.3	9.5
Other	10.4	10.6	1.9

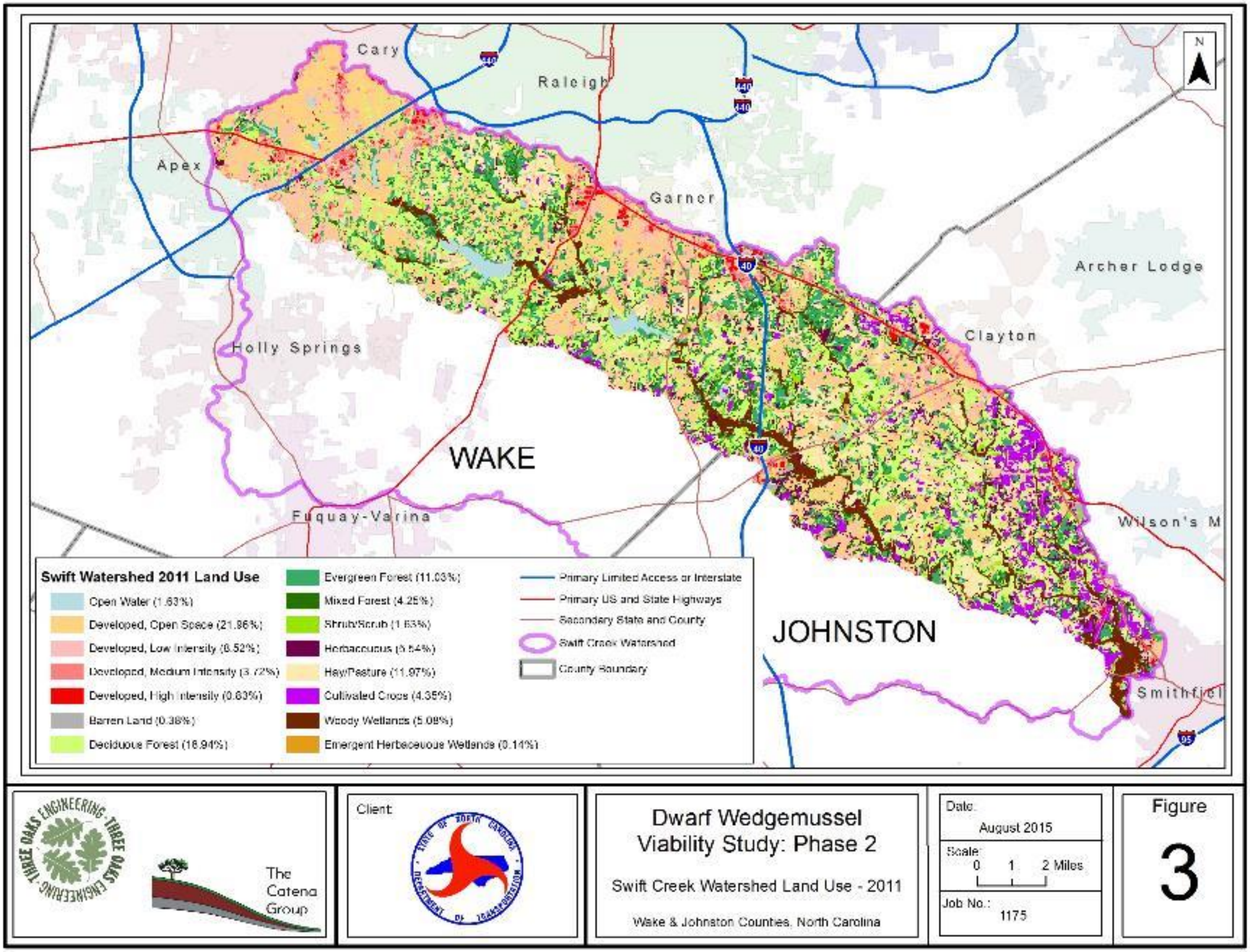
A more recent land cover dataset is available from the NLCD (Figure 3). The 2011 dataset is satellite data with a spatial resolution of 30 meters. The 2011 land use dataset is in a more manageable format, and thus SCW could be examined exclusively. Taken in coordination with the other land use dataset, it is a clearer picture of the amount of developed lands, compared to the amount of agriculture and forestry cover for SCW. The 2011 dataset also divides land use into more categories, such as varying degrees of development and types of forest (Table 3).

Table 3. Land Use cover in Swift Creek Watershed, NLCD 2011

Land Use	Sum of Area (Square Miles)	Percent*
Open water	2.58	1.63
Developed, open space	33.96	21.96
Developed, low intensity	13.17	8.52
Developed, medium intensity	5.75	3.72
Developed, high intensity	1.29	0.83
Barren land	0.59	0.38
Deciduous forest	29.29	18.94
Evergreen forest	17.06	11.03
Mixed forest	6.58	4.25
Shrub/scrub	2.52	1.63
Grassland/herbaceous	8.56	5.54
Pasture/hay	18.51	11.97
Cultivated crops	6.72	4.35
Woody wetlands	7.85	5.08
Emergent herbaceous wetlands	0.22	0.14
Total	154.65	99.97

* Due to rounding, this column does not add to exactly 100%

In the Phase 1 report, the NLCD data set used was from 2006, as that was the most recent dataset available at that time. There has been an increase in the combined “Developed” land use categories from 2006 to 2011 (30.86% to 35.03%), and a corresponding decrease in forested and agricultural (crops, pasture land etc.) land uses (from 2006 to 2011, 54.48% to 50.54%). Barren land has slightly decreased (0.44% to 0.38%), shrub/scrub land has increased (0.79% to 1.63%), and wetlands have remained about the same (5.20% to 5.22%). All of which further demonstrates the continued development in watershed. It should also be noted that the level of change in developed land from 2006 to 2011 was likely slowed by the economic recession that began in December of 2007 and continued into 2010. As the impact of the recession wanes, increased development in the SCW can be expected.



N
Cary
Raleigh
Apex
Garner
Archer Lodge
Clayton
Holly Springs
WAKE
Fuquay-Varina
Wilson's M
JOHNSTON
Smithfiel
Swift Watershed 2011 Land Use
Open Water (1.63%)
Developed, Open Space (21.86%)
Developed, Low Intensity (8.52%)
Developed, Medium Intensity (3.72%)
Developed, High Intensity (0.63%)
Barren Land (0.38%)
Deciduous Forest (16.94%)
Evergreen Forest (11.03%)
Mixed Forest (4.25%)
Shrub/Scrub (1.63%)
Herbaceous (5.54%)
Hay/Pasture (11.97%)
Cultivated Crops (4.35%)
Woody Wetlands (5.08%)
Emergent Herbaceuous Wetlands (0.14%)
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
Swift Creek Watershed
County Boundary
Three Oaks Engineering
The Catena Group
Client
Dwarf Wedgemussel Viability Study: Phase 2
Swift Creek Watershed Land Use - 2011
Wake & Johnston Counties, North Carolina
Date:
August 2015
Scale:
0 1 2 Miles
Job No.:
1175
Figure
3

Of the various water bodies within the watershed, Lake Wheeler makes up about 0.875 square mile, and Lake Benson about 0.521 square mile. Other ponded areas constitute the other 1.173 square miles of open water in the watershed.

3.1.1. *Natural Heritage Areas, Parks and Green Space*

There are several natural heritage areas, parks, and green spaces within the Upper SCW (Table 4; Figure 4). The Hemlock Bluffs Nature Preserve near Cary, upstream of Kildaire Farm Road, is approximately 122 acres in size and has a rating of Moderate (See Section 1.0). The Triangle Land Conservancy (TLC) maintains the Swift Creek Bluffs Nature Preserve, which is upstream of Holly Springs Road; it has a rating of Moderate, and is nearly 50 acres in size. TLC also maintains conservation easements on two farms, Theys and MacNair Farms (also referred to as Steep Hill Creek Bottomlands), totaling 130 acres. An area of approximately 160 acres around and including Yates Mill Pond has been rated as Exceptional.

In the Lower SCW (Figure 4), there is a 240-acre Natural Heritage Program natural area (NHNA) (Swift Creek Aquatic Habitat) along the main stem of Swift Creek from Lake Benson to Smithfield, as well as lower portions of White Oak and Little Creeks, which is rated as “High” (NCNHP 2015). A major portion of this NHNA is subject to protective measures that go above and beyond protective requirements that apply to the entire Neuse River (see section 4.2.7). However, in 2013, the NC legislature signed into law Session Law 2013-413, which prohibits local governments from enacting environmental ordinances in areas that are already regulated by an environmental agency. This potentially could dissolve some of the more protective requirements within the SCW.   The Environmental Review Commission discussed repealing this law in March of 2014, but it remains in place as of the writing of this report. NCNHP recommends a High Quality Water designation for this stretch of Swift Creek, which would not allow any additional discharges into the stream (NCNHP 2003). Adjacent to a portion of the Swift Creek Aquatic Habitat NHNA is the Swift Creek Magnolia Slopes, which has a rating of General and is almost 20 acres. Along Reedy Branch stream is the 14.7 acre Reedy Branch Floodplain NHNA with a rating of High.

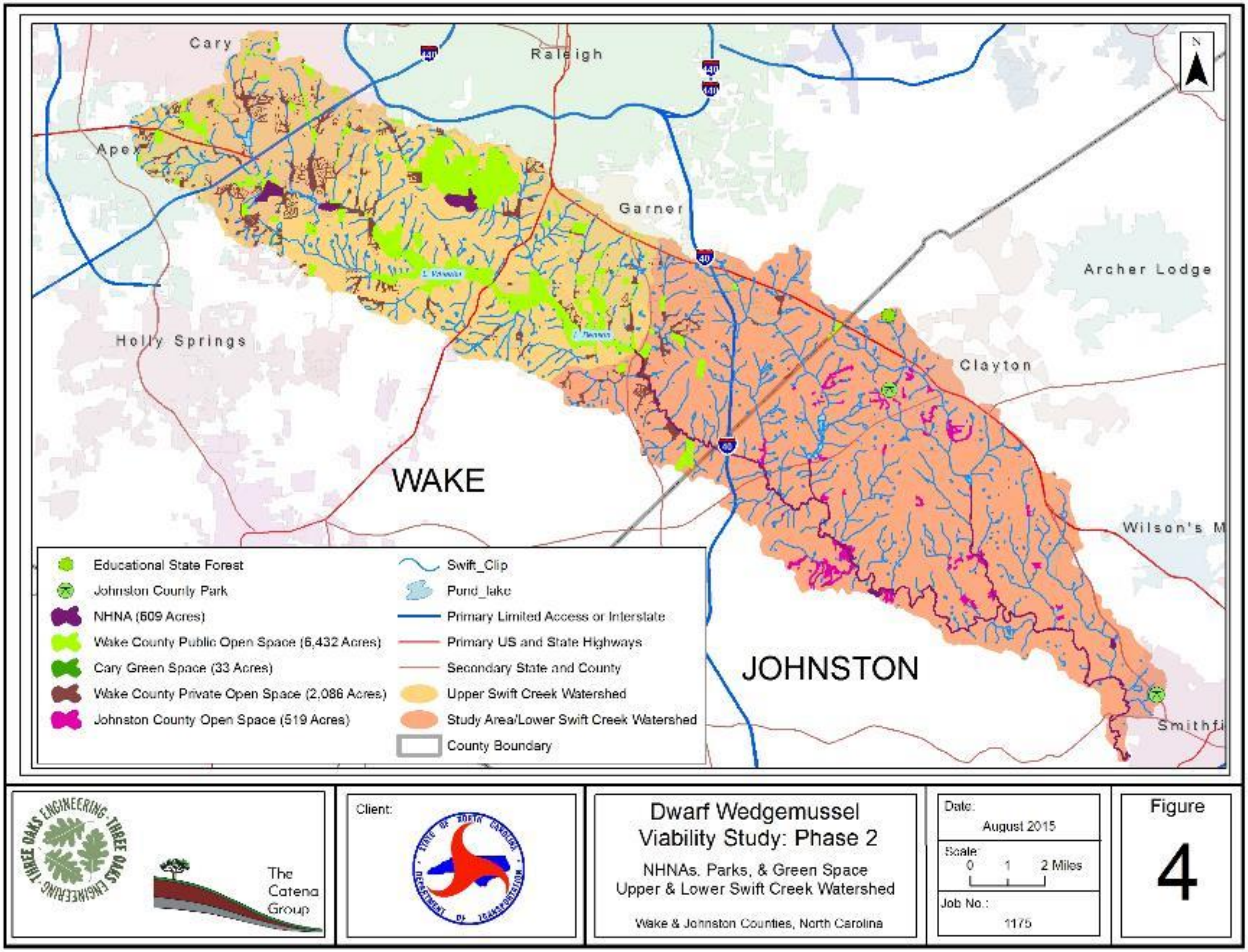

Cary
Raleigh
Apex
Garner
Archer Lodge
Holly Springs
Clayton
WAKE
Wilson's M
JOHNSTON
Smithfi
Educational State Forest
Johnston County Park
NHNA (609 Acres)
Wake County Public Open Space (6,432 Acres)
Cary Green Space (33 Acres)
Wake County Private Open Space (2,086 Acres)
Johnston County Open Space (519 Acres)
Swift_Clip
Pond_lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
Upper Swift Creek Watershed
Study Area/Lower Swift Creek Watershed
County Boundary
The Catena Group
Client:
Dwarf Wedgemussel
Viability Study: Phase 2
NHNAs, Parks, & Green Space
Upper & Lower Swift Creek Watershed
Wake & Johnston Counties, North Carolina
Date:
August 2015
Scale:
0 1 2 Miles
Job No.:
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Table 4. Upper SCW and Study Area Total Acreage of Open Space (compared to total area).

Upper SCW	Acres
NHNAs	332
Wake County Public	5,886
Wake County Private	1,638
Cary Green Space	32
TLC	130
Total Open Space	*8,018*
Total Area	*42,279*

Study Area (Lower SCW)	Acres
NHNAs	276
Wake County Public	416
Wake County Private	449
Johnston County Open Space	519
Parks	84
Total Open Space	*1,744*
Total Area	*56,673*

Also of significance are public parks and open or green spaces designated by municipalities. There are a number of such areas in both the Upper and Lower SCW (Table 4).

3.2.Surface Water Classification and Use Support Ratings in SCW

The State of North Carolina assigns a best usage classification to all waters of North Carolina. These classifications provide a level of water quality protection to ensure that the designated usage of that water body is maintained. The minimum designation of Class C waters are defined as waters that are suitable for aquatic life propagation and survival, fishing, wildlife, secondary recreation and agriculture. Class C imposes a minimum standard of protection for all waters of North Carolina. Swift Creek is classified as a Water Supply-III (WS-III), Nutrient Sensitive Waters (NSW) from the headwaters to the dam at Lake Benson (NCDENR 2015). WS-III classification indicates a water body used as a source for drinking water where a more strict classification is not feasible, and also protected for Class C uses. WS-III waters are generally in low to moderately developed watersheds. NSW is a supplemental classification intended for waters needing additional nutrient management due to being subject to excessive growth of microscopic or macroscopic vegetation. Swift Creek from the dam at Lake Benson to the Neuse River is a Class C, NSW stream, including Mahler’s Creek, White Oak Creek, Little Creek and Reedy Branch.

There is also a Critical Area (CA) classification on the waters of Swift Creek from about one mile above Lake Benson to the dam at Lake Benson and along an unnamed tributary of Swift Creek flowing into Lake Benson. A CA classification is defined as land within a half-mile upstream and draining to an intake area or draining to the water supply reservoir (NCDWR 2014a). These are areas where the risks associated with pollution to drinking water supplies are greater than in other areas in the watershed.

The entire Neuse River Basin is classified as NSW. Based on the use of surface water within the watershed as a drinking water source, in addition to the desire to protect the many natural resources present, the entire SCW is identified as a high priority for protection in Wake County (CH2M Hill 2003).

Both point source and non-point source discharges contribute to water quality degradation by introducing various pollutants into the water body. Federal and state legislation exists that is intended to help maintain or restore the environmental quality of North Carolina waters.

3.3. Water Quality Conditions in SCW

As discussed in Section 2.3, degradation of water quality is a major threat to aquatic species including DWM. Section (§) 304(a)(1) of the Clean Water Act (CWA) requires the EPA to develop criteria for water quality that accurately reflects the latest scientific knowledge. These criteria are used as guidance to States and authorized Tribes, which under § 303(c)(2)(B) of the CWA are required to adopt numeric standards for § 307(a) priority toxic pollutants, if the discharge or presence of the pollutant can reasonably be expected to interfere with designated uses, such as aquatic life. The § 307(a) list contains 65 compounds and families of compounds, which the EPA has interpreted to include 126 priority toxic pollutants. In addition to narrative and numeric (chemical-specific) criteria, other types of water quality criteria include:

- Biological Criteria (description of the desired aquatic community)
- Nutrient Criteria (protection against nutrient over-enrichment and eutrophication)
- Sediment Criteria (protection from adverse effects of contaminated and uncontaminated sediments)

The CWA also requires states to “hold public hearings for the purpose of reviewing applicable water quality standards and, as appropriate, modifying and adopting standards” at least once every three years, referred to as Triennial Reviews-33 U.S.C. § 1313(c)(1). The most recent Triennial Review hearing was held on November 19, 2013, with a comment period that ended on January 03, 2014. The NC Conservation Network (NCCN) provided numerous comments, pointing out that the Triennial Review hearing was “four years overdue” as the previous public hearing was held in 2006 (NCCN 2014). NCCN also stated that North Carolina “lags behind neighboring states in adopting standards” that meet EPA water quality criteria recommendations. They noted that NC currently does not have water quality standards for ammonia and various heavy metals including copper, and recommend the EPA criteria be used to develop these standards (NCCN 2014). Since then, new rules have been developed that provide water quality standards for heavy metals including copper, which became effective January 1, 2015 (NC Register 2014). Numerous other recommendations were also made with regard to establishing standards, and revising existing standards of various other toxicants. Dissolved metal water quality standards were proposed for arsenic, beryllium, cadmium, chromium III, chromium VI, copper, lead, nickel, silver and zinc. Iron and manganese standards were proposed for removal (NC Register 2014).

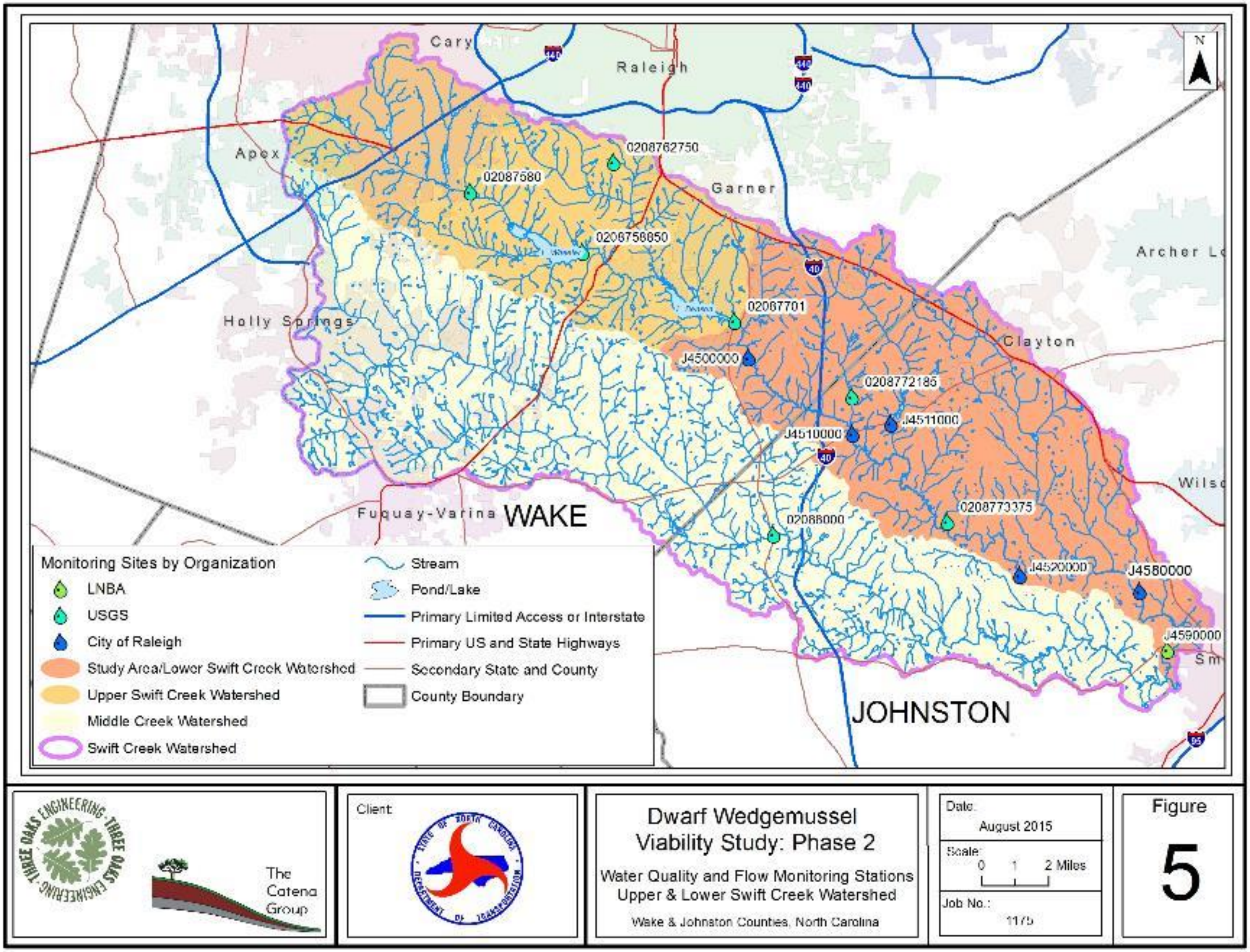
3.3.1. *Water Quality Monitoring*

Physical, chemical, and biological parameters are routinely monitored to assess water quality of a particular water body to determine if the established uses of the water body are being maintained. Water quality monitoring programs have been implemented by the NCDWR to assess water quality trends throughout the State. As discussed in Section 3.3, numeric standards of chemical and physical parameters have been established to determine if designated uses are met.

Biological criteria can be monitored in a variety of ways, including benthic macroinvertebrates and fish community composition. Benthic macroinvertebrates, or benthos, are monitored to assess water quality by sampling for selected organisms. The species richness and overall biomass, as well as the presence of various groups intolerant of water quality degradation, are reflections of water quality. A biodiversity rating is given to a sampled water body based on the taxa richness of the stream and a qualitative sampling for intolerant forms such as mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera), collectively referred to as EPT. Stream biodiversity can be rated as Excellent, Good, Good-Fair, Fair and Poor. Excellent and Good ratings indicate that the best usage classification for that stream is being Supported (S); Good-Fair rating indicates that the usage is Supported, but is also Threatened (ST); Fair rating indicates Partial Support (PS) of the best usage; and a Poor rating indicates that the best usage classification is Not Supported (NS).

There are 12 monitoring sites at which water quality and/or discharge rates are measured within SCW, operated by the US Geologic Survey (USGS), the City of Raleigh, or the Lower Neuse Basin Association (LNBA) (Table 5; Figure 5). For stations that monitor discharge, there are maximum, minimum, and mean of daily discharge values calculated in cfs for each day of the recording period. Discharge data is analyzed in Section 6.0. USGS monitoring stations were located via the USGS National Water Information System mapper (USGS 2015).

Water quality is determined based on a set of parameters that indicate the health and function of a water body. The NCDWQ's "Redbook" of Surface Waters and Wetlands Standards (NCDWQ 2003b) provides standard levels at which parameters should be measured to indicate good water quality. Additionally, USEPA has published guidelines on specific parameters, ammonia and copper in particular, that provide more detailed information for aquatic species sensitivity to these parameters (USEPA 2007 and 2013). In this analysis, the EPA's 2013 criteria for ammonia are used, which are dependent on pH and temperature to determine appropriate ammonia ecological thresholds. The EPA's criteria for copper, however, are not used, as this determination requires the measurement of an additional eight parameters, which were not always available. For simplicity, the NCDWQ copper standard (7 ug/L) is used instead. Other parameters of importance to aquatic life, particularly freshwater mussels, examined here are


Cary
Raleigh
Apex
Garner
Holly Springs
Archer Lo
Clayton
Wils
Fuquay-Varina
WAKE
JOHNSTON
Sm
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02087580
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02087701
J4500000
0208772185
J4511000
J4510000
0208773375
02088000
J4520000
J4580000
J4590000
N
Monitoring Sites by Organization
LNBA
USGS
City of Raleigh
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
Middle Creek Watershed
Swift Creek Watershed
Stream
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
County Boundary
The Catena Group
Client:
Dwarf Wedgemussel Viability Study: Phase 2
Water Quality and Flow Monitoring Stations
Upper & Lower Swift Creek Watershed
Wake & Johnston Counties, North Carolina
Date:
August 2015
Scale:
0 1 2 Miles
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1175
Figure
5

(with respective standard levels): DO (>5.0 mg/L), pH (6.0-9.0), turbidity (<50 Nephelometric Turbidity Units (NTU)), and temperature.

Table 5 Surface Water Monitoring Sites in Swift Creek Watershed

Upper/ Lower	Site No.	Location	Operator	Parameters measured*
Upper	02087580	Swift Crk near Apex	USGS	WQ, Discharge
Upper	0208762750	UT to Swift Crk near Yates Mill Pond	USGS	WQ, Discharge
Upper	0208758850	Swift Crk at McCullars Crossroads	USGS	Discharge
Upper	02087701	Lake Benson at Dam near Garner, NC	USGS	WQ
Lower	J4500000 (52)	Swift Crk near Garner (Indian Creek)	City of Raleigh	WQ
Lower	J4510000 (54)	Swift Crk at NC 42 near Clayton	City of Raleigh	WQ
Lower	J4520000 (56)	Swift Crk at SR 1562 near Smithfield	City of Raleigh	WQ
Lower	J4511000 (55)	White Oak Crk at NC 42 near Clayton	City of Raleigh	WQ
Lower	J4580000	Swift Creek at SR 1501 near Smithfield	LNBA	WQ
Lower	0208772185	Swift Crk at NC 42 near Clayton, NC	USGS	Discharge
Lower	0208773375	Swift Crk at SR1555 near Clayton	USGS	Discharge
Lower	J4590000	Swift Crk at NC 210 near Smithfield	LNBA	WQ

*WQ – Water quality

3.3.1.1. Upper SCW

The USGS station near Apex (Site No. 02087580) collected water quality data from 1989 to 1995, again from 2000 to September 2011, and from October 2012 to present. Monthly temperature measurements were taken and ranged between 1°C and 28.2°C. Ammonia, which was measured on a monthly basis, did not exceed either the acute or chronic levels (USEPA 2013) except on one occasion in March, 2011 (measured at 0.26 mg/L). Of the more than 200 DO measurements, approximately 24 dipped below the 5.0 mg/L standard, the lowest of which was 1.7 mg/L in August 2007. Monthly pH measurements indicated the pH levels fell outside the NCDWR recommended range (6.0 to 9.0, NCDWQ 2003b) five times. Copper measurements were taken 25 times between 1989 and 1995, none of which exceed the NCDWR water quality standard.

The LNBA also monitors water quality at USGS station 02087580, but refer to it as “Station SR 1152 Holly Springs Road near Macedonia” (J4414000). Water quality measurements taken included DO, pH, temperature, turbidity, and ammonia, among others. For the result statistics done by LNBA for years 2006 to 2014, see Appendix C.

The USGS station near Yates Mill Pond (0208762750) collected data from 2002 to 2011. Water quality measurements were less frequent than at other stations. Water temperature measurements were taken 19 times and ranged between 6.6°C and 21.2°C. Ammonia levels never exceeded acute or chronic levels, though some measurements did not have corresponding pH and temperature measurements. Ammonia chronic and acute standards are dependent on pH and temperature, but because the pH measurements were generally low (6.0 or below), and ammonia becomes less toxic with lower pH levels, there is less of a chance these ammonia levels posed a risk to aquatic life. Measurements of 19 samples for DO levels indicated just one sample below the standard level of 5.0 mg/L. Twelve of the 22 samples measuring pH were below 6.0, the level the NCDWR recommends for healthy water bodies. Two copper measurements were above the standard for that parameter (USGS 2015). The Yates Mill Pond station also has daily flow rate statistics for 2003 to 2004.

The USGS station in Lake Benson (02087701) collected data in 1970 and then from 1989 to 2011. Samples were taken from April to November. Approximately 100 temperature readings were taken ranging from 10°C to 33°C. Ammonia measurements exceeded the chronic levels in two out of 101 samples (August 30, 2006 and August 8, 2009), but did not exceed acute levels. DO readings on 100 samples noted 38 which were below 5 mg/L. Measurements of pH were taken in both the field and the lab; however, the latter of which not after 1995. The pH level at this station dropped below 6.0 on three occasions (July 5, 2006 and twice on April 26, 2007). Copper measurements were taken fairly regularly, and exceeded 7 ug/L on one occasion (April 15, 2010).

The USGS station at McCullars Crossroads collected discharge data starting in 1988, and continues collecting this data through the present (USGS 2015).

3.3.1.2. Lower SCW

Water quality data collected by the City of Raleigh from 2009 to 2015 includes collection of samples on 93 dates. These were obtained from Edward Buchan, Environmental Coordinator with the City of Raleigh on July 17, 2012, April 21, 2015, and June 23, 2015.

Temperatures at Indian Creek discharge (station number J4500000) near Garner ranged between 2.7°C and 29.4°C. Ammonia levels exceeded the chronic level on five occasions (September 2009, November 2010, January 2011, July 2011, and October 2012), and exceeded the acute level one time (January 2011). DO fell below 5.0 mg/L on 14 occasions. The pH levels remained between 6.0 and 9.0 on days when samples were collected. Turbidity levels did not exceed 50 NTU, except on two days of sampling (290 NTU in July 2012 and 200 NTU in January 2015) (Buchan 2015).

Temperatures at NC 42 (station number J4510000) near Clayton ranged between 2.1°C and 28.8°C. Ammonia levels exceeded the chronic level on three occasions (January 2010, January 2011, and July 2011), but did not exceed the acute level. DO did not dip below 5.0 mg/L. The pH levels remained between 6.0 and 9.0 on days when sampling was conducted. Turbidity exceeded the 50 NTU level on four occasions (January 2010, May 2013, July 2013, and January 2015) (Buchan 2015).

Temperatures at White Oak Creek at NC 42 near Clayton (J4511000) ranged from 2.2°C to 29.3°C. Ammonia levels exceeded the chronic levels on seven occasions, but did not exceed the acute standard level. DO measurements were below 5.0 mg/L on 13 days when samples were taken; pH levels remained between 6.0 and 9.0 on days when samples were taken during the sampling period. Turbidity exceeded the 50 NTU level on three occasions (March 2010, January 2014, and October 2014) (Buchan 2015).

Temperatures at SR 1562 (station number J4520000) near Smithfield ranged between 1.9°C and 27.4°C. Ammonia levels exceeded the chronic level on one occasion (January 2011), but did not exceed the acute level. DO and pH levels remained within the appropriate range on days when sampling at this station was conducted. Turbidity exceeded the 50 NTU level on four occasions (January 2010, May 2013, October 2014, and January 2015) (Buchan 2015).

The USGS station on Swift Creek at NC 42 near Clayton (0208772185) measured flow rates from 1988 to 1997 on 28 occasions, with an average flow of 73 cfs. The greatest flow occurred on May 1, 1996 (796 cfs) and the lowest flow occurred on August 8, 1990 (5.9 cfs). The USGS station on Swift Creek at SR 1555 near Clayton (0208773375) has been taking measurements of flow rates since 2008. For a more detailed discussion of this monitoring station, see Section 6.0.

The LNBA station at SR 1501 (Swift Creek Road) near Smithfield (J4580000) has been monitored since 2012 to present. Temperatures range between 1.7°C and 27.4°C. Ammonia measurements did not exceed chronic or acute standard levels. DO and pH levels remained within the appropriate range on days when sampling at this station was conducted. Turbidity exceeded the 50 NTU level on three occasions (June 2013, July 2013, and January 2015) (Buchan 2015)

The LNBA station at NC 210 near Smithfield (J4590000) was monitored from 2006 to 2012. Temperatures ranged between 3.9°C and 29.9°C in 85 samples. Ammonia measurements were taken a total of 65 times during sampling, with values ranging between 0.01 and 0.44 mg/L. Sample levels of DO were never below 4.0 mg/L from a total of 101 samples, and below 5.0 mg/L in one sample. The pH levels were not recorded outside of the 6.0 and 9.0 range during sampling. Turbidity measurements exceeded 50 NTU in four out of 65 samples. Detailed statistics for data recorded at this station are in Appendix C.

In addition to water quality data collected from USGS, the City of Raleigh, and LNBA, a study was done by the USFWS from June 2003 to July 2004 (Ward et al. 2007). Water quality samples were taken from three streams within North Carolina in which federally endangered freshwater mussel populations are known to exist. One of the watersheds studied was Swift Creek, including two monitoring locations on White Oak Creek, and the use of station J4510000 near Clayton was colocated with a sampling point in the study area. Ammonia, copper, and chlorine levels were analyzed. As discussed in Section 2.3.3, the study concluded that copper levels were elevated in Swift Creek. A more thorough assessment of this study can be found in the Water Quality Report (Three Oaks Engineering/ The Catena Group 2015a-Appendix B).

3.3.2. *303(d) Impaired Streams*

As mandated in Section 303(d) of the CWA, states, territories, and authorized tribes are required to develop lists of impaired waters, which are defined as water bodies that do not meet water quality standards that states, territories, and authorized tribes have set for them, even after point sources of pollution have installed the minimum required levels of pollution control technology. These water quality standards include designated uses, numeric and narrative criteria, and anti-degradation requirements as defined in 40 CFR 131. Failures to meet standards may be due to an individual pollutant, multiple pollutants, or unknown causes of impairment, originating from point and non-point sources and/or atmospheric deposition. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop Total Maximum Daily Load limits (TMDLs) of identified pollutants for these waters. All waters in NC are rated Category 5 on the 2012 303(d) list for Mercury; Category 5 impaired waters require development of a TMDL for the parameter of concern (NCDWQ 2012). Once a TMDL is established for a stream segment, the segment is removed from the 303(d) list.

There are a number of streams that are impaired in the SCW (NCDWR 2014b, Figure 6). Based on the most recent report by the NCDWR (NCDWR 2014b), much of the Upper SCW has recently been removed from the 303(d) list upon adoption of a TMDL. Several streams remain on the 303(d) list or have been recently added. A large portion of the Lower SCW is impaired, from Lake Benson to the confluence with Little Creek north east of Smithfield.

3.3.2.1. Upper SCW

There are three stream segments in the Upper SCW listed as impaired (NCDWR 2014b, Table 6). The headwaters of Swift Creek to the confluence with Williams Creek (Assessment Unit # 27-43-(1)a), a distance of 2.6 miles, was added to the 303(d) list in 1998 for Fair Bioclassification. This segment of Swift Creek now has an approved TMDL for ecological/biological integrity, and has therefore been removed from the 303(d) list of impaired streams.

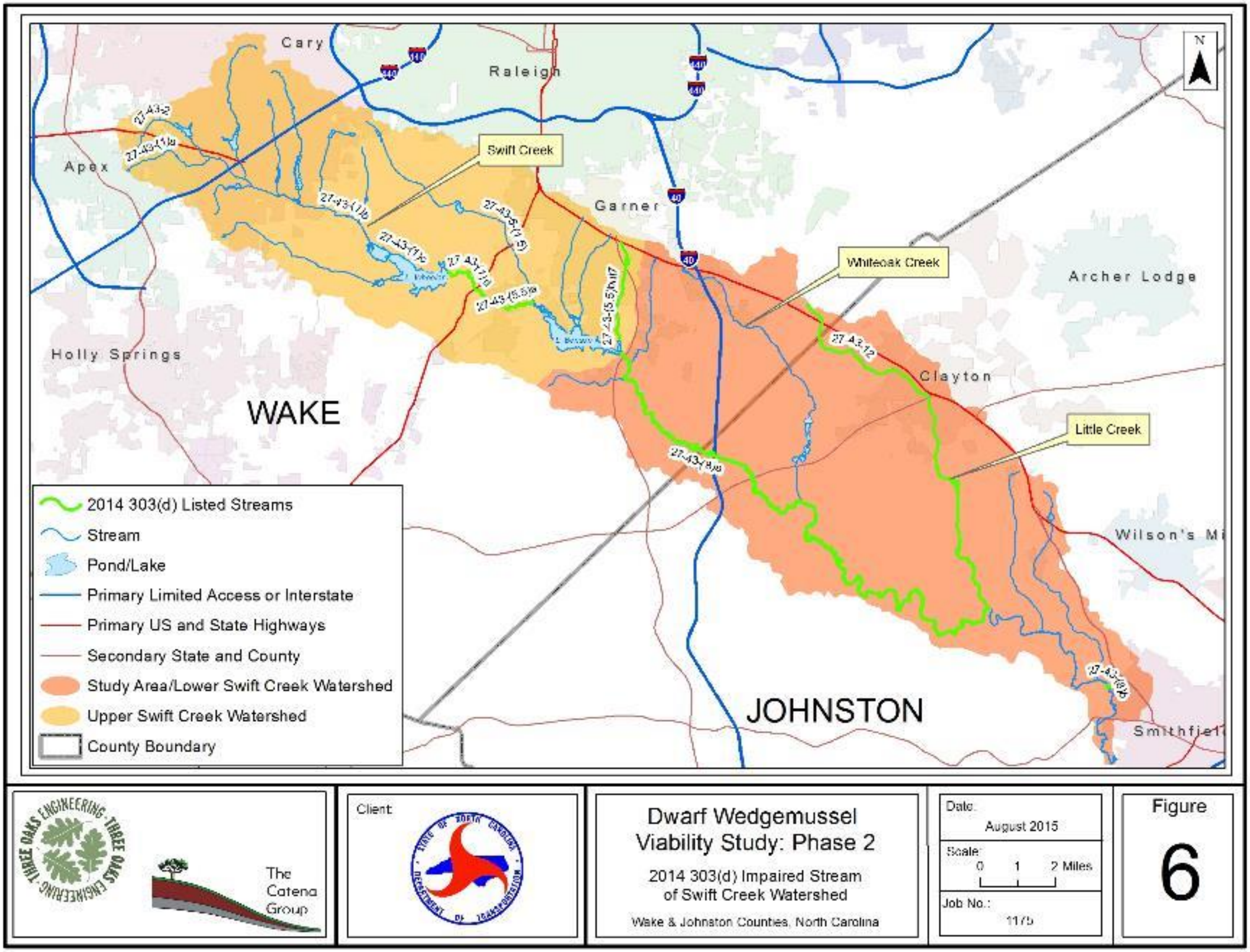

Cary
Raleigh
Apex
Garner
Swift Creek
Whiteoak Creek
Archer Lodge
Holly Springs
Clayton
Little Creek
WAKE
JOHNSTON
Wilson's Mi
Smithfiel
27-43-12
2014 303(d) Listed Streams
Stream
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
County Boundary
The Catena Group
Client
Dwarf Wedgemussel Viability Study: Phase 2
2014 303(d) Impaired Stream of Swift Creek Watershed
Wake & Johnston Counties, North Carolina
Date: August 2015
Scale: 0 1 2 Miles
Job No.: 1175
Figure
6

Table 6. Upper SCW Impaired (Category 5) Streams 2014. Use of streams is for "Aquatic Life".

Stream	AU Number	Length/Area	Reason for Rating	Parameter (Year)
Swift Creek	27-43-(1)d	2.4 FW Miles	Poor Bioclassification	Ecological/Bio Int, Benthos (2008)
Swift Creek (Lake Benson)	27-43-(5.5)a	0.87 FW Miles	Poor Bioclassification	Ecological/Bio Int. Benthos (2008)
UT to Swift Creek (Lake Benson)	27-43-(5.5)but	2.7 FW Miles	Fair Bioclassification	Ecological/Bio Int. Benthos (2014)

FW: Freshwater

From the confluence with Williams Creek to the backwaters of Lake Wheeler (assessment unit number (AU#) 27-43-(1)b), a distance of 5.5 miles, Swift Creek was listed as impaired in 1998 for Poor Bioclassification. This segment of Swift Creek also has an approved TMDL for this parameter (NCDWQ 2012). As determined in the 2009 Basinwide Water Quality Plan, this stretch of stream had Fair benthic ratings at two monitoring sites (JB52 – Holly Springs Road and JB53 – Hemlock Bluffs). The land cover along this stretch is predominantly residential, with severely eroding stream banks and little vegetation. Ambient water monitoring data within this stretch (JA24) has shown low DO levels, elevated fecal coliform levels, elevated turbidity levels and elevated conductivity levels, which are indicative of nonpoint source pollution. The Town of Cary had a wastewater spill in this stretch of the stream in June 2006 totaling 7.9 million gallons. This is, therefore, a stressed segment of Swift Creek and has been highly impacted by growth and an accidental sewage spill (NCDWQ 2009), though it now has a TMDL and has been removed from the 303(d) list (NCDWQ 2012).

Williams Creek (AU# 27-43-2) was also listed as impaired in 1998 for Poor Bioclassification. This segment is 2.6 miles and has an approved TMDL for Ecological/biological Integrity Benthos (NCDWQ 2012). Lake Wheeler (AU# 27-43-(1)c) was not rated on the 2012 303(d) list of impaired streams (NCDWQ 2012), though Chloraphyll a and pH were assessed and determined to have insufficient or inconclusive data. Primary recreational activities in the lake, including swimming and water skiing, were suspended in the summer of 2006 due to elevated bacteria levels which may partially be attributed to the wastewater spill mentioned above (NCDWQ 2009). Such closings of Lake Wheeler have been common in recent years due to high levels of bacteria (Raleigh Public Records 2009).

Swift Creek from Lake Wheeler Dam to the backwaters of Lake Benson (AU# 27-43-(1)d) and AU# 27-43-(5.5)a), a total of 3.3 miles, is impaired due to Poor Bioclassification at sampling site JB56 (NCDWR 2014b, Table 6). Erosion, habitat degradation and urban influences are all problems associated with this stretch of stream (NCDWQ 2009).

An unnamed tributary of Swift Creek (AU# 27-43-(5.5)but) is impaired for Poor Bioclassification as of 2014. This segment is 2.7 miles in length and ends in Lake Benson.

Lake Benson (AU# 27-43-(5.5)b) was not rated on the 2014 303(d) list (NCDWR 2014b). The City of Raleigh, as a condition of building the Dempsey E. Benton Water Treatment Plant in May 2010, has worked to ensure DO levels remain at optimum levels in the lake. An aeration system has been installed, and DO levels have been monitored at the raw water intake of the Dempsey Benton WWTP (below the aerator). This data indicates that during three years of monitoring (2012 to 2014), DO levels were lower than the 5 mg/L critical level recommended by the NCDWR on 338 days, most of which were during summer months (Buchan 2015). These low DO levels indicate the aeration system is not working effectively.

3.3.2.2. Lower SCW

Two stream segments are currently considered impaired in the Lower SCW (Table 6). In 2009, Swift Creek (AU# 27-43-(8), 32.7 miles) below Lake Benson was considered to have good water quality and stream conditions and was rated as Supporting for aquatic life and recreational uses based on Good and Good-Fair benthic ratings at JB54 and JB55 (NCDWQ 2009). Additionally, there were no exceedances at ambient monitoring sites JA25 and JA26. However, sedimentation and erosion were identified as moderately impacting parts of this segment of the stream. Good and Good-Fair benthic ratings were assigned to these segments in 1995 and 2000 as well. In 2012, the upper portion of this stretch of Swift Creek (AU# 27-43-(8)a, 20.6 miles from the dam at Lake Benson to Little Creek) was placed on 303(d) list for aquatic life because of a Fair Bioclassification rating, and this section was listed as impaired again in 2014 (Table 7). The current status of impairment and the previous data indicating good benthos classifications indicates a declining trend in water quality since the mid 1990's in the Study Area, which coincides with the changes in land use within the watershed during this time frame (See Section 3.1).

Little Creek (AU# 27-43-12) has been listed as impaired for ecological/biological integrity since 1998 (NCDWR 2014b), having consistently received a Fair benthic rating since 1991 when it was first sampled. The benthic ratings remained Fair in 2000 and 2005 despite the rerouting of the Clayton WWTP to the Neuse River prior to 2000, which suggests that non-point urban runoff may be a problem (NCDWQ 2009). The length of this segment, from the headwaters of Little Creek to the confluence with Swift Creek, is 11.4 miles.

Table 7. Study Area Impaired (Category 5) Streams 2014. Use of streams is for "Aquatic Life".

Stream	AU Number	Length/Area	Reason for Rating	Parameter (Year)
Swift Creek	27-43-(8)a	20.6 FW Miles	Fair Bioclassification	Ecological/Bio Int, Benthos (2012)
Little Creek	27-43-12	11.4 FW Miles	Fair Bioclassification	Ecological/Bio Int. Benthos (1998)

3.3.3. *Point Source Pollution*

Point source discharge is defined as discharge that enters surface waters through a pipe, ditch, or other well-defined point of discharge. This includes municipal (city and county) and industrial wastewater treatment facilities, small domestic discharging treatment systems (schools, commercial offices, subdivisions and individual residents), and stormwater systems from large urban areas and industrial sites. The primary substances and compounds associated with point source discharge include nutrients, oxygen demanding wastes, and toxic substances such as chlorine, ammonia, and metals.

Under Section 301 of the CWA, discharge of pollutants into surface waters is prohibited without a permit by the Environmental Protection Agency (EPA). Section 402 of the CWA establishes the National Pollutant Discharge Elimination System (NPDES) permitting program, which delegates permitting authority to qualifying states. In North Carolina, NCDWR is responsible for permitting and enforcement of the NPDES program. Point source dischargers located throughout North Carolina are permitted through the NPDES program. All dischargers are required to register for a permit. NPDES dischargers are divided into two classes: major and minor. Major discharges are permitted to discharge one million gallons per day (MGD) or greater. Minor discharges are permitted to discharge less than 1 MGD. In the SCW, there are two major discharges (Dempsey E. Benton WTP and Little Creek WWTP) and three minor discharges (Figure 7; Table 8).

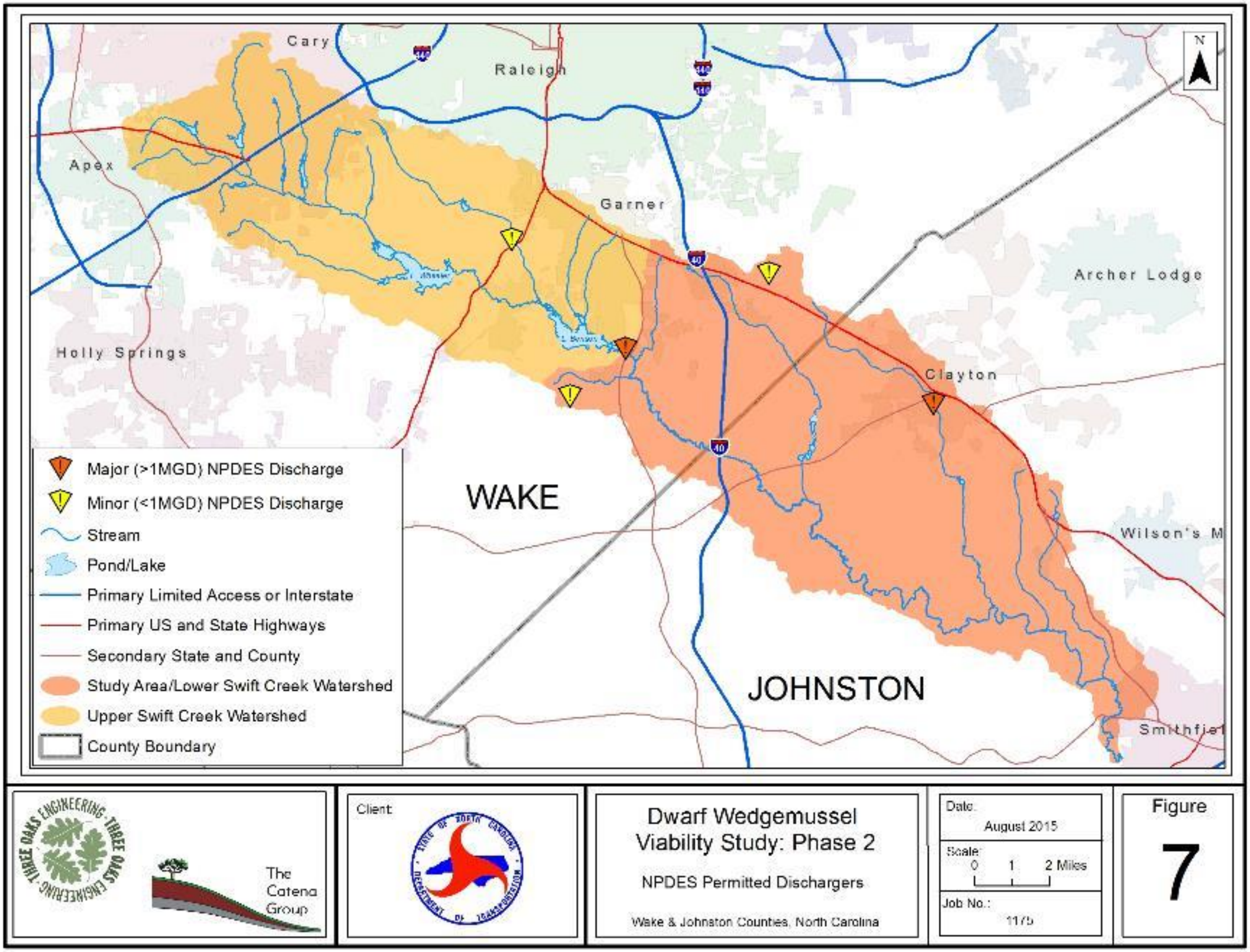
In SCW there are several types of permitted discharges (Figure 7, Table 8). The Dempsey E. Benton Water Treatment Plant (WTP), a municipal discharger, was opened May 12, 2010, and discharges into Lake Benson. The Indian Creek Overlook WWTP, a domestic source, was taken off line as part of the Dempsey E. Benton project in order to reduce the amount of pollutants being discharged into SCW (Buchan 2012).

Table 8. NPDES permitted dischargers in Swift Creek Watershed

Permit	Facility	Class	Type	Flow (Gal/day)
NC0088285	Dempsey E. Benton WTP	Major	Water Treatment Plant	Not limited
NC0025453	Little Creek WWTP	Major	Municipal, Large	2,500,000
NC0060526	Pope Industrial Park WWTP	Minor	100% Domestic < 1MGD	8,000
NC0055701	Nottingham WTP	Minor	Water Treatment Plant	Not limited
NC0049034	Mount Auburn Training Ctr WWTP	Minor	100% Domestic < 1MGD	2,400

3.3.4. *Non-point Source Pollution*

Non-point source (NPS) pollution refers to runoff that enters surface waters through stormwater or snowmelt. There are many types of land use activities that contribute to non-point source pollution, including land development, construction activity, animal waste disposal, mining, agriculture, and forestry operations, as well as impervious surfaces such as roadways and parking lots. Various NPS management programs have been developed by a number of agencies to control specific types of NPS pollution (e.g. pesticide, urban, and construction related pollution, etc.). Each of these management plans develops BMPs to control for a specific type of NPS pollution. For example, financial incentives to reduce agricultural NPS pollution are provided through North Carolina’s Agriculture Cost Share Program, administered by NCDENR’s Division of Soil and Water Conservation to protect water quality by installing BMPs on agricultural lands.


Cary
Raleigh
Apex
Garner
Holly Springs
Archer Lodge
Clayton
Wilson's M
Smithfiel
WAKE
JOHNSTON
N
Major (>1MGD) NPDES Discharge
Minor (<1MGD) NPDES Discharge
Stream
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
County Boundary
The Catena Group
Client
Dwarf Wedgemussel
Viability Study: Phase 2
NPDES Permitted Dischargers
Wake & Johnston Counties, North Carolina
Date:
August 2015
Scale:
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Job No.:
1175
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7

The effects of non-point pollution on aquatic species associated with impervious surface area are discussed in section 2.3.4.

3.4. NCDWQ 2003 Assessment Report on the Upper SCW

An assessment of the biological impairment in the Upper SCW above Holly Springs Road was conducted by the NCDWQ (NCDWQ 2003a). The goal of the report was to identify the sources and activities leading to impairments in the stream. Additionally, the report recommended a watershed plan for improving biological conditions in the stream. According to the report, the main sources of impairment appear to be toxicity from stormwater runoff, removal of organisms during storm events (stormwater scour), and hydromodificiation from impoundments along the stream (NCDWQ 2003a).

3.4.1. *Toxicity*

Toxicity levels in stormwater samples indicate it as a major contributor to biological impairment. Analysis of water collected after a storm event resulted in mortality of 50 percent of test organisms when a sample was diluted to approximately 60 percent of the ambient concentration. Tolerant species were the dominant organisms found at most of the benthos sampling stations in the Upper SCW (NCDWQ 2009). As such, two of the three streams sampled in the upper SCW received bioclassification scores of Poor, with the other receiving a Fair classification (Table 6).

In comparison, the two stations sampled in the Lower SCW received scores of Fair (Table 7). While streams with a score of Fair are still considered impaired, they are less impaired than streams with Poor scores like those in the Upper SCW. The headwaters of the Little Creek site in the Lower SCW occur in a highly urbanized portion of the City of Clayton, and non-point urban runoff was identified as a potential cause for the stream's impairment (NCDWQ 2002). The site on Swift Creek also received a Fair classification, and as discussed in Section 3.3.2.2, there has been a declining trend with regard to benthos since the mid 1990's. Sedimentation and erosion were identified as stressors in 2009 (NCDWQ 2009), which are often indicative of urbanizing streams. It is also possible that toxicity of the stormwater has contributed to this decline. Toxicants often occurring within stormwater were measured at various locations in Swift Creek as part of Phase 2 of this study (Section 3.5, Three Oaks Engineering 2015a).

3.4.2. *Stormflow Scour*

Scour as a result of high stormflow, and the resulting loss of organisms and microhabitat, is a likely cause of impairment in the stream. Though difficult to distinguish from other stressors, data from the Upper SCW suggest there is frequent loss of substrate due to storm events (NCDWQ 2009). Stormflow scour within the study area as it pertains to habitat viability will be discussed in further detail in Section 6.3.

3.4.3. *Hydromodification*

Hydromodification is the alteration of a stream by the construction of an impoundment or dam. There are 58 identified impoundments in the Upper SCW and the Study Area (Figure 8, NCDENR 2013), which obstruct movement of aquatic organisms such as fish. NCDENR regulates a structure that is 25 feet high or more and impounds 50 acre-feet or more. Of the 58 impoundments, 31 do not meet either of the two requirements, so are not regulated by the state. Most of these impoundments are not required to have a minimum release volume, meaning there could be zero flow downstream of the impoundment during drought conditions. This reduction in flow negatively impacts water quality in the stream by altering temperature, reducing DO, and reducing habitat (NCDWQ 2009). There are numerous other small impoundments in the SCW that have not been identified, that cumulatively also effect conditions in the watershed.

3.4.4. *Recommendations for Improvement*

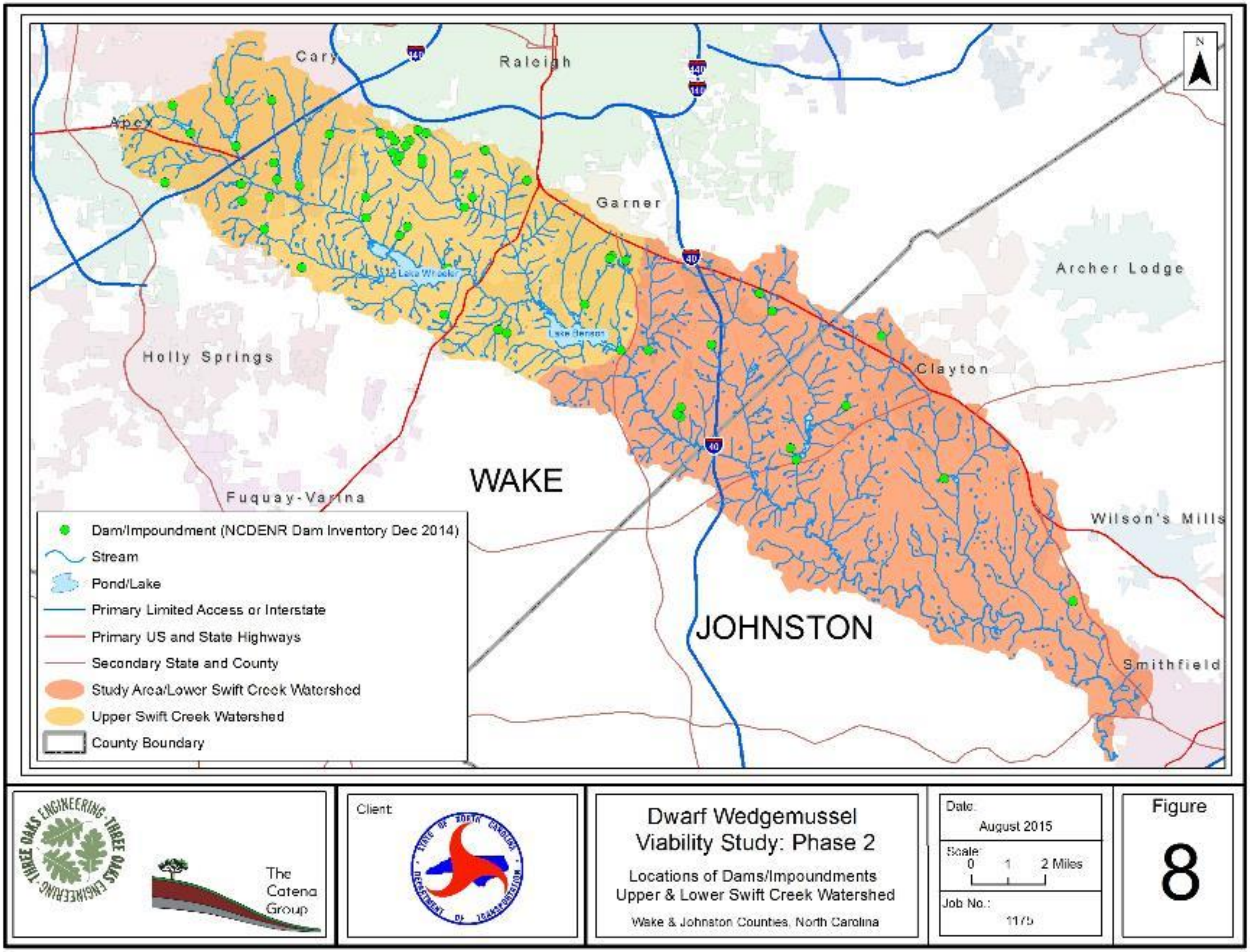
The 2003 Assessment Report (NCDWQ 2003a) provided the following action recommendations in order to curb impairment in the Upper SCW:

1. Implement cost effective stormwater retrofit projects
2. Identify and address toxic inputs
3. Minimum releases from impoundments should be investigated
4. Targeted stream channel restoration in conjunction with stormwater retrofits
5. Reduce nutrient and organic loading (through implementation of the above four)
6. Require effective post-construction stormwater management for any new development
7. Enforcement of sediment and erosion control (particularly Apex, Cary & Wake County)
8. Enhanced watershed education programs

Many of these recommendations could also be applied by the various entities within the Lower SCW as this portion of the watershed continues to develop.

3.5. Neuse 01 Regional Watershed Plan

A Regional Watershed Plan (RWP) is under development for the NC Department of Mitigation Services (DMS, formerly Ecosystem Enhancement Program) for the Neuse 01 watershed, which includes 18 subwatersheds. In the RWP the Upper SCW is divided into two subwatersheds (LakeWheeler-Swift Creek and Lake Benson-Swift Creek), and the Lower SCW is divided into three (Mahlers Creek-Swift Creek, Piney Grove Cemetery-Swift Creek and Reed Branch-Swift Creek). As part of the development of a watershed plan, existing water quality data is often supplemented with data collected specifically for the watershed plan. Coordination with the parties involved in the development of the Neuse 01 RWP should take place to enhance the knowledge of water quality conditions in the SCW.


Cary
Raleigh
Apex
Garner
Archer Lodge
Lake Wheeler
Lake Benson
Holly Springs
Clayton
WAKE
Fuquay-Varina
Wilson's Mills
JOHNSTON
Smithfield
N
Dam/Impoundment (NCDENR Dam Inventory Dec 2014)
Stream
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
County Boundary
THREE OAKS ENGINEERING
The Catena Group
Client:
Dwarf Wedgemussel
Viability Study: Phase 2
Locations of Dams/Impoundments
Upper & Lower Swift Creek Watershed
Wake & Johnston Counties, North Carolina
Date:
August 2015
Scale:
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3.5.1. *Preliminary Findings Report*

The Preliminary Findings Report submitted for the first phase of the RWP (Wildlands Engineering-Catena Group 2014a) developed a functional assessment on a variety of criteria that were evaluated through GIS and other desk-top approaches for each of the 18 subwatersheds. These functional criteria were used to assess subwatershed functions in terms of levels of degradation and identification of stressors and assets. Criteria were selected to provide a mostly quantitative analysis of functional conditions for each subwatershed based on particular, widely-used, and agreed-upon GIS variables and enabling comparisons between subwatersheds to prioritize them for project implementation. Four sets of criteria referred to as "functional conditions categories" were used to evaluate the 18 subwatersheds. These included:

- Stream corridor condition,
- Wetland condition,
- Water quality, and
- Presence of important habitats.

Based on these analyses, five priority subwatersheds were identified for each of the functional conditions categories. The prioritization of the subwatersheds was done to serve as a tool for directing mitigation projects in areas where they would provide maximum benefit. However, it does not imply that projects in non-priority subwatersheds should be excluded from consideration. Some of the subwatersheds were identified as priorities in more than one category, which lends itself to developing a more holistic approach to mitigation than traditional methods allow.

Prioritization of subwatersheds for important aquatic habitats was somewhat different from the other three functional conditions categories as the others assessed priorities based on problems (i.e. water quality issues, lack of stream buffers, etc.) as opposed to assets. The important aquatic habitat category also included a subjective component based on experience in monitoring of aquatic species populations. The 18 Neuse 01 RWP subwatersheds were evaluated through GIS analysis to identify priorities with regards to the highest quality aquatic habitats. The prioritization incorporated various measures of aquatic community importance (presence of rare species, significant natural area designations, etc.), various attributes that impact the quality of aquatic habitats (amount of developed lands, amount of forested lands, etc.), and point sources of water quality impairment (wastewater discharges). Various GIS data layers along with knowledge of the subwatersheds were used in the prioritization process. Using a combination of land use, Natural Heritage Natural Areas, Element Occurrences (EOs), core areas (Landscape/Habitat Indicator Guilds), anadromous fish spawning habitats, NPDES dischargers, and the subjective component described above. The five high priority watersheds from 1-5 include:

- Cattail Creek-Little River,
- Long Branch-Little River,
- Piney Grove Cemetery-Swift Creek,
- Mahlers Creek-Swift Creek, and
- Mill Creek-Neuse River.

The entire occupied range of DWM within Swift Creek is encompassed within the Mahlers Creek-Swift Creek and Piney Grove Cemetery-Swift Creek subwatersheds.

3.5.2. *Project Atlas*

Another component of the first phase of the Neuse 01 RWP was to develop a Project Atlas, which identified the most highly rated watershed improvement projects based on the Preliminary Findings Report. These projects focused only within the identified priority subwatersheds, and were considered “preliminary” as more details would need to be developed in the second phase of the RWP (Wildlands Engineering/Catena 2014b). However, the projects identified were presented as potential mitigation sites for DMS or other mitigation providers, as well as other entities seeking watershed improvement projects.

Two potential projects occurring within the Lower SCW were identified in the Project Atlas, the Swift Creek Ford Tract (Preservation and Buffer Enhancement), and Swift Creek in-stream Habitat Improvements.

3.5.2.1. Swift Creek Ford Tract

This 74 acre potential habitat preservation site is located near the I-40/NC 42 interchange, includes up to 0.72 mile of the mainstem of Swift Creek, and includes properties on both sides of the creek. This portion of Swift Creek is near the upper limits of the currently occupied range of DWM in the creek and occurs in an area that is rapidly being developed for commercial and residential uses. Until 2013, the tract had been used as pastureland, but currently consists largely of open fields and limited riparian buffers. The landowner is interested in selling the property and has been approached by developers (Wildlands Engineering-Catena 2014b). In addition to preservation, the project would also involve riparian buffer enhancement and an in-stream barrier removal caused by a perched utility easement ford crossing. A photograph of this crossing is included in Section 6.2.

3.5.2.2. Swift Creek in-stream Habitat Improvements

As mentioned in Section 2.3.7, ATV use has been identified as a threat to the DWM population in Swift Creek. In addition to ATV use, large log jams are also having localized adverse effect on habitat stability in Swift Creek. While woody debris generally contributes to habitat quality in aquatic environments, excessive amounts that block the channel flow can cause significant bank erosion, transform habitats from lotic to lentic, and create barriers to aquatic passage during some flows. This project would include developing measures to restrict/eliminate ATV use in the stream, and identifying and dislodging excessive log jams (Wildlands Engineering-Catena 2014b.

3.5.3. *Targeted Resource Area Project Sites Identified in Phase 2*

In addition to the Project Atlas Sites identified in the first phase of the Neuse 01 RWP, three additional Targeted Resource Area sites have been identified within the Lower SCW in Phase II of the RWP (Wildlands Engineering 2015).

3.5.3.1. Mahlers Creek Stream Restoration, Preservation and BMP Retrofit

Mahlers Creek is the first major tributary of Swift Creek below Lake Benson. The headwaters occur in a rapidly urbanizing area in the City of Garner near US 70, which has resulted in increased sediment loads being transported into Swift Creek. This potential project would involve traditional stream restoration of degraded reaches south of US 70, buffer preservation of old growth forest, and a BMP retrofit within an industrial development south of US 70.

3.5.3.2. Swift Creek Cattle Pasture Buffer Restoration/Preservation and Stream Restoration

This potential project involves a 97 acre cattle pasture that borders Swift Creek within the current occupied range of DWM. Cattle have direct access to three tributaries to Swift Creek, and the riparian buffer along Swift Creek is fragmented. The project would involve cattle exclusion, and stream and buffer restoration along the three tributaries, as well as buffer preservation and restoration along Swift Creek.

3.5.3.3. Trailer Park Development Buffer Preservation/Enhancement and Stream Restoration

This potential project includes buffer preservation, buffer enhancement and stream restoration on two large tracts of land along Swift Creek and an unnamed tributary to Swift Creek in Wake County below Lake Benson. The 124 acre trailer park development is partially completed and has been platted for additional development 400 feet east of Swift Creek. Between the platted parcels and Swift Creek is a large piece of land owned by the development company that has been severely disturbed by ATV use. Downstream of the trailer park development is a 116 acre agricultural parcel that contains limited amounts of riparian buffer along Swift Creek, and also includes two unnamed tributaries.

3.6. Water Quality Data Collection For DWM Viability Study

As discussed in Section 2.3.3, freshwater mussels have been shown to be highly sensitive to copper and ammonia. The Lower SCW has not been studied as extensively as the Upper SCW, particularly in regards to water quality analysis. One of the recommendations identified in the Phase 1 report was to sample Swift Creek within the occupied range of DWM to determine if these pollutants were of concern with regards to habitat viability. This recommendation has been implemented and the results follow.

3.6.1. *Approach/Methodology*

This component of the viability study involved collecting water quality samples below Lake Benson to identify potential water quality issues that could impact DWM habitat viability. Samples were collected from November 2014 through July 2015 at three locations; the Swift Creek crossings of NC 50 (Benson Road, near former USGS gauge 02087701), SR 1555 (Barber Mill Road, near USGS gauge 0208773375), and NC 210 (near LNBA monitoring site J4590000, Figure 5). Water quality parameters that were measured are listed in Table 9.

Table 9. Water quality parameters measured in Lower SCW.

Field Parameters	Laboratory Parameters
Dissolved Oxygen	Calcium
Temperature	Magnesium
Conductivity	Sodium
pH	Potassium
	Sulfate as SO4
	Chloride
	Total Alkalinity (as CaCO3)
	Total Organic Carbon
	Copper (Total and dissolved)
	Lead
	Nickel
	Zinc
	Cadmium

These parameters were measured in order to determine basic water quality conditions within the reach of Swift Creek where DWM is known to occur. Of particular importance are ammonia, chlorine, and copper. The most advanced method of determining copper toxicity for freshwater aquatic species is the biotic ligand model (BLM). The BLM uses 12 water quality parameters to evaluate copper toxicity. Therefore, several of these parameters were measured in order to use the BLM for toxicity analysis.

Water samples from each site were collected a total of eight times over the course of the sampling period: once during each season, twice during a high-flow event (when flow at USGS gauge 0208773375 was >50% above the median daily statistic), and twice during a low-flow event (when flow at the same gauge was <50% below the median daily statistic).

Field parameters were measured at the time of sampling by use of a multi-parameter meter (YSI Professional Plus, Yellow Spring, OH, USA). For all parameters, samples were collected from visibly flowing portions of the stream (not in stagnant pools), approximately one meter away from the bank toward mid-channel. Samples that were analyzed in a lab were stored on ice (at ~4°C) in the field and taken the same day to ENCO Laboratory (Cary, NC) for analysis.

3.6.2. *Results*

Total copper was detected in half of the samples, while dissolved copper was detected in about a third of the samples. Four of these samples exceeded the chronic event-specific North Carolina water quality standard for copper (derived from hardness levels measured at each sampling event). Additionally, three of these samples exceeded the acute event-specific water quality standard for copper (USEPA 2007, NC Register 2014). The elevated concentrations of copper appear to occur during lower flow rates, which is typically contrary to what would be expected; that copper levels spike during significant rain events when sediment loads into streams increases.

Ammonia was detected in 11 of 24 samples collected. None of these samples exceeded the event-specific chronic or the acute criteria (USEPA 2013). There were no exceedances of any other toxicants analyzed in this study. The results of the water quality analysis are presented in further detail in the Lower Swift Creek Water Quality Report (Three Oaks Engineering/ The Catena Group 20015a), which is included in Appendix B.

3.6.3. *Discussion*

Both ammonia and copper were detected in Swift Creek during the sampling period from November 2014 to July 2015. These parameters have been identified as the most significant toxicants to freshwater mussels (USEPA 2008), and the detection of them is cause for concern if detected at concentrations in excess of those thought to be safe for mussels. Whether or not the levels of ammonia and copper are high enough to be detrimental to mussels is still in question. To fully answer the question of whether water quality conditions in Swift Creek are harmful to DWM, long-term toxicity analysis on DWM analyzing growth, survival, and reproduction is needed. In the absence of that data, similar analysis on other species of the same genus and/or associate species could be done instead. Such analysis is outside the scope of this report.

Copper toxicity in Swift Creek appears to be mostly dependent on the organic content and pH of the water column, and appears to be elevated during low flow events, which by itself can be a stressor to freshwater mussels (See Section 2.3.4.3). Since toxicity can be determined by measuring only a few additional water quality parameters, monitoring could continue at less cost into the future to see how mussel populations respond to changing water quality conditions. The water quality parameters measured in this study were monitored for less than a year, thus a complete understanding of the water quality conditions in the Lower SCW as they pertain to habitat viability for freshwater mussel populations cannot be reached. Long-term monitoring would be needed to get a clearer picture of this relationship; however, the results identify copper as a potential threat to the habitat viability in Swift Creek.

Ammonia toxicity does not appear to be of concern in the majority of the study area, with the exception of some indication of potential toxicity limited to the section of the creek directly below Lake Benson. The long-term monitoring of Swift Creek by the USGS has demonstrated that event-specific criteria for ammonia are rarely exceeded. Monitoring efforts, however, could be improved to fill in gaps and better understand how to best reduce ammonia contamination.

Other pollutants that were measured, including some heavy metals, did not appear to be at toxic levels to aquatic organisms. As has been discussed, metal toxicity is more complex than just a simple measurement of water conditions at a single sampling. Future analysis may be possible, particularly with the use of the BLM, to determine toxicity to freshwater mussels and other aquatic organisms.

3.7. Watershed Conditions: Summary and Management Recommendations

In the later part of the 20th century, much of the land use in the SCW transformed from being relatively rural to largely urban, with the expansion of the greater Raleigh metropolitan area. This is particularly true in the Upper SCW. While the Lower SCW is less developed, it is trending towards urbanization as well.

There is a fairly comprehensive amount of water quality data in the Upper SCW. Periodic exceedances of various water quality parameters have occurred throughout the Upper SCW, and some stream segments in the watershed are listed as impaired (Section 3.3.2). Comparatively, less data are available for the Lower SCW, and what is available rarely extends beyond the past ten years. While there is a paucity of data, recent trends indicate water quality concerns in the Lower SCW as well, particularly in the section of Swift Creek from Lake Benson to the Little Creek confluence, as it recently was placed on the 303(d) list of impaired streams in 2012 (NCDWQ 2012).

Additionally, as mentioned above, continued monitoring of copper and ammonia at the three sampling locations selected for this study (Section 3.6.1) would help to gain a better understanding of the long term water quality component of habitat viability as it pertains to DWM. Efforts should also be made to identify the sources of these toxicants in the Lower SCW and to develop methods to reduce these inputs. This should be done in coordination with various stakeholders that have a vested interest in the protection and improvement of water quality conditions in the Lower SCW. A stakeholder group was formed for the Neuse 01 RWP, which consists of local municipalities, various regulatory and conservation groups, and local citizens, who collectively provide input in the data collection and analysis as well as decision making process. Additionally, several local government entities were interviewed for this study, including Johnston County, City of Raleigh and Town of Cary. Representatives from USFWS, DMS and NCNHP were also interviewed. A subset of the stakeholder group for the Neuse 01 RWP should be assembled to provide input on long term management of the Lower SCW, and Swift Creek DWM population.

Other potential stakeholders to be considered include:

- Wake/Johnston Soil and Water Conservation Districts
- Neuse Riverkeeper Foundation
- Triangle Land Conservancy
- Triangle J Council of Governments (TJCOG)
- Public and Private Schools (particularly science clubs) in the SCW

4.0 ACCOUNTING OF CONSERVATION MEASURES IN SCW

Several conservation measures have been implemented that are intended to protect water quality and habitat within the SCW. Some of these measures also apply to areas outside of the SCW, while others were developed and implemented specifically to protect SCW. The information discussed below was gathered by reviewing applicable rules and regulations that apply to water quality protection, as well as gathering information from various entities that have a specific stake in protection of SCW.

4.1. General Conservation Measures

There are a number of protective measures that have been adopted that apply to the entire Neuse River Basin, which go beyond what is required in many other river basins in North Carolina.

4.1.1. *Neuse River Riparian Buffer Rules*

The State of North Carolina requires 30-foot vegetated riparian buffers in its water supply watershed protection rules, while requirements for Neuse River basin are set at a 50-foot minimum buffer on each side of perennial and intermittent water bodies. New buffers are not required on existing land uses, unless that land use changes (NCDWQ 2003a). These buffers are not required on ephemeral channels. **Note:** The Regulatory Reform Act of 2015, along with Session Law 2015-246, have brought riparian buffer protections into question. Session Law 2015-246 required the Environmental Management Commission to review riparian buffer rules and whether these rules put undue burdens on property owners. The Commission found riparian buffers to be an effective means for protecting water quality, and are less expensive than placing more restrictions (point source discharge requirements, BMP's etc.) on other entities (such as farmers and local governments). Therefore, riparian buffer rules may be changing, as the Commission is currently in the process of reviewing and updating the rules. Proposed changes will be made public later in 2016.

4.1.2. *Neuse River Basin Stormwater Rules*

As of 1998, all waters of the Neuse River Basin have been under the Neuse Nutrient Sensitive Waters rules, a result of the NSW classification. In addition to the 50-foot minimum riparian buffer rule, new development within the Neuse River Basin cannot exceed nitrogen loads of 3.6 lbs/acre/yr. Only Jordan Lake and Falls Lake have more restrictive nitrogen loading rates (NCDWR 2013b). Also, post-development peak flow rates cannot be any greater than flows from pre-development sites for the 1-year 24-hour storm. The stormwater rules also required government entities to implement a public education program, remove illicit discharges, and install stormwater retrofits where feasible. The Town of Apex is not subject to these rules; development existing before 1998 is also not subject to these rules (NCDWQ 2003a).

4.1.3. *Phase II stormwater (NPDES Permits)*

Developed by the EPA, Phase II stormwater rules require small communities not previously under federal stormwater requirements to obtain permits for discharging stormwater. These rules apply to Cary and Apex. The rules include six minimum requirements: public education and outreach, public participation, illicit discharge detection and elimination, construction runoff control, post-construction management to new and redevelopment, and pollution prevention (NCDWQ 2003a).

4.2. Specific Conservation Measures for the SCW

A number of entities have developed various conservation measures specifically to conserve and protect SCW. However, as noted in Section 4.1.1, some of these rules may no longer be allowed under the Regulatory Reform Act of 2015.

4.2.1. *Swift Creek Land Management Plan*

Wake County and local governments (Apex, Cary, Raleigh, and Garner) adopted the Swift Creek Land Management Plan (SCLMP) on April 19, 1990, to allow for further development of SCW without jeopardizing the health of the stream as a water supply source for Lakes Benson and Wheeler (Wake County 2013). The plan requires vegetative buffers and places limits on impervious surfaces (Memorandum 1988, NCDWQ 2003a). The plan also calls for the control of point source discharges. Areas of critical importance for protection (called critical areas) were identified as: Lake Benson, Swift Creek between Lake Benson and Lake Wheeler, Lake Wheeler and Swift Creek above Lake Wheeler, Little Swift Creek, and Yates Mill Creek (Figure 9). The plan establishes imperviousness limitations for areas without stormwater control measures; 6%

in critical areas and 12% in non-critical areas (Figure 9) (AMEC 2004). Critical areas are those of the watershed closest to the water supply source where it is most important to minimize the discharge and maximize the filtration of potential pollutants (Wake County 2013).

4.2.2. *Apex*

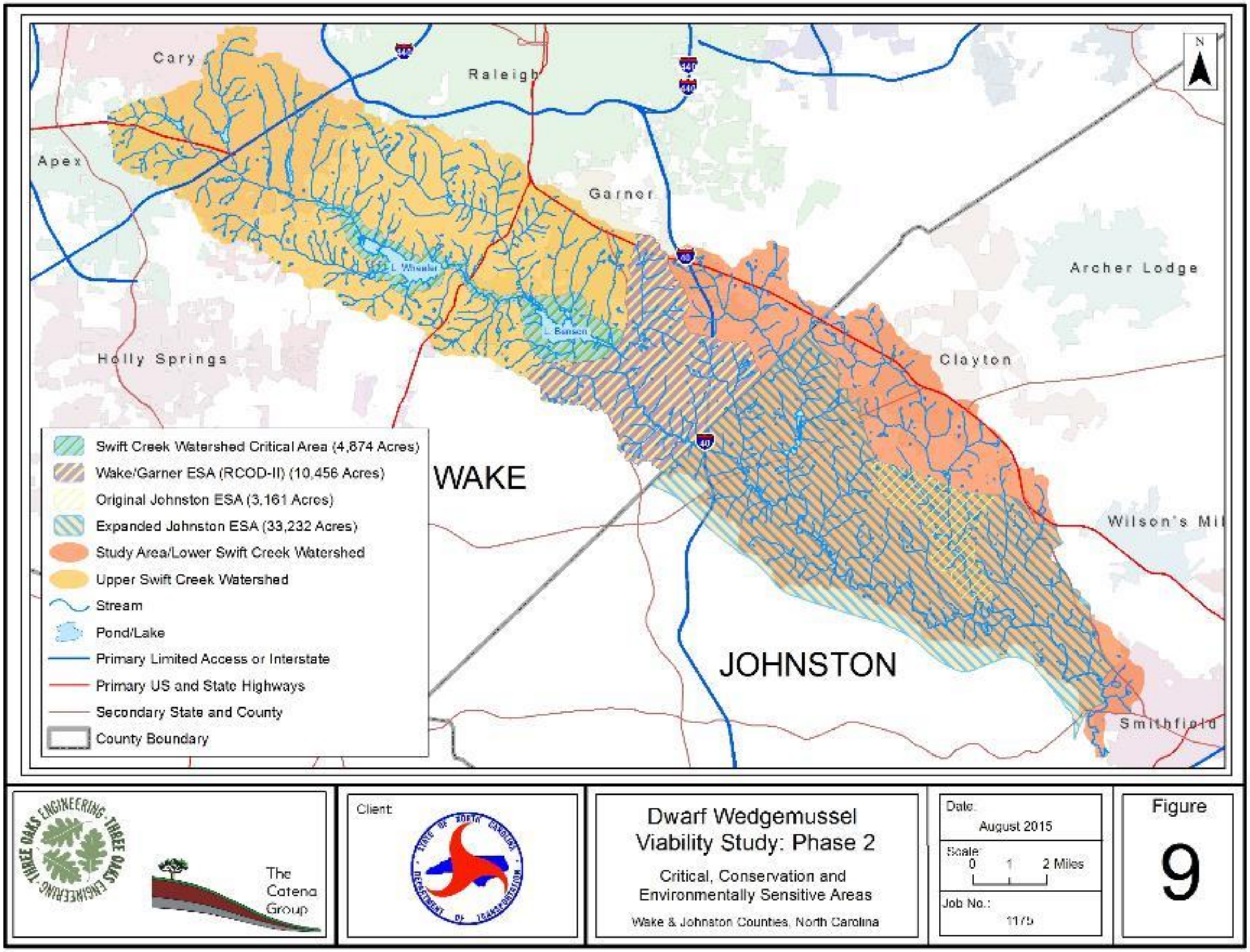
The Town of Apex adopted a Land Use Plan in 2010 that requires 40% of new developments in the resource conservation area be set aside for open space, a 100 foot riparian buffer on perennial streams, a 50 foot buffer on intermittent streams, and no residential development in the 100-yr floodplain. Additionally, the town must capture runoff from 1-inch of rainfall on areas in excess of 12% impervious cover while also removing 85% of TSS. A joint study with the Towns of Cary and Holly Springs of Secondary Cumulative Impact Mitigation Program (SCIMP) was also a requirement of the Plan (AMEC 2004).

4.2.3. *Cary*

The Town of Cary has an estimated 950 acres of land under strict impervious surface limitations. Cary joined Apex and Holly Springs in signing the SCIMP, as described in Section 4.2.2. Cary has a Growth Management Plan (Town of Cary 2000), in which riparian buffer rules are more restrictive than state requirements and 50 foot Neuse River Riparian Buffer requirements. These rules require a 100 foot buffer on perennial and intermittent streams, and a 50 foot buffer on all other streams that appear on the latest soil survey maps. Cary refers to these as Urban Transition Buffers. The Town has also investigated ways to implement a mitigation banking program (AMEC 2004), or a mitigation credit union, but the Final Stormwater Master Plan (Town of Cary 2013) does not indicate a specific mitigation mechanism is in place. The Stormwater Master Plan, however, details ways in which the Town is meeting or exceeding stormwater requirements.

4.2.4. *Garner*

Wake County implements the Town of Garner's Sediment and Erosion Control program. Garner maintains a Swift Creek Overlay District (or Resource Conservation Area), an area in which development is restricted in order to protect Swift Creek. Garner was a signatory of the SCLMP, and therefore has committed to protecting that resource. Garner also developed a Regional Retention Pond BMP Retrofit Plan to install BMPs in the SCW (Garner 2001, AMEC 2004).


Cary
Raleigh
Apex
Garner
Archer Lodge
L. Wheeler
L. Benson
Holly Springs
Clayton
WAKE
JOHNSTON
Wilson's Mil
Smithfield
Swift Creek Watershed Critical Area (4,874 Acres)
Wake/Garner ESA (RCOD-II) (10,456 Acres)
Original Johnston ESA (3,161 Acres)
Expanded Johnston ESA (33,232 Acres)
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
Stream
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
County Boundary
THREE OAKS ENGINEERING
The Catena Group
Client:
Dwarf Wedgemussel Viability Study: Phase 2
Critical, Conservation and Environmentally Sensitive Areas
Wake & Johnston Counties, North Carolina
Date: August 2015
Scale: 0 1 2 Miles
Job No.: 1175
Figure 9

As a conservation measure associated with the Clayton Bypass project, a 10.7-mile highway connecting I-40 in Wake County and US-70 in Johnston County that opened in 2008, Garner also entered into a Memorandum of Understanding (MOU) with NCDOT and USFWS (2006). Garner continues the use of its current buffer standards, defining an undisturbed buffer to include the 100 year floodplain plus 50 feet on streams (listed in Section 7.2.D of Garner's Unified Development Ordinance). The MOU also affirms Garner's Development Standards for Stormwater Management, which limits nitrogen export load to 3.6 lbs/acre/yr; otherwise, developers can make a one-time payment to the DMS. Residential development exceeding 6 lbs/acre/yr of nitrogen and other development that exceeds 10 lbs/acre/yr of nitrogen must implement stormwater control measures to achieve loads below those thresholds to be eligible for mitigation payments. Garner adheres to the rules set out in the SCLMP, with limits set at 6% and 12% for critical and non-critical areas, respectively. Garner has considered adopting stormwater controls equivalent to Wake County's Stormwater Control, Management, and Watercourse Buffer Regulations (Section 2-10-40). When Garner expands into Wake County's Resource Conservation Overlay District-II (RCOD-II, which is the Swift Creek watershed below Lake Benson), these controls will be amended to treat impervious surfaces on a project basis, rather than on an individual lot basis.

4.2.5. *Raleigh*

The City of Raleigh implements its own Sediment and Erosion Control (S&EC) program and requires standards that are more stringent than the state minimum (AMEC 2004). In particular, an S&EC plan must be submitted prior to any land-disturbing activity greater than 12,000 square feet. Land-disturbing activities resulting in uncovered areas are limited at any time to a maximum total area of 20 acres within High Quality Water Zones. Raleigh operates the Dempsey E. Benton WTP, which opened May 12, 2010. Raleigh coordinated with the USFWS on terms and conditions for mitigation of impacts from the WTP to the DWM. These measures are:

- Tiered minimum flow release schedule from the WTP, which would decrease the amount of water from Lake Benson/Swift Creek when outflows are reduced. Raleigh is required to notify the USFWS when Tier 3 flows (0.8 cubic feet per second) last for more than seven consecutive days
- Limit the maximum base withdrawal rate and the frequency of the maximum withdrawal rate
- Manage Lake Benson Dam to prevent rapid reductions in downstream flows
- Suitable intake-outlet structure designs
- Water quality and quantity monitoring programs
- Decommissioning two small wastewater treatment facilities on Swift Creek (Indian Creek Overlook and Mill Run Mobile Home Park WWTPs)

- Purchase of greenway corridors in the SCW: Steep Hill Creek Corridor and Lake Wheeler/Lake Benson Corridor (Arcadis 2005, USFWS 2006)

City of Raleigh Public Utilities representatives have confirmed that these measures have been implemented. There were no Tier 3 flows recorded (2012 to 2014), with measurements being taken on a daily basis. Water quality monitoring has been conducted (see Section 3.3.1), with temperature, DO, pH, conductivity, fecal coliform, suspended solids, turbidity, and ammonia being measured monthly. Mussel surveys, which the city of Raleigh is funding, will be conducted once every five years following construction for 20 years. The two WWTPs have been decommissioned. Steep Hill Creek Corridor has been purchased, and portions of the Lake Wheeler/Lake Benson Corridor are in preservation. A 27-acre property in Garner adjacent to Lake Benson was purchased for preservation with funding acquired through the Upper Neuse Clean Water initiative. Another project pursued by the City of Raleigh involving property between Lake Benson and Lake Wheeler was already in a conservation easement, so could not be claimed by the city (Buchan 2015).

The City of Raleigh constructed a new backwash facility at the Dempsey Benton WTP. The construction site, on-site control measures, stormwater outfalls, and general site conditions were inspected once per week. The City of Raleigh provided inspection forms from July 2013 to December 2014. During that period, there were ten instances when a control measure was not operating properly and corrective actions were taken. There were three instances of visible sediment from the construction site in the stream or on adjacent property. There were three instances of erosion near the stormwater outfall. Amount of rainfall and when it occurred were also noted on the inspection forms (Buchan 2015). The magnitude of the sedimentation and the time frame for the corrective measures to have been implemented are unknown.

4.2.6. *Wake County*

Wake County implements the S&EC Program for all unincorporated county lands and the following municipalities: Town of Garner, Fuquay Varina, Holly Springs, Morrisville, Knightdale, Wendell, and Zebulon. Buffer rules for Wake County exceed the Neuse River Riparian Buffer Rules and NSW nitrogen regulations, with buffer standards of 100 feet, instead of the 50 foot Neuse riparian buffer. Wake County also has a current land use plan, a Growth Management Plan, and a Consolidated Open Space Plan. Minimum lot sizes are required to be 40,000 sq ft in non-critical areas, and 80,000 sq ft in critical areas (AMEC 2004). In 2000, the Wake County Board of Commissioners established the Watershed Management Task Force, which was made up of officials from local governments. The Task Force was in charge of overseeing the development of the County Watershed Plan. As a result, CH2M Hill completed a Comprehensive Watershed Management Plan, a report in which recommendations were made to the commissioners and local governments in order to protect and enhance water quality (NCDWQ 2003a).

As part of the Section 7 Consultation process of the Endangered Species Act of 1973 as Amended for the Clayton Bypass project, Wake County signed a MOU with USFWS and NCDOT (NCDOT 2005). In this document, Wake County agreed to prohibit fill and new development in floodways or floodway fringes on lots created after May 19, 2003. The MOU also limits nitrogen export loads to 3.6 lbs/acre/yr. Developers can otherwise make a one-time payment to DMS; residential development exceeding 6 lbs/acre/yr and other development that exceeds 10 lbs/acre/yr must implement stormwater control measures to achieve loads below those thresholds to be eligible for mitigation payments. Peak stormwater runoff from new development can be no greater for post development for the one year, 24-hour storm event, except for the following: when increase in runoff is 10% or less; maximum impervious surface of a lot is 15% or less (30% or less for residential development); and pervious surfaces are used to control runoff to the maximum extent. An RCOD-II (Figure 9) was created in which perennial streams have a 100 foot buffer. The ordinance amendment will list the impervious surface limits that apply in the County's underlying zoning districts and that are required by its Storwmater Control, Management and Water Course Buffer Regulations (NCDOT 2005).

Wake County, in coordination with the USFWS, also agreed to several measures in preparation for the Dempsey E. Benton WTP. The USFWS issued a Biological Opinion (BO), requiring Wake County to implement the following measures: put further restrictions on the RCOD-II; restrict the allowed activities within stream buffers in the RCOD-II; recodify existing county stormwater regulations in the RCOD-II Ordinance; limit impervious surfaces to no more than 15% in residential areas and no more than 30% in residential areas with stormwater controls in place (USFWS 2006).

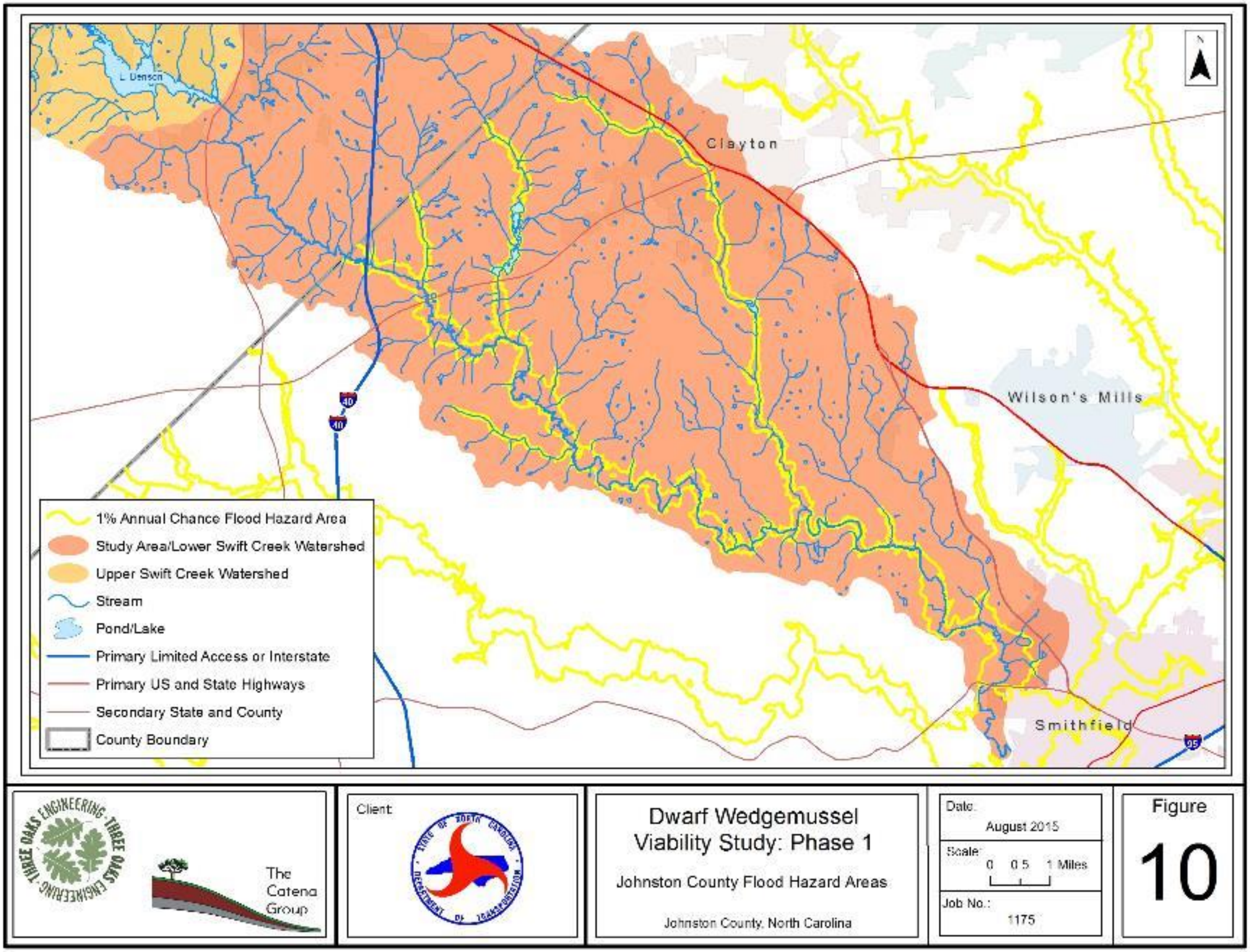
4.2.7. *Johnston County*

NCDOT provided funding to Johnston County for a Watershed Administrator position to implement watershed ordinances as part of development of the Clayton Bypass. The funds were initially received in 1999 and NCDOT supplied funding for five years ($25,000 per year, for a total of $125,000). At that time, the County's stormwater department had just been formed, and a stormwater administrator position was created for the entire county (not just SCW). The passing of the Neuse River Buffer Rules in 1998 was also a driver for creating both the department and the position. When the administrator position was created, Johnston County also developed an Environmentally Sensitive Area (ESA) designation that set limits on impervious surfaces and nitrogen loading rates within the ESA. The ESA was first established around Little Creek from US 70 Bypass to Swift Creek (Figure 9).

Johnston County also entered into an MOU with USFWS and NCDOT to protect SCW for the Clayton Bypass project. In this MOU, the county agreed to expand the boundaries of its ESA (Figure 9). There are stormwater restrictions within the ESA that limit impervious surfaces to 12% in residential areas and 50% in non-residential (versus 15% and 60%, respectively, outside of an ESA). The percent of impervious cover can be increased if BMPs are utilized, payments are made to Land Dedication Fund, or there is a direct dedication of land to preservation. No development is allowed within flood hazard areas (Figure 10), including residential and non-residential structures and improvements to existing structures (NCDOT 2005). Johnston County implemented modification to the Stormwater Management Ordinance limiting total nitrogen from new development to 3.6 lbs/acre/year. Commercial development may make an offset payment to DMS, but shall not exceed nitrogen loads of 8 lb/acre/yr. Residential development does not have the DMS offset payment option (NCDOT 2005). Additionally, the MOU states that Johnston County would consider requiring a 100-foot undisturbed riparian buffer along perennial streams in the ESA, which Johnston County has limited to the main stem channels of Swift Creek, White Oak Creek, Little Creek (from US 70 to Swift Creek) and Little River (from county line to NC 39). All other streams in the ESA do not require the increased 100-foot buffer, but do fall under Neuse River buffer requirements.

There are several areas that are exempt from the current ESA, such as some properties in the I-40/NC-42 interchange area, which drain to Swift Creek. For example, the Golden Corral property was exempt as it was approved prior to the adoption of the ESA regulations. However, the Wal-Mart property was not exempt, and various stormwater BMPs were incorporated into site development.

Under the BMP management program, developers must submit a stormwater management plan, get certification from an engineer in the final stages, and follow-up with an annual inspection approved by the county through a private company. If the inspections indicate non-compliance, they are then required to bring the project into compliance within a year or receive a Notice of Violation.

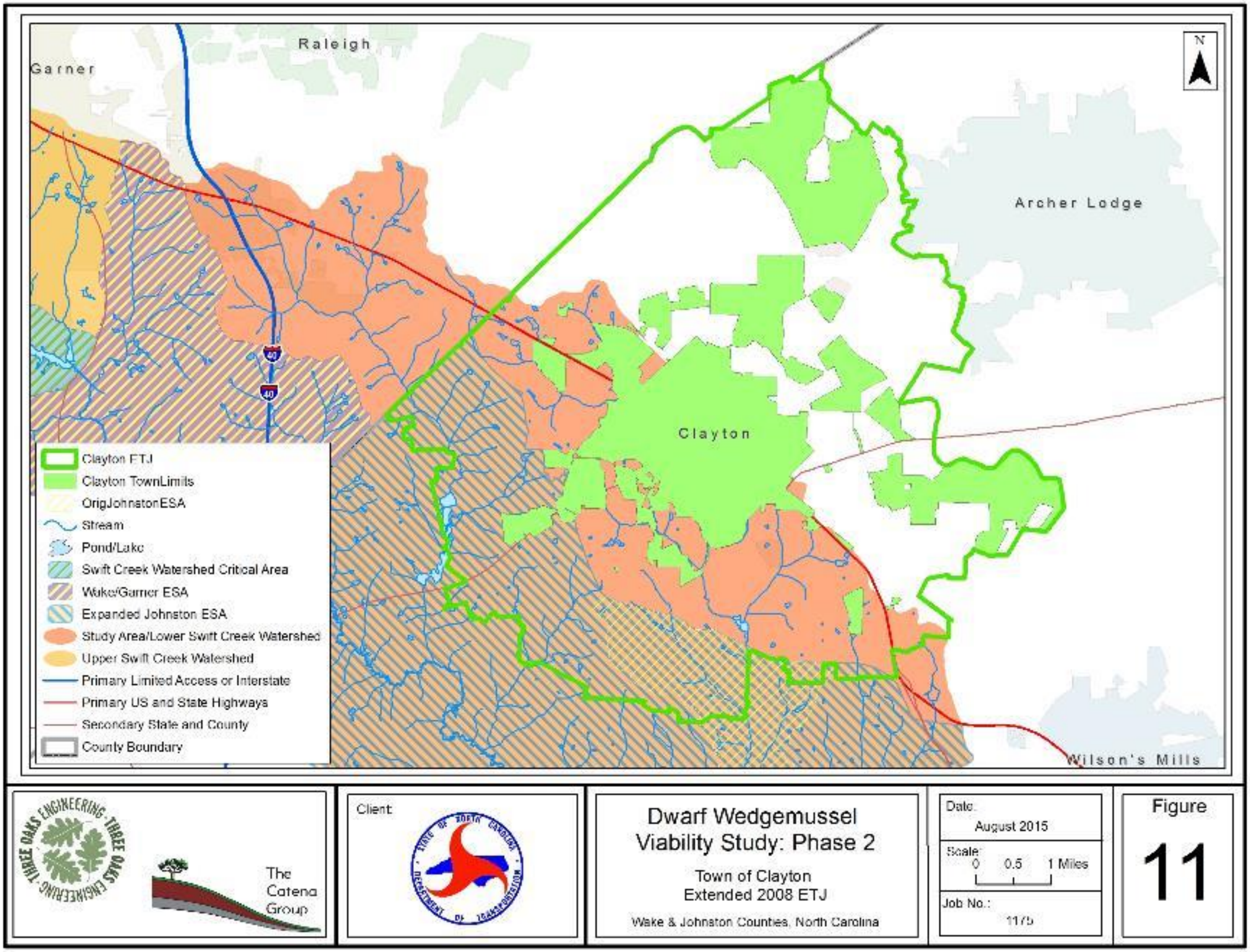


L. Benson
Clayton
Wilson's Mills
Smithfield
1% Annual Chance Flood Hazard Area
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
Stream
Pond/Lake
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
County Boundary
Client
Dwarf Wedgemussel Viability Study: Phase 1
Johnston County Flood Hazard Areas
Johnston County, North Carolina
Date:
August 2015
Scale:
0 0.5 1 Miles
Job No.:
1175
Figure
10
The Catena Group

Johnston County teamed with the Triangle Land Conservancy (TLC) to develop criteria to consider which lands warrant being purchased through the Land Dedication Fund. However, finding conservation areas within SCW has been very challenging (Guerrero, personal communication). While there is still a fair amount of land that has not been developed, many of the landowners in the watershed believe their land is highly sought after for developers and the County alike. So far, no lands have been dedicated within the Swift Creek watershed. Since the signing of the MOU in 2005 for the Clayton Bypass, which expanded the ESA to include Swift, White Oak, and Little Creeks, the Town of Clayton has expanded the Extraterritorial Jurisdiction (ETJ) from one mile to two miles around its boundary (Figure 11). This effectively made the ESA regulations no longer applicable within the ETJ. Therefore, Johnston County and Clayton signed another MOU to ensure that areas previously designated as ESA remained subject to the ESA regulations. Clayton is now part of the NPDES Phase II Stormwater Rule, indicating they must adopt a stormwater management plan, among other requirements. Johnston County noted that there are several other areas in SCW that may be in need of stormwater improvements or retrofits in order to improve water quality in the watershed:

- Summerwind (northwest of I-40/NC-42 interchange): A residential and multi-use development. As the site was in the early stages of development, off-site erosion was an issue. NCDWR took the developer to court for sediment loss into the stream and exceeding permitted limits. However, the original developer has since gone bankrupt, but the property is now under new ownership and development has reinitiated.
- Tetra (northwest of I-40/NC-42 interchange): A commercial and multi-use area.
- Pump Station (east of I-40/NC-42 interchange on Swift Creek): A sewer lift station located near Lowe’s at I-40/NC-42, next to Swift Creek, which has been degraded.

Johnston County passed an S&EC ordinance in June 2013, which the Public Utilities Department is responsible for overseeing. This ordinance regulates land-disturbing activities to control sediment and erosion and establishes procedures by which to accomplish these goals. Additionally, changes were made to the riparian buffer protection ordinance in January 2014, which abide by the Neuse River Buffer rules. Clayton’s buffer and S&EC also falls under Johnston County.



Raleigh
Garner
Archer Lodge
Clayton
Wilson's Mills
N
40
Clayton ETJ
Clayton TownLimits
OrigJohnstonESA
Stream
Pond/Lake
Swift Creek Watershed Critical Area
Wake/Garner ESA
Expanded Johnston ESA
Study Area/Lower Swift Creek Watershed
Upper Swift Creek Watershed
Primary Limited Access or Interstate
Primary US and State Highways
Secondary State and County
County Boundary
The Catena Group
Client
Dwarf Wedgemussel Viability Study: Phase 2
Town of Clayton Extended 2008 ETJ
Wake & Johnston Counties, North Carolina
Date: August 2015
Scale: 0 0.5 1 Miles
Job No.: 1175
Figure 11

4.2.8. *NCDOT Measures*

As part of the roadway design of the Clayton Bypass, and in coordination with USFWS, NCWRC, and other environmental agencies, NCDOT implemented the following measures:

- Added hazardous spill catch basins, extended controlled access to project sites
- Removed curbs and gutters, installed basin designed to meet runoff for 25-year storms
- Utilized faircloth skimmer with jute baffles and polyacrylamide
- Installed erosion control matting in exposed areas near critical habitat and in ditch lines.

Additionally, NCDOT implemented a water quality monitoring program, seeding and mulching, and erosion and sedimentation control measures. DWM propagation efforts by Dr. Richard Neves at Virginia Tech were funded by NCDOT in which 500 juveniles were propagated for release (Beck and Neves 2001); however, the juveniles were not released into Swift Creek over concern of contaminating current populations, as the brood stock came from other locations because efforts to find individuals in Swift Creek were not successful. Additionally, the design of the Clayton Bypass shifted the alignment of the I-40 interchange away from Swift Creek and included four bridges and drainage design features, thus reducing the impact on the stream (NCDOT 2005). NCDOT also provided funding to Johnston County for the creation of the aforementioned Watershed Administrator position.

The water quality monitoring program consisted of monitoring eight (8) sites for turbidity levels during construction of the Bypass (from 2006 to 2008). Four streams were monitored, with stations located upstream and downstream of the construction. Data was viewed on a weekly basis in order to detect possible sediment problems in the system. During the monitoring period, there were generally very dry conditions. These conditions were not conducive to very accurate data, as the sensors used were designed for deeper water. This resulted in many artificial spikes in turbidity levels and the need for frequent recalibration of the sensors (David Harris, personal communication). Turbidity levels were generally the same upstream and downstream of the construction, aside from the occasional increase downstream of construction (see Appendix D for Quarterly Reports).

4.2.9. *Stormwater Evaluation Tool*

The Stormwater Evaluation Tool (SET) was developed with the intent to identify areas of concern with respect to improperly managed stormwater devices and areas where stormwater is altogether unmanaged (Three Oaks Engineering/Catena 2015b). SET is used to provide a means of rating “sites” where stormwater retrofit could occur within the SCW. The SET was created specifically to evaluate potential sites for BMP retrofit and provide a priority ranking based on site specific characteristics. Potential retrofit sites will be prioritized on the following criteria:

- Ability to prevent stream erosion, sedimentation and water quality degradation
- Ability to prevent pollutant loading
- Ability to implement the BMP retrofit project

Evaluations are conducted through inspections that include looking for existing BMP devices, active erosion and potential for erosion, sediment accumulation, water discharge method, and impervious surface area, among other characteristics. These characteristics are rated and recorded on a SET form.

Each site is evaluated by examining select site attributes and assigning a numerical score for each. The evaluation form is used to record the score for each attribute and determine the total numerical score for each site. Evaluation sites will be prioritized for BMP retrofit based on their total score, as well as best professional judgement. Sites receiving scores above 35 are deemed high priority for retrofit. A site that already has an operational BMP should receive a lower numeric rating compared to a site with no BMP.

Areas of high intensity development within 500 feet of the mainstem of Swift Creek and its tributaries were deemed within the area of interest. Initial evaluations of sites located within the area of interest included shopping centers, hotels, office parks, industrial areas, and residential developments. The complete SET report (Three Oaks Engineering/Catena 2015b), including the forms, is contained in Appendix E.

4.2.10. *Preservation/Mitigation sites*

There are three DMS mitigation sites in Swift Creek Watershed below Lake Benson and up to the first impoundment along tributaries to Swift Creek:

- Big Bull Creek Restoration Site (DMS ID: 92214) is approximately 37 acres on White Oak Creek and an unnamed tributary to White Oak. The site was previously used as livestock pasture and hay production prior to 2006 when riparian buffer restoration was completed. The entire site was reforested with Piedmont Bottomland Forest community species. A conservation easement on the site provides buffer mitigation in the watershed below Austin Pond.
- The Moore Property site (DMS ID: 725, ONEID: 051-001) was conveyed as a conservation easement in perpetuity to NCDOT in 2003. The site is 84 acres and construction of restored wetlands was completed in July 2011. The site was a mitigation site for the Clayton Bypass project (TIP R-2552) on Swift Creek next to Johnston County Airport.
- Site 092-014 Underhill Property, which is a closed-out 84 acre preservation property that was part of the R-2000 (Northern Wake Expressway) mitigation project. The property is

now owned by Wake County and appears as a mitigation site on the Wake County Public Open Space files (Figure 4).

4.3. Accounting of Conservation Measures: Summary

As described in Section 4.2, there are multiple conservation measures that have been developed and implemented within the SCW. These measures consist largely of establishing minimum buffer requirements, limiting the amount of imperviousness and nutrient inputs, and providing stormwater and erosion control measures. Additionally, measures associated with the Dempsey Benton WTP provide for maintenance of minimum flows in the Lower SCW. Other measures, such as establishing a USGS gauging station in the Lower SCW and developing artificial propagation techniques for the DWM, may aid in management decisions for this species in Swift Creek.

The effectiveness of these measures with regards to providing sufficient protection for the Lower SCW in terms of maintaining a viable DWM population into the future is unclear for a number of reasons. First, many of the conservation measures were enacted as a response to the rapid urbanization of the watershed, and thus some of the degradation of the watershed had already occurred prior to measures being implemented. Second, in most instances there were no specific monitoring components associated with the various conservation measures to determine if the measures are accomplishing their goals (i.e. are limits on impervious surface reducing stormwater effects on Swift Creek, are stormwater and erosion control measures reducing the amount of sedimentation and channel erosion impacts in Swift Creek, etc.). Finally, there is no clear understanding of how long it takes from the time conservation measures are implemented until improvements become apparent. This is especially true in a watershed like SCW, where there are multiple stressors; however, mitigation/conservation efforts are often project specific, or narrowly focused on one area or specific problem, as opposed to a holistic approach.

As will be discussed in Section 5.0, there has been a declining trend in the relative abundance of most mussel species occurring within the project area since the period of 1992-1996, but especially during the period of 1997-2001. Given this decline, it would be easy to draw a conclusion that the conservation and protective measures that are in place in the SCW are not sufficient to maintain a viable DWM population. However, for the reasons just alluded to, this conclusion may not be completely accurate. In the three periods following 1997-2001 (2002-2006, 2007-2011, 2012-2015) the decline seems to have leveled off for most species. An alternate conclusion might then be that the declines occurred prior to the conservation measures being implemented, and that by putting those measures in place, a total collapse of the mussel fauna was avoided, and populations may rebound once the measures have been in place for a long enough period of time.

It is likely that neither of these conclusions are totally accurate and that the level of the effectiveness of the conservation measures, and their adequacy to maintain population viability is somewhere in between. Population and habitat viability will be discussed in further detail in the following three sections.

5.0 DWM POPULATION TRENDS IN SWIFT CREEK

The overall goal of this study is to determine the long term viability of the Swift Creek DWM population. The recovery goal for the DWM (USFWS 1993) is "to restore and maintain viable populations …to a significant portion of its historical range in order to remove the species from the Federal list of endangered and threatened species". As mentioned earlier, the maintenance of a viable population in Swift Creek is listed as a recovery objective (USFWS 1993). The recovery plan defines a viable population as "a population containing a sufficient number of reproducing adults to maintain genetic variability and in which annual recruitment is adequate to sustain a stable population." While the definition of what constitutes a viable population is clear, a quantifiable measure of population viability has been difficult to determine.

5.1. NC Scientific Council Recommendation on Viability Measures

The NC Scientific Council on Freshwater and Terrestrial Mollusks (The Council), which currently consists of 17 scientists recognized for their respective knowledge on the status of mollusk species in North Carolina, was assembled by the North Carolina Nongame Wildlife Advisory Committee, an advisory committee that reports to the NCWRC, to evaluate status listings of the rare, threatened, and endangered mollusks of North Carolina. The Council recognized a need to develop a quantitative ranking system to use as a tool for determining imperiled status of species to lessen the subjective biases of existing ranking systems. One component of developing such a ranking system is determining population viability. As such, the Council's quantifiable criteria to measure population viability of freshwater mussels suggested the species should:

- Occupy between 10-20 miles of continuous habitat if dendritic (occurring in main stem and tributaries), or greater than 20 miles if linear, with no gaps greater than 2 miles of unoccupied habitat.
- Occur at 75% of sites within occupied habitat.
- Have a relative abundance as measured by CPUE of $\geq$ 5 individuals per hour at 50% of sites within occupied habitat.
- Exhibit evidence of reproduction; contain gravid individuals, and/or multiple size classes, including younger individuals.

These criteria have not been tested on mussel populations in the state, but were based in the collective opinions of the Council, and will likely need to be adjusted as these methods are applied and more information becomes available. While these measures of viability have not been officially adopted, this study evaluated these parameters in the analysis.

5.2. Study Approach

The study consists of two components; a desktop evaluation of previous survey data to determine species abundances over time, and in-stream studies to evaluate particular indicators of population viability. The DWM has consistently been rare in Swift Creek since its discovery in 1991. Because of this rarity, the DWM cannot be analyzed singularly in this study. As with many rare species, it is often necessary to evaluate more common associate species to serve as surrogates in the analyses. Therefore, this analysis focuses on trend data specific to the DWM, while also considering the entire mussel fauna in Swift Creek.

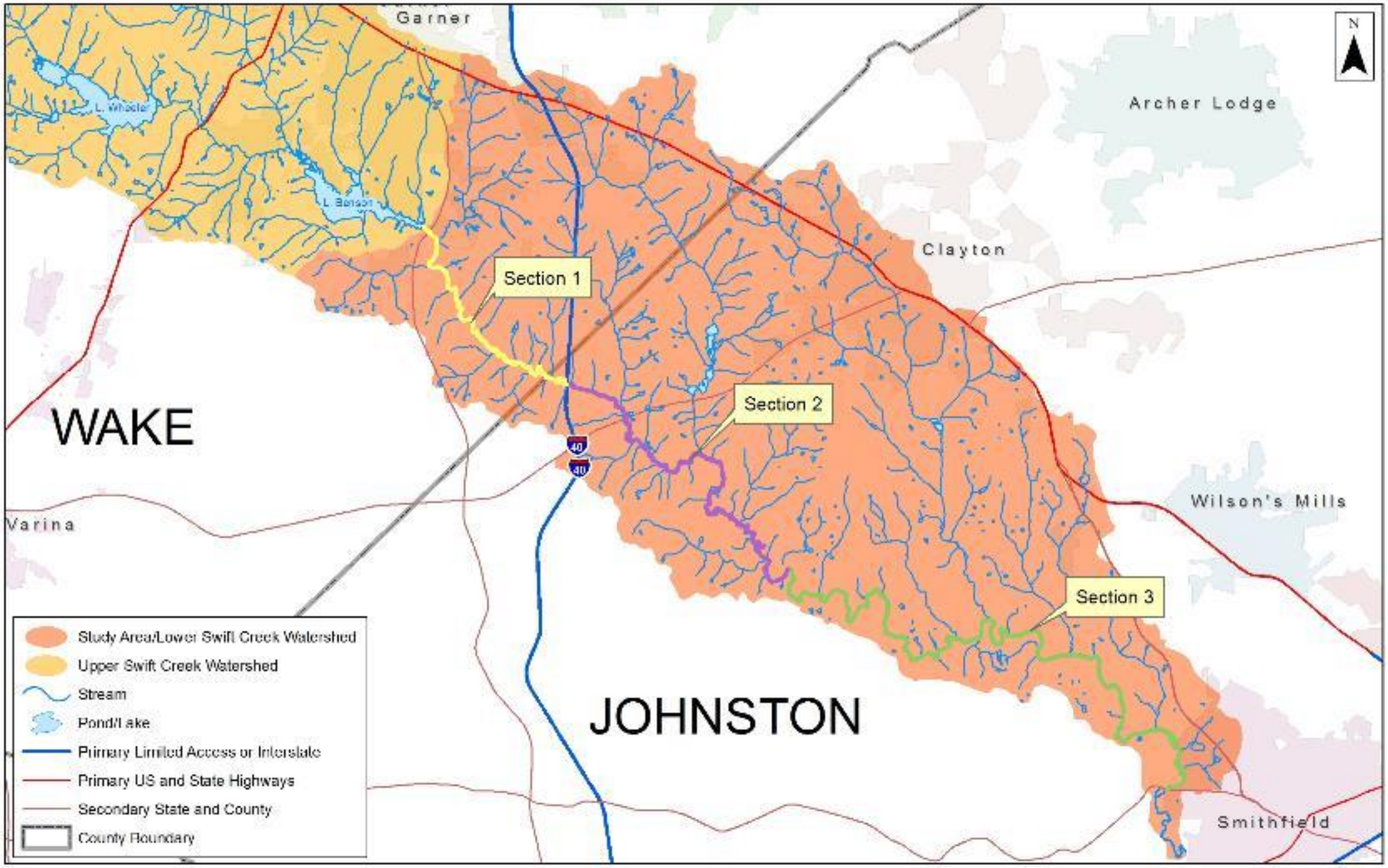
For purposes of data reporting, analysis, and discussion, the general study area of Swift Creek is divided into three sections of unequal length to account for general habitat conditions as follows (Figure 12):

1. Section 1 (Lake Benson to I-40),
2. Section 2 (I-40 to Barber Mill Road)
3. Section 3 (Barber Mill Road to the Neuse River)

With regards to the freshwater mussel fauna, Swift Creek is one of the most species rich and extensively surveyed water-bodies in North Carolina. However, nearly all of the surveys employed an "informal" sampling design using timed qualitative searches for mussels at various locations. The primary objective of this type of sampling is to determine presence/absence of a particular species, and is not recommended for population density studies, or long term monitoring (Strayer and Smith 2003). Thus, conclusions on population trends derived by simply analyzing the existing dataset without accounting for sampling variance would have inherent flaws as the dataset does not account for the level of uncertainty inherent with variables, such as survey effort, seasonality, surveyor experience, and survey conditions (water depth, visibility, flow, etc.). To account for this, a probability-based design that involved a number of repeat surveys at selected sites was incorporated into the field component of this study to develop detection probabilities for the mussel species occurring in Swift Creek. These detection probabilities will assist in making inferences of trends from previous survey data. While this will not totally eliminate the unknown biases of the informally sampled dataset, it will strengthen assumptions made with regard to previous survey data being representative of the overall population.

5.3. History of Mussel Surveys and Mussel Fauna in Swift Creek

Until the 1990s, documented collections of freshwater mussels in the Swift Creek subbasin were very limited. Walter (1956) sampled mollusks at five stations and reported only five mussel



The Catena Group

Client:

Dwarf Wedgemussel Viability Study: Phase 2

Study Area Section 1-3

Wake & Johnston Counties, North Carolina

Date: August 2015

Scale: 0 0.5 1 Miles

Job No.: 1175

Figure 12

species. Alderman (1991) reported 11 species, including the DWM at four stations. Since the discovery of DWM in Swift Creek in 1991, numerous mussel surveys have been conducted throughout the subbasin, including a relict shell survey at 118 stations in 1992 (Flowers and Miller 1993), various status/monitoring surveys by the NCWRC from 1992-2006, comprehensive efforts in 1996 and 2003 undertaken by the NCDOT for the Clayton Bypass roadway project (NCDOT 2005), and baseline and six-month post construction surveys for the Dempsey E. Benton WTP in 2007 and 2010 respectively. Additionally, surveys were conducted for the Complete 540 - Triangle Expressway Southeast Extension in 2010, 2011 and 2012. The results of these surveys were provided to Lochner and NCDOT in three separate reports, which are included in Appendix F.

Historically, at least 18 species of freshwater mussels have been reported to occur in the Swift Creek subbasin. The Green Floater reported as occurring in Swift Creek by Walter (1956) is the only species known from the creek that has not been found in recent years, as it was last collected (one specimen) in 1991 (Alderman 1991). Brief descriptions of each of the mussel species known from Swift Creek are provided in Appendix F.

5.4. DWM Occurrences and Distribution in Swift Creek

In Swift Creek a total of 49 live and 12 relict shells have been found through 21 stream miles from 1992-2016 (Figure 13). The lower 10 miles, however, are represented by only one individual, and the species has not been found in this 10 mile section since 1991. Additionally, two individuals have been recorded in both Little Creek and Middle Creek and one in White Oak Creek, which are tributaries to Swift Creek. A table listing all the DWM records from the SCW, including year and specific locations is included as Appendix G.

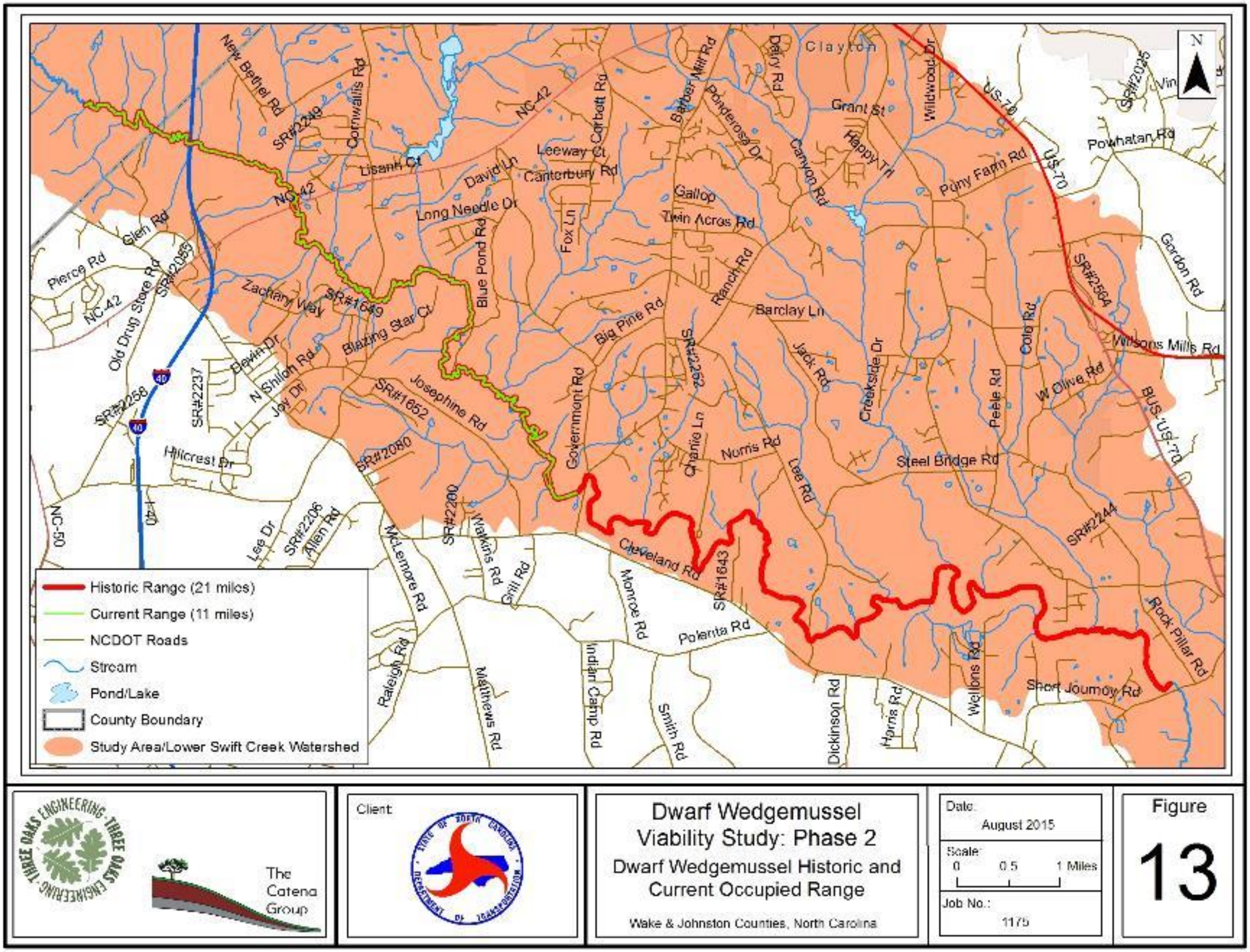
5.5. Mussel Population Trends in Swift Creek

The objective of this component of the study was to analyze population trends of the mussel species in Swift Creek. This analysis focuses on relative abundances, as measured by catch per unit effort (CPUE) of each species over time, and age class distribution (as inferred from size class data) over time for particular species when size class data is available.

5.5.1. *Relative Abundance Trends*

The CPUE, which indicates the number of individuals found in one hour of survey time, for each species occurring in Swift Creek was evaluated over time in the three sections of the study area. Two different measures of CPUE were considered:

1. CPUE for each species only at sites where it was detected within each section (Site Specific)


Historic Range (21 miles)
Current Range (11 miles)
NCDOT Roads
Stream
Pond/Lake
County Boundary
Study Area/Lower Swift Creek Watershed
Clayton
New Bethel Rd
Cornwallis Rd
NC-42
Lisann Ct
Leeway Ct
Canterbury Rd
Corbett Rd
Barber Mill Rd
Ponderosa Dr
Dairy Rd
Grant St
Happy Trl
Wildwood Dr
US-70
Powhatan Rd
Pony Farm Rd
Canyon Rd
Gallop
Twin Acres Rd
David Ln
Long Needle Dr
Fox Ln
Blue Pond Rd
Glen Rd
Pierce Rd
Old Drug Store Rd
Zachary Way
SR#1649
Blazing Star Ct
Big Pine Rd
Ranch Rd
Barclay Ln
Gordon Rd
SR#2564
Wilsons Mills Rd
Cole Rd
Jack Rd
Creekside Dr
Peele Rd
W Olive Rd
BUS US-70
Bevin Dr
N Shiloh Rd
Joy Dr
SR#2237
SR#2258
Josephine Rd
SR#1652
Government Rd
Charlie Ln
Norris Rd
Steel Bridge Rd
Lee Rd
Hillcrest Dr
SR#2080
NC-50
Lee Dr
Allen Rd
McLemore Rd
SR#2200
Watkins Rd
Grill Rd
Cleveland Rd
SR#1643
Monroe Rd
Polenta Rd
SR#2244
Rock Pillar Rd
Short Journey Rd
Wellons Rd
Harris Rd
Dickinson Rd
Smith Rd
Indian Camp Rd
Matthews Rd
Raleigh Rd
N
The Catena Group
Client:
Dwarf Wedgemussel
Viability Study: Phase 2
Dwarf Wedgemussel Historic and
Current Occupied Range
Wake & Johnston Counties, North Carolina
Date:
August 2015
Scale:
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13

2. CPUE for each species at all survey sites combined within each section, whether the species was detected or not (Total Effort).

These data were divided into the following six time periods:

1. ≤1991
2. 1992-1996
3. 1997-2001
4. 2002-2006
5. 2007-2011
6. 2012-2015

It is important to note that each of these periods contains variability in data collection as to methods, level of effort, survey site location, etc. Many of the survey sites, particularly in the first three time periods, focused on the best habitat for rare species, such as the DWM, Atlantic Pigtoe and Yellow Lance, while later surveys were more comprehensive of a variety of habitat conditions within the stream. As such, conclusions based on apparent trends, particularly for habitat specialists like the Atlantic Pigtoe, need to account for variability in survey methodologies. Variability in survey methodologies is less likely to be a factor when evaluating trends with habitat generalists such as the *Elliptio* species. The number of survey hours per section for each time period is shown in Table 10; however, it should be noted that at the time of the writing this report, an intensive survey effort in Swift Creek was underway as part of monitoring requirements, and the results of these on-going surveys are not reflected in the analyses below, but will be incorporated into the Biological Assessment that will be prepared for this project.

Table 10. Number of mussel survey hours by sections

	Study Area Section		
Time Period	**1**	**2**	**3**
≤1991	0	1	7
1992-1996	6	8	9
1997-2001	23	21	3
2002-2006	44	51	53
2007-2011	145.5	306.69	116.16
2012-2015	47.53	287.99	56.87

5.5.1.1. DWM

As mentioned in section 5.4, a total of 49 live DWM have been found in Swift Creek since 1991, with the majority (42) found in Section 2, and only one individual found in Section 3. The above values include one DWM found in 2016 in Section 2 that is not included in the CPUE calculations or charts below. Since the 1992-1996 period, the Site Specific CPUE has declined steadily from a high of 3.5/hr in Section 2 to <0.35/hr in both Section 1 and Section 2 in the

2007-2011 period, and <0.3/hr in Section 2 during the 2012-2015 period (Chart 1). It should be noted that the Site Specific CPUE (1.0/hr) for the 2002-2006 period is represented by only one individual. The Total Effort CPUE (Chart 2) highlights the amount of effort required to detect this species. While it has consistently taken a significant amount of survey effort to detect DWM in Swift Creek, as with the Site Specific CPUE (Chart 1), a declining trend is apparent over the same time periods.

Chart 1. CPUE of Dwarf Wedgemussel only at sites where it was detected within each section

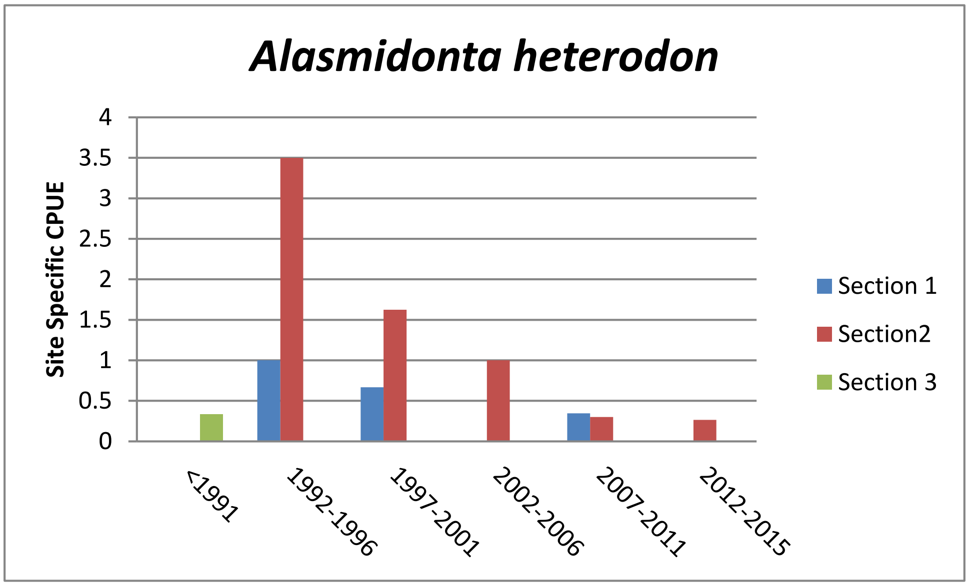
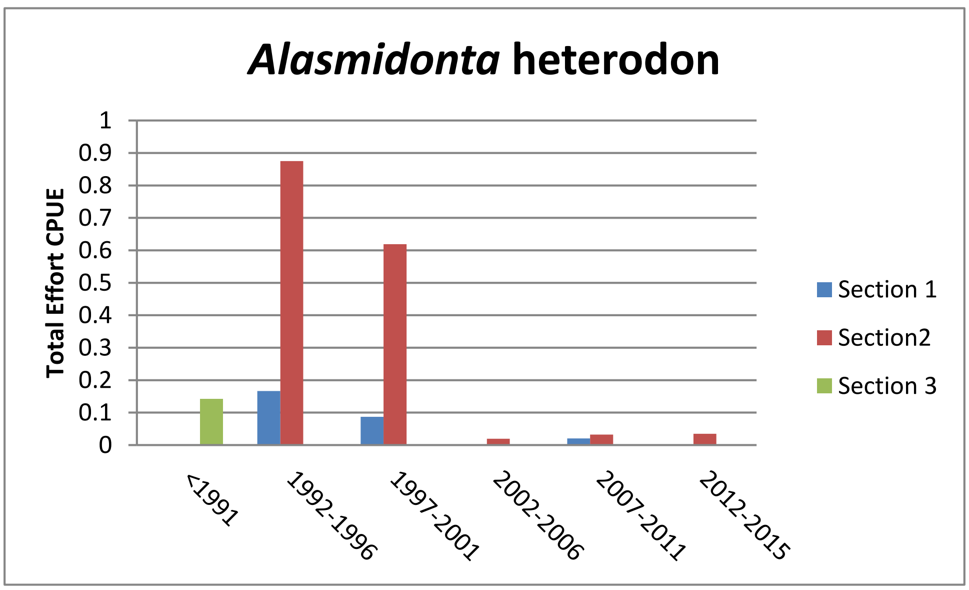


Chart 2. CPUE of Dwarf Wedgemussel at all survey sites combined within each section, whether the species was detected or not



5.5.1.2. Atlantic Pigtoe

The Atlantic Pigtoe has been found in all three sections of Swift Creek in every sampling period, with the exception of <1991, when it was reported only in Section 2. This is likely due to a limited amount of survey effort during that sampling period. Both measures of CPUE (Charts 3 and 4) indicate a declining trend of Atlantic Pigtoe CPUE since the 1992-1996 period, although the decline seems to have leveled off in the last three sampling periods.

Chart 3. CPUE of Atlantic Pigtoe only at sites where it was detected within each section

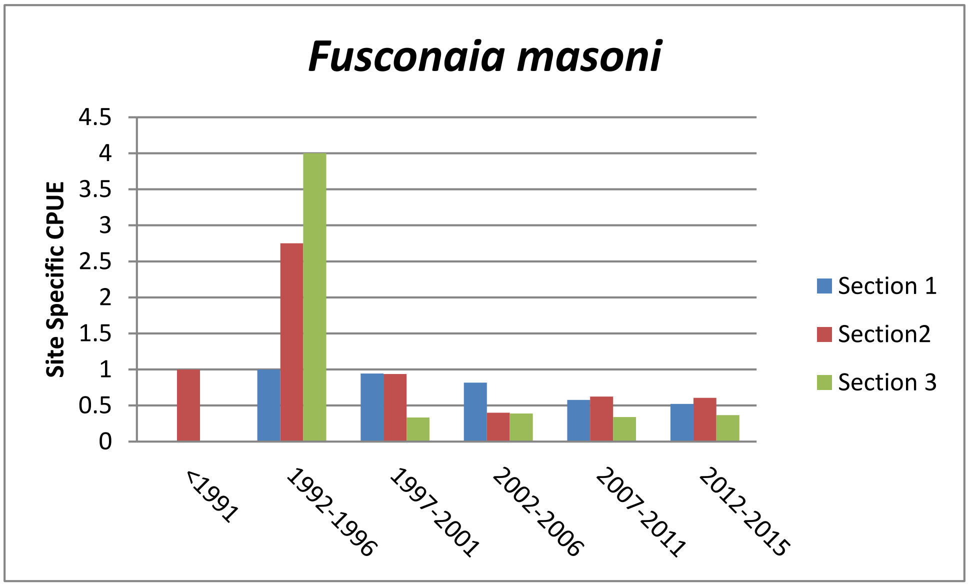
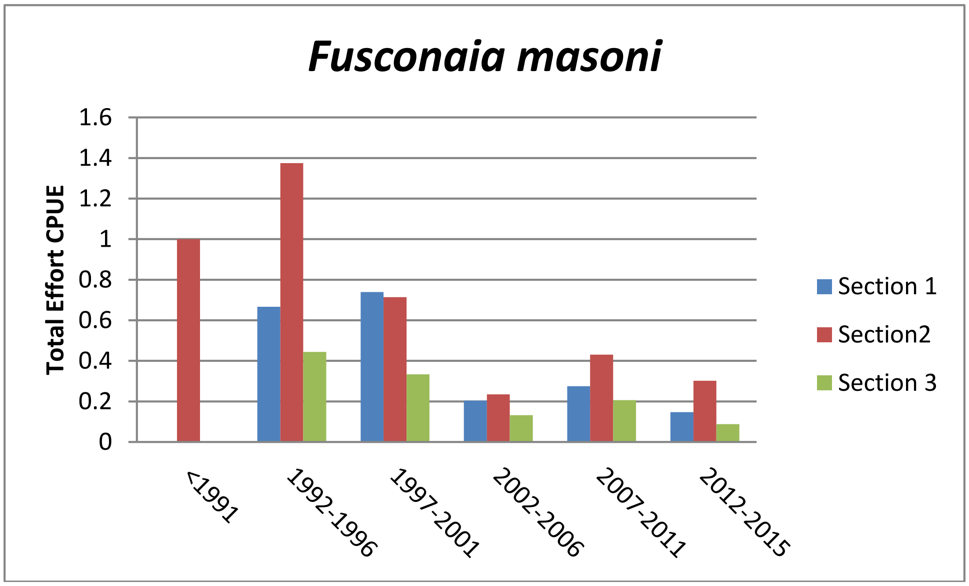


Chart 4. CPUE of Atlantic Pigtoe at all survey sites combined within each section, whether the species was detected or not



5.5.1.3. Elliptio Species

This composite of *Elliptio* species represents at least three species (*E. complanata* complex, *E. icterina* complex and *E. congerea*). Due to plasticity of shell morphologies and taxonomic uncertainties within the genus, discrepancies regarding species identification exist within the dataset. For example, the Box Spike (*E. cistelliformis*) is reported from Swift Creek. This species, which was described from the Neuse River Basin was synomonized with *E. complanata* (Johnson 1970). Thus, some surveyors in Swift Creek may have recognized the *E. cistelliformis* form as separate from *E. complanata*, while others may have grouped them together. To account for this, all *Elliptio* species excluding *E. lanceolata*, *E. roanokensis* and various lanceolate *Elliptio* forms (*E. fisheriana*, *E. producta*, *E.* spp. c.f. lance and *E. viridula*), were grouped together for this analysis. *Elliptio* species generally account for the highest percentage of the freshwater mussel fauna in most Southern Atlantic Slope streams (Johnson 1970), which is the case within Swift Creek.

As with the DWM and Atlantic Pigtoe, both measures of CPUE point to a declining trend in relative abundance of the *Elliptio* species since the 1992-1996 period in all three sections of Swift Creek, though the decline seems to have leveled off in the last two sampling periods (Charts 5 and 6). While *Elliptio* species were found at every site surveyed there are minor discrepancies between the two charts; for a few surveys, no search times were included or information about non-protected species was omitted; thus the CPUE values between the two charts are different during some sampling periods.

Chart 5. CPUE of Elliptio Species only at sites where it was detected within each section

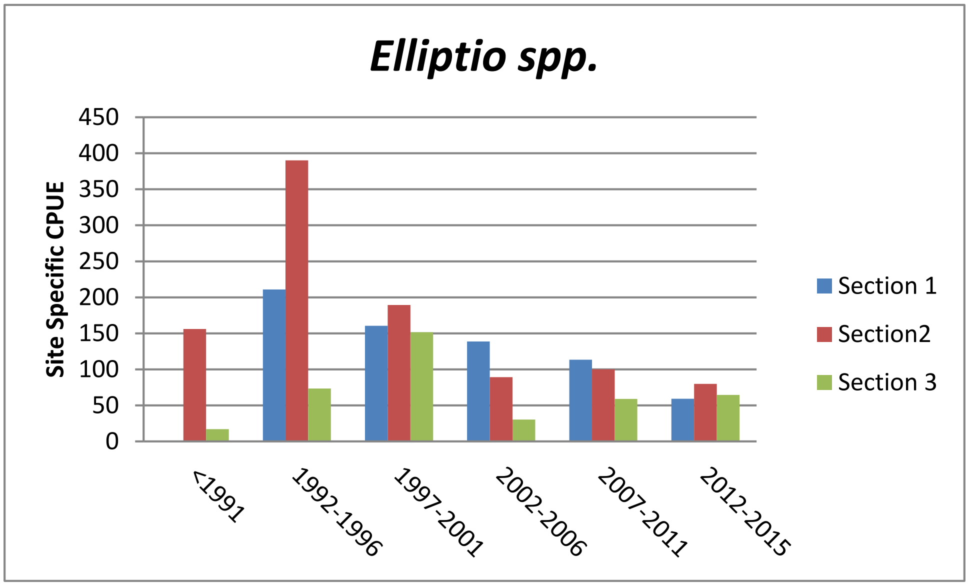
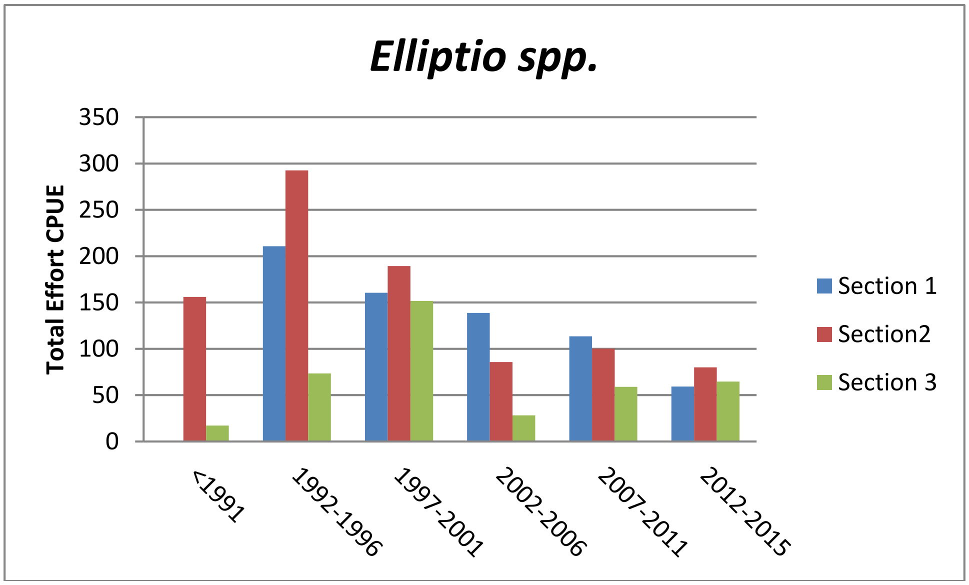


Chart 6. CPUE of Elliptio Species at all survey sites combined within each section, whether the species was detected or not



5.5.1.4. Notched Rainbow

The Notched Rainbow is extremely uncommon in the study area, being found only in Section 2 in very low numbers ($\leq$ 1.5/hr, and $\leq$ 0.125/hr in Chart 7 and 8, respectively). Live individuals have not been found since 2006; however, two fresh dead shells were found in 2012 as part of this study. Given its rarity, population trends are not able to be determined within the time period of the data set.

Chart 7. CPUE of Notched Rainbow only at sites where it was detected within each section

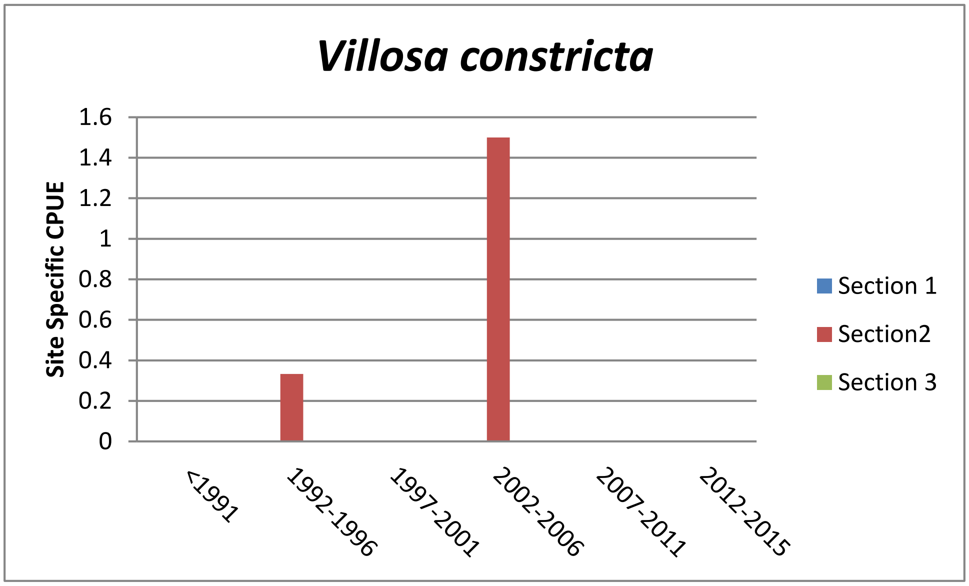
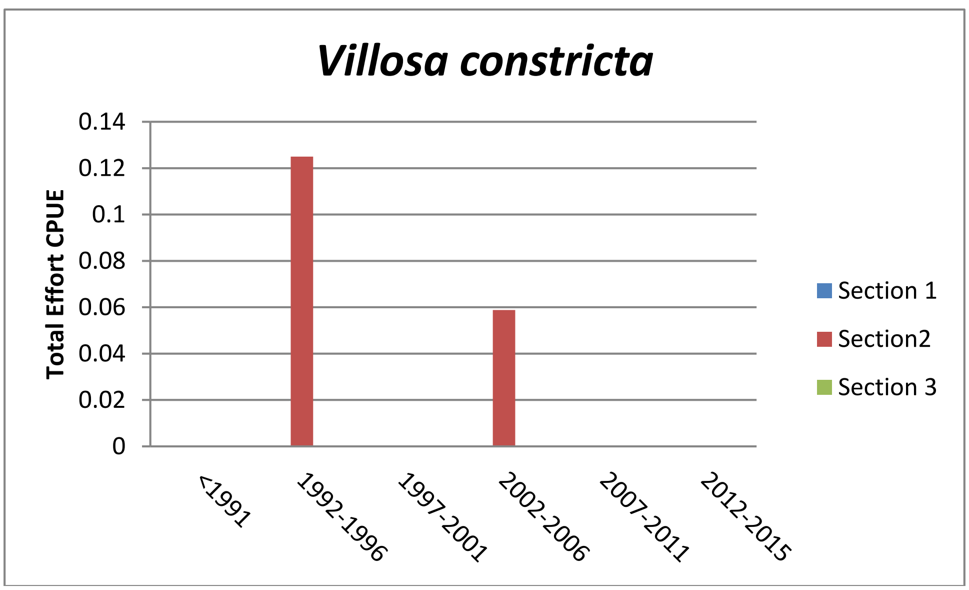


Chart 8. CPUE of Notched Rainbow at all survey sites combined within each section, whether the species was detected or not



5.5.1.5. Triangle Floater

The Triangle Floater has been found in all three sections, with the highest CPUE (Site Specific and Total Effort) occurring in Section 3. The CPUE dropped slightly in all three sections between the 1992-1996 and the 1997-2001 periods, and then declined significantly in the following periods (< 0.72/hr for Total Effort in all three sections). Both measures of CPUE (Charts 9 and 10) show similar declining trends, though the decline seems to have leveled off in the last two sampling periods (Charts 5 and 6)

Chart 9. CPUE of Triangle Floater only at sites where it was detected within each section

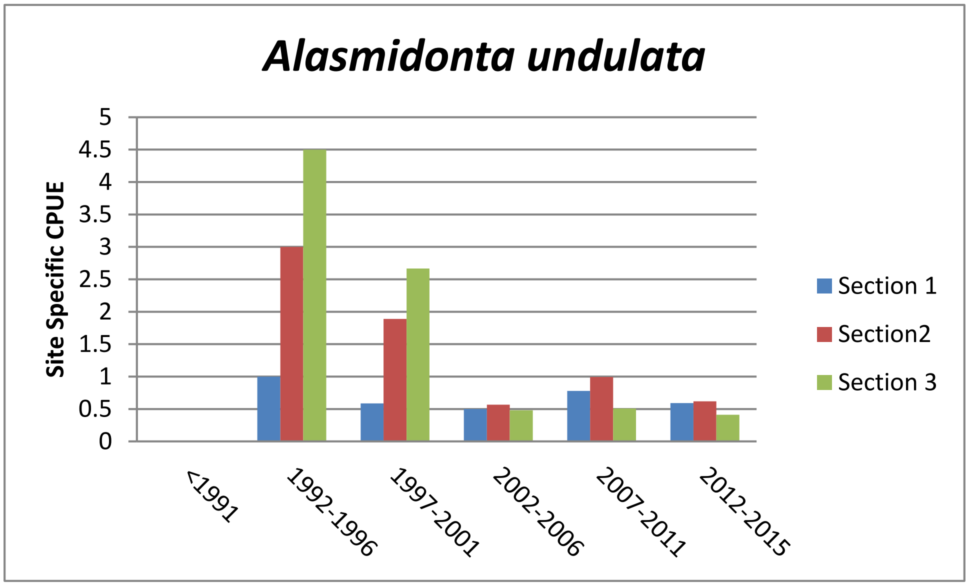
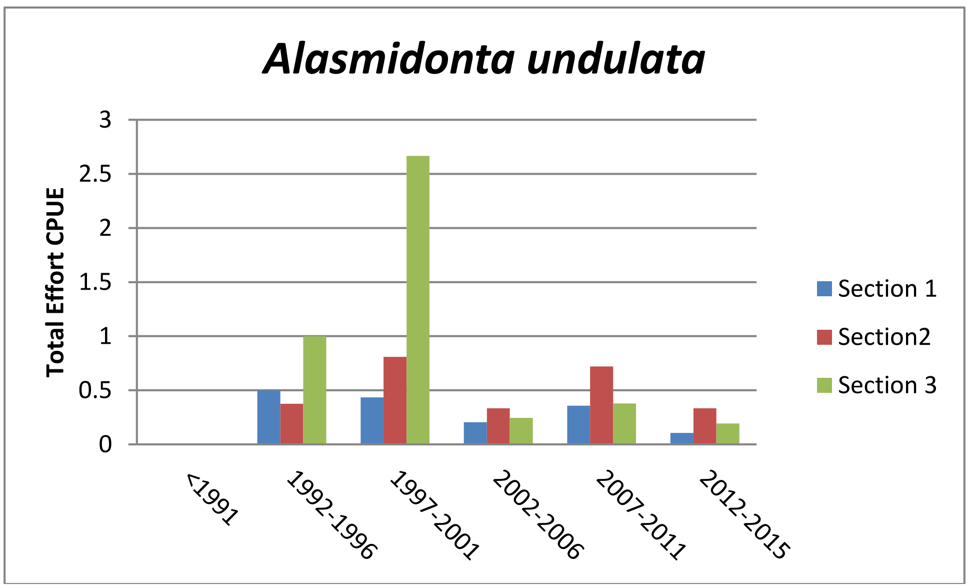


Chart 10. CPUE of Triangle Floater at all survey sites combined within each section, whether the species was detected or not



5.5.1.6. Yellow Lance

The Yellow Lance has been found in all three sections. Both measures of CPUE indicate that at least within Section 2 the Yellow Lance was much more common in the 1992-1996 period than in later years, and that it has become extremely rare since then (Charts 11 and 12).

Chart 11. CPUE of Yellow Lance only at sites where it was detected within each section

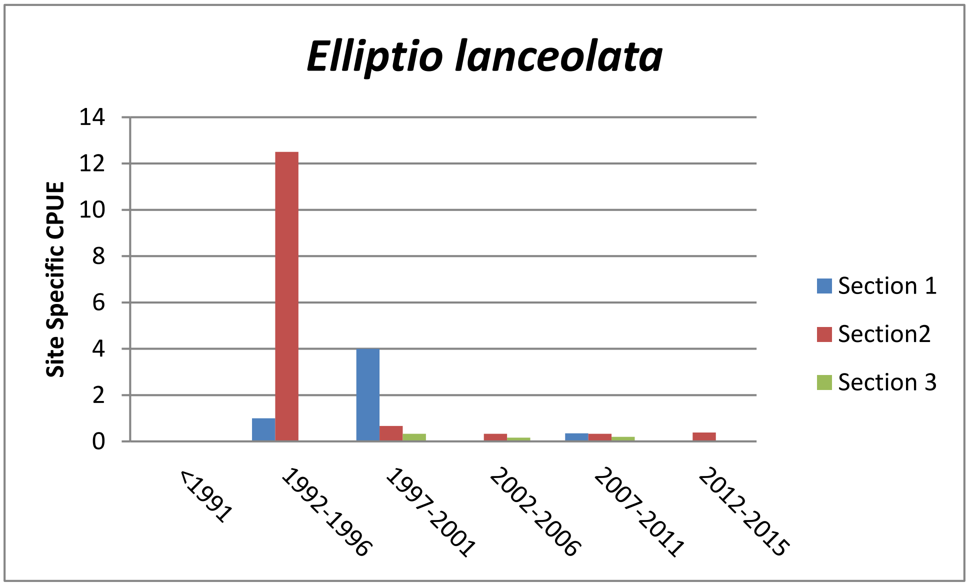
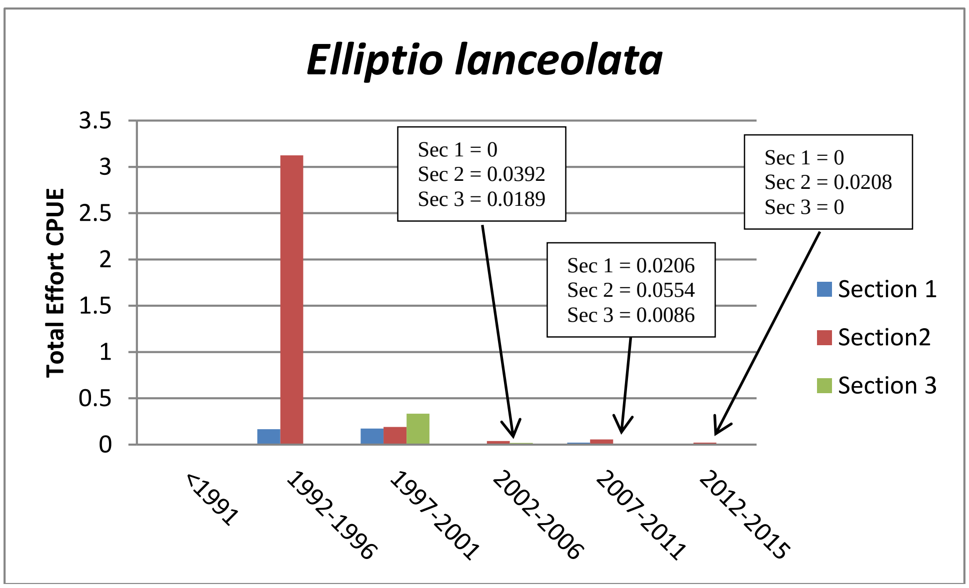


Chart 12. CPUE of Yellow Lance at all survey sites combined within each section, whether the species was detected or not



5.5.1.7. Eastern Lampmussel

The Eastern Lampmussel occurs in all three sections, and the CPUE declined from the 1992-1996 to the 1997-2001 period; however, it has remained fairly consistent since that time (Charts 13 and 14).

Chart 13. CPUE of Eastern Lampmussel only at sites where it was detected within each section

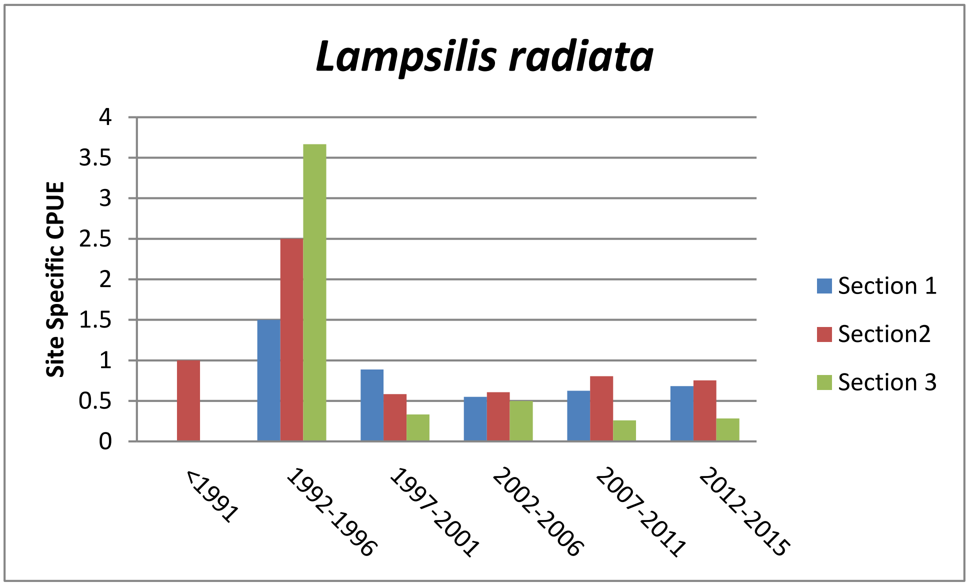
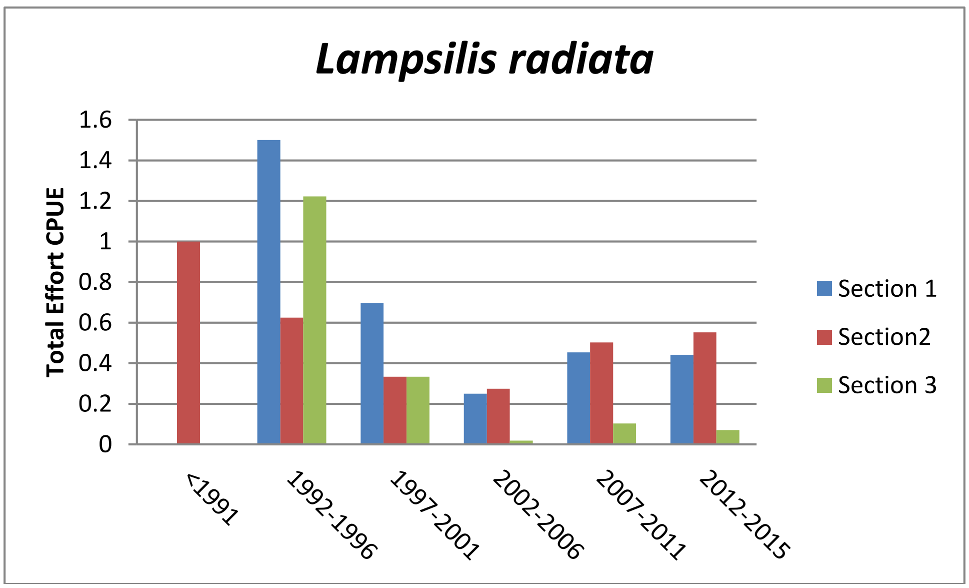


Chart 14. CPUE of Eastern Lampmussel at all survey sites combined within each section, whether the species was detected or not



5.5.1.8. Creeper

The CPUE declined after the 1992-1996 period, and has been consistently low (Site Specific and Total Effort) in all three sections in the last three sampling periods (Charts 15 and 16).

Chart 15. CPUE of Creeper only at sites where it was detected within each section

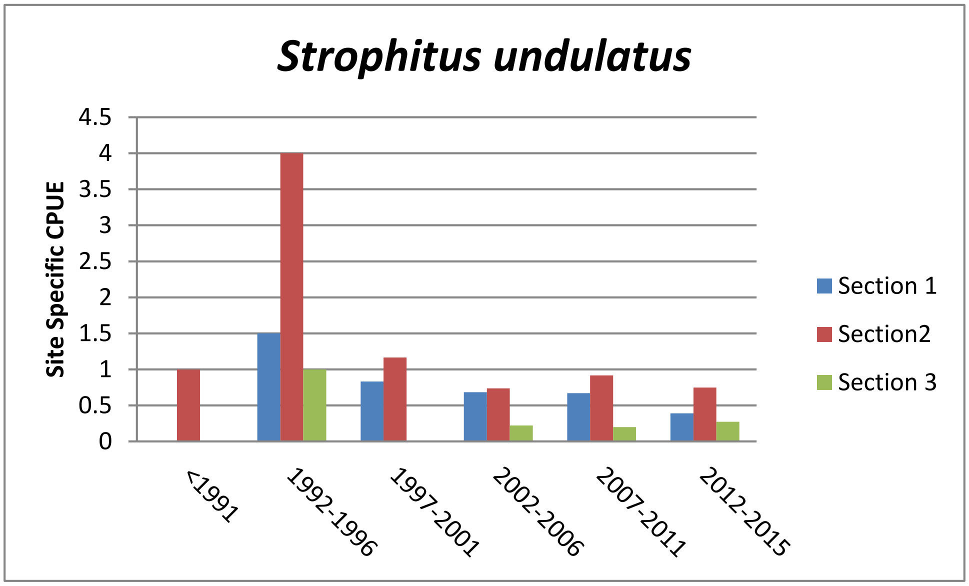
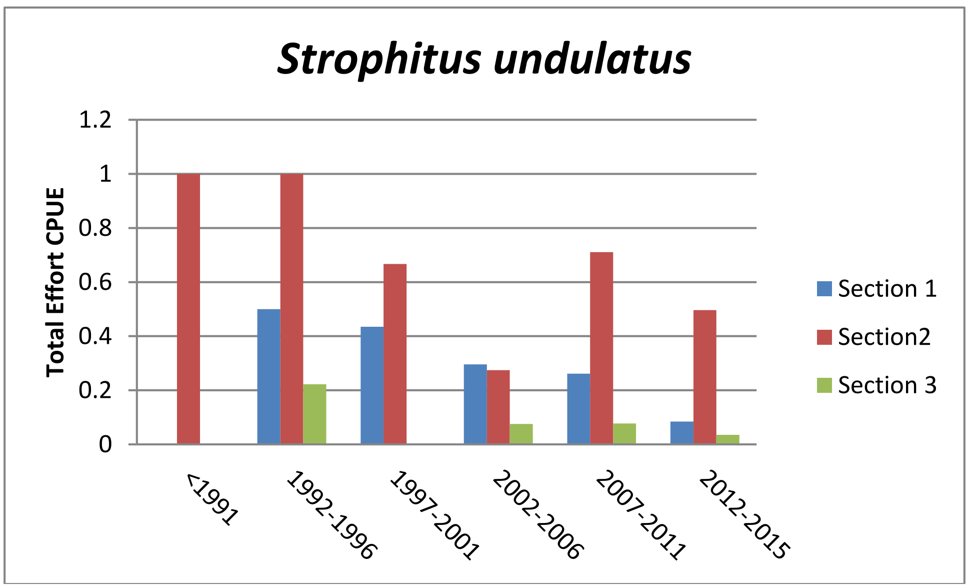


Chart 16. CPUE of Creeper at all survey sites combined within each section, whether the species was detected or not



5.5.1.9. Roanoke Slabshell

The Roanoke Slabshell has been found in all three sections. The highest Site Specific CPUE occurred in the <1991 sampling period; however, trends are very difficult to determine. In 2001, a total of 53 individuals were found at a site in section 3; no search time was recorded for this site resulting in no CPUE being calculated for Chart 17. The CPUE shown in Chart 18 is exaggerated as it does include those 53 mussels but the specific search time was not able to be factored into the Total Effort search time. Despite these flaws within the dataset, a declining trend does seem apparent after the 2002-2006 period. It should be noted however, that the relatively low CPUE for this species compared to other Elliptio species (*Elliptio* spp.), which are all generally easily detected when present (Section 5.7) may somewhat be a reflection of sampling effort, rather than actual rarity as this species typically occurs within the deeper habitats, which are not as easily sampled and are often not targeted.

Chart 17. CPUE of Roanoke Slabshell only at sites where it was detected within each section

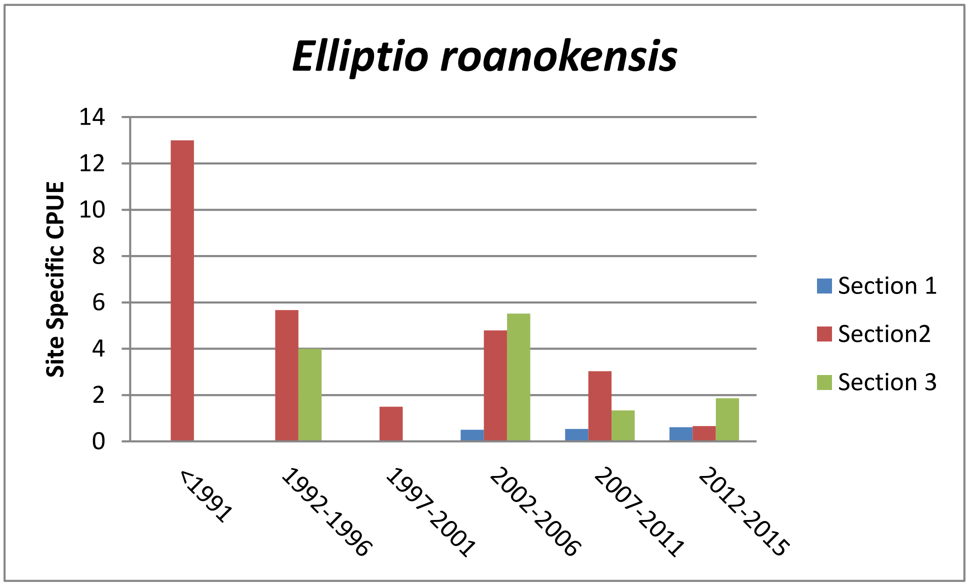
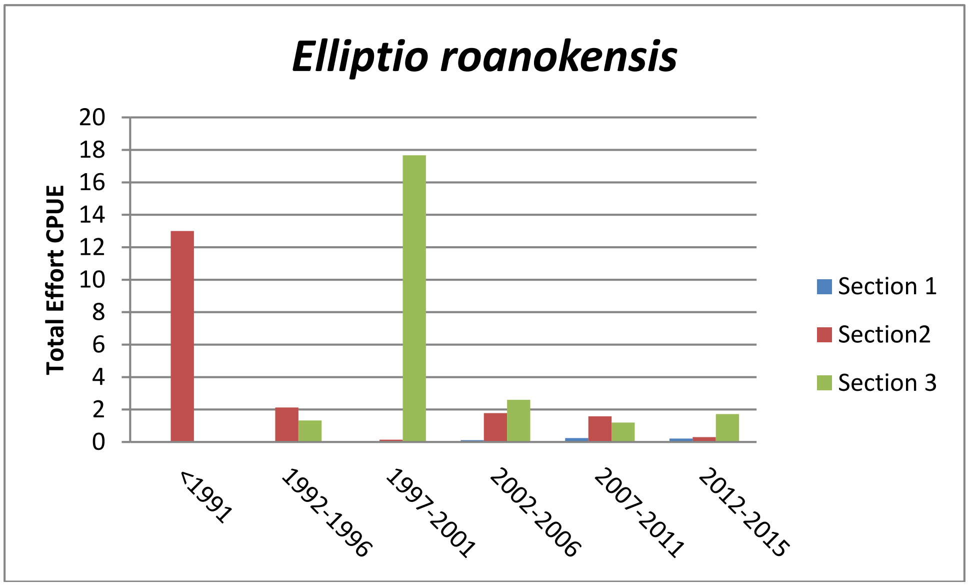


Chart 18. CPUE of Roanoke Slabshell at all survey sites combined within each section, whether the species was detected or not



5.5.1.10. Eastern Floater

The Eastern Floater is a wide-ranging, common species throughout the Southern Atlantic Slope and is considered more tolerant than most mussel species of habitat modification and many forms of pollution (Connecticut Dept. Environmental Protection 2011). This species was not detected in Section 1 of Swift Creek in surveys prior to the third sampling period (1997-2001), where it was found in low numbers in Section 1 (Charts 19 and 20). Since that time it appears this species is expanding its range in Swift Creek, as it was found more consistently in Section 1 and 2 during the fourth (2002-2006) and fifth sampling periods (2007-2011). This increase in range may be indicative of continuing habitat modification in the stream. Trends in CPUE are difficult to determine, as there were also individuals found with no search time recorded.

Chart 19. CPUE of Eastern Floater only at sites where it was detected within each section

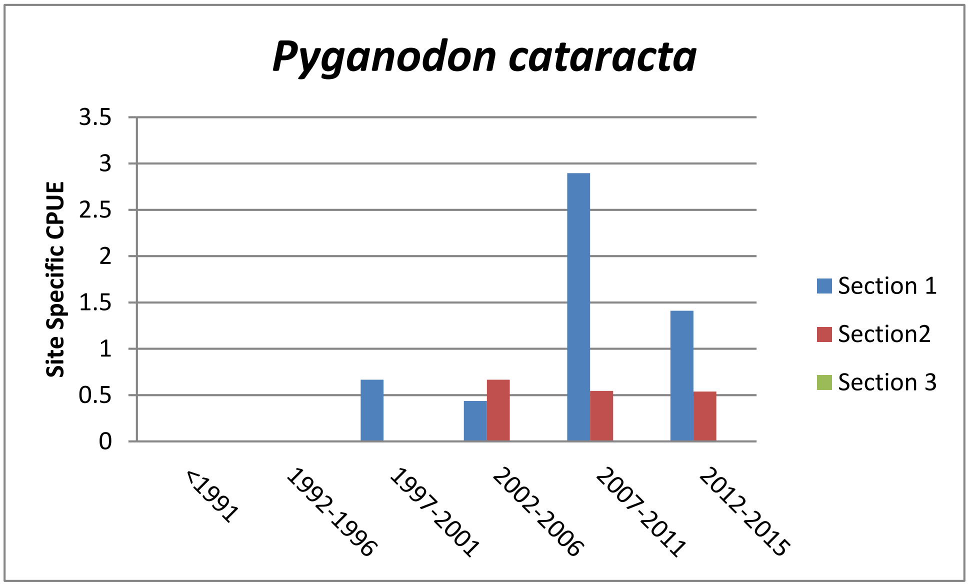
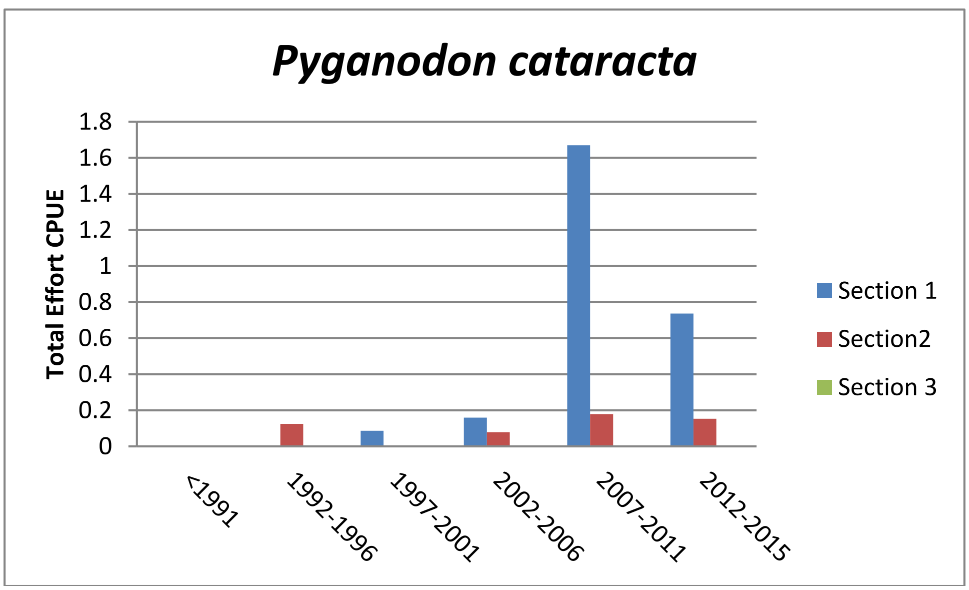


Chart 20. CPUE of Eastern Floater at all survey sites combined within each section, whether the species was detected or not



5.5.1.11. Paper Pondshell

Similar to the Eastern Floater, the Paper Pondshell is a wide-ranging, common species throughout the Southern Atlantic Slope and is considered more tolerant than most mussel species of habitat modification (Williams *et. al* 2008). This species has only been found in Section 1 and 2 of Swift Creek (Charts 21 and 22). It appears that there has been a slight increasing trend in relative abundance of this species in Swift Creek; however, this could easily be a function of sampling effort/bias rather than a reflection of abundance.

Chart 21. CPUE of Paper Pondshell only at sites where it was detected within each section

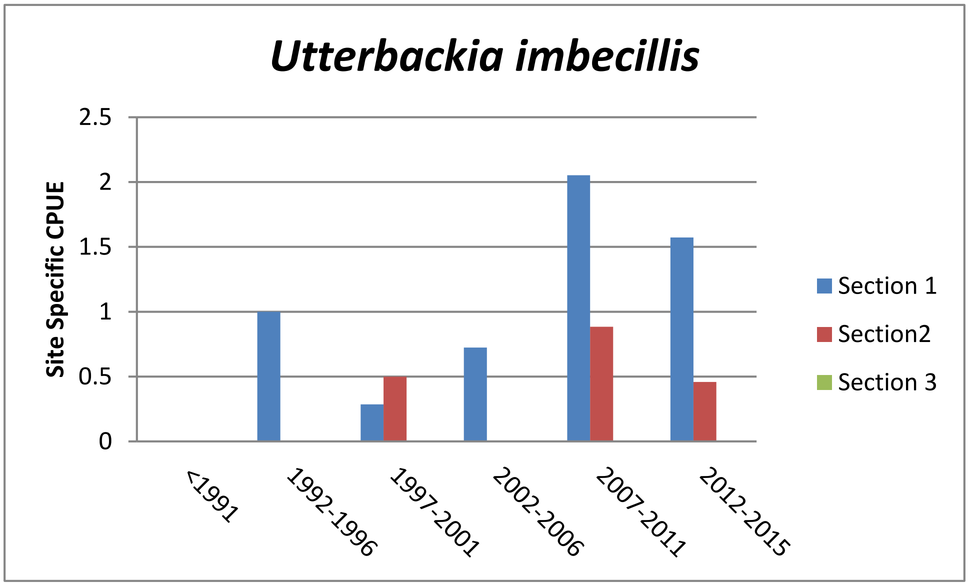
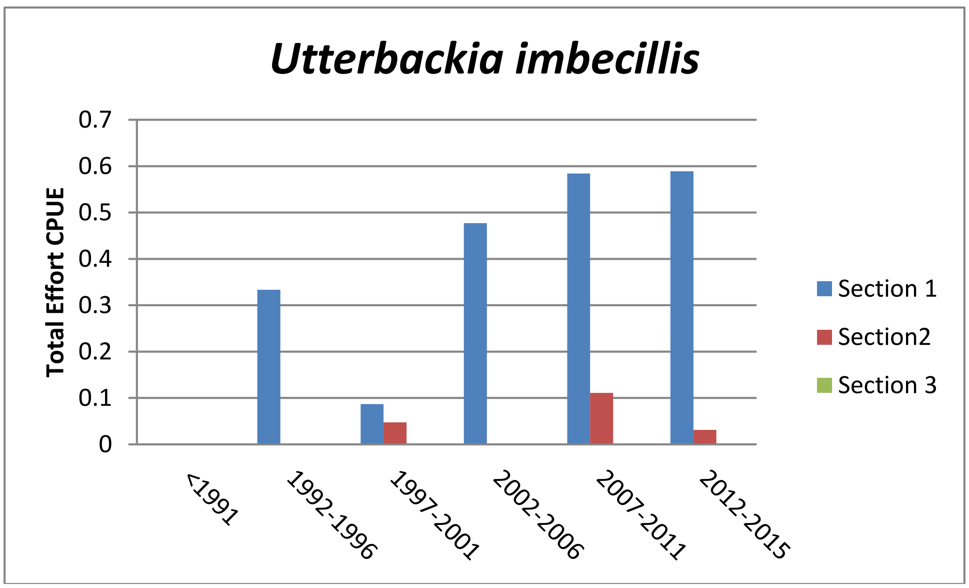


Chart 22. CPUE of Paper Pondshell at all survey sites combined within each section, whether the species was detected or not



5.6.Age Class Distribution Analysis

Healthy mussel populations are usually represented by multiple age classes, as age class diversity is an indicator of reproductive success over time (Grabarkiewicz and Gottgens 2011). Although not a perfect correlation, shell length is often used to estimate age of mussels. Size class data is readily available for sampling periods four, five and six for the following species:

- Dwarf Wedgemussel

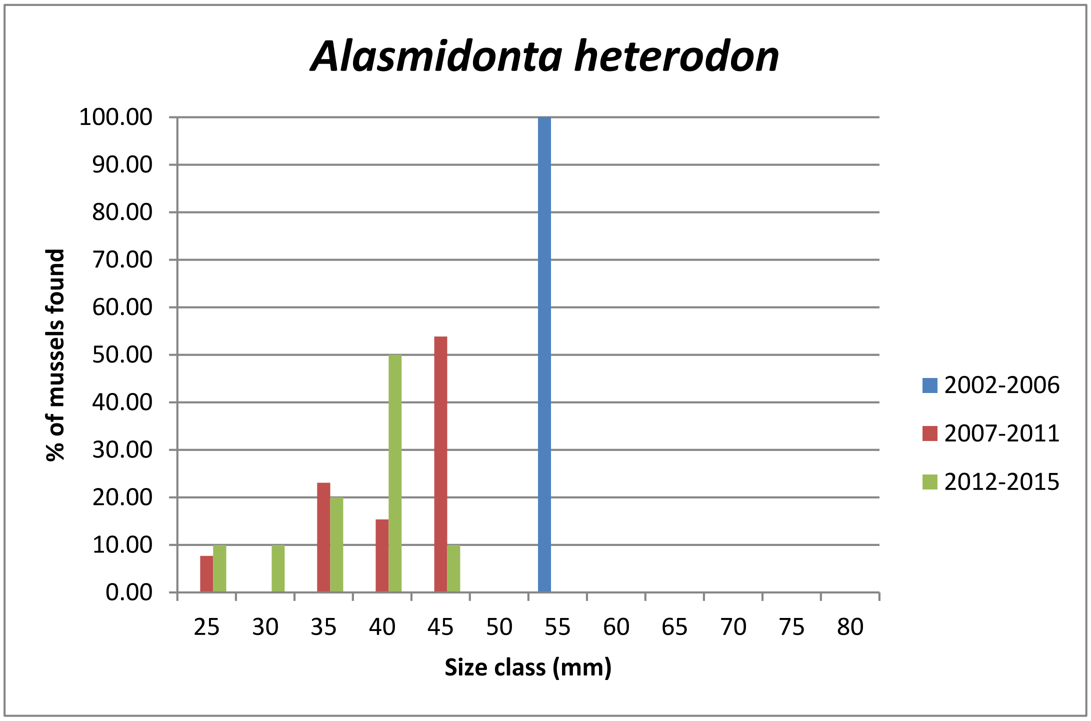
- Triangle Floater
- Yellow Lance
- Atlantic Pigtoe
- Eastern Lampmussel
- Creeper
- Notched Rainbow

This data was compiled and sorted into various size cohorts for each species. Size cohorts for each species were divided by five millimeter increments, with the exception of the Eastern Lampmussel, which was divided into 10 mm increment, as this species attains a large size and grows relatively quickly. While the size cohorts cannot be used to determine exact age of the populations, a population with multiple size cohorts is reflective of a population with multiple age classes. Some size class data also exists for these species for earlier sampling periods, but was not gathered consistently to be used in this analysis. In addition, the DWM, Yellow Lance, and Notched Rainbow were found too infrequently to make any conclusions on age class distribution over time. For example, in the 2002-2006 time period only one individual DWM and one Yellow Lance were found, and thus the population for that time period is represented by only one age class. It should also be noted that smaller individuals are more difficult to detect using the survey methodologies that produced the dataset; thus smaller (younger) size classes are more likely to be underrepresented.

5.6.1. *DWM*

There are three time periods where there is size class data readily available (2002-2006, 2007-2011, 2012-2015); however, only one individual was found during the 2002-2006 survey period, and the other two are represented by 13 and 10 individuals, respectively. Given the small dataset, it is not possible to decipher any trends overtime. Although represented by very few individuals, multiple size classes were observed in the last two sampling periods (Chart 23).

Chart 23. Size Class Distribution of Dwarf Wedgemussel



While determining the exact age of an individual mussel in the field is difficult, age can be estimated by size (total length) and growth rests. Michaelson (1995) determined the age of 43 DWM from the upper Tar River in North Carolina, and then evaluated the range in shell size for each age group (Table 11). For example, 75 % of the individuals in the 13.0-16.9 mm size class were one year old, and 25% were two years old. Aging individuals greater than 37 mm and 6 years old is difficult, as growth rates decline as individuals age (Michaelson 1995).

Table 11. Percent Composition in Age Groups (yr) adapted from Michaelson (1995)

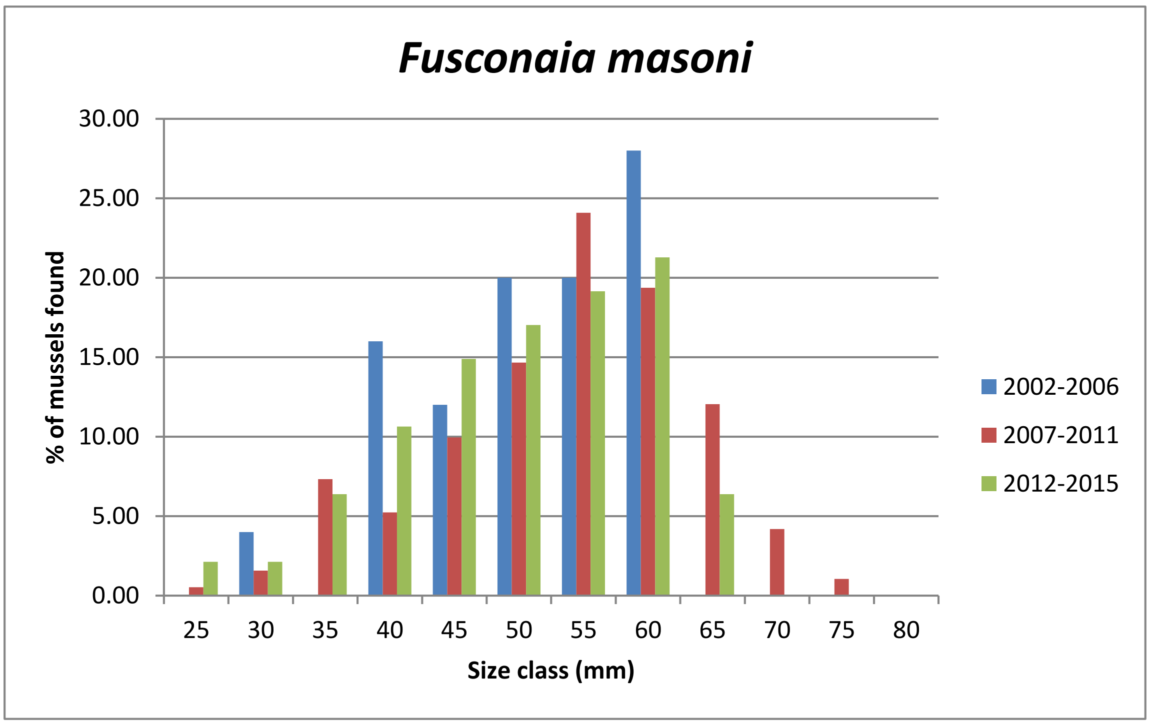
Length (mm)	1 yr	2 yr	3 yr	4 yr	5 yr	6 yr	> 6 yr
9.0-12.9	80	20	~	~	~	~	~
13-.0-16.9	75	25	~	~	~	~	~
17.0-20.9	~	100	~	~	~	~	~
21.0-24.9	~	22	78	~	~	~	~
25.0-28.9	~	~	27	64	9	~	~
29.0-32.9	~	~	~	20	60	20	~
33.0-36.9	~	~	~	~	~	100	~
N =	7	12	10	8	4	2	0

Using these age percentages for size classes, the DWM found in Swift Creek during the most recent sampling period (2012-2015) likely represent at least four age classes, including relatively young (3-4 year old) individuals (Table 11).

5.6.2. *Atlantic Pigtoe*

Comparison of size class distribution for Atlantic Pigtoe for the three time periods indicate that smaller size classes represent a higher percentage of the population in the two most recent sampling periods compared to the first one, suggesting multiple age classes with recent recruitment. If in fact the level of recruitment has increased during the last two time periods an increasing trend in relative abundance would be expected. However, the CPUE was fairly similar between these three time periods (Chart 2, Section 5.5.1.2), thus it is unclear if the rise in smaller size class individuals will result in increased population numbers.

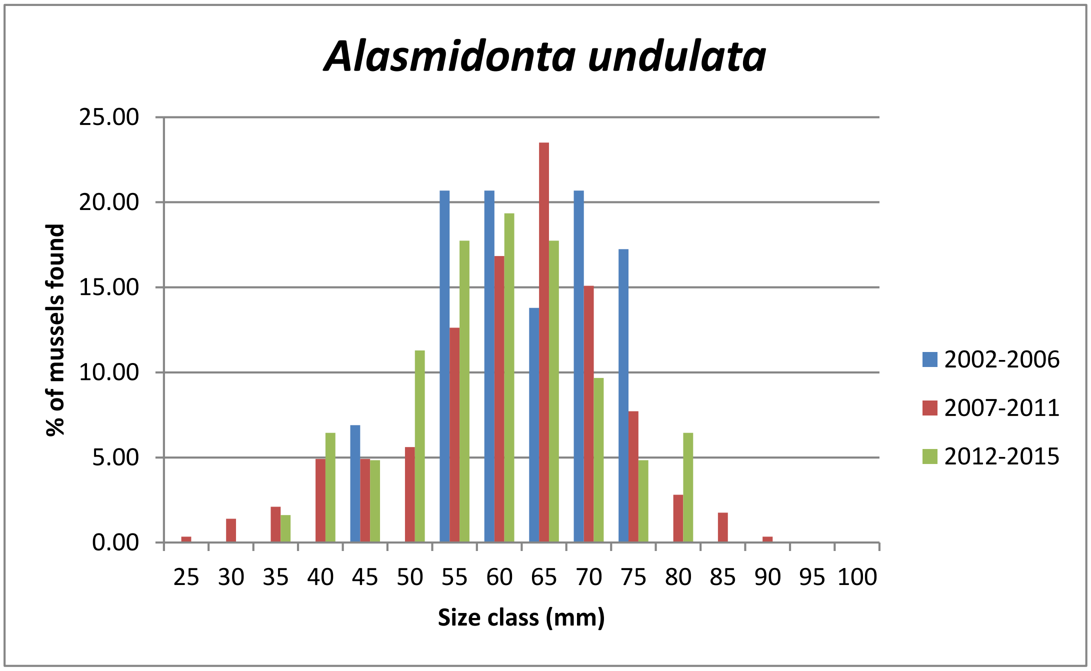
Chart 24. Size Class Distribution of Atlantic Pigtoe



5.6.3. *Triangle Floater*

Like with the Atlantic Pigtoe, similar trends are apparent in that the population is currently represented by multiple size classes and higher percentage of smaller ($\leq$ 50 mm) individuals were found in the second and third sampling period compared to the first (Chart 14), also suggesting multiple age classes with recent recruitment.

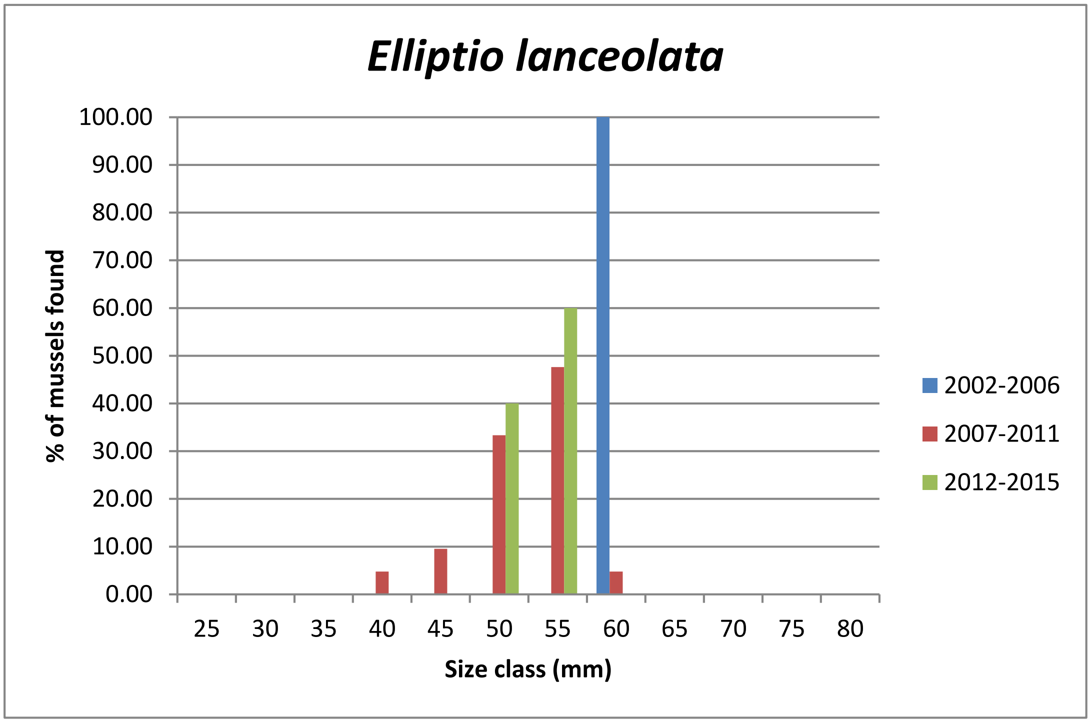
Chart 25. Size Class Distribution of Triangle Floater



5.6.4. *Yellow Lance*

While there are a number of size classes present, the Yellow Lance population is represented by very few individuals (one in the 2002-2006 period), thus it is difficult to make any conclusions regarding age class distribution (Chart 15).

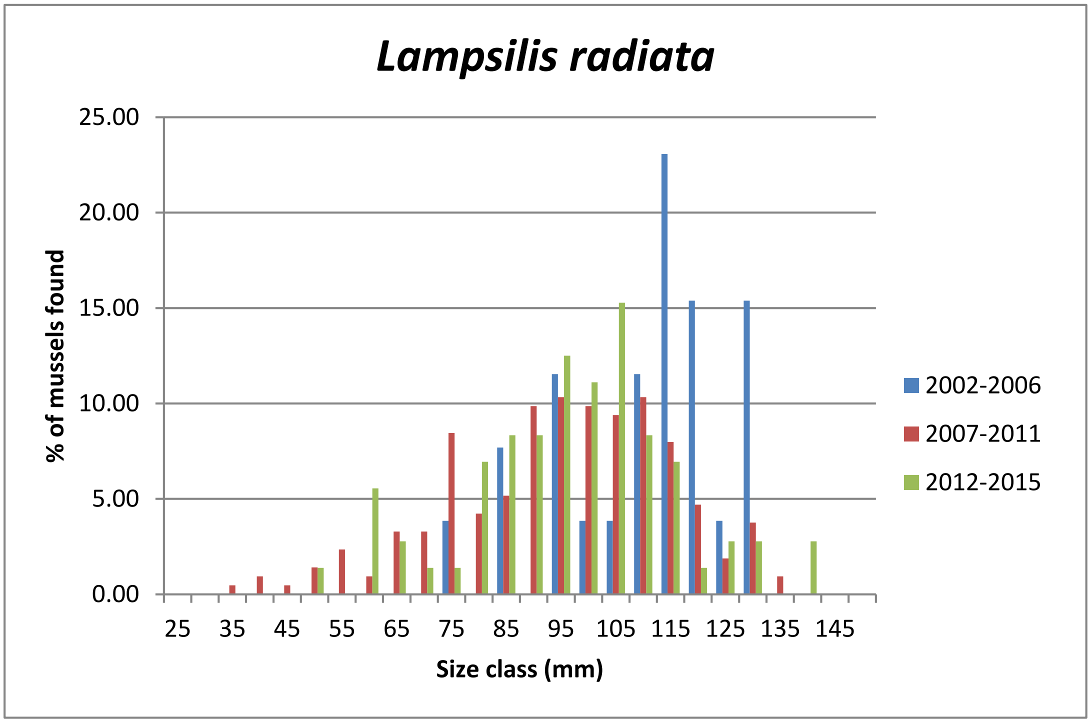
Chart 26. Size Class Distribution of Yellow Lance



5.6.5. *Eastern Lampmussel*

The Eastern Lampmussel population appeared to be represented by a higher number of large (older) individuals in the 2002-2006 period compared with the following two periods (Chart 16), again suggesting a trend towards a population with a more even distribution of age classes with indication of recent recruitment.

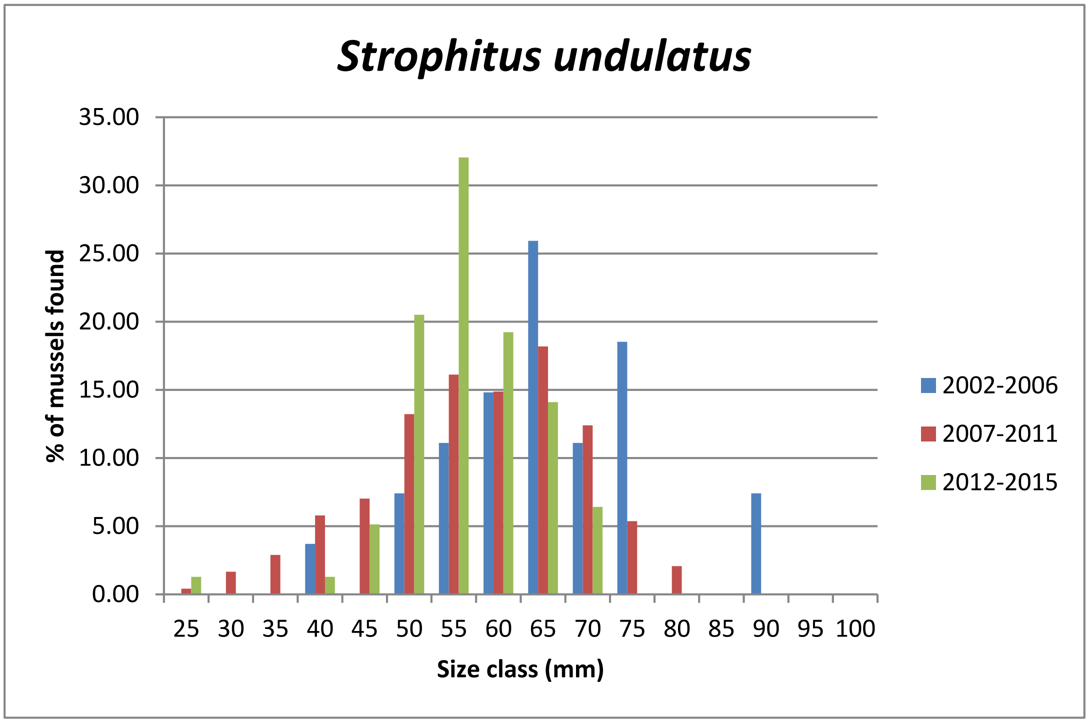
Chart 27. Size Class Distribution of Eastern Lampmussel



5.6.6. *Creeper*

Like the Eastern Lampmussel, the Creeper population appeared to be represented by a higher number of large (older) individuals in the 2002-2006 period compared with the following two periods (Chart 17), again suggesting trend towards a population with a more even distribution of age classes with indication of recent recruitment.

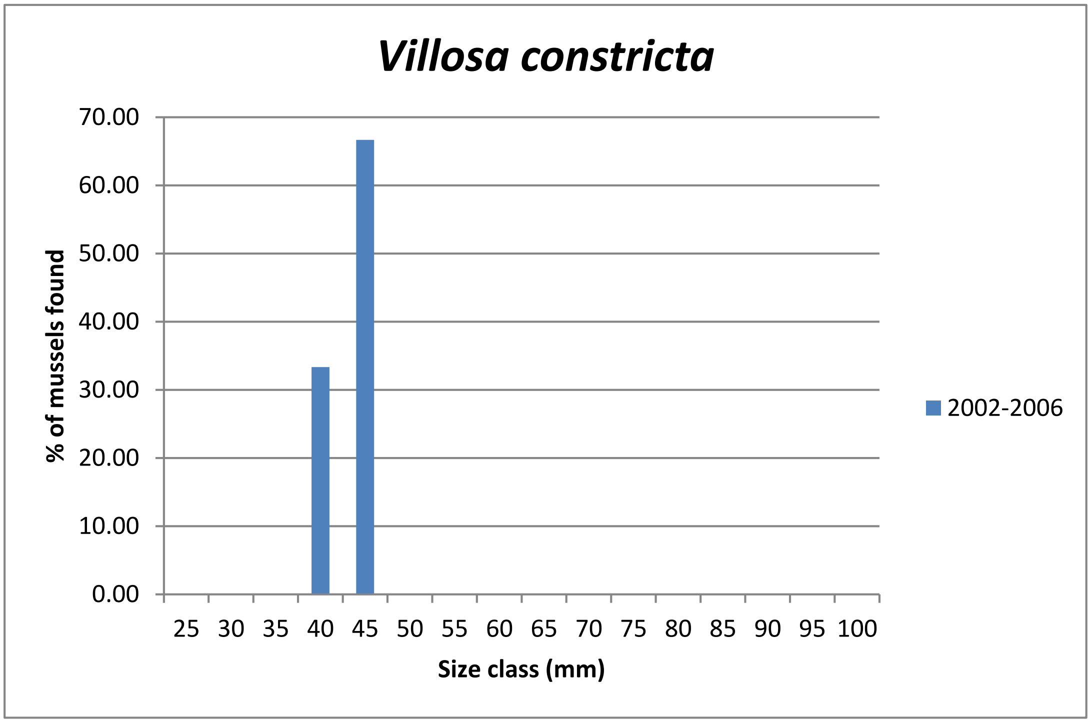
Chart 28. Size Class Distribution of Creeper



5.6.7. *Notched Rainbow*

The Notched Rainbow population is represented by only three individuals, and only within one time period (Chart 18), thus it is difficult to make any conclusions regarding age class distribution.

Chart 29. Size Class Distribution of Notched Rainbow



5.7. Mussel Detection Probability Analysis

One concern with making population trend conclusions for cryptic species like freshwater mussels is their inherent difficulty of being detected. The ability to detect a particular species during a mussel survey is dependent on a variety of factors including surveyor experience, survey conditions, and survey design, as well as particular biological traits of the particular species, including size, habitat preferences, and behavioral attributes such as vertical (burrowing up and down in the substrate), and horizontal (moving across the substrate) movement. Larger sized species such as the Elliptio mussels are typically easier to detect than very small species like the DWM. Detectability is further compounded for the DWM, as Deep Stream Margin Roots, one of the in-stream microhabitats identified as primarily supporting this species in Swift Creek (Entrix 2005), are very difficult to sample. As such, population size estimates for species that are difficult to detect may be underestimated because of this attribute.

Understanding the detection probability for a species is crucial in determining population size and viability. As discussed in Section 5.3, the DWM has consistently been detected in Swift Creek in low numbers since 1991. The fact that the species has persisted in the creek for well over 20 years, despite relatively few individuals ever being recorded, coupled with evidence of reproduction (presence of gravid individuals) and recruitment (small size classes present), there is a potential that the DWM has been under-detected in Swift Creek.

To account for the imperfect detection of the DWM and other mussel species, a sampling design was developed and implemented in 2012 where mussel surveys were conducted at nine sites: three currently occupied sites, three formerly occupied sites and three randomly selected sites. Each site was then re-surveyed in the same season using similar methodologies and under similar conditions. The results of these surveys are provided in Appendix H.

Detection probabilities for each species occurring at the nine sites were then developed using the statistical program PRESENCE version 5.9 (Hines 2006). PRESENCE is software that has been developed primarily to fit occupancy models to detection/non-detection data. Two models were evaluated for 13 different mussel species:

- Group 1: constant P: species at all sites/samples are detected with a single probability, P
- Group 2: survey-specific P: survey-specific detection probability at all sites, P(1)=detection probability for 1st survey, P(2)=detection probability for 2nd survey, etc.

The results of this analysis demonstrate the varying levels of detection between species. For instance, with both models the probability that *Elliptio complanata* and *E. icterina* occur at a site is 100%, with 100% detection probability. The Yellow Lance (*E. lanceolata*) on the other hand has a high detection probability (100% with both models) as well; however, there is a low probability (11% both models) that it is present. Whereas with the DWM, the probability that it occurs at a site is 44% with a 50% detection probability with one model, and a 33% presence probability with a range of detection probability from 33% to 100% with the second model. The occupancy and detection probabilities for each species are shown in Table 12.

Table 12. Detection Probabilities by Species

	Group 1: Constant P			Group 2: Survey Specific P		
Species	**Psi ***	**P** site 1**	**P** site 2**	**Psi ***	**P** site 1**	**P** site 2**
A. heterodon	0.4444	0.5000	0.5000	0.3333	1.0000	0.3333
A. undulata	0.6944	0.8000	0.8000	0.6667	1.0000	0.6667
E. complanata	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
E. congarea	0.9389	0.7692	0.7692	0.8889	1.0000	0.6250
E. icterina	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
E. lanceolata	0.1111	1.0000	1.0000	0.1111	1.0000	1.0000
E. roanokensis	1.0000	0.5000	0.5000	1.0000	0.5556	0.4444
E. sp cf mediocris	0.9259	0.6000	0.6000	0.9259	0.6000	0.6000
E. sp cf producta	1.0000	0.1111	0.1111	1.0000	0.1111	0.1111
F. masoni	0.8000	0.8333	0.8333	0.8000	0.8333	0.8333
L. radiate	0.9074	0.8571	0.8571	0.9074	0.8571	0.8571
P. cataracta	0.4444	0.5000	0.5000	0.3333	1.0000	0.3333
S. undulatus	0.9074	0.8571	0.8571	0.8889	0.75000	1.0000

* Psi = probability that species is present, ** P = probability that species will be detected

A larger number of sampling locations, with surveys conducted over multiple seasons would likely result in more precise detection probabilities for each species; however, this component of the study was not continued into the Phase 2 portion of the study, as the objective was met to demonstrate that the DWM has a relatively low detection rate and may often go undetected during a one-time survey.

5.8.Population Trends Summary

With the exception of the Eastern Floater and Paper Pondshell, which are considered tolerant of habitat degradation, the relative abundance (CPUE) of all other mussel species in Swift Creek has declined since the mid 1990's. As discussed in Section 5.1, there are imperfections with the Swift Creek mussel survey dataset in that it does not account for variables such as surveyor experience, survey design, survey effort, survey conditions and seasonal variations, all of which factor into the effectiveness of a survey. Additionally, as shown in Table 10 in Section 5.5.1, there has been a disproportionately greater amount of survey time spent in Swift Creek in the last three sampling periods compared with the previous three.

While these inherent flaws undoubtedly contribute to some of the differences in relative abundances over time, it is apparent that population levels have declined to some degree. Variability in survey methodologies may be more important in explaining CPUE differences of small sized species, which in Swift Creek tend to also be rare. The variability is less likely to be a factor when evaluating trends with larger sized species like the Elliptio mussels which, as shown in Table 12 have a high detection probability (100%), and also tend be habitat generalists. While still very common in Swift Creek, the measure of relative abundance (CPUE) of Elliptio mussels declined dramatically since the 1990's. This decline continued into the early 2000's, but seems to have leveled off in recent years.

Another species that is in obvious decline in Swift Creek is the Yellow Lance. While never abundant in Swift Creek, a Site Specific CPUE of greater than 12 /hr was recorded in Section 2 in the 1992-1996 time period. The CPUE has been < 0.5/hr in the last three sampling periods. Given the fact that the species has a high (100%) detection probability (Table 12), the current low CPUE can be attributed to increasing rarity. This is further supported by the low occupancy probability (11%) shown in Table 12. Additionally, it was not found during the 2015 surveys conducted for this study and has yet to be found during the on-going surveys being conducted for the Dempsey Benton project, suggesting the species is very near extirpation from Swift Creek.

The detection probability analysis suggests that DWM may be under detected in Swift Creek. While this may be true, it is still one of the rarest species occurring in the stream, which is reflected in the very low CPUE.

It is apparent that overall mussel populations have declined in Swift Creek over the 24 year period; however, the decline appears to have leveled off. Additionally, there are some indications of positive trends in the most recent years, particularly with some of the "sensitive" species, including Atlantic Pigtoe, Triangle Floater, Eastern Lampmussel, and Creeper. The CPUE for these species were very similar between the last three sampling periods, indicating the decline has subsided. Additionally, based on size class analysis the populations of these species seem to be represented by a greater level of size class distribution in the two most recent sampling periods compared to the previous one. This suggests recent recruitment, which if it continues will likely correlate to increased CPUE, as individuals grow and become more easily detected. A longer dataset with regards to size class is needed to determine if this is an actual trend.

As alluded to in Section 4.3 it is unclear if the various conservation/protection measures that have been implemented in the SCW have been in place for a long enough period of time to determine if they are having a positive effect on the freshwater mussel populations. It has been reported that recovery of mussel populations into areas where they have been eliminated can take many years to occur if it occurs at all (Waters 2000, Sietman et al. 2001). However, in most of these cases it appeared the lack of sufficient mussel refugia to serve as a seed source to allow for re-colonization is what inhibited re-colonization. Given the slow nature of mussel population recovery, it is possible that mussel populations are slow to respond to improving conditions. Fraley and Simmons (2004) reported a slow but steady range expansion of the Appalachian Elktoe (*Alasmidonta raveneliana*) another federally listed mussel species in the Nolichucky River system and suggested it was in response to improving water quality conditions associated with the enactment of the Clean Water Act in 1972.

6.0 IN-STREAM HABITAT VIABILITY IN SWIFT CREEK

The NC DWM Work Group identified "unsuitable physical habitat" as the most important threat to the Swift Creek population (Smith et al. 2014). Thus, the continued persistence of the DWM in Swift Creek will be largely dependent on the suitability of future habitat conditions. To evaluate this, various habitat parameters including water quantity, channel stability, and substrate composition were considered.

6.1. Stream Flow (Hydrograph Analysis)

The effects of extended drought on freshwater mussels were discussed in Section 2.3.4. As part of this component of the study, stream flow data from two USGS gauging stations were analyzed over the entire period of record to assess current and historic water quantity conditions (Figure 5). Only one gauging station currently exists on Swift Creek below Lake Benson that records discharge. It is at SR 1555 near Clayton (208773375) and has been in operation from 2008 to the present. There is a gauge on Middle Creek (02088000) at NC-50 near Clayton that has discharge records from 1939 to present. Though Middle Creek is not within the Lower SCW, the two watersheds are directly adjacent to one another and contribute to the larger Swift Creek watershed. Therefore, the gauge on Middle Creek is used here as a surrogate indicator for long term hydrograph data of the SCW.

Two drought indicator thresholds were evaluated;

1. More than one consecutive day at or below 1 cfs
2. More than one consecutive day at or below 5 cfs

For each gauge, the number of times (periods) either of the above two drought indicator thresholds was met, it was noted in Table 13 (see Appendix G for complete data table). For example in the 1980-1989 time period at the Middle Creek gauge, there were 20 different times (periods) when the flow was at or below 1 cfs for more than one consecutive day, with a total of 224 days below 1 cfs.

The data from the Swift Creek SR 1555 gauge demonstrates that the stream has experienced periodic episodes of low flow throughout the period of record. However, the relatively short period of record does not allow for extensive analysis of flow conditions in the lower portion of Swift Creek. The data from Middle Creek is much more extensive. The Lower SCW and Middle Creek watersheds can be assumed to have similar precipitation levels and land use, as headwaters of both streams are within the jurisdictions of Raleigh suburban towns, such as Apex, Cary and Garner. Middle Creek has also experienced periodic episodes of low flow, and sometimes extremely low flows, the most notable occurring in the summers of 1954 and 1986, which lasted more than 35 days.

Table 13. Periods of Extreme Low Flows: Swift Creek and Middle Creek

	Swift Creek at SR 1555 near Clayton (208773375)		Middle Creek at NC-50 near Clayton (02088000)	
	Number of Periods of Threshold Events (Total Number of Days)		Number of Periods of Threshold Events (Total Number of Days)	
Year Range	**at or Below 1cfs**	**at or Below 5cfs**	**at or Below 1cfs**	**at or Below 5cfs**
1940-1949	~	~	0	16 (93)
1950-1959	~	~	4 (55)	22 (251)
1960-1969	~	~	2 (27)	3 (90)
1970-1979	~	~	2 (26)	28 (222)
1980-1989	~	~	20 (224)	54 (696)
1990-1999	~	~	1 (3)	6 (41)
2000-2009	0	1 (4)	0	1 (1)
2010-2013	0	5 (14)	0	0
2014-2015	0	0	0	0

~ - Gauge was installed in 2009 – no previous data available

While there was also a gauge in the Lower SCW at NC-42 that operated between 1988 and 1997; unlike the other gauges, which collected the average daily flow rates, the NC 42 gauge only collected a single flow measurement during 28 different days during the eight year period. As such, this dataset is too limited to be used in this analysis.

6.1.1. *Stream Flow Summary*

As discussed in Section 2.3.4.3, the geology of the SCW makes it inherently susceptible to extended low flow periods, particularly in the upper portions. The stream flow data confirms the propensity for extended periods of low flow. The fact that the Swift Creek gauge had 14 days of consistently low flows in just the last four years suggests that Swift Creek has not had as consistent flows as Middle Creek, as no drought indicator thresholds were reached at the Middle Creek gauge during the last four years..

The tiered minimum flow releases guaranteed from Lake Benson provide a level of protection against extreme low flows that did not exist previously. Further analysis is needed to understand if these minimum flow guarantees are sufficient to maintain the DWM population.

6.2.Current and Historic Channel Stability

Aerial photos of the Study Area were obtained from NCDOT's Photogrammetry Unit, and analyzed to determine general channel course stability and adjacent land use during the time period available (1969 to 2010). It is important to note that complete aerial coverage of the Study Area is not available for any given year. The same three sections used in the viability component of this study were used here (Figure 12):

- Section 1 – Lake Benson to I-40

- Section 2 – I-40 to Barber Mill
- Section 3 – Barber Mill to Neuse River.

During the time period analyzed, there was no major channel migration observed. However, below the NC 42 crossing, the main channel is braided into two distinct smaller channels (east and west). According to the landowner, prior to the early 1990's the west channel carried the majority of flow, and the east channel had flow only during high flow periods (Henry Ford landowner, personal communication). Since that time, the majority of flow has been concentrated in the east channel, and the west channel consists of stagnant, deep scour pools, and very shallow sand bar dominated areas with very little flow. This is further supported by mussel survey data from that time period. In fact, the DWM was recorded at a site in the west channel in 1994; however, it was not located in 2011 or 2012 and, based on current habitat conditions (stagnant pool), that site is no longer considered to be occupied. There is a buried gas line with a ford crossing made of cinderblocks on the east channel that is significantly perched to a point that is likely a barrier to upstream migration of fish (Photo 3).

Photo 2. Perched Utility Crossing in East Braid of Swift Creek below NC 42

Examination of the aerial photography also provides a visual depiction of the conversion of land use that occurred within the Study Area in recent years. Some of the major land conversion events are noted for each of the sections.

Section 1: Between 1971 and 1986, sections of the I-40 corridor were cleared of vegetation. Between 1971 and 1991, square retention ponds off Wren Road were constructed as were the spray fields near New Bethel Church Road. Between 1986 and 1991 the Indian Creek Overlook neighborhood, which had a small domestic WWTP (recently decommissioned), was built. Between 1997 and 2010 the Southern Trace Neighborhood was built near the NC-50 and Benson Road intersection, southeast of the Ten-Ten Road intersection.

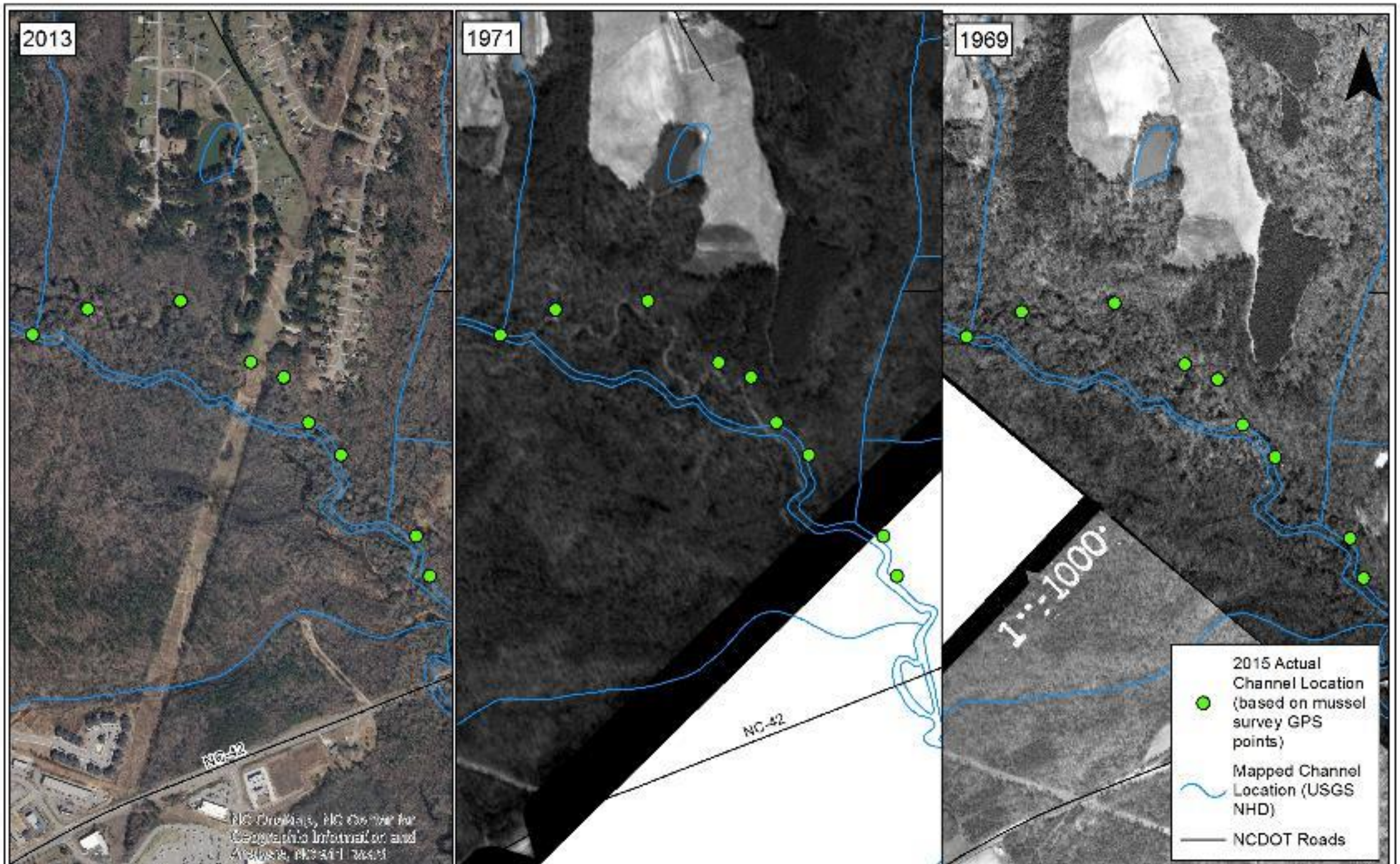
Section 2: In 1985, construction of the I-40/NC-42 intersection had begun and was completed by 1991. Between 1985 and 1997, an increase in development of the I-40/NC-42 interchange was evident (Photo 3). Between 1997 and 2010, a bigger pond was added at the end of Zachary Way (SR 2060), which is west of Cornwallis Road and south of Swift Creek. There was also a new area of houses on Cornwallis Road opposite of this pond site, and south of Swift Creek off Josephine Road (SR 1526).

Photo 3. I-40/NC 42 interchange: 1985 on the left and 2012 on the right.

Section 3: Between 1969 and 1991 the Johnston County Airport was constructed. Also during that time, a new area of houses was constructed at Norris Road and Sterling Drive, which is north of Swift Creek. Between 1991 and 1994, the Johnston County Airport runway was expanded. Between 1994 and 2010, there were several developments in this section. A new area of houses was constructed south of Swift Creek at Cleveland Road (SR 1010) and Wood Creek Lane near Monroe Road (SR 1513). A new pond was constructed at the end of Casey Road northeast of Swift Creek near the intersection of Little Church Road (SR 1563). Lastly, a new area of houses was built at Clayton Pointe Drive (SR 3174) and Rock Pillar Road (SR 1572).

6.2.1. *Channel Stability Summary*

While there is no definitive evidence that large scale channel migration and instability has occurred in the Study Area, an error in the USGS 7.5 minute topographic map depicting the Swift Creek channel was discovered. An approximately 0.5 mile stretch of Swift Creek above NC 42 is incorrectly mapped on the USGS map. At the furthest point the actual channel is close to 600 feet to the north of where it was mapped. A power line crossing that was put in sometime between 1971 and 1986 occurs right in the middle of this section. When this discrepancy was discovered it was speculated that the channel was relocated during the construction of the power line. However, examination of aerial photographs does not support this. Figure 14 clearly shows that in 1969 and 1971 the channel was basically in the location where it currently is. The Johnston County Soils Survey published in 1994 also depicts the channel it its current location (USDA 1994). The USGS map was created in 1973; however, it is unclear when the data used to create the map were generated; thus it is possible that the channel had migrated to the north



The Catena Group

Client:

Dwarf Wedgemussel Viability Study: Phase 2

Swift Creek Channel Mapping Discrepancy

Wake & Johnston Counties, North Carolina

Date: September 2015

Scale: 0 295 590 Feet

Job No.: 1175

Figure 14

sometime before 1969. It is very unlikely that the channel was intentionally moved, as channel relocation practices during this time frame generally did not incorporate the level of sinuosity that the existing channel contains. This error was reported to USGS the National Hydrography Dataset (NHD) Partner Support Regional Point of Contact.

There is some indication that smaller scale channel migration may have occurred. These small scale changes would not be evident using aerial photography. However, the aerial photo analysis clearly demonstrates the urbanization of the Lower SCW. The effects of urbanization on in-stream channel stability are described in Section 2.3.4.

6.3.In-stream DWM Habitat Assessment Analysis

Throughout its range, the DWM has been reported from a wide variety of habitats (from small streams to large rivers) and substrates (sand and gravel to muddy sand and clay) (USFWS 1993). Two general in-stream habitat types, Shallow Fast Coarse (SFC) or Deep Stream Margin Roots (DSMR) habitats were identified as primarily supporting this species in Swift Creek (Entrix 2005). As part of the Phase I Study, a Habitat Assessment within Swift Creek was performed to further understand the habitat requirements of DWM in Swift Creek. The geomorphology analysis component addressed then current habitat conditions in Swift Creek and its ability to continue to support the DWM. The habitat assessment was performed at nine sites within Swift Creek in 2012: three sites previously occupied (PO) by DWM, three sites considered currently occupied (CO) at that time, and three randomly selected (RS) sites (two of which supported DWM). Various habitat attributes were evaluated and quantified in the first phase of this study (Phase 1) and preliminary conclusions were drawn on what physical attributes are important habitat components for DWM in Swift Creek (Catena 2013). The results revealed a correlation in DWM presence and substrate particle size.

This analysis was expanded for the second phase of this study (Phase 2). The nine original sites were resurveyed, and nine additional sites were selected to be considered as potential augmentation (PA) sites based on the habitat attribute results of the Phase 1 habitat analysis. The nine PA sites were established mostly in an approximately 11 mile stretch of Swift Creek from Cornwallis Road to Steel Bridge Road.

Mussel and habitat surveys were conducted in 2015 within a 200 foot section at all 18 sites (PO, CO, RS, and PA). The assessment consisted of timed mussel surveys, stream cross sectional profiles, particle size distribution analyses, bank erosion hazard index (BEHI) analysis, streambed scour analysis, and qualitative analyses accompanied by photo documentation for each site. The report, Complete 540 – Triangle Expressway Dwarf Wedgemussel Habitat Assessment Survey Report – Phase 2 (Three Oaks Engineering/Catena 2015c), is Appended (I).

6.3.1. *Geomorphology Study Results*

Throughout all of the survey sites, Swift Creek is a low gradient, meandering, point-bar, riffle/pool dominated stream type that has alluvial channels within broad well defined floodplains. The CO sites are located between NC 42 and Barber Mill Road (SR 1555) while the PO sites are located from just above the Wake/Johnston County line downstream to approximately 0.3 mile below NC 42. The PA sites were established downstream of the CO and PO sites, with the exception of PA-9, which is located upstream of all of the CO and RS sites except one CO-1 (Figure 1 in Three Oaks Engineering/Catena 2015c (Appendix J)). The drainage area, wetted width, bankfull width, bankfull width/depth ratio, and bankfull cross sectional area are generally greater in the CO sites and PA sites than in the PO sites.

6.3.1.1 CO Sites

As was the case for the CO sites during Phase 1, mussel survey results from Phase 2 yielded some of the higher catch per unit efforts (CPUE) from these sites (53.7-116.0 mussels/hr) as well as species diversity ranging from 6-8 species per site. However, when comparing the results of the Phase 2 mussel surveys with those conducted for Phase 1, CPUE and species diversity were generally lower than mussel survey results from Phase 1 (Table 2 and Table 3 in Three Oaks Engineering/Catena 2015c (Appendix J)).

The habitat conditions at these sites have generally degraded since the Phase 1 surveys were conducted. CO-1 in particular, where mussel abundance and diversity was most notably reduced since Phase 1, is higher in the watershed and close to the development near the intersection of I-40 and NC-42. The major causes of change in habitat conditions at the CO-1 site appear to be associated with bank failure and a large tree that has fallen into the channel. As a result, there has been an increase in ponded areas, increased bank erosion, and the creation of a detritus/woody debris trap over the exact locations where DWM individuals had been found in previous years. DWM was not found at this site during the 2015 surveys. Two different DWM individuals were found at the CO-2 site, one while during surveys associated with this project, and the other while surveying for the Dempsey Benton project.

6.3.1.2 PO Sites

These sites consist of a deeper run/pool complex with a dominant shifting sand substrate. The channel banks are unstable and steep in areas throughout these reaches. Further indicators of an unstable channel, such as excess woody debris and detritus and mid-channel bar formations, were also evident. DWM was previously known from these locations, but has not been observed in several years during subsequent surveys. While habitat attributes were not quantitatively measured during the previous surveys when the DWM was recorded at each of these three sites, in each instance they were described as riffle/run habitats with heterogeneous substrate consisting of sand, pea gravel, gravel and rock, with minor bank erosion (NCWRC 2015). Streambank substrate is dominated by clay with some silt accumulations. Mussel survey results from 2015 yielded a CPUE of 33, 90.4, and 49.8 mussels/hr for Sites PO-1, PO-2, and PO-3 respectively. PO-1 had a low diversity with a total of only three species. PO-2 and PO-3 had a diversity of six and four species, respectively.

Evidence of sedimentation was observed at site PO-2 using a scour chain. One scour chain was established within the thalweg during the initial site visit on November 11, 2014. During the second cross-sectional survey conducted on February 6, 2015, there was approximately 1.5 feet of sand deposited on top of the location of the scour chain. Attempts to recover the scour chain were futile.

6.3.1.3 RS Sites

These 3 sites were randomly selected from 15 sites that were surveyed for the first time in 2012. DWM was found at sites RS-1 and RS-3 in 2012. RS-1 is a sand dominated pool/glide complex with high amounts of large woody debris. Adjacent land use is mainly floodplain with a large wetland system that flows into the RS-1 stream reach. Water levels are deep throughout, and a single DWM was observed there in 2012. During mussel surveys from 2015, RS-1 had a CPUE of 108.2 mussels/hr with a diversity of 9 species. RS-2 is approximately 1,000 feet upstream of RS-1. This site is very similar to RS-1 with a deeper run/ pool complex containing large amounts of woody debris with pockets of detritus dominated substrate. The substrate is mainly dominated by sand with clay banks. RS-2 had a CPUE of 97.8 mussels/hr with a diversity of 6 species. RS-3 is approximately 1.4 mile downstream of RS-1. This stream reach is a run/pool complex dominated by sand with silt accumulations along the base of the clay banks. Woody debris is at low to moderate levels. Adjacent land use consists of a forested riparian buffer with a cutover forest community beyond a 200 foot buffer on both sides of the creek. RS-3 had a CPUE of 130 mussels/hr with a diversity of 6 species, the highest CPUE for any of the sites surveyed to date.

6.3.1.4 PA Sites

These sites were chosen based on the heterogeneous nature of their substrate. Most of these sites have a forested riparian zone, though some are near busy roads or residential areas. Scour chains were established at survey sites PA-2, PA-3, and PA-5. Although efforts were made to recover them, scour chains at survey sites PA-2 and PA-3 were not found. Cross sectional surveys for these sites depicted little change in the channel dimension between site visits. The scour chain installed at survey site PA-5 depicted no evidence of scour or sedimentation, which indicates habitat stability. The PA sites are trending towards a larger substrate particle size, in general. Though no DWM were found at any of the PA sites, mussel abundance and diversity were relatively high and contained some associate species of DWM (Triangle Floater, Creeper, Eastern Lampmussel, Atlantic Pigtoe and Roanoke Slabshell). Efforts were made to find PA sites in the upper portions (between NC 50 and I-40), and lower portions (between Steele Bridge Road and NC 210) of the entire study area, but few areas that were considered "potentially suitable" were found during stream reconnaissance efforts.

6.3.2. *Geomorphology Study Conclusions*

The results of this component of the study reveal a pattern of larger substrate size correlating with higher freshwater mussel CPUE and greater species diversity. Three of the five sites with recent records of DWM contained a gravel component ranging from 25-46% of the substrate within the cross section. Data for the remaining two DWM sites (RS-1 and RS-3) reflected a finer substrate composition of a clay/sand substrate for RS-1 with no gravel, while RS-3 contained 1% gravel with the remaining composed of sand and clay. As observed during the 2012 geomorphology surveys, site RS-3 had a gravel trough within the thalweg of the cross section located left of center in the channel. This gravel component was buried under silt/clay deposits during the Phase 2 surveys. Even though DWM was found in RS-1, this site is still considered an outlier in that it does not contain the same habitat attributes as the other sites that support DWM, as it is largely composed of a sand dominant pool habitat. However, there was small, stable microhabitat of stream bank that supported one young DWM (~2-3 yrs old) during the 2012 surveys. RS-2 has a gravel component of approximately 12-17%, but DWM was not found.

Sites between Barber Mill Road and Steel Bridge Road, or PA-3 through PA-8, are thought to have the best habitat for supporting DWM through augmentation. This area appears to have the most stable banks with heterogeneous substrate, along with existing mussel abundance and diversity. These sites occur within the historic 21 mile range of DWM in Swift Creek; however, DWM has never been recorded in these locales. The lack of DWM occurrences may be a function of level of survey effort, as a greater amount of effort has occurred in the upper portions of the 21 mile range. The three previously occupied sites occur within the upper portion of the DWM range in Swift Creek. A likely reason these areas are no longer occupied is due to an apparent transition to a shifting sand substrate, which is generally indicative of unstable conditions.

7.0 DWM POPULATION VIABILITY IN SWIFT CREEK

Continued analysis and studies are needed before making a definitive conclusion regarding the long term viability of the DWM within Swift Creek. The preliminary indicators of long term viability are mixed; however, the potential for this species to persist into the future in Swift Creek is highly dependent on habitat viability, which was discussed in Section 6.0. Each of the population viability criteria, as set out by the NC Scientific Council on Freshwater and Terrestrial Mollusks (Section 5.1), are discussed below, along with overall mussel population trends. The consensus of the council was that a population is considered viable if each of these criteria should be met.

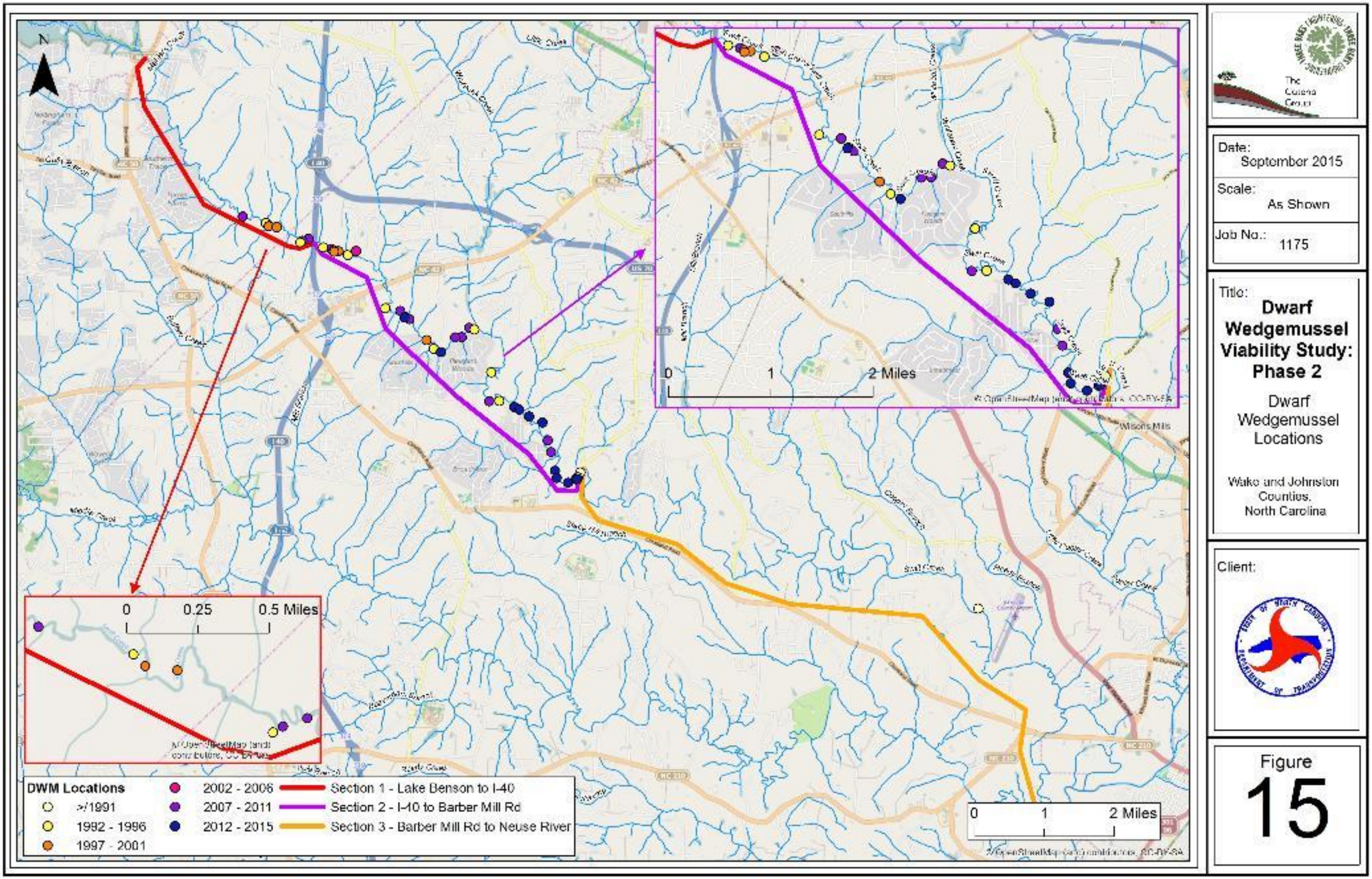
7.1. Length of Occupied Habitat Criterion

The historic range of the DWM population in the mainstem of Swift Creek has been reported to be approximately 21 miles (Figure 13). However, as mentioned in Section 6.3, the lower 10 miles of this range are represented by only one individual found in 1991. Considering the occurrences of DWM in the tributaries White Oak Creek, Little Creek, and Middle Creek, and the fact that there are no known physical barriers that would limit connectivity (thus creating > two miles of unoccupied habitat), the assumed historic occupied habitat would be approximately 53.7 miles. This 53.7 miles was derived by adding the historic 21 mile range in Swift Creek to the combined distances of the most upstream DWM records in the respective tributaries to the respective confluences with Swift Creek (0.2 mile in White Oak Creek, 2.0 miles in Little Creek and 25.0 miles in Middle Creek), plus an additional 5.5 miles of Swift Creek from the most downstream historic occurrence to the confluence of Middle Creek.

There is however, no survey data to support the 53.7 mile range, and using a two mile distance of un-occupied habitat as a distance to separate populations, it is possible that the 53.7 mile range represents a metapopulation, comprised of a number of smaller local populations. If this is the case, the Little Creek, Middle Creek and the lower 10 miles of Swift Creek are three local populations, of which the latter two appear to have been extirpated.

The survey efforts of 2007, 2010, 2011, and 2012 established a then current occupied range of at least 11 miles (Figure 13) in Swift Creek, with no gaps of unoccupied habitat greater than two miles. Whether that indicates a reduction in range of 10 miles of a population, or whether two distinct populations occurred in Swift Creek is unclear; however the 11 mile section has consistently been occupied since 1992. Eleven miles of occupied habitat are at the lower limits of the first population criterion. The DWM has not been found since 2007 in the upper portion of the 11 mile range during subsequent surveys, and habitat degradation (unstable substrate and stream banks) in this general portion of Swift Creek is evident. There also appears to be a tendency for the more recent findings of DWM to be clustered in the lower portion of the range (Figure 15). Though it may be premature to assume that the DWM no longer occurs in this portion of Swift Creek, the evidence suggests a declining range.

While the species was not found in Little Creek during the most recent surveys (2011), habitat conditions appear relatively stable and are similar to those observed when DWM was found in 2003, suggesting that the species may still persist in Little Creek. Based on this assumption, it is unclear if this would constitute a separate population since there are greater than two miles with no recent DWM records between the downstream limits of the current 11 mile occupied range in Swift Creek and the confluence of Little Creek, or if it would represent a dendriditic expansion



N
0
0.25
0.5 Miles
0
1
2 Miles
DWM Locations
>/1991
1992 - 1996
1997 - 2001
2002 - 2006
2007 - 2011
2012 - 2015
Section 1 - Lake Benson to I-40
Section 2 - I-40 to Barber Mill Rd
Section 3 - Barber Mill Rd to Neuse River
0
1
2 Miles
Date:
September 2015
Scale:
As Shown
Job No.:
1175
Title:
Dwarf Wedgemussel Viability Study: Phase 2
Dwarf Wedgemussel Locations
Wake and Johnston Counties, North Carolina
Client:
Figure
15

of the 11 miles of occupied habitat (assuming DWM is present in the greater than 2 mile gaps). More intensive surveys at various time intervals are needed in Little Creek as well as within Swift Creek near the confluence with Little Creek to determine DWM occupancy.

7.2. Occur at 75% of Sites within Occupied Habitat Criterion

Since 2007, within the 11 miles of Swift Creek believed to be occupied, the DWM was found at 6 of 62 surveyed sites (9.67%) in 2007, 5 of 83 sites (6.02%) in 2010, 3 of 47 sites (6.38%) in 2011, 8 of 44 (18.18%) in 2012, 1 of 1 (100%) in 2013, and 1 of 18 (5.56%) in 2015. However, when considering the results of the occupancy and detection probability analysis, the predicted occupancy is much higher (44% in one model and 33% in the other model). This rate is still well below the 75% occupancy target.

7.3. CPUE > 5 Individuals per hour at 50% of Occupied Sites Criterion

The CPUE for DWM has consistently been very low since its discovery in Swift Creek, and has declined from a high of 3.5/hr in Section 2 during the 1992-1996 period, to 1.0/hr also in Section 2 during the 1997-2001 (represented though by only one individual), to <0.5/hr in the subsequent two periods in both Section 1 and Section 2. Most of the DWM site occurrences are represented by one individual. The highest number of individuals ever recorded at a site during a single survey was 4 in 1997 (2.0/hr). One of the hypotheses for the low CPUE of DWM at occupied sites was attributed to non-specific survey methods to detect all mussel species rather than specifically targeted DWM. As such, habitat specific surveys targeting DWM were performed beginning in 2011 at all of the known DWM sites in the Swift Creek watershed. The theory was that the CPUE for DWM would be higher in occupied areas applying these targeted methodologies. However, these targeted surveys failed to detect the DWM at any of the previously known sites, although it was found at three previously unknown sites, further demonstrating its rarity in Swift Creek. The reasons for not detecting this species at any of the target sites are unclear, as many of these sites still contained the microhabitats associated with DWM. In addition, numerous mussels of other species that were tagged at some sites in 2007 were recovered in the same locations in 2011, which suggests a relatively stable habitat. In 2012 however, the DWM was detected at three of the previously known sites (CO), as well as at four previously un-sampled sites. In 2015, two individuals were found on two separate occasions at one of the three CO sites (CO-2), and another individual was found on another occasion at one of the three RS (RS-2). All three of these individuals were taken to the NCWRC fish hatchery in Marion to facilitate the propagation effort (See Section 8.2).

As mentioned in Section 5.1, the viability criteria have not been tested on mussel populations in the state, but were based in the collective opinions of the Council, and applied across the board to all mussel species. As demonstrated in this study, different species have differing levels of detection, and a CPUE criterion for one species may not necessarily be applicable to another species. When considering the CPUE measure of 5/hr as an indicator of viability, not only does the DWM population in Swift Creek not meet this criteria, with the exception of the Elliptio spp. none of the other species would currently meet this criteria, and most of them would not have met it in the early sampling periods either. Therefore, the CPUE criteria may need to be adjusted as these methods are applied to various species and populations and more information becomes available.

7.4. Evidence of Recent Reproduction Criterion

Evidence of recent reproduction within a population can be determined by either finding gravid (holding progeny) individuals, and/or finding multiple size classes, including younger individuals. In the southern portion of its range, the period of gravidity reported for DWM is from November through April. However, based on previous survey data in Swift Creek the majority (78%) of DWM were collected between mid-May and October, which may suggest that at least in Swift Creek, the DWM may be more easily detected during periods when it is not gravid. It is unclear if this is a reflection of seasonal variation in detection probability, or due to a smaller number of surveys conducted during periods of gravidity.

In order to evaluate this, surveys conducted in 2011 were initially designed to be performed during the later portion of the gravidity period, more specifically late March to late April. While these months are only a portion of the period of gravidity, survey conditions (amount of daylight, water levels and temperatures etc.) would allow for maximum survey efficiency. However, due to weather patterns, all of the surveys could not be performed during this time frame, and no gravid individuals were observed. In 2012 however, two of six live individuals found were gravid. One of those individuals was observed to be gravid in early March, and then again in late November, which indicates two successful periods of reproduction, as the species releases glochidia in late spring (Michaelson 1993).

Evidence of reproduction can also be determined by the presence of young age classes. While overall numbers of DWM in Swift Creek were very low, survey efforts conducted since 2007 indicate continuing reproduction, as small (young) size-class individuals were found in each of those years. It is unclear whether this reproduction is sufficient to maintain population viability, particularly when considering the indication of declines in relative abundances of the mussel fauna over time.

7.5. Overall Mussel Population Trends

As stated throughout this report, the DWM is very rare within Swift Creek, but it has persisted in the stream for the last 24 years. This rarity, whether inherent in southern populations, or a result of population declines, makes it difficult to project future viability when there is no information on population(s) numbers prior to 1991. As such, inferences on DWM must be made from also evaluating population trends of the other species occurring in the Study Area. As summarized in Section 5.8, the indicators of future viability developed from the population trends analyses are mixed. On one hand there is a declining trend in relative abundances of nearly all species, and on the other, there is some evidence that indicates these declines have leveled off, and there is increased recruitment of younger individuals.

7.6. Viability Conclusions

The results of the various components of this study indicate that the mussel fauna of Lower SCW is subject to multiple stressors which may threaten future viability. The Notched Rainbow, Yellow Lance and DWM appear to be the most vulnerable species. While further analysis of population and habitat trends would allow for a more definitive conclusion, the results of this study point to a population that is vulnerable to extirpation. Changes in the watershed have happened in a relatively short period of time, and the overall mussel fauna appears to have declined in conjunction with these changes.

Various conservation measures and protections have been put in place, in part as a response to the rapid urbanization of the watershed. Given the small dataset for DWM (47 individuals found over a 24 year time period) it is difficult to ascertain much in the way of population trends, other than it has been consistently rare over the time of the dataset. With regards to most other species occurring in Swift Creek that are also considered "sensitive" (Atlantic Pigtoe, Creeper, Eastern Lampmussel and Triangle Floater), it appears that the population declines have leveled off in recent years (Section 5.5), and the populations are represented by multiple age classes with evidence of recent reproduction. However, two of the sensitive species, the Notched Rainbow and the Yellow Lance may have declined to a point that they are below detection level, if they haven't already been extirpated from the creek. Only a few individuals of the Notched Rainbow have ever been found in Swift Creek, thus it is difficult to make any conclusions regarding population trends; however, with regards to the Yellow Lance it is obvious that this population has declined dramatically.

In terms of habitat viability, there are a number of indicators of degradation, particularly in the upper portion of the study. For instance as discussed in Section 3.3.2.2 the bioclassification ratings for the study area portion of Swift Creek has declined to the point where a major portion of the stream (11.4 miles) has been listed as impaired since 2009. Sedimentation and erosion were identified as sources of degradation in this portion of the stream (Section 3.3.2.2). Additionally, in the upper portion of the DWM range in Swift Creek some of the sites where DWM is considered to no longer be present (PO), habitats are dominated by shifting sand, scour pools, and unstable streambanks. These sites were described as riffle/run/pool sites with a heterogeneous substrate in previous years when DWM was found (Section 6.3.1.2).

While it is apparent that habitat has been degraded in some of the study area, relatively stable areas with heterogeneous substrate still exist (6.3.1.4). It is important to point out that the Swift Creek watershed in general is a dynamic stream system where changes in the watershed have occurred. The channel dimensions, and substrate composition in any given area have been adjusting to this change, and will continue to do so until a dynamic equilibrium has been reached. The same can be said about sites near Steele Bridge Road, which are now being considered as augmentation sites. While habitat attributes were not quantified, some surveys conducted in these areas in the early to mid-1990's describe sand as being the dominant substrate as opposed to gravel, which is currently present.

It is thus apparent that habitat conditions in some areas have changed overtime within the study area. As long as areas of suitable habitat continue to be present within the stream, and there are sufficient dispersal mechanisms to facilitate recruitment, the DWM has a chance of persisting in the stream (assuming water quality is sufficient). However, the lack of long-term quantitative habitat monitoring over time makes it difficult to predict long term habitat viability from a physical standpoint. There are recently developed High Definition Stream Survey (HDSS) monitoring methodologies that allow assessment of habitat conditions over long stretches of stream channels using geo-referenced video technology, which could be used to help determine long term habitat viability. These methods will be discussed further in Section 8.0.

The water quality component of habitat viability as it pertains to DWM population viability is also somewhat nebulous. As discussed in Section 3.6, copper may be a source of habitat degradation that could affect long term viability, as four of the 24 water quality samples collected during this study had copper levels that exceeded North Carolina water quality standard. These exceedances occurred during periods of low flow (Section 3.6.2). Ammonia and other heavy metals do not appear to be a major concern in the study area (Section 3.6.3). With the limited dataset (one year of monitoring) and not knowing the source of copper it is unclear if this is a chronic problem in Swift Creek, or an irregular occurrence.

In summary, there are still some high quality habitats present within the study area, there are some existing levels of protection, although not exceptional, there are some water quality concerns, and through the Neuse 01 RWP the Swift Creek watershed is being targeted for conservation/mitigation efforts. Additionally, there appears that there has been a levelling off in the decline of many of the sensitive mussel species and their populations appear to have some level of recruitment. When factoring in all of this information, coupled with evidence of recent reproduction and recruitment of DWM, it can be concluded with some level of uncertainty that there is a chance for this species to persist into the future. This chance of persistence is very tenuous, especially without active management and increased habitat protection.

This level of uncertainty is due to numerous factors, including a lack of historic population data, an insufficient amount of time to evaluate effectiveness of the various conservation measures that have been implemented, not knowing what additional protective measures may be implemented, and not knowing what population management resources will be available. For example, the NC DWM Work Group concluded that population augmentation through captive propagation is an essential component of management strategies to ensure DWM persistence in North Carolina (Smith et al. 2015). This is especially true with populations such as Swift Creek where the Allee effect (high risk of demographic extirpation due to low population abundance and lack of dispersal) is one of the major limiting factors of population viability. As mentioned in Section 4.2.8, the DWM has successfully been propagated (Beck and Neves 2001). Additionally, in North Carolina, a cooperative program between the NCWRC and the College of Veterinary Medicine at North Carolina State University is actively propagating imperiled mussel species. There is an ongoing commitment in developing a Swift Creek DWM population augmentation plan and acquiring the funds needed to implement this plan, which will be discussed further in Section 8.0.

8.0 DWM POPULATION MANAGEMENT RECOMENDATIONS

As discussed throughout this report, there are many uncertainties with regard to the future viability of the DWM population in Swift Creek. The reasons for the uncertainties have been explained, and are mainly related to existing data gaps and lack of historic information. One thing that is certain however, is that there are various active management tools and additional conservation measures that, if implemented, will increase the chances of long term viability. These measures will be discussed below. It is not to be implied that long term viability is dependent on all of these measures being implemented; however, the more that are done, will increase the chance for persistence, and some of them, like population augmentation appear to be critical. **Furthermore it is not being suggested that NCDOT be responsible for implementing, or funding all of these measures, rather it will take a cooperative effort with multiple stakeholders and multiple sources of funding to carry these out.** These measures are not discussed by level of importance, as some of them may have equal value.

8.1.In-stream Habitat Monitoring Using HDSS Approach

As discussed in Section 6.3.2 the Swift Creek channel is in a state of disequilibrium; however, there are still high quality habitats within the stream. The Geomorphology component of this study assessed habitat conditions within 200 foot sections at 18 sites within the portion of Swift Creek. While the methodologies employed for this study are very useful in characterizing and quantifying habitat conditions at specific locations, it is not feasible to apply these methods to the entire 32 miles of Swift Creek that constitutes the study area.

The HDSS approach uses geo-referenced video to develop spatially continuous maps of the existing stream bank and streambed conditions over long stream reaches in a relatively short period of time. A standard HDSS Kayak system consists of a sit-on-top kayak, three GPSenabled video cameras mounted facing forward, left, and right (90°), a hull-mounted down looking video camera, and a flush-mounted depth sensor. The GPS receiver provides sub three meter GPS accuracy and output time and location data (approximately one each second (1Hz)). The GPS data is combined with the depth data within the multiplexer and then is recorded onto a flash drive. The geo-referenced video is then combined with the GPS and depth data such that each data point is associated with Coordinated Universal Time (UTC) and coordinate information.

The data that can be gathered using these methods has a number of potentially useful applications in managing the DWM population:

1) Provide a baseline characterization of stream bank and substrate conditions, that can then be monitored overtime,

2) develop aquatic habitat GIS layers for depth, habitat type (pool, riffle, run), substrate type, percent embeddedness, and left and right bank condition scores, and combine this with recent mussel survey data, to further understand DWM habitat characteristics

3) document areas of high habitat suitability for endangered DWM and other species of concern

4) identify problem areas, which would help guide restoration efforts.

This HDSS was developed by members of Trutta Consulting (http://truttaconsulting.com/) and has been implemented on numerous occasions. The methodologies and utilities are explained in more detail in Connell and Parham (2015).

8.2.DWM Population Augmentation Using Captive Propagation Techniques

Captive propagation of freshwater mussels is becoming an increasingly useful tool in the management and restoration of freshwater mussel populations. The Allee effect (high risk of demographic extirpation due to low population abundance and lack of dispersal) has been recognized as one of the major limiting factors of DWM population viability in Swift Creek. Whether the cause for the Allee effect in Swift Creek is due to past, or ongoing anthropogenic factors is unclear. If the Allee effect is operating in Swift Creek causing unsustainable recruitment for the DWM population, the release of propagated individuals might increase population viability given the leveling off in population declines for some of the other mussel species (Section 5.5). However, if underlying conditions (habitat degradation) are not sufficient to sustain the population, the release of propagated individuals may not enhance viability even if the Allee effect is operating.

As mentioned in various sections of this report, the NC DWM Work Group concluded that population augmentation through captive propagation is an essential component of management strategies to ensure DWM persistence in North Carolina (Smith et al. 2015). The work group evaluated various scenarios to determine the relationship between the number of propagated DWM individuals released into a population, and the viability of that population (NC DWM Work Group workshop meeting notes provided by Sarah McRae USFWS). This evaluation factored in several parameters, including adult survival and life expectancy, the relationship between reproduction levels and population density, the number of glochidia per gravid female, as well as glochidia and juvenile survival. Based on knowledge of the species, and propagation techniques, it was estimated that approximately 5,000 DWM individuals could be propagated per year.

Based on these parameters, several models were evaluated with regards to the number of individuals released into the population and the number of years of release to achieve a lambda = 1. In ecology, lambda denotes the long term intrinsic growth of a population, often calculated as the dominant eigenvalue of the age/size class matrix. A lambda value of < 1 equates to population decline. Three scenarios resulted in lambda values = 1:

1) Release of 300 individuals ages 1-5 for 10 years
2) Release 900 at age 1 for 10 years
3) Release of 600 at age 2 for 10 years

The consensus of the group is that age 3 individuals are best suited for release, and it would take a minimum of a ten-year release schedule to potentially achieve viability in Swift Creek.

Other scenarios are being explored that factor in different magnitudes of release, different periods of release, and using the model in reverse (determine propagation capabilities, then calculate under what conditions (lambda = 1)), which would result in persistence.

As mentioned in Section 7.6, an ongoing commitment in developing a Swift Creek DWM population augmentation plan and acquiring the funds needed to implement this plan is underway, and choosing potential augmentation sites (Section 6.3) and collecting DWM individuals for brood stock was a component of the Phase 2 portion of this study. At the time of writing this report, three individuals have been collected in Swift Creek and were transported to the NCWRC fish hatchery in Marion, NC to serve as brood stock individuals.

Additionally, the USFWS and NCDOT have been in coordination with regards to logistics (location, costs, etc.) of developing a propagation facility in the Raleigh area as part of a conservation measure to help offset anticipated impacts to the Swift Creek DWM population resulting from the construction of the Triangle Expressway. Again, it is important to consider that a propagation effort in and of itself will not maintain population viability. Rather, physical habitat and water quality will also need to be sufficient to maintain population viability.

8.3. Continued Targeted Water Quality Monitoring

Water quality degradation due to copper contamination has been identified as a potential factor limiting DWM population viability. Continued water quality monitoring will aid in determining if contamination from copper is a chronic problem in Swift Creek, or an irregular occurrence, and whether it is localized, or throughout. In addition, uncovering the source(s) of contamination should also be investigated. Having this knowledge will be useful in determining potential stocking locations, as well as in developing measures to reduce the levels of contamination. To fully answer the question of whether water quality conditions in Swift Creek are a limiting factor for the DWM population, long-term toxicity analysis on DWM, analyzing growth, survival, and reproduction, is needed. In the absence of that data, similar analysis on other species of the same genus and/or associate species could be done instead. Lastly, developments through the use of the BLM to understand toxicity from other heavy metals should be monitored.

8.4. Monitoring of Sediment Toxicity within Swift Creek

The water quality sampling component of this study identified copper as a potential toxicant impacting the freshwater mussel fauna of Swift Creek. In addition to water quality contamination monitoring, evaluation of heavy metals within the sediments of Swift Creek will help further determine if copper and other metals are limiting population viability, and whether the contamination is an ongoing water quality issue, or a legacy effect. Freshwater bivalves are known for their ability to accumulate heavy metals in their tissues at several orders of magnitude above ambient water concentrations, and toxic concentrations of dissolved metals are more often associated with sediments rather than surface waters (Thorp and Rogers, 2015). The level of accumulation within the tissues of freshwater mussels is influenced by multiple factors including other sediment constituent metals and organic matter (Tessier et al.1984). Analysis of metal concentrations in tissues of associate mussel species within Swift Creek could help further determine if heavy metal contamination is impacting population viability.

8.5. Establishing a Lower SCW DWM Stakeholders Group

As mentioned in various sections of this report there have been numerous efforts implemented to conserve the SCW. However, these efforts have often been carried out in a vacuum by addressing a small area, or a single source of degradation. As mentioned, the Neuse 01 RWP is using a more holistic approach to characterize watershed conditions to guide improvement and mitigation efforts that will maximize ecological uplift. One of the goals of the Neuse 01 RWP was to identify traditional and non-traditional mitigation and water quality improvement measures. The entire occupied range of the DWM in Swift Creek is encompassed in two of the top five subwatersheds identified as Important Aquatic Habitats. While there is a Stakeholders

Group assembled as part of the Neuse 01 RWP, forming a stakeholders group specifically for the lower SCW is also recommended.

Establishing a specific stakeholders group that has a vested interest in maintaining a DWM population in Swift Creek would be useful in helping to identify and guide mitigation and conservation efforts and will also help to spread the burden of population management to multiple entities rather than a single agency. The stakeholder group could provide input on how to best direct available resources and to identify potential partners and funding sources.

9.0 RESOURCES

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