Technical Support Document for Consideration of Federally-listed Threatened or Endangered Aquatic Species in Water Quality Management Planning for the Goose Creek Watershed

I. Introduction

Goose Creek and Duck Creek, in Mecklenburg and Union Counties, are two of the only waterbodies in North Carolina which are listed as having impaired water quality by the State (NC Division of Water Quality [hereafter NCDWQ] 2000) and yet contain an existing population of a federally-listed endangered species (U.S. Fish and Wildlife Service [hereafter USFWS] 1996). In the most current rating cycle, Goose Creek is still listed as impaired as is Duck Creek (NCDWQ 2003). These streams are not meeting their designated uses which include aquatic life propagation and maintenance of biological integrity and secondary recreation. As such, a site-specific water quality management plan is being developed for Goose Creek and Duck Creek under the provisions of the *North Carolina Procedures for Assignment of Water Quality Standards* (15A NCAC 2B .0100) section .0110 *Considerations for Federally-listed Threatened or Endangered Species* which became effective in late 2000. Section .0100 states the following:

> Certain waters provide habitat for federally-listed aquatic animal species that are listed as threatened or endangered by the U.S. Fish and Wildlife Service or National Marine Fisheries Service under the provisions of the Endangered Species Act, 16 U.S.C. 1531-1544 and subsequent modifications. Maintenance and recovery of the water quality conditions required to sustain and recover federally-listed threatened and endangered aquatic animal species contributes to the support and maintenance of a balanced and indigenous community of aquatic organisms and thereby protects the biological integrity of the waters. The Division shall develop site-specific management strategies under the provisions of 15A NCAC 2B .0225 or 15A NCAC 2B .0227 for those waters. These plans shall be developed within the basinwide planning schedule with all plans completed at the end of each watershed's first complete five year cycle following adoption of this Rule. Nothing in this Rule shall prevent the Division from taking other actions within its authority to maintain and restore the quality of these waters.

An interagency team from the USFWS, the NC Wildlife Resources Commission (NCWRC) and the NC Natural Heritage Program (NCNHP) was asked to develop this technical report to support NCDWQ's development of site specific management strategies to restore water quality in Goose Creek and Duck Creek. It is intended to provide a framework for getting additional stakeholder input *prior* to formulating the water quality management strategy which will be completed through rule-making by NCDWQ (with the requisite public involvement and Environmental Management Commission oversight).

This draft captures what is known about six important issues: 1) the federally-listed species in Goose Creek and Duck Creek which makes the .0110 rule applicable; 2) the pollutants causing the impairment of Goose Creek and Duck Creek; 3) the sources of those pollutants; 4) the numeric or narrative standards to be attained for restoration of water quality; 5) the existing water quality management framework; and, 6) recommendations for the site-specific water quality management strategy. Each of these factors is discussed below with reference to existing data and studies for brevity.

II. Carolina Heelsplitter

Because the .0110 rule is targeted to watersheds supporting federally-listed endangered or threatened aquatic species, a summary of information on the listed species in Goose Creek is appropriate. The Goose Creek watershed supports the federally-listed as endangered and state critically endangered Carolina heelsplitter (*Lasmigona decorata*). The Carolina heelsplitter (Figure 1) is a medium sized freshwater mussel, that grows to about 115 mm (4.6 inches) in length, with a greenish brown to dark brown shell (Keferl 1991). The Carolina

Figure 1. Carolina heelsplitter (*Lasmigona decorata*), a federally- and North Carolina-listed endangered freshwater mussel. Photo by NCWRC

heelsplitter currently has a fragmented, relict distribution with only six known populations (Keferl and Shelly 1988, Keferl 1991, Alderman 1995 and 1998). In Union County, one small remnant population occurs in Waxhaw Creek (a tributary to the Catawba River), and another small population occurs in Goose Creek and its tributary, Duck Creek. In 1990, the species was found upstream of NC 218 in Goose Creek but is now known only downstream of US 601 (Johnson 2001). In Duck Creek, small numbers of Carolina heelsplitters have been found in the main channel from Mill Grove Road to Goose Creek's confluence with Duck Creek (Johnson 2001) (Figure 2).

Historically, the species was reported from small to large streams and rivers as well as ponds. The "ponds" referred to in historic records are believed to have been mill ponds on some of the smaller streams within the species' historic range (Keferl 1991, Bogan 2002). Presently, the species occurs in small streams and one small river and is usually found in mud, muddy sand, or muddy gravel substrates along stable, well-shaded stream banks (Keferl and Shelly 1988, Keferl 1991, Bogan 2002). However, in Mountain Creek, South Carolina, two live individuals were found near the center of the stream channel in a relatively silt-free substrate comprised primarily of a mixture of sand, gravel, and cobble (John Fridell, USFWS, pers. comm.). It is conceivable that this is the preferred habitat type for the species and that in other areas degradation of the gravel-dominated substrates has restricted the species to less suitable habitats. The stability of stream banks appears to be very important to the species (Keferl 1991).

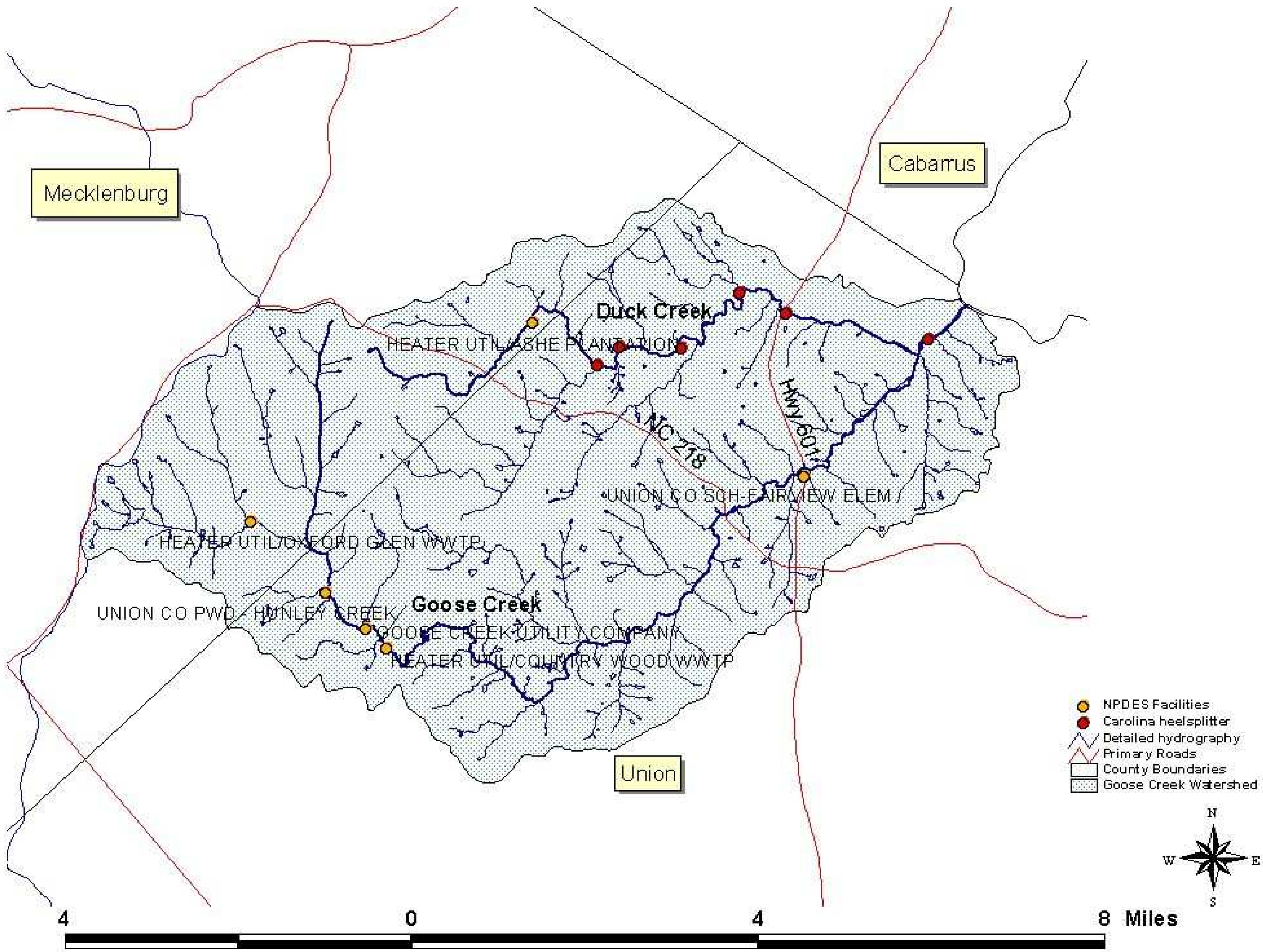


Figure 2. Goose Creek watershed, with approximate locations of recent records for occurrences of the Carolina heelsplitter

Like other freshwater mussels, the Carolina heelsplitter feeds by filtering food from water. The specific food habits of the species are unknown, but other freshwater mussels feed on detritus, diatoms, phytoplankton, and zooplankton. The reproductive cycle of the Carolina heelsplitter is likely similar to that of other freshwater mussels. Males release sperm into the water column; the sperm are taken in by the females through their siphons during feeding and respiration. Females retain the fertilized eggs in their gills until the larvae, known as glochidia, fully develop. The mussel glochidia are released into the water, and within a few days they must attach to the appropriate species of fish, which are then parasitized for a short time while the glochidia develop into juvenile mussels. Juvenile mussels then detach from their "fish host" and sink to the stream bottom where they continue to develop, provided they land in a suitable substrate with the correct water conditions. The Carolina heelsplitter life span, fish host species, and many other aspects of its life history are unknown (USFWS 1996, Starnes et al. 2002).

In 2002, the USFWS designated critical habitat for this species. The Federal Register publication includes the following account relative to the Goose Creek watershed. It is important to note that critical habitat represented occupied habitat at the time of designation.

> Critical Habitat Designation: Carolina heelsplitter - The main stem of Goose Creek, from the NC Highway 218 Bridge, downstream to its confluence with the Rocky River, and the main stem of Duck Creek, from the Mecklenburg/Union County line, downstream to its confluence with Goose Creek.

Critical habitat was also designated in the stem of Waxhaw Creek, the main stem of Flat Creek (South Carolina), and the main stem of Lynches River (South Carolina). Within these areas, the primary constituent elements include: 1) permanent, flowing, cool, clean water; 2) geomorphically stable stream channels and banks; 3) pool, riffle, and run sequences within the channel; 4) stable sand, gravel, cobble, boulder, and bedrock substrates with no more than low amounts of fine sediment; 5) moderate to high stream gradient; and, 6) fish hosts, with adequate living, foraging, and spawning areas for them.

With only these few populations remaining, the Goose Creek watershed is critically important for the continued existence of the Carolina heelsplitter. While the site-specific Goose Creek water quality restoration strategy to emerge from this document is aimed at improving the habitat of the Carolina heelsplitter, it will also benefit other rare species in this stream. The federal species of concern and state endangered Atlantic pigtoe (*Fusconaia masoni*) and Carolina creekshell (*Villosa vaughaniana*) occur in lower reaches of Goose Creek. Also, the state-listed as threatened creeper (*Strophitus undulatus*), the state special concern species notched rainbow (*Villosa constricta*), and the state significantly rare eastern creekshell (*Villosa delumbis*) occur in Goose Creek.

Mussel Surveys

The Carolina heelsplitter is surveyed about every five years to determine population status. About 15 years ago, the Goose Creek watershed population was considered one of the more viable of the known populations based on its size and stream condition (John Fridell, USFWS, pers. comm.). Results from the 1999 / 2000 mussel survey suggest a decline in density and diversity of freshwater mussels below wastewater treatment plants and the Carolina heelsplitter‘s range in Goose Creek was reduced by one-third (Figure 3). Preliminary results of the 2004 / 2005 survey suggest a further decline in all freshwater mussels and that Carolina heelsplitter range in Goose Creek has been further reduced to at least one-half their original range (John Fridell, USFWS, pers. comm.).

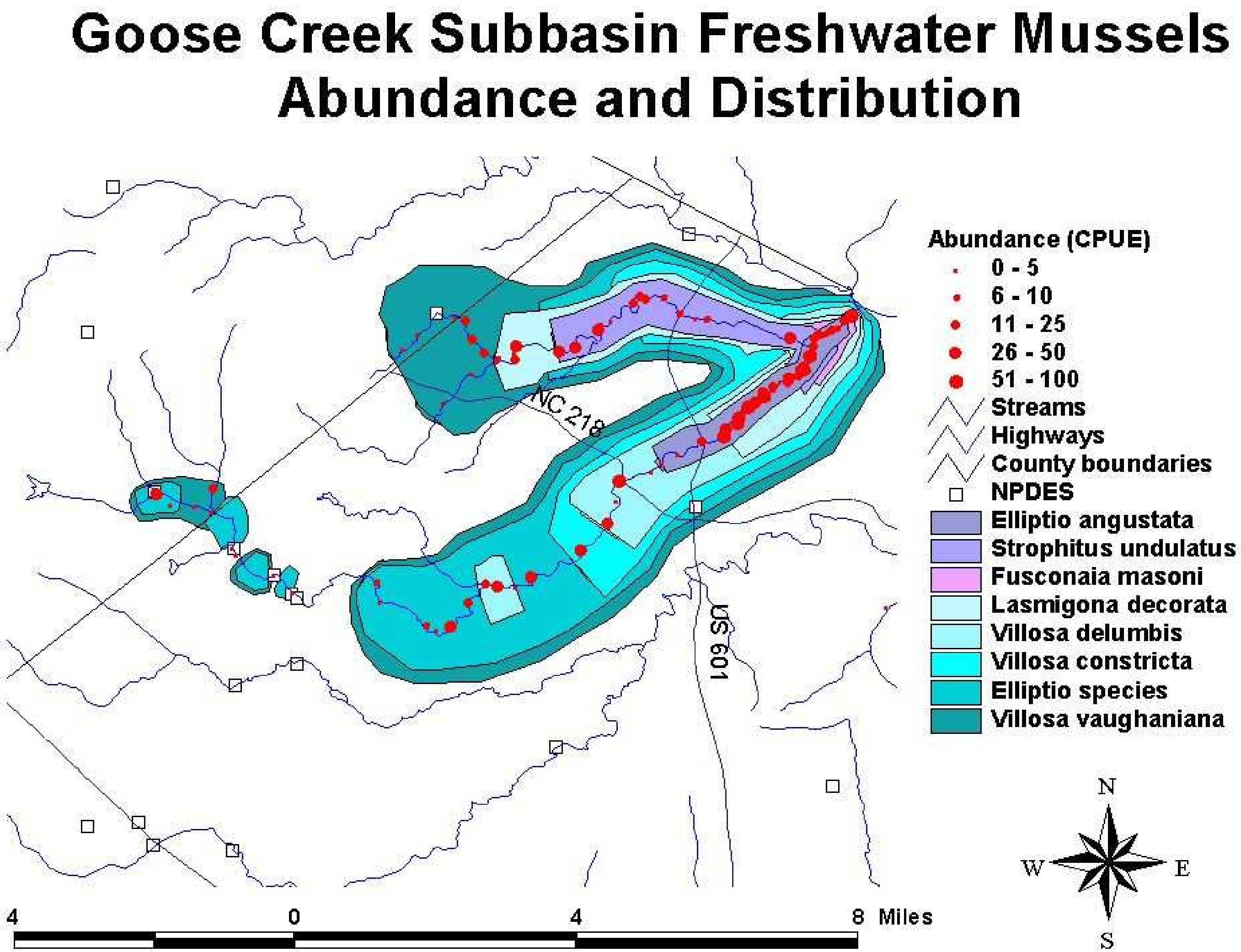


Figure 3. Goose Creek watershed freshwater mussel abundance and distribution from the 1999 - 2000 survey (NCWRC).

III.A. The Goose Creek Watershed

The Goose Creek watershed includes the Goose Creek and Duck Creek subbasins. Both creeks originate in eastern Mecklenburg County and flow into the Rocky River in Union County. Additional tributaries include Stevens Creek, located in Mecklenburg County, and Paddle Branch located in Union County. Two-thirds of the watershed, which covers approximately 27,000 acres of land (42 square miles) is within Union County. Like typical slate belt streams, the Goose Creek watershed is characterized by a substrate of bedrock and rubble and is susceptible to low flows during dry periods due to low groundwater recharge (NCDWQ 1997 and 1998a). There are approximately 25 stream miles with in the watershed, including main tributaries.

Land cover in the watershed is predominantly agricultural, although rapid urbanization from construction of I-485 and growth of nearby Charlotte is underway. Historically, cotton was the dominant local commercial agricultural crop. Following the turn of the century, production in the area grew to include soybeans, corn, cotton and wheat, with many poultry farms. The town of Fairview, located in Union County, is the largest municipality in the watershed. Smaller towns located wholly or partly within the watershed include Mint Hill, Hemby Bridge, Stallings, and Indian Trail (Table 1). The majority of the land in Hemby Bridge, Stallings, and Indian Trail is built-out in single family residential and commercial developments.

Table 1. Estimated acres for each jurisdiction by subwatershed and percent acres for the combined Goose Creek and Duck Creek subwatersheds.

Subwatershed	Mint Hill	Indian Trail	Stallings	Fairview	Union County	Hemby Bridge	Total
Goose Creek	4,938 (18.1%)	880 (3.2%)	1,415 (5.2%)	7,997 (29.3%)	3,050 (11.2%)	236 (0.9%)	18,516 (67.8%)
Duck Creek	2,354 (8.6%)			4,161 (15.2%)	2,267 (8.3%)		8,782 (32.2%)
Total	7,292 (26.7%)	880 (3.2%)	1,415 (5.2%)	12,158 (44.5%)	5,317 (19.5%)	236 (0.9%)	27,298 (100%)

III. B. Water Quality Parameters of Concern in the Goose Creek Watershed

Goose Creek and Duck Creek are rated as having poor water quality by the State, the lowest ranking in their system. The poor water quality rating has been recognized for over seven years (NCDWQ 1998a, 1998b, 2000, 2003) and progress has been made in identifying causes and solutions. This support document focuses on causes of the stream's impairment rather than a more narrow focus on the needs of the endangered Carolina heelsplitter. The decline in the species has been attributed to many factors, including siltation resulting from poorly implemented agricultural, forestry, and development activities; golf course construction; road construction and maintenance; runoff, and discharge of municipal, industrial, and agricultural pollutants (USFWS 1996). However, the stream would be rated as poor and impaired based on degraded water quality with or without the Carolina heelsplitter. Accordingly, the foundation of the water quality management strategy is an identification of pollutants that contribute to the stream's impairment.

The following water quality and habitat variables are known or suspected causes of impairment (with the source of this information provided in parentheses):

Bank / Channel Instability	(NCDWQ 1998a, 2002, Allan 2005)
Sediment / Suspended Solids	(NCDWQ 2000; Chen et al. 2001; Allan 2005)
Ammonia	(NCDWQ 1998a, 1998b, 2002; Chen et al. 2001; Allan 2005)
Dissolved oxygen (seasonally)	(NCDWQ 1997, 2002, 2003; Allan 2005)
Chlorine	(NCDWQ 1998a, 1998b)
Nitrate / Nitrite	(Chen et al. 2001; Allan 2005)
Phosphorus	(Chen et al. 2001; NCDWQ 2002, 2003; Allan 2005)
Pesticides	(NCDWQ 1998a)
Fecal coliform bacteria	(NCDWQ 1998b, 2000, 2002, 2003; MCWP 2005)
Copper	(NCDWQ 2002)

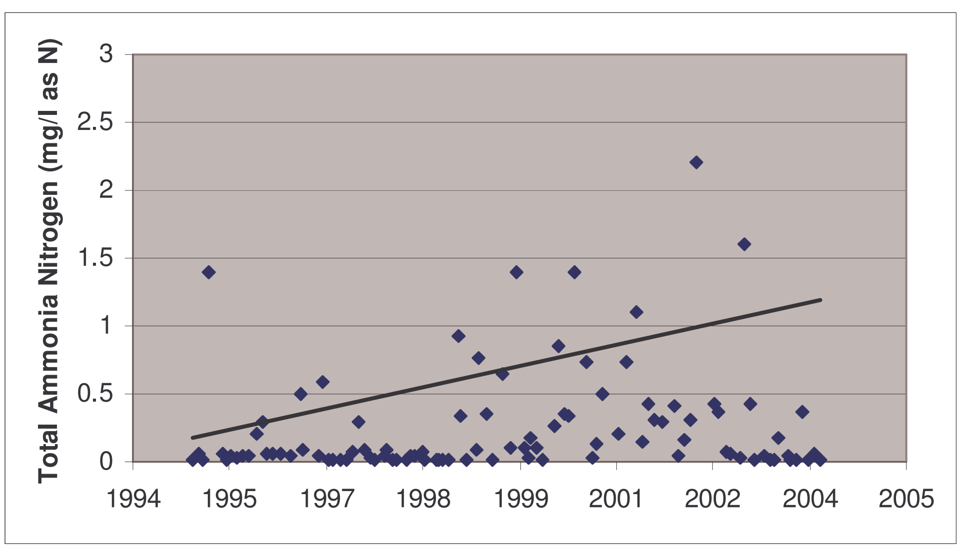
These water quality constituents need to be addressed in the site-specific water quality management plan in order to restore the basin's water quality. Although the basinwide assessment report (NCDWQ 2002), water quality trend analyses (Chen et al. 2001), and recent stream-wide water quality assessment (Allan 2005) provide detail on the extent of water quality problems, some highlights are offered here.

Ammonia

Ammonia is a natural degradation product of nitrogenous organic matter; significant sources of enrichment include municipal wastewater treatment plants, agricultural runoff (animal wastes and chemical fertilizers) and lawn or turf runoff. Ammonia is one of the most important pollutants of waters due to its relatively high toxicity to aquatic life and many sources (Russo 1985).

Average and maximum ammonia concentrations in Goose Creek are among the highest of any monitored site in the Yadkin-Pee River basin (NCDWQ 2002; Figure 85). The concentrations of ammonia also appear to be on an increasing trend within the subbasin (Figure 4).

Figure 4. Increasing trend-line for total ammonia as nitrogen (mg/l as N) in Goose Creek at SR 1524 near Mint Hill. Note that there are five values over this period of record which exceed 3 mg/l (off of the scale of this figure); they were documented on 12/96, 08/99, 10/00, 07/02 and 8/02.

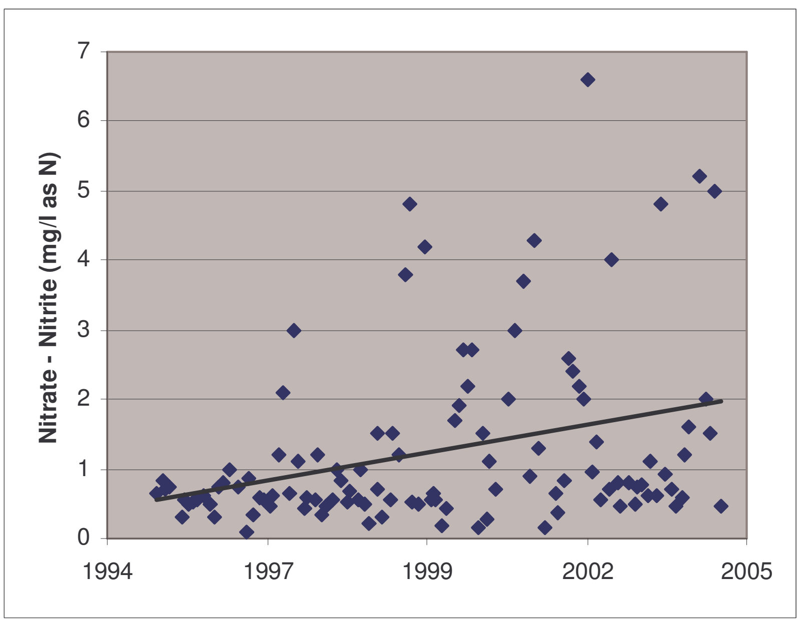


Sediment pore water (the water around sediment particles) concentrations of ammonia typically exceed those of overlying surface water (Frazier et al. 1996), thereby placing freshwater mussels, which burrow in sediment, in an area where ammonia concentrations are frequently elevated. Freshwater mussels' feeding strategies of filtering surface and pore water, suspended sediment and sediment-associated fine particles (Yeager et al. 1994) potentially increases ammonia exposure. Additionally, freshwater mussels are very sensitive to ammonia toxicity (Augspurger et al. 2003, and Appendix A). Because it is elevated in Goose Creek (relative to other streams in the basin), on an increasing trend, and extremely toxic to mussels, ammonia merits priority attention among the pollutants in Goose Creek. Elevated ammonia has been documented in Goose Creek by federal (USFWS), State (NCDWQ), County (Mecklenburg County Water Quality Program [hereafter MCWQP), local (Yadkin-Pee Dee Basin River Basin Association) and academic (UNC-Charlotte) entities.

Nitrate / Nitrite

Nitrate and nitrite are the major anionic inorganic forms of nitrogen in surface waters. From a toxicity standpoint, neither is particularly important: nitrite is very toxic, but it seldom occurs at concentrations of concern and nitrate, while commonly elevated, is not particularly toxic (Russo 1985). Both compounds are components of the stream's total nitrogen load, however, and thus they are an important marker of potential problems related to excessive nutrients, such as nuisance algal blooms and dissolved oxygen depletion. As with ammonia, the concentrations of nitrate and nitrite appear to be on an increasing trend within the Goose Creek (Figure 5).

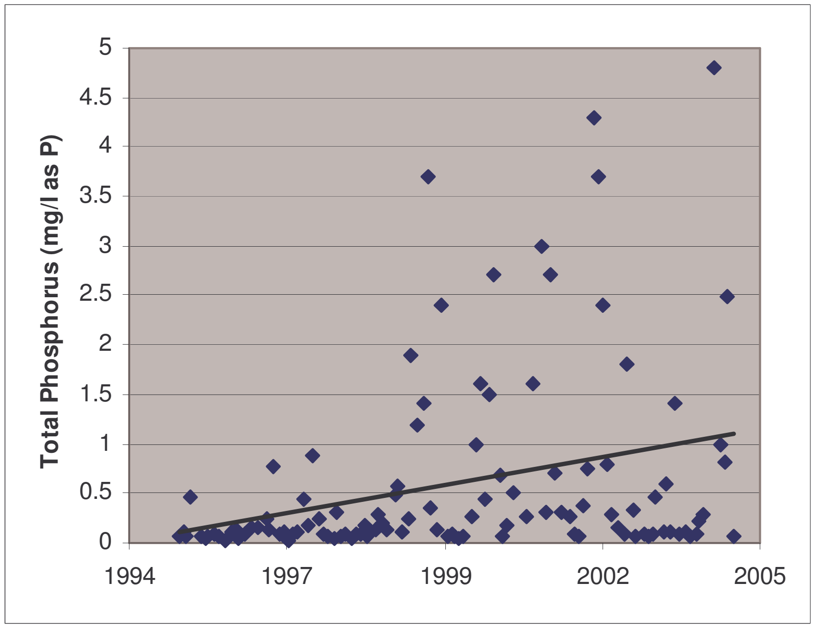
Figure 5. Increasing trend-line for nitrate / nitrite as nitrogen (mg/l) in Goose Creek at SR 1524 near Mint Hill.



Phosphorus

Phosphorus is a common component of igneous and sedimentary rock and therefore present in waters draining soils derived from these materials (Hem 1989). Phosphorus is also a component of sewage and can be enriched in waters receiving discharges of human and other animal wastes and chemical fertilizers. As with the nitrogen components, phosphorus appears to be increasing within Goose Creek (Figure 6), another marker for excessive nutrient loading of this stream.

Figure 6. Increasing trend-line for phosphorus (mg/l) in Goose Creek at SR 1524 near Mint Hill.



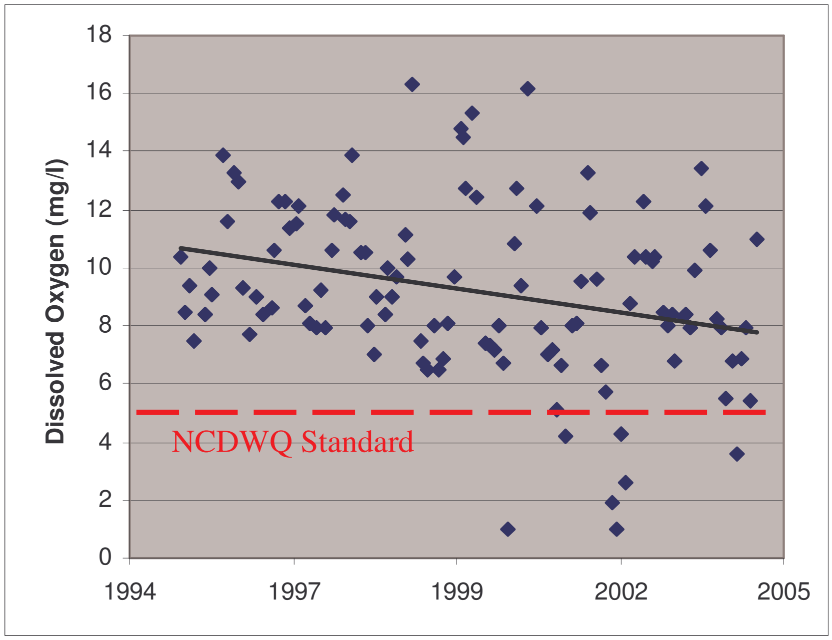
Dissolved oxygen

The amount of oxygen dissolved in water is a key limiting factor for all forms of aquatic life. Dissolved oxygen fluctuates naturally in relation to temperature, sunlight, and the balance between photosynthesis and respiration of aquatic organisms. The breakdown of organic material consumes oxygen as does the oxidation of ammonia. Hence, organic waste loadings, such as those from livestock or municipal wastewater, and excessive phytoplankton growth can deplete dissolved oxygen. The North Carolina dissolved oxygen water quality standard in Goose Creek is 5 mg/l (instantaneous minimum of 4 mg/l), and this value has typically been achieved (Table 2). However, recent data (NCDWQ 2002, Allan 2005) indicate several dissolved oxygen events lower than the standard, including values less than 3 mg/l which can be very detrimental to the aquatic community (USEPA 1986) (Figure 7). Low dissolved oxygen concentrations have been most pronounced during the drought from 1998 to 2002 with the most severe conditions in 2001 and 2002 (Table 2). Water flow that year was the lowest on record in much of the western North Carolina piedmont (Weaver 2005).

Table 2. Daily mean and every 15 minute instantaneous dissolved oxygen measurements taken at Goose Creek USGS station 2124692 at the Highway 601 crossing.

Year	Days with daily mean DO <5mg/l	Number of days	Every 15 min instantaneous DO measurements <4mg/l	Total number of instantaneous measurements	Percent <4mg/l
1999	0	47	0	4596	0.00%
2000	33	345	737	33674	2.2%
2001	37	344	1037	33387	3.1%
2002	35	328	936	32329	2.9%
2003	3	352	0	34203	0.0%
2004	2	363	0	35010	0.0%
2005	0	105	0	14500	0.0%
Total	110	1884	2710	187699	1.4%

Figure 7. Dissolved oxygen concentrations (mg/l) in Goose Creek at SR 1524 near Mint Hill. Note that the State water quality standard applicable to Goose Creek is 5 mg/l (instantaneous minimum of 4 mg/l) and that the few values below the standard have been relatively recent occurrences.



Sediment / Total Suspended Solids

Sedimentation is the process by which eroded soil is deposited into waters. Soil erosion, transport, and redeposition are among the most essential natural processes occurring in watersheds (NCDWQ 2003). However, land-disturbing activities such as the construction of roads and buildings, crop production, livestock grazing, and timber harvesting can accelerate erosion rates by causing more soil than usual to be detached and moved by water, especially during storms. Sedimentation can be increased when riparian vegetation is not present to filter runoff water or when the streambank itself is eroding.

Two aspects of sedimentation are important to mussels. First, suspended sediment can scour habitat and physically abrade mussels and their fish host species (Henley et al. 2000). Second, the sediment that settles to, and accumulates on, the bottom of streams can smother aquatic life and adversely affect the local habitat. Specific biological impacts on mussels from excessive sediment include reduced feeding and respiratory efficiency from clogged gills, disrupted metabolic processes, reduced growth rates, limited burrowing activity, and physical smothering (Watters 2000).

Physical characteristics of stream channels are affected when large quantities of sediment are added or removed (Watters 2000). Mussels are potentially impacted by changes in suspended and bed material load, bed sediment composition associated with increased sediment production and runoff in the watershed, channel changes in form, position, and degree of stability; and actively filling or scouring channels (Brim Box and Mossa 1999, USFWS 2004). When clogged, interstitial flow rates and spaces may become reduced, reducing habitat for juvenile mussels and some adults as well.

High sediment levels degrade water quality throughout the Goose Creek watershed (NCDWQ 1998b, Allan 2005). Elevated levels of suspended sediment, particularly during high flow periods, are a significant concern (Allan 2005).

Habitat degradation - Bank / Channel Instability

Extremely unstable stream banks (NCDWQ 1998b, 2002, 2003, Allan 2005) and need for riparian land restoration / protection (NCDWQ 1998b, 2003) are noted as concerns for Goose Creek The NCWRC characterized the geomorphology of sixteen stream reaches in the Goose Creek watershed (Appendix C). Reaches of Goose Creek were classified as unstable E5, E4, C5, C4, F4 and G4 stream types in the Rosgen (1994, 1996) rating system. Tributaries were classified as unstable B4, E4, F4, G4, G5 stream types. Head-cuts occurred on all tributaries, which is typical in the watershed. Increased bank erosion and high lateral and vertical instability were characterized in all reaches. Increases in unconsolidated depositional material over cobble / gravel substrate were identified as problems.

Fecal coliforms

Fecal coliforms are bacteriological indicators of the presence of enteric pathogens from warm blooded animals, including humans. Roughly 40% of the ambient water quality samples obtained for Goose Creek and Duck Creek exceed the State water quality standard for fecal coliforms (NCDWQ 2002). The standard is largely applied to assess the human health implications of primary contact with these waters. The impact of elevated fecal coliforms in particular or elevated pathogens from warm blooded animals in general, on freshwater mussels like the Carolina heelsplitter is not known. In a health assessment of non-endangered mussels, North Carolina State University researchers isolated 11 species of bacteria from the gastrointestinal tracts of Goose Creek mussels and found them to have a greater parasite load than those of nearby Waxhaw Creek (Chittick et al. 2001). The implications for mussel health were unclear. Bacterial contamination is likely less of a threat to mussels than toxicants such as ammonia and physical habitat alteration from excessive sediment. Also, Goose Creek's poor water quality rating and listing as impaired are known to be caused by additional water quality problems.

The NCDWQ and Mecklenburg County Water Quality Program (MCWQP) developed a fecal coliform total maximum daily load (TMDL) for Goose Creek and Duck Creek. The draft TMDL report (MCWQP 2005) provides information on bacteria loads and sources in the Goose Creek watershed and concludes that over 99% of fecal coliforms come from nonpoint source pollution. Permitted wastewater treatment plants are a main source of fecal coliforms during low flow conditions, but these were not addressed in the TMDL in order to focus on the larger nonpoint source problems. Nonpoint sources of fecal coliform bacteria would have to be reduced by 92.5% to attain the State water quality standard for bacteria, according to the MCWQP modeling. The TMDL report notes the need for cooperative development and implementation of strategies to address the load reductions needed to improve water quality.

Copper

Copper was listed as a parameter of concern for Goose Creek following the NCDWQ's summary of water chemistry data (NCDWQ 2002). The concern was raised because 20% of the values recorded by NCDWQ exceeded the State's 7 ug/l action level (Figure 8). Many waterbodies in the Yadkin basin exceed this action level, and it is probable that a significant portion of the exceedences are associated with suspended copper (i.e., that attached to suspended sediment). No data for dissolved copper, the most toxic form to aquatic life, are available.

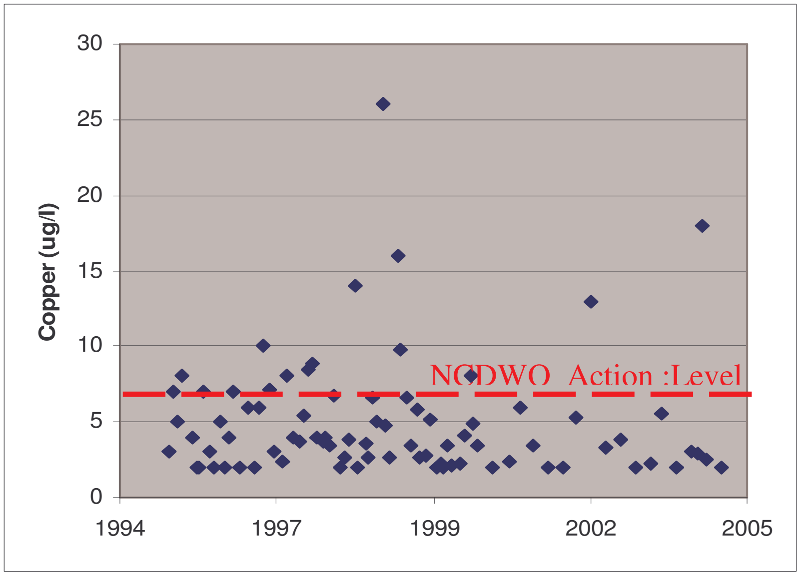


Figure 8. Total copper concentrations (ug/l) in Goose Creek at SR 1524 near Mint Hill. Note that the State water quality action level for copper is 7 ug/l

Chlorine

Chlorine is a commonly used disinfectant at wastewater treatment plants and is extremely toxic to a wide variety of freshwater organisms (USEPA 1985). Concentrations of chlorine that would be harmful to aquatic life have historically been documented at several of the wastewater treatment plants along Goose Creek (NCDWQ 2001). In 2003, the State adopted a new chlorine water quality standard (17 ug/l) which should address much of the concern for this parameter. Of the six wastewater treatment plants in the watershed, four still use chlorination for disinfection but have generally been in compliance with the new standard. One of these, the Fairfield Plantation facility, has had recent documented exceedences of the water quality standard, but concentrations in excess of standards attenuate rapidly downstream (Ward and Augspurger 2003).

Pesticides

Very little pesticide exposure data has been collected in the Goose Creek watershed. Pesticides have been implicated in some of the biological impairment noted in Goose Creek due to the types of land uses (golf courses, agriculture, residential lawns) adjacent to areas with poor biodiversity (NCDWQ 1998a) compared with other sites. Currently, pesticides should be considered a potential water quality problem (due to lack of confirmatory data) in contrast to the well-studied and well-documented problems such as sedimentation, ammonia and other nutrients.

III. C. Sources of Water Quality Impairment in the Goose Creek Watershed

The list of problem water quality parameters is a sound foundation for plan development, but the sources of excess pollutants must also be identified for an effective water quality management strategy. Several investigations of pollutant sources have been done for Goose Creek and Duck Creek.

The first detailed assessment of causes of water quality impairment in Goose Creek was the NCDWQ's 1996-1998 survey. They noted that nonpoint sources of sedimentation were a concern throughout the region but that the poor bioclassification of Goose Creek was atypical. They found the worst water quality conditions downstream of the County Woods development; despite good habitat conditions in that vicinity, they reported that biodiversity was low. Toxicity was postulated from ammonia and chlorine from wastewater treatment plants or pesticides from nonpoint sources.

When the State and USEPA listed Goose Creek as an impaired waterbody (NCDWQ 2000), they identified construction, urban runoff, and storm sewers as problem sources. These were listed as sources of sediments and fecal coliform bacteria.

In their review of water quality data and issues for the watershed, the Goose Creek Watershed Advisory Committee identified urban stormwater runoff, wastewater treatment discharges, and agriculture as “problem sources” of water pollution (WECO 2002). Effluent from wastewater treatment plants was also implicated in the decline of Goose Creek's mussel fauna.

In a study of trends in water quality data from the Stevens Road crossing of Goose Creek, Chen et al. (2001) noted significant increases in phosphorus, ammonia, and nitrate/nitrite; they postulate fertilizer-laden runoff from golf courses and residential lawns may be the sources noting that there has been no substantial increase in agricultural acreage to explain additional nutrient loads.

The NCDWQ 1998 basinwide water quality management plan attributed fecal coliform contamination to nonpoint source pollution, and identified construction and stormwater runoff as contributors. The plan also identified wastewater treatment plants as the source of ammonia and chlorine toxicity concerns (NCDWQ 1998b). The most recent basinwide water quality management plan reviews the NCDWQ’s previous findings and recommendations regarding pollutant sources, and the plan restated concerns related to stormwater runoff from construction and developed areas as well as agricultural activities (NCDWQ 2003).

In a recent intensive water quality monitoring effort in the Goose Creek watershed, a UNC-Charlotte researcher documented that sediment and nutrient concentrations increased dramatically during high flow episodes (Allan 2005). Stormwater runoff was cited as the primary concern for overall poor water quality with some local impacts attributed to wastewater treatment plants. The study also addressed streambank instability; citing stormwater runoff, livestock with free access to the stream channel, and degraded riparian vegetation as the sources of this problem (Allan 2005).

In the late 1990’s, NCDWQ prepared flow studies and a water quality model which indicate Goose Creek was over-allocated at current permitted wastewater treatment plant limits (NCDWQ 2001). Instream dissolved oxygen concentrations were predicted to drop below the instream water quality standard during summer low flow conditions along a 3.8-mile stream segment. Under low flow conditions, wastewater treatment plants were also noted as concern for bacteria (MCWQP 2005).

In Goose Creek, observed all-terrain-vehicle (ATV) tracks indicate the use of the stream channel as a travel corridor in addition to creek crossings. While the impacts to streams in the Goose Creek watershed from ATVs have not been quantified, other studies document the adverse effects of off-road vehicles (ORVs) upon riparian ecosystems. Taylor (2002) provides the most recent, comprehensive review of ORV impacts to riparian and forest ecosystems.

Other water quality concerns noted by the NCDWQ and others include excessive periphyton growth (an indication of eutrophic conditions), cattle access to the stream, and breaks in the riparian zone. The summation of all of these reports is the following list of known or suspected sources of the pollutants causing water quality problems in the Goose Creek watershed:

Construction	**Impervious surfaces**	**Urban runoff**
Storm sewers	**Agriculture (Livestock)**	**Turf / lawn care**
Wastewater treatment plants	**ATV use instream**	

IV. Special considerations for the Endangered Carolina Heelsplitter

The focus of the site-specific management plan is restoration of degraded water quality. Regardless of the presence of the Carolina heelsplitter, Goose Creek and Duck Creek are listed as impaired by the State and the USEPA and therefore they are the subject of restoration actions to achieve water quality standards. Goose Creek has been targeted as a high priority for water quality restoration in the 1998 and 2000 NCDWQ Clean Water Act 303(d) listing of impaired waterbodies.

For some aquatic endangered species, there are no indications that additional measures (i.e., beyond attaining the existing State water quality standards) are necessary for conservation. For other species, including the Carolina heelsplitter, additional measures will be required. Many factors are cited in the decline of freshwater mussels in North America and for the listing of greater than 70% of native mussels as endangered, threatened, or of special concern (Williams et al. 1993, Neves et al. 1997). Habitat alteration, introduction of exotic species, over-utilization, disease, predation, and pollution are considered causal or contributing factors to the decline of mussel populations in many areas of the United States (Fuller 1974, Havlik and Marking 1987, National Native Mussel Conservation Commission 1998).

Toxic substances were among the stressors frequently cited as limiting factors for freshwater mussels in a recent survey of experts for this taxa (Richter 1997). While mussels appear relatively tolerant to some organic solvents and pesticides (Keller 1993, Keller and Ruessler 1997, Conners and Black 2004) there are also published toxicological data indicating that early lifestages of freshwater mussels are among the most sensitive aquatic organisms tested for impacts of some inorganic chemicals, including metals (Keller and Zam 1991, Jacobson et al. 1993, 1997), and ammonia (Wade 1992, Goudreau et al.1993, Scheller 1997, Myers-Kinzie 1998, Augspurger et al. 2003, Mummert et al. 2003). This section provides the basis for site-specific numeric water quality standards falling into either of two categories: A) parameters without well-defined State numeric standards; and B) parameters for which toxicity data indicate that existing State standards may not be protective of the Carolina heelsplitter.

Ammonia

North Carolina does not have a water quality standard or action level for ammonia. Because this was one of the problem parameters identified for Goose Creek, a recommended standard was derived. The process used to derive the site-specific standard is provided in Appendix A; much of this process was documented in a publication which can be referenced for additional detail (Augspurger et al. 2003).

We compiled ammonia toxicity data by adding freshwater mussel toxicity test results to the database in the USEPA (1999) water quality criteria document for ammonia. Toxicity data were summarized by the methodology described in USEPA numeric water quality criteria guidelines (Stephan et al. 1985). The recommended acute (short-term) water quality standard for the Goose Creek watershed is 1.75 mg/l total ammonia as N. As with USEPA's criteria, this value should be applied as a one hour average exposure which should not be exceeded more than once every three years. The recommended chronic (long-term) standard is 0.5 mg/l as N. As with USEPA's criteria, this value should be applied as a four-day average exposure which should not be exceeded more than once every three years.

The appropriateness of the standards was evaluated relative to USEPA (Stephan et al. 1985) guidance. The data driving the calculation are robust. In addition to the toxicological appropriateness of the recommended site-specific standards, they were evaluated relative to ambient data. Clearly, a standard that was far lower than concentrations observed in relatively un-impacted waters of the State would not be appropriate (i.e., the standard would likely be too restrictive). Also, if the standard was far in excess of actual concentrations, it might not be relevant. To address this issue, we plotted Goose Creek ammonia concentrations from the NCDWQ dataset side-by-side with those of potential reference watersheds for ammonia. We defined potential reference watersheds for ammonia as those in the Yadkin and Catawba basins which the State has rated as having excellent water quality and which also had an ambient monitoring station collecting long-term ammonia data. From Figure A-1, it is apparent that Goose Creek site-specific ammonia standards would be reasonable. The acute standard is never exceeded in the reference watersheds, and the chronic standard is only rarely exceeded. On the basis of lab and field information, the standards are consistent with sound scientific evidence.

Ammonia is a parameter of concern in Goose Creek and concentrations above these recommended site-specific standards have been documented. Figure A-2 plots the NCDWQ's ammonia data for Goose Creek against these two proposed standards. Summary statistics indicate that only 5% of the values exceed the acute standard. The median or 50th percentile concentration of ammonia (0.09 mg/l) is 5 times lower than the chronic standard indicating it is readily achievable. The 75th percentile concentration of 0.5 mg/l equals the recommended chronic standard indicating exceedence of this value 25% of the time with 10% of the concentrations nearly double this value. Actions to reduce point source and nonpoint source ammonia loads to the creek will be needed to achieve these standards.

Copper

North Carolina does not have a state water quality standard for copper, but they do have an action level of 7 ug/l. Because this was one of the problem parameters identified for Goose Creek, a recommended standard was derived. The process used to derive the site-specific standard follows that discussed above for ammonia and can be referenced in Appendix B.

From 115 toxicity test endpoints with copper exposure to freshwater mussels, covering 20 species in 14 genera, we calculated an acute water quality standard of 3.6 ug/l copper and chronic standard of 2.2 ug/l for Goose Creek. These values were calculated to be protective at the 10th percentile hardness for Goose Creek; because copper toxicity increases with decreasing hardness, a standard protective at the 10th percentile for hardness will be protective in most conditions.

These proposed standards are frequently exceeded in Goose Creek. It is possible that a significant portion of the exceedences are associated with suspended copper (i.e., that attached to suspended sediment). No data for dissolved copper, the most toxic form to aquatic life, are available. It would be prudent to obtain these data as a component of implementing the proposed site-specific copper standards. This does not need to hold-up implementation of the overall water quality restoration plan; nonpoint source pollution reduction actions to address the well-documented ammonia, nutrient and sediment problems will likely reduce copper concentrations as well while additional data are being gathered.

Nutrients

North Carolina does not have a state water quality standard or action level for nitrate-nitrite or phosphorus. Because these nutrients were among the problem parameters identified for Goose Creek, recommended standards to be applied to the creek were derived. The mussel toxicity approach we used for deriving proposed standards for ammonia and copper are not appropriate for nitrate or phosphorus. From a toxicity standpoint, neither is particularly important, but they both contribute to problems related to excessive nutrient loading, such as nuisance algal blooms and dissolved oxygen depletion. It is important to derive some target or threshold for these constituents because they appear to be increasing in Goose Creek surface water.

We employed a reference watershed approach to define proposed numeric targets for these parameters. We defined potential reference watersheds for nutrients as those in the Yadkin-Pee Dee and Catawba basins which the State has rated as having excellent water quality and which also had an ambient monitoring station collecting long-term water chemistry data. From these data (Table A-5 in Appendix A) the average 90th-percentile nutrient concentration of each watershed were used to derive nutrient targets. The 90th percentile was used because it is consistent with how NCDWQ reviews ambient water quality data for compliance with State standards (i.e., if more that 10 percent of the results of ambient data exceed an existing State standard, it is further investigated for its significance). By definition, the 90th percentile values would not be expected to be exceeded more than 10 percent of the time. The average 90th percentile value for nitrate-nitrite in reference watersheds was 0.4 mg/l and the average 90th percentile value for total phosphorus in reference watersheds was 0.1 mg/l. These should be considered site-specific nutrient targets for the Goose Creek watershed.

Impervious surfaces

Development alters the land by replacing natural cover with roofs, roads, parking lots, driveways and sidewalks. These surfaces, impermeable to rainfall, are known as impervious cover. Imperviousness is defined as the sum of impermeable surfaces of the landscape (Center for Watershed Protection [hereafter CWP] 2003). There is evidence that relates impervious cover to specific changes in the hydrology, habitat structure, water quality, and biodiversity of aquatic systems (CWP 2003). Increased imperviousness causes higher peak discharge rates, greater runoff volumes and higher floodplain elevations. Groundwater recharge may decrease as imperviousness increases due to lower infiltration rates during storms. Streams respond to increases in imperviousness by increasing their cross-sectional area to accommodate higher flows. When the cross-sectional area is increased, the stream banks are widened and the streambed is downcut, causing severe erosion and habitat degradation (CWP 2003).

North Carolina has standards for certain waterbodies, such as drinking water supplies, that relate the extent of stormwater management requirements to the extent of impervious surfaces in the watershed. There are no similar impervious surface thresholds for Class C waters, such as Goose Creek and Duck Creek. Because stormwater runoff has been identified as an important source of pollution to the Goose Creek watershed (Allan 2005), site-specific impervious surface thresholds are needed.

Using their CITYgreen geographic information system software, American Forests estimated changes in vegetative cover within the Goose Creek and Duck Creek subbasins between 1984 and 2003 (American Forests 2005 a, b, c, d). Urban landuse has supplanted significant amounts of vegetative cover throughout the watershed (Table 3). Within the analyses are routines to estimate the environmental benefits (such as slowing stormwater, filtering runoff, providing habitat, etc) accrued or lost as a result of the changing vegetative component. For the water quality benefits calculations, the software relies on the Urban Hydrology for Small Watersheds model of the Natural Resources Conservation Service. While the comparison of landuse change over the 20-year period is instructive in itself, the water quality impacts assessment founded on those changes indicate increases in runoff and associated elemental contaminants, sediment, and biochemical oxygen demand.

Table 3. Results of American Forests analyses of land coverages (acres) and change (%) in Goose and Duck creek watersheds, 1984 – 2003.

Watershed	Landcover		1984	2003	Change
Goose Creek – Mecklenburg County	Trees		2,267	2,016	- 11%
	Open Space		2,334	1,770	- 24%
	Urban		293	1,103	276%
	Water		41	47	15%
	Total Acres	= 4,936			
Goose Creek – Union County	Trees		5,795	4,903	- 15%
	Open Space		7,525	6,533	- 13%
	Urban		206	2,077	908%
	Water		41	57	39%
	Total Acres	= 13,570			
Duck – Mecklenburg County	Trees		1,470	1,201	- 18%
	Open Space		829	777	- 6%
	Urban		53	371	600%
	Water		4	6	50%
	Total Acres	= 2,355			
Duck Creek – Union County	Trees		3,101	2,972	- 4%
	Open Space		3,246	2,894	- 11%
	Urban		65	535	723%
	Water		10	21	101%
	Total Acres	= 6,422			

The diversity of species in a stream also changes dramatically as impervious cover increases. Aquatic insects are frequently used as an indicator of stream health; insect diversity declines and sensitive species are lost when impervious cover increases. The CWP has integrated research findings into a general watershed planning model which predicts that streams are sensitive to disturbance in watersheds with 0-10% imperviousness, most stream quality indicators decline when watershed impervious surface cover exceeds 10%, and severe degradation is expected beyond 25% (Zielinski 2002). In North Carolina, the Wake County Watershed Management Plan Task Force performed a correlation analysis of impervious surfaces to watershed classification based on water quality data and found that watersheds of unimpaired streams averaged 8% imperviousness, impacted streams averaged 11%, and degraded streams averaged 24% (Wake County 2002). Recent research, including analyses of North Carolina piedmont streams, indicates that substantial impacts can be observed to benthic macroinvertebrate communities at even low levels of urbanization (Gilliam et al. 2005, Cuffney et al. 2005). That research indicates that there may well be no impervious surface threshold, or "safe level," because benthic diversity indices declined significantly at levels well below10% imperviousness.

Using building construction dates on Union and Mecklenburg counties' GIS data, we were able to reconstruct growth in the Goose Creek watershed up to 1999. Fifty-three percent of the buildings were constructed between 1980 and 1999 (Figure 9). Development pressure has further increased since the opening of I-485.

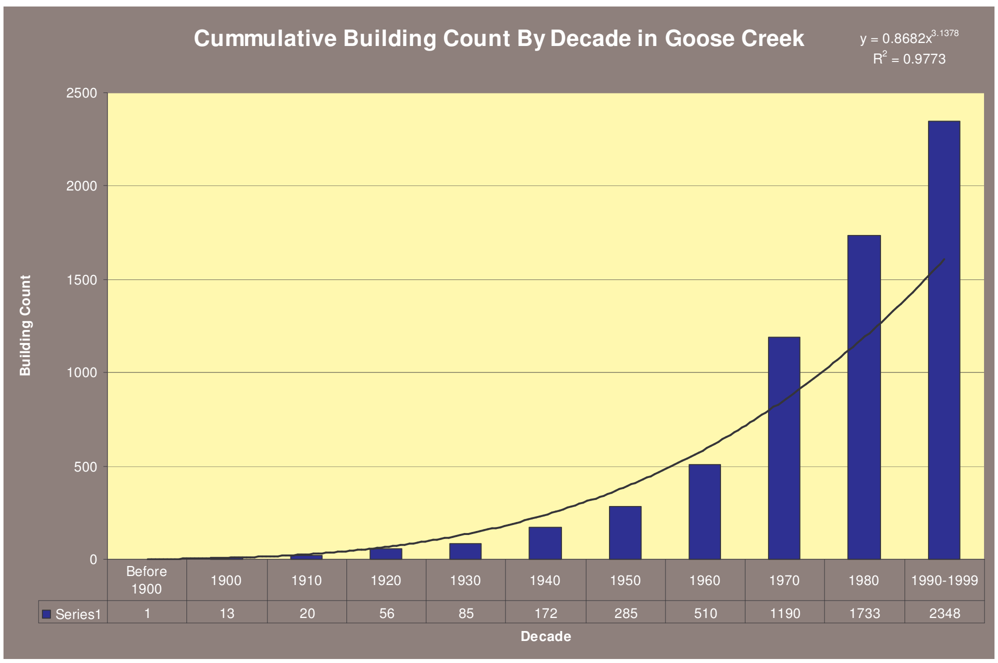


Figure 9. Cumulative building count by decade in Goose Creek watershed using Union and Mecklenburg counties' GIS data (unpublished data Mark Cantrell, USFWS).

Current estimated imperviousness in the Goose Creek watershed in Mecklenburg County is approximately 9% (Charlotte/Mecklenburg County Post-Construction Ordinance Stakeholder Group [hereafter CMPCSG] 2005) and 6.9% and 3.7% in the Goose Creek subwatershed and Duck Creek subwatershed in Union County, respectively (HNTB 2003a). Estimated future imperviousness under a build out scenario in Goose Creek, Mecklenburg County is 32% (CMPCSG 2005). Future imperviousness for Goose Creek and Duck Creek subwatersheds in Union County was estimated under different build out scenarios in relation to constructing Monroe Bypass and are identified in Table 4 (HNTB 2003a).

Table 4. Changes in imperviousness within the Union County portion of the Goose Creek and Duck Creek watersheds using existing and future build-out scenarios in relation to constructing Monroe Bypass and Connector (HNTB 2003a and b).

Watershed	Existing imperviousness	No-build	Build w/ no-change in controls	Build w/ controls
Goose Creek	6.9%	26.1%	29.2%	23.2%
Duck Creek	3.7%	30.2%	28.2%	21.7%

Imperviousness is one of the few variables that can be managed during land development (Zielinski 2002, CWP 2003). Because of the apparent lack of thresholds for aquatic community impact, the existing levels of impervious cover in the Goose Creek watershed, the currently impaired water quality, and the documented significant and continuing decline in the range and abundance of the Carolina heelsplitter and all other mussel species in the watershed, an argument can be made for requiring all new development in the watershed to implement stormwater control. At a minimum, permits for new developments exceeding 6% imperviousness should be required to include stormwater controls designed to replicate and maintain the hydrographic condition (peak and volume controls) at the site prior to the change in landscape and include provisions that satisfy WS II-HQW standards.

Flows

As impervious surface increases in the watershed, ground water infiltration will decrease and stormwater runoff will increase. In 2003, models were developed for the existing hydrology and different build-out scenarios to address indirect and cumulative impacts from the proposed Monroe Bypass (HNTB 2003b). A 25-year storm peak discharge in Goose Creek increased 42.2% for a "No Build" scenario, increased 46.1% for a "Build w/ no controls" scenario, and increased 39.1% for a "Build w/ controls" scenario. Peak discharge of a 25-year storm in Duck Creek increased 58.5% for a "No Build" scenario, increased 55.6% for a "Build w/ no controls" scenario, and increased 46.9% for a "Build w/ controls" scenario. (HNTB 2003b)

The increased runoff will have detrimental effects on channel stability, aquatic habitat and water quality. Higher velocities and increased bankfull events increase the likelihood that mussels will be scoured out and deposited on the floodplain, stranding individuals. Charlotte/Mecklenburg County's Post-construction ordinance stakeholder group is developing zoning ordinances to control and manage stormwater runoff and associated negative water quality issues resulting from post-construction stormwater discharges (CMPCSG 2005). The group has modeled streambed stability and loading rates of suspended solids, nitrogen and phosphorus under existing conditions and four future build-out scenarios. The modeling suggests significant increases in all parameters for future build-out with existing regulations and with no regulations compared to existing conditions. Additional stormwater management will be needed to protect aquatic habitat and water quality.

Low flows are also a concern. A stream-wide assessment found a negative, logarithmic correlation between groundwater discharge and drainage area (Allan 2005). The lower groundwater recharge is attributed to the slate belt region, making the watershed the Carolina heelsplitter occupies extremely susceptible to periods of drought. The NCDWQ (1997) noted significant water withdrawals in Goose Creek which should be monitored and managed due to their potential impact during low flows.

Sediment

Sediment is considered the most important cause of water pollution in the United States (Waters 1995) and has been cited as a concern in the Goose Creek watershed by several entities. Scientific literature suggests freshwater mussels are sensitive to impacts from excessive sediment. Because of the unique geomorphology of slate belt streams, we were not able to use a reference watershed-based approach for a total suspended sediment standard. Sediment will likely be reduced by some of the same practices to be recommended for nutrient reduction and bank stability because high nutrient concentrations in this watershed are correlated with high sediment levels and stormflow runoff (Allan 2005).

Riparian Buffers

A forested riparian buffer is an area of trees and other vegetation on the banks of rivers and streams. Buffers of trees, shrubs, and grass along waterways are integral to bank stability, slow runoff of stormwater flows, filter out nonpoint source pollutants, and provide habitat for riparian wildlife. Research provides strong evidence that stream banks with insufficient riparian vegetation are more likely to collapse and erode. The collapse of stream banks causes excess sediment and alters the course of the stream, making the stream wider, shallower, and straighter. The erosion and collapse of stream banks is a primary source of sediment pollution in watersheds.

Maintaining forested riparian buffers is a well-known method for protecting aquatic habitat and water quality by reducing stream sedimentation and other runoff. Riparian buffers may yield the greatest gains for aquatic habitat and water quality than other watershed protection measures (NCWRC 2002). Riparian buffers are particularly important for freshwater mussels (Neves et al. 1997). Several recent reviews of riparian buffer widths, extent, and vegetation are available to guide evaluation of buffer design and efficacy (Palone and Todd 1998, Wenger 1999, Klapproth and Johnson 2001, NCWRC 2002, ELI 2003, McNaught et al. 2003).

In a review of literature and application of professional judgment for protecting North Carolina's endangered fauna, the NCWRC (2002) and partners concluded that insufficient information exists to definitely state the minimum buffer widths needed to ensure the continued survival of federally endangered and threatened aquatic species. The NCWRC report recommended a minimum 200-feet native, forested buffer on perennial streams and a 100-feet forested buffer on intermittent streams, or the full extent of the 100-year floodplain, be required for new developments. They noted that minimum buffer widths may actually need to be more or less stringent depending on local conditions.

In their assessment of riparian buffer literature and existing buffer protections in North Carolina, Environmental Defense recommended a statewide riparian buffer rule that incorporates a two-zone, 50-foot (15 meter) buffer, coupled with sediment and erosion control and stormwater runoff control implementation (McNaught et al. 2003). The authors note their state-wide proposal represents a minimum buffer width essential to protect the most critical streamside lands. They further note that wider buffers should be protected either by regulation or incentive programs in environmentally sensitive watersheds (McNaught et al. 2003).

In 1998 the Clean Water Management Trust Fund funded a study to characterize existing riparian buffers along Goose, Stevens and Duck Creeks and the extent of protection provided by Mecklenburg County's Surface Water Improvement and Management (SWIM) program. While development has dramatically increased since that assessment, it is still instructive. The majority of forested riparian buffers along Stevens Creek were wider than 150-feet with a good mix of overstory and understory vegetation. Over 80% of the stream and its tributaries received a good or excellent buffer quality rating. However, there are several areas along Stevens Creek and tributaries that contain little or no vegetation. These areas include home lots with cleared riparian vegetation and farms with livestock access to the stream. There are many degraded areas along Goose Creek and its tributaries that contain little or no vegetation. Only 68% of the main stem of Goose Creek and its tributaries received good or excellent buffer quality ratings. Disturbed areas include home lots with cleared riparian vegetation and farms with livestock access to the stream. Many reaches of riparian buffers along Duck Creek and its tributaries contain wider than 150-feet forested riparian buffers. Approximately 77% of the mainstem of Duck Creek and its tributaries received good or excellent buffer quality ratings. There are several degraded areas that contain little to no vegetation. These also include home lots with cleared riparian vegetation, golf course maintenance areas, and farms with livestock access to the stream.

In addition to the available literature on buffers and the conservation easement study in Mecklenburg County, a site-specific examination of forested buffers in the critical habitat (and headwaters) of Carolina heelsplitter range-wide is available (Catena Group 2005). Using aerial photographs of the basins to estimate vegetated buffer widths, it was determined that greater proportions of the watersheds with the best remaining Carolina heelsplitter populations (Flat Creek / Lynches River, Cuffytown Creek and Turkey Creek in South Carolina) were in wider buffers. Over 80% of the riparian areas had buffers exceeding 200-feet; the corresponding figure for Goose Creek and Duck Creek was about 60%. Between 73 and 80% of the South Carolina streams with the best Carolina heelsplitter populations had buffers exceeding 500-feet. Only 50% of Goose Creek has vegetated riparian buffers this wide. While the analysis does not establish minimum buffer widths to protect Carolina heelsplitters, it does provide anecdotal evidence that the best remaining populations are associated with wider riparian buffers (Catena Group 2005).

Union County, Fairview, and Stallings are proposing a riparian buffer ordinance of 200-feet perpendicular from the top of the bank on perennial streams and 100-feet on intermittent streams. Because there is an interest in expanding buffers to include the full extent of the 100-year floodplain or a portion of the floodplain (e.g., the 50% of the FEMA fringe, as in Mecklenberg County) we evaluated regulatory implications of expanding buffers into various portions of the floodplain (Appendix D). Analysis of the land uses in the 100-year floodplain of Goose Creek indicates the majority of the existing 100-year floodplain area is comprised of forested and undeveloped land cover types (Figures D-1 through D-4). The average 100-year floodplain width on each side of the channel was 380-feet and 483-feet, respectively. Existing ordinances extend buffer protections to 100-feet plus 50% of the FEMA fringe area in other portions of Mecklenburg County; therefore, the average transect widths (190- and 240-feet, respectively, on each side of the channel) corresponding to 50% of the linear transect length were calculated for this scenario as well.

V. Existing Water Quality Management Framework

This overview of existing regulations and programs related to water quality management in the Goose Creek watershed highlights those that relate to the pollutant parameters of concern identified above. More thorough summaries of rules, programs, and policies noted here can be found the Yadkin-Pee Dee River basinwide water quality management plan (NCDWQ 2003) and the multi-stakeholder Goose Creek Watershed Plan (WECO 2002).

Federal Rules and Initiatives

Clean Water Act (33 U.S.C. 1251-1376)

Many of the provisions and programs of the federal Clean Water Act (including water quality classifications, standards, and point-source permitting) are implemented in North Carolina under the State's water quality management program administered by the NCDWQ. A few of the most pertinent sections of the Act are summarized here as they relate to Goose Creek watershed water quality issues.

Section 401 and 404 of the Clean Water Act regulate the filling or draining of wetlands. Section 404 (regulation of dredged and fill activities) is enforced by the U.S. Army Corps of Engineers), and Section 401 (certification that a project does not violate the state's water quality standards) is enforced by NCDWQ. All construction activities over a specific acreage that affect jurisdictional wetlands are required to obtain required wetlands permits. Although the State's 401 Water Quality Certification Program and the Corps 404 Program offer protection for wetlands by requiring avoidance and mitigation for wetlands, it is possible for permits to be issued under both the state and federal programs that allow small areas of wetlands to be lost.

Section 319 of the Clean Water Act provides grants for nonpoint source pollution reduction projects. One section 319 project has been funded in the Goose Creek watershed. The NCWRC received funds for a project to reduce peak stormwater and pollutant flows into Stevens Creek, restore degraded streambank, educate the community, and help them take ownership of further restoration and protection efforts. The project called for bioretention or stormwater retrofits working with willing residential owners of lots adjacent to the stream. Also, a pasture operation in the watershed would be contacted in an effort to fence its cattle out of the stream. Beginning in September 1999, the project conducted baseline biological, chemical and physical monitoring of Stevens Creek, selected a neighborhood for retrofits, made initial homeowner contacts, and found a willing participant. Finding significant homeowner resistance in the neighborhood, the contractor limited initial installation to one retrofit site, which was installed by June 2000. The contractor also conducted community meetings and grade school presentations and published articles in the local Mint Hill newsletter.

State Regulations and Incentives Programs

North Carolina Surface Water Classifications and Standards

North Carolina's Water Quality Standards program classifies waters for their best usage and applies water quality standards to protect those uses. The best use classification in Goose Creek and Duck Creek is Class C - aquatic life propagation/protection and secondary recreation. Class C water quality standards apply to this watershed, and they establish the level of water quality that must be maintained to support the aquatic life propagation and secondary recreation uses. Goose Creek and Duck Creek have no special supplemental designations, however the presence of the federally-endangered species and the watershed's poor water quality require a site-specific water quality management plan.

Point source discharges of wastes to waters of the State are also managed by NCDWQ. While general rules and policies apply State-wide, the NCDWQ (2001) developed a Goose Creek NPDES Permitting Policy for the facilities in that watershed due to its water quality problems. The wastewater facilities discharging to Goose Creek are relatively small, but their flows are significant sources of nutrients and chlorine. That policy affects existing and potential dischargers to the watershed with the following requirements: 1) no new or expanding discharges will be allowed; 2) existing facilities received chlorine limits between 17 and 28 ug/l; 3) facilities received new ammonia limits; and, 4) facilities were required to conduct additional monitoring of their effluents.

Clean Water Management Trust Fund

North Carolina's Clean Water Management Trust Fund helps finance projects that address water pollution problems. Projects may include those that enhance or restore degraded waters, protect unpolluted waters, and restore or protect buffers and greenways. In the Goose Creek watershed, one CWMTF project has been funded. In 1998 the NCWRC received funds for a Goose Creek buffer acquisition and planning project. The final report on this effort includes a point source removal feasibility study, a stormwater retrofit study in Mecklenburg County, and a conservation easements study in Mecklenburg County (Greenvest 2001).

NC Ecosystem Enhancement Program

The North Carolina Ecosystem Enhancement Program (NCEEP) is a non-regulatory program responsible for implementing wetland and stream restoration projects throughout the state. The program's mission is to improve watershed functions including water quality protection, floodwater retention, fisheries and wildlife habitat, and recreational opportunities. The NCEEP works with the basinwide planning approach to identify targeted local watersheds which receive priority for NCEEP planning and restoration project funds. In the Yadkin-Pee Dee River basin, Goose Creek has been identified as a priority watershed, due in large part to the presence of rare species and the impaired water quality that would benefit from restoration project implementation.

Erosion and Sedimentation Control

NC Division of Land Resources administers programs to control erosion and sedimentation caused by land disturbing activities on one or more acres of land. Control measures must be planned, designed and constructed to provide protection from the calculated peak rate of runoff from a 10-year storm. Enforcement of the program is at the state level, but can be delegated to local governments (usually counties or large municipalities) with certified erosion control programs. Mecklenburg County enforces its own erosion and sedimentation control program based on State requirements. The advantages of local program administration, like Mecklenburg County's Sediment and Erosion Control Program, are locally-crafted ordinances and increased staffing to provide technical assistance.

Regional Programs

Yadkin-Pee Dee River Basin Association

The Yadkin-Pee Dee River Basin Association was formed in 1997 to protect and improve water quality in the North Carolina portion of the basin and to represent the interests of NPDES permitted dischargers. The association's water quality monitoring program includes a station on Goose Creek, and those data are used by the NCDWQ in their basinwide planning; many of the same issues identified as problems in NCDWQ monitoring were also identified in the YPDRBA monitoring.

Local Government Rules and Initiatives

Town of Mint Hill-Mecklenburg County

The Mecklenburg County water quality management program is engaged in outreach, monitoring, assessment, modeling, enforcement, regulation, and restoration through their Surface Water Improvement and Management (SWIM) Program. In the Goose Creek watershed, Mint Hill adopted the Mecklenburg County SWIM Stream Buffer Ordinance with the exception that the buffer requirements begin at the point where the stream drains 50 acres or greater (the Mecklenburg County buffer policy begins at 100 acres) and the full extent of the 100-year floodplain is protected (the Mecklenburg County buffer policy protects 50% of the floodplain). The buffers require protection of a three-zone urban stream buffer system, with increased land use restrictions closer to the stream bank. The plan requires protection of natural vegetative and forested buffers around all perennial streams with drainage basins greater than 50 acres. According to the SWIM Stream Buffer Plan, total buffer widths requiring protection vary from 35 to 100+ feet, with wider buffers further downstream and increased use restrictions closer to the stream bank.

Table 5. Mint Hill SWIM Buffer requirements

Drainage Area	Stream Side Zone	Managed Use Zone	Upland Zone	Total Width of Buffer on each side of stream
> 50 acres	20 feet	None	15 feet	35 feet
> 300 acres	20 feet	20 feet	10 feet	50 feet
> 640 acres	30 feet	45 feet	Balance of floodway plus 100% of flood fringe, but no less than 25 feet	Floodway plus 100% of flood fringe, but no less than 100 feet

The SWIM buffer ordinance does not allow fill material into the buffer, however it is allowed in the upland zone. Maintaining diffuse flow within the buffer is required. In Mecklenburg County, perennial streams begin around 50 to 80 acre drainage areas (Rusty Rozzell, MCWQP, pers. comm.). The current SWIM buffer ordinance may not protect intermittent and some perennial streams. The complete ordinance specifies managed uses which are permitted, grandfathering provisions, mitigation options, and other specifics.

Mint Hill's stormwater ordinance requires that detention be provided for new development creating more than 20,000 ft^2 of impervious area. The ordinance allows for the exemption of sites adjacent to the regulated floodway and it is a working policy to exempt single-family developments. The detention ordinance does not contain design standards for detention facilities, but refers to the Charlotte-Mecklenburg Storm Water Design Manual. Detention facilities must be designed to match pre-development peaks for the two-year and 10-year design storms and safely pass the 50-year event. Property and development adjacent to the floodplain are exempt from stormwater treatment.

Mint Hill is required to implement NPDES - Phase II stormwater regulations. They have a conservation subdivision ordinance that requires 20 percent open space. The Town has proposed a Low Impact Development ordinance for the portion of the town in the Goose Creek watershed.

Mecklenburg County has a sediment and erosion control program. Required erosion control measures must be designed to provide protection from the calculated maximum peak of runoff from the 10-year storm. Structures must be designed so that post construction velocity of the 10-year storm does not exceed the maximum non-erosive velocity tolerated by the soil of the receiving watercourse or the soil of the receiving land. Mecklenburg County has addressed developers using the "forestry exemption" to clear land for development by not allowing land cleared in Mecklenburg County using forestry guidelines for sediment and erosion control to be developed within two years. Mecklenburg County would consider land cleared under forestry guidelines and developed with in two years as land cleared for development that did not have an approved sediment and erosion control plan.

Union County

Union County's protection of riparian buffers is a 20-feet setback along streams with no designated floodplain. A forested riparian buffer ordinance is being proposed; 200-feet perpendicular from the top of the bank on perennial streams and 100-feet on intermittent streams.

Union County's stormwater management ordinance states that "all developments shall be constructed and maintained so that adjacent properties are not unreasonably burdened with surface waters as a result of such developments." Union County has proposed to implement NPDES - Phase II stormwater requirements. This will require post-construction discharge rate be equal to the pre-development discharge rate from the one-year 24-hour storm and provide 85% total suspended solids removal. This rule will apply to new development projects that cumulatively disturb one acre or more, and to projects less than an acre that are part of a larger common plan currently under development when more than one acre cumulatively will be disturbed. The ordinance will also require the post-development discharge rate for the 10-year storm be addressed to manage water quantity concerns.

Agriculture, ground level streets, parking areas, lawns, play areas, parks, tennis courts and similar recreational uses are allowed in the floodway. The ordinance limits construction of buildings in the 100-year floodplain unless an engineer certifies that the bottom floor of the structure is at least two feet above the 100-year flood elevation. In addition, fill is allowed in the 100-year floodplain as long as fill does not increase the base stage by one foot or more. They are currently proposing an ordinance that allows no fill in the 100-year floodplain, with some exceptions.

Stallings

Currently, riparian buffers for Stallings include a 20-feet setback along streams with a designated floodplain. The town has proposed a forested riparian buffer ordinance; 200-feet perpendicular from the top of the bank on perennial streams and 100-feet on intermittent stream.

Stallings' stormwater ordinance requires that detention be provided for new development creating more than 20,000 ft^2 of impervious area. The ordinance allows for the exemption of sites adjacent to the regulated floodway and it is a working policy to exempt single-family developments. The detention ordinance does not contain design standards for detention facilities, but refers to the Charlotte-Mecklenburg Storm Water Design Manual. Detention facilities must be designed to match pre-development peaks for the two-year and 10-year design storms and safely pass the 50-year event. . Stallings is required to implement NPDES - Phase II stormwater requirements.

Stallings prohibits filling in the floodways. Agriculture, ground level streets, parking areas, lawns, play areas, parks, tennis courts and other similar recreational uses are allowed in the floodway. The ordinance also limits construction of buildings in the 100-year floodplain unless an engineer certifies that the bottom floor of the structure is at least two-feet above the 100-year flood elevation. In addition, fill is allowed in the 100-year floodplain as long as the fill does not increase the base stage by one-foot or more. They are proposing an ordinance that allows no fill in the 100-year floodplain, with some exceptions.

Indian Trail

Indian Trail's protection of riparian buffers is a 20-feet setback along blue-line streams. Indian Trail expects to have a new floodplain protection ordinance in 2006.

Indian Trail's stormwater ordinance requires that detention be provided for new development creating more than 20,000 ft^2 of impervious area. The detention ordinance does not contain design standards for detention facilities, but refers to the Indian Trail Storm Water Design Manual. Detention facilities must be designed to match pre-development runoff rates for the two-year and 10-year design storms and safely pass the 50-year event. The design must ensure no upstream or downstream impacts.

Stormwater detention are required on any site with a post-developed impervious area of greater than 20,000 ft^2 including PUD, PRD, and PND Cluster development and all single family district except for R-20, RA-20, R-40 and RA-40. Areas adjacent to floodplains may be exempt from the detention requirement if documentation sealed by a professional engineer is approved by the Town of Indian Trail Engineer. Detention facilities shall be required to control the peak run off release rate for both the two-year and 10-year storms with an emergency overflow capable of out letting the 50-year discharge. Engineering calculations shall be provided to demonstrate that the post-developed discharge rate is no greater than the pre-developed discharge rate. Routing calculations must be used to demonstrate that this volume is adequate. Engineering shall be provided to document that the post development discharge rate is no greater than the pre-developed discharge rate. Storage volume shall be sufficient to attenuate the post-development peak discharge rate to the pre-development discharge. Routing calculations must be used to demonstrate if this volume is adequate. Indian Trail is required to implement NPDES - Phase II stormwater regulations for small MS4s.

Fairview

Fairview does not allow fill or buildings within 20-feet of streams that are outside of a designated floodplain. A forested riparian buffer ordinance is being proposed; 200-feet perpendicular from the top of the bank on perennial streams and 100-feet on intermittent streams.

Fairview's stormwater management ordinance states that all developments shall be constructed and maintained so that adjacent properties are not unreasonably burdened with surface waters as a result of such developments. It also requires the use of grass swales where applicable.

Agriculture, ground level streets, parking areas, loading areas, lawns, play areas, parks, tennis courts, golf courses and similar recreational uses are allowed in the floodway as long as there is no change in base flood levels. The ordinance prohibits residential and non-residential buildings in the floodway and the 100-year floodplain. Residential accessory structures are allowed within a floodplain if there are no other locations on the lot outside of the floodplain where they can reasonably be located. Substantial improvements to non-residential buildings may be possible. Fill is allowed in the 100-year floodplain.

VI. Water Quality Restoration and Management Recommendations for NCDWQ and other Stakeholder Consideration

Water quality restoration in Goose Creek and Duck Creek is already a goal of interested parties locally. The Goose Creek Watershed Advisory Committee has made broad-scale recommendations to protect and improve water quality and wildlife habitat (WECO 2002) under the following priority goals: 1) protect creek from runoff and urbanization; 2) maintain and improve integrity of the stream; 3) achieve a rating of "fully supporting" for Goose Creek; 4) protect open space; and, 5) preserve farmland. The following recommendations for additional measures to achieve water quality improvement in Goose Creek were derived from the information in this technical support document.

Establish site-specific water quality standards for ammonia, copper, nitrate-nitrite and phosphorus : Ammonia and copper were listed as parameters of concern by several investigators of water quality impairment in Goose Creek. Available toxicological information indicates that freshwater mussels are quite sensitive to these common pollutants, but there are at present no State water quality standards for them. To improve water quality and address conservation of Goose Creek and Duck Creek's aquatic mussels, an acute water quality standard of 1.75 mg/l total ammonia as N and chronic standard of 0.50 mg/l are recommended (based on the 90th percentile pH of 8 for Goose Creek). An acute water quality standard of 3.6 ug/l copper and chronic standard of 2.2 ug/l are recommended (based on the 10th percentile hardness of 34 mg/l). The proposed ammonia standards are exceeded in Goose Creek at present, but rarely exceeded in reference watersheds with recognized excellent water quality. They are scientifically sound, reasonable and achievable. The proposed copper standards would be protective of mussels and are exceeded in Goose Creek at present. Part of their implementation should include monitoring for the more toxic dissolved copper (in addition to the currently monitored total copper) to gage the significance of elevated concentrations in Goose Creek. A reference watershed approach was used to derive proposed numeric targets for nitrate-nitrite (0.4 mg/l) and total phosphorus (0.1 mg/l).

Because of the unique geomorphology of slate belt streams, it was not possible to develop a reference watershed-based approach for a total suspended sediment standard. Sediment will likely be reduced by some of the same practices to be recommended for nutrient reduction and bank stability because high nutrient concentrations in this watershed are correlated with high sediment levels and stormflow.

Revisit point source permit loads: The Goose Creek NPDES Permitting Policy was a significant contribution to restoration of water quality in the basin. However, there are a few point source issues that remain to be addressed. First, the low flow statistics used in the strategy for establishing the extent of expected dilution need to be revised. Recent droughts have revealed that portions of Goose Creek (and even more frequently Duck Creek) do not have flow for significant periods, and the dilution potential of the creeks at these times is nonexistent. Accordingly, permit limits will need to be revised to reflect this lack of dilution. Secondly, the permit limits for ammonia, nitrate-nitrite and phosphorus will need to be revised to meet the standards recommended above. Attention should be given to converting wastewater facilities to land application or tying into a larger regional facility; eliminating their discharge to the creek is justified with the extremely low dilution potential. The policy of no additional point source discharges should be continued.

Address existing nonpoint source concerns: Livestock entry to Goose Creek is a documented problem which can contribute to the stream bank instability, nutrient enrichment, fecal coliform contamination, and sedimentation. Efforts should be made to restrict this practice.

Continuing existing efforts to inventory unstable stream banks and seek their restoration should be expanded. Restricting ATVs from the Goose Creek and Duck Creek streambed will prevent damage to mussels and other aquatic fauna and support other water quality restoration measures. Rules for the Goose Creek watershed should specifically prohibit motorized vehicle traffic, including ATVs, from the stream.

New impervious surface thresholds and stormwater controls: Because of the apparent lack of thresholds for aquatic community impact, the existing levels of impervious cover in the Goose Creek watershed, the currently impaired water quality, and the documented significant and continuing decline in the range and abundance of the Carolina heelsplitter and all other mussel species in the watershed, an argument can be made for requiring all new development in the watershed to implement stormwater control. At a minimum, permits for new developments exceeding 6% imperviousness should be required to include stormwater controls designed to replicate and maintain the hydrographic condition (peak and volume controls) at the site prior to the change in landscape and include provisions that satisfy WS II-HQW standards. Proposed developments should identify anticipated impervious surface amounts prior to sketch plan and plat approval.

Low impact development techniques for stormwater control (*Low Impact Development;* EPA Document # 841– B-00-002 and 841-B-00-003) are encouraged. Infiltration practices (e.g., reduced road widths, rain gardens, parking lot bioretention areas, increased sheet flow instead of ditching, and disconnect impervious areas) to maintain predevelopment hydrographic conditions should be emphasized over detention ponds. To minimize impacts from impervious surfaces, grassed swales should be used in place of curb and gutter for new developments. Curbs and gutters may be used in combination with sidewalks in areas where clustering of uses increases the net local density to greater than four dwelling units per acre.

Stream habitats are maintained most effectively when stormwater runoff is dispersed through a vegetated or grassed buffer zone prior to entering the riparian buffer and well before entering the stream. Stormwater collected in piped conveyance systems should be directed away from surface waters and BMPs should be employed at both the intake and the outlet areas for energy dissipation. Point or concentrated discharges to surface waters, filter strips or protected buffers should be avoided (with check dams, level spreaders, and other associated BMPs used outside the buffer to minimize effects of stormwater runoff entering riparian buffers).

Emergency management procedures should be provided for the containment of runoff from fighting residential, commercial, or industrial fires and for the removal and clean up of any hazardous spills that may endanger nearby streams, instead of flushing contaminants into waterways. Site gas stations, car washes, and other “spill” land uses at least 200-feet from streams and wetlands.

Expand riparian buffer protections: Reduced forested riparian buffers in the Goose Creek watershed and the need for riparian land restoration and protection have been cited as a concern by several investigators. Increased development pressure will further reduce the extent of riparian buffers. Mint Hill’s SWIM buffer ordinance does not adequately protect intermittent and perennial streams from increased development. Union County, Town of Stallings, Fairview and the Town of Indian Trail do not have buffer ordinances; however, several of these municipalities have proposed protecting 200-feet along each side of the bank on perennial streams and 100-feet along each side of the bank on intermittent streams. Those buffer widths would adequately protect aquatic resources and riparian buffer functions in the Goose Creek watershed, but consideration should be given to expanding them to include the extent of the 100-year floodplain and to require they be forested upon changes in landuse. No new fill or buildings should be allowed in the 100-year floodplain. All waters of the State in the Goose Creek watershed should be delineated according to the U. S. Army Corps of Engineers and NCDWQ methodology and identified on all proposed development sketch plans to facilitate buffer implementation.

Revisit state minimum requirements for sediment and erosion control: To improve water quality and aquatic habitat in the Goose Creek watershed, the state minimum requirements for sediment and erosion control will need to be revised. Sediment and erosion control measures should be state-of-the-science and employ advanced settling devices. Clearing and grading should be phased and minimized. Disturbed soils should be required to have sites planted and stabilized within a week after disturbance. Control measures should rely on a treatment train as opposed to end of pipe treatment. Point or concentrated discharges to filter strips or protected buffers should be avoided. Flow should be diffused throughout the entire filter strip or buffer. Mecklenburg County's draft sediment and erosion control measures for sensitive watersheds should be examined for use in this watershed.

Policies should not allow developers to use forestry and agricultural exemptions for clearing, filling, and grading. Developers and builders, including land-clearing operators, should be required to participate in a stormwater and sediment erosion control education program. Certification and bonding is recommended.

Expand monitoring to assess the efficacy of restoration efforts: Currently, water chemistry data is collected only in the upper portion of the Goose Creek watershed (by NCDWQ, YPDRBA and MCDWQP). This should be expanded to include water quality monitoring stations on Stevens and Duck Creeks (to cover important tributaries) as well as at the Highway 601 or Brief Road crossing of Goose Creek (to cover the lower portions of the watershed). These stations will be important in determining the efficacy of the restoration effort (e.g., attaining the site-specific water quality standards and stabilizing or reversing increasing pollutant trends).

Minimize impacts from wastewater, water, and utility infrastructure: To protect streams and riparian buffers, we recommend that sewer lines, water lines, and other utility infrastructure be kept out of riparian buffer areas and follow along the outside of the 100-year floodplain contour unless topographic features, existing development, or other conditions restrict this technique. Force mains should be used to the greatest extent practicable for wastewater. Sewer lines close to streams should be constructed of ductile iron or other substance of equal durability. All water lines and utilities should follow roads or meet the requirements associated with sewer line placements. All utility crossings should be kept to a minimum, which includes careful routing design and the combination of utility crossings into the same right-of-way (provided there is not a safety issue). Discontinuous buffer segments can impair riparian functions disproportionate to the relative occurrence of the breaks in the buffer, and multiple crossings can result in cumulative impacts. The directional bore (installation of utilities beneath the riverbed, avoiding impacts to the stream and buffer) stream crossing method should be used for utility crossings wherever practicable, and the open cut stream crossing method should only be used when water level is low and stream flow is minimal. Manholes or similar access structures should not be allowed within buffer areas. Stream crossings should be near perpendicular (75^{o} to 105^{o}) to stream flow and should be monitored at least every three months for maintenance needs during the first 24 months of the project and then annually thereafter. Sewer lines associated with crossing areas should be maintained and operated to prevent the discharge to land or waters.

Maintenance of Right-of-Ways: Right-of-ways can fragment the already reduced native forested buffers in the Goose Creek watershed. Native, forested plant communities should be maintained within a 200-feett buffer area of streams, floodplains, and associated wetlands. A closed canopy should be maintained over streams. Emphasis will be placed upon trimming trees, instead of tree removal, within 200-feet of streams, floodplains, and associated wetlands. Pesticides use in rights-of-way should avoid areas within 200-feet of streams, floodplains, and associated wetlands except when needed to protect native flora and fauna from exotics and when using appropriately labeled products, such as biopesticides (http://www.epa.gov/pesticides/biopesticides/; accessed May 2002).

Pesticide monitoring and use: Pesticide data has not been collected in the Goose Creek watershed. However land use practices that use pesticides, such as golf courses, agriculture, residential are located within the watershed. In order to protect the aquatic resources in the watershed, we recommend monitoring for pesticides in the headwaters and lower reaches of Goose Creek and Duck Creek. Because there are hundreds of pesticides registered for use and commonly used, monitoring should focus on those compounds used in the watershed. The Union County and Mecklenburg County Extension Services have provided lists of these compounds for agriculture, golf course management, and construction activities. As precautionary measures, we recommend aerial application of pesticides be at least 200-yards from Goose Creek and Duck Creek and ground applications follow the recommendations outlined by USEPA (1996).

Minimize water withdrawals: The Goose Creek watershed is susceptible to low flows during dry periods due to low groundwater recharge. Effects of wastewater treatment plants are exacerbated during these dry events. Therefore, we recommend not allowing water withdrawals in the Goose Creek watershed during summer months.

Enhance resource agency coordination: Goose Creek, Duck Creek and their tributaries have been directly impacted without regulatory agency notification or review by resource agencies. Although nationwide permits are designed for regulatory streamlining of otherwise routine activities, degraded water quality and presence of listed species in the Goose Creek watershed will need a modified approach. It is recommended that any impacts to jurisdictional streams, wetlands, or streamside buffers require review by NCDWQ (under the CWA section 401 provisions). Resource agencies should be allowed to review and comment on all activities or requests for variances.

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Appendix A. Derivation of Ammonia Water Quality Standard for Freshwater Mussels

North Carolina does not have a water quality standard or action level for ammonia, and ambient water quality data indicate this parameter is a concern for Goose Creek. To derive an estimate of the ammonia concentration that would not be harmful to freshwater mussels, available toxicity data were reviewed and summarized as described here. We started with the recent U.S. Environmental Protection Agency (USEPA) water quality criteria document for ammonia (USEPA 1999) and added data for freshwater mussels. Note that much of this process has been documented in a publication which can be referenced for additional detail (Augspurger et al. 2003).

The steps to deriving an ammonia standard for Goose Creek included the following:

1) First, we compiled available ammonia toxicity data. We reviewed the dataset used in the revised USEPA water quality criteria document for ammonia (USEPA 1999). Next, we searched the Toxline® and AQUIRE databases, and queried researchers familiar to us with experience in mussel toxicity testing to incorporate mussel toxicity data in the database. Test endpoints were LC50s (median lethal concentration, or an estimated concentration that is expected to be lethal to 50% of a group of test organisms). Note that LC50s are not protective values because the endpoint is lethality; they are a commonly reported toxicity testing statistic and used as a staring point for deriving safe concentrations.

2) We evaluated data from all sources for acceptability using guidance modified from the USEPA (Stephan et al 1985). Studies that demonstrated acceptable survival in control treatments ($\geq$ 80 %), used measured rather than nominal values for ammonia test concentrations, and documented test water pH and temperature to allow calculation of total and un-ionized ammonia concentrations were deemed acceptable and were used in our analysis.

3) The toxicity of ammonia varies with temperature and pH (which influence the fraction of total ammonia that exists in the ionized, and more toxic, un-ionized states). Recommended water quality criteria for ammonia have been presented as un-ionized ammonia (NH_3) (USEPA 1985) and as total ammonia as nitrogen ($NH_3 + NH_4^+$ - N) (USEPA 1999). We used the original studies' reported total ammonia LC50s, if available. All reported un-ionized ammonia LC50s were converted to total ammonia as nitrogen using the reported temperature and pH data and a published pK relationship (Emerson et al. 1975); these were also normalized to pH 8 using the equations in Appendix 3 of the USEPA ammonia criteria document. Concentrations for acute exposures are correspondingly reported as mg/l total ammonia as N at pH 8 (Table A-1).

4) Toxicity data were summarized by the methodology described in USEPA numeric water quality criteria guidelines (Stephan et al. 1985). National water quality criteria in the U.S. generally consist of two estimated values designed to protect aquatic organisms; these are commonly referred to as the acute and chronic water quality criteria, but more specifically, they are the criteria maximum concentration (CMC) and criteria continuous concentration (CCC), respectively.

   A. The CMC is an estimate of the highest one-hour average concentration that should not result in unacceptable adverse effects to aquatic organisms; the number is derived from acute, or short-term, toxicity tests (generally 48 to 96 h exposures) that use lethality or immobilization as the measured endpoints. In deriving the CMC, available toxicity data are critically reviewed, and geometric mean LC50s for each genus (genus mean acute values, or GMAVs, the geometric mean of the LC50s from all acceptable tests for that genus) are calculated (Table A-2).

We added the freshwater mussel GMAVs to the acute dataset for ammonia toxicity in the current USEPA criteria document (USEPA 1999). The GMAVs are ranked from highest (most tolerant) to lowest (most sensitive) (Table A-3). A cumulative probability is assigned based on those ranks, and a Final Acute Value (FAV) is derived as the fifth percentile of the GMAVs using an equation that gives equal weight to the GMAVs of the four genera with percentile ranks closest to 0.05. The CMC is calculated by dividing the FAV by 2 and results in a concentration that should not severely adversely affect too many individuals within the taxa that were used for deriving the FAV (Stephan et al. 1985). Evaluation of acute toxicity data has generally shown that dividing an LC50 or EC50 by 2 provides a concentration equal to a very low effect or no effect concentration. The process, by definition, is designed to protect populations of 95% of the species tested from adverse effects of short term exposures to non-bioaccumulative chemicals.

Addition of freshwater mussel GMAVs to the acute dataset for ammonia toxicity in the current USEPA criteria document and use of equations from the USEPA water quality criteria methodology allowed us to recalculate water quality guidance with a dataset in which mussels are well represented. We defined outputs from this process as a freshwater mussel FAV (FAV_{FM}) and a freshwater mussel criteria maximum concentration (CMC_{FM}). The FAV_{FM} was 3.50 mg/l total ammonia as N at pH 8 and corresponding CMC_{FM} was 1.75 mg/l total ammonia as N at pH 8.

Our CMC_{FM} was calculated by normalizing all data to pH 8. Because the acute toxicity of ammonia varies strongly with pH, the equations in the USEPA criteria document (1999) were used to adjust the CMC_{FM} for other pH values observed in Goose Creek. To determine the range of pH values for the creek, we summarized available data from the North Carolina Division of Water Quality (NCDWQ) ambient monitoring station at Stevens Mill Road (SR 1524). From a dataset of 80 values for which there are matched ammonia and pH values (with 4 outliers above pH 9 removed), Table A-4 was created and used to translate the CMC_{FM} at pH 8 derived above to other pH values for Goose Creek.

For the Goose Creek site specific water quality management plan, it is recommended that the CMC_{FM} for pH 8 be used. This was the 90th percentile value of the NCDWQ dataset (Table A-4) and as such will be protective most of time. The recommended acute water quality standard for Goose Creek is 1.75 mg/l total ammonia as N. As with USEPA's criteria, this value should be applied as a one hour average exposure which should not be exceeded more than once every three years.

B. The Continuous Criterion Concentration (CCC) addresses chronic (longer-term) exposures. The CCC is derived from a set of 'chronic values' - the average of the highest no observed effect concentrations and lowest observed effect concentrations for survival, growth, or reproduction in tests which range from seven days to several months or more. Either by direct calculation or by the use of acute-chronic ratios (ACR, or a mathematical relationship defining the additional sensitivity in long versus short term exposures), the CCC is set to an estimated fifth percentile of Chronic Values. To make exceeding the level of toxicity associated with the CCC a relatively rare event, the criteria further state that four-day average exposure concentrations should not exceed the CCC more frequently than once every three years on the average.

There were no chronic ammonia exposure data for freshwater mussels, so we could not directly derive a criteria continuous ammonia concentrations which may be protective of freshwater mussels (defined here as a CCC_{FM}) with actual long-term exposure data. Without chronic exposure data, no ammonia ACRs for freshwater mussels could be calculated. Consequently, we estimated the upper and lower bounds of ACRs (defined here as estimated ACRs, or eACRs) that could be applied to the FAV_{FM}s to adjust that toxicity estimate for longer-term exposures. Note that use of ACRs is an acceptable approach for criteria development when chronic data are lacking (Stephan et al. 1985). The USEPA (1999) ammonia criteria document reports seven genus mean ACRs for fish and aquatic invertebrates ranging from 1.9 to 10.9, and the maximum value from that range defined our upper bound eACR. Our lower bound eACR was derived by evaluating two sub-chronic freshwater mussel ammonia tests. In juvenile *Lasmigona subviridis* exposures, a geometric mean 4 d LC50 of 3.83 mg/l total ammonia as N at pH 8 and a 15 d LC50 of 0.57 mg/l total ammonia as N at pH 8 have been reported (Black 2001); the ratio of these two LC50s is 6.7. In juvenile *Utterbackia imbecillis* studies (Wade 1992), a 4 d LC50 of 10 mg/l total ammonia as N at pH 8, and a 9 d no observed effect concentration of 2.6 mg/l total ammonia as N at pH 8 can be estimated; the ratio of these concentrations is 3.8. The geometric mean of these two acute to sub-chronic ratios (5.0) defined our lower bound eACR.

The FAV_{FM} was divided by the lower and upper bound eACRs (5.0 and 10.9, respectively) to yield estimates of CCC_{FM}s from 0.3 to 0.7 mg/l total ammonia as N at pH 8 and 25^{o}C. For the Goose Creek site specific water quality management plan, the mean of these two estimates (0.5 mg/l as N) is recommended as a site specific chronic water quality standard. As with USEPA's criteria, this value should be applied as a four-day average exposure which should not be exceeded more than once every three years.

5) The appropriateness of the standard was evaluated relative to USEPA (Stephan et al. 1985) guidance. The data driving the calculation appear robust. The range of acute values for all of the mussel species was less than a factor of ten (i.e., not highly variable), and there was also a less than ten-fold difference between the four lowest genus mean acute values.

The final acute value appears reasonable in comparison with species mean acute values (SMAVs, or the geometric mean of the LC50s from all acceptable tests for that species) and GMAVs. The FAV_{FM} was 3.50 mg/l total ammonia as N at pH 8 and is not the lowest value that could be recommended based on the existing data. Note that SMAVs for the Atlantic pigtoe and fatmucket are lower than this value. However, lowering the FAV to the SMAVs for these species does not appear necessary; the fatmucket is not a resident of Goose Creek and therefore additional protection for that species is not recommended. The Atlantic pigtoe should be protected by the chronic standard recommendation.

The site-specific chronic standard of 0.5 mg/l also appears reasonable. Recall that this value was the average of two estimates (0.3 to 0.7 mg/l total ammonia as N at pH 8), making it not the highest or lowest estimate that could be defended on the basis of existing data. It is also noteworthy that the 0.5 mg/l recommendation is similar to estimated safe ammonia concentrations recently reported by Mummert et al (2003) for two unionid species (0.2 and 0.5 mg/l total ammonia as N when normalized to pH 8). Since our initial analysis of the ammonia data in 2003, the U.S. Geological Survey's Columbia Environmental Science Center has completed a 28-day exposure of juvenile *Villosa iris* to ammonia. They report an ammonia ACR of 7.6 (Chris Ingersoll, USGS, pers. comm..). This brackets the ACRs we used (5 to 10.9) and is quite close to the geometric mean of those two estimates (7.4).

In addition to the toxicological appropriateness of the recommended site-specific standards, they were evaluated relative to ambient data. Clearly, a standard that was far lower than concentrations observed in relatively un-impacted waters of the State would not be appropriate (i.e., the standard would likely be too restrictive). Also, if the standard was far in excess of actual concentrations, it might not be relevant.

To address this issue, we plotted Goose Creek ammonia concentrations from the NCDWQ dataset side-by-side with those of potential reference watersheds for ammonia. We defined potential reference watersheds for ammonia as those in the Yadkin and Catawba basin which the State has rated as having excellent water quality and which also had an ambient monitoring station collecting long-term ammonia data. From Figure A-1, it is apparent that the Goose Creek proposed site-specific ammonia standards for acute (1.75 mg/l) and chronic (0.5 mg/l) are reasonable. The acute standard is never exceeded in the reference watersheds, and the chronic standard is only rarely exceeded.

On the basis of lab and field information, the standards appear consistent with sound scientific evidence.

6) An evaluation of ammonia standard uncertainties was conducted. Ammonia toxicity data do not exist for the Carolina heelsplitter, and those data are unlikely to become available due to the rarity of this species (i.e., there are not enough individuals to test directly). Consequently, the ammonia sensitivity of this species is unknown. The database we compiled has data for ten other species of freshwater mussel in eight genera, including the genus *Lasmigona*, which contains the Carolina heelsplitter. There appears to be sufficient data to support establishment of the site-specific acute standard for Goose Creek. Of the four genera with a cumulative probability closest to 0.05 (which drive the calculation of the CMC), all are genera which occur in North Carolina (*Medionidus*, *Lampsilis*, *Lasmigona* and *Fusconaia*).

Chronic exposure data and sublethal endpoints assessments are generally lacking for mussels and should be initiated. Also, the lack of ACRs for mussels and ammonia is a hindrance. Our eACRs, however, appear reasonable. Our lower bound eACR of 5.0, derived from 9 to 15 d ammonia toxicity tests with mussels which measured lethality as the test endpoints, is only an initial approximation of a suitable ACR. Our upper bound eACR of 10.9 is also uncertain; it is merely the highest of the seven genus mean ACRs reported in the USEPA (1999) ammonia criteria document, but individual species ACRs for fish and aquatic invertebrates ranged from 1.2 to 20.7. Until long term ammonia exposure and sublethal effects data are produced for mussels, it will be difficult to generate definitive protective State or site-specific standards for chronic exposure. While a lower value could be rationalized, the geometric mean approach we used is reasonable. Our calculations did not consider additional margins of safety that could be recommended for protection of threatened or endangered mussel species in instances where information is specifically lacking. It could be argued that our lower estimate (0.3 mg/l) of the CCC_{FM} should apply to address this uncertainty.

7) We also addressed the implications of the site-specific criteria. As noted under section 5 in this appendix (which references Figure A-1 and Table A-5), the site-specific standards appear reasonable with respect to ammonia concentrations in waters relatively un-impaired by nutrients like ammonia. Ammonia is a parameter of concern in Goose Creek and concentrations above these site-specific standards have been documented. Figure A-2 plots the NCDWQ's ammonia data for Goose Creek against these two standards. Summary statistics indicate that only 5% of the values exceed the acute standard. The median or 50th percentile concentration of ammonia (0.09 mg/l) is 5 times lower than the chronic standard indicating it is readily achievable. The 75th percentile concentration of 0.5 mg/l equals the recommended chronic standard indicating exceedence of this value 25% of the time with 10% of the concentrations nearly double this value. Actions to reduce point-source and nonpoint-source ammonia loads to the creek will be recommended to achieve these standards as part of the implementation component of the site-specific water quality management plan.

Table A-1. Toxicity data for ammonia and freshwater mussels. LC50s reported in original references have been converted to mg/l total ammonia as N, normalized to pH 8.

Species	Lifestage	Duration	Temp.	pH	LC50	Reference
Rainbow	glochidia	24 h	22	8.1	5.17	Goudreau et al. 1993
(*Villosa iris*)	glochidia	24 h	20	7.9	2.42	Scheller 1997
	juvenile	96 h	25	8.2	9.09	Scheller 1997
	juvenile	96 h	25	8.2	8.21	Scheller 1997
	juvenile	96 h	25	8.1	5.64	Scheller 1997
	juvenile	96 h	12	7.3	6.60	Mummert et al. 2003
	juvenile	96 h	21	7.4	4.23	Mummert et al. 2003
Paper pondshell	glochidia	48 h	25	8.0	10.42	Black 2001
(*Utterbackia imbecillis*)	glochidia	48 h	25	8.0	2.38	Black 2001
	glochidia	48 h	25	8.0	3.15	Black 2001
	glochidia	48 h	25	8.1	7.46	Keller, pers. comm..
	juvenile	96 h	25	8.0	2.73	Black 2001
	juvenile	96 h	25	8.3	15.46	Black 2001
	juvenile	96 h	25	8.2	8.00	Black 2001
	juvenile	96 h	25	8.2	7.13	Black 2001
	juvenile	96 h	25	8	19.67	Keller, pers. comm..
Giant floater	adult	96 h	25	7.5	8.69	Scheller 1997
(*Pyganodon grandis*)	adult	96 h	25	7.7	9.26	Scheller 1997
Green floater	juvenile	96 h	24	7.7	4.05	Black 2001
(*Lasmigona subviridis*)	juvenile	96 h	24	7.7	4.05	Black 2001
	juvenile	96 h	25	7.9	3.42	Black 2001
Atlantic pigtoe (*Fusconaia masoni*)	glochidia	24 h	25	7.6	2.56	Black 2001
Pheasantshell	glochidia	48 h	25	8	3.76	Keller, pers. comm..
(*Actinonaias pectorosa*)	juvenile	96 h	25	8	14.05	Keller, pers. comm..
Cumberland moccasinshell (*Medionidus conradicus*)	glochidia	48 h	25	8	4.24	Keller, pers. comm..

Table A-1 (continued)

Species	Lifestage	Duration	Temp.	pH	LC50	Reference
Fatmucket	juvenile	96 h	24	8.3	0.74	Myers-Kinzie 1998
(*Lampsilis siliquoidea*)	juvenile	96 h	24	8.3	2.27	Myers-Kinzie 1998
Plain pocketbook	juvenile	96 h	20	8.5	9.97	Newton, pers. comm..
(*Lampsilis cardium*)						
Wavy-rayed lampmussel	juvenile	96 h	12	7.8	10.88	Mummert et al. 2003
(*Lampsilis fasciola*)	juvenile	96 h	21	8.0	7.18	Mummert et al. 2003
Longer term tests						
Utterbackia imbecillis	juvenile	9 d	24	7.8	3.05	Wade 1992
Lasmigona subviridis	juvenile	15 d	22	8.0	0.57	Black 2001

Table A-2. Freshwater mussel genus mean acute values (GMAVs) for ammonia toxicity, listed in order of increasing sensitivity. All GMAVs are in mg/l total ammonia as N, normalized to pH 8.

Genus Rank	Genus	GMAV
8	*Pyganodon*	8.97
7	*Actinonaias*	7.27
6	*Utterbackia*	6.71
5	*Villosa*	5.47
4	*Medionidus*	4.24
3	*Lampsilis*	4.20
2	*Lasmigona*	3.83
1	*Fusconaia*	2.56

Table A-3. Ranked genus mean acute values (GMAVs) from the USEPA (1999) ammonia water quality criteria document with the **freshwater mussel GMAVs from Table A-2 (listed in bold type here**) added. Taxa are ranked from least sensitive to most sensitive. The 5th percentile of these median lethal values was calculated as the Final Acute Value (FAV). This value was divided by 2 (to compensate for the lethal effect endpoint) to derive the criteria maximum concentration (CMC), a value that should be protective in short-term exposures.

Rank	Genus	GMAV (mg/l total ammonia as N at pH8)		
42	*Philarctus*	388.8		
41	*Orconectes*	246.0		
40	*Asellus*	210.6		
39	*Ephemerella*	189.2		
38	*Callibaetis*	115.5		
37	*Stenelmis*	113.2		
36	*Crangonyx*	108.3		
35	*Tubifex*	97.82		
34	*Helisoma*	93.52		
33	*Arcynopteryx*	77.10		
32	*Physa*	73.69		
31	*Cottus*	51.73		
30	*Gambusia*	51.06		
29	*Pimephales*	43.55		
28	*Catostomus*	38.11		
27	*Daphnia*	36.82		
26	*Salvelinus*	36.39		
25	*Musculium*	35.65		
24	*Ictalurus*	34.44		
23	*Simocephalus*	33.99		
22	*Poecilia*	33.14		
21	*Dendrocoelum*	32.82		
20	*Morone*	30.89		
19	*Campostoma*	26.97		
18	*Micropterus*	26.50		
17	*Stizostedion*	26.11		
16	*Ceriodaphnia*	25.78		
15	*Notropis*	25.60		
14	*Salmo*	23.74		
13	*Lepomis*	23.61		
12	*Oncorhynchus*	21.95		
11	*Etheostoma*	17.96		
10	*Notemigonus*	14.67		
9	*Prosopium*	12.11		
8	***Pyganodon***	**8.97**		
7	***Actinonaias***	**7.27**		
6	***Utterbackia***	**6.71**		
5	***Villosa***	**5.47**		
4	***Medionidus***	**4.24**		
3	***Lampsilis***	**4.20**		
2	***Lasmigona***	**3.83**	Final Acute Value (FAV)	3.50
1	***Fusconaia***	**2.56**	Criteria Maximum Concentrations (CMC)	1.75

Table A-4 Freshwater mussel criteria maximum concentration (CMC_{FM}) (mg/l total ammonia as N) for various pH conditions of Goose Creek.

Goose Creek pH[1]		Corresponding CMC_{FM} for that pH [2]
Minimum	6.6	9.80
10th percentile	6.9	8.20
25th percentile	7.1	6.85
50th percentile	7.4	4.80
75th percentile	7.7	3.00
90th percentile	8.0	1.75
Maximum	9.0	0.30

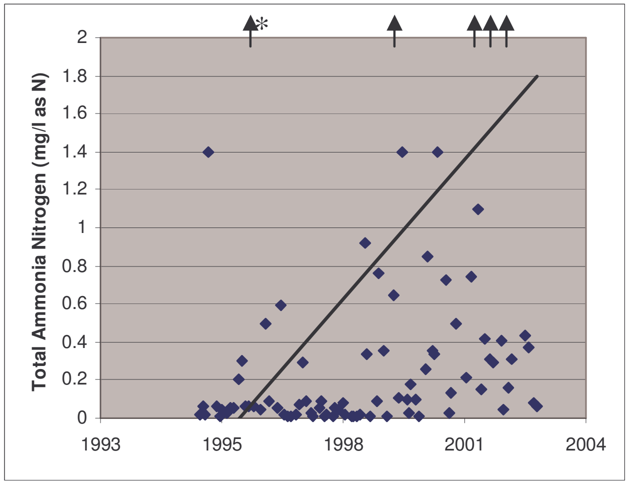
1 Summarized available data from the ambient monitoring station at Steven Mill Road (SR 1524) (n = 80 values from 1995 to 2003 for which there are matched ammonia and pH values, with 4 outliers above pH 9 removed).

2 A pH-specific CMC obtained by substituting the CMC_{FM} at pH 8 into equation 11 (pg 34) of USEPA 1999

Table A-5. Median, 90th-percentile and maximum nutrient concentrations of selected ambient monitoring sites in the Yadkin-Pee Dee (1996-2000) and Catawba (1997-2002) river basins as potential reference watersheds for nutrient targets in Goose Creek. All values are mg/ l.

		Drainage		-------- Total ammonia --------			--------- Nitrate / Nitrite ---------			-------- Phosphorus --------		
Watershed	Class	Area	Rating	Median	90th	Maximum	Median	90th	Maximum	Median	90th	Maximum
Dutchmans Creek	WSIV	3	Excellent	0.01	0.08	0.12	0.01	0.05	0.11	0.01	0.03	0.20
Uwharrie River	WSIV		Excellent	0.02	0.10	0.81	0.21	0.38	0.81	0.03	0.13	0.50
Hunting Creek	WSIII	155	Excellent	0.01	0.13	0.50	0.79	0.92	1.1	0.04	0.13	0.50
Little River	C-HQW	106	Excellent	0.01	0.20	0.39	0.15	0.30	0.63	0.06	0.19	0.50
Linville River	B-HQW	67	Excellent	0.01	0.09	0.23	0.18	0.30	0.38	0.01	0.03	0.10
Jacob Fork	WSIII-ORW	26	Excellent	0.01	0.08	0.50	0.06	0.16	0.50	0.01	0.05	0.50
Goose Creek	C	10	Poor	0.09	0.99	14	0.67	2.82	4.8	0.18	1.60	3.7

Goose Creek at SR 1524 near Mint Hill (station Q8360000)
Dutchmans Creek at SR 1150 near Uwharrie (station Q6820000) (Excellent 8/96, Not Rated 8/01)
Uwharrie River at NC 109 near Uwharrie (Q6810000) (Good 8/96, Not Rated 8/01)
Hunting Creek at SR 2115 near Harmony (station Q3484000) (Excellent 8/96, Excellent 8/01)
Little River at SR 1340 near Star (station Q9200000) (Excellent 8/96, Excellent 8/01)
Linville River at NC 126 near Nebo (station C1000000) (Excellent 8/97, Excellent 8/02)
Jacob Fork at SR 1924 near Ramsey (station (C4370000) (Excellent 8/97, Good 8/02)



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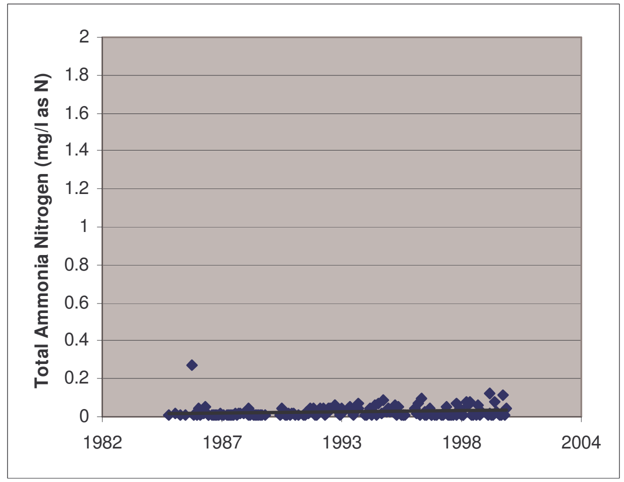

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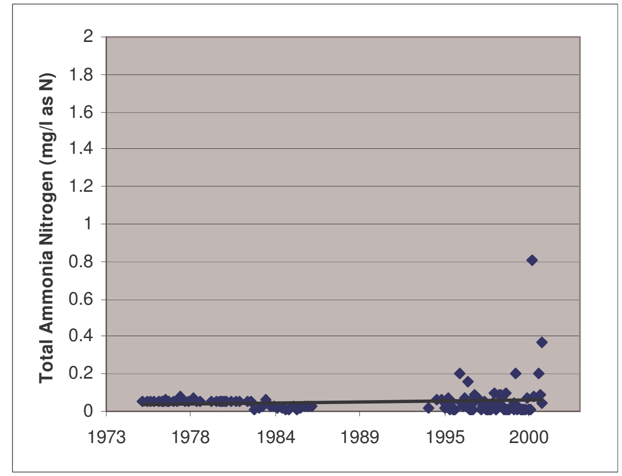

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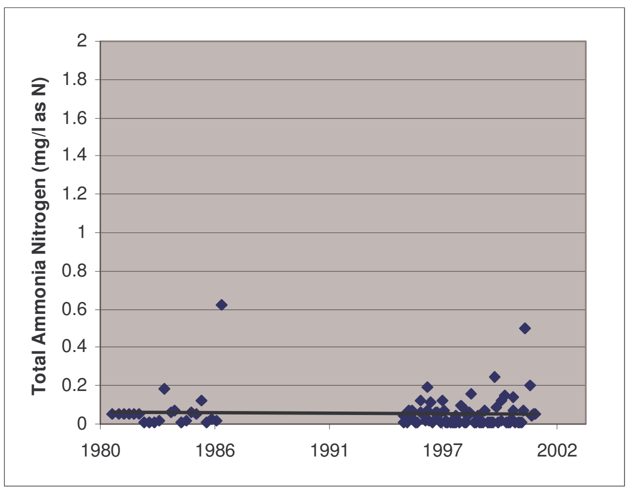

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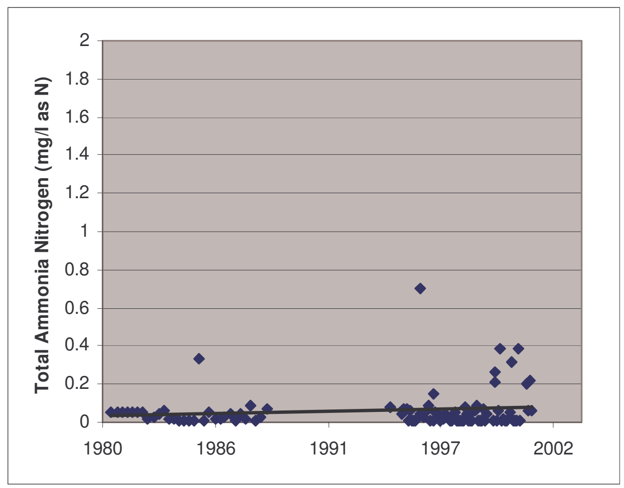

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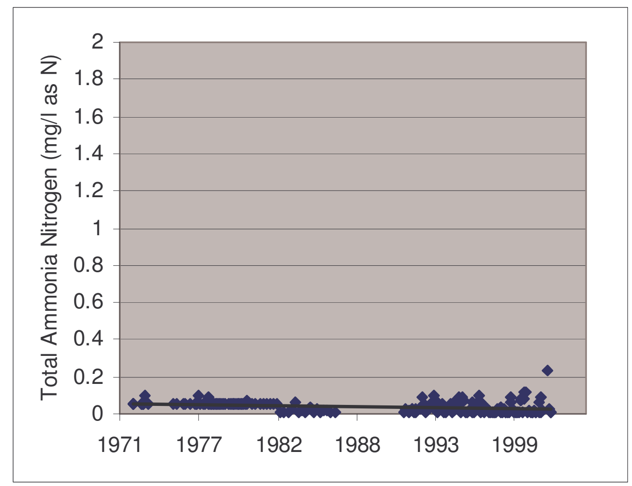

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Figure A-1. Total ammonia nitrogen concentrations in Goose Creek (A) compared to reference streams in the Yadkin and Catawba basins with excellent water quality (Dutchmans Creek (B), Uwharrie River (C), Hunting Creek (D), Little River (E) and Linville River (F)). Note that Goose Creek proposed site-specific ammonia standards for acute (1.75 mg/l) and chronic (0.5 mg/l) exposures are reasonable (i.e., acute standard never exceeded and chronic standard rarely exceeded) with respect to other streams.

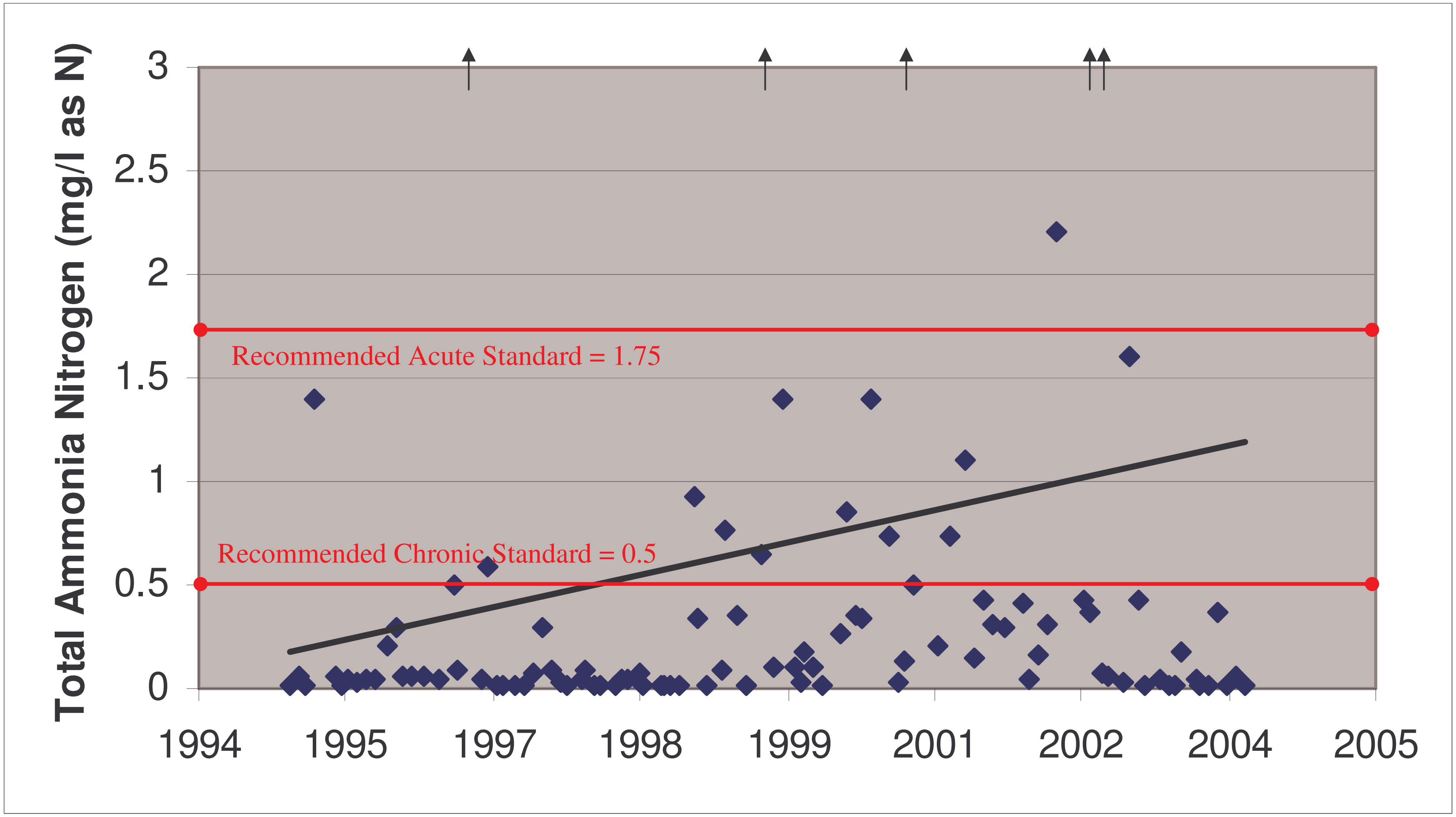

Figure A-2 Goose Creek ammonia concentrations at Stevens Mill Road crossing plotted with the recommended site-specific water quality standards for the creek. The symbol (↑) indicates values off this scale.

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Appendix B. Derivation of Copper Water Quality Standard for Freshwater Mussels

North Carolina does not have a water quality standard for copper (there is an action level of 7 ug/l), and ambient water quality data indicate this parameter is a concern for Goose Creek. To derive an estimate of the copper concentration that would not be harmful to freshwater mussels, available toxicity data were reviewed and summarized as described here. We started with the U.S. Environmental Protection Agency (USEPA) water quality criteria document for copper (USEPA 1996) and added data for freshwater mussels. The steps to deriving a copper standard for Goose Creek included the following:

1) We compiled available copper toxicity data. We reviewed the dataset used in the revised USEPA water quality criteria document for copper (USEPA 1996). Next, we searched the Toxline® and AQUIRE databases, and queried researchers familiar to us with experience in mussel toxicity testing to incorporate mussel toxicity data in the database. Test endpoints were EC50s (median effects concentration, or an estimated concentration that is expected to adversely effect 50% of a group of test organisms; the adverse effect in this case is immobilization) and LC50s (median lethal concentration, or an estimated concentration that is expected to be lethal to 50% of a group of test organisms). Note that EC50s and LC50s are not protective values because the endpoints are immobilization and lethality; they are commonly reported toxicity testing statistics and are used as a staring point for deriving safe concentrations.

2) The initial database compiled from this search yielded 217 copper EC50s and LC50s for freshwater mussels. We evaluated data from all sources for acceptability using guidance of the ASTM *draft Standard Guide for Conducting Toxicity Tests with Freshwater Mussels* (ASTM 2005) and USEPA *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (Stephan et al 1985).

   First, the dataset was restricted to include tests conducted at a duration recommended in the ASTM draft guide (96-hr for juvenile mussels, unless no test of this duration is available for the species in which case 48-hr tests can be considered) (24-hr for mussel glochidia, unless aspects of a species' life history indicate that a longer test duration is warranted). The database modified for test duration considerations contained results from 126 tests.

   Next, the dataset was further restricted to include only test results that demonstrated acceptable survival in control treatments ($\geq$ 90 %), used measured rather than nominal values for copper test concentrations, and documented test water hardness to allow calculation of total hardness-normalized values. The database that met all of these restrictions contained 115 tests for 20 species in 14 freshwater mussel genera.

3) The toxicity of copper varies with water hardness (copper toxicity declines as waster hardness increases). Water hardness is, in general, a measure of the concentrations of calcium and magnesium ions in water, typically expressed as mg/l calcium carbonate ($CaCO_3$) equivalent. To summarize toxicity tests conducted at different water hardness, we used the original studies' reported copper EC50s and LC50s and reported hardness to convert all EC50s and LC50s for acute exposures to ug copper/l at a standardized hardness of 50 mg/l $CaCO_3$ (using equations from USEPA 1985, 1996).

To correct toxicity data to a constant hardness:

$\ln Y = \ln W - V (\ln X - \ln Z)$
V = slope of water quality relationship (for acute copper exposures = 0.9422
W = toxicity value from test
X = hardness of test
Y = hardness corrected value (corrected to hardness of Z)
Z = standardized hardness (e.g. 50 mg/l)

The raw data and hardness-normalized values are provided in Table B-1.

4) Toxicity data were summarized by the methodology described in USEPA numeric water quality criteria guidelines (Stephan et al. 1985). National water quality criteria in the U.S. generally consist of two estimated values designed to protect aquatic organisms; these are commonly referred to as the acute and chronic water quality criteria, but more specifically, they are the criteria maximum concentration (CMC) and criteria continuous concentration (CCC), respectively.

A. The CMC is an estimate of the highest one-hour average concentration that should not result in unacceptable adverse effects to aquatic organisms; the number is derived from acute, or short-term, toxicity tests that use lethality or immobilization as the measured endpoints. In deriving the CMC, available toxicity data are critically reviewed, and geometric mean EC50s and LC50s for each genus (genus mean acute values, or GMAVs, the geometric mean of the EC50s and LC50s from all acceptable tests for that genus) are calculated (Table B-2).

We added the freshwater mussel GMAVs to the acute dataset for copper toxicity in the current USEPA criteria document (USEPA 1996). The GMAVs are ranked from highest (most tolerant) to lowest (most sensitive) (Table B-3). A cumulative probability is assigned based on those ranks, and a Final Acute Value (FAV) is derived as the fifth percentile of the GMAVs using an equation that gives equal weight to the GMAVs of the four genera with percentile ranks closest to 0.05. The CMC is calculated by dividing the FAV by 2 and results in a concentration that should not severely adversely affect too many individuals within the taxa that were used for deriving the FAV (Stephan et al. 1985). Evaluation of acute toxicity data has generally shown that dividing an LC50 or EC50 by 2 provides a concentration equal to a very low effect or no effect concentration. The process, by definition, is designed to protect populations of 95% of the species tested from adverse effects of short term exposures to non-bioaccumulative chemicals.

Addition of freshwater mussel GMAVs to the acute dataset for copper toxicity in the current USEPA criteria document and use of equations from the USEPA water quality criteria methodology allowed us to recalculate water quality guidance with a dataset in which mussels are well represented. We defined outputs from this process as a freshwater mussel FAV (FAV_{FM}) and a freshwater mussel criteria maximum concentration (CMC_{FM}). The FAV_{FM} was 5.31 ug/l copper at 50 mg/l hardness and the corresponding CMC_{FM} was 2.66 ug/l.

Because two of the four most sensitive genera which drive the criteria calculation are not known to occur in North Carolina (*Potamilus* and *Venustaconcha*), we further truncated the species sensitivity distribution in Table B-3 to include freshwater mussel data only for those mussel genera occurring in North Carolina (Table B-4). Addition of only North Carolina freshwater mussel GMAVs to the acute dataset yielded a FAV_{FM} of 10.5 ug/l copper at 50 mg/l hardness and a corresponding CMC_{FM} of 5.25 ug/l.

Our CMC_{FM} was calculated by normalizing all data to a hardness of 50 mg/l. Recommended water quality criteria for copper are typically expressed as an equation dependent upon an input value for natural water hardness (USEPA 1985, 1996). Because the acute toxicity of copper varies strongly with hardness, the equations in the USEPA criteria document (1996) were used to adjust the CMC_{FM} for other hardness values observed in Goose Creek. To determine the range of hardness values for the creek, we summarized available data from the North Carolina Division of Water Quality (NCDWQ) ambient monitoring station at Stevens Mill Road (SR 1524). Table B-5 was created and used to translate the CMC_{FM} at hardness 50 mg/l derived above to other hardness values for Goose Creek.

For the Goose Creek site specific water quality management plan, it is recommended that the CMC_{FM} for a hardness of 34 mg/l be used. This was the 10^{th} percentile value of the NCDWQ dataset (Table B-5) and as such will be protective most of time (toxicity decreases with increasing hardness, so concentrations of copper established to be protective at the lower end of the hardness range will be protective at any higher hardness):

FAV_{FM} = 10.5 ug/l at hardness of 50 mg/l
CMC_{FM} = 5.25 ug/l at hardness of 50 mg/l

To make a new CMC hardness-dependent equation with this FAV:
Pooled slope = 0.9422 (see Table 3 of EPA 1985 Cu Criteria document)
ln (new CMC_{FM} intercept) = ln (CMC_{FM}) - (slope * ln50) = -2.027

To estimate CMC at hardness of 34 mg/l:

$CMC_{FM@hardness\ 34} = e^{0.9422(\ln hardness)-2.027}$ = **3.6 ug/l @ 34 mg/l hardness**

The recommended copper acute water quality standard for Goose Creek is 3.6 ug/l. As with USEPA's criteria, this value should be applied as a one hour average exposure which should not be exceeded more than once every three years.

B. The Continuous Criterion Concentration (CCC) addresses chronic (longer-term) exposures. The CCC is derived from a set of 'chronic values ' (CV), the geometric mean of the highest no observed effect concentrations (NOEC) and lowest observed effect concentrations (LOEC) for survival, growth, or reproduction in tests which range from seven days to several months or more. Either by direct calculation or by the use of acute-chronic ratios (ACR, or a mathematical relationship defining the additional sensitivity in long versus short term exposures), the CCC is set to an estimated fifth percentile of Chronic Values. To make exceeding the level of toxicity associated with the CCC a relatively rare event, the criteria further state that four-day average exposure concentrations should not exceed the CCC more frequently than once every three years on the average.

There are very limited chronic copper exposure data for freshwater mussels. In a site-specific copper derivation for the Clinch River, the authors reported results of acute and chronic toxicity tests with the mussel *Medionidus conradicus*. In six toxicity tests for acute effects of copper, EC50/LC50s were 46, 41, 81, 37, 40 and 69 ug/l copper. The species mean acute value (SMAV) from these exposures (geometric mean of these six tests) was 50 ug/l copper. The chronic test measured reduction in cellulolytic activity after 30 day copper exposure and reported a NOEC of 12.4 ug/l copper and a LOEC of 19.5 ug/l copper. The CV is the geometric mean of the NOEC and LOEC which is 15.5 for this test. An ACR for this study (the SMAV/CV) = 50/15.5 = 3.226

The USGS recently conducted acute and chronic toxicity tests with the mussel *Villosa iris*. In four toxicity tests for acute effects of copper, they reported an SMAV of 23.9 ug/l copper. The chronic test measured reduction in growth after 28 day copper exposure and reported a NOEC of 3.1 ug/l copper and a LOEC of 6.25 ug/l copper. The CV for this test is 4.4, and the ACR for this study (the SMAV/CV) = 23.9/4.4 = 5.432 (Ning Wang, USGS, pers. comm.. 2005).

The USEPA (1996) copper criteria update reports two ACRs and a final ACR of 2.823 as the geometric mean of these two:

Amphipod	*Gammarus pseudolimnaeus*	Species Mean ACR = 3.297
Cladoceran	*Daphnia magna*	Species Mean ACR = 2.418

We added the two mussel ACRs to the USEPA dataset used to calculate a final ACR and re-calculated a revised ACR of 3.438 as the geometric mean of the four:

Mussel	*Villosa iris*	Species Mean ACR = 5.432
Amphipod	*Gammarus pseudolimnaeus*	Species Mean ACR = 3.297
Mussel	*Medionidus conradicus*	Species Mean ACR = 3.226
Cladoceran	*Daphnia magna*	Species Mean ACR = 2.418

To derive a criteria continuous ammonia concentrations which may be protective of freshwater mussels (defined here as a CCC_{FM}), we divided the mussel FAV_{FM} by this revised ACR = 10.5/3.438 = 3.0 ug/l copper.

To make a new CCC hardness-dependent equation with this CCC_{FM}:

Pooled slope = 0.8545 (see Table 3 of EPA 1985 Cu Criteria document)

ln (new CCC_{FM} intercept) = ln (CCC_{FM}) - (slope * ln50) = -2.244

To estimate CCC_{FM} at hardness of 34 mg/l:

$CCC_{FM@hardness\ 34} = e^{0.8545(\ln hardness)-2.244}$ = **2.2 ug/l @ 34 mg/l hardness**

As with USEPA's criteria, this value should be applied as a four-day average exposure which should not be exceeded more than once every three years.

C) The appropriateness of the standard was evaluated relative to USEPA (Stephan et al. 1985) guidance. The data driving the calculation appear robust. There was a less than ten-fold difference between the four lowest genus mean acute values. The final acute value appears reasonable in comparison with SMAVs and GMAVs. The FAV_{FM} was 5.25 ug/l and is not the lowest value that could be recommended based on the existing data. Note that including the SMAVs and GMAVs for *Potamilus* and *Venustaconcha* would lower the mussel-specific criteria recalculations. However, lowering the FAV by including these GMAVs does not appear necessary as they are not resident in North Carolina. The site-specific chronic standard of 2.2 ug/l also appears reasonable. Larger or smaller ACRs could have been employed, but the geometric mean approach is sound.

If only *extant* mussel genera in North Carolina are included in the database, the most sensitive genera remaining, *Epioblasma*, would be deleted from the dataset we used. *Epioblasma capsaeformis* was the species tested, and although it occurred in North Carolina, it is presumed extirpated. A copper standard calculated with the data in Table B-4, further excluding *Epioblasma*, yields a CMC_{FM} of 4.8 ug/l and a CCC_{FM} of 2.8 ug/l at the 10^{th} percentile hardness value for Goose Creek of 34 mg/l. These values are about 20% higher than the standards we recommended based on inclusion of data for all species that occur (or occurred) in North Carolina. This is an option for consideration.

D) In addition to the toxicological appropriateness of the recommended site-specific standards, they were evaluated relative to ambient data. Clearly, a standard that was far lower than concentrations observed in relatively un-impacted waters of the State would not be appropriate (i.e., the standard would likely be too restrictive). Also, if the standard was far in excess of actual concentrations, it might not be relevant. From Figure B-1, the copper standards appear achievable but frequently exceeded in Goose Creek.

It is possible that a significant portion of the exceedences are associated with suspended copper (i.e., that attached to suspended sediment). No data for dissolved copper, the most toxic form to aquatic life, are available. It would be prudent to obtain these data as a component of implementing the proposed site-specific copper standards. This does not need to hold-up implementation of the overall water quality restoration plan; nonpoint source pollution reduction actions to address the well-documented ammonia, nutrient and sediment problems will likely reduce copper concentrations as well while additional data are being gathered.

Table B-1. Toxicity data for copper and freshwater mussels. Toxicity values reported in original references are normalized to hardness of 50 mg/l (as $CaCO_3$).

Species	Lifestage	Duration	----Reported------ EC50/LC50 (ug/l)	Hardness (mg/l)	EC50/LC50 (ug/l) @ Hardness 50	Reference
Mucket	glochidia	24-h	59	170	18.6	USGS 2005
(*Actinonaias ligamentina*)	glochidia	24-h	66	170	20.8	USGS 2005
	glochidia	24-h	53	170	16.7	USGS 2005
	glochidia	24-h	38	170	12.0	USGS 2005
	glochidia	24-h	35	170	11.0	USGS 2005
	glochidia	24-h	29	170	9.2	USGS 2005
	glochidia	24-h	24	170	7.6	USGS 2005
Pheasantshell	glochidia	24-h	132	140	50.0	Jacobson 1997
(*Actinonaias pectorosa*)	glochidia	24-h	93	150	33.0	Jacobson 1997
	glochidia	24-h	67	170	21.2	Jacobson 1997
	glochidia	24-h	42	140	15.9	Jacobson 1997
	juvenile	48-h	66.6	50	66.6	McCann 1993
	juvenile	48-h	61.4	40	75.8	McCann 1993
	glochidia	24-h	23.1	50	23.1	McCann 1993
	juvenile	48-h	154.3	160	51.6	McCann 1993
	juvenile	48-h	116.4	160	38.9	McCann 1993
	juvenile	48-h	110.5	140	41.9	McCann 1993
	juvenile	48-h	43.7	140	16.6	McCann 1993
	juvenile	48-h	100.4	150	35.7	McCann 1993
Dwarf wedgemussel (*Alasmidonta heterodon*)	glochidia	48-h	86	170	27.1	USGS 2005
Oyster mussel	juvenile	96-h	17	170	5.4	USGS 2005
(*Epioblasma capsaeformis*)	juvenile	96-h	6.8	170	2.1	USGS 2005
Plain pocketbook (*Lampsilis cardium*)	glochidia	24-h	210	170	66.3	Milam 2005
Wavy-rayed lampmussel	glochidia	24-h	48	170	15.2	Jacobson 1997
(*Lampsilis fasciola*)	glochidia	24-h	26	160	8.7	Jacobson 1997
	glochidia	24-h	46	75	31.4	Jacobson 1997
	glochidia	24-h	18	170	5.7	USGS 2005
	glochidia	24-h	16	170	5.1	USGS 2005
	juvenile	96-h	25	170	7.9	USGS 2005
	juvenile	96-h	21	170	6.6	USGS 2005
Pink mucket	glochidia	24-h	34	170	10.7	USGS 2005
(*Lampsilis abrupta*)	juvenile	96-h	37	170	11.7	USGS 2005

Table B-1 (continued)

Species	Lifestage	Duration	----Reported------ EC50/LC50 (ug/l)	Hardness (mg/l)	EC50/LC50 (ug/l) @ Hardness 50	Reference
Neosho mucket	glochidia	24-h	41	170	12.9	USGS 2005
(*Lampsilis rafinesqueana*)	juvenile	96-h	43	170	13.6	USGS 2005
	juvenile	96-h	43	170	13.6	USGS 2005
	juvenile	96-h	23	170	7.3	USGS 2005
Fatmucket	glochidia	24-h	130	170	41.0	Milam 2005
(*Lampsilis siliquoidea*)	glochidia	24-h	36	170	11.4	USGS 2005
	glochidia	24-h	42	170	13.3	USGS 2005
	glochidia	24-h	29	170	9.2	USGS 2005
	glochidia	24-h	31	170	9.8	USGS 2005
	glochidia	24-h	30	170	9.5	USGS 2005
	glochidia	24-h	38	170	12.0	USGS 2005
	glochidia	24-h	41	170	12.9	USGS 2005
	glochidia	24-h	28	170	8.8	USGS 2005
	glochidia	24-h	33	170	10.4	USGS 2005
	juvenile	96-h	18	170	5.7	USGS 2005
	juvenile	96-h	60	170	18.9	USGS 2005
Green floater	juvenile	96-h	64.62	84	39.6	Black 2001
(*Lasmigona subviridis*)	juvenile	96-h	92.99	84	57.0	Black 2001
	juvenile	96-h	52.05	84	31.9	Black 2001
Fragile papershell (*Leptodea fragilis*)	glochidia	24-h	90	170	28.4	Milam 2005
Scaleshell (*Leptodea leptodon*)	juvenile	96-h	22	170	6.9	USGS 2005
Pondmussel (*Ligumia subrostrata*)	glochidia	24-h	150	170	47.4	Milam 2005
Cumberland moccasin shell	glochidia	24-h	69	185	20.1	Jacobson 1997
(*Medionidus conradicus*)	glochidia	24-h	40	185	11.7	Jacobson 1997
	glochidia	24-h	37	185	10.8	Jacobson 1997
	glochidia	24-h	46	170	14.5	Jacobson 1997
	glochidia	24-h	41	160	13.7	Jacobson 1997
	glochidia	24-h	81	150	28.8	Jacobson 1997
Washboard (*Megalonaias nervosa*)	glochidia	24-h	180	170	56.8	Milam 2005

Table B-1 (continued)

Species	Lifestage	Duration	----Reported------ EC50/LC50 (ug/l)	Hardness (mg/l)	EC50/LC50 (ug/l) @ Hardness 50	Reference
Pink papershell (*Potamilus ohiensis*)	glochidia	24-h	11	170	3.5	USGS 2005
Giant floater (*Pyganodon grandis*)	glochidia	24-h	347	170	109.5	Jacobson 1997
	glochidia	24-h	46	50	46.0	Jacobson 1997
	juvenile	24-h	33	70	24.0	Jacobson 1993
	juvenile	24-h	44	70	32.0	Jacobson 1993
Paper pondshell (*Utterbackia imbecillis*)	juvenile	96-h	86	44	97.0	Keller and Zam 1991
	juvenile	96-h	199	90	114.4	Keller and Zam 1991
	glochidia	24-h	63.65	88	37.4	Black 2001
	glochidia	24-h	25.88	88	15.2	Black 2001
	glochidia	48-h	22.45	88	13.2	Black 2001
	glochidia	48-h	23.51	88	13.8	Black 2001
	glochidia	24-h	37.4	85	22.7	Connors and Black 2004
	juvenile	96-h	23.6	84	14.5	Black 2001
	juvenile	96-h	24.6	84	15.1	Black 2001
	juvenile	96-h	18.5	84	11.3	Black 2001
	glochidia	24-h	520	170	164.2	Milam 2005
	glochidia	48-h	23	103	11.6	Warren 1996
	juvenile	96-h	54	103	27.3	Warren 1996
	juvenile	96-h	81	103	41.0	Warren 1996
	juvenile	96-h	40	103	20.2	Warren 1996
	juvenile	96-h	33	103	16.7	Warren 1996
	juvenile	96-h	60	103	30.4	Warren 1996
	juvenile	96-h	53	103	26.8	Warren 1996
	juvenile	96-h	79	103	40.0	Warren 1996
	juvenile	96-h	111	103	56.2	Warren 1996
	juvenile	96-h	50	103	25.3	Warren 1996
	juvenile	96-h	46	103	23.3	Warren 1996
	juvenile	96-h	63	103	31.9	Warren 1996
	juvenile	96-h	58	103	29.4	Warren 1996
	juvenile	96-h	39	103	19.7	Warren 1996
	juvenile	96-h	36	103	18.2	Warren 1996
	juvenile	96-h	44	103	22.3	Warren 1996
	juvenile	96-h	22	103	11.1	Warren 1996
	juvenile	96-h	27	103	13.7	Warren 1996
Ellipse (*Venustaconcha ellipsiformis*)	glochidia	24-h	10	170	3.2	USGS 2005

Table B-1 (concluded)

Species	Lifestage	Duration	Reported EC50/LC50 (ug/l)	Reported Hardness (mg/l)	EC50/LC50 (ug/l) @ Hardness 50	Reference
Rainbow	glochidia	24-h	37	155	12.7	Jacobson 1997
(*Villosa iris*)	glochidia	24-h	46	150	16.3	Jacobson 1997
	glochidia	24-h	55	55	50.3	Jacobson 1997
	glochidia	24-h	38	55	34.7	Jacobson 1997
	glochidia	24-h	71	50	71.0	Jacobson 1997
	glochidia	24-h	46	160	15.4	Jacobson 1997
	glochidia	24-h	37	170	11.7	USGS 2005
	juvenile	96-h	17	170	5.4	USGS 2005
	juvenile	96-h	33	170	10.4	USGS 2005
	juvenile	96-h	30	170	9.5	USGS 2005
	juvenile	96-h	24	170	7.6	USGS 2005
	glochidia	24-h	80	190	22.7	Jacobson 1997
	glochidia	24-h	73	190	20.8	Jacobson 1997
	glochidia	24-h	65	185	18.9	Jacobson 1997
	glochidia	24-h	46	185	13.4	Jacobson 1997
	glochidia	24-h	75	170	23.7	Jacobson 1997
	glochidia	24-h	46	160	15.4	Jacobson 1997
	glochidia	24-h	36	160	12.0	Jacobson 1997
	glochidia	24-h	39	155	13.4	Jacobson 1997

Table B-2. Freshwater mussel genus mean acute values (GMAVs) for copper toxicity, listed in order of increasing sensitivity. All GMAVs are in ug/l, normalized to a hardness of 50 mg/l.

Genus Rank	Genus	GMAV
14	*Megalonaias*	56.82
13	*Ligumia*	47.35
12	*Pyganodon*	44.38
11	*Lasmigona*	41.63
10	*Alasmidonta*	27.15
9	*Utterbacki*a	25.44
8	*Actinonaias*	21.21
7	*Villosa*	16.47
6	*Lampsilis*	15.68
5	*Medionidus*	15.61
4	*Leptodea*	14.05
3	*Potamilus*	3.47
2	*Epioblasma*	3.39
1	*Venustaconcha*	3.16

Table B-3. Ranked genus mean acute values (GMAVs) from the USEPA (1996) copper water quality criteria document with the **freshwater mussel GMAVs from Table B-2**) added. Taxa are ranked from least sensitive to most sensitive. The 5th percentile of these median lethal values was calculated as the Final Acute Value (FAV). This value was divided by 2 (to compensate for the lethal effect endpoint) to derive the criteria maximum concentration (CMC), a value that should be protective in short-term exposures.

Rank	GMAV	Genus		
57	10240	Stonefly - *Acroneuria*		
56	7184	Clam - *Corbicula*		
55	6200	Caddisfly - unidentified species		
54	4600	Damselfly - unidentified species		
53	4305	Eel - *Anguilla*		
52	1990	Crayfish - *Procambarus*		
51	1877	Snail - *Campeloma*		
50	1397	Crayfish - *Orconectes*		
49	1290	Amphipod - *Crangonyx*		
48	1057	Fish - *Lepomis*		
47	900	Snail - *Amnicola*		
46	790.6	Killifish - *Fundulus*		
45	684.3	Tilapia - *Tilapia*		
44	331.8	Shiner - *Notropis*		
43	289	Goldfish - *Carassius*		
42	242.7	Worm - *Lumbriculus*		
41	196.1	Mosquitofish - *Gambusia*		
40	170.2	Midge - *Chironomus*		
39	166.2	Snail - *Goniobasis*		
38	156.8	Carp - *Cyprinus*		
37	141.2	Darter - *Caeruleum*		
36	135	Bryozoan - *Pectinatella*		
35	133	Chiselmouth - *Acrocheilus*		
34	110.4	Trout - *Salvelinus*		
33	109.9	Salmon - *Salmo*		
32	97.9	Minnow - *Pimephales*		
31	90	Worm - *Nais*		
30	86.67	Dace - *Rhinichthys*		
29	83.97	Chub - *Semotilus*		
28	83	Guppy - *Poecilia*		
27	78.55	Stoneroller - *Campostoma*		
26	73.99	Salmon - *Oncorhynchus*		
25	69.81	Bullhead - *Ictalurus*		
24	**56.82**	**Mussel - *Megalonaias***		
23	56.21	Snail - *Gyraulus*		
22	53.08	Worm - *Limnodrilus*		
21	52	Perch - *Morone*		
20	**47.35**	**Mussel - *Ligumia***		
19	**44.38**	**Mussel - *Pyganodon***		
18	**41.63**	**Mussel - *Lasmigona***		
17	39.33	Snail - *Physa*		
16	37.05	Bryozoan - *Lophopodella*		
15	37.05	Bryozoan - *Plumatella*		
14	**27.15**	**Mussel - *Alasmidonta***		
13	**25.44**	**Mussel - *Utterbackia***		
12	22.09	Amphipod - *Gammarus*		
11	**21.21**	**Mussel - *Actinonaias***		
10	16.74	Squawfish - *Ptychocheilus*		
9	**16.47**	**Mussel - *Villosa***		
8	**15.68**	**Mussel - *Lampsilis***		
7	**15.61**	**Mussel - *Medionidus***		
6	14.48	Cladoceran - *Daphnia*		
5	**14.05**	**Mussel - *Leptodea***		
4	9.92	Cladoceran - *Ceriodaphnia*		
3	**3.47**	**Mussel - *Potamilus***		
2	**3.39**	**Mussel - *Epioblasma***	Final Acute Value (FAV)	5.31
1	**3.16**	**Mussel - *Venustaconcha***	Criteria Maximum Concentrations (CMC)	2.66

Table B-4. Ranked genus mean acute values (GMAVs) from the USEPA (1996) copper water quality criteria document with the **freshwater mussel GMAVs *only for those mussel genera found in North Carolina* (listed in bold type here**) added. Taxa are ranked from least sensitive to most sensitive. The 5th percentile of these median lethal values was calculated as the Final Acute Value (FAV). This value was divided by 2 (to compensate for the lethal effect endpoint) to derive the criteria maximum concentration (CMC), a value that should be protective in short-term exposures.

Rank	GMAV	Genus
53	10240	Stonefly - *Acroneuria*
52	7184	Clam - *Corbicula*
51	6200	Caddisfly - unidentified species
50	4600	Damselfly - unidentified species
49	4305	Eel - *Anguilla*
48	1990	Crayfish - *Procambarus*
47	1877	Snail - *Campeloma*
46	1397	Crayfish - *Orconectes*
45	1290	Amphipod - *Crangonyx*
44	1057	Fish - *Lepomis*
43	900	Snail - *Amnicola*
42	790.6	Killifish - *Fundulus*
41	684.3	Tilapia - *Tilapia*
40	331.8	Shiner - *Notropis*
39	289	Goldfish - *Carassius*
38	242.7	Worm - *Lumbriculus*
37	196.1	Mosquitofish - *Gambusia*
36	170.2	Midge - *Chironomus*
35	166.2	Snail - *Goniobasis*
34	156.8	Carp - *Cyprinus*
33	141.2	Darter - *Caeruleum*
32	135	Bryozoan - *Pectinatella*
31	133	Chiselmouth - *Acrocheilus*
30	110.4	Trout - *Salvelinus*
29	109.9	Salmon - *Salmo*
28	97.9	Minnow - *Pimephales*
27	90	Worm - *Nais*
26	86.67	Dace - *Rhinichthys*
25	83.97	Chub - *Semotilus*
24	83	Guppy - *Poecilia*
23	78.55	Stoneroller - *Campostoma*
22	73.99	Salmon - *Oncorhynchus*
21	69.81	Bullhead - *Ictalurus*
20	56.21	Snail - *Gyraulus*
19	53.08	Worm - *Limnodrilus*
18	52	Perch - *Morone*
17	**47.35**	**Mussel - *Ligumia***
16	**44.38**	**Mussel - *Pyganodon***
15	**41.63**	**Mussel - *Lasmigona***
14	39.33	Snail - *Physa*
13	37.05	Bryozoan - *Lophopodella*
12	37.05	Bryozoan - *Plumatella*
11	**27.15**	**Mussel - *Alasmidonta***
10	**25.44**	**Mussel - *Utterbackia***
9	22.09	Amphipod - *Gammarus*
8	16.74	Squawfish - *Ptychocheilus*
7	**16.47**	**Mussel - *Villosa***
6	**15.68**	**Mussel - *Lampsilis***
5	**15.61**	**Mussel - *Medionidus***
4	14.48	Cladoceran – *Daphnia*
3	**14.05**	**Mussel - *Leptodea***
2	9.92	Cladoceran - *Ceriodaphnia*
1	**3.39**	**Mussel - *Epioblasma***

Final Acute Value (FAV_{FM}) 10.5

Criteria Maximum Concentrations (CMC_{FM}) 5.25

To make a new CMC hardness-dependent equation with this FAV:

Pooled slope = 0.9422 (see Table 3 of USEPA 1985

ln (new CMC intercept) = ln (newCMC) - (slope * ln50) = -2.027

New CMC equation = $e^{(0.9422 (\ln (\text{hardness}))-2.027}$

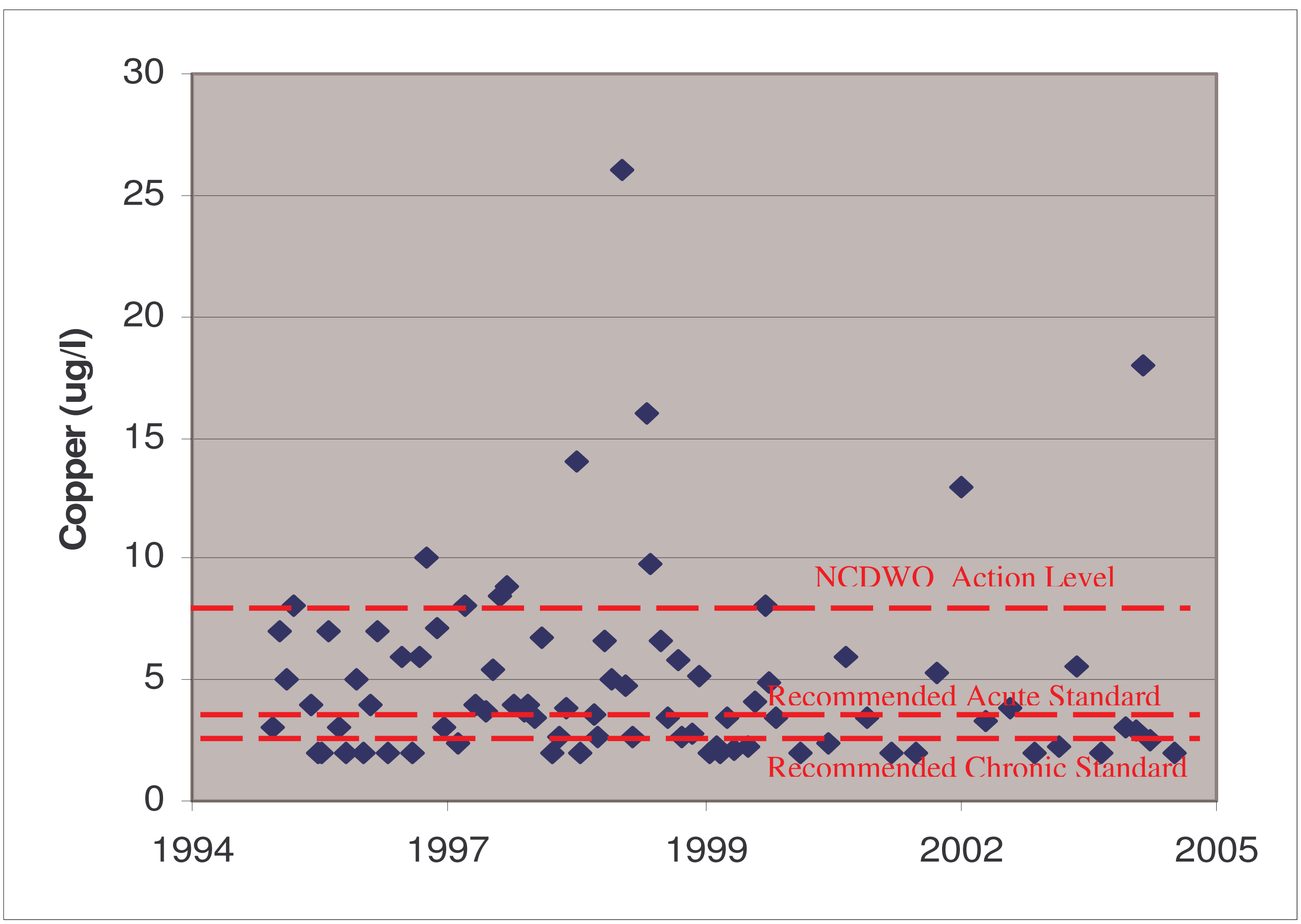
Table B-5 Freshwater mussel criteria maximum concentration (CMC_{FM}) for copper (ug/l total copper) at various hardness conditions of Goose Creek.

Goose Creek Harndess[1]		Corresponding CMC_{FM} for that Hardness[2]
Minimum	22	2.4
10th percentile	34	3.6
25th percentile	40	4.2
50th percentile	44	4.6
75th percentile	51	5.3
90th percentile	65	6.7
Maximum	82	8.3

[1] Summarized available data from the ambient monitoring station at Steven Mill Road (SR 1524) (data are mg/L as $CaCO_3$)

[2] A hardness-specific CMC obtained by substituting the CMC_{FM} at hardness of 50 mg/L into equations in original criteria document (USEPA 1985, Table 3, page 57) (data are total copper, ug/L).

Figure B-1. Goose Creek copper concentrations compared to recommended standards and existing action level.



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Appendix C. NCWRC's Rosgen Level II Goose Creek Stream Reach Characterization

The geomorphologies of sixteen stream reaches in the Goose Creek watershed were classified using Rosgen Level II classification system (Rosgen 1994, 1996) (Table C-1 and Figure C-1). Reaches of Goose Creek were classified as unstable E5, E4, C5, C4, F4, and G4 stream types. Unnamed tributaries were classified as unstable B4, E4, F4, G4, G5 stream types. Head-cuts occurred on all tributaries, which is typical throughout the watershed. Increased bank erosion and high lateral and vertical instability were characterized in all reaches studied (see, for example Figure C-2 through C-4). Increases in unconsolidated depositional material over existing cobble / gravel substrate was identified as a problem. The following description of stream types are from EPA's Watershed Academy website (http://www.epa.gov/watertrain/).

The "B" Stream Type:

The "B" stream types exist primarily on moderately steep to gently sloped terrain, with the predominant landform seen as a narrow and moderately sloping basin. Many of the "B" stream types are the result of the integrated influence of structural contact zones, faults, joints, colluvial-alluvial deposits, and structurally controlled valley side-slopes which tend to result in narrow valleys that limit the development of a wide floodplain. "B" stream types are moderately entrenched, have a cross-section width/depth ratio (greater than 12), display a low channel sinuosity, and exhibit a "rapids" dominated bed morphology. Bedform morphology, which may be influenced by debris constrictions and local confinement, typically produces scour pools (pocket water) and characteristic "rapids." Streambank erosion rates are normally low as are the channel aggradation/degradation process rates. Pool-to-pool spacing is generally four to five bankfull widths, decreasing with an increase in slope gradient. Meander width ratios (belt width/bankfull width) are generally low which reflect the low rates of lateral extension. "B" stream types are usually found within valley types II, III, and VI.

The "C" Stream Type:

The "C" stream types are located in narrow to wide valleys, constructed from alluvial deposition. The "C" type channels have a well developed floodplain (slightly entrenched), are relatively sinuous with a channel slope of 2% or less and a bedform morphology indicative of a riffle/pool configuration. The shape and form of the "C" stream types are indicated by cross-sectional width/depth ratios generally greater than 12, and sinuosities exceeding 1.2. The "C" stream type exhibits a sequencing of steeps (riffles) and flats (pools), that are linked to the meander geometry of the river where the riffle/pool sequence or spacing is on the average one-half a meander wavelength or approximately 5-7 bankfull channel widths. The primary morphological features of the "C" stream type are the sinuous, low relief channel, the well developed floodplains built by the river, and characteristic "point bars" within the active channel. The channel aggradation/degradation and lateral extension processes, notably active in "C" stream types, are inherently dependent on the natural stability of streambanks, the existing upstream watershed conditions and flow and sediment regime. Channels of the "C" stream type can be significantly altered and rapidly de-stabilized when the effects of imposed changes in bank stability, watershed condition, or flow regime are combined to cause an exceedance of a channel stability threshold. "C" stream types may be observed in valley types IV, V, VI, VIII, IX and X. They can also be found on the lower slope positions of the very low gradient valley type III.

The "E" Stream Type:

The "E" type stream channels are conceptually designated as evolutionary in terms of fluvial process and morphology. The "E" stream type represents the developmental "end-point" of channel stability and fluvial process efficiency for certain alluvial streams undergoing a natural dynamic sequence of system evolution. The "E" type system often develops inside of the wide, entrenched and meandering channels of the "F" stream types, following floodplain development on and vegetation recovery of the former "F" channel beds. The "E" stream types are slightly entrenched, exhibit very low channel width/depth ratios, and display very high channel sinuosities which result in the highest meander width ratio values of all the other stream types. The bedform features of the "E" stream type are predominantly a consistent series of riffle/pool reaches, generating the highest number of pools per unit distance of channel, when compared to other riffle/pool stream types (C, DA, and F). "E" type stream systems generally occur in alluvial valleys that exhibit low elevational relief characteristics and physiographically range from the high elevations of alpine meadows to the low elevations of coastal plains. While the "E" stream types are considered as highly stable systems, provided the floodplain and the low channel width/depth characteristics are maintained, they are very sensitive to disturbance and can be rapidly adjusted and converted to other stream types in relatively short time periods. The "E" stream type typically develops within valley types VIII, X, and XI.

The "F" Stream Type:

The "F" stream types are the classic "entrench-ed, meandering" channels described by early day geomorphologists, and are often observed to be working towards re-establishment of a functional floodplain inside the confines of a channel that is consistently increasing its width within the valley. "F" stream types are deeply incised in valleys of relatively low elevational relief, containing highly weathered rock and/or erodible materials. The "F" stream systems are characterized by very high channel width/depth ratios at the bankfull stage, and bedform features occurring as a moderated riffle/pool sequence. "F" stream channels can develop very high bank erosion rates, lateral extension rates, significant bar deposition and accelerated channel aggradation and/or degradation while providing for very high sediment supply and storage capacities. The "F" stream types occur in low relief valley type III, and in valley types IV, V, VI, VIII, IX, and X

The "G" Stream Type:

The "G" or "gully" stream type is an entrenched, narrow, and deep, step/pool channel with a low to moderate sinuosity. Channel slopes are generally steeper than .02, although "G" channels may be associated with gentler slopes where they occur as "down-cut" gullies in meadows. The "G" stream type channels are found in a variety of landtypes to include alluvial fans, debris cones, meadows, or channels within older relic channels. The "fanhead trench" which is a channel feature deeply incised in alluvial fans is typical of "G" type stream channels. With the exception of those channels containing bedrock and boulder materials, the "G" stream types have very high bank erosion rates and a high sediment supply. Exhibiting moderate to steep channel slopes, low channel width/depth ratios and high sediment supply, the "G" stream type generates high bedload and suspended sediment transport rates. Channel degradation and sideslope rejuvenation processes are typical. The valley types supporting the "G" stream types are I, III, V, VI, VII, VIII, and X. The "G" stream type can also be observed in valley types II, VI, VIII and X, under conditions of instability or disequilibrium that are often imposed by watershed changes and/or direct channel impacts.

Table C-1. Results of Rosgen Level II Stream Reach Characterization of Goose Creek and Tributaries

Number	Site	Stream	Length of site	Stream type	Riffle pebble count (D50)	Reach pebble count (D50)	Comments
1	Seventh Day Adventist Church Site	Goose Creek	850	Degraded E5, C5	5 mm Fine gravel	0.2 mm Sand	Drainage area 2.0 mi^2. Sinuosity 1.1. Bank erosion due to cattle, little riparian vegetation, high sediment load from banks, cattle and development
2	Greene Mitigation Site	Goose Creek	773	F4, G4	9.98 mm Medium gravel	5.7 mm Fine gravel	Drainage area 3.15mi^2. Sinuosity 1.22. Severe bank erosion resulted channel over widening; deposition of fine sediments created formation of mid-channel bars and blanketing gravel bed materials; signs of vertical and lateral instability and abandonment of former floodplain.
3	Steven's Creek 0.1 mile above I-485	Trib to Goose Creek	555	Unstable G/4	10.4 medium gavel		Drainage area 3.93 mi^2. Sinuosity 1.43. Many vertical, eroding banks, trees undercut and falling into creek, high sand bedload
4	Haigler / Rowell Mitigation Site	Trib to Goose Creek	1,174	F4, G4	12.6 mm medium gravel	17.6 coarse gravel	Drainage area 0.12 mi^2 (77 a), sinuosity 1.13, channel incision has caused abandonment of former floodplain, eroding banks, channel head cutting.
5	Haigler - McConnaughey Site	Trib to Goose Creek	972	B4, F4		Small gravel	Drainage area 0.06 mi^2. Sinuosity appears to be 1.0. Sediment supply from the agricultural field and bank erosion is moderate to high.

6	Haigler / Price Mitigation Site	Trib to Goose Creek	1,696	Unstable E4, G4	12.87 mm Medium gravel	9.06 mm Medium gravel	Drainage area 0.33 mi^2. Sinuosity 1.11. High bank erosion and sediment rates in E4 and G4; channel over-widening occurred in some places; stream appears to have been channelized; vegetation provides minimal stability due to high vertical banks; large amount of unconsolidated depositional material
7	Earl Haigler Mitigation Site	Goose Creek	250	C5 Urban regional curves?	1.9 mm Coarse sand		Drainage area 21.3 mi^2. Lateral movement of streambank caused the widening of channel and development of new point bars inside the existing channel. The effects of vertical and lateral instability are primarily the result of high stream-flow energy. Trees along streambank are undercut and may fall into the stream channel. Bank erosion is causing adverse water quality conditions
8	Haigler -218 Site	Trib to Goose Creek	117	G5		Small to medium gravel	Head-cut moving into ag. field; sediment supply is moderate to high.
9	Lemmond and Debarry Site	Trib to Goose Creek	208	G4, E4		Small to medium gravel	Drainage area 0.1 mi^2. Sediment input from eroding stream banks and agricultural fields is moderate. Vegetation along the channel consists of lawn grasses and Chinese privet
10	Lemmond/Deberry Mitigation Site	Trib to Goose Creek	519	F4/5, G4/5	4.24 riffle, fine gravel	Bar material 1.22 mm, coarse sand	Drainage area 0.1 mi^2. Sinuosity 1.03, gully stream, channelized in the past, vertical, eroding banks and serous head cutting at lower end of channel.
11	Sasser/Carriker Mitigation Site	Goose Creek	701	Original channel - E4, C4 New channel - very unstable E/4	7.21 mm Fine gravel	10.47 mm Medium gravel	Drainage area 22mi^2. New channel/head-cut formed; old channel filled with logs and sediment; vertical banks; high bank erosion and sediment rates; large amount of unconsolidated depositional material.

12	Williams/Mattlock Mitigation Site	Trib to Goose Creek	1,064	G/4	12.61 mm medium gravel	Bar material 5.59 mm, fine gravel	Drainage area 0.6 mi^2. Sinuosity of 1.15, stream channelized in the past, causing serious head cutting, vertical banks with high erosion rates.
13	Little Site	Trib to Goose Creek	109	entrenched E4 and G4		Small gravel	drainage area of less than 0.2 mi^2 Sinuosity of 1.0. The only pool in the stream is the culvert outlet; portion of channel has been filled with construction debris and rocks
14	Meadows, Davis, Coppola Site	Trib to Duck Creek	125	unstable E4 and G4		Coarse sand to fine gravel	Sediment supply in the channel is considered moderate to high since it drains an agricultural field. Major head-cuts occur; observed effects of vertical and lateral instability
16	Duck Creek above NC 218 crossing	Trib to Duck Creek	657	E/4	11.9 medium gravel		Drainage area 2.64 mi^2. Sinuosity 1.4. Stable but slightly entrenched E/4 stream channel. Good riparian vegetation and pool/riffle formations.

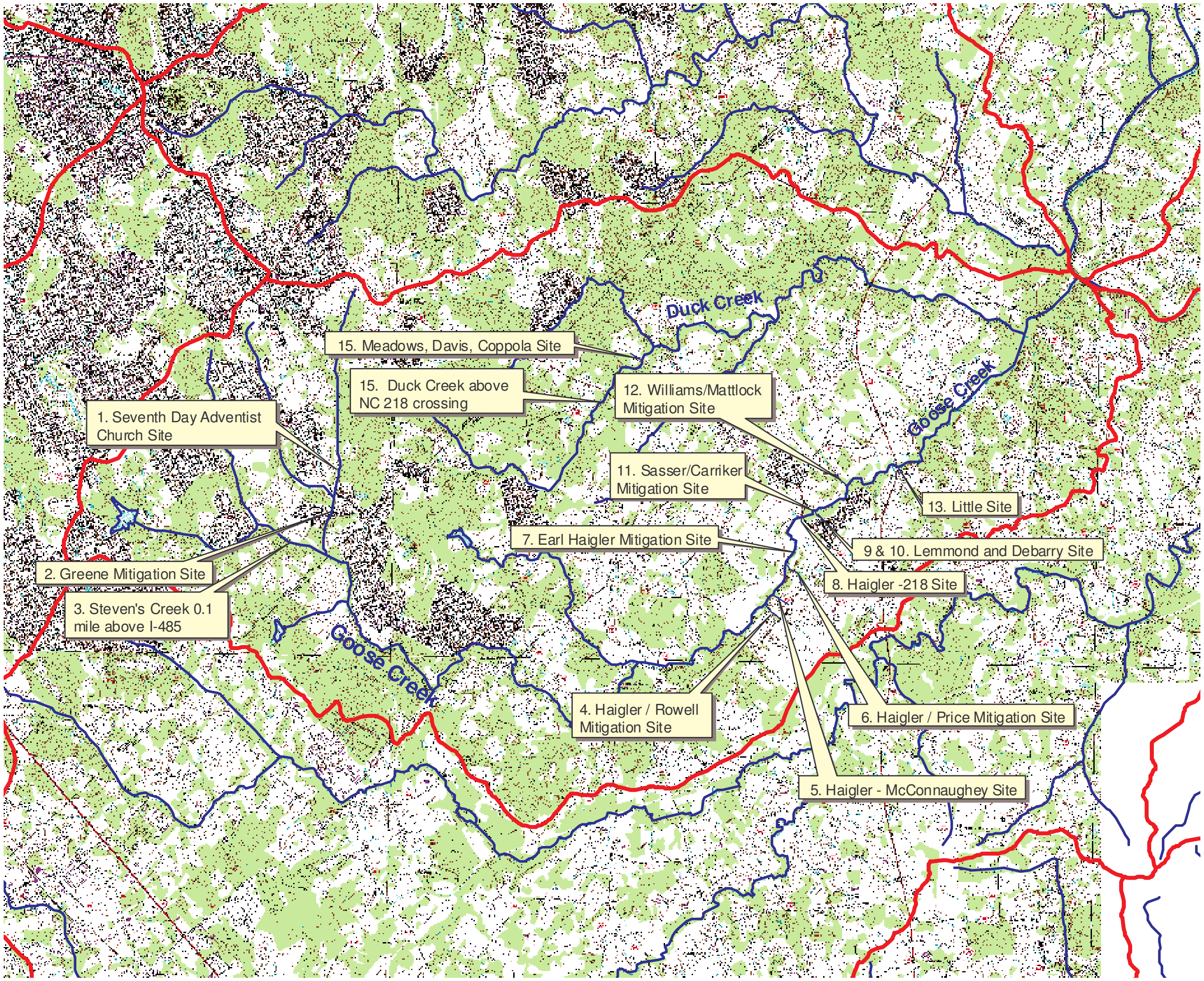

Figure C-1. Locations of stream reaches classified using Rosgen Level II classification system

Figure C-2. Greene Mitigation Site (Site 2 in Table C-1): These pictures, taken over a span of 18 months, show continuing bank erosion in Goose Creek downstream of Country Woods Drive, Mecklenburg County. Notice the angle of the pine tree from March 2003 to November 2004. Photos by Joe Mickey, NCWRC.

Figure C-3. Sasser / Carriker Mitigation Site (Site 11 in Table C-1): New channel formation downstream of Highway 218, Union County, 2003

Figure C-4. Lemmond / Deberry Site (Site 10 in Table C-1) : Typical unnamed tributary of Goose Creek, Union County 2003.

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Appendix D. Riparian Buffer Geographic Information System (GIS) Analysis

Riparian areas in the Goose Creek watershed were evaluated using GIS analysis based on existing land uses and the extent of the floodplain. As discussed in the Existing Water Quality Management Framework section, existing regulatory mechanisms for riparian area protection in Mecklenberg County (as outlined in the Surface Water Improvement and Management Stream Buffer Zoning Ordinance) provide a 100 foot minimum buffer plus 50 percent of the area of the 100-year floodplain in areas draining more than 640 acres. A similar SWIM buffer ordinance in Mint Hill provides additional protection by extending the minimum buffer to the outer edge of the 100-year FEMA fringe beyond 100-feet (for drainage areas equal to or greater than 640 acres). No buffer ordinances have been established in the Union County portion of the Goose Creek watershed. Union County, Fairview, Indian Trail and Stallings are proposing a riparian buffer ordinance of 200-feet perpendicular from the top of the bank on perennial streams and 100-feet on intermittent stream.

Existing land use data was obtained from NC Gap Analysis Project (NC GAP) and NC Center for Geographic Information Analysis (NC CGIA) (data current as of 1993 and 1998, respectively). The total acreage for individual land cover types using each dataset was calculated for both 1) the entire watershed (Figures D-1 and D-3), and 2) lands within the 100-year FEMA floodplain (Figures C-2 and C-4). NC GAP data indicate that the Goose Creek watershed consists of approximately 36 percent agriculture lands (defined as agricultural crop fields and/or pasture, hay, and natural herbaceous types) and 40 percent piedmont cover types (defined as dry-mesic pine forests, mesic forest, xeric pine forests, xeric woodlands, mountains dry-mesic oak and hardwood forest, and mountain mixed bottomland hardwood forests). The remaining lands are primarily forested with the exception of 3.5% of the watershed which is classified as "human dominated". When the analysis is restricted to the floodplain, agriculture and piedmont lands remain the dominant cover types (comprising about 17 and 64 percent of the floodplain, respectively).

NCCGIA data similarly indicate that cultivated and forested cover types are dominant in the Goose Creek watershed (land cover is approximately 14 percent cultivated, 30 percent managed herbaceous cover, and 31 percent mixed hardwoods/conifers). When the analysis is limited to floodplain areas within the Goose Creek Watershed mixed hardwoods (45 percent), managed herbaceous cover (14 percent), and cultivated (13 percent) cover types dominate. Developed lands comprise only a small portion of the overall watershed (about 3 percent) and less than 1 percent of the floodplain area.

FEMA floodplain data was used to estimate the average width of the floodplain along each side of Goose Creek using perpendicular transects (linear extent of the 100-year floodplain was estimated every 400 meters along Goose Creek from the headwaters downstream towards the confluence). The results of this analysis are presented in Table D-1. As expected, transect widths were narrower in the headwaters of Goose Creek and generally broadened as the drainage area increased. For the 62 transects evaluated, the average 100-year floodplain width on each side of the channel was 380-feet and 483-feet, respectively, corresponding to a total average floodplain width (including the stream channel) of about 860-feet. Existing ordinances extend buffer protections to 100-feet plus 50 percent of the FEMA fringe area in Mecklenburg County;

therefore, the average transect widths (190- and 240-feet, respectively, on each side of the channel) and total width of the floodplain corresponding to 50 percent of the linear transect length (about 430-feet) were calculated for this scenario as well.

Figure D-1. Goose Creek Watershed Land Use (NC GAP Data)

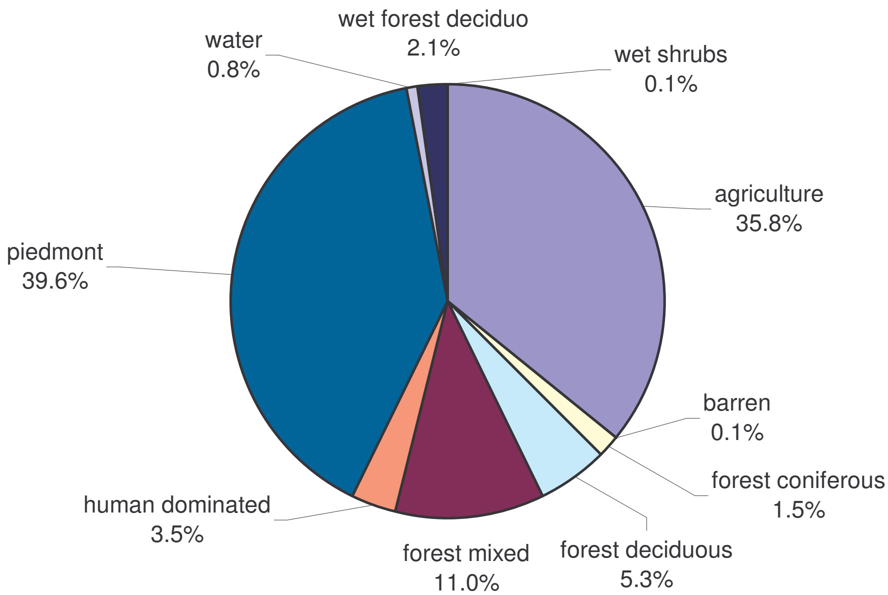

Figure D-2. Goose Creek Watershed Land Use (NC GAP Data) in 100-Year Floodplain

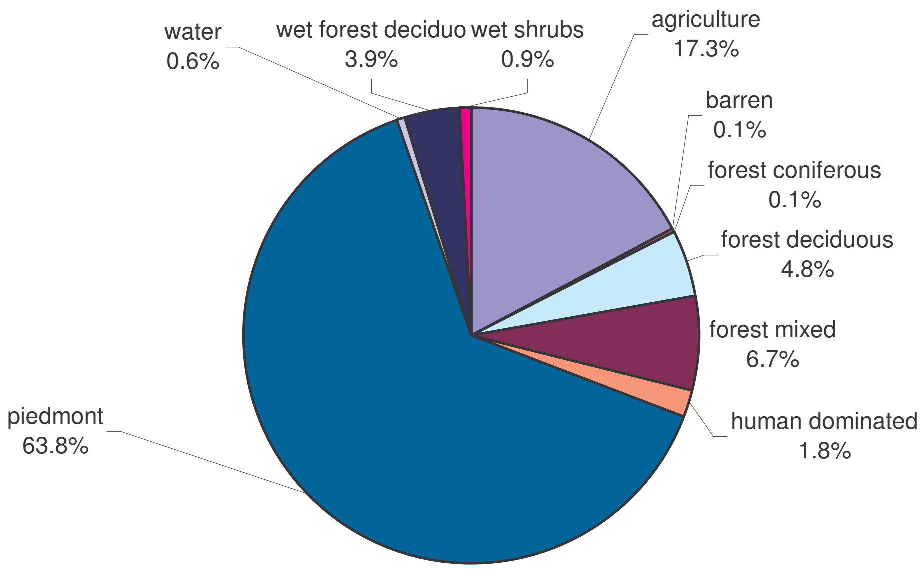

Figure D-3. Goose Creek Watershed Land Use (CGIA 1998 Data)

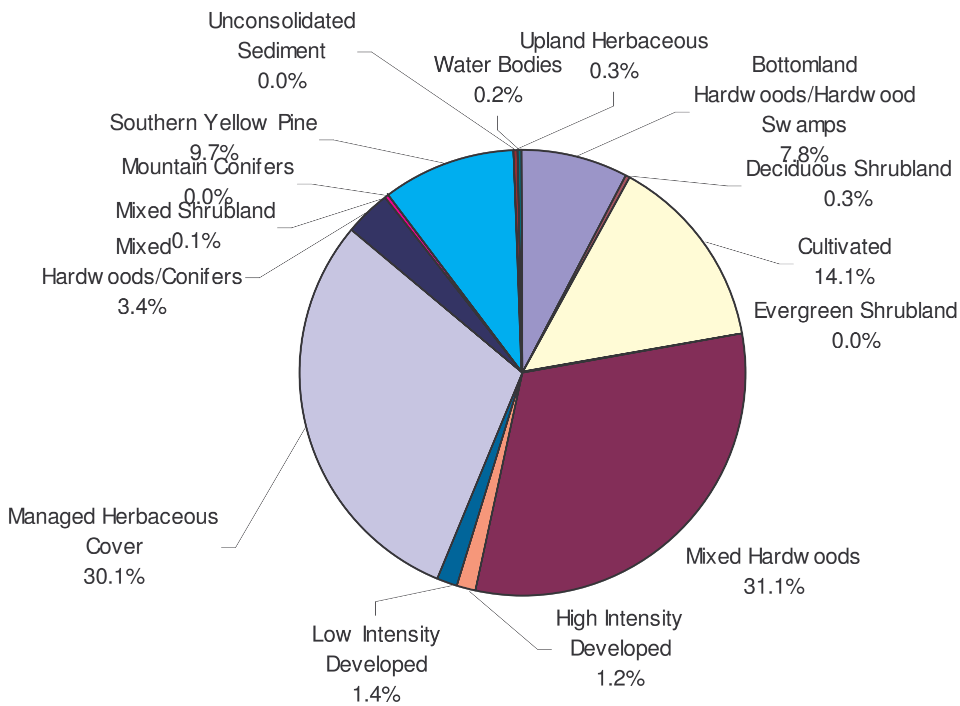

Figure D-4. Goose Creek Watershed Land Use (CGIA 1998 Data) in 100-Year Floodplain

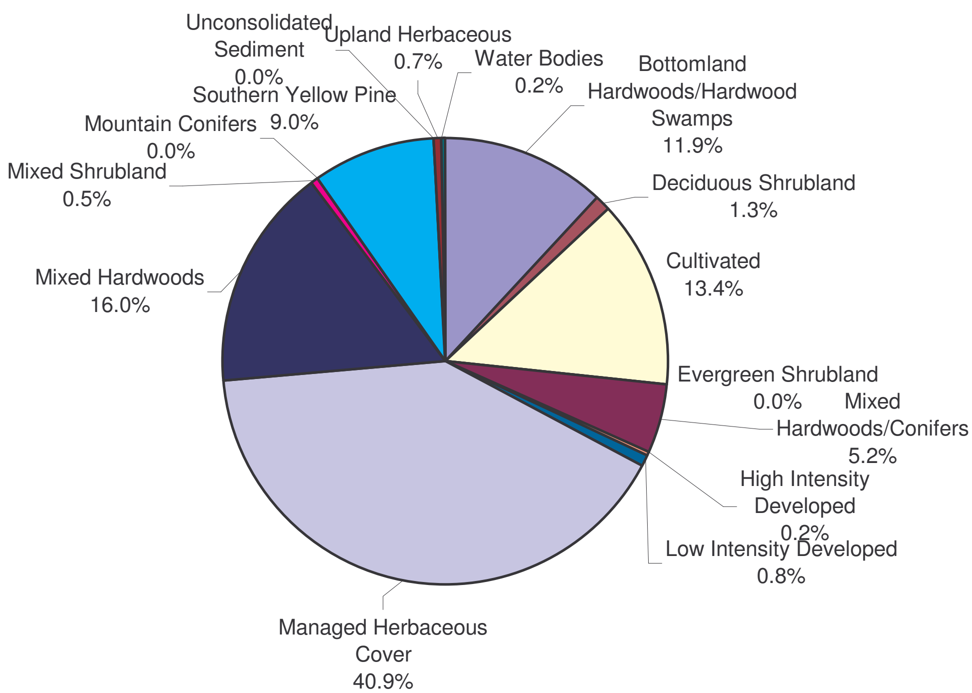

Table D-1. Goose Creek Floodplain Transect Analysis for Two Buffer Protection Scenarios

Transect # (from upstr. to downstr.)	Buffer Width Extending to Edge of 100-Year Floodplain						Buffer Width Extending to 50% of linear Distance to Edge of 100-Year Floodplain					
	Left Bank (facing upstr) Transect Length		Right Bank (facing upstr) Transect Length		Total Buffer Corridor Width		Left Bank (facing upstr) Transect Length		Right Bank (facing upstr) Transect Length		Total Buffer Corridor Width	
	meters	feet	meters	feet	meters	feet	meters	feet	meters	feet	meters	feet
1	41	135	6	20	47	154	21	67	3	10	24	77
2	35	115	18	59	53	174	18	57	9	30	27	87
3	41	135	17	56	58	190	21	67	9	28	29	95
4	33	108	44	144	77	253	17	54	22	72	39	126
5	79	259	0	0	79	259	40	130	0	0	40	130
6	74	243	23	75	97	318	37	121	12	38	49	159
7	35	115	13	43	48	157	18	57	7	21	24	79
8	147	482	9	30	156	512	74	241	5	15	78	256
9	75	246	163	535	238	781	38	123	82	267	119	390
10	97	318	105	345	202	663	49	159	53	172	101	331
11	162	532	74	243	236	774	81	266	37	121	118	387
12	114	374	67	220	181	594	57	187	34	110	91	297
13	71	233	155	509	226	742	36	116	78	254	113	371
14	39	128	260	853	299	981	20	64	130	427	150	491
15	84	276	69	226	153	502	42	138	35	113	77	251
16	37	121	84	276	121	397	19	61	42	138	61	199
17	26	85	138	453	164	538	13	43	69	226	82	269
18	22	72	219	719	241	791	11	36	110	359	121	395
19	115	377	36	118	151	495	58	189	18	59	76	248
20	39	128	28	92	67	220	20	64	14	46	34	110
21	108	354	86	282	194	637	54	177	43	141	97	318
22	58	190	37	121	95	312	29	95	19	61	48	156
23	84	276	24	79	108	354	42	138	12	39	54	177
24	42	138	70	230	112	367	21	69	35	115	56	184
25	81	266	37	121	118	387	41	133	19	61	59	194
26	112	367	144	472	256	840	56	184	72	236	128	420
27	179	587	108	354	287	942	90	294	54	177	144	471
28	82	269	154	505	236	774	41	135	77	253	118	387
29	292	958	25	82	317	1040	146	479	13	41	159	520
30	267	876	141	463	408	1339	134	438	71	231	204	669
31	163	535	87	285	250	820	82	267	44	143	125	410
32	325	1066	220	722	545	1788	163	533	110	361	273	894
33	164	538	305	1001	469	1539	82	269	153	500	235	769
34	128	420	306	1004	434	1424	64	210	153	502	217	712
35	274	899	128	420	402	1319	137	449	64	210	201	659
36	49	161	178	584	227	745	25	80	89	292	114	372
37	70	230	223	732	293	961	35	115	112	366	147	481
38	102	335	312	1024	414	1358	51	167	156	512	207	679
39	65	213	332	1089	397	1303	33	107	166	545	199	651
40	66	217	258	846	324	1063	33	108	129	423	162	532
41	114	374	263	863	377	1237	57	187	132	431	189	618

Table D-1 (cont.) Goose Creek Floodplain Transect Analysis for Two Buffer Protection Scenarios

Transect # (from upstr. to downstr.)	Buffer Width Extending to Edge of 100-Year Floodplain						Buffer Width Extending to 50% of linear Distance to Edge of 100-Year Floodplain					
	Left Bank (facing upstr) Transect Length		Right Bank (facing upstr) Transect Length		Total Buffer Corridor Width		Left Bank (facing upstr) Transect Length		Right Bank (facing upstr) Transect Length		Total Buffer Corridor Width	
	meters	feet	meters	feet	meters	feet	meters	feet	meters	feet	meters	feet
42	309	1014	285	935	594	1949	155	507	143	468	297	974
43	265	869	96	315	361	1184	133	435	48	157	181	592
44	245	804	150	492	395	1296	123	402	75	246	198	648
45	229	751	138	453	367	1204	115	376	69	226	184	602
46	55	180	216	709	271	889	28	90	108	354	136	445
47	115	377	219	719	334	1096	58	189	110	359	167	548
48	205	673	332	1089	537	1762	103	336	166	545	269	881
49	24	79	445	1460	469	1539	12	39	223	730	235	769
50	67	220	224	735	291	955	34	110	112	367	146	477
51	73	240	152	499	225	738	37	120	76	249	113	369
52	239	784	355	1165	594	1949	120	392	178	582	297	974
53	239	784	214	702	453	1486	120	392	107	351	227	743
54	124	407	190	623	314	1030	62	203	95	312	157	515
55	105	345	177	581	282	925	53	172	89	290	141	463
56	138	453	152	499	290	951	69	226	76	249	145	476
57	51	167	190	623	241	791	26	84	95	312	121	395
58	19	62	136	446	155	509	10	31	68	223	78	254
59	142	466	204	669	346	1135	71	233	102	335	173	568
60	187	614	59	194	246	807	94	307	30	97	123	404
61	50	164	98	322	148	486	25	82	49	161	74	243
62	107	351	128	420	235	771	54	176	64	210	118	386
Average	116	380	147	483	263	863	58	190	74	241	131	431