Monroe Connector/Bypass (STIP R-3329/R-2559)

Indirect and Cumulative Effects Water Quality Analysis

Prepared for the North Carolina Turnpike Authority

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1.0 INTRODUCTION

The North Carolina Turnpike Authority (NCTA) has proposed State Transportation Improvement Program project R-3329/R-2559, also known as the Monroe Connector/Bypass (the Project), to improve mobility and capacity within the Project study area by providing a facility for the US 74 corridor from near I-485 in Mecklenburg County to between the towns of Wingate and Marshville in Union County that allows for high-speed regional travel consistent with the designations of the North Carolina SHC program and the North Carolina Intrastate System, while maintaining access to properties along existing US 74. The proposed project alignment includes improvements to existing facilities and construction of approximately 20 miles of roadway on new alignment.

The Monroe Connector/Bypass Draft Environmental Impact Statement (DEIS), circulated in April 2009, included a qualitative Indirect and Cumulative Effects (ICE) analysis describing potential environmental effects. The U.S. Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (USFWS), N.C. Department of Environment and Natural Resources (NCDENR), and N.C. Wildlife Resources Commission (NCWRC), collectively referred to as the Resource Agencies hereafter, provided comments on the DEIS. The comments cover a range of issues related to the Project's projected environmental effects. The analysis described in this Technical Report specifically addresses comments concerning the Project's water quality effects. These comments can be summarized as follows:

1) What are the Project's indirect and cumulative effects on the water quality of waters supporting sensitive and rare aquatic species?

2) What are the Project's indirect and cumulative effects on the water quality of impaired waters on the North Carolina 303(d) list?

This Technical Report presents a quantitative water quality analysis performed with a focus on not only answering the above questions, but also with the broader goal of determining if induced land use change resulting from the Project affects water quality throughout the 330-square mile Study Area defined for this analysis (Figure A1, Appendix A). To this end, watershed models were constructed for portions of eighteen 14-digit hydrologic units (HUs) composing the Study Area. The watershed models were used to estimate annual streamflow, runoff, and annual overland pollutant loadings of total nitrogen (TN), total phosphorus (TP), total suspended sediment (TSS), and fecal coliform (FC) loads produced from the three land use scenarios described in Table 1. Comparison of the streamflow, runoff, and pollutant loadings projected for the 2030 No Build and 2030 Recommended Preferred Alternative (RPA) scenarios provides an indication of the Project's potential water quality effects. The RPA includes an interchange at US 601.

Table 1: Land Use Scenarios Considered in the Quantitative Water Quality Analysis

Full Name of Land Use Scenario	Abbreviated Name	Definition
Baseline Condition	Baseline	Land use conditions existing in 2007
2030 No Build Alternative	2030 No Build	Forecasted land use for the year 2030 without construction of the Project
Year 2030 Recommended Preferred Alternative (RPA)	2030 RPA	Forecasted land use for the year 2030 with construction of the RPA as presented in the DEIS

The watershed modeling suite chosen for this analysis was ArcView Generalized Watershed Loading Functions (AVGWLF). AVGWLF encompasses models specific to rural (GWLF-E) and urban (RUNQUAL-E) simulation (Evans et al. 2008). Both models calculate runoff and overland nutrient (TN and TP) and sediment (TSS) loading by considering variable land uses. Therefore, the difference between runoff and loadings calculated by AVGWLF for the 2030 No Build and 2030 RPA scenarios is dictated by the Project induced development captured in the 2030 RPA scenario. AVGWLF is considered an effective tool for watershed planning efforts where runoff and overland pollutant loadings are primary concerns (EPA 2008). The modeling methodology was presented at the October 13, 2009 Turnpike Environmental Agency Coordination (TEAC) meeting. No objections were raised by the agencies regarding this proposed methodology.

2.0 STUDY AREA

The Study Area marks the extent of the water quality analysis. The following sections describe the process by which the Study Area was defined and the condition of the Study Area water resources. A brief discussion is dedicated to the water quality protection measures currently in place in the Goose Creek watershed, a watershed of particular interest in this analysis.

2.1 Study Area Definition

The DEIS and accompanying qualitative ICE analysis concluded that the Project's ICE would occur within a five-mile radius of the various alignments under consideration. This five-mile envelope, referred to as the Future Land Use Study Area (FLUSA), defined the extent of the qualitative ICE analysis. The FLUSA encompasses an approximately 280-square mile area extending from southeast Charlotte in Mecklenburg County to east of Marshville in Union County.

The Study Area used for the purposes of this Technical Report (Figure A1, Appendix A) was developed to approximate the FLUSA. However, the Study Area deviates from the FLUSA in two substantive ways. First, at the request of Resource Agencies, the Study Area was expanded to include the entirety of the Goose Creek watershed, 14-digit HU 03040105070060 (U.S. Geological Survey [USGS] and U.S. Department of Agriculture 1999). The resource agencies are particularly interested in the Project's impact to water quality in the Goose Creek watershed because it along with Sixmile Creek supports two of six known remaining populations of the federally-listed endangered freshwater mussel, the Carolina heelsplitter (*Lasmigona decorata*).

Second, the FLUSA was delineated as a linear distance from the Project alignments with no consideration for hydrologic divides. While adequate for the qualitative ICE, water quality analyses, such as the one documented in this Technical Report, conventionally use an analysis area defined along appropriate hydrologic divides. Following this standard, the Study Area was created by splitting the eighteen 14-digits HUs intersecting the FLUSA (Table 2) at watershed divides proximal to the FLUSA boundary. The resulting 330-square miles Study Area includes the entirety of the Goose Creek watershed and captures the portions of the HUs falling within the FLUSA (Figure A2, Appendix A). Section 3.2.8 further details the methodology used to delineate catchments of the HUs.

Table 2: Study Area Hydrologic Units (HUs)

14-digit Hydrologic Unit Code	Watershed Name	N.C. Division of Water Quality (NCDWQ) Subbasin Number
03040105030020	Goose Creek	03-07-12
03040105040010	Crooked Creek	03-07-12
03040105070010	Richardson Creek (Upper)	03-07-14

14-digit Hydrologic Unit Code	Watershed Name	N.C. Division of Water Quality (NCDWQ) Subbasin Number
03040105070020	Richardson Creek (Middle)	03-07-14
03040105070030	Bearskin Creek	03-07-14
03040105070040	Rays Fork	03-07-14
03040105070050	Stewarts Creek	03-07-14
03040105070060	Richardson Creek (Lower)	03-07-14
03040105070070	Salem Creek	03-07-14
03040105070080	Gourdvine Creek	03-07-14
03040105081020	Bakers Branch	03-07-14
03040105081030	Beaverdam Creek	03-07-14
03040105081040	Wide Mouth Branch	03-07-14
03050103020050	McAlpine Creek	03-08-34
03050103020060	Irvins Creek	03-08-34
03050103020070	Four Mile Creek	03-08-34
03050103030010	Sixmile Creek	03-08-38
03050103030020	Twelve Mile Creek	03-08-38

2.2 Water Resources

The majority of the Study Area is located within the Yadkin Pee-Dee River Basin (USGS HU 03040105) including Subbasins 03-07-12 and 03-07-14 (NCDWQ 2008b). A smaller portion at the western end of the Study Area is located within Subbasins 03-08-34 and 03-08-38 of the Catawba River Basin (USGS Hydrologic Unit 03050103) (NCDWQ 2004). Subbasins 03-07-12 and 03-07-14 are located in the Rocky River watershed, the largest tributary to the Yadkin-Pee Dee River (NCDWQ 2008b).

The Study Area contains 54 named streams (Table 3) including Goose Creek and Crooked Creek, which are located in the largest and second largest watersheds. The headwaters of 35 named streams occur within the Study Area: Austin Branch, Barkers Branch, Becky Branch, Bearskin Creek, Beaverdam Creek, Buck Branch, Bull Branch, Chinkapin Creek, Davis Mine Creek, Dry Fork, Duck Creek, East Fork Stewarts Creek, Flag Branch, Fourmile Creek, Goose Creek, Haney Branch, Horsepen Branch, Irvins Creek, Joes Branch, Lacey Branch, Lick Branch, Maple Springs Branch, Middle Fork Rays Fork, North and South Fork Crooked Creek, Paddle Creek, Price Mill, Reedy Branch, Salem Creek, Sixmile Creek, Spring Branch, Stevens Creek, Stumplick Branch, West Fork Twelvemile Creek, and Wide Mouth Branch. The Study Area also contains numerous unnamed ponds and reservoirs as well as Lake Lee, Lake Stewart [Lake Twitty], McEwan Lake, and a portion of Lake Monroe.

Classifications are assigned to waters of the State of North Carolina based on the existing or contemplated best usage. All ten of the named streams within the Catawba portion of the Study Area and 36 streams within the Yadkin Pee-Dee portion are Class C streams. Class C streams are protected for secondary recreation, fishing, wildlife, fish and aquatic life propagation, and other uses (NCDWQ 2010b). The Yadkin Pee-Dee portion of the Study Area also includes nine WS-III (Water Supply III) streams, six WS-IV (Water Supply IV) streams, and seven WS-V (Water Supply V) streams. Water Supply III and IV streams are used as sources of water supply for drinking, culinary, or food processing purposes and are protected through restrictions on development and waste water discharges. Water Supply V streams are also used as sources of water supply but have no categorical restrictions on watershed development or wastewater discharges. Local governments are not required to adopt watershed protection ordinances for Water Supply V streams but are required to do so for WS-III and WS-IV streams (NCDWQ 2010b). Of the 22 streams with Water Supply classifications, six are also assigned a CA (Critical Area) designation. CA refers to an area adjacent to the water supply intake where risk

associated with pollution is greater than from the remaining portions of the watershed (NCDWQ 2007a). CAs require additional restrictions on watershed development beyond those required for a WS classification. Table 3 lists the best usage classifications for all named streams within the Study Area.

The North Carolina Division of Water Quality (NCDWQ) has initiated a whole-basin approach to water quality management for the 17 river basins within the state. Water quality for the Study Area is summarized in the Catawba River Basinwide Water Quality Plan (NCDWQ 2004) and the Yadkin Pee-Dee River Basinwide Water Quality Plan (NCDWQ 2008b). Water quality within the Catawba and Yadkin-Pee Dee River Basins is assessed by sampling of fish and benthic macroinvertebrates, and data collected at ambient (chemical and physical water quality) monitoring stations. The collected data is compared against water quality standards in order to evaluate the various best uses of North Carolina waters including aquatic life or biological integrity, recreation or swimming, and water supply. Table 3 lists the use support categories for aquatic life, recreation, and water supply use for all NCDWQ evaluated streams within the Study Area. Blank cells indicate use support category was not rated.

Table 3: Study Stream Classifications and Use Support Ratings

Stream Classification Index	Stream Name	Description	River Basin	Classification	Use Support Rating		
					Aquatic Life	Recreation	Water Supply
11-137-9-1	Campbell Creek	From source to McAlpine Creek	Catawba	C			
11-138-2-2-1	Davis Mine Creek	From source to Price Mill Creek	Catawba	C	Supporting		
11-138-2	East Fork Twelvemile	From source to Twelvemile Creek	Catawba	C	Supporting		
11-137-9-4	Fourmile Creek	From source to McAlpine Creek	Catawba	C	Impaired		
11-137-9-2	Irvins Creek (McEwen	From source to McAlpine Creek	Catawba	C			
11-137-9a	McAlpine Creek	From source to NC-51	Catawba	C			
11-137-9c	McAlpine Creek	From NC-51 to US-521	Catawba	C	Impaired		
11-138-2-2	Price Mill Creek	From source to East Fork Twelvemile Creek	Catawba	C	Supporting		
11-138-3	Sixmile Creek	From source to North Carolina-South Carolina	Catawba	C	Impaired		
11-138-1	West Fork Twelvemile	From source to Twelvemile Creek	Catawba	C	Supporting		
13-17-36-15-1	Austin Branch	From source to Negro Head Creek	Yadkin	C	Supporting		
13-17-40-10	Barkers Branch	From source to Lanes	Yadkin	WS-V	Supporting		Supporting
13-17-36-6	Bearskin Creek	From source to Richardson Creek	Yadkin	C			
13-17-40-11	Beaverdam Creek	From source to Lanes Creek	Yadkin	WS-V	Impaired		Supporting
13-17-36-15-3	Becky Branch	From source to Negro Head Creek	Yadkin	C	Supporting		
13-17-36-15-2	Buck Branch	From source to Negro Head Creek	Yadkin	C	Supporting		
13-17-36-4-1-(2)	Buck Branch	From a point 0.5 mile upstream of mouth to	Yadkin	WS-IV;CA	Impaired		
13-17-36-4-1-(1)	Buck Branch	From source to a point 0.5 mile upstream of	Yadkin	WS-IV	Impaired		

Stream Classification Index	Stream Name	Description	River Basin	Classification	Use Support Rating		
					Aquatic Life	Recreation	Water Supply
13-17-36-12	Bull Branch	From source to Richardson Creek	Yadkin	C	Impaired	Supporting	
13-17-36-6-2	Camp Branch	From source to Bearskin Creek	Yadkin	C			
13-17-36-9-5-	Chinkapin Creek	From source to a point 0.2 mile upstream of	Yadkin	WS-III	Impaired		Supporting
13-17-36-9-5-(0.7)	Chinkapin Creek	From a point 0.2 mile upstream of Union	Yadkin	WS-III;CA	Impaired		Supporting
13-17-20	Crooked Creek	From source to Rocky River	Yadkin	C	Supporting	Supporting	
13-17-36-6-3	Dry Fork	From source to Bearskin Creek	Yadkin	C			
13-17-18-3	Duck Creek	From source to Goose Creek	Yadkin	C	Impaired		
13-17-36-9-2	East Fork Stewarts Creek	From source to Stewarts Creek	Yadkin	WS-III	Impaired		
13-17-36-8-2	Flag Branch	From source to Rays Fork	Yadkin	C	Impaired	Supporting	
13-17-36-9-5-1-(1)	Flag Branch (Tobacco	From source to a point 0.3 mile upstream of	Yadkin	WS-III	Impaired		Supporting
13-17-36-9-5-1-(2)	Flag Branch (Tobacco	From a point 0.3 mile upstream of mouth to	Yadkin	WS-III;CA	Impaired		Supporting
13-17-18a	Goose Creek	From source to Rocky River	Yadkin	C	Supporting	Impaired	
13-17-18b	Goose Creek	From SR 1524 to Rocky River	Yadkin	C	Impaired	Impaired	
13-17-36-16	Gourdvine Creek	From source to Richardson Creek	Yadkin	C	Supporting		
13-17-20-3	Grassy Branch	From source to Crooked Creek	Yadkin	C	Supporting	Supporting	
13-17-40-11-3	Haney Branch	From source to Beaverdam Creek	Yadkin	WS-V			
13-17-36-6-1	Horsepen Branch	From source to Bearskin Creek	Yadkin	C			
13-17-40-11-2-1	Horsepen Branch	From source to Maple Springs Branch	Yadkin	WS-V			
13-17-36-15-4	Jacks Branch	From source to Negro Head Creek	Yadkin	C			
13-17-36-7	Joes Branch	From source to Richardson Creek	Yadkin	C			
13-17-40-15	Lacey Branch	From source to Lanes Creek	Yadkin	C			
13-17-36-9-3	Lick Branch	From source to Stewarts Creek	Yadkin	WS-III			
13-17-40-13	Lick Branch	From source to Lanes Creek	Yadkin	C			
13-17-36-10-1	Little Mill Creek	From source to Mill Creek	Yadkin	C			
13-17-36-4-(2)	Little Richardson	From a point 0.6 mile upstream of Buck Creek	Yadkin	WS-IV;CA	Impaired		
13-17-36-4-(0.5)	Little Richardson	From source to a point 0.6 mile upstream of	Yadkin	WS-IV	Impaired		
13-17-40-11-2	Maple Springs Branch	From source to Beaverdam Creek	Yadkin	WS-V			
13-17-36-11	Meadow Branch	From source to Richardson Creek	Yadkin	C			

Stream Classification Index	Stream Name	Description	River Basin	Classification	Use Support Rating		
					Aquatic Life	Recreation	Water Supply
13-17-36-8-1	Middle Fork Rays Fork	From source to Rays Fork	Yadkin	C			
13-17-36-10	Mill Creek	From source to Richardson Creek	Yadkin	C			
13-17-36-15	Negro Head Creek (Salem	From source to Richardson Creek	Yadkin	C	Supporting		
13-17-36-8-3	Nelson Branch	From source to Rays Fork	Yadkin	C			
13-17-20-1	North Fork Crooked Creek	From source to Crooked Creek	Yadkin	C	Impaired		
13-17-18-2	Paddle Branch	From source to Goose Creek	Yadkin	C			
13-17-36-8	Rays Fork	From source to Richardson Creek	Yadkin	C			
13-17-40-11-1	Reedy Branch	From source to Beaverdam Creek	Yadkin	WS-V			
13-17-36-(5)a1a	Richardson Creek	From Monroe Water Supply Dam (Lake Lee)	Yadkin	C	Impaired	Supporting	
13-17-36-(5)a1b	Richardson Creek	From Mill Creek 13-17-36-10 to Watson Creek	Yadkin	C	Impaired	Supporting	
13-17-36-(5)a2	Richardson Creek	From Watson Creek to Negro Head Creek	Yadkin	C	Supporting	Supporting	
13-17-36-(5)b	Richardson Creek	From mouth of Negro Head Creek (Salem	Yadkin	C	Supporting		
13-17-36-(1)	Richardson Creek	From source to a point 0.2 mile downstream of	Yadkin	WS-IV			
13-17-36-(3.5)	Richardson Creek (Lake	From a point 0.2 mile downstream of mouth	Yadkin	WS-IV;CA	Impaired		Supporting
13-17a	Rocky River	From source to mouth of Reedy creek	Yadkin	C	Impaired		
13-17b	Rocky River	From mouth of Reedy Creek to mouth of	Yadkin	C	Impaired	Supporting	
13-17c	Rocky River	From mouth of Dutch Buffalo Creek to mouth	Yadkin	C	Impaired		
13-17d	Rocky River	From mouth of Island Creek to the Pee Dee	Yadkin	C	Impaired		
13-17-20-2a	South Fork Crooked Creek	From source to SR 1515	Yadkin	C	Impaired		
13-17-20-2b	South Fork Crooked Creek	From SR 1515 to Crooked Creek	Yadkin	C	Impaired		
13-17-36-11-1	Spring Branch	From source to Meadow Branch	Yadkin	C			
13-17-18-1	Stevens Creek	From source to Goose Creek	Yadkin	C			
13-17-36-9-(1)	Stewarts Creek	From source to a point 0.4 mile downstream of	Yadkin	WS-III	Impaired		
13-17-36-9-(6)	Stewarts Creek	From Union County SR 1681 to Richardson	Yadkin	C			
13-17-36-9-(4.5)	Stewarts Creek [Lake Twitty	From a point 0.4 mile downstream of mouth	Yadkin	WS-III;CA	Impaired		Supporting
13-17-36-9-4	Stumplick Branch	From source to Stewarts Creek	Yadkin	WS-III			
13-17-36-13	Watson Creek	From source to Richardson Creek	Yadkin	C			
13-17-40-14	Wide Mouth Branch	From source to Lanes Creek	Yadkin	C			

NCDWQ has assembled a list of impaired water bodies according to the Clean Water Act Section 303(d) and 40 CFR 130.7, which is typically complied every two years. The most recent, effective final list is dated 2006, while draft lists exist for both 2008 and 2010. The draft 2010 303(d) list is currently open for comments. These lists will be hereafter referred to using the year releases, such as the 2006 final list, 2008 revised draft list and 2010 draft list, respectively (NCDWQ 2006, NCDWQ 2008a, NCDWQ 2010b). These lists are a comprehensive accounting of all impaired water bodies. An impaired water body is one that does not meet water quality standards including designated uses, numeric and narrative criteria, and anti-degradation requirements defined in 40 CFR 131. The standard violations may be due to an individual pollutant, multiple pollutants, or an unknown cause of impairment. The impairment could come from point sources, non-point sources and/or atmospheric deposition. North Carolina's designations are strongly based upon the aquatic-life use-support guidelines in the Section 305(b) guidelines (USEPA-841-B-97-002A and -002B). Those streams only attaining Partially Supporting or Not Supporting status are included on the 2006 list (NCDWQ 2006). Streams are further categorized into one of six parts within the 2006 list, according to the source of impairment and degree of rehabilitation required for the stream to adequately support aquatic life. Within Parts 1, 4, 5, and 6 of the list, North Carolina has developed a priority ranking scheme (low, medium and high) that reflects the relative value and benefits those water bodies provide to the State. Table 4 lists the Study Area streams that are found on the 2006 final, 2008 revised draft, and 2010 draft 303d lists.

Table 4: Study Area Streams on the 2006 303(d) List and/or 2008 and 2010 Draft 303(d) Lists

Stream Name	Description	River Basin	Stressor	2006 list	2008 list	2010 list
McAlpine Creek (Waverly Lake)	From source to SR 3356, (Sardis Rd)	Catawba	Impaired biological integrity, fecal coliform, and turbidity	Yes	Yes	Yes
McAlpine Creek (Waverly Lake)	From SR 3356 to NC 51	Catawba	Impaired biological integrity, fecal coliform, and turbidity	Yes	Yes	Yes
Sixmile Creek	From source to North Carolina-South Carolina State Line	Catawba	Impaired biological integrity	Yes	Yes	Yes
Beaverdam Creek	From source to Lanes Creek	Yadkin	Low dissolved oxygen and copper	No	Yes	Yes
Crooked Creek	From sources to Rocky River	Yadkin	Turbidity	Yes	No	Yes
Duck Creek	From source to Goose Creek	Yadkin	Impaired biological integrity	No	Yes	Yes
Goose Creek	From source to SR 1524	Yadkin	Fecal coliform	Yes	No	No
Goose Creek	From SR 1524 to Rocky River	Yadkin	Impaired biological integrity	No	Yes	Yes
Little Richardson Creek (Lake Monroe)	From source to Richardson Creek	Yadkin	Chlorophyll a	No	Yes	Yes
North Fork Crooked Creek	From source to Crooked Creek	Yadkin	Impaired biological integrity and turbidity	Yes	Yes	Yes
Richardson Creek (Lake Lee)	From a point 0.2 mile downstream of mouth of Beaverdam Creek to Monroe Water Supply Dam	Yadkin	Chlorophyll a and high pH	No	Yes	Yes
Richardson Creek	From Monroe Water Supply Dam (Lake Lee) to Mill Creek 13-17-36-10	Yadkin	Turbidity	Yes	Yes	Yes
Richardson Creek	From Mill Creek 13-17-36-10 to Watson Creek	Yadkin	Impaired biological integrity	Yes	Yes	Yes
Richardson Creek	From Watson Creek to Negro Head Creek	Yadkin	Copper	Yes	Yes	Yes
South Fork Crooked Creek	From source to SR 1515	Yadkin	Impaired biological integrity	Yes	Yes	Yes
South Fork Crooked Creek	From SR 1515 to Crooked Creek	Yadkin	Impaired biological integrity	Yes	Yes	Yes
Stewarts Creek	From source to a point 0.4 mile downstream of mouth of Stumplick Branch	Yadkin	Impaired biological integrity	No	Yes	Yes

Stream Name	Description	River Basin	Stressor	2006 list	2008 list	2010 list
Stewarts Creek [Lake Twitty (Lake Stewart)]	From a point 0.4 mile downstream of mouth of Stumplick Branch to Union County SR 1681	Yadkin	Copper and Chlorophyll a	No	Yes	Yes

2.2.1 Trends in Water Quality

Yadkin Pee-Dee River Basin (USGS HU 03040105)

The USGS hydrologic unit code (HUC) 03040105 represents the largest watershed of the Yadkin Pee-Dee River basin with the Rocky River flowing for nearly 100 miles from its headwaters in Iredell County to the Pee Dee River. This watershed is located adjacent to the City of Charlotte where rapid development along with limited stream waste assimilation capacity is having a major impact on water quality (NCDWQ 2008b).

The most obvious water quality trend that has been detected in HUC 03040105 is the further deterioration of water quality indicated by the number of streams added to the 2008 revised draft and 2010 draft 303d lists. The 2008 revised draft 303d list includes seven additional Study Area stream reaches that were not listed on the 2006 final list (Table 2). All of the additional streams also appear on the draft 2010 list. Stressors to streams that led to a listing in the 2008 and 2010 draft lists include copper, turbidity, chlorophyll a, and impaired biological integrity. Crooked Creek, from its source to the Rocky River, was listed on the 2006 final list, removed from the 2008 revised list, and added back to the draft 2010 list. The only stream reach removed from the list between 2006 and 2010 is Goose Creek. However, it should be noted that while the reach of Goose Creek from its source to SR1524 was removed, the reach immediately downstream of SR1524 was added to both the 2008 and 2010 draft lists.

The network of ambient monitoring sites in the Rocky River watershed indicate that turbidity and nutrients (nitrogen and phosphorus) are notably higher in this area than in other parts of the Yadkin – Pee Dee River basin (NCDWQ 2008b). Tributaries in the Study Area that are monitored as part of the Yadkin Pee-Dee River Basin Plan (NCDWQ 2008b) are shown on Table 1. Aquatic life, recreation, and water supply support ratings are assigned based on data collected at monitoring sites for fish and benthic macroinvertebrates, habitat quality, and water quality (turbidity, fecal coliform, nutrients, etc). Of the 33 stream reaches in the Yadkin Pee-Dee River Basin portion of the Study Area that are assigned use support ratings, 22 were classified as impaired for aquatic life and two were classified as impaired for recreation. All Water Supply classified streams were designated as Supporting.

A comparison of streams within the Study Area that were evaluated in 2003 (NCDWQ 2003) and again in 2008 (NCDWQ 2008b) indicate the following changes: Duck Creek (13-17-18-3) was rated as Supporting for aquatic life in 2003, but classified as Impaired in 2008. The reach of Rocky River from the mouth of Island Creek to the Pee Dee River was classified as Supporting in 2003 and 2008 for aquatic life (benthos). However, a standard violation and impairment was also assigned for turbidity in 2008. In 2003 Richardson Creek from Lake Lee to Negro Head Creek was rated as Impaired due to dissolved oxygen and fecal coliform. The same portion of Richardson Creek was evaluated in three separate reaches in 2008 and was rated as Impaired from Lake Lee to Watson Creek, and Supporting from Watson Creek to Negro Head Creek. Streams within the Study Area that were assigned use support ratings and exhibited no change from 2003 to 2008 include Goose Creek (13-17-18a/b), Negro Head Creek (13-17-36-15), and Rocky River (13-17b).

Catawba River Basin (USGS HU 03050103)

USGS HUC 03050103 represents the lower Catawba River and includes NCDWQ subbasins 03-08-34 and 03-08-38. Both these subbasins are located in an area of rapid development, with Union County expecting the highest population growth rate (more than 40 percent) of any in the basin over the next 20 years (NCDWQ 2004). The

large amount of existing cultivated land, combined with rapid urban growth, has resulted in nonpoint runoff that causes nutrient enrichment and habitat degradation in streams (NCDWQ 2004).

Streams within the Study Area that are monitored as part of the Catawba River Basin Plan (NCDWQ 2004) are shown on Table 3. Aquatic life ratings are assigned based on data collected at monitoring sites for fish, and benthic macroinvertebrates, and habitat. No Study Area streams within the Catawba River Basin were rated for recreation or water supply. Of the 7 stream reaches within the Catawba River Basin portion of the Study Area that are assigned use support ratings for aquatic life, three were classified as Impaired and four were classified as Supporting. McAlpine Creek (11-137-9c) is the only Study Area stream that received use support ratings in both 1998 and 2004. Between those years, McAlpine Creek was classified as Partially Supporting in 1998 (NCDWQ 1998) and Impaired in 2004 (NCDWQ 2004).

The 2006 final 303d list includes three Study Area stream reaches as shown in Table 4. The streams all remain on both the revised draft 2008 and draft 2010 303d lists.

2.2.2 Existing Water Quality Measures

As part of the preparation for the modeling effort, and in order to determine whether existing regulations and ordinances are sufficient to protect water quality, PBS&J inventoried the variety of protective measures for riparian buffer widths and stormwater requirements of the different planning jurisdictions within the Study Area. Government organizations that were considered include the EPA (Phases I and II Stormwater Rules), the Towns of Indian Trail, Stallings, Matthews, Mint Hill, Monroe and Wesley Chapel, and Mecklenburg and Union Counties. In addition to buffer regulations in place in each of these jurisdictions (Section 3.2.10, Table 8), the following requirements are in place.

NCDWQ identifies the City of Charlotte as a Phase I storm water permittee by the EPA. As required by National Pollutant Discharge Elimination System (NPDES) regulations, Charlotte must develop and implement a storm water program including public education, illicit discharge detection and elimination, storm sewer system and land use mapping, and analytical monitoring.

The towns of Matthews, Mint Hill, Weddington, Wesley Chapel, Indian Trail, Stallings, Hemby Bridge, Lake Park and Monroe, and both Mecklenburg and Union Counties are identified as Phase II storm water permittees. Consequently, as required by NPDES regulations, they must, at a minimum, develop, implement, and enforce a storm water program designed to reduce the discharge of pollutants from the municipal separate storm sewer system (MS4).

Stormwater best management practices (BMPs) drafted by individual municipalities are provided in Table 5.

Table 5: Study Area Stormwater BMPs

Planning Jurisdiction	Post-Construction Stormwater BMP Requirements
Mecklenburg County[1] (and the Towns of Cornelius, Davidson, Huntersville, Matthews, Mint Hill and Pineville)	• establishes minimum post-construction storm water management standards and design criteria for the regulation and control of storm water runoff quantity and quality • establishes design and review criteria for the construction, function, and use of structural storm water best management practices (BMPs) • provides pollutant removal efficiency requirements of BMPs for TSS and TP
Monroe[2]	• Establishes minimum post-development stormwater management standards and design criteria for the regulation and control of stormwater runoff quantity and quality; • Establishes design and review criteria for the construction, function, and use of *structural stormwater BMPs* that may be used to meet the minimum post-*development* stormwater management standards • All structural storm water treatment systems used to meet these requirements shall be designed to have a minimum of 85% average annual removal for TSS
Wesley Chapel[3]	• Establishes construction specifications for stormwater design in accordance with the Village of Wesley Chapel Stormwater Design Manual.
Indian Trail[4]	• Establishes minimum post-development stormwater management standards and design criteria for the regulation and control of stormwater runoff quantity and quality; • Establishes design and review criteria for the construction, function, and use of structural storm water best management practices that may be used to meet the minimum post-development storm water management standards required by state and federal authorities • All structural storm water treatment systems used to meet these requirements shall be designed to have a minimum of 85% average annual removal for TSS
Stallings[5]	• Establishes minimum post-development stormwater management standards and design criteria for the regulation and control of stormwater runoff quantity and quality; • Establishes design and review criteria for the construction, function, and use of structural storm water best management practices that may be used to meet the minimum post-development storm water management standards required by state and federal authorities • All structural storm water treatment systems used to meet these requirements shall be designed to have a minimum of 85% average annual removal for TSS
Union County	• No stormwater BMP requirements

[1]Stormwater Post Construction Controls Ordinance Administrative Manual (Charlotte Mecklenburg July 2009)
[2]Stormwater Management Ordinance (City of Monroe October 2007)
[3]Flood Damage Prevention, Drainage, Stormwater Management, and Wetland Protection (Village of Wesley Chapel Jan 2009)
[4]Town of Indian Trail Post-construction Storm Water Ordinance (September 2007)
[5]Post Construction Storm Water Ordinance (Town of Stallings September 2007)

2.2.3 Goose Creek

Goose Creek is a Class C stream spanning from its source in Mecklenburg County to the confluence with the Rocky River in Union County. The Goose Creek (approximately 17 miles long) watershed is approximately 42 square miles. Goose Creek, and its major tributary Duck Creek, contain habitat for the federally-listed freshwater mussel Carolina heelsplitter (*Lasmigona decorata*), that was listed as an endangered species in 1993. Portions of Goose Creek and Duck Creek are designated critical habitat for the heelsplitter. Historically, water quality in Goose Creek has been poor due to elevated fecal coliform levels from construction and urban runoff (NCDWQ 2008b). In addition, Goose Creek (13-17-18b) was rated impaired based on biological sampling and recreation value (NCDWQ 2008b). However, a portion of the creek (13-17-18a) was recently removed from the 2008 draft 303(d) list – the reach from the headwaters to SR 1524 (Table 2). A TMDL has also been developed and approved by EPA for fecal coliform.

In order to protect and improve the water quality and habitat required by the Carolina heelsplitter population within Goose Creek, the following management rules were developed as part of the Site Specific Water Quality Management Plan (NCDENR 2009):

- No new wastewater discharges or expansions of existing discharges are permitted.
- Any new development that disturbs one acre or more of land, and increases impervious surface, must control and treat the difference in stormwater runoff from pre-development and post-development conditions. The stormwater runoff difference must be treated with structural controls that meet rule requirements for the one year, 24-hour storm.
- No activity that results in a direct or indirect discharge is allowed if it causes toxicity to the Carolina heelsplitter, with special attention to ammonia inputs.
- For new activities, undisturbed riparian buffers are required within 200 feet of waterbodies within the 100-year flood plain, and within 100-feet of waterbodies outside of the 100-year floodplain.

3.0 WATER QUALITY ANALYSIS APPROACH

This section outlines the methodology used to quantify the Project's potential water quality effects. The AVGWLF watershed modeling suite employed in the analysis is discussed in detail. The procedures used to derive model input parameters, special model considerations, and model calibration are also presented.

3.1 AVGWLF Description

AVGWLF is Geographic Information System (GIS) interface for the GWLF-E and RUNQUAL-E watersheds models – the former is included for modeling rural watersheds and the latter for urban watersheds. AVGWLF facilitates the construction of GWLF-E and RUNQUAL-E watershed models by deriving model parameters from user-provided GIS data. The latest version AVGWLF was released in April 2009. GWLF-E and RUNQUAL-E are described in the following sections.

3.1.1 GWLF History and Application

The core watershed simulation model for the AVGWLF software application is the GWLF (Generalized Watershed Loading Function) model developed by Haith and Shoemaker (1987). GWLF simulates runoff, sediment delivery, and average nutrient concentration based on land use. Figure 1 depicts the major components of GWLF. The model uses daily steps for weather data and water balance calculation. Evapotranspiration is determined using daily weather data and a cover factor dependent upon land use/land cover type. Sediment and nutrient loads are estimated monthly, based on the daily water balance accumulated to monthly values.

GWLF is considered a combined distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/land cover scenarios, but each area is assumed to be homogenous with regard to various attributes considered by the model. The model does not spatially distribute the source areas, but simply aggregates the loads from each area into a watershed total; in other words there is no spatial routing. Groundwater runoff and discharge are obtained from a lumped-parameter watershed water balance for both shallow saturated and unsaturated zones.

Runoff is calculated by means of the U.S. Soil Conservation Service's (SCS) curve number equation. The Universal Soil Loss Equation (USLE) is applied to simulate erosion. Rural nutrients are estimated using empirical concentrations of each land use, which are based on both dissolved concentration in runoff and solid concentration in sediment. Urban nutrient loads are computed by exponential accumulation and washoff functions. Nutrient loads from septic systems are calculated by estimating the per capita daily load from each type of septic system and the number of people in the watershed served by each type. Sub-surface losses are calculated using dissolved N and P coefficients for shallow groundwater contributions to stream nutrient loads, and the sub-surface sub-model only considers a single, lumped-parameter contributing area, as mentioned previously. GWLF does not include instream flow and transport of loads. However GWLF provides for ground water discharges to stream systems, offering an opportunity for calibrating instream flow volume.

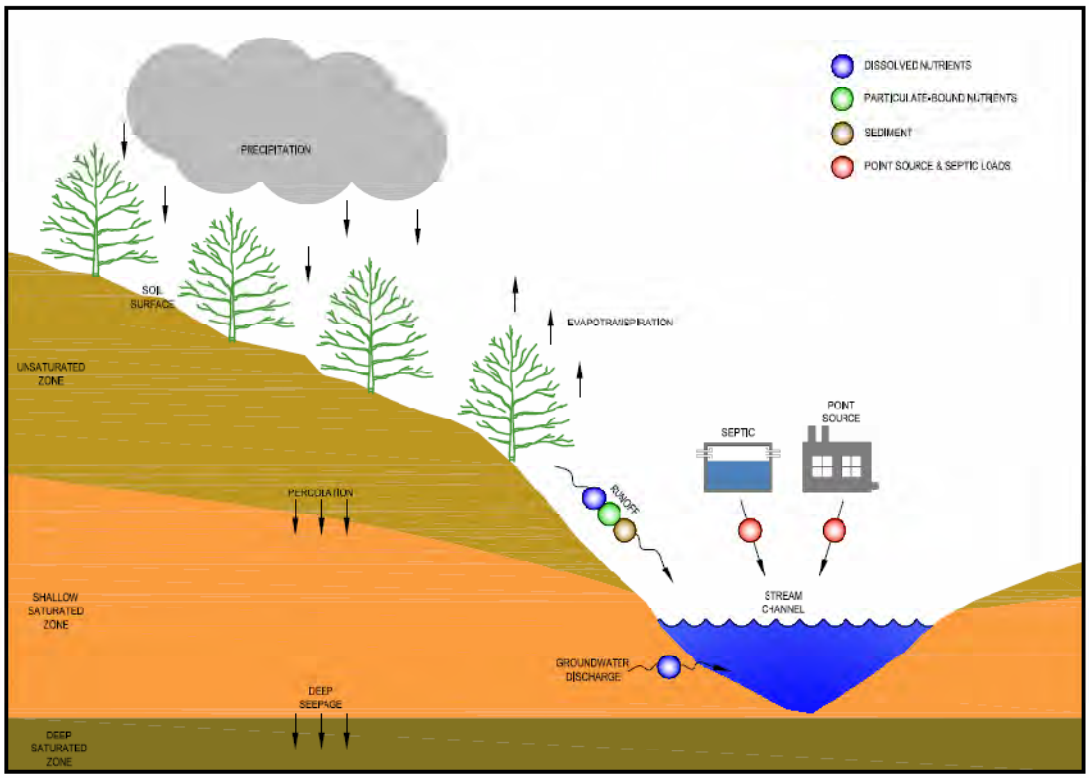


Figure 1: GWLF surface and sub-surface hydrology and loading pathways (adapted from Haith et al. 1992).

The original DOS version of the GWLF was re-written in Visual Basic by Evans et al. (2002) to facilitate integration with ArcView. The GWLF model employed with AVGWLF (GWLF-E) has been revised to include a number of routines and functions not found in the original model. For example, a significant revision in one of the earlier versions of AVGWLF was the inclusion of a streambank erosion routine. This routine is based on an approach often used in the field of geomorphology in which monthly streambank erosion is estimated using a watershed-specific lateral erosion rate (LER). Also the capability to account for point source effluent (i.e. flows) in the hydrology for a given area, and the ability to consider the potential effects of best management practices

(BMPs) have been relatively recent enhancements to the original model. In the newest version of AVGWLF (Ver. 7.23), several additional routines have been included. The most important changes to GWLF-E for this project are related to the incorporation of a new pathogen load estimation routine. Surface and groundwater withdrawals, tile drainage, and farm animal loading are among the other notable additions to GWLF-E.

3.1.2 RUNQUAL History and Application

As described in the previous section, the GWLF-E model provided within AVGWLF can be used to simulate flows and loads within watersheds containing a variety of land use categories, including two types of developed land (i.e., low-density development and high-density development). However, in intensively developed watersheds, it may be more appropriate to use a model that more specifically considers hydrologic and pollutant transport processes in such areas. In the latest version of AVGWLF, the RUNQUAL model developed by Haith (1993) has been added expressly for this purpose.

Both RUNQUAL and GWLF make generalizing assumptions. In doing so, each tends to favor a conceptual model which better fits areas with either more impervious cover or more pervious cover. These assumptions are exemplified in the general behavior each model chooses for determining sediment loading. GWLF's choice is an empirical technique based on agricultural erosion. RUNQUAL models sediment loading as the buildup of sediments (and nutrients) on impervious services using an empirical technique more frequently used in urban models. Since both are statistically-based empirical techniques, parameter values can be chosen that enable each technique to cover a large range of situations, urban or rural. One key factor in choosing one conceptual model over another is the logical fit of the model's parameters to the situation it's applied to and the availability of those parameters. For instance, the USLE used by GLWF allows the manipulation of a cover-management factor (which describes cropping and management practices) and the support practice factor (the ratio of soil loss with contouring and/or strip cropping). Values for these parameters are readily available for rural areas with time-tested results and the parameters themselves make more sense when describing a rural setting. Likewise TSS event mean concentrations (EMCs), as used by RUNQUAL, are more frequently available and more accurate for urban land uses.

Both RUNQUAL and GWLF generally calculate runoff using the SCS curve number equation. Nutrient load in urban areas is calculated in both models using accumulation and wash relationships. GWLF calculates nutrient load from rural areas using two methods. Dissolved loads are calculated using an EMC. Solid phase loads are calculated similarly but using monthly sediment yields and average sediment nutrient concentrations. RUNQUAL calculates total loads, for urban and rural areas, using build accumulation rates for nutrients and EMCs for sediment yields. Contaminant load is then partitioned into solid or dissolved phase assuming a constant ratio of dissolved to total contaminant for each land use. As previously mentioned, GWLF calculates sediment yields based on the USLE.

The most important benefit provided by RUNQUAL to this project is the fact that, while GWLF provides two types of urbanized or developed land, RUNQUAL (in AVGWLF) allows finer grained description of urban areas with six predefined urban categories and one general ("open land") category. Also, as in GWLF, RUNQUAL uses an exponential accumulation and wash-off function for urban loadings but in RUNQUAL urban nutrient inputs are not assumed to be only solid-phase. RUNQUAL does not simulate nutrient loads from septic systems and does not calculate fecal coliform loads.

RUNQUAL in AVGWLF (RUNQUAL-E) has been modified from its original source to contain components of GWLF in order to facilitate its implementation within AVGWLF however the fundamentals of the original model remain. RUNQUAL (and RUNQUAL-E) provides continuous daily simulation of surface runoff and contaminant loads from pervious and impervious surfaces in developed land uses. Subsurface flow, streambank erosion, evapotranspiration, point source discharge, and street sweeping are among the notable additions to RUNQUAL-

E. The most relevant RUNQUAL-E enhancement to this analysis involves buffer BMPs. The original RUNQUAL model assumes that vegetative buffer strips pertain to the entire watershed area. Currently however, buffers may apply to less than the entire area with the modified version. In this case, the fraction of total stream length treated is assumed to be proportional to the quantity of contaminated runoff treated. In RUNQUAL-E, accumulation and wash-off routines are not used to estimate runoff volumes and pollutant loads for the "open land" land use category. Rather, the EMC approach to calculating loads is used for these areas.

For fecal coliform loads from urban sub-catchments (i.e., RUNQUAL-E sub-catchments), PBS&J calculated fecal coliform loads outside of the model using runoff and an EMC in urban land uses in the same manner used by GWLF-E. GWLF-E fecal coliform estimates for natural areas are assumed to be equivalent to those loads generated by a population density of 25 deer per square mile of "open land" (EPA 2001). For rural land uses in RUNQUAL-E sub-catchments, PBS&J calculated fecal coliform loads outside of the model in the same manner used by GWLF-E.

3.2 Rural and Urban Sub-Catchments

Both GWLF-E and RUNQUAL-E were used to model streamflow, runoff, and pollutant loading in the Study Area. GWLF-E was employed in rural sub-catchments of the Study Area, while RUNQUAL-E was used in urban sub-catchments. PBS&J defined urban sub-catchments as having greater than 40 percent developed land uses, less than 15 percent in agricultural land uses, and were served by sewer systems in the Baseline Condition. Sub-catchments not fitting these criteria were considered rural. Depending on the development pattern in a given catchment, the catchment may comprise multiple GWLF-E and RUNQUAL-E sub-catchments. As a model aimed at a broad spatial scale, AVGWLF warns of model runs on areas less than one square mile. Where possible areas smaller than one square mile were combined with areas of similar land uses surrounding it. Of the 18 catchments in the Study Area, three were defined as entirely rural and four as entirely urban. These catchments were modeled with exclusively with GWLF-E or RUNQUAL-E. The remainder of the catchments contain a combination of rural and urban sub-catchments. These catchments were modeled with both GWLF-E and RUNQUAL-E. Figure A3 (Appendix A) depicts the GWLF-E and RUNQUAL-E sub-catchments. As expected, RUNQUAL-E sub-catchments are concentrated in the Mecklenburg County portion of the Study Area and along the US-74 corridor. GWLF-E sub-catchments generally occur in the east and northeast portions of the Study Area.

3.3 Input Parameters

GIS data layers were used as inputs by AVGWLF to derive spatially related input parameters for the GWLF-E and RUNQUAL-E models. Additionally, important non-spatial data was required by the models. Data sources are listed in Table 6 and their use is described in the following sections. Table 6 also lists the units, significant figures, and decimal places used for the GWLF-E and RUNQUAL-E model inputs. Significant figures are not relevant to some of the data listed, such as the aerial photography, parcel, and sewer service extent data. With the exception of the Study Area land use, the significant figures and decimal places listed are determined by the data provider.

Table 6: Model Inputs and Data Sources

Dataset	Source	Units by Parameter	Significant Figures by Parameter	Decimal Places by Parameter
Study Area land use	Michael Baker Engineering, Inc.	Area: hectares	Area: Generally 5 or 6 figures	Area: 0
2007 Mecklenburg and Union County aerial photography	Mecklenburg and Union County GIS	Not Applicable	Not Applicable	Not Applicable
Parcels	Union County GIS	Not Applicable	Not Applicable	Not Applicable
National Hydrography Dataset	USGS	Not Applicable	Not Applicable	Not Applicable
Weather station locations and data	National Oceanic and Atmospheric Administration and USGS	Temperature: °Fahrenheit Precipitation: inches	Temperature: 2 Precipitation: 3	Temperature: 0 Precipitation: 2
Digital Elevation Model	North Carolina Floodplain Mapping Program	Elevation: feet	Elevation: 5	Elevation: 2
1997 Sanitary Sewer Systems – Pipes	NC OneMap	Not Applicable	Not Applicable	Not Applicable
2005 Force Mains	Union County GIS	Not Applicable	Not Applicable	Not Applicable
2005 Gravity Lines	Union County GIS	Not Applicable	Not Applicable	Not Applicable
2004 Public Sewer Systems – Current Service Areas Municipal Boundaries	NC OneMap	Not Applicable	Not Applicable	Not Applicable
Streamflow data, stream lines, weather station locations and data, HU boundaries	USGS	Streamflow: $feet^3$/second Temperature: ° Fahrenheit Precipitation: inches	Streamflow: 1 to 3 Temperature: 2 Precipitation: 3	Streamflow: 0 to 2 Temperature: 0 Precipitation: 2
Soil Survey Geographic (SSURGO) Database	Natural Resource Conservation Service	Available Water Storage: centimeters Soil Erodibility Factor: unitless	Available Water Storage: 4 Soil Erodibility Factor: 2	Available Water Storage: 2 Soil Erodibility Factor: 2
Point source dischargers location and discharges	NCDWQ	Total nitrogen: milligrams/Liter Total phosphorus: milligrams/Liter	Total nitrogen: 2 Total phosphorus: 2	Total nitrogen: 0 to 1 Total phosphorus: 0 to 1

3.3.1 Land Use

Study Area land use for the Baseline Condition, 2030 No Build, and 2030 RPA scenarios was provided by Michael Baker Engineering, Inc. (Baker 2009). The land use datasets were developed as part of the Monroe Connector/Bypass quantitative ICE analysis. For the purposes of this Technical Report, the 26 land use classes defined for the quantitative ICE analysis were translated to 12 land use classes for use in the GWLF-E model and 14 land use classes for use in the RUNQUAL-E model (Table 7); RUNQUAL-E considers two more urban land use classes than GWLF-E.

Table 7: Quantitative ICE Land Use Class Conversion to GWLF-E and RUNQUAL-E Land Use Classes

ICE LULC Classes	GWLF LULC Classes	RUNQUAL LULC Classes
Open Water	Water	Water
Piedmont Submerged Aquatic Vegetation	Water	Water
Commercial	High-Density Development	High-Density Development
Industrial/Office/Institutional	Medium-Density Development	Medium-Density Development
Transportation[1]	Low-Density Development	Low-Density Development
Agricultural Pasture/Hay and Natural	Hay/Pasture	Hay/Pasture
Agricultural Fields	Row Crops	Row Crops
Coniferous Cultivated Plantation	Coniferous Forest	Coniferous Forest
Piedmont Dry-Mesic Pine Forests	Coniferous Forest	Coniferous Forest
Piedmont Xeric Pine Forests	Coniferous Forest	Coniferous Forest
Dry Mesic Oak Pine Forests	Mixed Forest	Mixed Forest
Piedmont Mixed Bottomland Forests	Mixed Forest	Mixed Forest
Piedmont Xeric Woodlands	Mixed Forest	Mixed Forest
Riverbank Shrublands	Mixed Forest	Mixed Forest
Xeric Pine-Hardwood Woodlands and	Mixed Forest	Mixed Forest
Piedmont Deciduous Mesic Forest	Deciduous	Deciduous
Piedmont Dry-Mesic Oak and Hardwood	Deciduous	Deciduous
Successional Deciduous Forest	Deciduous	Deciduous
Floodplain Wet Shrublands	Woody Wetland	Woody Wetland
Piedmont Oak Bottomland and Swamp	Woody Wetland	Woody Wetland
Piedmont Emergent Vegetation	Emergent Wetland	Emergent Wetland
Barren (quarries, strip mines, and gravel	Quarries	Quarries
Barren (bare rock and sand)	Transitional	Transitional
Low Density Residential	Low-Density Development	Low-Density Residential
Medium Density Residential	High-Density Development	Medium-Density Residential
High Density Residential	High-Density Development	High-Density Residential

[1]Includes road and its right-of-way with an impervious percentage of 50

AVGWLF definitions of the GWLF-E and RUNQUAL-E land uses classes listed above, and an additional land use class (Turfgrass/Golf Course) described in the Special Land Uses of Water Quality Concern section below, are shown in Table 8 (Evans and Corradini, 2007, Evans et al., 2008).

Table 8: AVGWLF Land Use Class Descriptions

GWLF and RUNQUAL LULC Classes	Description
Water	Open water.
Hay/Pasture	Cover crops similar to "Row Crops" category with lower runoff and generally lower surface erosion, but similar nutrient loading characteristics.
Row Crops	Cover crops similar to "Hay/Pasture" category with higher runoff and generally higher surface erosion, but similar nutrient loading characteristics.
Coniferous Forest	Wooded areas dominated by non-deciduous species. AVGWLF treats all forested areas similarly with regard to runoff, erosion, and nutrient loading.
Mixed Forest	Wooded areas with a mixture of deciduous and evergreen species. AVGWLF treats all forested areas similarly with regard to runoff, erosion, and nutrient loading.
Deciduous	Wooded areas dominated by deciduous species. AVGWLF treats all forested areas similarly with regard to runoff, erosion, and nutrient loading.
Woody Wetland	Wetlands dominated by woody vegetation but treated the same as Emergent Wetland by AVGWLF.
Emergent Wetland	Wetlands dominated by herbaceous vegetation but treated the same as Woody Wetland by AVGWLF.
Quarries	Quarries and transitional areas may be lumped into one category since both areas are treated as "non-vegetated, disturbed" areas within AVGWLF.
Transitional	Quarries and transitional areas may be lumped into one category since both areas are treated as "non-vegetated, disturbed" areas within AVGWLF.
Turfgrass/Golf Course	Highly-maintained, intensively-fertilized area such as golf courses or sod farms.
Low Density Residential	Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for less than 30% of the total cover. These areas most commonly include large-lot, single-family housing units.
Medium Density Residential	Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for 30-75% of the total cover. These areas commonly include low and medium density housing in suburban or smaller urban areas.
High Density Residential	Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for greater than 75% of the total cover. These areas most commonly include small-lot housing or row houses. Some commercial uses, usually converted residences, may be present but represent less than 20% of the total area.
Low Density Mixed	Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for less than 30% of the total cover. These areas commonly include schools, hospitals, commercial areas and industrial parks with extensive, surrounding open land.
Medium Density Mixed	Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for 30-75% of the total cover. These areas are typically found in smaller cities and suburban locations.
High Density Mixed	Areas with a mixture of constructed materials, with vegetation mostly in the form of lawn grasses, shrubs and/or trees. Impervious surfaces account for greater than 75% of the total cover. These areas are typically high-intensity commercial/industrial/institutional zones in large and small urban areas. They may include some dense residential development which should not exceed 20% of the total area.

GWLF and RUNQUAL LULC Classes	Description
Low-Density Development	AKA Low-Density Mixed in RUNQUAL-E.
High-Density Development	AKA High-Density Mixed in RUNQUAL-E.

3.3.2 Special Land Uses of Water Quality Concern

This section describes measures taken to better represent the water quality impacts of land uses of special concern within the Study Area to watershed models. Both land use types are recognized for their potential to degrade water quality.

Golf courses

Of the land uses in the urban landscape, turf is the most intensively managed. Given the intense management and substantial inputs of water and fertilizers required to maintain healthy turf, the perception that substantial nutrient loadings result from golf courses is widespread (Shuman 2002 and Soldat and Petrovic 2008) and well documented (Shuman 2002 and King et al. 2007). Golf courses were identified in the Study Area from 2007 aerial photography. Parcels containing golf courses were identified in GWLF as having a land use category of Turfgrass/Golf Course which is defined as a highly maintained and intensively fertilized area. As such, these areas are associated with high concentrations of dissolved nitrogen and phosphorus in runoff, similar to what would be expected from manure application areas. Golf courses currently existing in the Study Area were assumed to persist into the 2030 RPA and 2030 No Build scenarios. This analysis assumes no new golf courses will be constructed as none is identified in the 2030 RPA and 2030 No Build scenarios.

Chicken Houses

Union County is among the leading North Carolina counties for chicken broiler production and table egg production. A large number of facilities for chicken production exist within the Study Area. Because of the dense animal concentration on these sites, Natural Resource Conservation Service (NRCS) county extension agents (Ferguson, NRCS, personal communication, 10/15/2009) suggested that water quality modeling in Union County should consider the phosphorus contribution of chicken operations. Given that recovery of nutrient inputs in animal products is about 30 percent, substantial quantities of nutrients are accumulated on-farm in animal waste. An excess of phosphorus inputs (fertilizer and feed) over phosphorus outputs (crop and animal production) presents an imbalance that can result in a buildup of phosphorus in soil (N.C. PLAT Committee 2005). Such an imbalance was described in GWLF by assigning locations with chicken operations a higher level of phosphorus in the soil than the surrounding locations which were assigned an average soil phosphorus level.

Chicken houses in the Union County portion of the Study Area were identified from 2007 aerial photography. Parcels containing the chicken houses were identified in GWLF-E as areas with high levels of soil test phosphorus. All other areas in Union and Mecklenburg Counties were identified in GWLF-E as areas of average soil test phosphorus. Values for high and average soil test phosphorus results were derived for Union County along with average soil test phosphorus results for Mecklenburg County by downloading soil test summaries by crop from the N.C. Department of Agriculture (NCDA) for Union and Mecklenburg Counties (NCDA 2009a). The latest available summaries (2007) were used to find median soil test phosphorus values.

In Union County, a high soil test phosphorus value was determined by distributing all agricultural crop samples which fell into ranges predefined by NCDA. The median value for all agricultural samples has a Phosphorus Index (PI) greater than 100 which NCDA defines as excessive phosphorus levels (Myers, NCDA, personal communication, 10/22/2009). A PI of 100 equates to 120 parts per million (ppm) (NCDA 2009b). High soil test

phosphorus values in Union County were thereby defined as 120 ppm. Also in Union County, an average soil test phosphorus value was identified by distributing all residential samples, which included lawns, gardens, and other residential land uses, because roughly 70 percent of the Union County portion of the Study Area is not in agriculture. The median value for all residential samples has a PI in the range of 51 to 100. PBS&J assumed an average soil test phosphorus value for Union County of 51 which equate to 61 ppm. Average soil test phosphorus values in Union County were defined as 61 ppm. In Mecklenburg County, an average soil test phosphorus value was identified by distributing all residential samples (roughly 96 percent of the Mecklenburg County portion of the Study area is not in agriculture). The median value for all residential samples has a PI in the range of 26 to 50. Because more than 31 percent of samples had a PI greater than 26 and 52 percent of the samples had a PI less than 50, a PI of 50 was chosen as a median value which equates to 60 ppm. Average soil test phosphorus values in Mecklenburg County were defined as 60 ppm.

On existing parcels with chicken houses that were projected to be developed in the future, using either the 2030 RPA or 2030 No Build scenario, the soil test phosphorus values were changed from high to average. . Likely the change from high soil phosphorus to average soil phosphorus would be a gradual one but PBS&J assumes that soil phosphorus would return to average levels once inputs from chicken operations cease. This analysis assumes no new chicken houses will be constructed as none is identified in the 2030 RPA and 2030 No Build scenarios.

3.3.3 Soils

Spatial and tabular Soil Survey Geographic (SSURGO) soil information was downloaded from NRCS (NRCS 2009) for Union and Mecklenburg Counties. The soils were clipped to the Study Area boundary. Soil series, or map units, which occurred in the Study Area, were assigned available water-holding capacity, soil erodibility (K) factor, dominant hydrologic soil group, and organic matter content as required by GWLF. Available water-holding capacity was assigned by using the Available Water Storage 0-100 cm - Weighted Average value provided for each map unit in the Mapunit Aggregated Attribute table. Soil erodibility (K) factor was assigned using the Kf value provided for the top horizon in the Horizon table for each map unit. Dominant hydrologic soil group was assigned by using the Hydrologic Group - Dominant Conditions value provided for each map unit in the Mapunit Aggregated Attribute table. Organic matter content is not currently used by the model and was not assigned a value.

3.3.4 Curve Numbers

GWLF-E and RUNQUAL-E automatically calculate Curve Numbers (CNs) based on land use class and hydrologic soil group. The resulting CNs are often of a reasonable magnitude, but appear to be an average across the CNs for a particular land use. Moreover, the model-generated CNs were found to be different than CNs manually calculated for the land use classes in the Study Area catchments. The manual CN calculation involved computing the CN for each land use class as an area-weighted average based on the area of the land use class overlying the four hydrologic soil groups. It was assumed that the manually-calculated CNs better reflected the catchment conditions that the model-calculated CNs. As such, the model-calculated CNs for each catchment were replaced with manually calculated CNs. The CNs assigned to each of the quantitative ICE land use classes are presented in Table 9.

Table 9: Quantitative ICE Land Use Class CN Assignments.

Quantitative ICE Land Use Classes	CN for Soil Hydrologic Group			
	A	B	C	D
Transportation	98	98	98	98
Medium Density Residential	61	75	83	87
Industrial/Office/Institutional	81	88	91	93

Quantitative ICE Land Use Classes	CN for Soil Hydrologic Group			
	A	B	C	D
High Density Residential	77	85	90	92
Commercial	89	83	94	95
Low Density Residential	54	70	80	85
Open Water	98	98	98	98
Coniferous Cultivated Plantation	30	55	70	77
Successional Deciduous Forest	30	55	70	77
Agricultural Fields	67	78	85	89
Agricultural Pasture/Hay and Natural Herbaceous	49	69	79	84
Barren (quarries, strip mines, and gravel pits)	77	86	91	94
Barren (bare rock and sand)	77	86	91	94
Piedmont Xeric Pine Forests	30	55	70	77
Piedmont Dry-Mesic Pine Forests	30	55	70	77
Piedmont Xeric Woodlands	30	55	70	77
Piedmont Dry-Mesic Oak and Hardwood Forests	30	55	70	77
Piedmont Deciduous Mesic Forest	30	55	70	77
Xeric Pine-Hardwood Woodlands and Forests	30	55	70	77
Piedmont Submerged Aquatic Vegetation	98	98	98	98
Piedmont Emergent Vegetation	68	79	86	89
Riverbank Shrublands	30	48	65	73
Floodplain Wet Shrublands	30	48	65	73
Dry Mesic Oak Pine Forests	30	55	70	77
Piedmont Mixed Bottomland Forests	30	55	70	77
Piedmont Oak Bottomland and Swamp Forests	36	60	73	79

3.3.5 Streams

The stream layer was derived from the National Hydrography Dataset (NHD) (USGS 2009) by extracting and merging the high resolution NHD flow lines for 2 prestaged subregions, the Pee Dee and Edisto-Santee. The merged streams were then clipped to the Study Area boundary. The clipped streams were converted to 2-D streams for use by AVGWLF.

3.3.6 Weather Stations

The location of weather stations with daily temperature (maximum and minimum) and precipitation records for the period 2000-2008 were retrieved from National Oceanic and Atmospheric Administration (NOAA) (NOAA 2009) and USGS (USGS 2009). Weather data from the Monroe 2 SE station in Monroe and the CRN-32 rain gauge at Bain Elementary School in Mint Hill was formatted for use by AVGWLF.

3.3.7 Point Sources

Location of point source dischargers within the Study Area were identified by retrieving NPDES permits from NCDWQ (NCDWQ 2009). Monthly discharge reports for all dischargers were retrieved from NCDWQ for the period 2007-2008. Additionally, monthly discharge permits for dischargers in the calibration watersheds were retrieved for the period 2000-2007.

3.3.8 Surface Elevation

A 20-foot resolution Digital Elevation Model (DEM) of the Study Area was constructed from Mecklenburg and Union County DEM tiles obtained from N.C. Floodplain Mapping Program (NCFMP) (NFFMP 2009).

3.3.9 Basins

Drainage basins (catchments) were defined by subdividing USGS 14-digit HUs into watersheds wholly contained in the Study Area. Catchment boundaries were delineated using software (Arc Hydro) which automatically delineates drainage areas and stream networks from a DEM. Arc Hydro delineated catchments by detecting flow direction and accumulation using surface elevation and established flow routes (i.e., NHD flowlines).

3.3.10 Septic Areas

GIS layers describing sanitary sewer pipes and the extent of current public sewer systems for Union and Mecklenburg Counties were retrieved from NC OneMap (NC OneMap 2009) along with sanitary sewer pipes from Union County (Union County 2009). When the sewer pipe layers and current service area were overlaid, it appeared that the current service area was only a general approximation of the sewer service extent. To more accurately delineate the current service area, the current service area layer was contracted in areas that according to aerial photography did not appear to have sewer service (i.e., sparsely populated areas). The current service area layer was expanded to include areas of dense population (identified by aerial photography interpretation) that occur inside the corporate limits of municipalities (NC Department of Transportation 2009). It was assumed that the current service area had expanded to include populated areas within municipal boundaries given that at least four years had passed since the publication of the current service layer and pipes layers. This analysis assumes no changes to septic areas in the either of the future land use scenarios.

3.3.11 Best Management Practice (BMP) Implementation

GWLF-E and RUNQUAL-E are capable of calculating pollutant load reductions attributable to riparian buffers (buffers). The buffer parameter requirements of the two models vary slightly. GWLF-E requires the length of buffered stream in rural (GWLF-E land uses row crops and hay/pasture), high-density urban (GWLF-E land use high-density development), and low-density urban (GWLF-E land use low-density development) areas. A single reduction efficiency is assigned for nitrogen, phosphorus, and overland sediment. The provided efficiencies reduce runoff-bound pollutants generated from the above land uses. By accommodating only a single reduction efficiency per pollutant, GWLF-E in effect simulates a single buffer width. Buffer inputs for RUNQUAL-E include the buffered fraction of the stream network and a buffer width value. The reduction efficiencies applied to the runoff are hardwired into the model and not available for editing. RUNQUAL-E also does not consider variable buffer widths.

Buffer parameter values required for GWLF-E and RUNQUAL-E were derived by delineating and characterizing buffers throughout the Study Area. The process was initiated by identifying buffer regulations in the various planning jurisdictions of the Study Area. Table 10 summarizes the Study Area buffer regulations as reported in the qualitative ICE (NCTA 2009). Using GIS, the stream network represented by the NHD flowlines was buffered based on the buffer requirements applicable to the streams' location. Overlapping jurisdictions are described more fully in the qualitative ICE. The resulting buffer layer establishes the extent of regulated buffer zones in the Study Area. The buffer layer does not reflect the existing extent of intact buffers. To delineate the existing extent of intact buffers, the buffer layer was overlaid on 2007 Mecklenburg and Union aerial photography (Mecklenburg County 2007 and Union County 2007). Areas of disturbed buffer were removed from the buffer layer, leaving only intact buffers within regulated buffer zones. The final buffer layer represents the Baseline Condition buffer extent.

Table 10: Study Area Regulated Buffer Widths.

Jurisdictional Area	Criterion	Width (feet)
Union County	Intermittent stream	30
Union County	Perennial stream, drainage area < 640 acres	50
Union County	Perennial stream, drainage area > 640 acres	100
Union County – Sixmile and Waxhaw watersheds	Intermittent stream	100
Union County – Sixmile and Waxhaw watersheds	Perennial stream	200
Union County - Goose Creek watershed	Waterbodies within the 100-year floodplain	200
Union County - Goose Creek watershed	Waterbodies outside of the 100-year floodplain	100
Monroe	Perennial stream	100
Union County - WS-III watersheds	High density - > 2 units/acre	100
Union County - WS-IV watersheds	High density - > 2 units/acre	100
Wesley Chapel	Open channels on properties less than 25 acres	20
Wesley Chapel	Open channels on properties less than 75 acres	50
Indian Trail	Intermittent stream	100
Indian Trail	Perennial stream	200
Stallings	Intermittent stream	30
Stallings	Perennial stream	30
Mecklenburg County	Drainage area >= 50 acres	0
Mecklenburg County	Drainage area >= 100 acres	35
Mecklenburg County	Drainage area >= 300 acres	50

Jurisdictional Area	Criterion	Width (feet)
Mecklenburg County	Drainage area >= 640	100 + 50% floodplain fringe
Matthews	Drainage area >= 50 acres	35
Matthews	Drainage area >= 300 acres	50
Matthews	Drainage area >= 640	Wider of floodway + floodplain fringe or 100 ft.
Mint Hill	Drainage area >= 50 acres	35
Mint Hill	Drainage area >= 300 acres	50
Mint Hill	Drainage area >= 640	Wider of floodway + floodplain fringe or 100 ft.
Union County	Intermittent stream	30

Buffer parameter values were calculated for the GWLF-E and RUNQUAL-E sub-catchments of each Study Area HU using the Baseline Condition buffer extent described above. Intact buffers are characterized for the Study Area in Figure A2 (Appendix A). In the case of the GWLF-E sub-catchments, the length of buffered streams in rural, high-density urban and low-density urban areas was determined using the Baseline Condition land use produced by Michael Baker Engineering, Inc. (Baker 2009). Pollutant reduction efficiencies required by GWLF-E are selected based on buffer width. Because GWLF-E allows only one reduction efficiency per pollutant, an average buffer width representative of the GWLF-E sub-catchments as a whole was determined prior to selecting the reduction efficiency. The average sub-catchments buffer width was calculated as a weighted average based on the length of the buffered stream segments. The average buffer width was placed into one of two categories: 50-foot and 100-foot buffers. Average buffer widths of 52 feet or less were placed in the former category and widths greater than 52 feet in the latter. Table 11 presents the reduction efficiencies associated with the two buffer width categories. The 50-foot buffer reduction efficiencies were taken from the NCDWQ Stormwater Best Management Practices Manual (2007b). The 100-foot buffer efficiencies were derived by applying the 50-foot buffer efficiencies in series as described in the North Carolina State University (NCSU) stormwater guidelines (NCSU 2006).

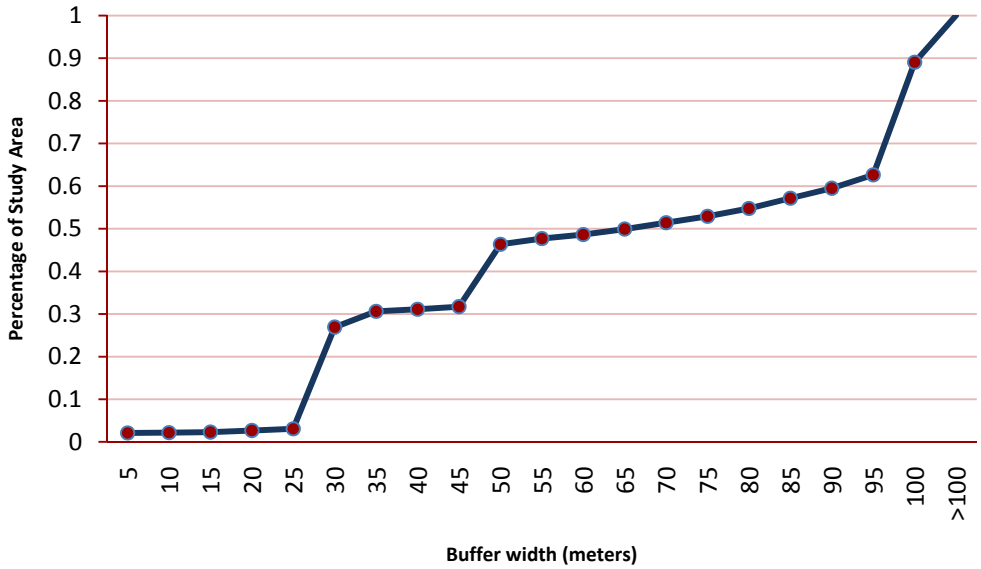


Figure 2: Study Area Buffer Cumulative Distribution.

Table 11: GWLF-E Buffer Reduction Efficiencies.

Buffer Width (ft)	Reduction Efficiency (%)		
	TN	TP	TSS
50	30	35	60
100	51	58	84

The buffered stream fraction required for RUNQUAL-E sub-catchments was determined from the Baseline Condition buffer extent. The average buffer width for RUNQUAL-E sub-catchments was calculated as a weighted average, in similar fashion to the GWLF-E sub-catchments. However, unlike GWLF-E, the average buffer width is input into RUNQUAL-E as is, without any generalization.

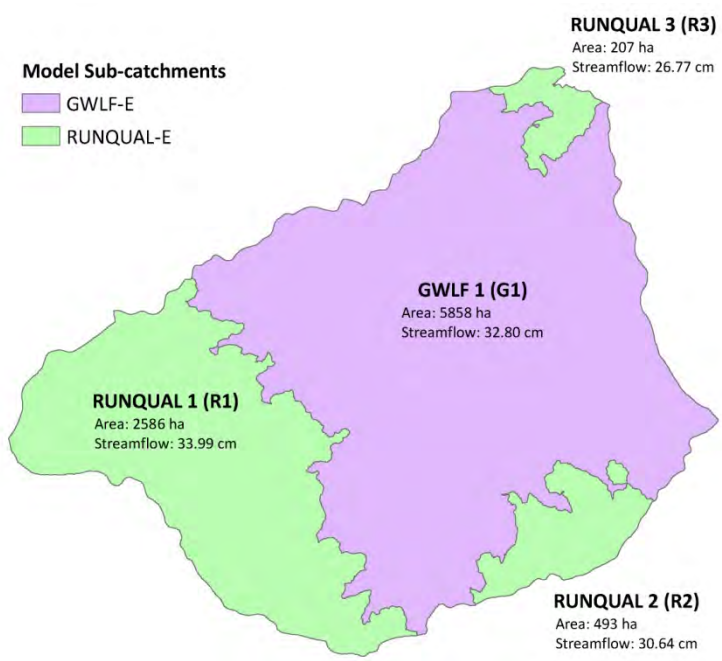
The Baseline Condition buffer extent was delineated for riparian areas currently protected by local regulations. It is assumed that current regulations will remain in place and be enforced thereby maintaining the Baseline Condition buffer extent throughout the analysis timeframe. As such, Baseline Condition buffer parameter values were used in the 2030 No Build and 2030 RPA GWLF-E and RUNQUAL-E models.

Riparian buffers were the only BMP considered in this analysis. Implementation of other BMPs – bioretention basins, stormwater ponds, grass swales, etc. – requires site-specific information unavailable at this time. Land use controls and BMPs, identifiable from remote sensing data sources or through coordination with representatives from local municipal centers, were considered in this analysis; however, PBS&J believes that, without site-specific information, simulating such BMPs for developed areas in the future land use scenarios amounts to applying a blanket pollutant loading reduction to all runoff from these areas. Table 5 outlines post-construction BMP requirements for planning jurisdictions in the Study Area. Substantial pollutant load reductions beyond those provided by the simulated riparian buffers could be realized if the mandated BMP requirements are enforced and the BMPs are properly constructed and maintained.

3.4 Combining GWLF-E and RUNQUAL-E Results

Annual streamflow, runoff, and pollutant loads were estimated for Study Area catchments and sub-catchments using the GWLF-E and RUNQUAL-E models. The degree of catchment or sub-catchment development determined the model used. In some cases, a catchment was segregated into multiple GWLF-E and RUNQUAL-E sub-catchments, as with Stewarts Creek (Figure 3A, Appendix A). For these catchments, total catchment annual streamflow, runoff, and pollutant loads were calculated by combining the streamflow, runoff, and pollutant loads estimated for the GWLF-E and RUNQUAL-E sub-catchments.

TN, TP, and TSS loads are reported in units of mass (kilograms) for both GWLF-E and RUNQUAL-E. Calculating the total catchment load of these pollutants required only adding the corresponding GWLF-E and RUNQUAL-E loads together. Calculating total catchment streamflow, runoff, and FC was more involved. GWLF-E and RUNQUAL-E report streamflow and runoff in depth (centimeters) over the modeled area. As such, total catchment streamflow and runoff was calculated as the area-weighted average of the GWLF-E and RUNQUAL-E sub-catchment streamflows and runoff. This approach uses area to scale the contribution of each sub-catchment to the total streamflow and runoff. Figure 3 details the total catchment streamflow calculation for the Baseline Condition of Stewarts Creek. Runoff is handled similarly. FC results are reported in two units of measurement: total colony forming units (cfu) and mean concentration (cfu/100 ml). Total catchment FC cfu's were calculated by summing the number of cfu's for all GWLF-E and RUNQUAL-E sub-catchments, similar to the TN, TP, and TSS calculation. However, total FC mean concentration was calculated as a streamflow-weighted average, which is more in line with the total streamflow calculation. The sub-catchment contributing the greatest amount of streamflow has the most influence over the total catchment FC mean concentration.



$$Total\ Catchment\ Streamflow = \frac{(Area_{G1} \times Streamflow_{G1}) + (Area_{R1} \times Streamflow_{R1}) + (Area_{R2} \times Streamflow_{R2}) + (Area_{R3} \times Streamflow_{R3})}{Area_{G1} + Area_{R1} + Area_{R2} + Area_{R3}}$$

$$Total\ Catchment\ Streamflow = \frac{(5858 \times 32.80) + (2586 \times 33.99) + (493 \times 30.64) + (207 \times 26.77)}{5858 + 2586 + 493 + 207} = 32.88\ cm$$

Figure 3: Total Catchment Streamflow Calculation for Stewarts Creek (Baseline Condition)

3.5 Model Calibration

A modeling analysis of any type may include a calibration procedure in which model parameters are adjusted to achieve a best-fit model, or a model that best accords with observed data. This process occurs in two steps: calibration and validation. Before either is performed, the observed data record is split into corresponding calibration and validation periods. Alternatively, two independent systems with observation records, watersheds in the case of water quality analyses, may be designated calibration and validation systems (Lee et al. 2000 and Evans et al. 2002). During calibration, model parameters are adjusted within reasonable ranges until the model results best fit the observed data of the calibration period or system. The performance of the calibrated model is then tested in the validation step by executing the model for the validation period or system and comparing the results to observed data (EPA 2008). In watershed modeling studies, the scope of the calibration effort in part depends on the nature of the analysis and the availability of observed data. Comparative analysis such as one the described in this Technical Report often do not require a rigorous calibration effort as model error is expected to affect the study scenarios equally.

The goal of the calibration effort for this analysis was to produce the best fit between modeled total annual streamflow and observed streamflow. The watersheds of two USGS gage stations in the Goose Creek watershed (HU 03040105070060) (USGS, 2009a and 2009b) (Table 12) were used in the calibration procedure. The watershed of gage 0212467595 was designated as the calibration watershed and the watershed of gage 02124692 the validation watershed. The gage 0212467595 watershed is nested within the larger watershed of gage 02124692. Ideally, the calibration and validation watersheds should be spatially distinct; however, the paucity of monitoring data in the Study Area prevented following this convention. Pollutant loadings also were not calibrated, again due to the lack of adequate monitoring data. The established calibration and validation periods reported in Table 12 were limited by the gage record lengths. Both periods do, however, capture years of varying rainfall; the root mean square error for monthly precipitation averages ranges from a low of 1.65 inches in 2002 to a high of 3.48 inches in 2004.

The developed calibration procedure was shaped by several factors, the foremost being that the RUNQUAL-E model inappropriately produced negative monthly streamflow values in some cases. This matter was brought to the attention of the AVGWLF developers, who attributed it to a problem with the RUNQUAL-E subsurface hydrology routines (Evans, personal communication, January 26, 2010). The AVGWLF developers did recommend some model adjustments, but none rectified the problem. Despite the instances of negative monthly streamflows, the total annual streamflow values produced by RUNQUAL-E were ultimately found to be of reasonable magnitude for use in the analysis. However, accepting the negative RUNQUAL-E streamflows forced the model calibration to be performed on the annual time step. Since the results of previous analyses of this nature have typically been reported at the annual time scale, calibrating to the annual total observed streamflow was not judged to be a problem. Others, including Lee et al. (1999), have employed a similar calibration strategy using the annual time scale.

The rate of land use change in the PSA was also taken into account. The AVGWLF developer suggested the calibration timeframe be limited to five to six years for any single land use dataset (Evans personal communication, October 18, 2009), a maxim that takes on more relevance in fast developing areas. The calibration and validation periods used for the two gages in Table 12 extend 4 to 6 years before the Baseline Condition land use, which captures the 2007 land use condition. Given the observation records extend to 2003 and 2001, coupled with the high rate of growth in the Charlotte metropolitan area in the beginning of the decade – the area grew at a rate of 14 percent between 2000 and 2005 (U.S. Census Bureau 2006) – it was assumed that the land use condition at the beginning of the observation records may reflect a significantly different hydrologic condition than the Baseline Condition. Consequently, dividing the observation records into calibration and validation periods (e.g., dividing the observation record at gage 0212469 into a calibration period from 2001-2004 and validation period from 2005-2008) would possibly lead to calibrating the model to a

distinctly different land use condition than the validation period. Keeping the observation records intact by establishing separate calibration and validation watersheds has the effect of averaging the land use condition across the relatively longer calibration and validation periods. This reduces the influence of any single observation year, thereby minimizing the affect that potentially non-representative land use conditions may have on the calibration procedure.

Table 12: Calibration Watersheds.

Gage Station	Stream	Location	Calibration / Validation	Observation Record (month/year)	Calibration / Validation Period (years)
0212467595	Goose Creek	Mill Grove Road, Indian Trail, NC	Calibration	09/2002 - Current	2003 - 2008
02124692	Goose Creek	US 601, Fairview, NC	Validation	01/2001 - Current	2001 - 2008

As previously discussed, the GWLF-E and RUNQUAL-E models employed in this analysis represent the hydrologic process as an interaction between climatic (precipitation, evapotranspiration), land cover (runoff), and sub-surface (soil infiltration, hydraulic conductivity, and groundwater seepage) factors. Of these factors, Evans et al. (2002) and Evans (personal communication 12/21/2009) recommended calibrating streamflow by adjusting the evapotranspiration (ET) parameters. ET can be estimated relatively easily from the observed weather record. Parameters related to other factors are more difficult to estimate or should only be adjusted over a narrow range (groundwater recession, groundwater seepage) (Haith et al. 1992).

Calibration involved adjusting the GWLF-E and RUNQUAL-E parameters of the gage 0212467595 watershed models to achieve better agreement between the model annual streamflow and observed streamflow. Table 13 identifies the Parameters adjusting during calibration. The final parameter values are listed in Appendix B.

Table 13: Calibrated Parameters.

Model	Parameter
GWLF-E	Evapotranspiration Cover Coefficient
GWLF-E	Groundwater Recession Coefficient
GWLF-E	Seepage Coefficient
RUNQUAL-E	Impervious Cover Curve Number
RUNQUAL-E	Evapotranspiration Adjustment Factor

The Nash-Sutcliffe statistic (Nash and Sutcliffe 1970), a goodness-of-fit statistic recommended by the American Society of Civil Engineers (1993) for hydrologic studies, was used to evaluate the fit of the modeled streamflow to observed stream. The Nash-Sutcliffe statistic (N-S value) can range from $-\infty$ to 1. The statistic measures the models predictive performance relative to the mean of the observed data. A value of 1 indicates a perfect fit, while a value of 0 indicates the model is predicting no better than mean of the observed data. The relationship

between the calibrated, best-fit streamflow and observed streamflow is illustrated in Figure 4. Modeled streamflows produced for the gage 0212467595 watershed correlated reasonably well with the observed annual streamflow (N-S value = 0.78). The root mean square error (RMSE) between the modeled and observed annual streamflows for the calibration watershed was 6.1 cm.

Validation involved using the validation model constructed for the gage 02124692 watershed to further evaluate the appropriateness of the ET parameter adjustments made to the calibrated model. The best-fit parameter values found for the calibration watershed were incorporated in the validation model and the model executed. The annual streamflows produced by the validation model exhibited equally as strong a relationship with the observed streamflows as did the calibrated model (N-S = 0.78). The RMSE between the modeled and observed annual streamflows for the validation watershed was 6.2 cm.

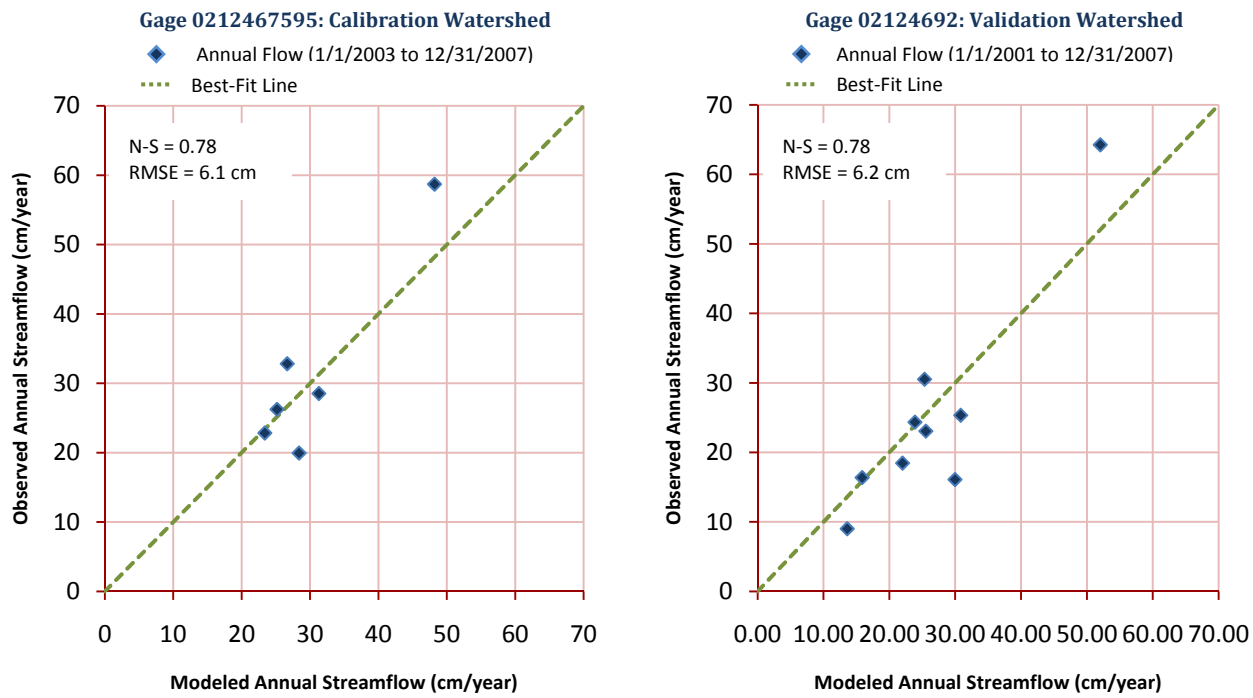
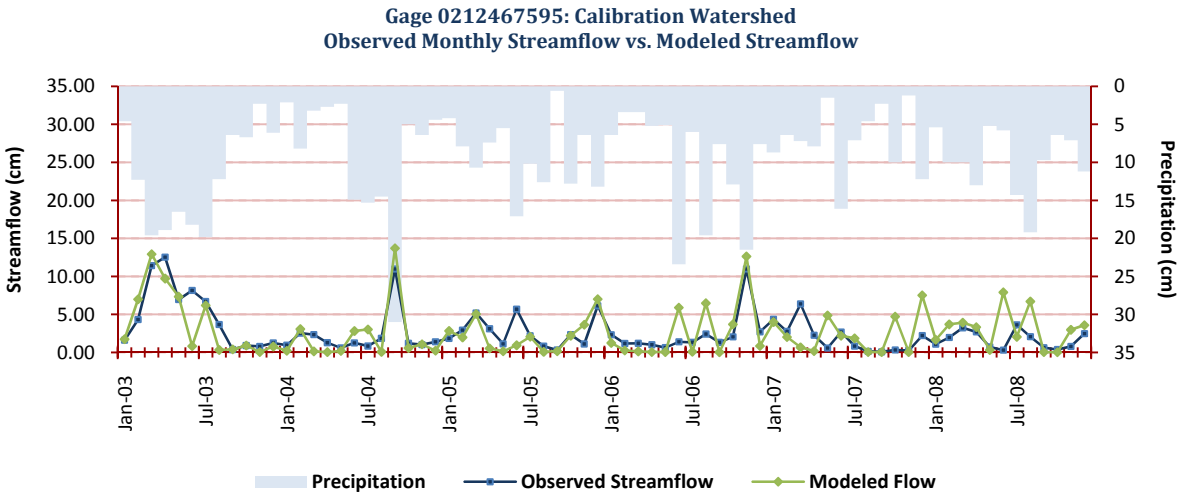


Figure 4: Calibration and Validation Model Annual Streamflows Related to Observed Annual Streamflow.

Modeled monthly flows are plotted against the observed monthly streamflows of the calibration and validation watersheds in Figure 5; monthly precipitation is plotted along the top axis. In general, the peaks of the modeled streamflow align with the observed streamflow in terms of magnitude and duration; although, the amplitudes of the modeled peaks often larger than those of the observed streamflow in the later portion of the calibration period. Examining the results of the GWLF-E and RUNQUAL-E models individually indicated the outsized peaks are attributable to excessive runoff produced by the RUNQUAL model. This condition is likely a consequence of RUNQUAL-E's incomplete subsurface flow routine. As precipitation is simulated in the RUNQUAL-E model, the primary pathways for the water are evapotranspiration, runoff, and subsurface flow. Water that does not evaporate converts to runoff and is discharged into the stream network or enters subsurface storage for later release. However, water entering subsurface storage appears to be immediately released to the stream network, in much the same way runoff is, and does not demonstrate the typical lag caused by the movement of water through subsurface. The overall effect is that the RUNQUAL-E model immediately discharges all excess precipitation to the stream network, creating an exaggerated pulse of streamflow.

Special attention was paid to the RUNQUAL-E monthly streamflow values. RUNQUAL-E often reported negative streamflows for two to three months of every year in the calibration and validation periods. These incorrect streamflow values are, again, likely the consequence of the incomplete subsurface flow routine in RUNQUAL-E. The negative monthly streamflows serve to counterbalance excessive streamflows of wetter months, thereby artificially moderating the annual total streamflow. All efforts to eliminate the negative streamflows were unsuccessful. However, a compromise was reached by re-assigning all negative streamflows to a value of zero. Recalculating the annual total streamflow with negative monthly values replaced by zeros caused the annual total streamflow values to far exceed the observed annual totals. Further adjustment to the calibration parameters was made to bring the model annual streamflow in line with the observation record. The monthly streamflow values estimated by the final calibration and validation models are plotted in Figure 5.

Ultimately, it was concluded the watershed models constructed for the gage 0212467595 and 02124692 watersheds performed adequately well in calibration and validation procedures. The ET parameter values used in the best-fit models were incorporated in the watershed models constructed for the eighteen 14-digit HUs in composing the Study Area.



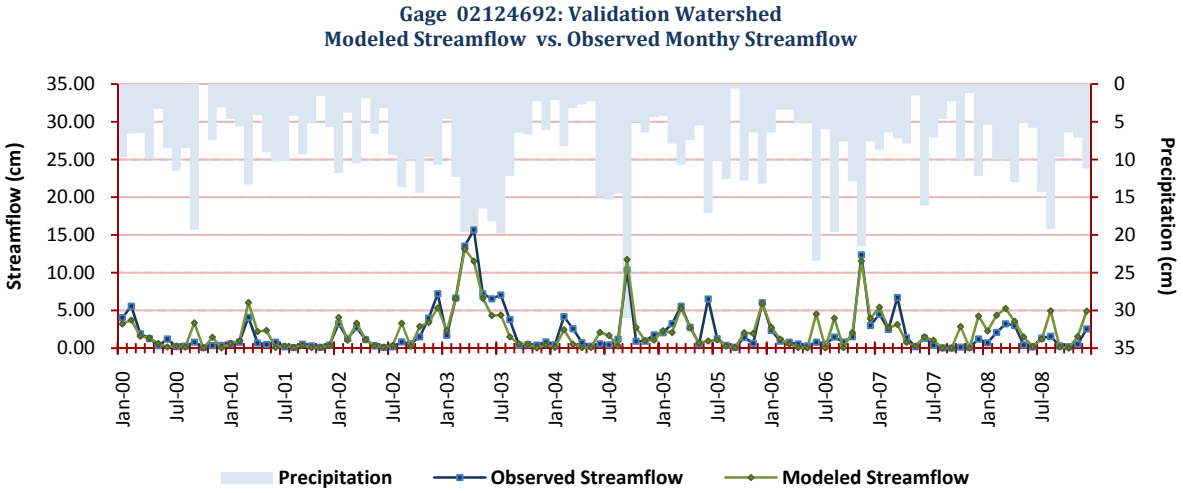


Figure 5: Calibration and Validation Model Monthly Streamflows Plotted with Observed Monthly Streamflow.

4.0 RESULTS AND DISCUSSION

AVGWLF was run for three land use scenarios – Baseline Condition, 2030 No Build, and 2030 RPA. Between scenarios, land use and soil phosphorus were modified as per the assumptions described above. Other input parameters (Appendix B) remained constant for all modeled scenarios. Simulations were run for two years using weather data for the period 2007 to 2008. Some parameters which reflect model initial conditions have a short-term effect on model results (e.g., unsaturated, saturated storage, and initial snow). The effects of these variables can be avoided by running the model for a year prior to the time period of interest (Lee 2000). Model results are reported for the second year of the simulation period.

Streamflow, runoff, and loading rates of TN, TP, TSS, and FC (referred to cumulatively as "pollutants") vary as land use patterns change within the Study Area. In both future scenarios increased coverage by impervious surfaces resulted in increases in runoff. These results are expected as increased urbanization occurs. Higher pollutant loads are anticipated as currently undeveloped, unmanaged land use categories are converted to residential, commercial, and industrial categories. Nutrient export loads from forest lands are significantly less

than export loads from commercial and industrial parcels. However, the change from undeveloped but managed land use categories to developed land use categories can result in decreased pollutant loads but increases in runoff.

The results of the water quality analysis are discussed individually for the three modeled land use scenarios. Tables comparing the streamflow and pollutant loadings for the three scenarios are provided (Tables 12-18). The presentation format of the tables is discussed in section 4.4. Analysis results are graphically presented in Figures A4-A9 in Appendix A.

4.1 Baseline Condition

The Study Area is a mosaic of urban and rural land uses which has developed rapidly (NCTA 2009). Urban and suburban land uses are concentrated in the western portion of the Study Area and rural land uses predominate in the eastern portion. Urban land use emanates from Charlotte decreasing in density with distance with the exception of clusters in Monroe, Wingate, and Marshville extending primarily along the existing US 74 corridor.

Catchments with high impervious percentages, as described in Baker (2009), contribute high runoff and streamflow (e.g., McAlpine, Irvins, and Four Mile Creeks). TSS comes from two sources in the model, overland erosion and streambank erosion. Both are related to runoff but are influenced by watershed specific conditions such as slope and soil properties. McAlpine, Irvins, and Four Mile Creeks are the major exporters of TSS under existing conditions.

Frequently nutrients, particularly TP, are correlated to TSS loads. Richardson Creek (Middle) is a special case due to the presence of the Monroe Municipal Waste Water Treatment Plant (WWTP); the WWTP is by far the largest point source discharger in the Study Area. Richardson Creek (Middle), because of the WWTP, is the largest source of TP followed by Crooked Creek, Widemouth Branch, and Gourdvine Creek which have agriculture as their primary source. Richardson Creek also contributes the highest amount of streamflow in the Study Area.

Richardson (Middle), Crooked Creek, Widemouth Branch, and Bakers Branch are the leading exporters of TN under the Baseline Condition. The Richardson Creek (Middle) TN load is attributable to the WWTP. Agricultural runoff is the cause of the large TN loads in the others.

The largest sources of FC are wildlife and urban runoff. In rural catchments, wildlife constitutes the largest FC source. Conversely, runoff contributes the largest portion of the FC load in urban catchments. Generally, the catchments within or bordering Mecklenburg County (e.g., McAlpine, Irvin, Four Mile, and Sixmile Creeks) are the largest exporters of FC per acre in the Baseline Condition. Although, Richardson Creek (Middle) and Bearskin Creek also export a higher than average FC load. The comparatively larger FC loads for all the mentioned catchments are attributable to urban runoff. The mean FC concentration results are more difficult to interpret as values vary depending on rainfall event timing and monthly streamflow amounts. Moreover, the catchments with the largest total FC loads do not necessarily have the largest mean FC concentrations. With that said, the mean FC concentrations are reported for informational purposes, and the discussion from here out will focus on the total FC loads.

Lastly, it is worth noting that many of the catchments identified in the Baseline Condition as the largest contributors of pollutant loads are included on the 2006 303(d) list: McAlpine, Six Mile, Crooked, and Richardson (Middle) Creeks (NCDWQ 2006).

4.2 2030 No Build

Development in the Study Area is predicted to increase (Baker 2009, NCTA 2009). Mecklenburg County is predicted to remain an engine of economic growth, growing at a rate larger than the rest of North Carolina.

Union County is predicted to grow at an even greater rate than Mecklenburg County (NCTA 2009). In the 2030 No Build scenario impervious area is projected to increase in each of the Study Area catchments. Increases in runoff and sediment loading are predicted across all catchments with the exception of Gourdvine Creek which is predicted to add only a small area of new development resulting in a small increase in runoff. Nutrient loading is mitigated to an extent by the loss of agricultural land use in many of the catchments.

The major contributors of streamflow do not change much in the No Build scenario. Catchments with high impervious percentages continue to contribute high streamflow and runoff (McAlpine, Four Mile, and Irvins Creeks). Sixmile Creek, with its predicted five percent increase in impervious cover, experiences the largest percentage increase. Richardson Creek (Middle) with its WWTP is still the major contributor of streamflow in the Study Area.

McAlpine, Crooked, Irvins, and Four Mile Creeks are the major exporters of TSS under this scenario; however, all catchments experience an absolute increase in TSS loading, except Gourdvine Creek, with Stewarts, Richardson (Lower), and Sixmile Creeks having the largest percentage change.

The pattern of largest TP and TN exporters holds from the Baseline Condition: Richardson Creek (Middle) remains the largest exporter of nutrients; Bakers Branch, Crooked Creek, and Widemouth Branch are also among the largest exporters. However, urbanization becomes a more frequent source with Twelve Mile Creek experiencing the largest percentage change in TP load. TN loads decrease in all of the catchments, reflecting the transition from agricultural land uses (cropland and pasture) to urban land uses. TP decreases in 13 of the 18 catchments. However, a point of inflection is reached after a certain degree of urban development where additional urbanization causes increases in TP loads, not decreases. This is the case in the five catchments that experienced increased TP loads.

FC decreases as land use transitions from natural areas to urban land uses, reflecting a reduction in FC loads from wildlife. Similar to TP, a point is reached where increased runoff from further urbanization produces increased FC loads. FC loads decrease five of the 18 catchments because of the loss of natural areas. FC loads increase in the remainder of the catchments due to increased runoff from urbanization. The largest FC load increase in terms of both magnitude and percentage occurred in Sixmile Creek.

4.3 2030 Recommended Preferred Alternative (RPA)

The land use condition captured by the 2030 RPA scenario is differentiated from the 2030 No Build scenario by construction of the Project. The 2030 RPA scenario would see approximately 1,000 additional acres of development, including approximately 200 additional commercial acres, and approximately 100 additional acres of industrial/office development in the Study Area as compared to the 2030 No-Build scenario (Baker 2009). Most of this induced development is expected within approximately one mile of the interchanges (Figure A3, Appendix A). In aggregate, the 2030 RPA scenario shows little difference as compared to the 2030 No-Build scenario. Within the detailed land use categories, however, there is a decrease of 1,200 acres in low-density residential land use, but an increase of 700 acres in medium-density residential, which is estimated to produce the net increase of 1,300 households with the RPA. The decreases in projected low-density residential land use acres are a result of displacement or replacement by the direct effects of the RPA, replacement by commercial or industrial development near interchanges, or replacement with medium-density residential development in the 2030 RPA scenario.

The additional development is concentrated along the RPA in 6 catchments: Crooked, Stewarts, Richardson (Middle), Ray's Fork, Richardson (Lower), and Salem Creeks. All 6 catchments add impervious surface cover in the 2030 RPA scenario. Of these catchments, Stewarts, Crooked, and Richardson (Lower) had the largest area of change between the 2030 No Build and the 2030 RPA scenarios while no change exceeded 2 percent of the

catchment. Of these catchments, Stewarts had the largest change in development density between the No Build and Build scenarios. Stewarts also had the largest amount of new development between 2030 No Build and the 2030 RPA.

The changes in development density along with the location of those changes drive the differences in streamflow, runoff, and pollutant loading in the 2030 RPA scenario as compared to the 2030 No Build scenario. Specifically, differences in streamflow, runoff, and pollutant loads are caused by increased impervious surface coverage in the 2030 RPA scenario and the attendant increase in runoff. Areas with large increases in the highest density development are projected to experience the largest increase in streamflow, runoff, and pollutant loading. To some extent, an increase in the highest density land use is offset by decreases in lower density development (Figure 6). However, increases in the highest density always increases runoff. The effect of runoff on pollutant loading is determined by whether the increase occurred in a rural portion of the catchment or an urban portion because urban nutrient loads are less tied to sediment loads. The magnitude of the increases in streamflow, runoff, and pollutant load brought on by the changes shown in Figure 6 is amplified in the case of Richardson Creek (Lower) by the catchment size. Richardson Creek (Lower) adds roughly the same area of the highest density land use as Stewarts, but to a much smaller catchment with more of the additional highest density land use in the urbanized portion of the catchment, leading to higher runoff and streamflow.

4.4 Results Tables

The water quality analysis results are compared in the series of tables that follow (Tables 15-21). Each table presents the results of a single experimental parameter for the 18 catchments composing the Study Area. The percent difference between the 2030 No Build and 2030 RPA results are reported in the rightmost column of the tables, with the heading "2030 RPA – 2030 No Build". The values in this column quantify the water quality effect of the Project as measured by this analysis. Catchments exhibiting a difference between the 2030 No Build and 2030 RPA streamflow or pollutants loadings are highlighted yellow.

GWLF-E and RUNQUAL-E consume the data listed in Table 6 to produce streamflow, runoff, and pollutant loads. The number of decimal places and significant figures generally used by GWLF-E and RUNQUAL-E for reporting various model outputs are displayed in Table 14. The significant figures listed in Table 14 determined the significant figures used to report the analysis results in Tables 15-21. Some pollutant loads are presented as annual loading per unit catchment area. In these cases, the five significant figure pollutant load is divided by the five significant figure catchment area. The resulting quotient should also contain five significant figures. However, reported values have been truncated to three or four signification figures (i.e., three decimal places) to avoid excessively long decimal values.

Table 14: Reported Significant Figures

Parameter (units)	Decimal Places	Significant Figures
Streamflow (centimeters/year)	2	4
Runoff (centimeters/ year)	2	4
Total Nitrogen (kilograms/year)	1	6
Total Phosphorus (kilograms)	1	5
Sediment (kilograms x 1000/year)	1	5

Parameter (units)	Decimal Places	Significant Figures
Total Fecal Coliform (colony forming units/year)	0	4
Mean Fecal Coliform Concentration (colony forming units/100 milliliters of streamflow)	1	6
Area (hectares)	0	5

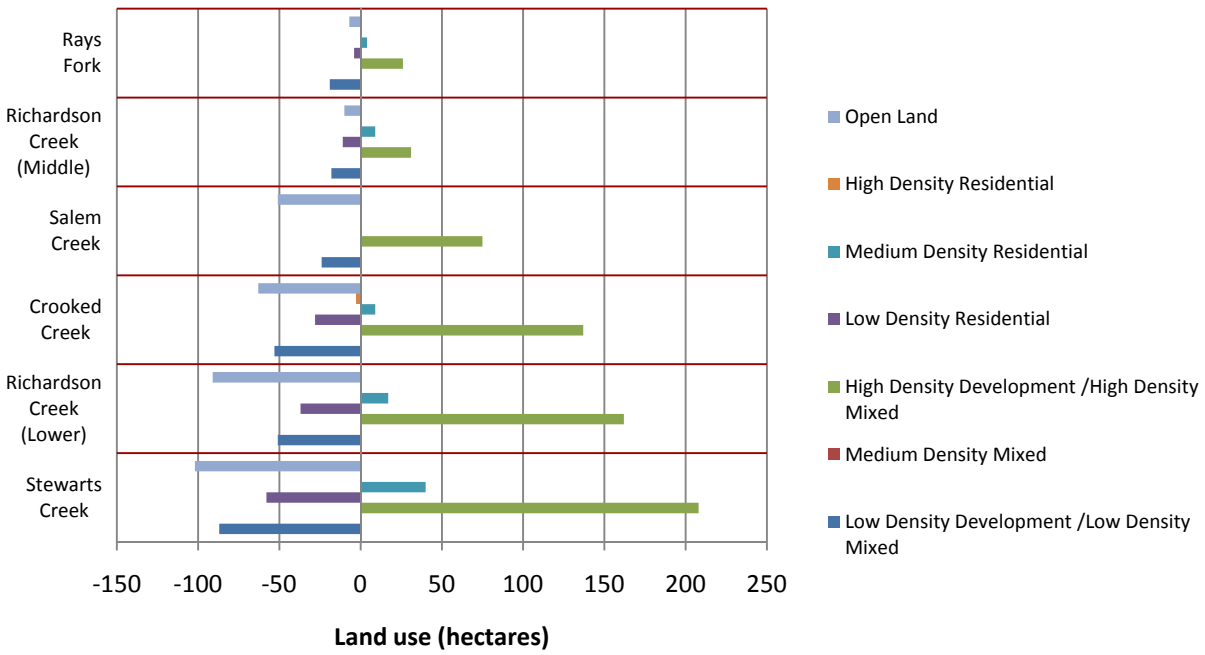


Figure 6: Land Use Density Changes - 2030 RPA as Compared to 2030 No Build.

Table 15: Comparison of Annual Streamflow Results for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		Streamflow (cm/yr)[1]	Streamflow (cm/yr)[1]	Δ[2]	%Δ[3]	Streamflow (cm/yr)[1]	Δ[2]	%Δ[3]	%Δ[4]
Goose Creek	03040105030020	30.04	29.65	-0.38	-1.27	29.65	-0.38	-1.27	0.00
Crooked Creek	03040105040010	32.12	32.33	0.21	0.65	32.64	0.52	1.62	0.96
Richardson Creek (Upper)	03040105070010	31.21	31.17	-0.05	-0.15	31.17	-0.05	-0.15	0.00
Richardson Creek (Middle)	03040105070020	66.25	66.67	0.42	0.63	66.67	0.42	0.64	0.01
Bearskin Creek	03040105070030	33.36	33.50	0.14	0.43	33.50	0.14	0.43	0.00
Rays Fork	03040105070040	33.25	33.26	0.01	0.04	33.27	0.02	0.05	0.01
Stewarts Creek	03040105070050	32.88	32.88	0.00	0.00	33.06	0.18	0.53	0.53
Richardson Creek (Lower)	03040105070060	31.06	31.04	-0.02	-0.06	31.23	0.17	0.54	0.61
Salem Creek	03040105070070	31.62	31.74	0.12	0.38	31.73	0.11	0.35	-0.03
Gourdvine Creek	03040105070080	30.25	30.25	0.00	0.00	30.25	0.00	0.00	0.00
Bakers Branch	03040105081020	34.10	34.14	0.04	0.12	34.14	0.04	0.12	0.00
Beaverdam Creek	03040105081030	33.86	33.87	0.01	0.03	33.87	0.01	0.03	0.00
Wide Mouth Branch	03040105081040	33.15	33.20	0.05	0.14	33.20	0.05	0.14	0.00
McAlpine Creek	03050103020050	37.64	37.97	0.33	0.88	37.97	0.33	0.88	0.00
Irvins Creek	03050103020060	30.37	30.78	0.41	1.35	30.78	0.41	1.35	0.00
Four Mile Creek	03050103020070	28.82	28.86	0.04	0.14	28.86	0.04	0.14	0.00
Sixmile Creek	03050103030010	35.22	37.08	1.86	5.28	37.08	1.86	5.28	0.00
Twelve Mile Creek	03050103030020	28.78	28.87	0.09	0.30	28.87	0.09	0.30	0.00

[1]Centimeters of streamflow generated over the catchment area per year
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

Table 16: Comparison of Annual Runoff Results for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		Runoff (cm/yr/ac)[1]	Runoff (cm/yr/ac)[1]	Δ[2]	%Δ[3]	Runoff (cm/yr/ac)[1]	Δ[2]	%Δ[3]	%Δ[4]
Goose Creek	03040105030020	0.64	0.70	0.06	10.07	0.70	0.06	10.07	0.00
Crooked Creek	03040105040010	1.09	1.18	0.10	9.01	1.23	0.14	13.06	3.72
Richardson Creek (Upper)	03040105070010	0.68	0.70	0.02	3.16	0.70	0.02	3.16	0.00
Richardson Creek (Middle)	03040105070020	1.02	1.09	0.08	7.49	1.10	0.08	8.22	0.68
Bearskin Creek	03040105070030	1.15	1.28	0.13	10.91	1.28	0.13	10.91	0.00
Rays Fork	03040105070040	0.73	0.76	0.03	4.05	0.76	0.03	4.68	0.61
Stewarts Creek	03040105070050	0.83	0.93	0.10	12.08	0.97	0.13	16.22	3.70
Richardson Creek (Lower)	03040105070060	0.53	0.53	0.00	0.90	0.57	0.04	6.93	5.97
Salem Creek	03040105070070	0.61	0.63	0.02	3.15	0.63	0.02	3.77	0.59
Gourdvine Creek	03040105070080	0.44	0.44	0.00	0.23	0.44	0.00	0.23	0.00
Bakers Branch	03040105081020	0.63	0.64	0.02	2.72	0.64	0.02	2.72	0.00
Beaverdam Creek	03040105081030	0.62	0.63	0.00	0.32	0.63	0.00	0.32	0.00
Wide Mouth Branch	03040105081040	0.82	0.84	0.02	2.84	0.84	0.02	2.84	0.00
McAlpine Creek	03050103020050	1.63	1.68	0.05	2.82	1.68	0.05	2.82	0.00
Irvins Creek	03050103020060	1.65	1.76	0.11	6.67	1.76	0.11	6.67	0.00
Four Mile Creek	03050103020070	1.49	1.57	0.08	5.29	1.57	0.08	5.29	0.00
Sixmile Creek	03050103030010	0.72	1.22	0.50	70.06	1.22	0.50	70.06	0.00
Twelve Mile Creek	03050103030020	0.69	1.07	0.38	55.67	1.07	0.38	55.67	0.00

[1]Centimeters per year per acre
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

Table 17: Comparison of Annual Total Nitrogen (TN) Results for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		TN (kg/yr/ac)[1]	TN (kg/yr/ac)[1]	Δ[2]	%Δ[3]	TN (kg/yr/ac)[1]	Δ[2]	%Δ[3]	%Δ[4]
Goose Creek	03040105030020	1.548	1.471	-0.077	-4.97	1.471	-0.077	-4.97	0.00
Crooked Creek	03040105040010	3.145	3.057	-0.088	-2.79	3.067	-0.078	-2.47	0.32
Richardson Creek (Upper)	03040105070010	1.461	1.301	-0.160	-10.95	1.301	-0.160	-10.95	0.00
Richardson Creek (Middle)	03040105070020	44.193	44.074	-0.119	-0.27	44.085	-0.109	-0.25	0.02
Bearskin Creek	03040105070030	1.556	1.491	-0.065	-4.19	1.491	-0.065	-4.19	0.00
Rays Fork	03040105070040	1.876	1.722	-0.154	-8.20	1.725	-0.152	-8.08	0.14
Stewarts Creek	03040105070050	1.460	1.355	-0.105	-7.22	1.364	-0.096	-6.59	0.69
Richardson Creek (Lower)	03040105070060	1.339	1.217	-0.122	-9.13	1.235	-0.104	-7.74	1.52
Salem Creek	03040105070070	1.846	1.717	-0.129	-6.99	1.714	-0.132	-7.16	-0.19
Gourdvine Creek	03040105070080	1.917	1.862	-0.055	-2.86	1.862	-0.055	-2.86	0.00
Bakers Branch	03040105081020	2.042	1.930	-0.111	-5.46	1.930	-0.111	-5.46	0.00
Beaverdam Creek	03040105081030	1.973	1.895	-0.078	-3.95	1.895	-0.078	-3.95	0.00
Wide Mouth Branch	03040105081040	2.231	2.156	-0.075	-3.38	2.156	-0.075	-3.38	0.00
McAlpine Creek	03050103020050	1.306	1.286	-0.020	-1.56	1.286	-0.020	-1.56	0.00
Irvins Creek	03050103020060	1.326	1.271	-0.054	-4.11	1.271	-0.054	-4.11	0.00
Four Mile Creek	03050103020070	0.961	0.904	-0.058	-6.02	0.904	-0.058	-6.02	0.00
Sixmile Creek	03050103030010	1.426	1.394	-0.031	-2.21	1.394	-0.031	-2.21	0.00
Twelve Mile Creek	03050103030020	1.181	1.145	-0.037	-3.11	1.145	-0.037	-3.11	0.00

[1]Kilograms per year per acre
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

Table 18: Comparison of Annual Total Phosphorus (TP) Results for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		TP (kg/yr/ac)[1]	TP (kg/yr/ac)[1]	Δ[2]	%Δ[3]	TP (kg/yr/ac)[1]	Δ[2]	%Δ[3]	%Δ[4]
Goose Creek	03040105030020	0.139	0.122	-0.017	-11.95	0.122	-0.017	-11.95	0.00
Crooked Creek	03040105040010	0.373	0.371	-0.002	-0.57	0.374	0.000	0.01	0.58
Richardson Creek (Upper)	03040105070010	0.085	0.062	-0.022	-26.15	0.062	-0.022	-26.15	0.00
Richardson Creek (Middle)	03040105070020	5.245	5.231	-0.014	-0.28	5.232	-0.013	-0.25	0.02
Bearskin Creek	03040105070030	0.100	0.089	-0.011	-10.98	0.089	-0.011	-10.98	0.00
Rays Fork	03040105070040	0.114	0.103	-0.011	-9.37	0.104	-0.010	-9.06	0.34
Stewarts Creek	03040105070050	0.083	0.080	-0.003	-3.83	0.082	-0.001	-1.41	2.52
Richardson Creek (Lower)	03040105070060	0.072	0.060	-0.013	-17.67	0.062	-0.010	-13.97	4.50
Salem Creek	03040105070070	0.133	0.113	-0.019	-14.64	0.113	-0.020	-14.98	-0.40
Gourdvine Creek	03040105070080	0.168	0.156	-0.012	-7.28	0.156	-0.012	-7.28	0.00
Bakers Branch	03040105081020	0.157	0.138	-0.019	-12.23	0.138	-0.019	-12.23	0.00
Beaverdam Creek	03040105081030	0.137	0.125	-0.012	-8.66	0.125	-0.012	-8.66	0.00
Wide Mouth Branch	03040105081040	0.196	0.184	-0.012	-6.05	0.184	-0.012	-6.05	0.00
McAlpine Creek	03050103020050	0.122	0.125	0.002	1.78	0.125	0.002	1.78	0.00
Irvins Creek	03050103020060	0.160	0.162	0.002	1.03	0.162	0.002	1.03	0.00
Four Mile Creek	03050103020070	0.072	0.072	0.000	0.18	0.072	0.000	0.18	0.00
Sixmile Creek	03050103030010	0.063	0.065	0.002	3.66	0.065	0.002	3.66	0.00
Twelve Mile Creek	03050103030020	0.071	0.080	0.009	12.10	0.080	0.009	12.10	0.00

[1]Kilograms per year per acre
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

Table 19: Comparison of Annual Total Suspended Sediment (TSS) Results for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		TSS (MT/yr/ac)[1]	TSS (MT/yr/ac)[1]	Δ[2]	%Δ[3]	TSS (MT/yr/ac)[1]	Δ[2]	%Δ[3]	%Δ[4]
Goose Creek	03040105030020	0.277	0.346	0.069	24.73	0.346	0.069	24.73	0.00
Crooked Creek	03040105040010	0.304	0.376	0.072	23.57	0.382	0.078	25.53	1.59
Richardson Creek (Upper)	03040105070010	0.173	0.201	0.028	16.00	0.201	0.028	16.00	0.00
Richardson Creek (Middle)	03040105070020	0.247	0.292	0.045	18.10	0.293	0.046	18.48	0.32
Bearskin Creek	03040105070030	0.179	0.225	0.045	25.35	0.225	0.045	25.35	0.00
Rays Fork	03040105070040	0.210	0.255	0.045	21.52	0.256	0.045	21.60	0.07
Stewarts Creek	03040105070050	0.278	0.406	0.128	46.24	0.413	0.135	48.69	1.68
Richardson Creek (Lower)	03040105070060	0.241	0.334	0.093	38.44	0.341	0.100	41.49	2.20
Salem Creek	03040105070070	0.295	0.375	0.081	27.43	0.381	0.086	29.28	1.45
Gourdvine Creek	03040105070080	0.184	0.181	-0.003	-1.86	0.181	-0.003	-1.86	0.00
Bakers Branch	03040105081020	0.201	0.217	0.016	7.99	0.217	0.016	7.99	0.00
Beaverdam Creek	03040105081030	0.287	0.328	0.041	14.21	0.328	0.041	14.21	0.00
Wide Mouth Branch	03040105081040	0.269	0.288	0.019	7.01	0.288	0.019	7.01	0.00
McAlpine Creek	03050103020050	0.682	0.713	0.031	4.59	0.713	0.031	4.59	0.00
Irvins Creek	03050103020060	0.311	0.345	0.034	10.84	0.345	0.034	10.84	0.00
Four Mile Creek	03050103020070	0.312	0.337	0.025	7.87	0.337	0.025	7.87	0.00
Sixmile Creek	03050103030010	0.093	0.131	0.038	40.48	0.131	0.038	40.48	0.00
Twelve Mile Creek	03050103030020	0.294	0.323	0.029	9.91	0.323	0.029	9.91	0.00

[1]Metric tons per year per acre
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

Table 20: Comparison of Annual Total Fecal Coliform (FC) Results for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		FC (cfu/yr/ac)[1]	FC (cfu/yr/ac)[1]	Δ[2]	%Δ[3]	FC (cfu/yr/ac)[1]	Δ[2]	%Δ[3]	%Δ[4]
Goose Creek	03040105030020	5.712E+08	6.473E+08	7.614E+07	13.33	6.473E+08	7.614E+07	13.33	0.00
Crooked Creek	03040105040010	1.383E+09	1.578E+09	1.958E+08	14.16	1.649E+09	2.665E+08	19.28	4.48
Richardson Creek (Upper)	03040105070010	6.917E+08	6.887E+08	-3.009E+06	-0.43	6.887E+08	-3.009E+06	-0.43	0.00
Richardson Creek (Middle)	03040105070020	1.587E+09	1.677E+09	9.053E+07	5.70	1.677E+09	8.979E+07	5.66	-0.04
Bearskin Creek	03040105070030	1.602E+09	1.708E+09	1.053E+08	6.57	1.708E+09	1.053E+08	6.57	0.00
Rays Fork	03040105070040	5.380E+08	5.434E+08	5.437E+06	1.01	5.429E+08	4.942E+06	0.92	-0.09
Stewarts Creek	03040105070050	9.258E+08	1.077E+09	1.516E+08	16.38	1.114E+09	1.881E+08	20.32	3.39
Richardson Creek (Lower)	03040105070060	2.179E+08	2.057E+08	-1.216E+07	-5.58	2.479E+08	3.000E+07	13.77	20.49
Salem Creek	03040105070070	2.249E+08	2.361E+08	1.125E+07	5.00	2.368E+08	1.193E+07	5.31	0.29
Gourdvine Creek	03040105070080	1.088E+08	1.013E+08	-7.504E+06	-6.90	1.013E+08	-7.504E+06	-6.90	0.00
Bakers Branch	03040105081020	1.407E+08	1.176E+08	-2.302E+07	-16.37	1.176E+08	-2.302E+07	-16.37	0.00
Beaverdam Creek	03040105081030	1.132E+08	1.031E+08	-1.011E+07	-8.93	1.031E+08	-1.011E+07	-8.93	0.00
Wide Mouth Branch	03040105081040	4.488E+08	4.878E+08	3.899E+07	8.69	4.878E+08	3.899E+07	8.69	0.00
McAlpine Creek	03050103020050	2.833E+09	2.911E+09	7.824E+07	2.76	2.911E+09	7.824E+07	2.76	0.00
Irvins Creek	03050103020060	2.753E+09	2.959E+09	2.058E+08	7.48	2.959E+09	2.058E+08	7.48	0.00
Four Mile Creek	03050103020070	2.733E+09	2.702E+09	-3.017E+07	-1.10	2.702E+09	-3.017E+07	-1.10	0.00
Sixmile Creek	03050103030010	1.156E+09	2.082E+09	9.262E+08	80.12	2.082E+09	9.262E+08	80.12	0.00
Twelve Mile Creek	03050103030020	9.179E+08	1.562E+09	6.445E+08	70.21	1.567E+09	6.491E+08	70.72	0.30

[1]Colony forming units per year per acre
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

Table 21: Comparison of Mean Fecal Coliform (FC) Concentrations for Baseline Condition, 2030 No Build, and 2030 RPA Scenarios.

Name	Hydrologic Unit Code	Baseline	2030 No Build			2030 RPA			2030 RPA - 2030 No Build
		FC (cfu/100ml)	FC (cfu/100ml)	Δ^2	$\%\Delta^3$	FC (cfu/100ml)	Δ^2	$\%\Delta^3$	$\%\Delta^4$
Goose Creek	03040105030020	1103.6	2130.3	1026.7	93.0	2130.3	1026.7	93.0	0.0
Crooked Creek	03040105040010	600.1	493.9	-106.2	-17.7	465.5	-134.6	-22.4	-5.8
Richardson Creek (Upper)	03040105070010	838.9	588.3	-250.7	-29.9	588.3	-250.7	-29.9	0.0
Richardson Creek (Middle)	03040105070020	715.4	493.3	-222.2	-31.1	467.9	-247.5	-34.6	-5.1
Bearskin Creek	03040105070030	584.3	806.3	221.9	38.0	806.3	221.9	38.0	0.0
Rays Fork	03040105070040	953.2	1251.6	298.4	31.3	1838.4	885.2	92.9	46.9
Stewarts Creek	03040105070050	931.3	782.7	-148.6	-16.0	684.0	-247.4	-26.6	-12.6
Richardson Creek (Lower)	03040105070060	998.6	710.2	-288.4	-28.9	890.3	-108.3	-10.8	25.4
Salem Creek	03040105070070	1106.8	778.7	-328.1	-29.6	500.4	-606.4	-54.8	-35.7
Gourdvine Creek	03040105070080	977.5	921.1	-56.4	-5.8	921.1	-56.4	-5.8	0.0
Bakers Branch	03040105081020	626.9	518.5	-108.4	-17.3	518.5	-108.4	-17.3	0.0
Beaverdam Creek	03040105081030	583.5	531.6	-52.0	-8.9	531.6	-52.0	-8.9	0.0
Wide Mouth Branch	03040105081040	501.7	880.3	378.6	75.5	880.3	378.6	75.5	0.0
McAlpine Creek	03050103020050	1144.0	363.6	-780.4	-68.2	363.6	-780.4	-68.2	0.0
Irvins Creek	03050103020060	579.9	405.5	-174.4	-30.1	405.5	-174.4	-30.1	0.0
Four Mile Creek	03050103020070	1299.2	919.8	-379.4	-29.2	919.8	-379.4	-29.2	0.0
Sixmile Creek	03050103030010	1037.8	349.6	-688.3	-66.3	349.6	-688.3	-66.3	0.0
Twelve Mile Creek	03050103030020	463.9	386.7	-77.2	-16.6	386.7	-77.2	-16.6	0.0

[1]Colony forming units per 100 milliliters of streamflow
[2]Difference between future condition and Baseline Condition: future condition – Baseline Condition
[3]Percent difference between future condition and Baseline Condition: (future condition – Baseline Condition) ÷ Baseline Condition × 100
[4]Percent difference between 2030 RPA and 2030 No Build: (2030 RPA – 2030 No Build) ÷ 2030 No Build × 100

5.0 CONCLUSIONS

The analysis described in this Technical Report was undertaken to answer the following questions:

1) What are the Project's indirect and cumulative effects on the water quality of waters supporting sensitive and rare aquatic species?

2) What are the Project's indirect and cumulative effects on the water quality of impaired waters on the North Carolina 303(d) list?

Additionally, the analysis assumed the broader goal of determining if induced land use change resulting from the Project affects water quality throughout the 330-square mile Study Area (Figure A1, Appendix A).

The analysis was performed by constructing watershed models for portions of eighteen 14-digit hydrologic units (HUs) composing the Study Area (Figure A2, Appendix A) using the ArcView Generalized Watershed Loading Functions (AVGWLF) modeling suite. Model estimates of annual streamflow, runoff, and annual overland pollutant loadings of total nitrogen (TN), total phosphorus (TP), total suspended sediment (TSS), and fecal coliform (FC) loads produced from the three land use scenarios – Baseline Condition, 2030 No Build, and 2030 RPA (Table 1) – were reviewed to assess the Project effects. Specifically, model results of the 2030 No Build and 2030 RPA scenarios were compared. Differences in streamflow and pollutant loadings exhibited between the 2030 scenarios are attributable to the Project.

The waters mentioned in the first question above refer specifically to those of the Goose Creek and Sixmile Creek watersheds. Streams within both watersheds are known to support populations of the endangered Carolina heelsplitter, a freshwater mussel. As such, Resource Agencies are particularly concerned with potential impacts to these watersheds. In terms of this analysis, the effect of the Project on these watersheds is determined by comparing the 2030 No Build and 2030 RPA streamflow, runoff, and pollutant loadings reported in Tables 15-21. Neither watershed was found to be affected by the project: in both cases, the 2030 No Build streamflows, runoff, and pollutant loads equal those of the 2030 RPA scenario. This result was expected as the quantitative ICE analysis performed by Baker (Baker 2009) concluded no Project induced growth would occur in the Goose Creek and Sixmile Creek watersheds.

As to the second question, four of the catchments composing the Study Area contain streams on the North Carolina 303(d) list (NCDWQ 2006) (Figure 2A, Appendix A). The Project alignment intersects three of these catchments: Crooked, Richardson (Middle), and Richardson (Lower) Creeks. Further, interchanges are proposed in Crooked Creek (4 interchanges) and Richardson Creek (Lower) (1 interchange). The watershed model results for these three catchments indicate increased streamflow, runoff, and pollutant loads in the 2030 RPA scenario compared to the 2030 No Build scenario. Richardson Creek (Lower) experiences the greatest increases for all modeled parameters; an observation explained by the fact that Richardson Creek (Lower) incurs the largest increase in high-density development per catchment area. Goose Creek, which is not intersected by the Project alignment, is not expected to experience any direct or indirect effects from the Project (Baker 2009). The estimated streamflow and pollutant loadings for Goose Creek remained unchanged between the 2030 No Build and 2030 RPA scenarios; therefore, the Project is not anticipated to affect the water quality of Goose Creek.

For the Study Area as a whole, increases in streamflow, runoff, and pollutant loadings are confined to the six catchments intersected by the Project alignment: Crooked, Richardson (Middle), Rays Fork, Stewarts, Richardson (Lower), and Salem Creeks. Of these catchments, Stewarts had the largest change in development density

between the No Build and Build scenarios. Stewarts also had the largest amount of new development between 2030 No Build and the 2030 RPA. However, Richardson Creek (Lower) experiences the largest percent increases in runoff, streamflow, runoff, and pollutant loads because the development largely takes place in an urban portion of the catchment. The remainder of the Study Area (13 catchments) are not expected to experience any direct or indirect effects from the Project (Baker 2009). Water quality in these catchments was found to be unaffected by the Project, as the estimated runoff, streamflow and pollutant loadings for the catchment remained unchanged between the 2030 No Build and 2030 RPA scenarios.

Lastly, several further points warrant mentioning. First, the analysis documented in the Technical Report was not conducted for the purpose of predicting the specific amount of pollutants delivered at the outlet of each modeled catchment. Rather, the aim of the analysis was to determine the magnitude of streamflow and pollutant change between the 2030 No Build and 2030 RPA scenarios, which indicates the trend of water quality over time in each catchment and the Study Area as a whole. And second, in terms of BMPs, the analysis only considered riparian buffers. No site-specific BMPs, such as – bioretention basins, stormwater ponds, grass swales, etc., are accounted for in the results. Consequently, the watershed model likely overestimates pollutant loadings from areas with treated stormwater. In reality, substantial reductions in pollutant loadings could be attained as future development takes place if existing BMP regulations are enforced and BMPs are constructed and maintained properly.

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Appendix A

Large Format Figures

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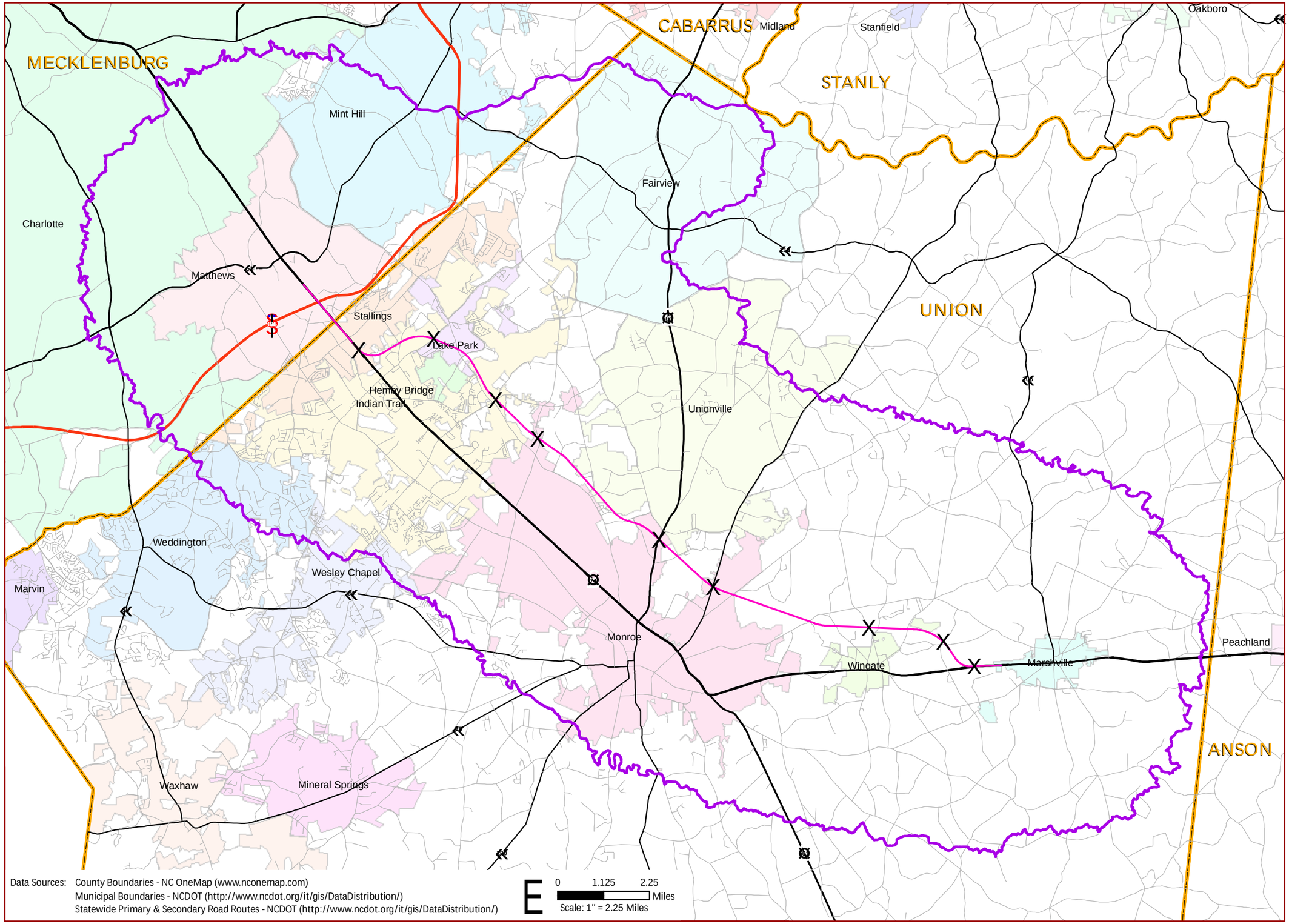
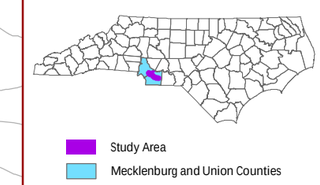


Legend

- Proposed Interchange
- RPA Centerline
- Study Area
- Interstate
- NC Route
- Secondary Road
- US Route
- County Boundary

Location Map



Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Water Quality Analysis Study Area

Figure A1

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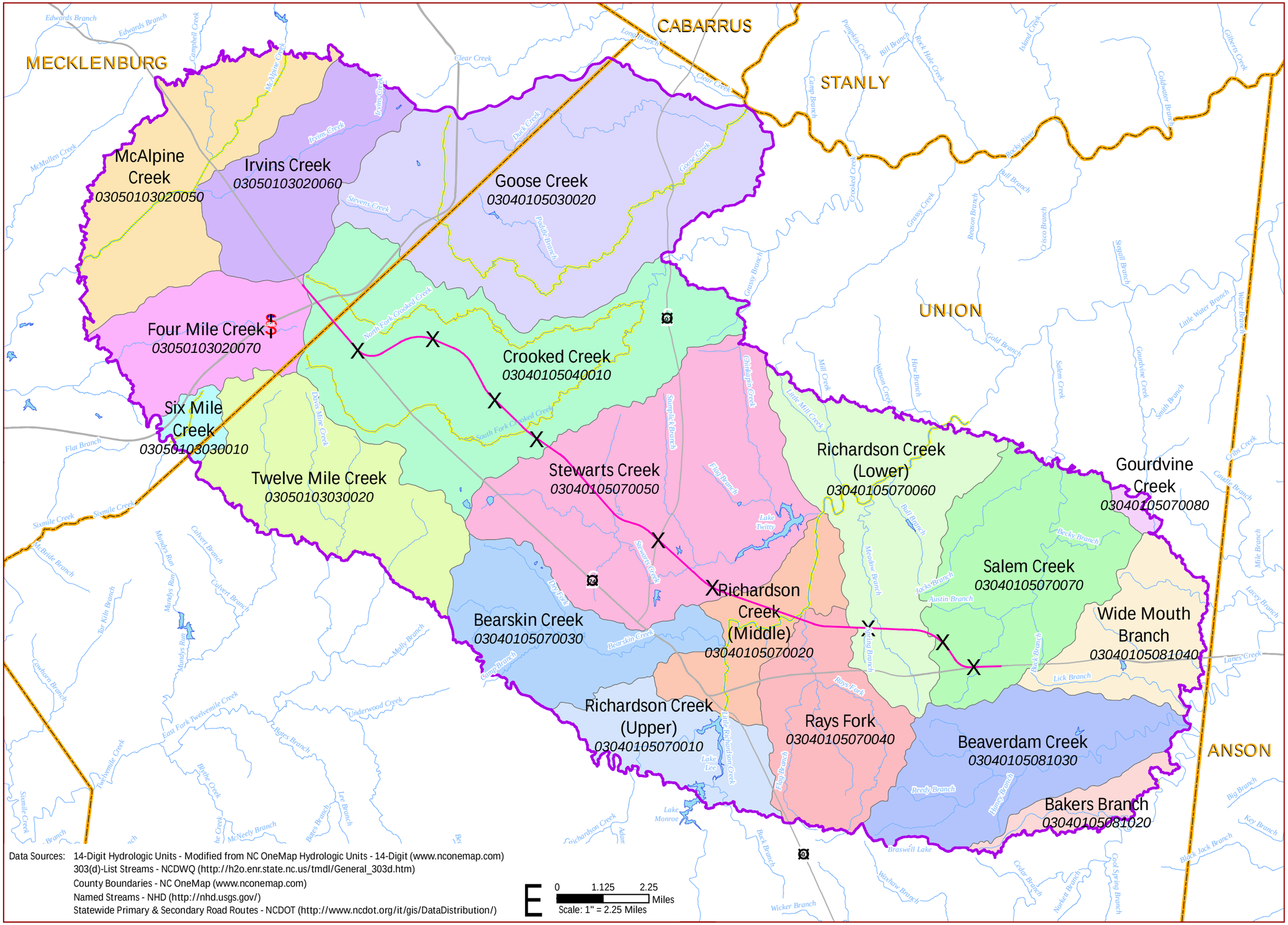
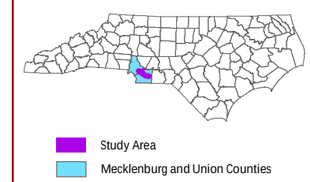


Legend

- Proposed Interchange
- RPA Centerline
- 303(d)-List Streams - 2006
- Named Streams
- Waterbody
- Study Area
- Roads
- County Boundary

Location Map



Project

NORTH CAROLINA Turnpike Authority

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Study Area Catchments & Water Resources

Figure A2

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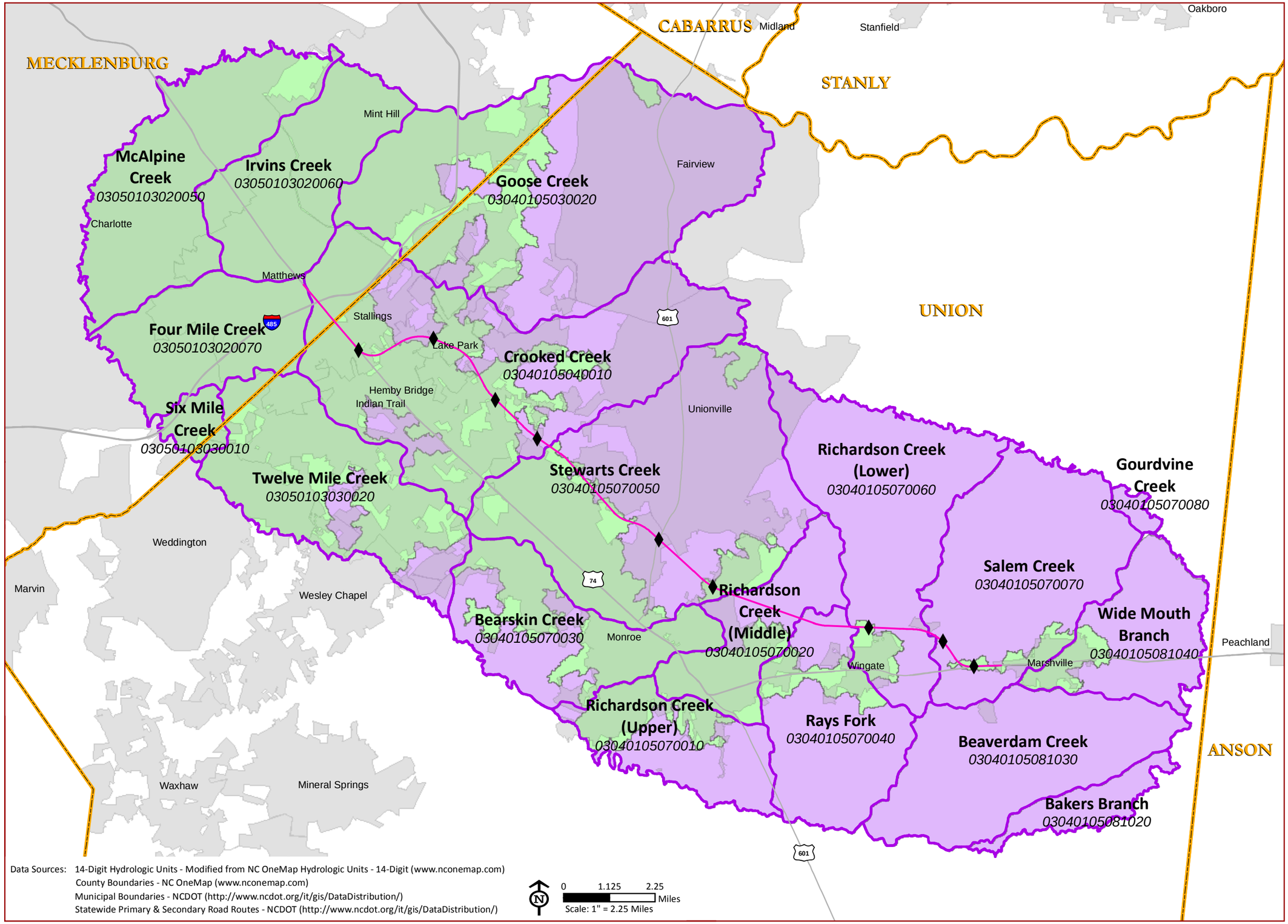


Data Sources: 14-Digit Hydrologic Units - Modified from NC OneMap Hydrologic Units - 14-Digit (www.nconemap.com)
County Boundaries - NC OneMap (www.nconemap.com)
Municipal Boundaries - NCDOT (http://www.ncdot.org/it/gis/DataDistribution/)
Statewide Primary & Secondary Road Routes - NCDOT (http://www.ncdot.org/it/gis/DataDistribution/)

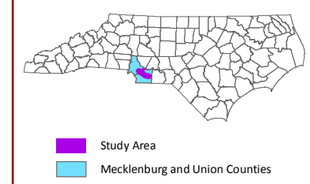
Legend

- Proposed Interchange
- RPA Centerline
- Roads
- County Boundary
- Municipal Boundary

Model Sub-catchments

- GWLF-E
- RUNQUAL-E

Location Map



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GWLF-E & RUNQUAL-E Sub-Catchments

Figure A3

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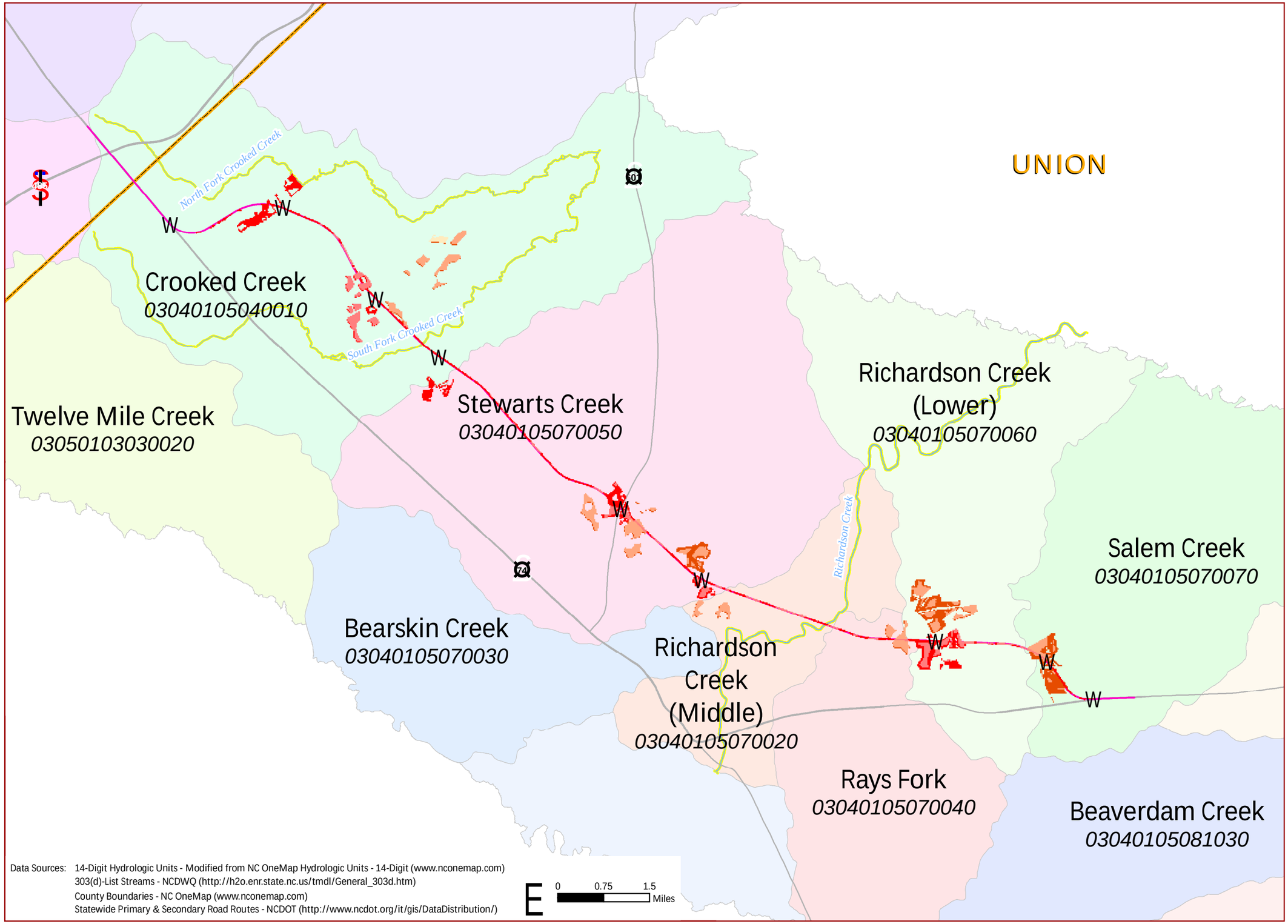


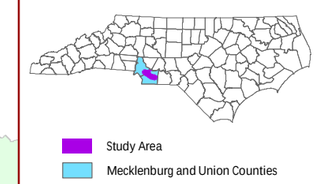
Legend

- W Proposed Interchange
- RPA Centerline
- Roads
- County Boundary
- 303(d)-List Streams - 2006

2030 No Build - 2030 RPA Land Use Change

- New Highest Density (HD)
- HD Replacing Lower Density
- HD Density Replacing Lower Density
- New Medium Density (MD)
- MD Replacing Lower Density
- MD Replacing Lower Density

Location Map



Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

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Mecklenburg and Union Counties, North Carolina

Title

2030 No Build - 2030 RPA Differential Land Use Change

Figure A4

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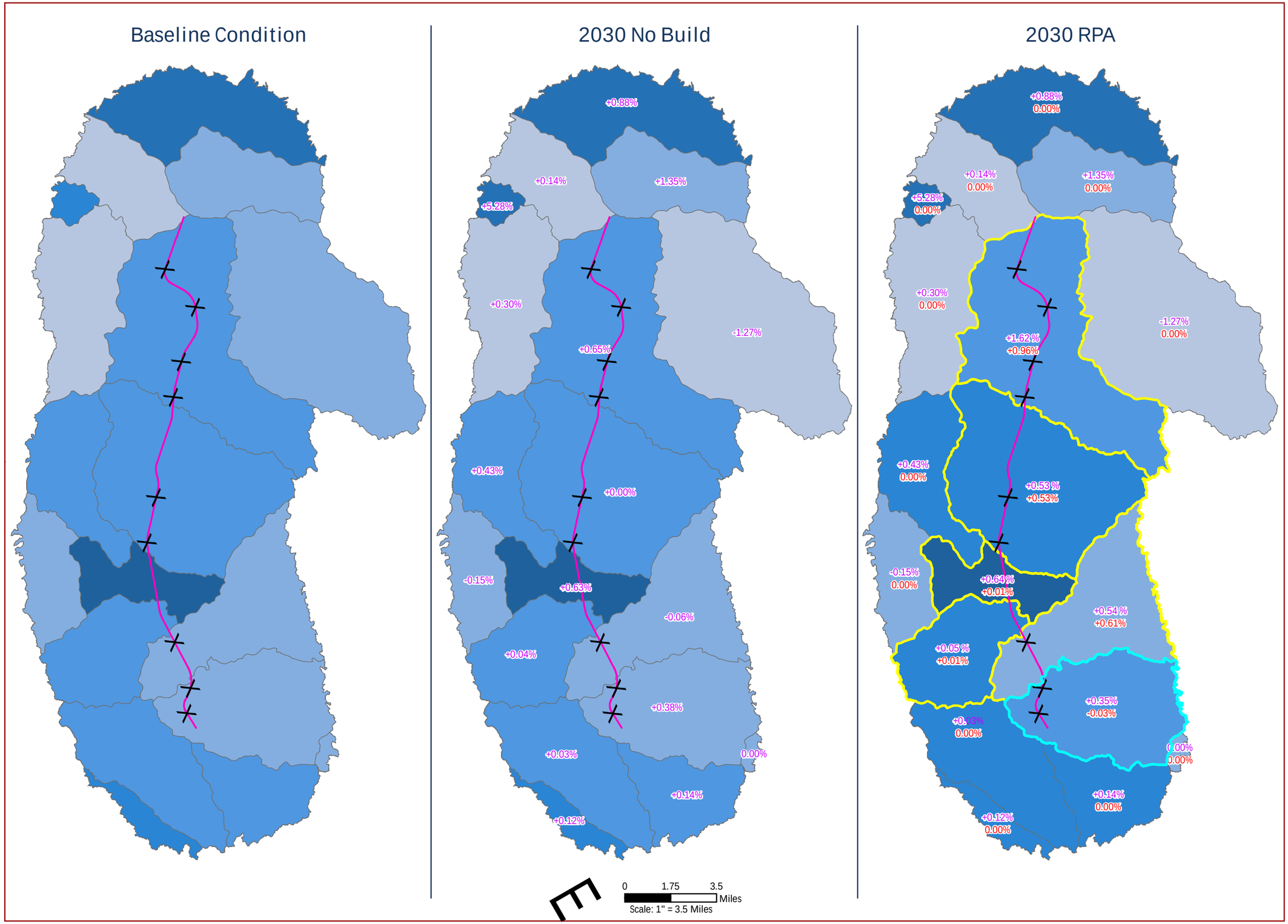

Legend

X Proposed Interchange

RPA Centerline

Streamflow (cm/year)*

- 28.00 - 30.00
- >30.00 - 32.00
- >32.00 - 34.00
- >34.00 - 36.00
- >36.00 - 38.00
- 66.00 - 68.00

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

Streamflow increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Annual Streamflow for 3 Modeled Scenarios

Figure A5

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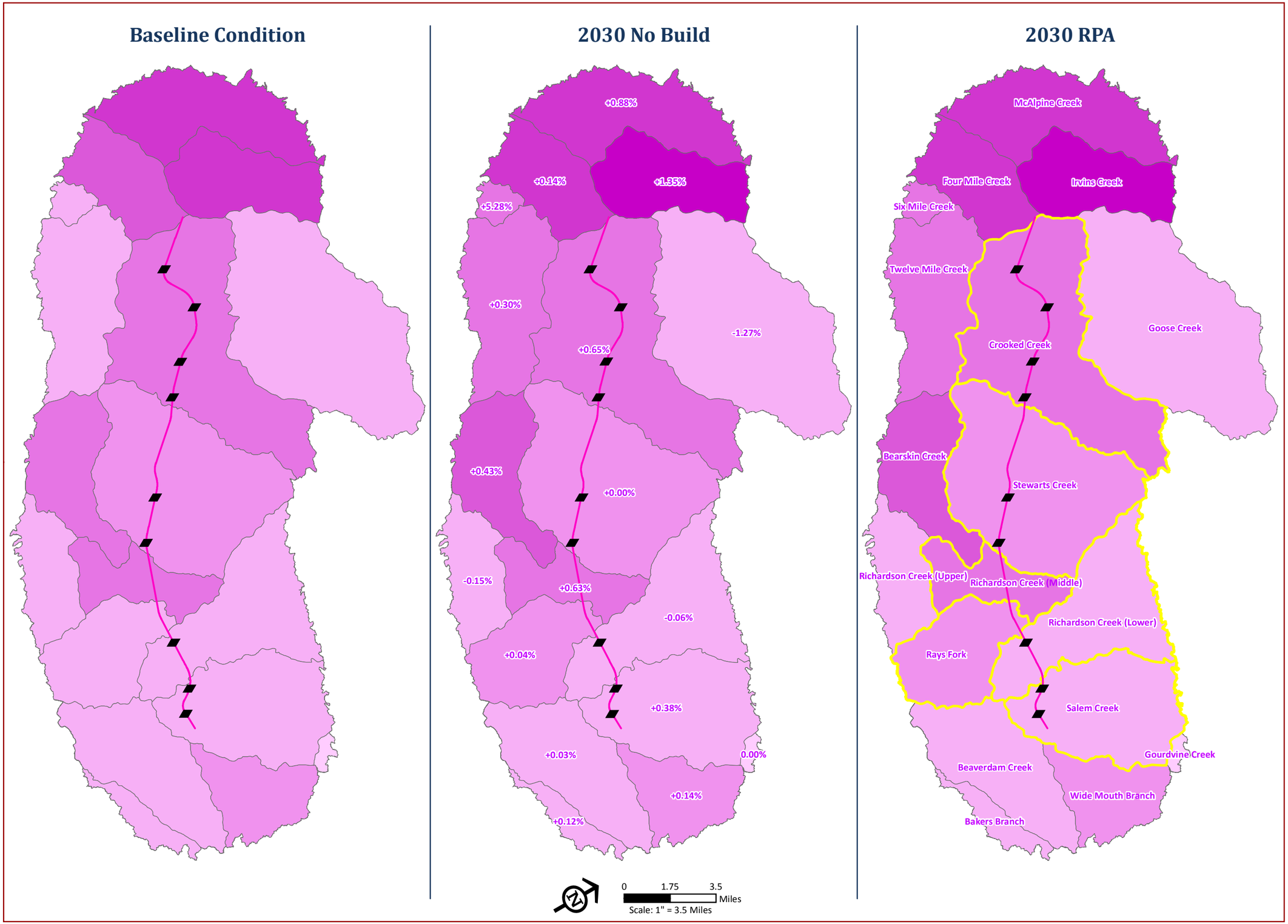

Legend

Proposed Interchange

RPA Centerline

Runoff (cm/acre/year)*

- 0.250 - 0.500
- >0.500 - 0.750
- >0.750 - 1.000
- >1.000 - 1.250
- >1.250 - 1.500
- >1.500 - 1.750
- 1.750 - 2.000

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

Streamflow increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Annual Streamflow for 3 Modeled Scenarios

Figure A5

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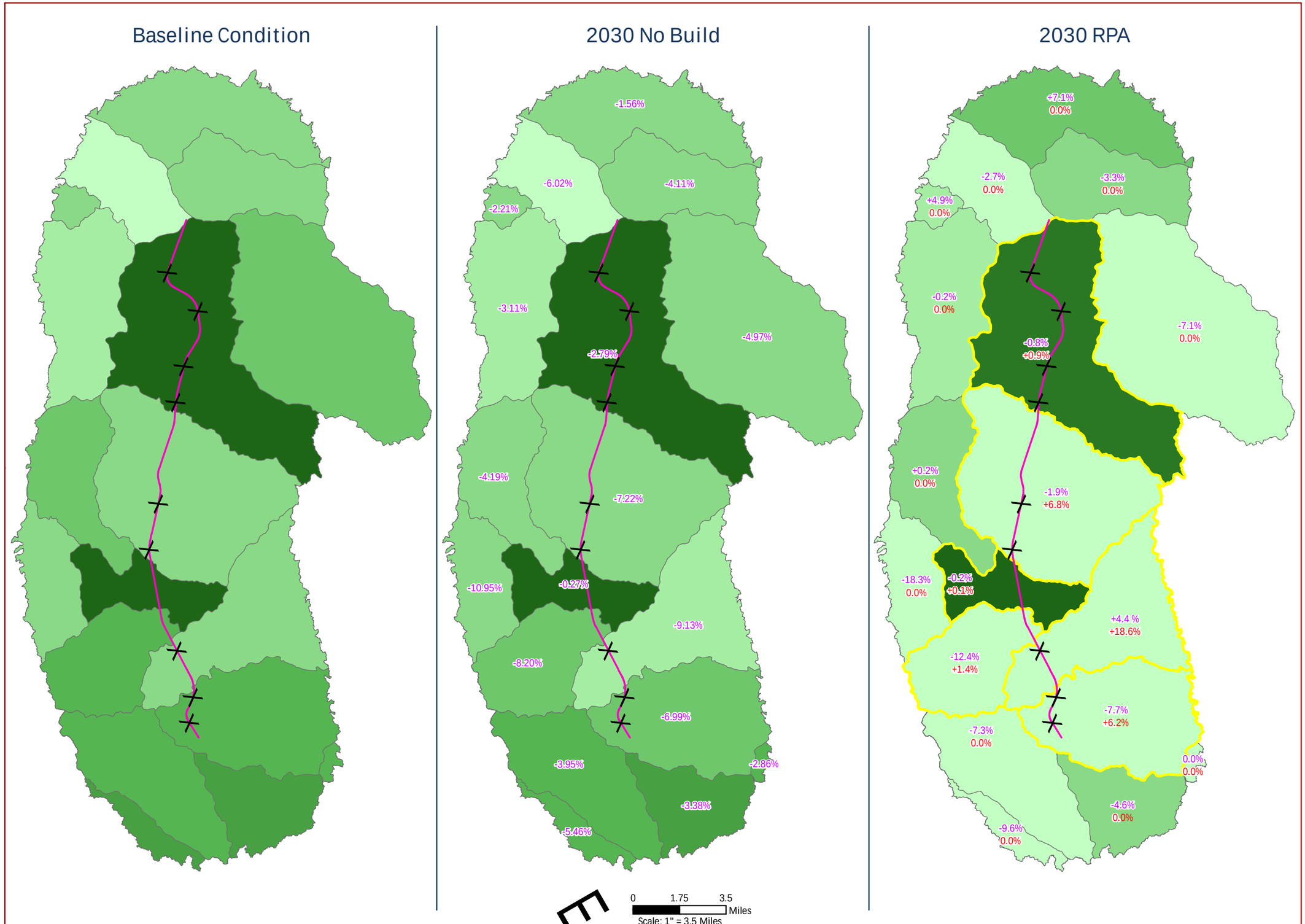

Legend

X Proposed Interchange

RPA Centerline

TN (kg/acre/year)*

- 0.750 - 1.000
- >1.000 - 1.250
- >1.250 - 1.500
- >1.500 - 1.750
- >1.750 - 2.000
- >2.000 - 2.250
- >2.250 - 2.500
- >2.500 - 3.000
- 40.000 - 45.000

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

TN increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Annual Total Nitrogen Load for 3 Modeled Scenarios

Figure A7

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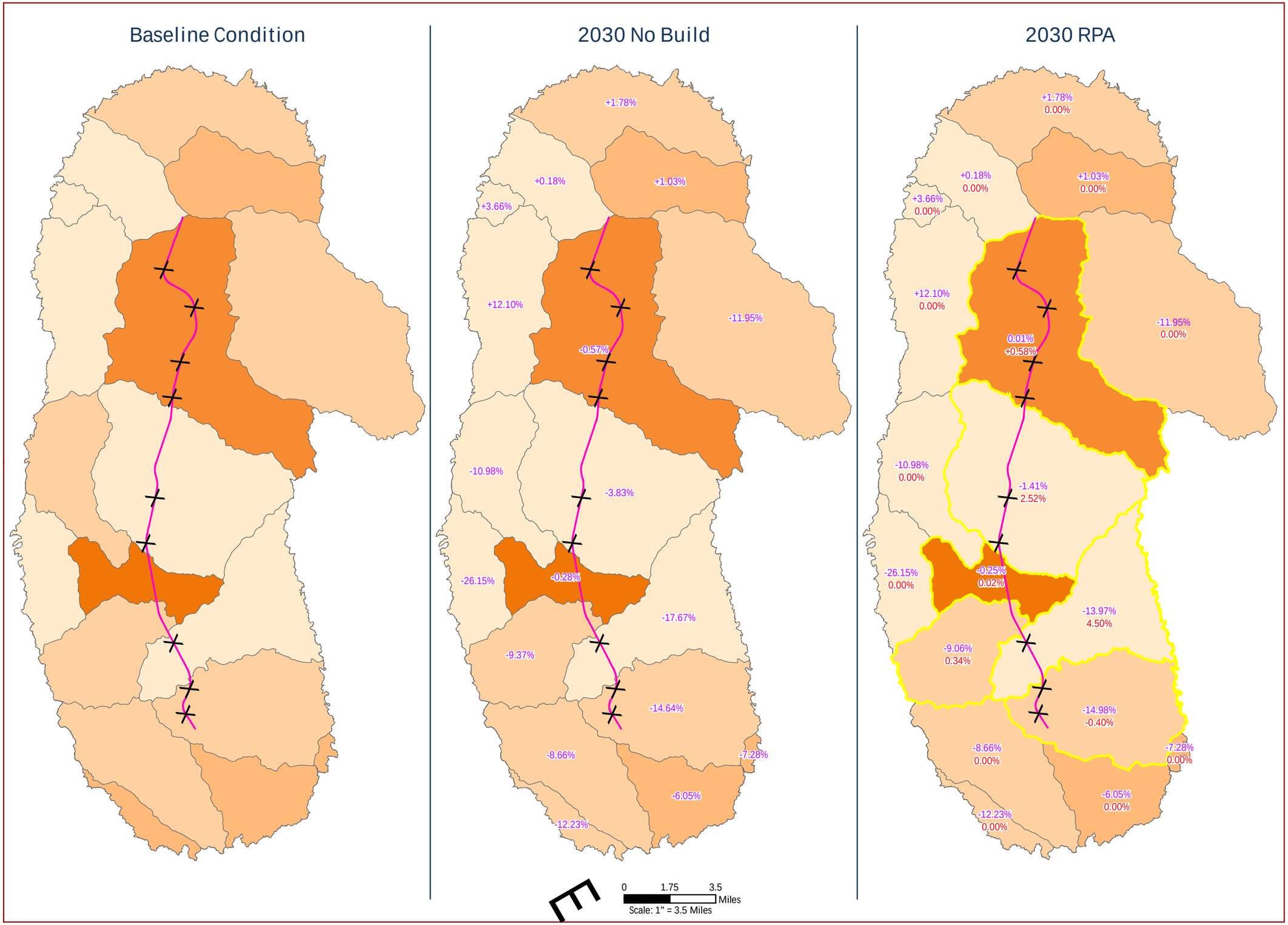

Legend

X Proposed Interchange

RPA Centerline

TP (kg/acre/year)*

- 0.000 - 0.100
- >0.100 - 0.150
- >0.150 - 0.200
- >0.200 - 0.250
- >0.250 - 0.400
- >5.200 - 5.300

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

TP increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Annual Total Phosphorus Load for 3 Modeled Scenarios

Figure A8

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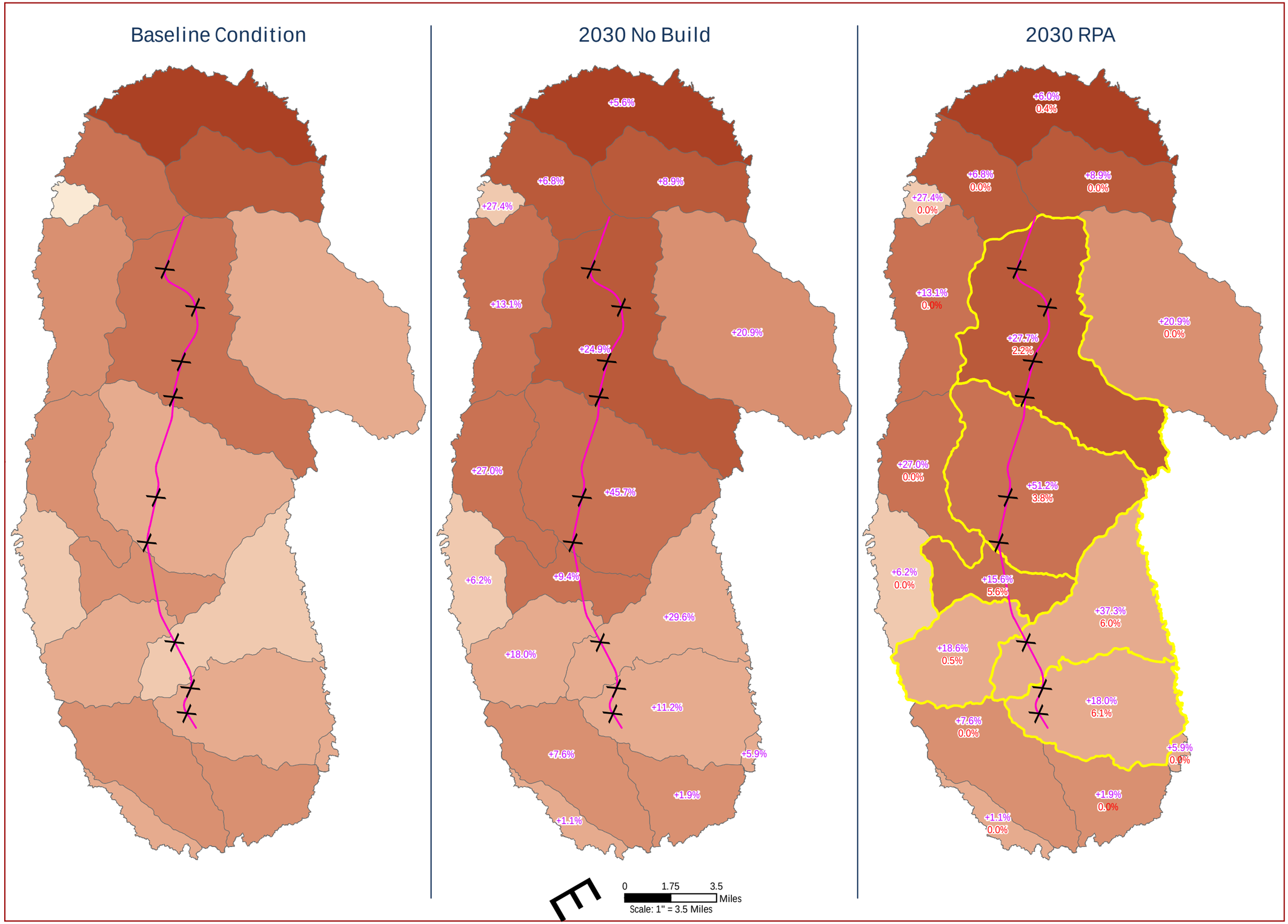

Legend

X Proposed Interchange

RPA Centerline

TSS (MT/acre/year)*

- 0.050 - 0.100
- >0.100 - 0.150
- >0.150 - 0.200
- >0.200 - 0.250
- >0.250 - 0.300
- >0.300 - 0.350
- >0.350 - 0.650

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

Sediment increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Annual Total Suspended Sediment Load for 3 Modeled Scenarios

Figure A9

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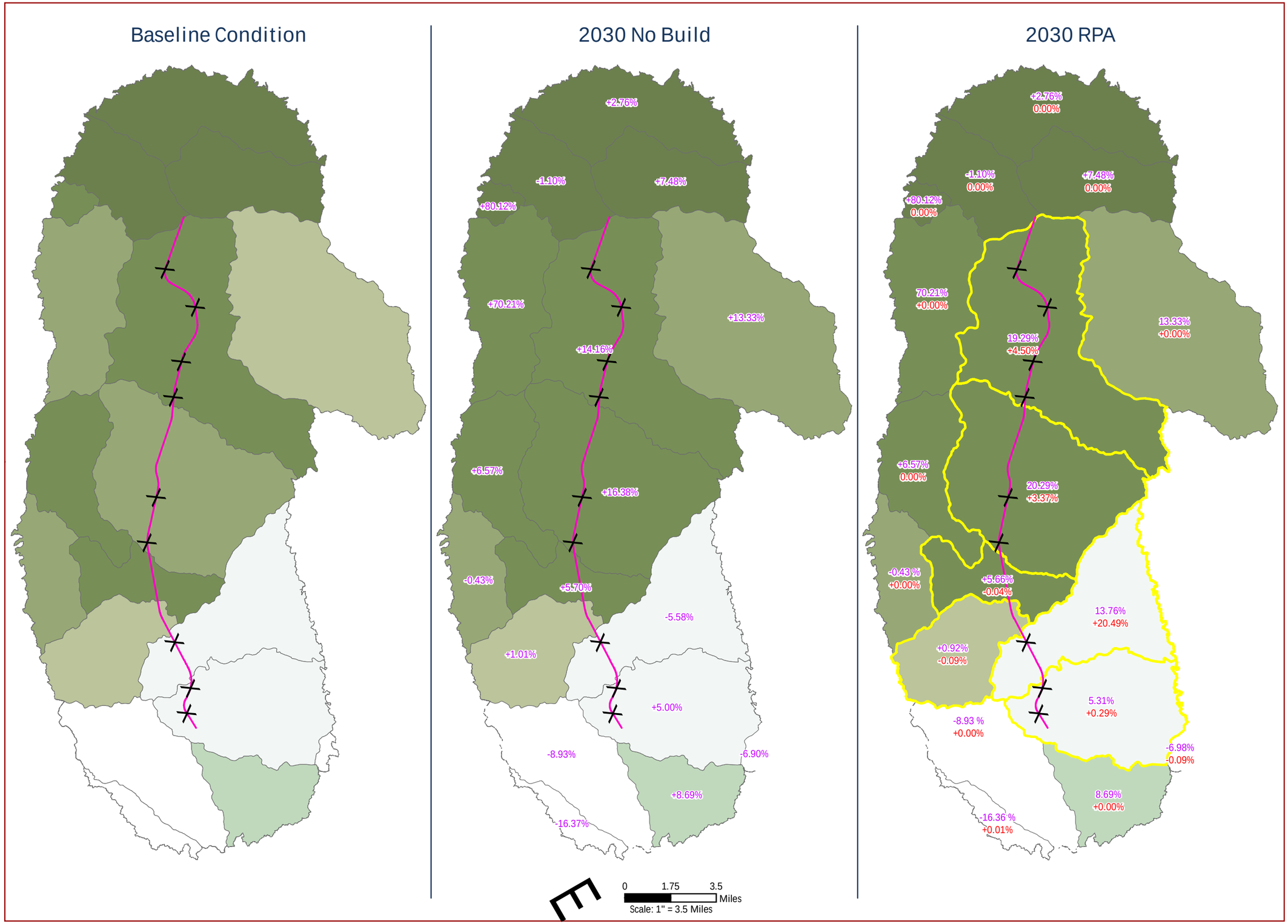

Legend

X Proposed Interchange

RPA Centerline

Total FC (cfu/acre/year)*

- 1.00e+008 - 2.00e+008
- >2.00e+008 - 3.00e+008
- >3.00e+008 - 4.00e+008
- >4.00e+008 - 5.00e+008
- >5.00e+008 - 6.00e+008
- >9.00e+008 - 1.00e+009
- >1.00e+009 - 2.00e+009
- >2.00e+009 - 3.00e+009
- >3.00e+009 - 4.00e+009

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

Total fecal coliform increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Annual Total Fecal Coliform for 3 Modeled Scenarios

Figure A10

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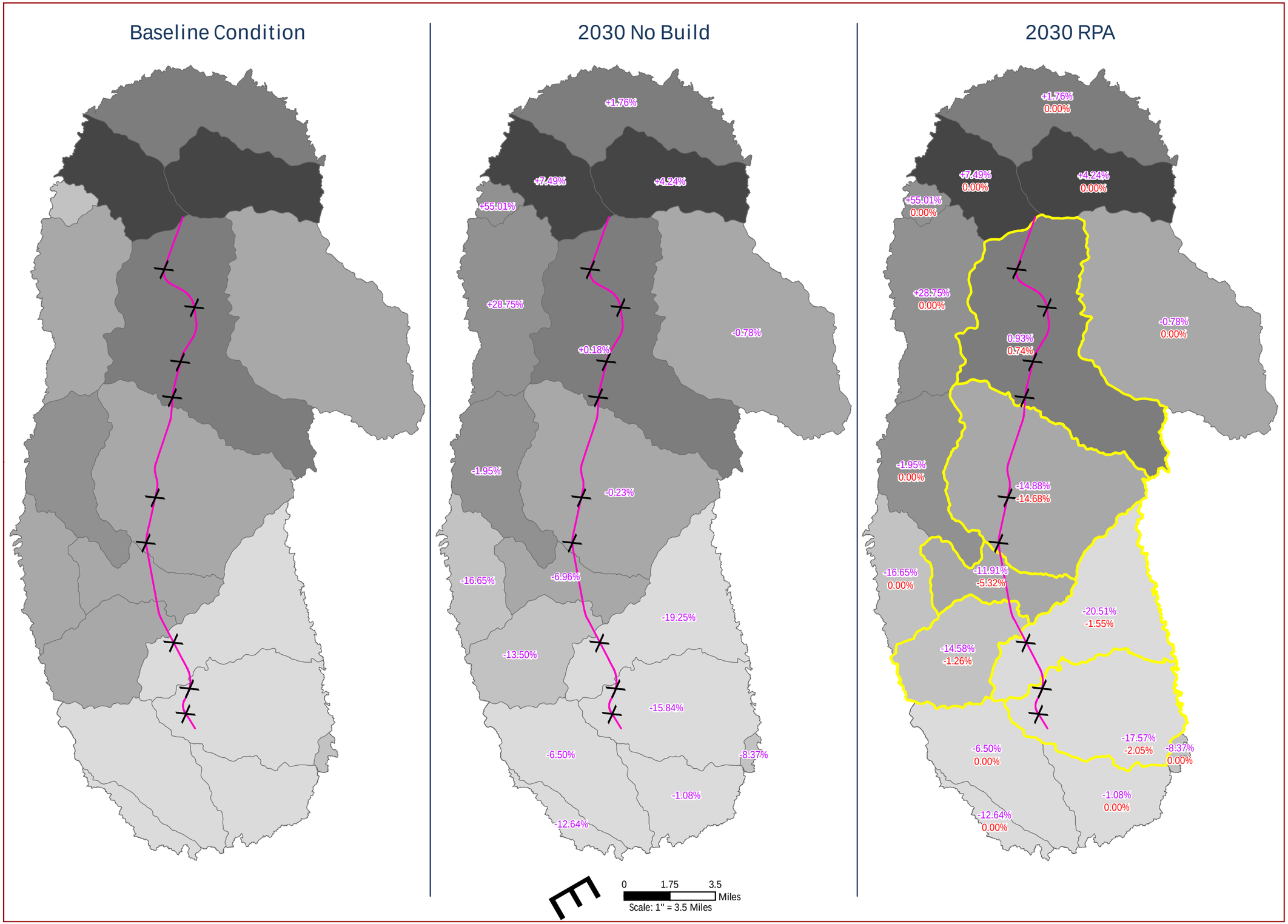

Legend

X Proposed Interchange

RPA Centerline

MonroeResults$.NoBuild_M_FC

- 200 - 400
- >400 - 600
- >600 - 800
- >800 - 1000
- >1000 - 1200
- >1200 - 1400
- >1400 - 1700
- >1700 - 20000

Percent Change

% - From Baseline to Future Scenario

% - From 2030 No Build to 2030 RPA

Mean fecal coliform increases from 2030 No Build to 2030 RPA

*Note: Intervals not equally distributed.

Project

NORTH CAROLINA Turnpike Authority

Monroe Connector/ Bypass

(STIP R-3329/R-2559)

Mecklenburg and Union Counties, North Carolina

Title

Mean Fecal Coliform Concentration for 3 Modeled Scenarios

Figure A11

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Appendix B

GWLF-E and RUNQUAL-E Input Parameters

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Parameter	Model	Upper	Lower	Units	Group[1]	Remarks
Dissolved nitrogen runoff coefficient	GWLF	2.9	0.012	mg/L	2	AVGWLF supplied default. Varies by land use and watershed based on input GIS layers.
Dissolved phosphorus runoff coefficient	GWLF	0.752	0.002	mg/L	2	AVGWLF supplied. Varies by land use and watershed based on input GIS layers including soil test phosphorus.
Manure nitrogen runoff coefficient	GWLF	2.44	2.44	mg/L	1	Default constant supplied by AVGWLF.
Manure phosphorus runoff coefficient	GWLF	0.38	0.38	mg/L	1	Default constant supplied by AVGWLF.
High intensity urban nitrogen runoff coefficient	GWLF	0.101	0.101	Kg/ha/d	1	Default constant supplied by AVGWLF.
Low intensity urban nitrogen runoff coefficient	GWLF	0.12	0.12	Kg/ha/d	1	Default constant supplied by AVGWLF.
High intensity urban phosphorus runoff coefficient	GWLF	0.011	0.011	Kg/ha/d	1	Default constant supplied by AVGWLF.
Low intensity urban phosphorus runoff coefficient	GWLF	0.002	0.002	Kg/ha/d	1	Default constant supplied by AVGWLF.
Groundwater Nitrogen content	GWLF	1	1	mg/L	1	Default constant provided by AVGWLF
Groundwater Phosphorus content	GWLF	0.01	0.01	mg/L	1	Default constant provided by AVGWLF
Tile Drainage Nitrogen content	GWLF	15	15	mg/L	1	Default constant supplied by AVGWLF.
Tile Drainage Phosphorus content	GWLF	0.1	0.1	mg/L	1	Default constant supplied by AVGWLF.
Per capita tank effluent - Nitrogen	GWLF	12	12	g/d	1	Default constant supplied by AVGWLF.
Per capita tank effluent - Phosphorus	GWLF	2.5	2.5	g/d	1	Default constant supplied by AVGWLF.
Growing season Nitrogen uptake	GWLF	1.6	1.6	g/d	1	Default constant supplied by AVGWLF.
Growing season Phosphorus uptake	GWLF	2.5	2.5	g/d	1	Default constant supplied by AVGWLF.
Sediment Nitrogen content	GWLF	3000	3000	mg/Kg	1	Default constant supplied by AVGWLF.
Sediment Phosphorus content	GWLF	6143	474	mg/Kg	2	Default constant supplied by AVGWLF. Varies by watershed based on GIS including soil test phosphorus.

[1] Group 1- Default Value, Not Data-Derived
Group 2- Value Derived by AVGWLF From Input GIS layers
Group 3- PBS&J Input

Parameter	Model	Upper	Lower	Units	Group[1]	Remarks
Septic system populations	GWLF	4386	0	people	2	AVGWLF supplied default. Varies by watershed based on input GIS layers.
Point source Nitrogen loads	GWLF	6379.9	0	Kg	2	AVGWLF supplied default. Varies by watershed based on input GIS layers.
Point source Phosphorus loads	GWLF	652.3	0	Kg	2	AVGWLF supplied default. Varies by watershed based on input GIS layers.
Point source discharge	GWLF	1.2	0	MGD	2	AVGWLF supplied default. Varies by watershed based on input GIS layers.
Curve number	GWLF	91	59	unitless	3	PBS&J calculated. Modified AVGWLF defaults by using area weighted curve numbers based on land use and soils.
K = soil erodibility factor	GWLF	0.44	0.17	unitless	2	AVGWLF supplied default. Varies by land use and watershed based on input GIS layers.
LS = slope length factor * slope steepness factor	GWLF	1.3	0.22	unitless	2	AVGWLF supplied default. Varies by land use and watershed based on input GIS layers.
C = cover-management factor	GWLF	0.42	0.001	unitless	2	AVGWLF supplied default. Varies by land use based on input GIS layers.
P = support practice factor	GWLF	0.74	0.1	unitless	2	AVGWLF supplied default. Varies by land use and watershed based on input GIS layers.
Evapotranspiration (ET) cover coefficient	GWLF	1.8	0.76	unitless	3	Calibrated value. Modified from AVGWLF default to better reflect observed streamflows in the Study Area.
Daylight	GWLF	14.4	9.6	hours	2	AVGWLF supplied. Varies by month.
Growing season	GWLF	TRUE	FALSE	Boolean	3	Required parameter with no default. Used March - November growing season as defined in county soil surveys.
Erosion coefficient	GWLF	0.28	0.18	unitless	1	Default value provided by GWLF. Varies by month.
Stream extraction	GWLF	0	0	cubic meters/month	1	Default constant supplied by AVGWLF.
Ground extraction	GWLF	0	0	cubic meters/month	1	Default constant supplied by AVGWLF.
Initial unsaturated storage	GWLF	10	10	cm	1	Default constant supplied by AVGWLF.
Initial saturated storage	GWLF	0	0	cm	1	Default constant supplied by AVGWLF.
Unsaturated available water	GWLF	18.403	10.68	cm	2	AVGWLF supplied. Varies by watershed based on input GIS layers.

[1] Group 1- Default Value, Not Data-Derived
Group 2- Value Derived by AVGWLF From Input GIS layers
Group 3- PBS&J Input

Parameter	Model	Upper	Lower	Units	Group[1]	Remarks
Initial snow	GWLF	0	0	cm	1	Default constant supplied by AVGWLF.
Sediment delivery ratio	GWLF	0.196	0.122	unitless	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Tile drain ratio	GWLF	0.5	0.5	unitless	1	Default constant supplied by AVGWLF.
Tile drain density	GWLF	0	0	unitless	1	Default constant supplied by AVGWLF.
Recession coefficient	GWLF	0.05	0.05	unitless	3	Calibrated value. Modified from AVGWLF default to better reflect observed streamflows in the Study Area.
Seepage coefficient	GWLF	0.01	0.01	unitless	3	Calibrated value. Modified from AVGWLF default to better reflect observed streamflows in the Study Area.
Sediment lateral erosion factor for streambank erosion	GWLF	0.00649	0.00117	unitless	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Sediment lateral erosion factor for streambank erosion adjustment factor	GWLF	1	1	unitless	1	Default constant supplied by AVGWLF.
Streams in agricultural areas	GWLF	18.3	0.2	Km	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Streams in agricultural areas with vegetated buffers	GWLF	18.3	0.2	Km	3	PBS&J calculated. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Streams in high density urban areas	GWLF	1.9	0	Km	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Streams in high density urban areas with vegetated buffers	GWLF	1.9	0	Km	3	Optional parameter with no default. PBS&J calculated in order to model BMPs. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Streams in low density urban areas	GWLF	39.9	0.1	Km	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Streams in low density urban areas with vegetated buffers	GWLF	39.9	0.1	Km	3	PBS&J calculated. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Vegetated buffer strips BMP Nitrogen load efficiency	GWLF	0.51	0.3	unitless	3	Modified default value to fit NC standards from the NCDWQ stormwater manual.
Vegetated buffer strips BMP Phosphorus load efficiency	GWLF	0.51	0.3	unitless	3	Modified default value to fit NC standards from the NCDWQ stormwater manual.
Vegetated buffer strips BMP sediment load efficiency	GWLF	0.9775	0.85	unitless	3	Modified default value to fit NC standards from the NCDWQ stormwater manual.
Curve number for impervious fractions	RUNQUAL	98	90	unitless	3	Calibrated value. Modified AVGWLF defaults by using area weighted curve numbers based on land use and soils to better reflect observed streamflows in the Study Area.

[1] Group 1- Default Value, Not Data-Derived
Group 2- Value Derived by AVGWLF From Input GIS layers
Group 3- PBS&J Input

Parameter	Model	Upper	Lower	Units	Group[1]	Remarks
Curve number for pervious fractions	RUNQUAL	93	61	unitless	3	PBS&J calculated. Modified AVGWLF defaults by using area weighted curve numbers based on land use and soils.
Nitrogen accumulation on impervious surfaces	RUNQUAL	0.101	0.045	Kg/Ha/day	2	AVGWLF supplied. Varies by land use based on input GIS layers.
Nitrogen accumulation on pervious surfaces	RUNQUAL	0.045	0.012	Kg/Ha/day	2	AVGWLF supplied. Varies by land use based on input GIS layers.
Nitrogen dissolved fraction	RUNQUAL	0.33	0.28	Kg/Ha/day	2	AVGWLF supplied. Varies by land use based on input GIS layers.
Phosphorus accumulation on impervious surfaces	RUNQUAL	0.0112	0.0045	Kg/Ha/day	2	AVGWLF supplied. Varies by land use based on input GIS layers.
Phosphorus accumulation on pervious surfaces	RUNQUAL	0.0078	0.0016	Kg/Ha/day	2	AVGWLF supplied. Varies by land use based on input GIS layers.
Phosphorus dissolved fraction	RUNQUAL	0.4	0.37	Kg/Ha/day	2	AVGWLF supplied. Varies by land use based on input GIS layers.
TSS EMC	RUNQUAL	110	60	mg/L	2	AVGWLF supplied. Varies by land use based on input GIS layers.
Open land nitrogen EMC	RUNQUAL	1.5	1.5	mg/L	1	Default constant supplied by AVGWLF.
Open land phosphorus EMC	RUNQUAL	0.12	0.12	mg/L	1	Default constant supplied by AVGWLF.
Groundwater (subsurface) nitrogen	RUNQUAL	1	1	mg/L	1	Default constant supplied by AVGWLF.
Groundwater (subsurface) phosphorus	RUNQUAL	0.01	0.01	mg/L	1	Default constant supplied by AVGWLF.
Soil nitrogen	RUNQUAL	50	50	ppm	1	Default constant supplied by AVGWLF.
Soil phosphorus	RUNQUAL	100	100	ppm	1	Default constant supplied by AVGWLF.
Lateral erosion factor for streambank erosion	RUNQUAL	0.00535	0.00299	unitless	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
ET adjustment percentage	RUNQUAL	3.1	0.9	unitless	3	Calibrated value. Modified from AVGWLF default to better reflect observed streamflows in the Study Area.
Daylight	RUNQUAL	14.4	9.6	hours	2	AVGWLF supplied. Varies by month.
Growing season	RUNQUAL	TRUE	FALSE	Boolean	3	Required parameter with no default. Used March - November growing season as defined in county soil surveys.

[1] Group 1- Default Value, Not Data-Derived
Group 2- Value Derived by AVGWLF From Input GIS layers
Group 3- PBS&J Input

Parameter	Model	Upper	Lower	Units	Group[1]	Remarks
Point source Nitrogen loads	RUNQUAL	27082	0	Kg	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Point source Phosphorus loads	RUNQUAL	3679	0	Kg	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Point source discharge	RUNQUAL	7.87	0	MGD	2	AVGWLF supplied. Varies by watershed based on input GIS layers.
Fraction of streams with vegetated buffers	RUNQUAL	0.61	0.02	Km	3	Optional parameter with no default. PBS&J calculated in order to model BMPs. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Vegetated buffer strip width	RUNQUAL	33.9	14.28	m	3	Optional parameter with no default. PBS&J calculated in order to model BMPs. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Combined sewer overflows - nitrogen	RUNQUAL	35	35	mg/L	1	Default constant supplied by AVGWLF.
Combined sewer overflows - phosphorus	RUNQUAL	10	10	mg/L	1	Default constant supplied by AVGWLF.
Critical rainfall	RUNQUAL	1	1	cm/day	1	Default constant supplied by AVGWLF.

[1] Group 1- Default Value, Not Data-Derived
Group 2- Value Derived by AVGWLF From Input GIS layers
Group 3- PBS&J Input