Memorandum on Water Quality Modeling Methodology and Results (Quantitative ICE Assessment Memo #3)

For

Complete 540 – Triangle Expressway Southeast Extension

Wake and Johnston Counties, North Carolina

STIP Nos. R-2721, R-2828, R-2829

Prepared for:

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Added two footnotes to Table 16: Water Quality Study Area Riparian Buffer Widths

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1. Introduction

The North Carolina Department of Transportation (NCDOT) and the Federal Highway Administration (FHWA) propose building a new, controlled-access highway from NC 55 Bypass in Apex to US 64/US 264 Bypass (I-495) in Knightdale, a distance of approximately 28 miles. The project, known as Complete 540 – Triangle Expressway Southeast Extension, is proposed as a toll facility.

Through the National Environmental Policy Act (NEPA) process, NCDOT previously completed a Qualitative Indirect and Cumulative Effects (ICE) Report (H.W. Lochner, Inc., 2014) and a summary of the results are included in the Draft Environmental Impact Statement (DEIS), which was published in November 2015 (H.W. Lochner, Inc., 2015). The Quantitative ICE is under development to support the Final Environmental Impact Statement (FEIS), and the project team has developed a serious of technical memoranda to summarize the procedures, decisions, and results related to this analysis.

Quantitative ICE Memo #1 (Michael Baker Engineering, 2017a) documented the NCDOT and FHWA determination that the CommunityViz model from the Imagine 2040 regional land use planning initiative would be a reasonable and appropriate tool to develop land use scenarios for this project. NCDOT and FHWA came to this conclusion in large part because the CommunityViz model has already been calibrated to regional conditions and has been applied to regionally approved transportation plans.

Quantitative ICE Memo #2 (Michael Baker Engineering, 2017b) outlined the methodology used in this analysis to forecast land use changes between the base year (2010) and year 2040 and summarized the results of the land use scenarios developed for the Quantitative ICE. The outputs of the forecasting and modeling documented in this memo were used for the Quantitative Indirect and Cumulative Effects (ICE) Assessment and Water Quality Indirect and Cumulative Impacts (ICI) Assessment discussed in this Memo #3. The methodology described in Memo #2 is based on information collected from regional and local planners who are most familiar with the Future Land Use Study Area (FLUSA), land use forecasting and socioeconomic data approved for use in long-range transportation planning, and a review of recent literature on land use changes associated with construction of transportation infrastructure.

The purpose of this Memo #3 is to describe the methodology and results of the Water Quality ICI, including the inputs and methods used in the water quality modeling. Results are presented, but a more complete discussion of the ICI for water quality and endangered species is included in Indirect and Cumulative Effects Memorandum - Quantitative ICE Memo #4 (Michael Baker Engineering, 2017c). The ICI combines the data collected and CommunityViz model output from Quantitative ICE Memo #2 with a watershed model to estimate the water quality impacts that may occur as indirect and cumulative effects from planned and anticipated development in the FLUSA with and without the construction of the proposed facility.

This analysis is a critical component of the Quantitative ICE analysis, as documented in ICE Memo #4, due in part to requests from resource agencies during coordination to focus on water quality and endangered species in indirect and cumulative effect analysis. The dwarf wedgemussel (*Alasmidonta heterodon*) is the endangered species of primary concern to this analysis as known populations and suitable habitat for this species are found along Swift Creek within the FLUSA. On April 5, 2017, the USFWS proposed threatened species status for the yellow lance (*Elliptio lanceolate*; 82 FR 16559). The historical range, habitat, and stressors overlap for both species; therefore, this analysis will assess effects to the dwarf wedgemussel and will also apply to the yellow lance.

The water quality analysis used a watershed model, Generalized Watershed Loading Function – Enhanced (GWLF-E), to estimate the annual streamflow, runoff, and annual overland contaminant loadings of total nitrogen (TN), total phosphorus (TP), total suspended sediment (TSS), and copper for the three land use scenarios examined as part of the Quantitative ICE Assessment. These three scenarios, described in Table 1, are the 2010 Condition (2010), 2040 No-Build Land Use (2040 No-Build), and 2040 Preferred Alternative Build Land Use (2040 Build) scenarios. The ICE Memos #1 and #2 provide a full explanation of the development of the land use scenarios and the conversion from land use to land cover, which is the basis for water quality modeling. Comparison of the streamflow, runoff, and contaminant loadings projected for the 2040 No-Build and 2040 Build scenarios provides an indication of the project's potential Water Quality ICI.

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

Full Name of Land Use Scenario	Abbreviated Name	Definition
2010	2010	Land use conditions existing in 2010
2040 No-Build Land Use	2040 No-Build	Forecast land use for the year 2040 without construction of the project
2040 Preferred Alternative Build Land Use	2040 Build	Forecasted land use for the year 2040 with construction of the Preferred Alternative

The GWLF-E model was run twice for each scenario to estimate a range of likely indirect and cumulative impacts to the water quality study area. For both model runs, the process described in Quantitative ICE Memo #2 was used to estimate land cover in the water quality study area. The first, more-conservative model run used the land cover results and the GWLF-E defaults to convert land cover results to an "upper limit" of percent impervious coverage for each HUC in the study area. The second model run used the observed percent impervious coverage by land cover type in the Baseline condition to estimate the "lower limit" of impervious coverage for the 2010, 2040 No-Build, and 2040 Build scenarios. The percent impervious coverage estimates by land use category developed for use in the second model run provide a closer approximation of regulatory limits that currently apply in much of the FLUSA, including open space regulations and impervious surface limits, as discussed in Section 2 of ICE Memo #4.

This approach could produce some under-estimation of impervious surface percentages; therefore, Model Run 2 provides a low-end-of-range estimate, and Model Run 1 provides a high-end-of-range estimate. It should be noted that the percent impervious coverages for both model runs under the 2010 scenario are theoretical estimates calculated from the GWLF-E defaults (Model Run 1) or from an average of observed percent impervious by land cover type observed in the FLUSA (Model Run 2). Table 2 shows the percent impervious coverage by land cover type used in each model run. With one exception, the observed impervious surface ratios are lower than the default values from the model for each land use type. The one exception is Low Density Mixed Urban land cover category, which accounts for a very small amount (approximately 4 percent) of the land cover in the FLUSA.

Table 2: Percent Impervious Coverage by Land Cover Type Used in Model Runs 1 and 2

Land Use Code	Land Cover Category	Percent Impervious	
		Model Run 1 GWLF-E Defaults Upper Limit	Model Run 2 Observed Baseline Lower Limit
2	Low Density Mixed Urban	15	18
3	High Density Mixed Urban	87	29
17	Low Density Residential	15	9
18	Medium Density Residential	52	12
19	High Density Residential	87	33
20	Medium Density Mixed Urban	52	25

2. Water Quality Study Area

The following sub-sections describe the selection of the water quality study area, its definition, and the conditions of the study area.

2.1 Water Quality Study Area Definition

The FLUSA for the ICE analysis was selected in cooperation with NCDOT, FHWA, and other federal and state regulatory and resource agencies. The FLUSA encompasses an approximately 450-square mile area south and east of Raleigh, NC, including parts of Wake, Johnston, and Harnett counties.

The water quality study area used for this analysis was slightly modified from the FLUSA for modeling purposes. The study area was created by selecting the 12-digit Hydrologic Unit Code (HUC) watersheds within the original FLUSA boundary (See Figure 1). For those watersheds where the natural boundary extended beyond the original FLUSA boundary, the area of analysis for the purpose of this study was limited to just the watershed area within the original FLUSA. Two of the 12-digit HUCs were subdivided to provide data for the endangered species analysis. Seven HUCs or portions of HUCs along the fringes of the FLUSA were excluded from the water quality study area because such small areas of these watersheds were located within the FLUSA that modeling data for these areas would present data quality concerns. The final water quality study area (Figure 2) consisted of about 430 square miles. Table 3 displays a list of the twenty-one HUC watersheds in the water quality study area, and Table 4 shows the seven HUCs, or portions thereof, excluded from the study area. The subdivided White Oak Creek (030202011003) and Little Creek watersheds appear twice (ID #22 and #23) in the data results tables at the end of this document. In the water quality and related discussions, the subdivided White Oak Creek (030202011003 – Neuse River Basin) and Little Creek (030202011005 – Neuse River Basin) watersheds are referred to with (Upper) and (Lower) modifiers in text and table references, and the White Oak Creek watershed in the Cape Fear Basin (030300040102) is also referred to with the modifier (Cape Fear Basin) to provide clarity (see Table 3). Note that HUCs beginning with 0302 are in the Neuse River basin and those beginning with 0303 are in the Cape Fear River Basin.

Figure 1: Watersheds and Impaired Streams in the Water Quality Study Area

Figure 2: Water Quality Study Area Compared to FLUSA

Table 3: Water Quality Study Area Hydrologic Unit Codes (HUCs)

12-digit HUC[1]	Watershed Name
030202011003	White Oak Creek
030300040106	Avents Creek-Cape Fear River[2]
030300040502	Hector Creek-Cape Fear River
030202011202	Camp Branch-Black Creek
030300040501	Neills Creek
030202011201	Little Black Creek-Black Creek
030300040103	Buckhorn Creek
030202010903	Lower Middle Creek
030202011007	Reed Branch-Swift Creek
030202011006	Piney Grove Cemetery-Swift Creek
030202010902	Middle Middle Creek
030300040102	White Oak Creek (Cape Fear Basin)
030202011005	Little Creek
030202010901	Upper Middle Creek
030202011004	Mahlers Creek-Swift Creek
030202011002	Lake Benson-Swift Creek
030202011001	Lake Wheeler-Swift Creek
030202011101	Walnut Creek[2]
030202011103	Poplar Creek-Neuse River
030202011102	Marks Creek
030202010804	Lower Crabtree Creek

[1] *HUCS beginning with 0302 are in the Neuse River basin and those beginning with 0303 are in the Cape Fear River Basin.*

[2] *Small portions of this HUC were excluded from the water quality study area because these portions were small and spatially separated from the rest of the HUC modeled during this study.*

Table 4: Hydrologic Unit Codes (HUCs) Excluded from the Water Quality Study Area

12-digit HUC[1]	Watershed Name
030202010705	Mango Creek-Neuse River
030202011101	Walnut Creek[2]
030202011104	Mill Creek-Neuse River
030202011105	Buffalo Creek-Neuse River
030202011203	Holts Lake-Black Creek
030300060101	Upper Black River
030300040106	Avents Creek-Cape Fear River[2]

[1] *HUCS beginning with 0302 are in the Neuse River basin and those beginning with 0303 are in the Cape Fear River Basin.*

[2] *The portions of this HUC excluded from the water quality study area were small and spatially separated from the rest of the HUC modeled during this study.*

2.2 Water Resources

The majority of the water quality study area is located in the Neuse River watershed. A small portion of the western study area is within the Cape Fear River watershed. Named creeks in the water quality study area include Swift Creek, Middle Creek, Walnut Creek, Crabtree Creek, Buckhorn Creek, and Black Creek. Water quality classifications for study area streams are shown in Table 5.

Table 5: NC Department of Environmental Quality Classifications for Water Quality Study Area Streams

Classification Index	Name	Description	Classification[1]
18-13-(1)	Avents Creek	From source to a point 1.3 miles upstream of Harnett County SR 1418 (River Rd.)	C; HQW
18-15-(0.4)	Hector Creek	From source to a point 1.1 miles upstream of Harnett County SR 1415 (Rawls Church Rd.)	C; HQW
18-15-(0.7)	Hector Creek	From a point 1.1 miles upstream of Harnett County SR 1414 to Cape Fear River	WS-IV; HQW
18-16-(0.3)	Neills Creek (Neals Creek)	From source to a point 0.3 mile upstream of Wake-Harnett County Line	C
18-16-(0.7)	Neills Creek (Neals Creek)	From a point 0.3 mile upstream of Wake-Harnett County Line to Cape Fear River	WS-IV
18-16-1-(1)	Kenneth Creek	From source to Wake-Harnett County Line	C
18-16-1-(2)	Kenneth Creek	From Wake-Harnett County Line to Neills Creek	WS-IV
18-7-(1)	Buckhorn Creek	From source to Norfolk Southern Railroad	C
18-7-(3)	Buckhorn Creek (Harris Lake)	From backwaters of Harris Lake to dam at Harris Lake	WS-V
18-7-5	Cary Branch	From source to Harris Lake, Buckhorn Creek	C
18-7-5-1	Norris Branch	From source to Cary Branch	C
18-7-5.5	Utley Creek	From source to Harris Lake, Buckhorn Creek	C
18-7-6	White Oak Creek	From source to Harris Lake, Buckhorn Creek	C
18-7-6-1	Big Branch	From source to White Oak Creek	C
18-7-6-1-1	Little Branch	From source to Big Branch	C
18-7-7	Little White Oak Creek	From source to Harris Lake, Buckhorn Creek	C
27-(22.5)	Neuse River	From Town of Wake Forest proposed water supply intake to mouth of Beddingfield Creek	C; NSW
27-(36)	Neuse River	From mouth of Beddingfield Creek to a point 0.2 mile downstream of Johnston County SR 1700 (Covered Bridge Rd.)	WS-V; NSW
27-(38.5)	Neuse River	From a point 0.2 mile downstream of Johnston County SR 1700 to a point 1.4 mile downstream of Johnston County SR 1908 (Fire Department Rd.)	WS-IV; NSW
27-(41.7)	Neuse River	From City of Smithfield water supply intake to a point 1.4 miles downstream of Gar Gut	WS-V; NSW
27-33-(10)	Crabtree Creek	From mouth of Richlands Creek to Neuse River	C; NSW
27-33-22	Carolina Lake	Entire lake and connecting stream to Crabtree Creek	C; NSW
27-34-(4)	Walnut Creek	From dam at Lake Raleigh to Neuse River	C; NSW

Classification Index	Name	Description	Classification[1]
27-34-11	Big Branch	From source to Walnut Creek	C; NSW
27-34-11-1	Poplar Branch	From source to Big Branch	C; NSW
27-34-11-2	Little Arm Branch	From source to Big Branch	C; NSW
27-35	Poplar Creek	From source to Neuse River	C; NSW
27-37	Beddingfield Creek	From source to Neuse River	C; NSW
27-38	Marks Creek (Lake Myra)	From source to Neuse River	C; NSW
27-43-(1)	Swift Creek (Lake Wheeler)	From source to a point 0.6 mile upstream of Wake County SR 1006 (Old Stage Rd.)	WS-III; NSW
27-43-(5.5)	Swift Creek (Lake Benson)	From a point 0.6 mile upstream of Wake County SR 1006 (Old Stage Rd.) to dam at Lake Benson	WS-III; NSW,CA
27-43-(8)	Swift Creek	From dam at Lake Benson to Neuse River	C; NSW
27-43-10	Neal Branch	From source to Swift Creek	C; NSW
27-43-11	White Oak Creek (Austin Pond)	From source to Swift Creek	C; NSW
27-43-12	Little Creek	From source to Swift Creek	C; NSW
27-43-13	Cooper Branch	From source to Swift Creek	C; NSW
27-43-14	Reedy Branch (Little Branch)	From source to Swift Creek	C; NSW
27-43-15-(1)	Middle Creek	From source to backwaters of Sunset Lake	C; NSW
27-43-15-(2)	Middle Creek (Sunset Lake)	From backwaters of Sunset Lake to dam at Sunset Lake	B; NSW
27-43-15-(4)	Middle Creek	From dam at Sunset Lake to Swift Creek	C; NSW
27-43-15-10	Little Creek	From source to Middle Creek	C; NSW
27-43-15-10-1	Juniper Creek	From source to Little Creek	C; NSW
27-43-15-10-2	Guffy Branch	From source to Little Creek	C; NSW
27-43-15-10-2-1	Ditch Branch	From source to Guffy Branch	C; NSW
27-43-15-11	Buffalo Branch	From source to Middle Creek	C; NSW
27-43-15-12	Mill Branch	From source to Middle Creek	C; NSW
27-43-15-13	Beaverdam Branch	From source to Middle Creek	C; NSW
27-43-15-14	Cow Branch	From source to Middle Creek	C; NSW
27-43-15-15	Shop Branch	From source to Middle Creek	C; NSW
27-43-15-16	Steep Hill Branch	From source to Middle Creek	C; NSW
27-43-15-3	Basal Creek [(Bass Lake, (Mills Pond)]	From source to Sunset Lake, Middle Creek	B; NSW
27-43-15-4.5	Rocky Branch	From source to Middle Creek	C; NSW
27-43-15-5	Camp Branch	From source to Middle Creek	C; NSW
27-43-15-6	Bells Lake	Entire lake and connecting stream to Middle Creek	C; NSW
27-43-15-7	Mills Branch	From source to Middle Creek	C; NSW

Classification Index	Name	Description	Classification[1]
27-43-15-8-(1)	Terrible Creek (Johnsons Pond)	From source to dam at Johnsons Pond	B; NSW
27-43-15-8-(2)	Terrible Creek	From dam at Johnsons Pond to Middle Creek	C; NSW
27-43-15-9	Panther Branch	From source to Middle Creek	C; NSW
27-43-2.2	MacGregor Downs Lake	Entire lake and connecting stream to Swift Creek	WS-III; NSW
27-43-2.5	Regency Park Lake	Entire lake and connecting stream to Swift Creek	WS-III; NSW
27-43-2.8	Long Branch	From source to Swift Creek	WS-III; NSW
27-43-3	Lynn Branch (Meadows Creek) (Lochmere Lake)	From source to Swift Creek	WS-III; NSW
27-43-3.5	Speight Branch	From source to Swift Creek	WS-III; NSW
27-43-4	Woodys Lake	Entire lake and connecting stream to Swift Creek	WS-III; NSW
27-43-4.5	Dutchmans Branch	From source to Swift Creek	WS-III; NSW
27-43-5-(1)	Unnamed Tributary to Swift Creek (Silver Lake)	From source to dam at Silver Lake	WS-III,B; NSW
27-43-5-(1.5)	Unnamed Tributary to Swift Creek (Yates Mill Pond)	From dam at Silver Lake to a point 0.5 mile upstream of mouth	WS-III; NSW
27-43-5-(2)	Unnamed Tributary to Swift Creek	From a point 0.5 mile upstream of mouth to Swift Creek	WS-III; NSW,CA
27-43-6-(1)	Buck Branch	From source to a point 0.6 mile upstream of mouth	WS-III; NSW
27-43-6-(2)	Buck Branch	From a point 0.6 mile upstream of mouth to Lake Benson, Swift Creek	WS-III; NSW,CA
27-43-7-(1)	Reedy Branch	From source to a point 0.5 mile upstream of mouth	WS-III; NSW
27-43-7-(2)	Reedy Branch	From a point 0.5 mile upstream of mouth to Lake Benson, Swift Creek	WS-III; NSW,CA
27-43-9	Mahlers Creek	From source to Swift Creek	C; NSW
27-45-(1)	Black Creek (Partins Pond, Panther Lake)	From source to dam at Panther Lake	B; NSW
27-45-(2)	Black Creek	From dam at Panther Lake to mouth of Sassarixa Creek	C; NSW
27-45-3	Little Black Creek	From source to Black Creek	C; NSW
27-45-4	Hooks Branch	From source to Black Creek	C; NSW
27-45-6	Camp Branch	From source to Black Creek	C; NSW

[1] B - Primary Recreation, Fresh Water; C - Aquatic Life, Secondary Recreation, Fresh Water; CA - Critical Area; HQW - High Quality Waters; NSW - Nutrient Sensitive Waters; WS-III - Water Supply III - Moderately Developed; WS-IV - Water Supply IV- Highly Developed; WS-V - Water Supply V - Upstream

NC Department of Environmental Quality (NCDEQ) Division of Water Resources (DWR) maintains a list of waters classified as impaired under Section 303(d) of the Clean Water Act. The list of 303(d) impaired waterbodies identifies each impaired waterway and the contaminant(s) causing its impairment. Table 6, below, shows water quality study area waterways that are included in the current (2014) 303(d) list.

Table 6: Water Quality Study Area Streams on North Carolina 2014 303(d) List and Listing Year

Watershed Name	**Impaired Stream or Water Body**	**Impaired Reasons (Year)**	**Likely Origin**
Neills Creek	Neills Creek (from source to a point 0.3 mile upstream of Wake-Harnett County line)	Benthos Poor (2006)	Non-point source
	Neills Creek (from a point 0.3 mile upstream of Wake-Harnett County line to SR 1441 [East Williams St.])	Benthos Poor (2006)	Non-point source
	Kenneth Creek (from Wake-Harnett County line to Neills Creek)	Benthos Fair (1998)[1]	Non-point source
		pH (2012)[1]	
		Dissolved Oxygen (2014)	
Poplar Creek-Neuse River	Neuse River (from Crabtree Creek to SR 2555 [Auburn Knightdale Road])	Copper (2008)[1]	Non-point and point sources
		Polychlorinated biphenyl (PCB) Fish Tissue Advisory (2010)	
	Neuse River[2] (from mouth of Beddingfield Creek to a point 0.2 mile downstream of Johnston County SR 1700 [Covered Bridge Rd.])	Copper (2008)	Non-point source
		Zinc (2008)	
	Neuse River[2] (from a point 0.2 mile downstream of Johnston County SR 1700 [Covered Bridge Rd.] to point 1.4 mile downstream of Johnston County SR 1908 [Fire Dept. Rd])	Copper (2012)	Non-point and point sources
	Beddingfield Creek (from its source to Neuse River)	Benthos Fair (2014)	Non-point and point sources
Lower Crabtree Creek	Crabtree Creek (from 2.75 miles upstream of Neuse River to Neuse River)	PCB Fish Tissue Advisory (2008)	Non-point source
Walnut Creek	Walnut Creek (from an unnamed tributary [UT] 0.6 miles west of I-440 to Neuse River)	Copper (2008)[1]	Non-point source
		PCB Fish Tissue Advisory (2010)	
Lake Benson-Swift Creek	Swift Creek (from Lake Wheeler Dam to a point 0.6 mile upstream of Wake	Benthos Poor (2008)	Non-point source

Watershed Name	Impaired Stream or Water Body	Impaired Reasons (Year)	Likely Origin
	County SR 1006 [Old Stage Rd.])		
	Swift Creek (from a point 0.6 mile upstream of Wake County SR 1006 [Old Stage Rd.] to the backwaters of Lake Benson)	Benthos Poor (2008)	Non-point source
	UT to Swift Creek (from its source to Lake Benson)	Benthos Fair (2014)	Non-point source
Piney Grove Cemetery-Swift Creek	Swift Creek (from dam at Lake Benson to Little Creek)	Benthos Fair (2012)	Non-point and point sources
Mahlers Creek-Swift Creek	Swift Creek (from dam at Lake Benson to Little Creek)	Benthos Fair (2012)	Non-point and point sources
Little Creek (Upper)	Little Creek (from source to Swift Creek)	Benthos Fair (1998)	Non-point and point sources
Little Creek (Lower)	Little Creek (from its source to Swift Creek)	Benthos Fair (1998)	Non-point and point sources
Upper Middle Creek	Terrible Creek (from Johnsons Pond to Middle Creek)	Benthos Fair (2012)	Non-point and point sources
	Middle Creek (from 0.8 mile south of US 1 to UT on west side of creek 3.0 miles downstream)	Benthos Fair (2008)	Point source
	Middle Creek (from UT on west side of creek 3.0 miles downstream to backwaters of Sunset Lake)	Benthos Fair (2012)	Non-point and point sources
	Middle Creek (from dam at Sunset Lake to small impoundment upstream of US 401)	Fish Community Poor (2014)	Non-point and point sources

[1] *Impaired reason proposed for delisting in 2016.*

[2] *Segment proposed for delisting in 2016.*

The Neuse River has been affected for decades by human activity, including construction of impoundments, discharge from water and wastewater treatment plants, runoff from agricultural activities, and runoff from development (NC WRC, 2015; Harned, 1980). The remainder of the FLUSA is in the Cape Fear River basin. Common human-induced water quality issues in the Cape Fear Basin include sedimentation, invasive species, eutrophication (elevated nutrient levels that lead to algal blooms), and impoundments (NC WRC, 2015).

In 1998, the Neuse River Buffer Rules were enacted to reduce nitrogen inputs to the Neuse River (15A NCAC 02B.0233). These regulations include requiring property owners to protect 50-foot riparian buffers along the river and its tributaries, limiting point source pollution and stormwater runoff in new developments. The 50-foot buffers are not uniform and consist of two zones: 30 feet of undisturbed “forest” vegetation nearest the stream and 20 feet of herbaceous or woody vegetation to provide filtration of pollutants further from the stream. The Wake County Board of Commissioners adopted the *Swift Creek Land Management Plan* in 1990, further protecting the water supply watershed in the upper Swift Creek. This plan was adopted by local jurisdictions and identifies how each jurisdiction proposes to promote development while maintaining the water quality in the basin. Some communities have additional, more restrictive buffer requirements for perennial and intermittent streams. Importantly, Wake County has a 100-foot buffer requirement on perennial streams (comprised of two 50-foot zones, comparable in vegetation to the two zones on the Neuse River buffers), and Johnston County has a 100-foot buffer requirement specifically on perennial streams within the Swift Creek watershed.

3. Impervious Surface Results

The impervious surface coverage is estimated from the land cover forecasts discussed in Memo #2 and used in the water quality modeling. Table 7 shows the Model Run 1 impervious surface estimates for all three scenarios for the water quality study area and all the watersheds therein. Table 8 shows the Model Run 2 impervious surface estimates for all three scenarios for the water quality study area and all the watersheds therein. Figure 3 presents a graphic comparison of the difference in estimated percent impervious coverage by water quality study area and HUC between the 2010 and future scenarios for each model run. Throughout this memo, to avoid confusion, Model Run 1 results are presented in purple and Model Run 2 results are presented in green. The results can only be compared within each model run and not across the model runs. As explained in Section 4, comparisons across model runs are not valid because of the differences in each model run’s calibration.

In the water quality study area, estimated impervious surface coverage increases by 12 percent using the Model Run 1 estimation methodology and by 3 percent using Model Run 2 methodology from the 2010 to 2040 No-Build scenarios. Between the 2010 and 2040 Build scenarios, the estimated percent impervious increases by 13 percent for Model Run 1 and by 3 percent for Model Run 2. From the 2040 No-Build to 2040 Build scenarios, estimated impervious surface coverage increases by one percent or less for the entire water quality study area for both model runs. These figures and the corresponding acreage amounts for the Water Quality Study Area are shown in Table 9. In acres, the difference in estimated impervious surface between 2010 and the 2040 No Build scenario is over 32,000 acres and the difference from the 2040 No-Build to the 2040 Build scenario is 3,400 acres in Model Run 1. For Model Run 2, these figures are 8,800 acres from 2010 to the 2040 No-Build Scenario, and 500 acres for the difference between 2040 No-Build and 2040 Build scenarios.

Most watersheds see an increase in impervious surface from the 2010 to 2040 No-Build scenarios, as is consistent with growth projections for the area in most watersheds, with a relatively small incremental increase from the 2040 No-Build to 2040 Build scenarios. Impervious surface coverage is projected to increase by one percent or less from the 2040 No-Build to the 2040 Build scenarios in most watersheds for Model Run 1 and by less than one percent in all watersheds for Model Run 2. In Model Run 1, three percent increases in impervious surface coverage were estimated between the 2040 No-Build to 2040 Build scenarios in Middle Middle Creek, Poplar Creek-Neuse River, and White Oak Creek (Upper). In addition, the estimation method for Model Run 1 projected a 6 percent increase in the Mahlers Creek-Swift Creek watershed from the 2040 No-Build to 2040 Build scenarios. Projected increases in estimated percent impervious coverage were less than one percent in these watersheds for Model Run 2.

Some watersheds show a decrease in estimated impervious surface coverage from the 2040 No-Build to 2040 Build scenarios. These reductions are likely due to changes in the types of development and associated density assigned to the parcels in these watersheds. This finding is consistent with the qualitative ICE documentation provided in the DEIS. Development associated with the 2040 No-Build scenario is influenced more by the existing (and projected) roadway network (without Complete 540) as compared to the 2040 Build scenario. As explained in Quantitative ICE Memo 1, the CommunityViz model accounts for this influence by utilizing customized inputs for attractiveness factors to forecast future land use.

Four watersheds are of concern with respect to habitat for the endangered dwarf wedgemussel (and yellow lance mussel):

- White Oak Creek (Lower)
- Piney Grove Cemetery-Swift Creek
- Mahlers Creek-Swift Creek
- Little Creek (Lower)

Impervious surface coverage increases in these areas from the 2040 No-Build scenario to the 2040 Build scenario are 1 percent or less, with the exception of the Mahlers Creek-Swift Creek watershed for Model Run 1. Although this watershed has the largest increase among those in the study area, it is only six percent for Model Run 1, and the estimated percent increase for Model Run 2 is less than one percent.

Table 7: Upper-Limit Impervious Surface Results for Model Run 1 of the 2010, 2040 No-Build, and 2040 Build Scenarios

Watershed ID	Name	2010 (%)	2040 No-Build (%)	Difference between 2010 and 2040 No-Build[1] (%)	2040 Build (%)	Difference between 2010 and 2040 Build[1] (%)	Difference between 2040 No-Build and 2040 Build[1] (%)
	Water Quality Study Area	14	26	12	27	13	1
1	White Oak Creek (Lower)	10	28	18	29	20	1
2	Avents Creek-Cape Fear River	4	5	<1	5	<1	<1
3	Hector Creek-Cape Fear River	5	7	2	7	3	<1
4	Camp Branch-Black Creek	6	7	<1	7	<1	<1
5	Neills Creek	16	33	18	33	18	<1
6	Little Black Creek-Black Creek	9	22	13	23	15	1
7	Buckhorn Creek	12	29	17	30	18	<1
8	Lower Middle Creek	8	13	5	14	6	1
9	Reed Branch-Swift Creek	12	21	10	22	10	<1
10	Piney Grove Cemetery-Swift Creek	7	12	5	13	6	<1
11	Middle Middle Creek	16	28	12	31	15	3
12	White Oak Creek (Cape Fear Basin)	14	20	6	20	6	<1
13	Little Creek (Lower)	9	22	13	22	13	<1
14	Upper Middle Creek	22	39	17	39	18	<1
15	Mahlers Creek-Swift Creek	14	29	15	34	21	6
16	Lake Benson-Swift Creek	19	26	7	26	7	<1
17	Lake Wheeler-Swift Creek	21	24	3	24	3	<1
18	Walnut Creek	21	38	17	38	17	<1
19	Poplar Creek-Neuse River	11	27	16	30	20	3
20	Marks Creek	7	25	18	26	18	<1
21	Lower Crabtree Creek	39	40	2	40	2	<1
22	White Oak Creek (Upper)	20	38	18	40	21	3
23	Little Creek (Upper)	25	38	13	38	14	<1

[1] Note: all results are rounded and, as such, may not appear to add/subtract correctly. For example, 1.4% rounds to 1%, while 1.7% rounds to 2%, but the difference between them, 0.3%, would be shown as <1. Note that all figures use the watershed acreage as the denominator and are mathematically comparable (i.e., the difference between the 2040 No-Build and 2040 Build scenarios is the mathematical difference between each scenario's percentage result, as opposed to a relative percentage change from the 2040 No-Build result).

Table 8: Low-Limit Impervious Surface Estimates for Model Run 2 of the 2010, 2040 No-Build, and 2040 Build Scenarios

Water-shed ID	Name	2010 (%)	2040 No-Build (%)	Difference between 2010 and 2040 No-Build[1] (%)	2040 Build (%)	Difference between 2010 and 2040 Build[1] (%)	Difference between 2040 No-Build and 2040 Build[1] (%)
	Water Quality Study Area	5	8	3	9	3	<1
1	White Oak Creek (Lower)	4	9	5	9	5	<1
2	Avents Creek-Cape Fear River	2	2	<1	2	<1	<1
3	Hector Creek-Cape Fear River	2	3	<1	3	<1	<1
4	Camp Branch-Black Creek	3	4	<1	4	<1	<1
5	Neills Creek	5	10	4	10	4	<1
6	Little Black Creek-Black Creek	3	6	3	7	4	<1
7	Buckhorn Creek	4	8	4	8	4	<1
8	Lower Middle Creek	3	5	1	5	2	<1
9	Reed Branch-Swift Creek	4	7	2	7	3	<1
10	Piney Grove Cemetery-Swift Creek	4	5	1	5	1	<1
11	Middle Middle Creek	5	8	3	9	4	<1
12	White Oak Creek (Cape Fear Basin)	5	7	2	7	2	<1
13	Little Creek (Lower)	4	7	3	7	3	<1
14	Upper Middle Creek	7	11	4	11	4	<1
15	Mahlers Creek-Swift Creek	5	10	5	11	5	<1
16	Lake Benson-Swift Creek	7	10	3	10	3	<1
17	Lake Wheeler-Swift Creek	9	10	1	10	1	<1
18	Walnut Creek	7	12	4	12	4	<1
19	Poplar Creek-Neuse River	4	8	5	9	5	<1
20	Marks Creek	2	7	5	7	5	<1
21	Lower Crabtree Creek	15	16	<1	16	<1	<1
22	White Oak Creek (Upper)	7	13	6	14	6	<1
23	Little Creek (Upper)	9	12	3	12	3	<1

[1] Note: all results are rounded and, as such, may not appear to add/subtract correctly. For example, 1.4% rounds to 1%, while 1.7% rounds to 2%, but the difference between them, 0.3%, would be shown as <1. Note that all figures use the watershed acreage as the denominator and are mathematically comparable (i.e., the difference between the 2040 No-Build and 2040 Build scenarios is the mathematical difference between each scenario's percentage result, as opposed to a relative percentage change from the 2040 No-Build result).

Figure 3: Change in Percent Impervious from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2

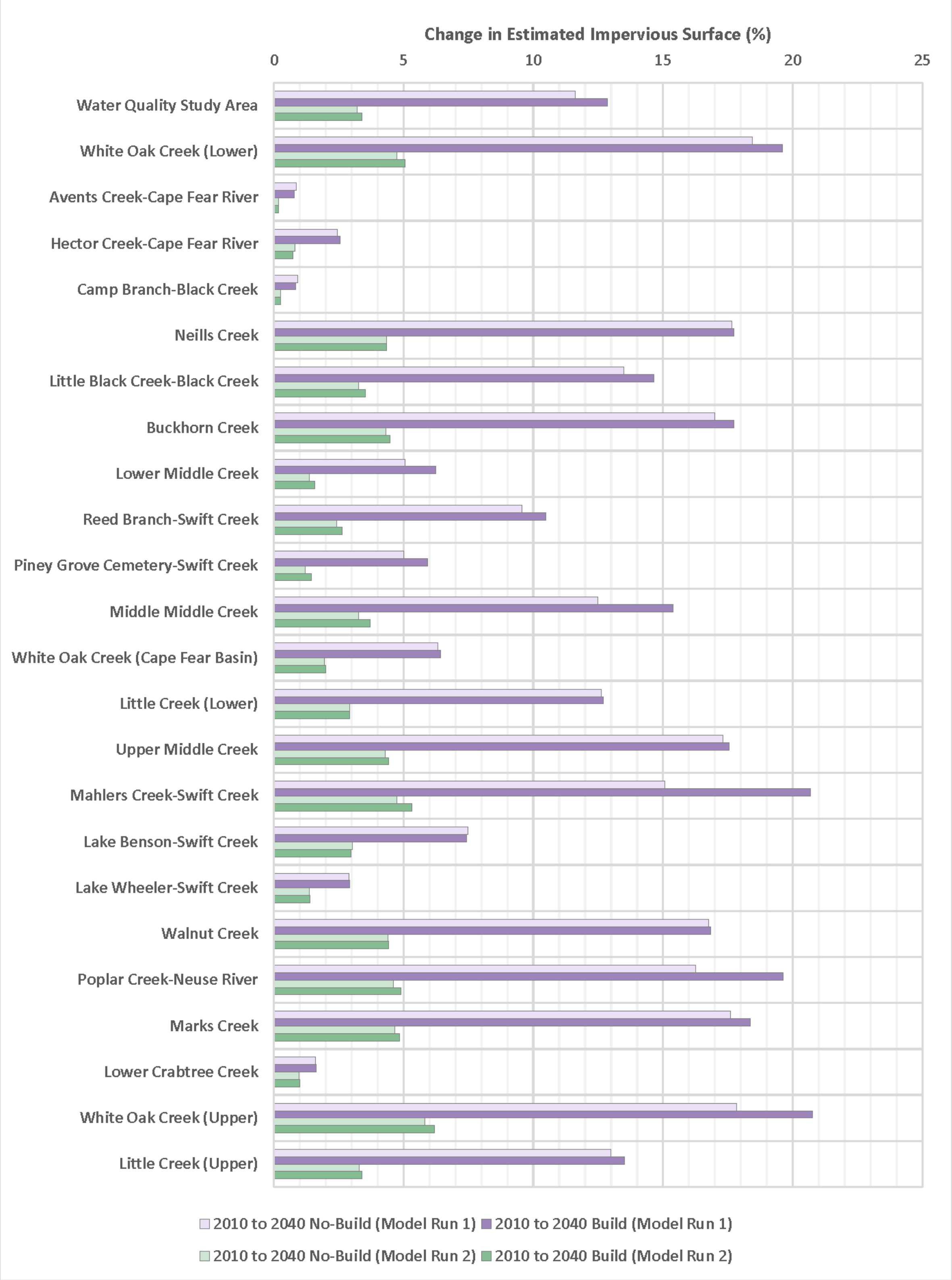


Table 9: Water Quality Study Area Summary Results for Impervious Surface

Model Run and Units	2010	2040 No-Build	Difference between 2010 and 2040 No-Build[1]	2040 Build	Difference between 2010 and 2040 Build[1]	Difference between 2040 No-Build and 2040 Build[1]
Model Run 1 - percentage	14	26	12	27	13	1
Model Run 1 - Acres	38,600	72,000	32,100	75,400	35,500	3,400
Model Run 2 - percentage	5	8	3	9	3	<1
Model Run 2 - Acres	14,600	23,400	8,800	23,900	9,300	500

The Water Quality Study Area (as shown in Figure 2) includes approximately 275,800 acres. The acreages above are based on detailed impervious surface calculations and are not a product of the rounded percentages shown.

4. Water Quality Analysis Approach

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

4.1 MapShed Description

MapShed is a customized Geographic Information System (GIS) interface developed in MapWindow, an open-source GIS platform, to create input data for the GWLF-E watershed model. The watershed simulation tools used in MapShed are based on the unenhanced GWLF and Runoff Quality from Development Sites (RUNQUAL) models originally developed by Dr. Douglas Haith and colleagues at Cornell University, as described in Section 4.1.1, below. Routines associated with both models, originally written in QuickBasic, were converted to Visual Basic by Evans et al. (2002) and enhanced with additional functionality to facilitate their use in MapShed. In MapShed, the functionality provided by these two models has been further enhanced and combined into a new model called GWLF-E. MapShed provides an interface to select and modify various GIS datasets, creates GWLF-E input files, provides interfaces to modify the GWLF-E model input files, runs the model, and provides interfaces to display the outputs from the model.

4.1.1 GWLF History and Application

The core watershed simulation model for the MapShed software application is the unenhanced GWLF model developed by Haith and Shoemaker (1987). The GWLF model simulates runoff, sediment, and nutrient (nitrogen [N] and phosphorus [P]) loads from a watershed based on various source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads and allows for the inclusion of point source discharge data. This continuous simulation model uses daily time steps for weather data and water-balance calculations. Monthly calculations are made for sediment and nutrient loads based on the daily water balance accumulated to monthly values.

GWLF is a combined distributed/lumped parameter watershed model. For surface loading, it allows multiple land use/land cover inputs, but assumes each area is homogenous regarding the attributes considered by the model. The model does not spatially distribute the source areas, but simply aggregates the loads from each source area into a watershed total; in other words, there is no spatial routing. For sub-surface loading, the model acts as a lumped parameter model using a water-balance approach. No distinctly separate areas are considered for sub-surface flow contributions. Daily water balances are computed for unsaturated and saturated sub-surface zones, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff and evapotranspiration.

The Natural Resources Conservation Service (NRCS) Curve Number (CN) approach is used to simulate surface runoff within the GWLF model. The CN is an empirical parameter that can be used to estimate the potential maximum soil moisture retention and thereby predict the direct runoff from a rainfall. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm, monthly rainfall-runoff coefficients, and monthly soil erosion values for each source area. The soil erosion calculation uses the following variables: soil loss erosion (K), the length slope factor (LS), the vegetation cover factor (C), and daily weather inputs (temperature and conservation practices factor, or P in KLSCP). These variables, known collectively as KLSCP, are used in calculations and can be thought to depict the susceptibility of soil to erosion. A sediment-delivery ratio is calculated from the watershed size and a transport capacity (based on average daily runoff) and then applied to the calculated erosion to determine sediment yield for each source area. Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and applying sediment coefficients to the yield portion for each agricultural source area. The dissolved nitrogen and phosphorus coefficient values are default values in the model, derived from national-level studies. Point source discharges, manured areas, and septic systems can also be considered to contribute to dissolved losses and are specified in terms of kilograms per month. The CN approach uses an exponential accumulation and wash-off function to calculate the urban nutrient loadings. Sub-surface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads, and the sub-surface sub-model only considers a single, lumped-parameter contributing area. Evapotranspiration is determined using daily weather data and a cover factor dependent upon land use/land cover type. Finally, a water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values.

In GWLF-E, transport-related data define the necessary parameters for each source area as well as global parameters (e.g., initial storage, sediment delivery ratio) that apply to all source areas. Nutrient data specifies the various loading parameters for the different source areas. The weather file (weather.dat) contains daily average temperature and total precipitation values for the simulation time period.

Since its initial incorporation into the ArcView interface of GWLF (AVGWLF), the GWLF model has been revised to include routines and functions not found in the original model. These include the streambank erosion routine, the simulation of water withdrawals from surface and ground water sources, and more comprehensive watershed modeling capabilities, such as loads from farm animals and a new pathogen-load estimation routine. Another significant change has been an improvement in the simulation of hydrology and loads from urban areas. These new functions are based on the RUNQUAL model developed by Haith (1993) at Cornell University. The model input structure used by RUNQUAL is very similar to GWLF, which greatly facilitated implementation of these new functions within the GWLF-E model used in MapShed.

As with older versions of GWLF, the new urban routines derived from RUNQUAL and included in GWLF-E provide for continuous daily simulation of surface runoff and contaminant loads from developed land within a given watershed. In contrast to the original GWLF, flows and loads in GWLF-E are calculated from both the pervious and impervious fractions associated with each land use/land cover category. The contaminated runoff may also be routed through various urban Best Management Practices (BMPs) to simulate reductions that may occur prior to being discharged at the watershed outlet. These routines in GWLF-E are adapted from the urban runoff component of the original GWLF model (Haith and Shoemaker, 1987). Runoff volumes are calculated from procedures given in the US Soil Conservation Service's Technical Release 55 (1986). Contaminant loads are based on exponential accumulation and wash-off functions similar to those used in the Storm Water Management Model (SWMM) (Huber and Dickinson, 1988) and Storage, Treatment, Overflow Runoff Model (STORM) (USACE, 1977). The pervious and impervious fractions of each land use type are modeled separately, and runoff and contaminant loads from the various surfaces are calculated daily and aggregated monthly in the model output. With the RUNQUAL-derived routines in GWLF-E, it is assumed that the area being simulated is small enough that travel times are on the order of one day or less.

As mentioned above, the RUNQUAL-derived routines in GWLF-E allow the user to consider the potential effects of BMPs on contaminated runoff. Three basic types of BMPs can be modeled using GWLF-E – detention basins, infiltration/retention facilities, and vegetated filter strips (buffers). Detention basins may be dry or wet (sometimes referred to as extended dry basins and wet ponds, respectively). Infiltration facilities are trenches, basins, and/or porous areas designed to allow specific volumes of runoff water to drain to underlying groundwater rather than directly to streams via overland flow. Filter (or buffer) strips are grassed or forested areas through which runoff passes as sheet (un-channelized) flow. In the original version of RUNQUAL, all runoff is routed through the BMPs. In GWLF-E, the user can specify the extent to which the three BMPs are implemented within any given watershed. If the practices are used in combination, runoff is routed through them in the following order: infiltration/retention, filter strips, and detention basins.

Finally, another significant revision that has been included in MapShed and GWLF-E is the ability to simulate the transport and attenuation of contaminant loads from multiple sub-watersheds within a larger watershed. In this case, loads are attenuated (i.e., reduced) using a combination of daily loss rates for contaminants and travel times based on the distances of each sub-watershed to the larger watershed outlet. This new functionality allows for better identification of contaminant "hot-spots" within the larger watershed, as well as better evaluation of the potential load-reduction effects of various contaminant mitigation activities in different geographic locations.

4.1.2 Estimation of Copper Loads

Copper loads are of concern in the study area because several studies have indicated that freshwater mussels, including the federally endangered dwarf wedgemussel and the proposed threatened yellow lance, are sensitive to copper and ammonia during their early life stages (Jacobson et al., 1993; Jacobson et al., 1997; Milam et al., 2005; Wang et al., 2007a; Wang et al., 2007b). The GWLF-E models TN, which includes ammonia. The model does not have the capability to directly model copper loads from the land use categories; however, the model does have the capability to model sediment loading by land use category. For this analysis, the watershed loading of copper was estimated based on modeled sediment loading and average copper levels in sediment for each county. This approach is based on TMDL studies in which copper was a modeled pollutant (KDHE, 2006; MapTech, Inc., 2004). The average sediment copper concentrations for each county were obtained from HealthGrove (2016) and are available in Table 10.

Table 10: Average Sediment Copper Concentrations by County

County	Concentration (ppm)
Wake County	8.870
Johnston County	6.921
Harnett County	7.266

4.2 Input Parameters

GIS data layers were used as inputs by MapShed to derive spatially aggregated input parameters for the GWLF-E model. Additionally, important non-spatial data were required by the model. Sources for these data are listed in Table 11. The sections below describe the use of each dataset.

Table 11: Model Inputs and Data Sources Used

Dataset	Data Source
Study Area Land Use	Michael Baker Engineering, Inc. and U.S. Geological Survey (USGS)
National Hydrography Dataset	USGS
Weather Station Locations and Data	National Oceanic and Atmospheric Administration (NOAA)
Digital Elevation Model	USGS
2004 Public Sewer Systems – Current Service Areas Municipal Boundaries	North Carolina Department of Water Resources (NCDWR)
Streamflow Data	USGS
Hydrologic Unit Code (HUC) Boundaries	Natural Resources Conservation Service (NRCS) Watershed Boundary Dataset/USGS
Soil Survey Geographic (SSURGO) Database	NRCS
Point Source Dischargers Location and Discharges	NCDWR, U.S. Environmental Protection Agency (USEPA) Discharge Monitoring Report (DMR)

4.2.1 Land Use and Land Cover

Study area land use datasets for the Baseline Condition, 2040 No-Build, and 2040 Build scenarios were developed as part of the ICE analysis for this project. The development of these datasets is detailed in *Memorandum on Land Use Scenario Methodology and Results (Quantitative ICE Assessment Memo #2).* The memorandum explains the methodology for developing the datasets, assigning the 29 land use classifications (Place Types), and converting the model outputs into land cover results. For the purposes of this water quality study, each of the Place Types defined for the Quantitative ICE analysis (Memo #2) were assigned to the land cover categories compatible with the GWLF-E model requirements (see Tables 12 and 13).

Table 12: Description of Land Cover Categories Used in the GWLF-E Model

GWLF-E Land Cover Categories	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. GWLF-E treats all forested areas similarly with regard to runoff, erosion, and nutrient loading.
Mixed Forest	Wooded areas with a mixture of deciduous and coniferous species. GWLF-E treats all forested areas similarly with regard to runoff, erosion, and nutrient loading.
Deciduous Forest	Wooded areas dominated by deciduous species. GWLF-E 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 GWLF-E.
Emergent Wetland	Wetlands dominated by herbaceous vegetation, but treated the same as Woody Wetland by GWLF-E.
Quarries	Quarries and transitional areas are grouped together in one category since both areas are treated as "non-vegetated, disturbed" areas within GWLF-E.
Transitional	Quarries and transitional areas are grouped together in one category since both areas are treated as "non-vegetated, disturbed" areas within GWLF-E.
Turfgrass/ Golf	Highly-maintained, intensively-fertilized areas 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 percent 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 to 75 percent 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 percent 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 percent 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 percent of the total cover. These areas commonly include schools, hospitals, commercial areas and industrial parks with extensive, surrounding open land.

GWLF-E Land Cover Categories	Description
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 to 75 percent 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 percent 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 percent of the total area.

Table 13: Mapping of Quantitative ICE Place Type Codes to GWLF-E Land Cover Categories

Place Type	Place Type Code	GWLF-E Land Cover Category
Light Industrial Center	LIC	Low Density Mixed Urban
Health Care Campus	HCC	Low Density Mixed Urban
University Campus	UC	Low Density Mixed Urban
Urban Neighborhood	UN	High Density Mixed Urban
Suburban Commercial Center	SCC	High Density Mixed Urban
Suburban Hotel	SH	High Density Mixed Urban
Suburban Office Center	SOC	High Density Mixed Urban
Regional Employment Center	REC	High Density Mixed Urban
Heavy Industrial Center	HIC	High Density Mixed Urban
Transit-Oriented Development	TOD	High Density Mixed Urban
Metropolitan Center	MC	High Density Mixed Urban
Airport	AIR	High Density Mixed Urban
Working Farm	WF	Cropland
Rural Living	RL	Low Density Residential
Large-Lot, Residential Neighborhood	LLRN	Low Density Residential
Mobile Home Community	MHC	Low Density Residential
Rural Cross Roads	RCR	Low Density Residential
Small-Lot, Residential Neighborhood	SLRN	Medium Density Residential
Shade Tree Residential Neighborhood	STRN	Medium Density Residential
Mixed Residential Neighborhood	MXR	Medium Density Residential
Multifamily Residential Neighborhood	MFRN	High Density Residential
High-Rise Residential	HRR	High Density Residential
Neighborhood Commercial Center	NCC	Medium Density Mixed Urban
Mixed-Use Center	MUC	High Density Mixed Urban
Mixed-Use Neighborhood	MUN	Medium Density Mixed Urban
Village Center	VC	Medium Density Mixed Urban
Town Center	TC	Medium Density Mixed Urban
Civic & Institutional Facilities	CIV	Medium Density Mixed Urban
Parks and Open Space	POS	Varies[1]

[2] Underlying NLCD inputs were used to determine the Land Use Category

Because the Place Types focus on developed land uses, some lands within the water quality study area were not categorized in the Quantitative ICE (see quantitative discussion of these differences by scenario in ICE Memo #4). National Land Cover Database (NLCD) data were used to fill in these gaps in the ICE dataset. The additional NLCD land cover types included in the modeling are Water, Coniferous Forest, Mixed Forest, and Deciduous Forest.

4.2.3 Soils

Spatial and tabular Soil Survey Geographic (SSURGO) database soil information for Johnston, Wake, and Harnett counties was downloaded from NRCS. The average available water-holding capacity, soil erodibility factor (KF), and dominant hydrologic soil group were calculated for each soil map unit and joined to the appropriate GWLF-E soil feature class. SSURGO stores the available water storage as centimeters (cm) of water in its map unit components root zone layers table (chorizon table). The weighted average available water-holding capacity of all the soil components were calculated and assigned to each soil feature. Similarly, the weighted average of the KF value corresponding to the top soil layer for all components of the map unit was calculated and assigned to each feature as the representative KF value. For each map unit, the soil hydrologic group (stored in SSURGO component table) was assigned based on the value corresponding to the dominant soil component for each soil map unit.

4.2.4 Curve Numbers

MapShed automatically calculates CNs based on land use class and hydrologic soil group information in the soil data to simulate surface runoff in the GWLF-E model. The CNs used for each of the GWLF-E land use categories are presented in Table 14. The CNs were the same for both model runs.

4.2.5 Streams

The stream network was obtained from the National Hydrography Dataset (NHD) (USGS, 2016a) by extracting and merging the high-resolution NHD flow lines for the 8 digit-HUCs Upper Neuse (03020201) and Upper Cape Fear (03030004). The merged streams were used with MapShed.

4.2.6 Weather Stations

General climate conditions for the study area can be characterized using data from meteorological observations made by the Raleigh Airport National Climatic Data Center station (GHCND:USW00013722). This station is in the Upper Neuse Watershed approximately three miles north of the water quality study area. Average annual precipitation at this station is 46.58 inches, and the average annual daily temperature is 60.8°F. The highest average daily temperature of 89°F occurs in July while the lowest average daily temperature of 32°F occurs in January, as obtained from the 1961-1990 climate normals (U.S. Climate Data, 2017). Figure 4 provides a summary of rainfall and climate data for the Raleigh Airport Station based on the same period.

Table 14: Curve Number Values for Land Use Soil Hydrologic Group Combinations

Land Use Category	CN for Soil Hydrologic Group			
	A[1]	B[2]	C[3]	D[4]
Water	98	98	98	98
Low Density Mixed Urban	74[5]/92[6]	74/92	74/92	74/92
High Density Mixed Urban	79[5]/98[6]	79/98	79/98	79/98
Hay/Pasture	43	63	75	81
Cropland	64	75	82	85
Forest	37	60	73	80
Mixed Forest	37	60	73	80
Deciduous Forest	37	60	73	80
Wetland	69	80	87	90
Emergent Wetland	72	82	87	89
Disturbed	76	85	89	91
Sandy Areas	20	20	20	20
Turf/Golf	30	58	71	78
Low Density Residential	74[5]/92[6]	74/92	74/92	74/92
Medium Density Residential	74[5]/92[6]	74/92	74/92	74/92
High Density Residential	74[5]/92[6]	74/92	74/92	74/92
Medium Density Mixed Urban	79[5]/98[6]	79/98	79/98	79/98
Open land	43	63	75	81
Bare Rock	98	98	98	98

[1] Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures.

[2] Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures.

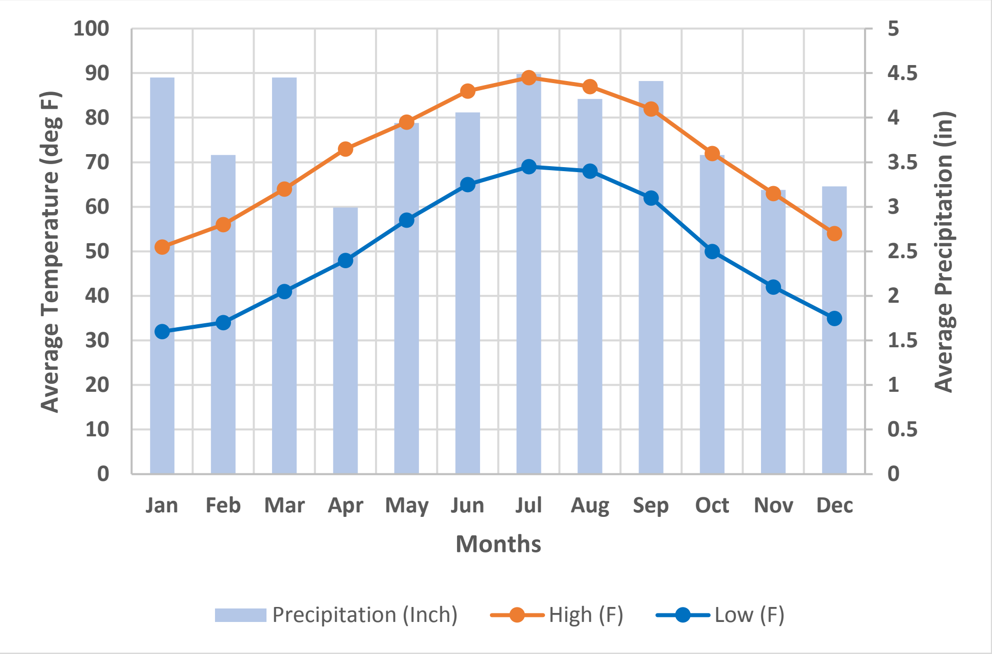
[3] Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures.

[4] Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, have less than 50 percent sand, and have clayey textures.

[5] CN for pervious portion

[6] CN of impervious portion

Figure 4: Monthly average temperature and precipitation for Raleigh Airport Station over a 30-year period



In addition to the Raleigh Airport station, data from two other stations were also used in the study as these stations are closer to some of the water quality study area watersheds. The location of weather stations with daily temperature (maximum and minimum) and precipitation records for the period 2000 to 2008 were retrieved from NOAA. Weather data from the Raleigh Airport NC (GHCND:USW00013722), Smithfield NC (GHCND:USC00317994), and Raleigh State University NC (GHCND:USC00317079) stations were formatted for use by MapShed.

4.2.7 Point Sources

Locations of facilities within the study area with National Pollutant Discharge Elimination System (NPDES) permits were obtained from NCDEQ. These facilities include large municipal wastewater treatment plants (WWTPs) and are listed in Table 15. The 2016 annual nitrogen and phosphorus loading rates (annual discharges) from each point source was obtained from the USEPA DMR data and used for all scenarios modeled.

Table 15: Point Sources Located within the Water Quality Study Area

NPDES Permit Number	Facility Name
NC0025453	Little Creek WWTP
NC0029033	City of Raleigh Public Utilities
NC0063096	Holly Springs WWTP
NC0063096	Holly Springs WWTP
NC0064050	Apex Water Reclamation Facility
NC0065102	Town of Cary - South Cary WWTP
NC0066516	Terrible Creek WWTP

Cropland land use is the major contributor of TN to the study area. However, a number of point sources in the study area also contribute TN. These are the Neuse River WWTP in Poplar Creek-Neuse River watershed; Terrible Creek WWTP, South WWTP, and Middle Creek WWTP in Upper Middle Creek watershed; Little Creek WWTP in Little Creek watershed (Upper); and Holly Springs WWTP in White Oak Creek (Cape Fear Basin) watershed. Based on the 2016 data, the Neuse River WWTP facility contributes more TN to the study area than the other point sources. The only point source that contributed phosphorus was the Holly Springs WWTP located in the White Oak Creek (Cape Fear Basin) watershed.

4.2.8 Surface Elevation

Topography and relief data were obtained from the USGS National Data Set at a resolution of approximately 10 meters. The region is characterized by low, rolling hills ranging in elevation from 70 to 500 feet above sea level. The slope ranges between 0 degrees and 60 degrees.

4.2.9 Basins

Drainage basins were defined based on the 12-digit HUCs collaboratively developed by USGS and NRCS. Out of the 23 watersheds within the water quality study area, some are partial areas of the selected 12-digit HUCs. The White Oak Creek (030202011003 – Neuse River Basin) and Little Creek (030202011005 – Neuse River Basin) 12-digit HUCs were subdivided to provide data for the endangered species analysis (See Table 3).

4.2.10 Best Management Practice (BMP) Implementation

GWLF-E can include contaminant reductions based on various BMPs including riparian buffers in rural and urban areas. The model requires inputting the total length of buffered streams in rural areas. Reduction efficiency coefficients are assigned for each contaminant - nitrogen, phosphorus, and overland sediment. These coefficients estimate reductions in runoff-bound contaminant levels due to riparian buffers in rural areas. By accommodating only a single reduction efficiency coefficient per contaminant in rural areas, GWLF-E, in effect, simulates a single buffer width. In urban areas, the reduction efficiency coefficient is calculated by the model from the amount of the stream network with a buffer and a buffer width value for the urban area. The reduction efficiency coefficients applied to the runoff are hardwired into the model and not available for editing. GWLF-E also does not consider variable buffer widths within a single watershed.

To calculate the reduction efficiency coefficient in urban areas, GWLF-E requires information about the amount of the stream network with a riparian buffer and an average buffer width value. This information was derived by delineating and characterizing buffers throughout the study area based on the buffer regulations in the various planning jurisdictions in the study area (Wake County, 2016; Johnston County, 2016; Johnston County Dept. of Utilities, 2008). Using GIS, the stream network represented by the NHD flowlines was buffered based on the applicable buffer requirements for each waterbody type and jurisdiction (Table 16). The resulting buffer layer establishes the extent and width of regulated buffer zones in the study area. Note that the model uses a weighted average buffer for each watershed; therefore, minor differences in buffer width assumptions do not readily affect the model results.

Table 16: Water Quality Study Area Riparian Buffer Widths

Jurisdiction	Criterion	Width (feet) [1]
Wake County	Perennial Watercourse	100
Swift Creek Watershed (Johnston portion)	Perennial Watercourse	100
Neuse River and Cape Fear River Watershed	Perennial and intermittent streams	50
Wake County	Non-Perennial/Non-intermittent Watercourse, 25+acre-stream drainage area	50
Wake County	Non-Perennial/Non-intermittent Watercourse, 5 to 25 acre – stream drainage area [2]	30

[1] Implementation or enforcement of the stream buffers may vary within the FLUSA. For example, the NC Regulatory Reform Act of 2015 could reduce the implementation of local watershed buffers that exceed state statutes, such as the Wake County 100-foot buffers on perennial streams in the Neuse River Basin; however, in the FLUSA, the NCDOT and USFWS Memoranda of Understanding with localities in the lower Swift Creek and Little Creek watersheds for the Clayton Bypass water quality permits would be expected to allow 100-foot buffers to be enforced in those areas. In total, given that the buffers are the sole BMP included in the model, they represent a conservative estimate (i.e., less pollution reduction) than would be expected to occur in reality (as discussed further in Section 5, page 32).

[2] In the applicable watersheds, streams with drainage areas less than 5 acres were also included, with minimal impact to the model results as noted in text prior to Table 16.

Source: Wake County, 2016; Johnston County Dept. of Utilities, 2008

4.3 Model Calibration

Although the GWLF-E model was originally developed for use in ungauged watersheds, calibration is routinely performed to ensure that hydrology is being simulated accurately. This process minimizes errors in sediment simulations due to potential errors in hydrology-related parameters. The model's parameters are assigned based on available soils, land use, and topographic data. During calibration, adjustments are made to parameters including the recession constant, the monthly evapotranspiration cover coefficients, and the seepage coefficient.

In order to conduct the hydrology calibration for this analysis, a GWLF-E model was set up for the Swift Creek watershed for the January 2009 to December 2015 time period. The GWLF-E model-simulated streamflow was compared to the observed data available for the USGS station 208773375 (Swift Creek at SR 1555 [Barber Mill Rd.] near Clayton, NC) (USGS, 2016d). Additional information about this gauge station is available in Table 17. The calibration involved adjusting the model parameters to obtain an acceptable match between GWLF-E monthly simulated streamflow and the observed monthly streamflow. Other hydrologic components were calculated including baseflow, seasonal streamflow, and total annual streamflow.

Simulated and observed monthly flows for the model calibration are compared in Figure 5 for Model Run 1 and in Figure 6 for Model Run 2. Figures 7 and 8 show the average simulated and observed monthly flows aggregated by month for Model Runs 1 and 2, respectively. A visual inspection of the results indicates that the GWLF-E model was able to adequately predict the observed values. The root mean square error between simulated and observed monthly values was 1.58 percent for Model Run 1 and 1.45 percent for Model Run 2. In addition, the Nash-Sutcliffe Efficiency (N-S) value was calculated to be 0.43 for Model Run 1 and 0.52 for Model Run 2. These values suggest that the model was able to predict the observed values well, as shown in Figures 7 and 8, which compare the average monthly simulated flow and the average monthly observed flow at the USGS gauge for each month of the year. N-S values range between one and negative infinity. The closer N-S is to one (exact match), the better the model fit. An N-S value that is lower than zero indicates that the mean value of the observed time series is a better predictor than the model. A value of 0.4 or higher for N-S indicates a reasonably well-calibrated model for use in predicting annual averages. In particular, the error in the model as calibrated appears to result primarily from differences in the predicted level of variation, as shown in Figures 5 and 6, but the directional fit is very good, as shown in Figures 5 through 8. In other words, the model tracks rise and fall based on the precipitation levels well, is not as effective at predicting the precise degree of highs and lows, and tracks average conditions very well. Since the model is only used to predict averages, not extremes, this level of calibration appears suitable for use in this study.

Table 17: Information about the Swift Creek Gauge Station near Clayton, NC

Gauge Station	208773375
Stream	Swift Creek
Location	SR 1555 (Barber Mill Rd.) near Clayton, NC
Observation Record (month/year)	10/2008 - current
Calibration Period	2009 - 2015

Figure 5: Comparison of Monthly Simulated and Observed Flow at the Outlet of Swift Creek Watershed between January 2009 and December 2015 for Model Run 1 Calibration

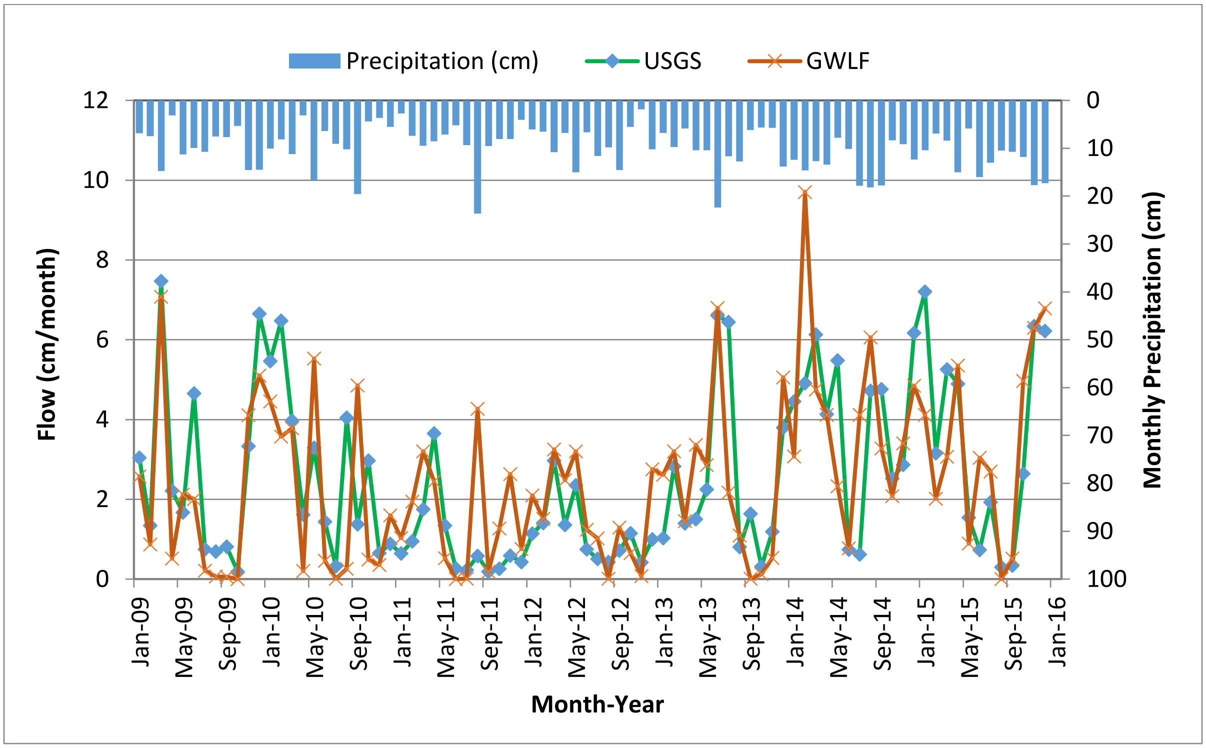


Figure 6: Comparison of Monthly Simulated and Observed Flow at the Outlet of Swift Creek Watershed between January 2009 and December 2015 for Model Run 2 Calibration

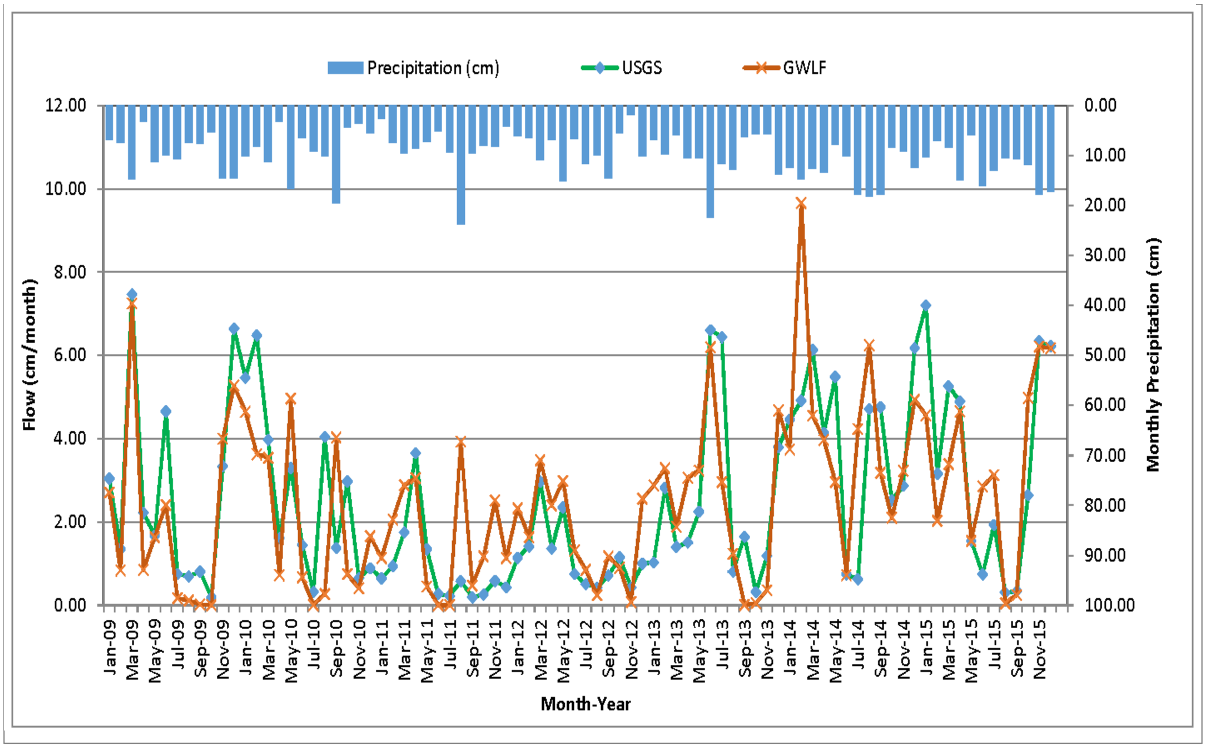


Figure 7: Comparison of Average Monthly Simulated and Average Monthly Observed Flow at the Outlet of Swift Creek Watershed between January 2009 and December 2015 for Model Run 1 Calibration

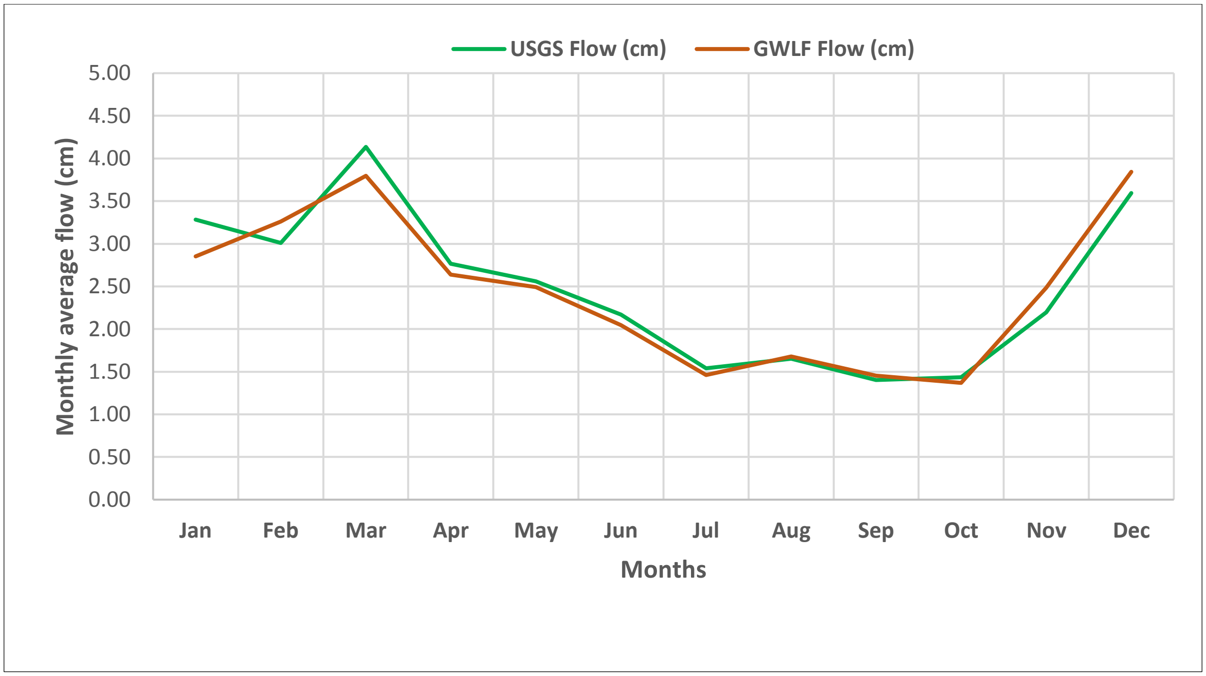
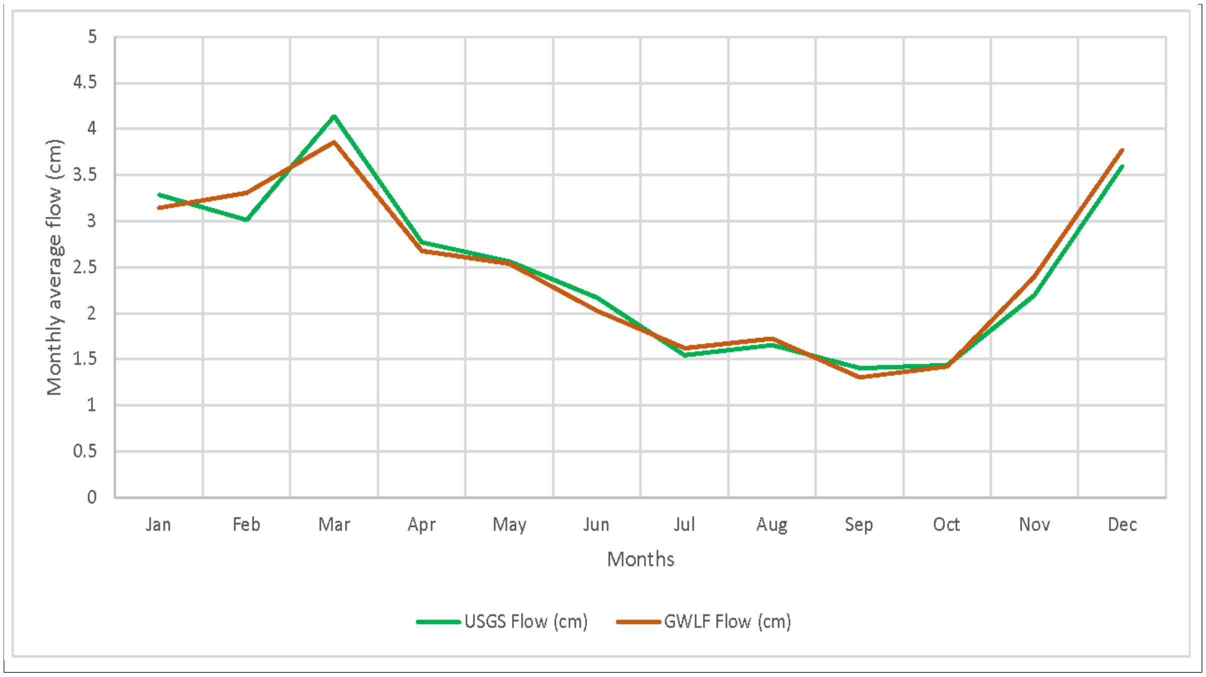


Figure 8: Comparison of Average Monthly Simulated and Average Monthly Observed Flow at the Outlet of Swift Creek Watershed between January 2009 and December 2015 for Model Run 2 Calibration



5. Results and Discussion

The GWLF-E model was run twice for each of the three Quantitative ICE scenarios – 2010, 2040 No-Build, and 2040 Build (as explained in the Introduction section of this memo). The input parameters remained constant for each of the modeled scenarios and, with the exception of impervious surface coverage, for each model run. Simulations were conducted using data for the period between 2009 and 2015 to establish the 2010 scenario as well to analyze the changes in 2040 No-Build and 2040 Build scenarios. The results from each model run represent the average condition of the watershed over a period of time for each scenario. This provides a more accurate representation of overall watershed conditions than considering only a single year because it includes periods of dry, wet, and medium flow regimes. The results of the GWLF-E model runs for each scenario are reported in the Tables 21 through 32. In addition, the figures in Appendix A correspond to the annual average of the model results.

Streamflow, runoff, and loading rates of the contaminants (TN, TP, TSS, and copper) vary as land use patterns change within a study area. In both of the 2040 scenarios, increased impervious surface coverage, due to additional development relative to the 2010 scenario, resulted in increased runoff. These results are expected as increased urbanization occurs. Contaminant loads are anticipated to increase as undeveloped and unmanaged land is converted to residential, commercial, or industrial use. Nutrient export loads from commercial and industrial parcels are significantly higher than from forest lands. However, some changes to more urbanized land uses can result in lower contaminant loads. For example, the conversion of agricultural lands to other land uses may reduce nutrient loads, depending on the type of development. The change from “undeveloped, but managed” land use categories to "developed" land use categories can result in decreased contaminant loads, but increases in runoff, which can alter in-stream habitat.

The results of the water quality analysis are discussed individually for the three modeled land use scenarios and for each model run. Tables 21 through 32 compare the streamflow and contaminant loads among the three scenarios for each model run. Sections 5.1 through 5.4 describe the results in more detail. Maps of the analysis results are presented in Appendix A.

NOTE: *When reviewing the water quality comparison tables or the following summary text, please keep in mind that the percent change calculated between the 2010 and the 2040 No-Build scenarios and between the 2010 and the 2040 Build scenarios both use the same denominator (the 2010 scenairo) while the 2040 Build to 2040 No-Build percentage change uses the 2040 No-Build scenario as the denominator. Therefore, the 2010 to 2040 No-Build percent change cannot be simply subtracted from the 2010 to 2040 Build percent change to get the 2040 Build to 2040 No-Build percent change, as these ratios have different denominators. In addition, all results are rounded and, as such, may not appear to add/subtract correctly. For example, 1.4% rounds to 1%, while 1.7% rounds to 2%, but the difference between them, 0.3%, would be shown as <1.*

All watershed models are simplified representations of real world conditions. GWLF-E is one of the mid-range models widely used for watershed hydrology, sediment, and nutrients. As per the normal procedure with this model, calibration for hydrology was conducted. In this case, the period from January 2000 to December 2015 was used, based on regional weather data. Typically, other calibrations are not required for this type of model, as comparative analyses would have a consistent model error that is expected to affect the study scenarios equally. The GWLF-E has been widely accepted as an appropriate tool for watershed-scale assessments and has been used in previous studies for NCDOT projects.

A key qualification about this water quality analysis is that it was not conducted to predict the specific amount of contaminants delivered at the outlet of each modeled catchment. Rather, the goal of the analysis was to determine the magnitude of the change in streamflow and contaminant loading between the 2040 No-Build and 2040 Build scenarios. This change indicates the trend of water quality over time in each catchment and in the water quality study area as a whole. In addition, the analysis only considered riparian buffers as a BMP. No other site-specific BMPs, such as bioretention basins, stormwater ponds, grass swales, etc., are accounted for in the results. Consequently, both runs of the watershed model likely over-estimate contaminant loadings from areas with treated stormwater and can be considered a conservative estimate. In reality, substantial reductions in contaminant loadings could be attained as future development takes place, if existing BMP regulations are enforced and BMPs are constructed and properly maintained. This topic is discussed in greater detail in ICE Memo #4.

5.1 2010 Scenario

The 2010 scenario corresponds to the Baseline (2010) land uses within the water quality study area. The watersheds with the highest streamflow and runoff quantities for both model runs are Lower Crabtree Creek, Little Creek (Upper), Lake Wheeler-Swift Creek, White Oak Creek (Upper), and Walnut Creek. This is expected as the percentages of urban land uses are higher in these watersheds than in the others. Urban land uses account for over 70 percent of the land in the Lower Crabtree and Lake Wheeler-Swift Creek watersheds. For both model runs, Upper Middle Creek has the highest TSS unit area load (sediment loadings in metric tons per acre per year [MT/ac/year]) followed by Lake Wheeler-Swift Creek. Since the copper load is calculated from the sediment load, these same watersheds have the highest copper unit area loads as well.

Of the 23 watersheds, the Poplar Creek-Neuse River watershed contributes the largest share of TN based on either model run and contributes greater than three times more TN than any other modeled watershed. The Little Creek (Upper) watershed is the second largest contributor in both model runs.

The unit area contribution of TP is higher for Hay/Pasture, Turf/Golf, and Cropland land use categories than for other uses. The Avents Creek-Cape Fear River, Neills Creek, Little Black Creek-Black Creek, and Upper Middle Creek watersheds show highest unit area load of TP in the study area for both runs.

5.2 2040 No-Build Scenario

As shown in Tables 21 and 22, the GWLF-E model projected comparable streamflow values for the watersheds when comparing 2010 and 2040 No-Build scenarios for both model runs. The largest increase for Model Run 1 was only 13%, and Model Run 2 projected most watersheds would either not have a streamflow increase or would have a slight streamflow reduction in the 2040 No-Build scenario as compared to the 2010 scenario.

Runoff from the Marks Creek, Poplar Creek-Neuse River, White Oak Creek (Upper), and White Oak Creek (Lower) watersheds increased from the 2010 scenario to the 2040 No-Build scenario for both model runs. These modeled increases are expected as the No-Build Scenario assumes increases in urban land use and percent impervious in these watersheds relative to the 2010 scenario.

The largest percent increases in the TSS loads and copper loads from the 2010 to the 2040 No-Build scenarios were projected in the Marks Creek, Poplar Creek-Neuse River, Mahlers Creek-Swift Creek, and White Oak Creek (Upper) watersheds for both model runs.

Marks Creek, Poplar Creek-Neuse River, Mahlers Creek-Swift Creek, White Oak Creek (Upper), and Walnut Creek watersheds showed greater increases in TP loads between the 2010 and 2040 No-Build scenarios than the other watersheds in the study area. The TP loads in these watersheds from the 2010 to 2040 No-Build scenarios increased 48 to 81 percent in Model Run 1 and 35 to 66 percent in Model Run 2. Upper Middle Creek, Marks Creek, Mahlers Creek-Swift Creek, White Oak Creek (Upper), Lake Benson-Swift Creek, and Walnut Creek watersheds showed the greatest watershed percent increases from the 2010 scenario in TN loading with increases of 9 to 23 percent in Model Run 1 and 5 to 12 percent in Model Run 2.

5.3 2040 Build Scenario

The land cover condition captured by the 2040 Build scenario is different from the 2040 No-Build scenario in that it assumes construction of the project and its anticipated indirect land use effects. The 2040 Build scenario adds approximately 8,000 acres of Medium Density Residential, 730 acres of Low Density Mixed Urban, and 300 acres of High Density Mixed Urban development. However, this scenario also includes about 7,700 fewer acres of Low Density Residential Area in the water quality study area as compared to the 2040 No-Build scenario. The decrease in acres of projected Low Density Residential land cover results from displacement or replacement by the proposed roadway, commercial or industrial development near interchanges, or Medium Density Residential development in the 2040 Build scenario.

The changes in development density, along with the location of those changes, drive the differences in streamflow, runoff, and contaminant loading in the 2040 Build scenario as compared to the 2040 No-Build scenario. Areas with large increases in the highest density development are projected to experience the largest increases in streamflow, runoff, and contaminant loading. To some extent, an increase in the highest density land use is offset by decreases in lower density development. The effect of runoff on contaminant loading is determined by whether the increase occurred in a rural or urban portion of the catchment because urban nutrient loads are influenced by the buildup/wash-off processes and not directly tied to sediment loads.

The watersheds with the highest increase in TSS and copper loading for the 2040 Build scenario compared to the 2040 No-Build scenario for both model runs are Piney Grove Cemetery-Swift Creek, Middle Middle Creek, Little Black Creek-Black Creek, and Lower Middle Creek. The highest percent increase in TN loads for the 2040 Build scenario compared to the 2040 No-Build are the Mahlers Creek-Swift Creek, White Oak Creek (Upper), and Middle Middle Creek for Model Run 1. The percent change in TN loads to all watersheds was less than one percent between the 2040 No-Build and 2040 Build scenarios for Model Run 2. The highest percent increase in TP load for the 2040 Build scenario compared to the 2040 No-Build scenario in both model runs were projected in Mahlers Creek-Swift Creek and Middle Middle Creek watersheds.

Overall for the water quality study area, Model Run 1 projects that the streamflow would increase by <1 percent and runoff would increase by 2 percent under the 2040 Build scenario as compared to the 2040 No-Build scenario. Similarly, the TSS, TN, TP, and copper loads would increase by <1 percent. Model Run 2 projects that all parameters would increase by <1 percent for the water quality study area as a whole (Table 18). With the exception of streamflow and runoff projected in Model Run 1, these increases, as well as the maximum observed increase between the 2040 Build and 2040 No-Build scenarios, were observed to be within the standard error of each pollutant as modeled (see Table 19). For Model Run 1, the maximum change in streamflow and runoff exceeded the standard error. Results within the standard error cannot be distinguished from a random occurrence.

Table 18: Percent Change from the 2040 No-Build Scenario to the 2040 Build Scenario for the Water Quality Study Area as a Whole

Modeled Parameter	**Percent Change from 2040 No-Build to 2040 Build**	
	Model Run 1 GWLF-E Defaults Upper Limit	**Model Run 2 Observed Baseline Lower Limit**
Streamflow	<1	<1
Runoff	2	<1
TSS	<1	<1
TN	<1	<1
TP	<1	<1
Copper	<1	<1

Table 19: Standard Error of Pollutants as Modeled

Parameter	Value		Maximum Change (2040 Build – 2040 No-Build)	
	Model Run 1	Model Run 2	Model Run 1	Model Run 2
TSS (MT/ac/year)	0.24	0.25	0.17	0.14
TN (kg/ac/year)	0.34	0.34	0.05	0.01
TP (kg/ac/year)	0.01	0.01	0.01	<0.01
Streamflow (cm)	0.36	0.18	0.72	0.07
Runoff (cm)	0.55	0.25	1.12	0.14
Copper (g/yr/ac)	0.22	0.23	0.15	0.12

In the four watersheds of concern for the dwarf wedgemussel, increases from the 2040 No-Build scenario to 2040 Build scenario are presented in Table 20, including totals for weighted average increases in these watersheds combined. The weighted average changes are projected to be 1 and less than one percent for streamflow and 7 and 2 percent for runoff in Model Runs 1 and 2, respectively. For TSS, TN, and copper loads, the weighted average increases are 2 percent for Model Run 1 and less than one percent for Model Run 2. Weight average TP loads are projected to be 5 percent for Model Run 1 and 1 percent for Model Run 2. Water quality conditions and results by watershed are discussed in greater detail in the Indirect and Cumulative Effect discussion of ICE Memo #4. The ICE Memo #4 also provides more information about the stormwater management regulations that will serve to reduce the effects of development in these watersheds beyond that reflected in the model results.

Table 20: Percent Change in Modeled Parameters between the 2040 Build and 2040 No-Build Scenarios in the Lower Swift Creek Watersheds

Watershed	Percent Change											
	Streamflow		Runoff		TSS		TN		TP		Copper	
	MR1[1]	MR2[2]	MR1	MR2	MR1	MR2	MR1	MR2	MR1	MR2	MR1	MR2
Mahlers Creek-Swift Creek	2	<1	10	2	2	<1	3	<1	7	2	2	<1
Piney Grove Cemetery-Swift Creek	<1	<1	4	2	4	3	<1	<1	2	1	4	3
White Oak Creek (Lower)	<1	<1	2	1	1	<1	<1	<1	2	1	1	<1
Little Creek (Lower)	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1
Weighted Average Increase	1	<1	7	2	2	<1	2	<1	5	1	2	<1

[1] *Model Run 1*

[2] *Model Run 2*

5.4 Results Tables

The water quality analysis results are compared in the series of tables in this section (Tables 21-32). Each table presents the results of a single experimental parameter for the 23 watersheds composing the water quality study area. The watersheds of concern for the dwarf wedgemussel are outlined in orange. The percent difference between the 2040 No-Build and 2040 Build scenario results are reported in the right-most column of the tables, with the heading “2040 Build – 2040 No-Build”. The values in this column quantify the potential water quality effect of the proposed project as measured by this analysis. Figures 9 through 14 graphically display the modeling results by watershed against the standard error (black bar) for each parameter. The change in value of each modeled parameter is displayed in purple (Model Run 1) or green (Model Run 2). The black standard error bar graphically represents the amount of change in the value of each modeled parameter that cannot be distinguished from a random occurrence. The graphics in Appendix A present the level of pollutants for each watershed through the thematic mapping. The differences between the 2010 and 2040 No-Build scenarios and the 2040 No-Build and 2040 Build scenarios are presented through labeling.

Table 21: Comparison of the Upper-Limit Annual Streamflow Results for 2010, 2040 No-Build, and 2040 Build Scenarios Under Model Run 1

Watershed ID	**Name**	**HUC**	**2010 Streamflow (cm/yr)[1]**	**2040 No-Build**			**2040 Build**			**2040 Build – 2040 No-Build**
				Streamflow (cm/yr)[1]	**Change[2]**	**% Change[3]**	**Streamflow (cm/yr)[1]**	**Change[2]**	**% Change[3]**	**% Change[4]**
1	White Oak Creek (Lower)	030202011003	25.42	28.51	3.09	12	28.67	3.25	13	<1
2	Avents Creek-Cape Fear River	030300040106	24.99	25.14	0.15	<1	25.14	0.15	<1	<1
3	Hector Creek-Cape Fear River	030300040502	24.24	24.57	0.33	1	24.58	0.34	1	<1
4	Camp Branch-Black Creek	030202011202	25.02	25.15	0.13	<1	25.14	0.12	<1	<1
5	Neills Creek	030300040501	26.55	29.20	2.65	10	29.20	2.65	10	<1
6	Little Black Creek-Black Creek	030202011201	25.47	27.21	1.74	7	27.36	1.89	7	<1
7	Buckhorn Creek	030300040103	25.56	28.20	2.64	10	28.29	2.73	11	<1
8	Lower Middle Creek	030202010903	25.41	26.13	0.72	3	26.28	0.87	3	<1
9	Reed Branch-Swift Creek	030202011007	26.33	27.74	1.41	5	27.81	1.48	6	<1
10	Piney Grove Cemetery-Swift Creek	030202011006	24.95	25.66	0.71	3	25.79	0.84	3	<1
11	Middle Middle Creek	030202010902	26.23	28.03	1.80	7	28.40	2.17	8	1
12	White Oak Creek (Cape Fear Basin)	030300040102	26.10	27.34	1.24	5	27.35	1.25	5	<1
13	Little Creek (Lower)	030202011005	25.09	26.88	1.79	7	26.90	1.81	7	<1
14	Upper Middle Creek	030202010901	27.27	30.15	2.88	11	30.23	2.96	11	<1
15	Mahlers Creek-Swift Creek	030202011004	26.15	28.86	2.71	10	29.58	3.43	13	2
16	Lake Benson-Swift Creek	030202011002	27.02	28.78	1.76	7	28.74	1.72	6	<1
17	Lake Wheeler-Swift Creek	030202011001	27.82	28.66	0.84	3	28.66	0.84	3	<1
18	Walnut Creek	030202011101	27.30	30.28	2.98	11	30.30	3.00	11	<1
19	Poplar Creek-Neuse River	030202011103	24.86	27.74	2.88	12	28.13	3.27	13	1
20	Marks Creek	030202011102	24.30	27.12	2.82	12	27.23	2.93	12	<1
21	Lower Crabtree Creek	030202010804	32.11	32.64	0.53	2	32.64	0.53	2	<1
22	White Oak Creek (Upper)	030202011003	27.49	31.18	3.69	13	31.53	4.04	15	1
23	Little Creek (Upper)	030202011005	28.73	31.03	2.30	8	31.14	2.41	8	<1

[1] *Centimeters of streamflow generated over the catchment area per year*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Table 22: Comparison of Lower-Limit Annual Streamflow Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 2

Watershed ID	Name	HUC	2010 Streamflow (cm/yr)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				Streamflow (cm/yr)[1]	Change[2]	% Change[3]	Streamflow (cm/yr)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	28.18	28.13	-0.05	<1	28.18	0.00	<1	<1
2	Avents Creek-Cape Fear River	030300040106	27.06	27.07	0.01	<1	27.06	0.00	<1	<1
3	Hector Creek-Cape Fear River	030300040502	26.29	26.29	0.00	<1	26.29	0.00	<1	<1
4	Camp Branch-Black Creek	030202011202	27.07	27.07	0.00	<1	27.07	0.00	<1	<1
5	Neills Creek	030300040501	28.25	28.25	0.00	<1	28.25	0.00	<1	<1
6	Little Black Creek-Black Creek	030202011201	27.58	27.51	-0.07	<1	27.58	0.00	<1	<1
7	Buckhorn Creek	030300040103	27.82	27.81	-0.01	<1	27.82	0.00	<1	<1
8	Lower Middle Creek	030202010903	27.40	27.38	-0.02	<1	27.40	0.00	<1	<1
9	Reed Branch-Swift Creek	030202011007	27.80	27.79	-0.01	<1	27.80	0.00	<1	<1
10	Piney Grove Cemetery-Swift Creek	030202011006	27.12	27.06	-0.06	<1	27.12	0.00	<1	<1
11	Middle Middle Creek	030202010902	27.90	27.84	-0.06	<1	27.90	0.00	<1	<1
12	White Oak Creek (Cape Fear Basin)	030300040102	27.32	27.32	0.00	<1	27.32	0.00	<1	<1
13	Little Creek (Lower)	030202011005	27.41	27.41	0.00	<1	27.41	0.00	<1	<1
14	Upper Middle Creek	030202010901	28.64	28.62	-0.02	<1	28.64	0.00	<1	<1
15	Mahlers Creek-Swift Creek	030202011004	28.52	28.46	-0.06	<1	28.52	0.00	<1	<1
16	Lake Benson-Swift Creek	030202011002	28.45	28.46	0.01	<1	28.45	0.00	<1	<1
17	Lake Wheeler-Swift Creek	030202011001	28.52	28.52	0.00	<1	28.52	0.00	<1	<1
18	Walnut Creek	030202011101	28.65	28.65	0.00	<1	28.65	0.00	<1	<1
19	Poplar Creek-Neuse River	030202011103	27.68	27.67	-0.01	<1	27.68	0.00	<1	<1
20	Marks Creek	030202011102	27.29	27.27	-0.02	<1	27.29	0.00	<1	<1
21	Lower Crabtree Creek	030202010804	29.95	29.94	-0.01	<1	29.95	0.00	<1	<1
22	White Oak Creek (Upper)	030202011003	29.36	29.30	-0.06	<1	29.36	0.00	<1	<1
23	Little Creek (Upper)	030202011005	29.15	29.13	-0.02	<1	29.15	0.00	<1	<1

[1] *Centimeters of streamflow generated over the catchment area per year*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Figure 9: Change in Streamflow from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2

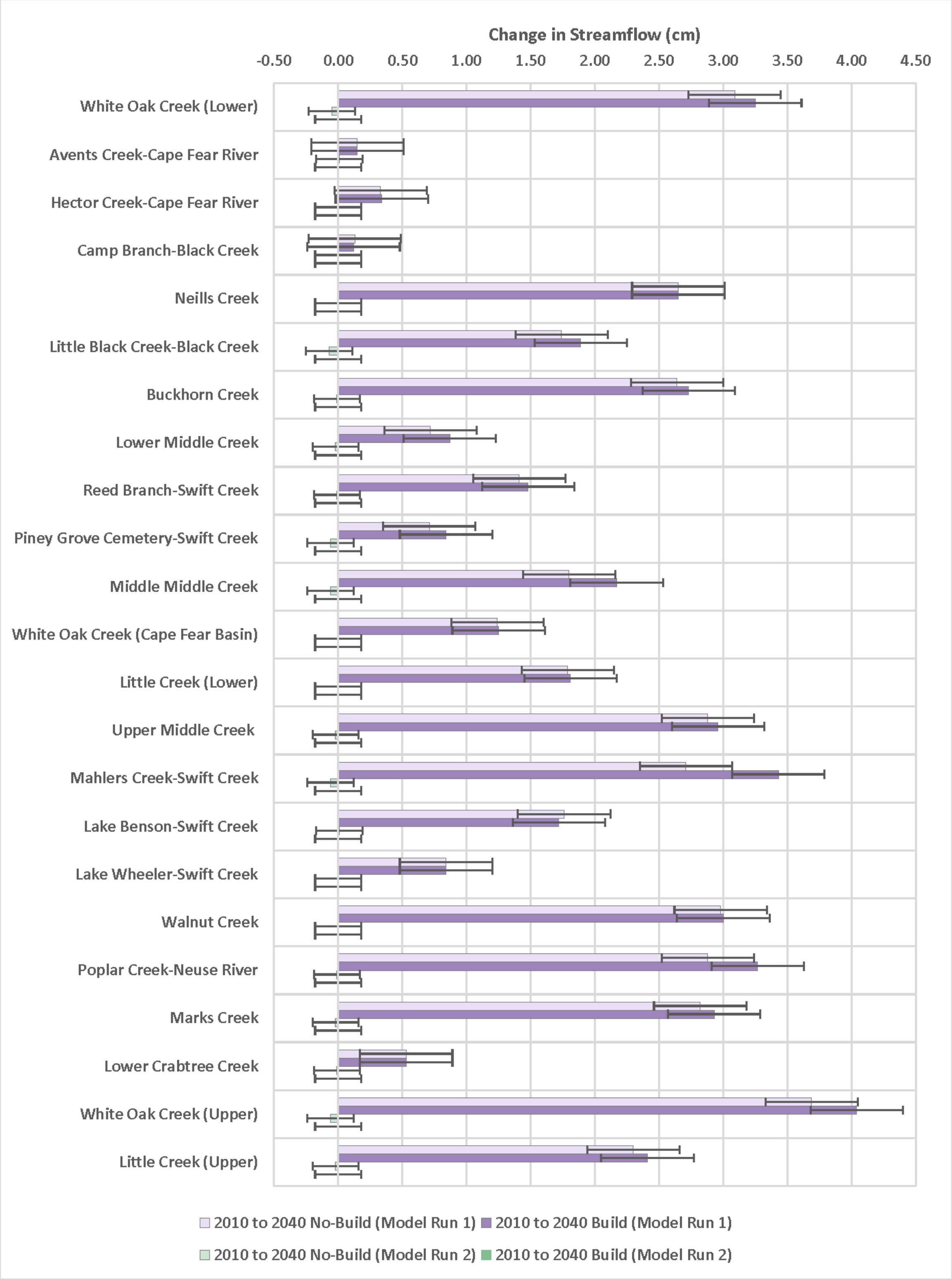


Table 23: Comparison of Upper-Limit Annual Runoff Results of the 2010, 2040 No-Build, and 2040 Build Scenarios Under Model Run 1

Watershed ID	Name	HUC	2010 Runoff (cm/yr)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				Runoff (cm/yr)[1]	Change[2]	% Change[3]	Runoff (cm/yr)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	5.99	10.69	4.70	78	10.91	4.92	82	2
2	Avents Creek-Cape Fear River	030300040106	5.36	5.58	0.22	4	5.58	0.22	4	<1
3	Hector Creek-Cape Fear River	030300040502	4.14	4.70	0.56	14	4.71	0.57	14	<1
4	Camp Branch-Black Creek	030202011202	5.42	5.62	0.20	4	5.58	0.16	3	<1
5	Neills Creek	030300040501	7.77	11.71	3.94	51	11.72	3.95	51	<1
6	Little Black Creek-Black Creek	030202011201	6.10	8.73	2.63	43	8.97	2.87	47	3
7	Buckhorn Creek	030300040103	6.23	10.21	3.98	64	10.33	4.10	66	1
8	Lower Middle Creek	030202010903	6.01	7.10	1.09	18	7.32	1.31	22	3
9	Reed Branch-Swift Creek	030202011007	7.42	9.54	2.12	29	9.68	2.26	30	1
10	Piney Grove Cemetery-Swift Creek	030202011006	5.28	6.33	1.05	20	6.57	1.29	24	4
11	Middle Middle Creek	030202010902	7.27	9.93	2.66	37	10.47	3.20	44	5
12	White Oak Creek (Cape Fear Basin)	030300040102	7.03	8.93	1.90	27	8.97	1.94	28	<1
13	Little Creek (Lower)	030202011005	5.51	8.24	2.73	50	8.25	2.74	50	<1
14	Upper Middle Creek	030202010901	8.80	13.09	4.29	49	13.21	4.41	50	<1
15	Mahlers Creek-Swift Creek	030202011004	7.11	11.14	4.03	57	12.26	5.15	72	10
16	Lake Benson-Swift Creek	030202011002	8.41	11.02	2.61	31	10.99	2.58	31	<1
17	Lake Wheeler-Swift Creek	030202011001	9.62	10.84	1.22	13	10.84	1.22	13	<1
18	Walnut Creek	030202011101	8.86	13.32	4.46	50	13.34	4.48	51	<1
19	Poplar Creek-Neuse River	030202011103	5.13	9.49	4.36	85	10.08	4.95	96	6
20	Marks Creek	030202011102	4.27	8.57	4.30	101	8.71	4.44	104	2
21	Lower Crabtree Creek	030202010804	16.12	16.88	0.76	5	16.89	0.77	5	<1
22	White Oak Creek (Upper)	030202011003	9.15	14.61	5.46	60	15.15	6.00	66	4
23	Little Creek (Upper)	030202011005	11.02	14.47	3.45	31	14.61	3.59	33	<1

[1] *Centimeters of runoff generated over the catchment area per year*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Table 24: Comparison of Lower-Limit Annual Runoff Results of the 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 2

Watershed ID	Name	HUC	2010 Runoff (cm/yr)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				Runoff (cm/yr)[1]	Change[2]	% Change[3]	Runoff (cm/yr)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	4.74	6.71	1.97	42	6.81	2.07	44	1
2	Avents Creek-Cape Fear River	030300040106	5.01	5.06	0.05	<1	5.06	0.05	<1	<1
3	Hector Creek-Cape Fear River	030300040502	3.49	3.75	0.26	7	3.74	0.25	7	<1
4	Camp Branch-Black Creek	030202011202	4.96	5.05	0.09	2	5.05	0.09	2	<1
5	Neills Creek	030300040501	5.54	6.90	1.36	25	6.90	1.36	25	<1
6	Little Black Creek-Black Creek	030202011201	5.02	5.79	0.77	15	5.85	0.83	17	1
7	Buckhorn Creek	030300040103	4.56	6.18	1.62	36	6.21	1.65	36	<1
8	Lower Middle Creek	030202010903	5.14	5.54	0.40	8	5.60	0.46	9	1
9	Reed Branch-Swift Creek	030202011007	5.62	6.27	0.65	12	6.27	0.65	12	<1
10	Piney Grove Cemetery-Swift Creek	030202011006	4.63	5.02	0.39	8	5.13	0.50	11	2
11	Middle Middle Creek	030202010902	5.32	6.28	0.96	18	6.37	1.05	20	1
12	White Oak Creek (Cape Fear Basin)	030300040102	4.45	5.40	0.95	21	5.43	0.98	22	<1
13	Little Creek (Lower)	030202011005	4.62	5.58	0.96	21	5.59	0.97	21	<1
14	Upper Middle Creek	030202010901	5.82	7.48	1.66	29	7.53	1.71	29	<1
15	Mahlers Creek-Swift Creek	030202011004	5.27	7.20	1.93	37	7.34	2.07	39	2
16	Lake Benson-Swift Creek	030202011002	5.71	7.25	1.54	27	7.23	1.52	27	<1
17	Lake Wheeler-Swift Creek	030202011001	6.56	7.35	0.79	12	7.36	0.80	12	<1
18	Walnut Creek	030202011101	5.52	7.56	2.04	37	7.56	2.04	37	<1
19	Poplar Creek-Neuse River	030202011103	3.82	5.96	2.14	56	5.98	2.16	57	<1
20	Marks Creek	030202011102	3.38	5.32	1.94	57	5.39	2.01	59	1
21	Lower Crabtree Creek	030202010804	9.12	9.64	0.52	6	9.65	0.53	6	<1
22	White Oak Creek (Upper)	030202011003	5.83	8.59	2.76	47	8.65	2.82	48	<1
23	Little Creek (Upper)	030202011005	7.00	8.35	1.35	19	8.39	1.39	20	<1

[1] *Centimeters of runoff generated over the catchment area per year*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Figure 10: Change in Runoff from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2

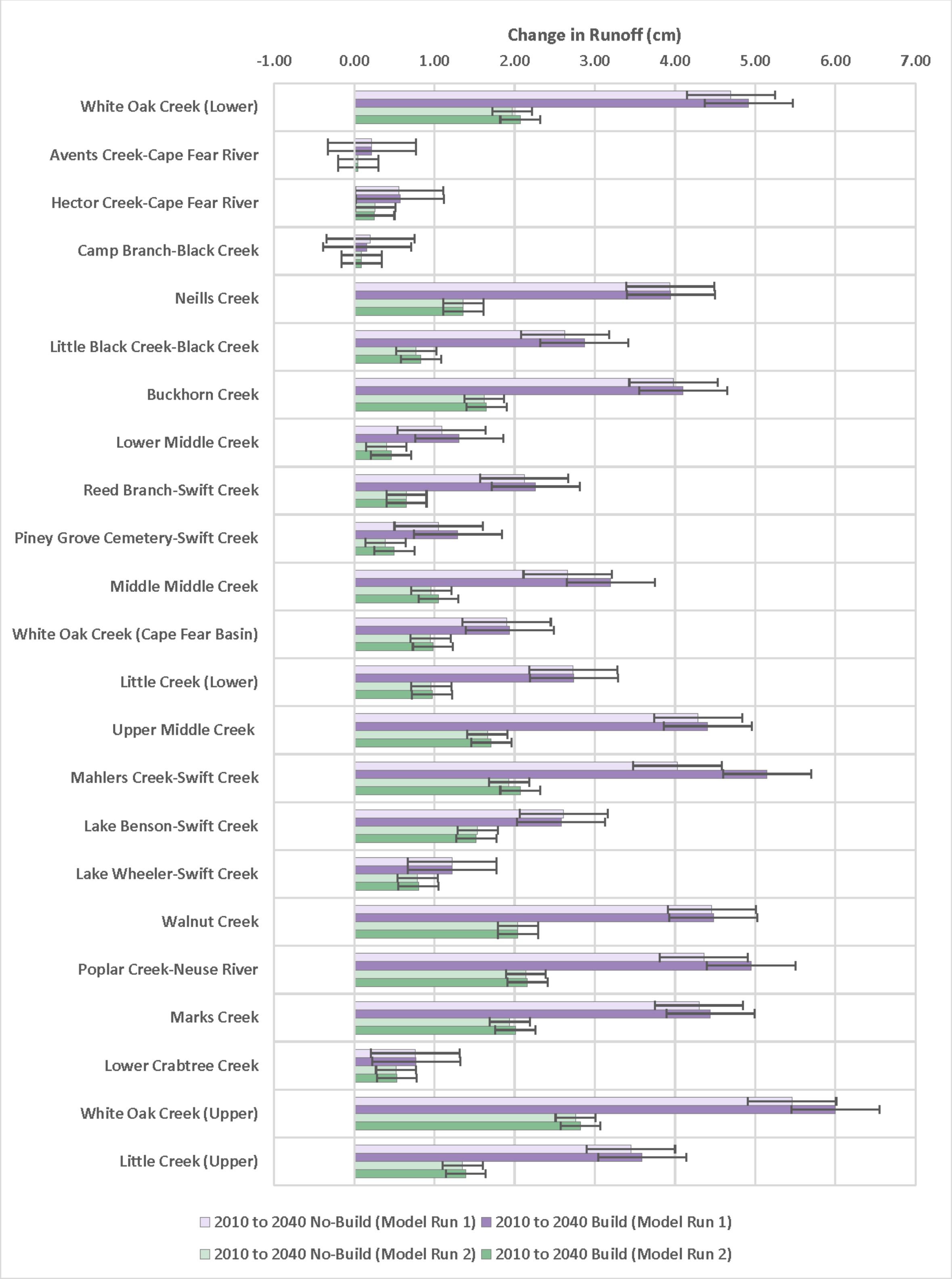


Table 25: Comparison of Upper Limit Annual Total Suspended Sediment (TSS) Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 1

Watershed ID	Name	HUC	2010 TSS (MT/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				TSS (MT/yr/ac)[1]	Change[2]	% Change[3]	TSS (MT/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	0.08	0.11	0.03	38	0.11	0.03	40	1
2	Avents Creek-Cape Fear River	030300040106	0.15	0.15	0.00	1	0.15	0.00	1	<1
3	Hector Creek-Cape Fear River	030300040502	0.11	0.13	0.02	20	0.13	0.02	18	<1
4	Camp Branch-Black Creek	030202011202	0.16	0.16	0.00	2	0.16	0.00	2	<1
5	Neills Creek	030300040501	0.34	0.57	0.23	67	0.57	0.23	67	<1
6	Little Black Creek-Black Creek	030202011201	0.27	0.43	0.17	62	0.45	0.18	68	3
7	Buckhorn Creek	030300040103	0.19	0.34	0.15	77	0.35	0.15	79	1
8	Lower Middle Creek	030202010903	0.33	0.43	0.10	30	0.44	0.11	34	3
9	Reed Branch-Swift Creek	030202011007	0.17	0.23	0.06	38	0.24	0.07	41	2
10	Piney Grove Cemetery-Swift Creek	030202011006	0.20	0.24	0.04	20	0.24	0.05	24	4
11	Middle Middle Creek	030202010902	0.32	0.49	0.17	55	0.51	0.19	60	3
12	White Oak Creek (Cape Fear Basin)	030300040102	0.16	0.26	0.09	56	0.26	0.09	57	<1
13	Little Creek (Lower)	030202011005	0.11	0.14	0.03	27	0.14	0.03	28	<1
14	Upper Middle Creek	030202010901	0.54	0.88	0.34	63	0.88	0.34	63	<1
15	Mahlers Creek-Swift Creek	030202011004	0.26	0.50	0.24	94	0.51	0.25	97	2
16	Lake Benson-Swift Creek	030202011002	0.36	0.54	0.18	50	0.54	0.18	49	<1
17	Lake Wheeler-Swift Creek	030202011001	0.41	0.49	0.08	20	0.49	0.08	20	<1
18	Walnut Creek	030202011101	0.21	0.38	0.17	79	0.38	0.17	79	<1
19	Poplar Creek-Neuse River	030202011103	0.24	0.54	0.30	123	0.54	0.30	124	<1
20	Marks Creek	030202011102	0.07	0.16	0.10	144	0.17	0.10	150	2
21	Lower Crabtree Creek	030202010804	0.09	0.10	0.01	8	0.10	0.01	8	<1
22	White Oak Creek (Upper)	030202011003	0.19	0.36	0.17	86	0.36	0.17	88	1
23	Little Creek (Upper)	030202011005	0.22	0.29	0.07	32	0.29	0.07	33	<1

[1] *Metric tons per year per acre*
[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*
[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*
[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Table 26: Comparison of Lower Limit Annual Total Suspended Sediment (TSS) Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 2

Watershed ID	Name	HUC	2010 TSS (MT/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				TSS (MT/yr/ac)[1]	Change[2]	% Change[3]	TSS (MT/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	0.08	0.10	0.02	26	0.10	0.02	27	<1
2	Avents Creek-Cape Fear River	030300040106	0.15	0.15	0.00	<1	0.15	0.00	<1	<1
3	Hector Creek-Cape Fear River	030300040502	0.12	0.14	0.02	19	0.14	0.02	18	<1
4	Camp Branch-Black Creek	030202011202	0.16	0.16	0.00	2	0.16	0.00	2	<1
5	Neills Creek	030300040501	0.34	0.55	0.21	61	0.55	0.21	60	<1
6	Little Black Creek-Black Creek	030202011201	0.27	0.43	0.16	58	0.44	0.17	62	3
7	Buckhorn Creek	030300040103	0.19	0.33	0.14	71	0.33	0.14	72	<1
8	Lower Middle Creek	030202010903	0.34	0.44	0.10	29	0.45	0.11	32	3
9	Reed Branch-Swift Creek	030202011007	0.17	0.23	0.06	34	0.23	0.06	37	2
10	Piney Grove Cemetery-Swift Creek	030202011006	0.20	0.24	0.04	18	0.25	0.04	22	3
11	Middle Middle Creek	030202010902	0.32	0.48	0.16	51	0.49	0.17	55	3
12	White Oak Creek (Cape Fear Basin)	030300040102	0.16	0.25	0.09	54	0.25	0.09	55	<1
13	Little Creek (Lower)	030202011005	0.11	0.13	0.02	21	0.13	0.02	21	<1
14	Upper Middle Creek	030202010901	0.54	0.84	0.31	57	0.85	0.31	57	<1
15	Mahlers Creek-Swift Creek	030202011004	0.26	0.49	0.23	88	0.48	0.23	87	<1
16	Lake Benson-Swift Creek	030202011002	0.36	0.53	0.17	47	0.53	0.17	47	<1
17	Lake Wheeler-Swift Creek	030202011001	0.41	0.49	0.08	19	0.49	0.08	19	<1
18	Walnut Creek	030202011101	0.20	0.35	0.15	72	0.35	0.15	72	<1
19	Poplar Creek-Neuse River	030202011103	0.25	0.53	0.28	115	0.52	0.28	113	<1
20	Marks Creek	030202011102	0.07	0.15	0.09	132	0.16	0.09	137	2
21	Lower Crabtree Creek	030202010804	0.08	0.09	0.01	8	0.09	0.01	8	<1
22	White Oak Creek (Upper)	030202011003	0.19	0.34	0.15	78	0.34	0.15	79	<1
23	Little Creek (Upper)	030202011005	0.21	0.27	0.06	28	0.27	0.06	28	<1

[1] *Metric tons per year per acre*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Figure 11: Change in TSS from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2

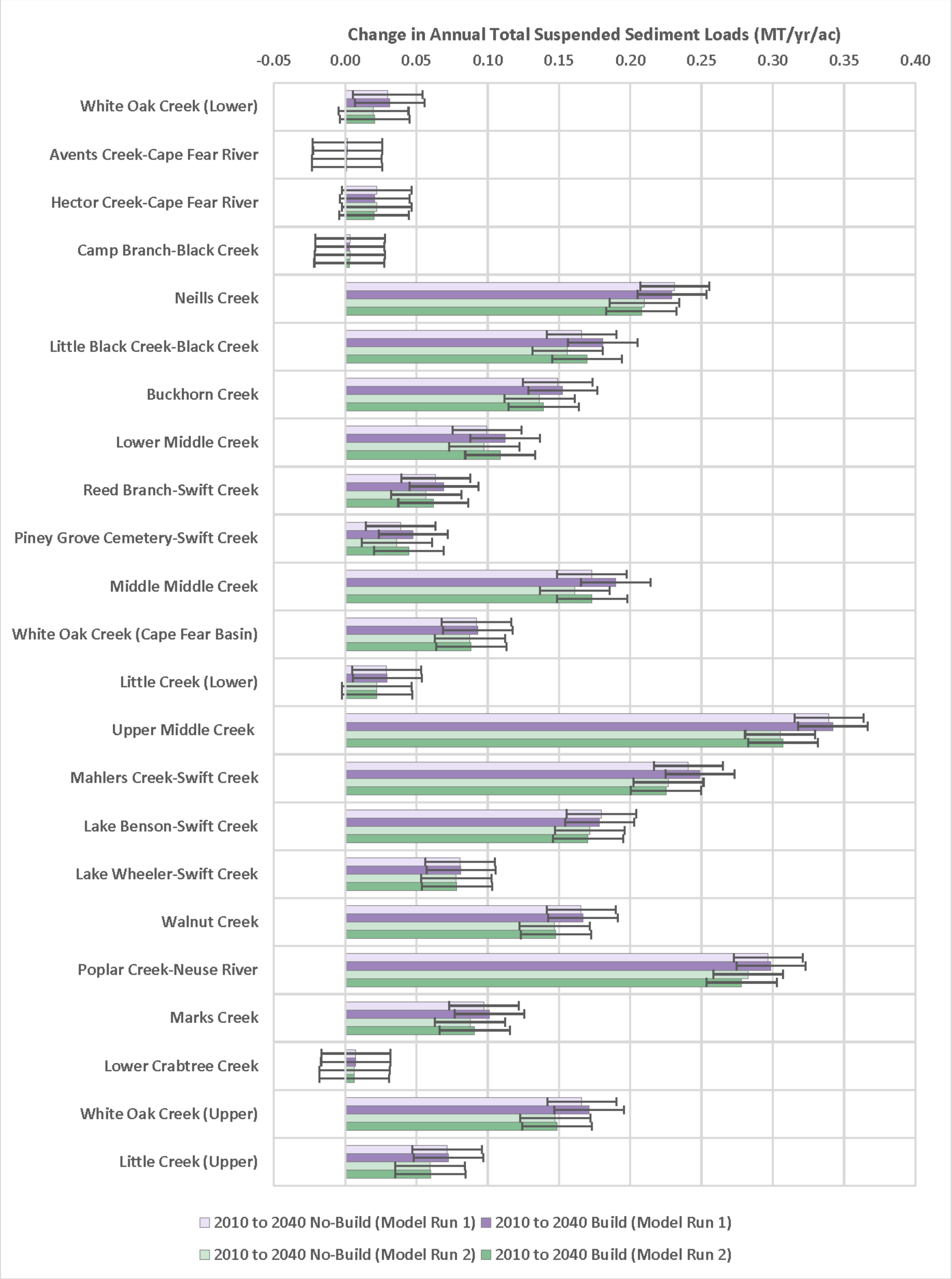


Table 27: Comparison of Upper Limit Annual Total Nitrogen (TN) Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 1

Watershed ID	Name	HUC	2010 TN (kg/yr/ac) [1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				TN (kg/yr/ac)[1]	Change[2]	% Change[3]	TN (kg/yr/ac) [1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	1.61	1.72	0.11	7	1.72	0.11	7	<1
2	Avents Creek-Cape Fear River	030300040106	2.27	2.28	0.01	<1	2.28	0.01	<1	<1
3	Hector Creek-Cape Fear River	030300040502	1.31	1.31	0.00	<1	1.32	0.01	<1	<1
4	Camp Branch-Black Creek	030202011202	2.37	2.37	0.00	<1	2.37	0.00	<1	<1
5	Neills Creek	030300040501	1.85	1.95	0.10	6	1.95	0.10	6	<1
6	Little Black Creek-Black Creek	030202011201	1.91	1.97	0.06	3	1.97	0.06	3	<1
7	Buckhorn Creek	030300040103	1.56	1.65	0.09	6	1.65	0.08	5	<1
8	Lower Middle Creek	030202010903	1.87	1.94	0.07	4	1.95	0.08	4	<1
9	Reed Branch-Swift Creek	030202011007	1.55	1.64	0.09	6	1.65	0.10	6	<1
10	Piney Grove Cemetery-Swift Creek	030202011006	1.87	1.91	0.04	2	1.92	0.04	2	<1
11	Middle Middle Creek	030202010902	1.62	1.71	0.10	6	1.74	0.13	8	2
12	White Oak Creek (Cape Fear Basin)	030300040102	1.35	1.46	0.11	8	1.46	0.12	9	<1
13	Little Creek (Lower)	030202011005	1.78	1.81	0.03	2	1.82	0.03	2	<1
14	Upper Middle Creek	030202010901	2.41	2.64	0.23	10	2.65	0.23	10	<1
15	Mahlers Creek-Swift Creek	030202011004	1.43	1.63	0.20	14	1.68	0.25	18	3
16	Lake Benson-Swift Creek	030202011002	1.48	1.61	0.13	9	1.61	0.13	8	<1
17	Lake Wheeler-Swift Creek	030202011001	1.94	2.00	0.05	3	2.00	0.05	3	<1
18	Walnut Creek	030202011101	1.02	1.26	0.24	23	1.26	0.24	23	<1
19	Poplar Creek-Neuse River	030202011103	9.15	9.42	0.27	3	9.45	0.30	3	<1
20	Marks Creek	030202011102	0.86	1.05	0.19	21	1.06	0.19	22	<1
21	Lower Crabtree Creek	030202010804	1.14	1.15	0.01	1	1.15	0.01	1	<1
22	White Oak Creek (Upper)	030202011003	1.33	1.54	0.20	15	1.56	0.23	17	2
23	Little Creek (Upper)	030202011005	2.86	2.91	0.05	2	2.91	0.05	2	<1

[1] *Kilograms per year per acre*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Table 28: Comparison of Lower Limit Annual Total Nitrogen (TN) Results for 2010 Condition, 2040 No-Build, and 2040 Build Scenarios under Model Run 2

Watershed ID	Name	HUC	2010 TN (kg/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				TN (kg/yr/ac)[1]	Change[2]	% Change[3]	TN (kg/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	1.63	1.61	-0.02	<1	1.61	-0.02	<1	<1
2	Avents Creek-Cape Fear River	030300040106	2.40	2.40	0.00	<1	2.40	0.00	<1	<1
3	Hector Creek-Cape Fear River	030300040502	1.36	1.35	-0.01	<1	1.36	0.00	<1	<1
4	Camp Branch-Black Creek	030202011202	2.47	2.47	0.00	<1	2.47	0.00	<1	<1
5	Neills Creek	030300040501	1.88	1.88	0.00	<1	1.88	0.00	<1	<1
6	Little Black Creek-Black Creek	030202011201	1.99	1.96	-0.02	<1	1.96	-0.03	<1	<1
7	Buckhorn Creek	030300040103	1.59	1.58	-0.01	<1	1.57	-0.02	<1	<1
8	Lower Middle Creek	030202010903	1.92	1.96	0.04	2	1.97	0.04	2	<1
9	Reed Branch-Swift Creek	030202011007	1.56	1.59	0.03	2	1.59	0.03	2	<1
10	Piney Grove Cemetery-Swift Creek	030202011006	1.93	1.93	0.00	<1	1.93	0.00	<1	<1
11	Middle Middle Creek	030202010902	1.61	1.63	0.02	1	1.64	0.02	2	<1
12	White Oak Creek (Cape Fear Basin)	030300040102	1.27	1.34	0.07	5	1.34	0.07	5	<1
13	Little Creek (Lower)	030202011005	1.83	1.78	-0.05	<1	1.79	-0.05	<1	<1
14	Upper Middle Creek	030202010901	2.36	2.48	0.11	5	2.48	0.12	5	<1
15	Mahlers Creek-Swift Creek	030202011004	1.41	1.51	0.10	7	1.52	0.10	7	<1
16	Lake Benson-Swift Creek	030202011002	1.43	1.51	0.08	6	1.51	0.08	6	<1
17	Lake Wheeler-Swift Creek	030202011001	1.88	1.92	0.04	2	1.92	0.04	2	<1
18	Walnut Creek	030202011101	0.91	1.02	0.11	12	1.02	0.11	13	<1
19	Poplar Creek-Neuse River	030202011103	9.14	9.29	0.15	2	9.29	0.15	2	<1
20	Marks Creek	030202011102	0.87	0.92	0.05	6	0.92	0.05	6	<1
21	Lower Crabtree Creek	030202010804	0.96	0.97	0.01	<1	0.97	0.01	<1	<1
22	White Oak Creek (Upper)	030202011003	1.25	1.34	0.08	7	1.34	0.09	7	<1
23	Little Creek (Upper)	030202011005	2.83	2.81	-0.02	<1	2.81	-0.02	<1	<1

[1] *Kilograms per year per acre*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Figure 12: Change in TN from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2

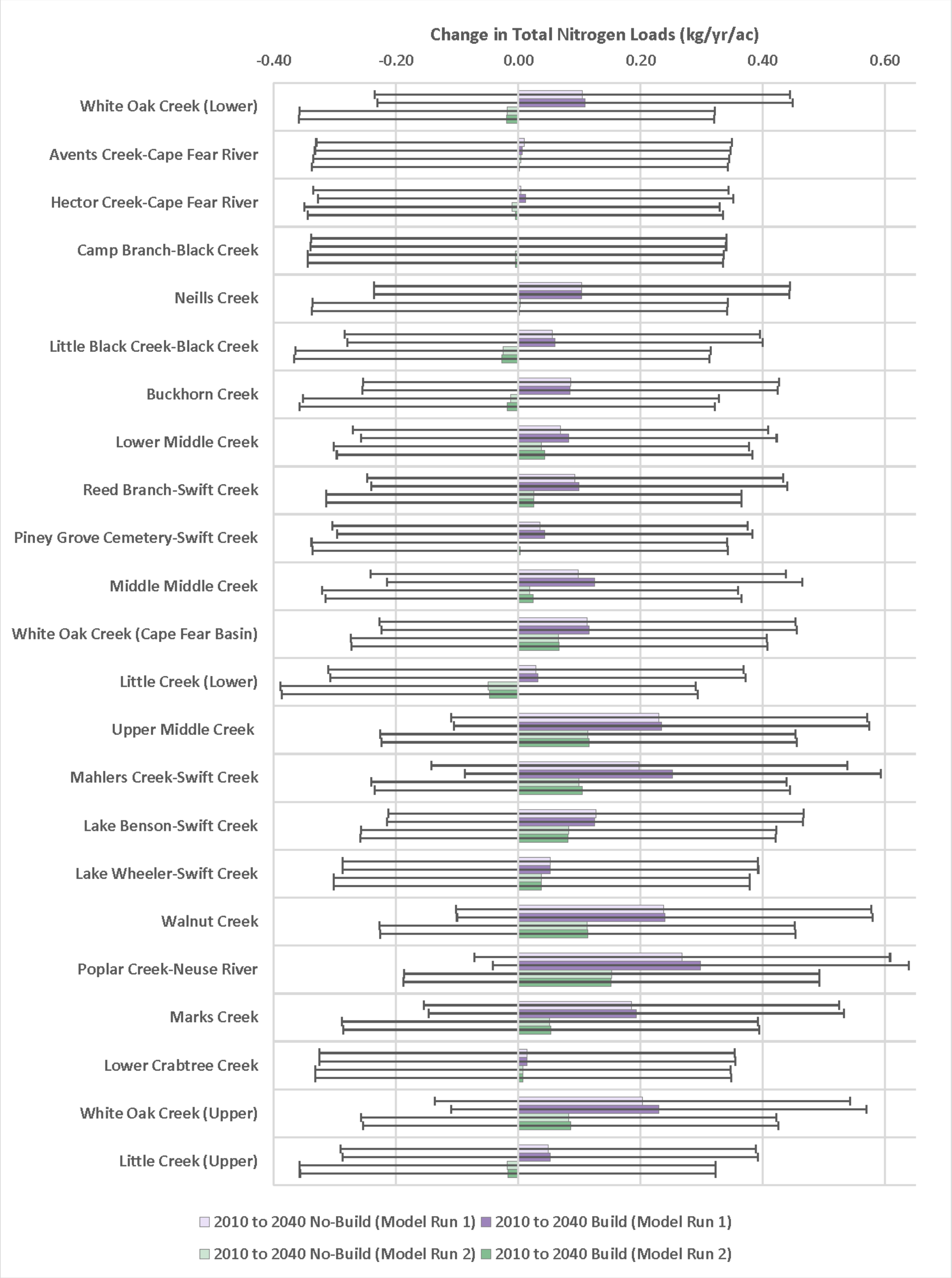


Table 29: Comparison of Upper Limit Annual Total Phosphorus (TP) Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 1

Watershed ID	Name	HUC	2010 TP (kg/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				TP (kg/yr/ac)[1]	Change[2]	% Change[3]	TP (kg/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	0.06	0.07	0.01	25	0.07	0.02	27	2
2	Avents Creek-Cape Fear River	030300040106	0.14	0.14	0.00	<1	0.14	0.00	<1	<1
3	Hector Creek-Cape Fear River	030300040502	0.06	0.06	0.00	2	0.06	0.00	4	2
4	Camp Branch-Black Creek	030202011202	0.10	0.10	0.00	<1	0.10	0.00	<1	<1
5	Neills Creek	030300040501	0.13	0.16	0.03	24	0.16	0.03	23	<1
6	Little Black Creek-Black Creek	030202011201	0.13	0.15	0.02	14	0.15	0.02	15	1
7	Buckhorn Creek	030300040103	0.09	0.12	0.02	23	0.12	0.02	23	<1
8	Lower Middle Creek	030202010903	0.10	0.12	0.02	16	0.12	0.02	19	2
9	Reed Branch-Swift Creek	030202011007	0.09	0.10	0.02	20	0.10	0.02	21	1
10	Piney Grove Cemetery-Swift Creek	030202011006	0.08	0.09	0.01	9	0.09	0.01	11	2
11	Middle Middle Creek	030202010902	0.10	0.13	0.02	23	0.13	0.03	28	4
12	White Oak Creek (Cape Fear Basin)	030300040102	0.12	0.14	0.02	17	0.14	0.02	17	<1
13	Little Creek (Lower)	030202011005	0.07	0.07	0.00	5	0.07	0.00	7	1
14	Upper Middle Creek	030202010901	0.13	0.18	0.05	42	0.18	0.05	43	<1
15	Mahlers Creek-Swift Creek	030202011004	0.08	0.12	0.04	54	0.13	0.05	65	7
16	Lake Benson-Swift Creek	030202011002	0.09	0.12	0.03	30	0.12	0.03	30	<1
17	Lake Wheeler-Swift Creek	030202011001	0.09	0.10	0.01	13	0.10	0.01	13	<1
18	Walnut Creek	030202011101	0.07	0.11	0.04	58	0.11	0.04	59	<1
19	Poplar Creek-Neuse River	030202011103	0.07	0.12	0.05	81	0.13	0.06	88	4
20	Marks Creek	030202011102	0.04	0.07	0.03	69	0.07	0.03	73	2
21	Lower Crabtree Creek	030202010804	0.06	0.07	0.00	3	0.07	0.00	4	<1
22	White Oak Creek (Upper)	030202011003	0.08	0.11	0.04	48	0.12	0.04	54	4
23	Little Creek (Upper)	030202011005	0.10	0.11	0.01	12	0.11	0.01	13	<1

[1] *Kilograms per year per acre*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Table 30: Comparison of Lower Limit Annual Total Phosphorus (TP) Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 2

Watershed ID	Name	HUC	2010 TP (kg/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				TP (kg/yr/ac)[1]	Change[2]	% Change[3]	TP (kg/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	0.05	0.05	0.00	<1	0.05	0.00	<1	1
2	Avents Creek-Cape Fear River	030300040106	0.14	0.14	0.00	<1	0.14	0.00	<1	<1
3	Hector Creek-Cape Fear River	030300040502	0.06	0.06	0.00	<1	0.06	0.00	<1	2
4	Camp Branch-Black Creek	030202011202	0.10	0.10	0.00	<1	0.10	0.00	<1	<1
5	Neills Creek	030300040501	0.12	0.14	0.02	13	0.14	0.02	12	<1
6	Little Black Creek-Black Creek	030202011201	0.12	0.13	0.01	5	0.13	0.01	5	<1
7	Buckhorn Creek	030300040103	0.09	0.10	0.01	9	0.09	0.01	8	<1
8	Lower Middle Creek	030202010903	0.10	0.11	0.01	13	0.12	0.01	14	2
9	Reed Branch-Swift Creek	030202011007	0.08	0.09	0.01	11	0.09	0.01	11	<1
10	Piney Grove Cemetery-Swift Creek	030202011006	0.08	0.08	0.00	4	0.08	0.00	5	1
11	Middle Middle Creek	030202010902	0.09	0.11	0.01	14	0.11	0.02	17	2
12	White Oak Creek (Cape Fear Basin)	030300040102	0.11	0.12	0.01	14	0.12	0.01	14	<1
13	Little Creek (Lower)	030202011005	0.06	0.06	-0.01	<1	0.06	-0.01	<1	<1
14	Upper Middle Creek	030202010901	0.11	0.15	0.04	32	0.15	0.04	33	<1
15	Mahlers Creek-Swift Creek	030202011004	0.07	0.10	0.03	42	0.10	0.03	44	2
16	Lake Benson-Swift Creek	030202011002	0.08	0.10	0.02	28	0.10	0.02	27	<1
17	Lake Wheeler-Swift Creek	030202011001	0.08	0.09	0.01	12	0.09	0.01	13	<1
18	Walnut Creek	030202011101	0.05	0.08	0.03	48	0.08	0.03	48	<1
19	Poplar Creek-Neuse River	030202011103	0.06	0.10	0.04	66	0.10	0.04	66	<1
20	Marks Creek	030202011102	0.04	0.05	0.01	36	0.05	0.01	38	2
21	Lower Crabtree Creek	030202010804	0.04	0.04	0.00	4	0.04	0.00	4	<1
22	White Oak Creek (Upper)	030202011003	0.06	0.08	0.02	35	0.08	0.02	37	1
23	Little Creek (Upper)	030202011005	0.08	0.08	0.00	2	0.08	0.00	3	<1

[1] *Kilograms per year per acre*
[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*
[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*
[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Figure 13: Change in TP from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2

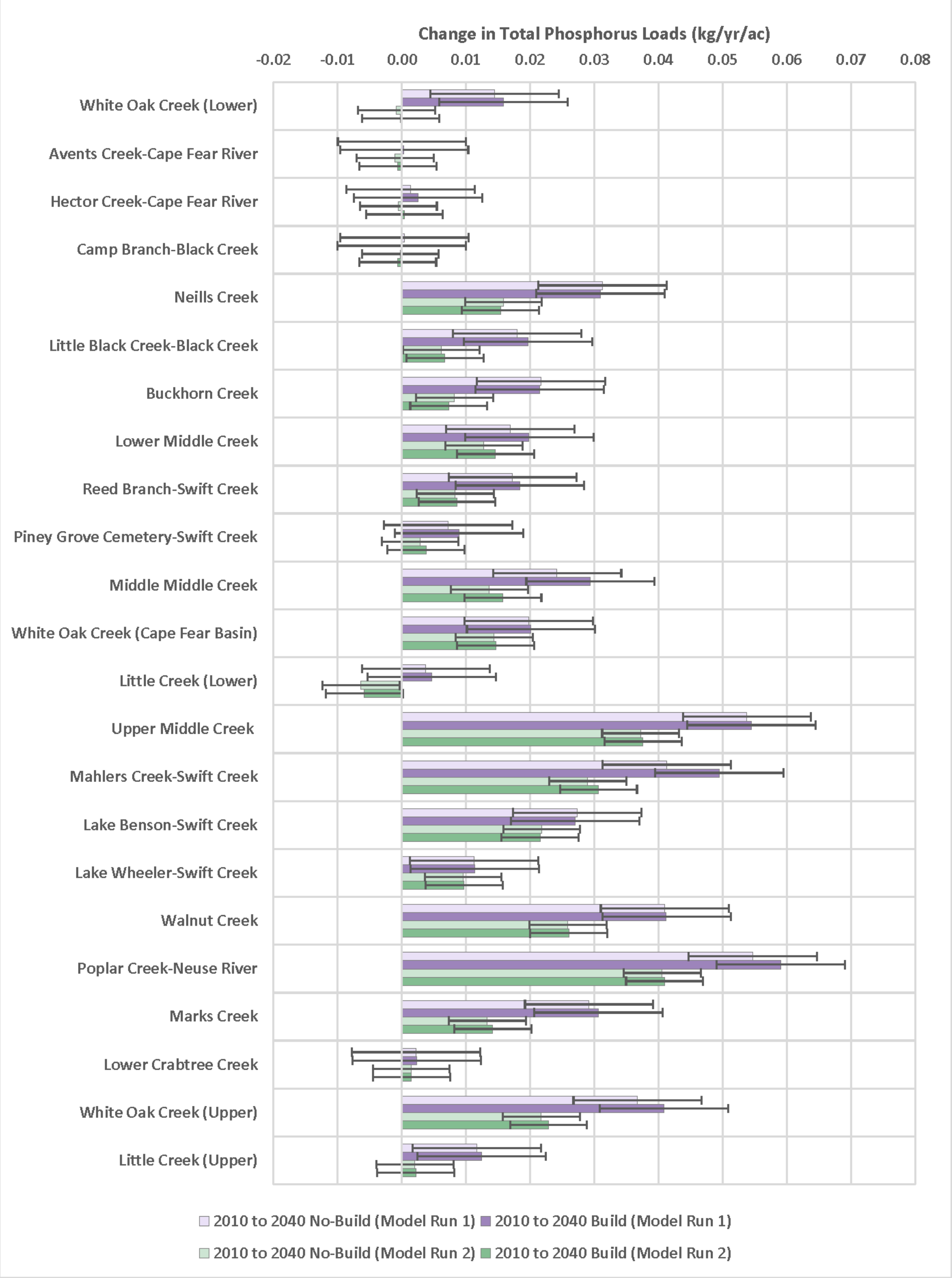


Table 31: Comparison of Upper Limit Annual Copper (Cu) Results for 2010 Condition, 2040 No-Build, and 2040 Build Scenarios under Model Run 1

Watershed ID	Name	HUC	2010 Cu (g/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				Cu (g/yr/ac)[1]	Change[2]	% Change[3]	Cu (g/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	0.70	0.96	0.27	38	0.97	0.28	40	1
2	Avents Creek-Cape Fear River	030300040106	1.09	1.10	0.01	1	1.11	0.01	1	<1
3	Hector Creek-Cape Fear River	030300040502	0.82	0.98	0.16	20	0.97	0.15	18	<1
4	Camp Branch-Black Creek	030202011202	1.09	1.12	0.02	2	1.11	0.02	2	<1
5	Neills Creek	030300040501	3.05	5.10	2.05	67	5.08	2.03	67	<1
6	Little Black Creek-Black Creek	030202011201	2.36	3.84	1.47	62	3.97	1.60	68	3
7	Buckhorn Creek	030300040103	1.71	3.03	1.32	77	3.06	1.35	79	1
8	Lower Middle Creek	030202010903	2.26	2.95	0.69	30	3.04	0.78	34	3
9	Reed Branch-Swift Creek	030202011007	1.17	1.61	0.44	38	1.65	0.48	41	2
10	Piney Grove Cemetery-Swift Creek	030202011006	1.36	1.63	0.27	20	1.69	0.33	24	4
11	Middle Middle Creek	030202010902	2.80	4.34	1.54	55	4.49	1.68	60	3
12	White Oak Creek (Cape Fear Basin)	030300040102	1.45	2.26	0.82	56	2.27	0.83	57	<1
13	Little Creek (Lower)	030202011005	0.74	0.94	0.20	27	0.94	0.20	28	<1
14	Upper Middle Creek	030202010901	4.79	7.81	3.01	63	7.83	3.04	63	<1
15	Mahlers Creek-Swift Creek	030202011004	2.27	4.41	2.14	94	4.48	2.21	97	2
16	Lake Benson-Swift Creek	030202011002	3.22	4.81	1.59	50	4.80	1.58	49	<1
17	Lake Wheeler-Swift Creek	030202011001	3.66	4.37	0.72	20	4.38	0.72	20	<1
18	Walnut Creek	030202011101	1.87	3.34	1.47	79	3.35	1.48	79	<1
19	Poplar Creek-Neuse River	030202011103	2.14	4.77	2.63	123	4.79	2.65	124	<1
20	Marks Creek	030202011102	0.60	1.46	0.86	144	1.50	0.90	150	2
21	Lower Crabtree Creek	030202010804	0.82	0.89	0.07	8	0.89	0.07	8	<1
22	White Oak Creek (Upper)	030202011003	1.72	3.19	1.47	86	3.24	1.52	88	1
23	Little Creek (Upper)	030202011005	1.96	2.59	0.63	32	2.60	0.64	33	<1

[1] *Grams per year per acre*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Table 32: Comparison of Lower Limit Annual Copper (Cu) Results for 2010, 2040 No-Build, and 2040 Build Scenarios under Model Run 2

Watershed ID	Name	HUC	2010 Cu (g/yr/ac)[1]	2040 No-Build			2040 Build			2040 Build – 2040 No-Build
				Cu (g/yr/ac)[1]	Change[2]	% Change[3]	Cu (g/yr/ac)[1]	Change[2]	% Change[3]	% Change[4]
1	White Oak Creek (Lower)	030202011003	0.69	0.86	0.18	26	0.87	0.18	27	<1
2	Avents Creek-Cape Fear River	030300040106	1.10	1.11	0.01	<1	1.11	0.01	<1	<1
3	Hector Creek-Cape Fear River	030300040502	0.84	1.00	0.16	19	0.98	0.15	18	<1
4	Camp Branch-Black Creek	030202011202	1.12	1.14	0.02	2	1.14	0.02	2	<1
5	Neills Creek	030300040501	3.06	4.92	1.86	61	4.90	1.84	60	<1
6	Little Black Creek-Black Creek	030202011201	2.41	3.79	1.38	58	3.91	1.51	62	3
7	Buckhorn Creek	030300040103	1.71	2.92	1.21	71	2.95	1.24	72	<1
8	Lower Middle Creek	030202010903	2.34	3.02	0.68	29	3.09	0.75	32	3
9	Reed Branch-Swift Creek	030202011007	1.17	1.56	0.39	34	1.60	0.43	37	2
10	Piney Grove Cemetery-Swift Creek	030202011006	1.40	1.66	0.25	18	1.71	0.31	22	3
11	Middle Middle Creek	030202010902	2.82	4.24	1.43	51	4.35	1.54	55	3
12	White Oak Creek (Cape Fear Basin)	030300040102	1.44	2.21	0.78	54	2.22	0.78	55	<1
13	Little Creek (Lower)	030202011005	0.74	0.89	0.15	21	0.89	0.16	21	<1
14	Upper Middle Creek	030202010901	4.78	7.49	2.71	57	7.51	2.72	57	<1
15	Mahlers Creek-Swift Creek	030202011004	2.29	4.31	2.01	88	4.29	2.00	87	<1
16	Lake Benson-Swift Creek	030202011002	3.21	4.74	1.52	47	4.73	1.51	47	<1
17	Lake Wheeler-Swift Creek	030202011001	3.65	4.34	0.69	19	4.35	0.70	19	<1
18	Walnut Creek	030202011101	1.81	3.11	1.30	72	3.12	1.31	72	<1
19	Poplar Creek-Neuse River	030202011103	2.18	4.69	2.51	115	4.65	2.47	113	<1
20	Marks Creek	030202011102	0.59	1.36	0.78	132	1.39	0.81	137	2
21	Lower Crabtree Creek	030202010804	0.72	0.78	0.06	8	0.77	0.06	8	<1
22	White Oak Creek (Upper)	030202011003	1.68	2.98	1.31	78	2.99	1.32	79	<1
23	Little Creek (Upper)	030202011005	1.89	2.42	0.53	28	2.43	0.53	28	<1

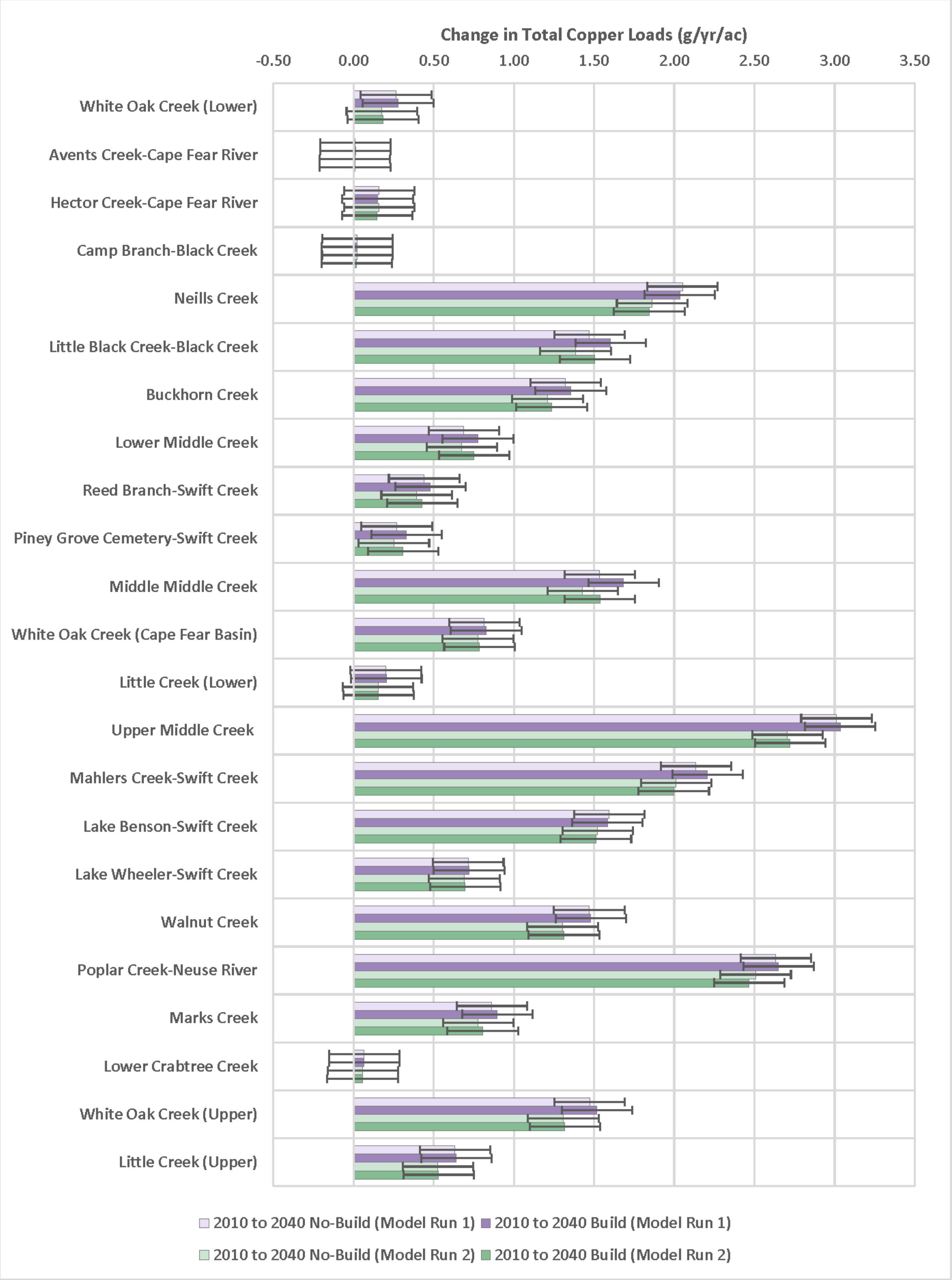
[1] *Grams per year per acre*

[2] *Difference between future scenario and 2010: future scenario – 2010 scenario*

[3] *Percent difference between future scenario and 2010 scenario: [(future scenario – 2010 scenario) × 100]/2010 scenario*

[4] *Percent difference between 2040 Build and 2040 No-Build: [(2040 Build – 2040 No-Build) × 100]/2040 No-Build*

Figure 14: Change in Copper from 2010 to 2040 No-Build Scenarios and 2010 to 2040 Build Scenarios for Model Runs 1 and 2



6. Conclusions

The water quality analysis was performed by constructing watershed models for portions of twenty-one 12-digit HUCs within the water quality study area, using the MapShed/GWLF-E modeling tool (note - two of the 12-digit HUCs were subdivided to provide data for the endangered species analysis). Model estimates of annual streamflow, runoff, and annual overland contaminant loadings of TN, TP, TSS, and copper loads produced from the three land use scenarios – 2010, 2040 No-Build, and 2040 Build were reviewed and compared to assess the project effects. Differences in streamflow and contaminant loadings exhibited between the 2040 scenarios would be attributable to the proposed project.

Impervious surface estimations were also derived from the land use analysis. The majority of the total changes in impervious surface in the water quality study area from 2010 to 2040 are projected to occur for either the 2040 No-Build scenario or the 2040 Build scenario. The changes in impervious surface coverage from the 2040 No-Build scenario to the 2040 Build Scenario range from less than one percent to six percent, with an overall average of one percent or less. The largest changes occur in the Mahlers Creek-Swift Creek, White Oak (Upper), Poplar Creek-Neuse River, and Middle Middle Creek watersheds under the more conservative model run.

Overall for the water quality study area, Model Run 1 projects that the streamflow would increase by <1 percent and runoff would increase by 2 percent under the 2040 Build scenario as compared to the 2040 No-Build scenario. Similarly, the TSS, TN, TP, and copper loads would increase <1 percent, <1 percent, 1 percent, and <1 percent, respectively. For Model Run 1, the maximum change in streamflow and runoff exceeded the standard error (See Table 19).

Model Run 2 projects the following for the water quality study area as a whole: the streamflow would increase by <1 percent and runoff would increase by <1 percent under the 2040 Build scenario as compared to the 2040 No-Build scenario; similarly, the TSS, TN, TP, and copper loads would each increase by <1 percent. These increases, as well as the maximum observed increase between the 2040 Build and 2040 No-Build scenarios, were observed to be within the standard error of each pollutant as modeled (see Table 19).

Table 20 shows the weighted average changes are projected to be 1 and less than one percent for streamflow and 7 and 2 percent for runoff in Model Runs 1 and 2, respectively. For TSS, TN, and copper loads, the weighted average increases are 2 percent for Model Run 1 and less than one percent for Model Run 2. Weight average TP loads are projected to be 5 percent for Model Run 1 and 1 percent for Model Run 2. Water quality conditions and results by watershed are discussed in greater detail in the Cumulative Effects discussion of ICE Memo #4.

A key qualification about this water quality analysis is that it only considered riparian buffers as a BMP. No other site-specific BMPs, such as bioretention basins, stormwater ponds, grass swales, etc., are accounted for in the results. Consequently, the watershed model likely over-estimates contaminant loadings from areas with treated stormwater. In reality, substantial reductions in contaminant loadings could be attained as future development takes place, if existing BMP regulations are enforced and BMPs are constructed and properly maintained. This topic is discussed in greater detail in ICE Memo #4.

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Appendix A: Maps

Complete 540 Water Quality

Study Area Catchments & Water Resources

Legend

- FLUSA Boundary
- Counties
- River Basin
- Major Highways
- Proposed 540
- Streams

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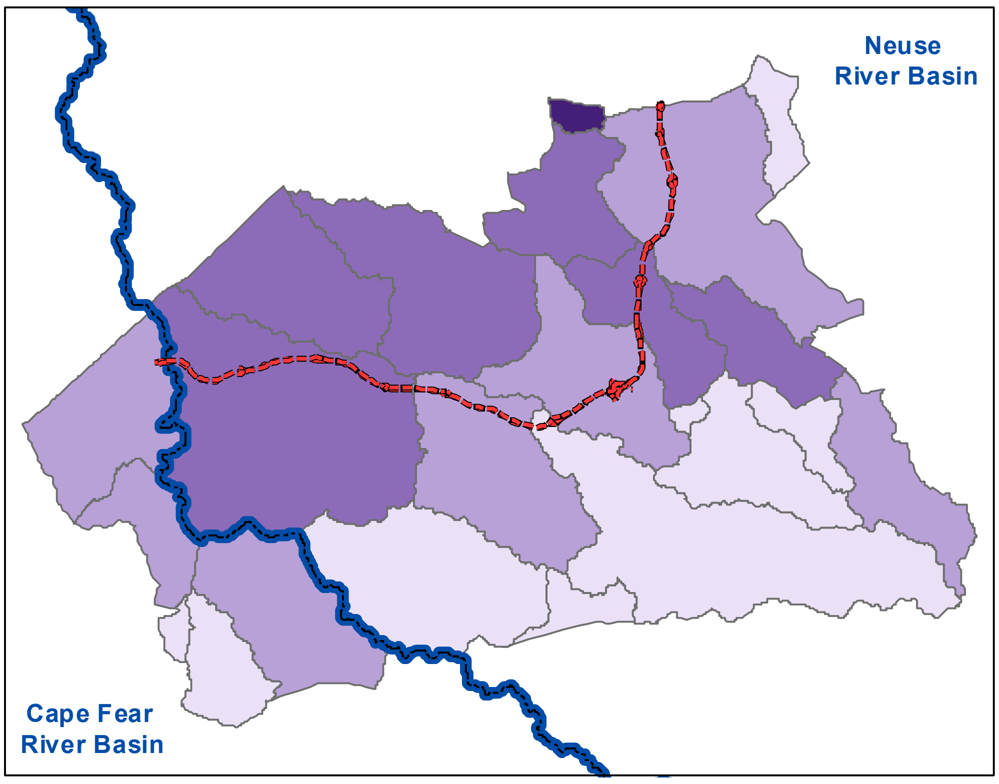
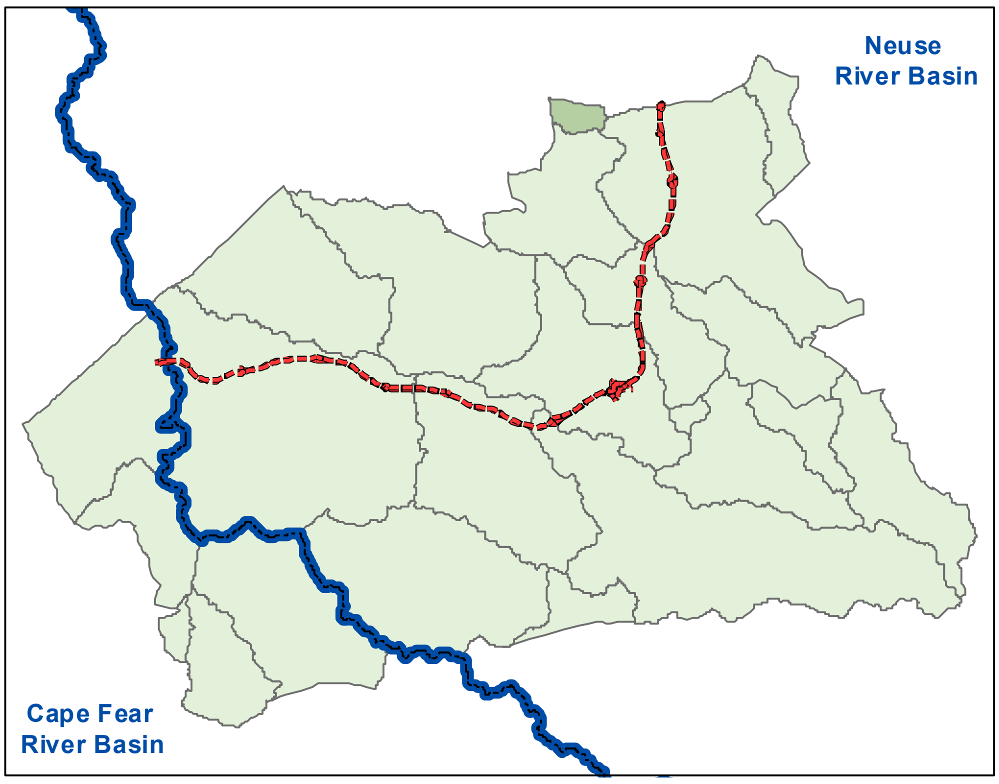
Complete 540 Water Quality
Percent Impervious for Three Modeled Scenarios

2010 (Model Run 1)

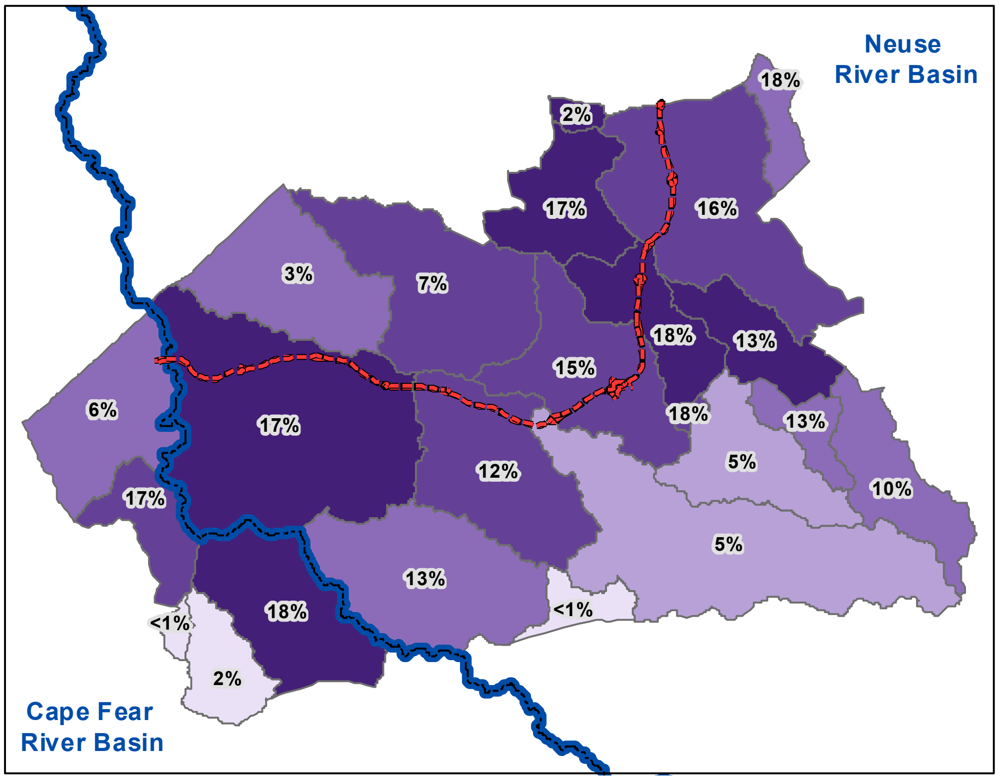


2010 (Model Run 2)



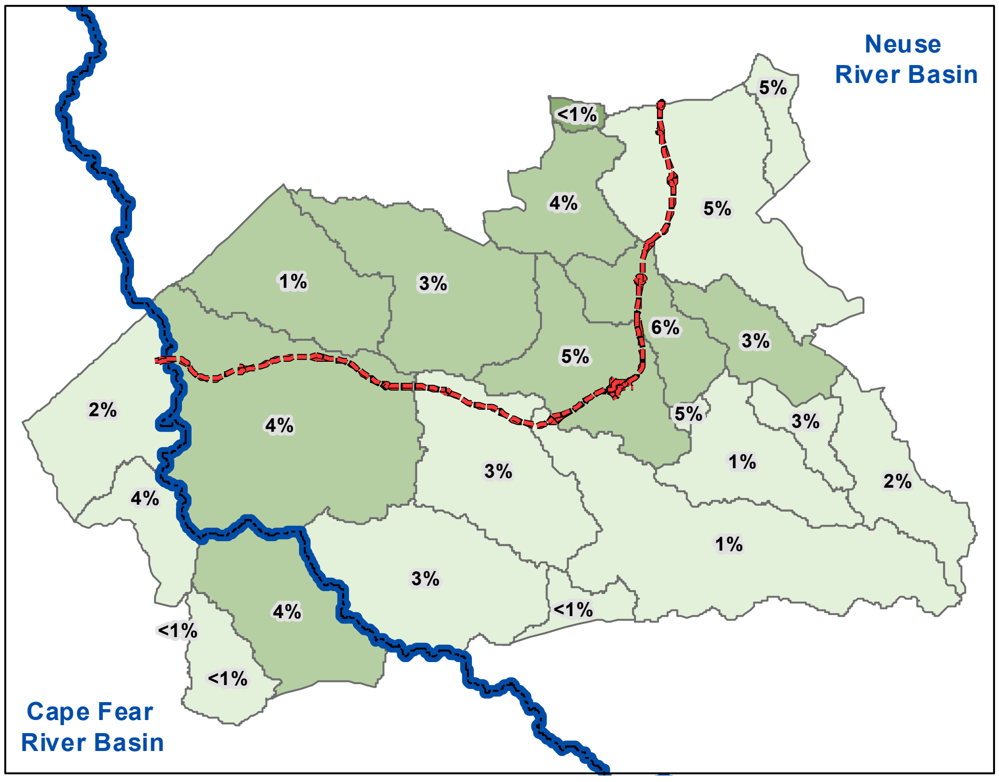
2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build



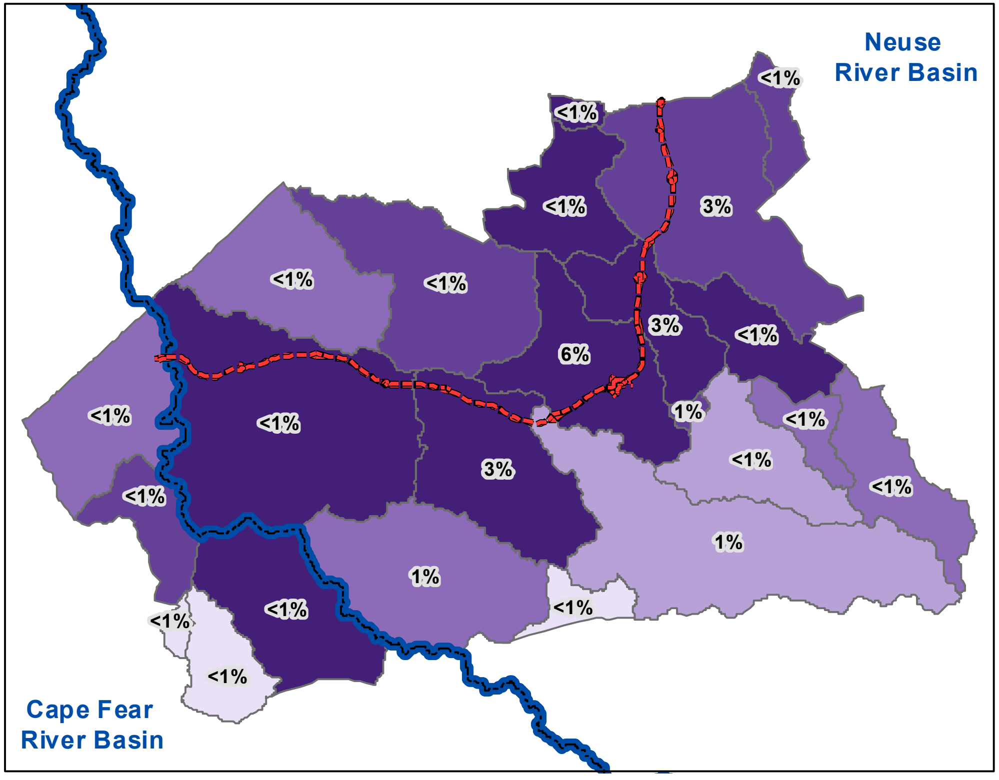
2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build



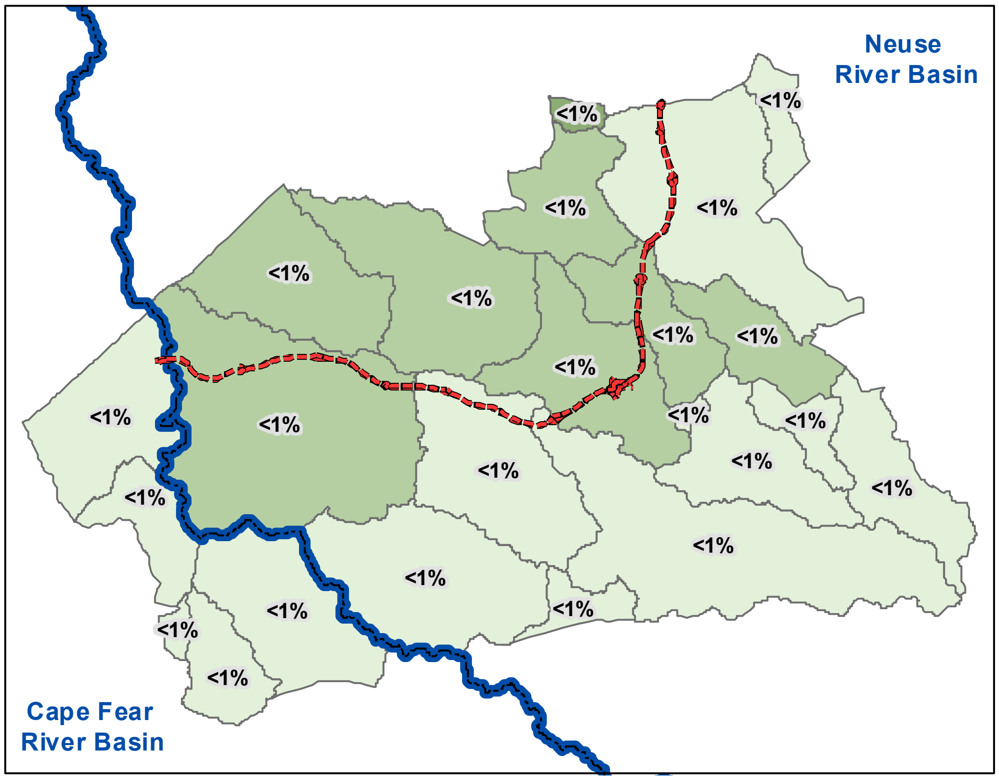
2040 Build (Model Run 1)

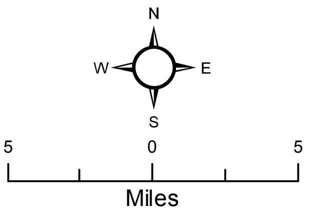
Percent Change - From 2040 No-Build to 2040 Build



2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build





Legend

Percent Impervious (Model Run 1)

- 4.03% - 9.83%
- 9.84% - 15.85%
- 15.86% - 24.99%
- 25% - 31.25%
- 31.26% - 40.49%

- Proposed 540
- River Basin Boundary

Percent Impervious (Model Run 2)

- 4.03% - 9.83%
- 9.84% - 15.85%
- 15.86% - 24.99%
- 25% - 31.25%
- 31.26% - 40.49%

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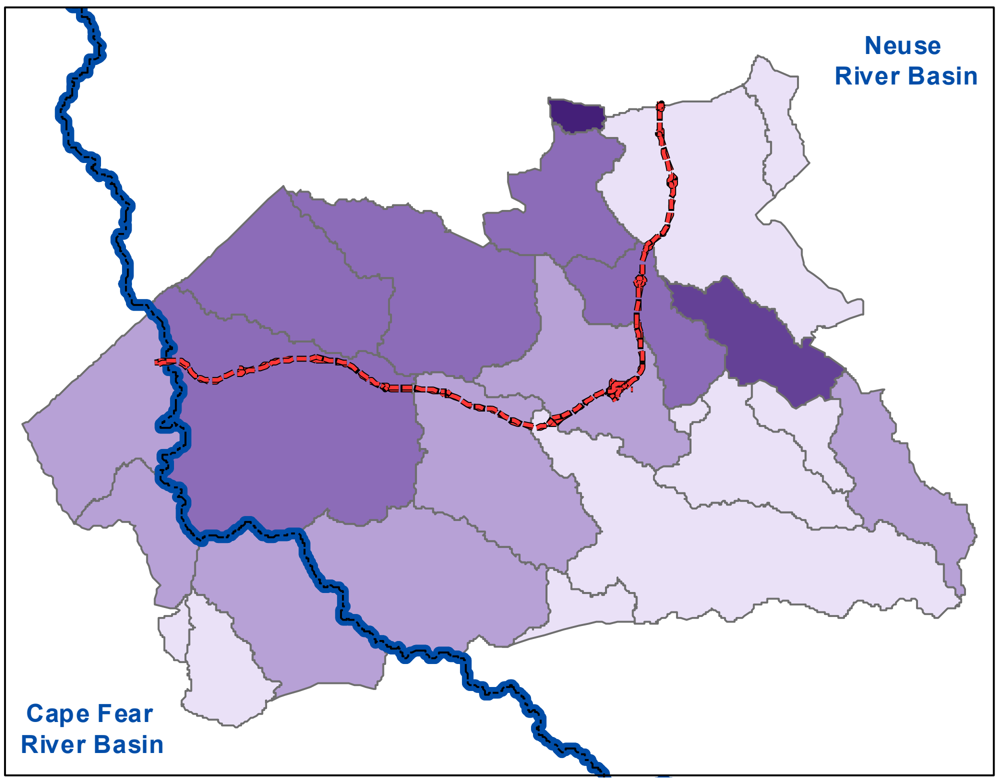
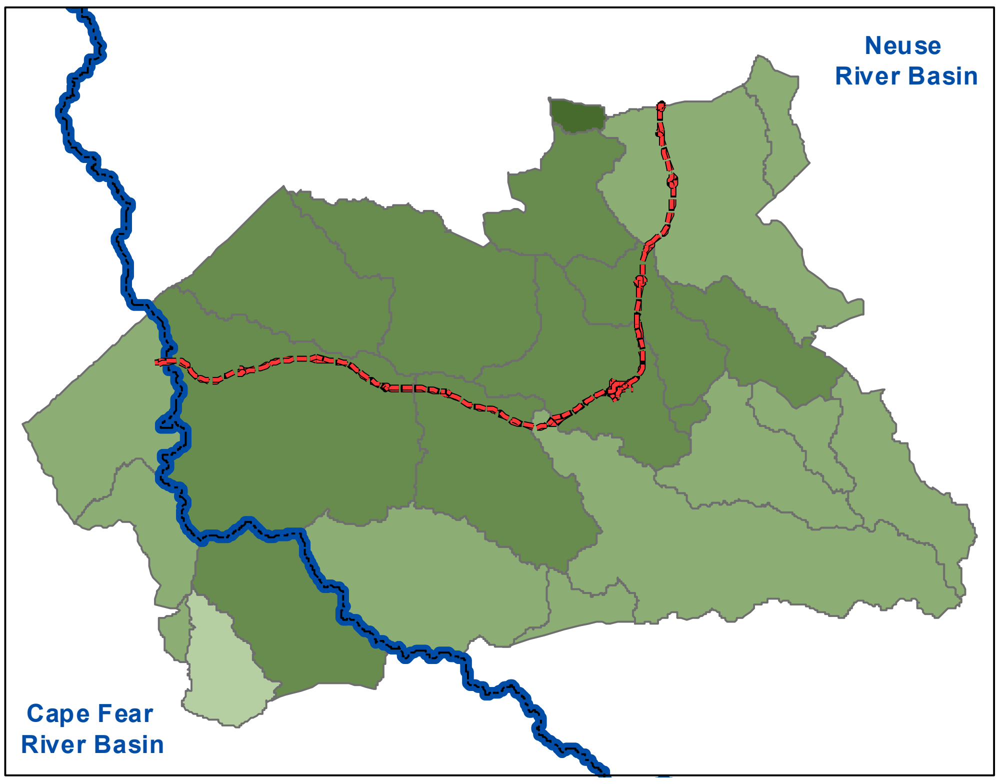
Complete 540 Water Quality
Streamflow for Three Modeled Scenarios

2010 (Model Run 1)

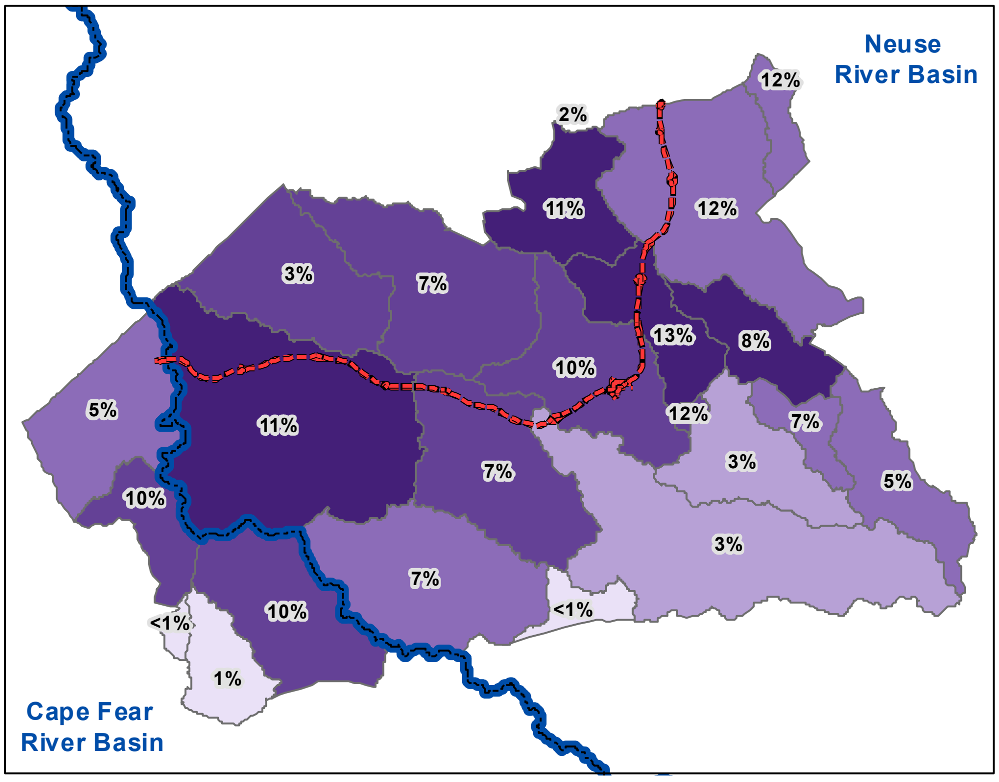


2010 (Model Run 2)



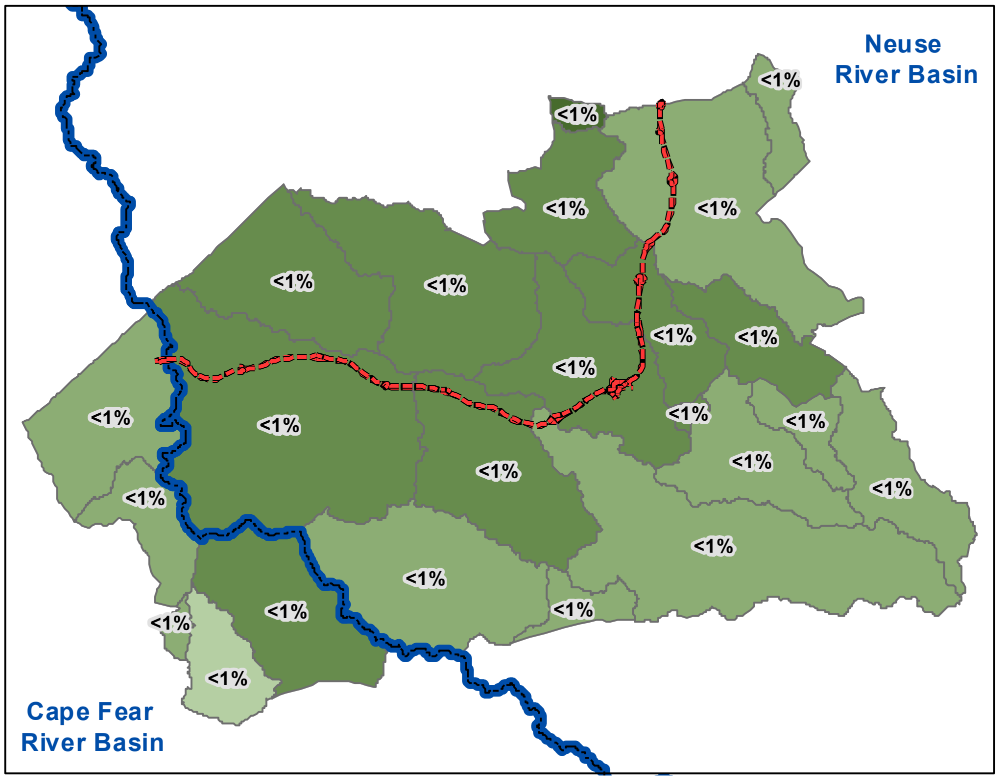
2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build



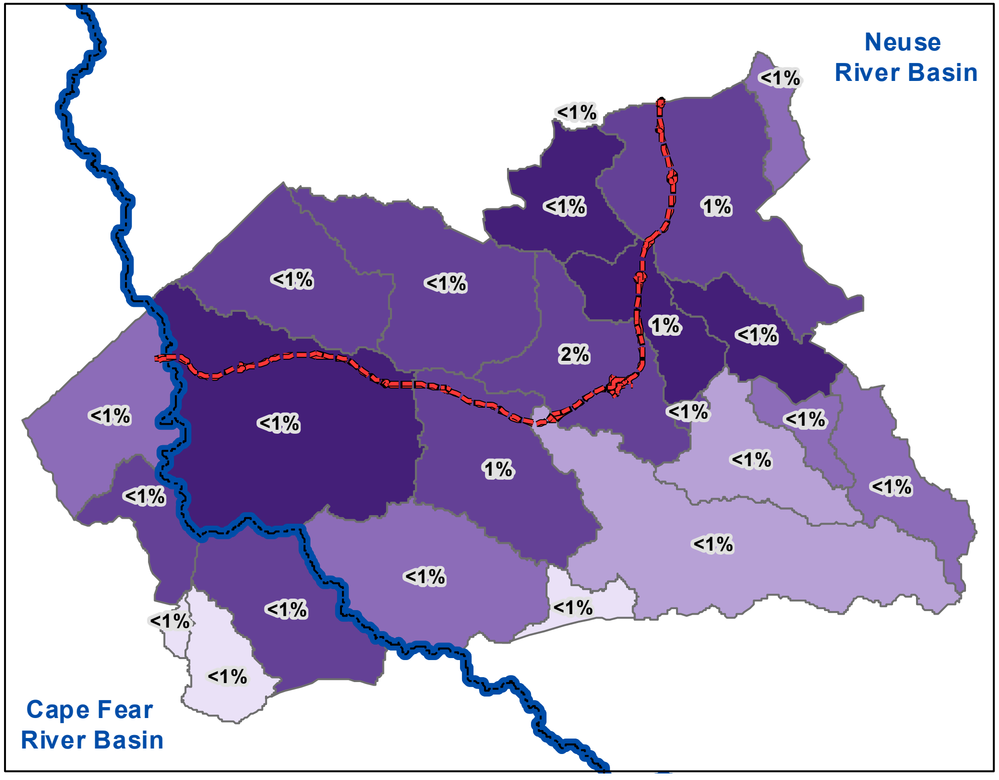
2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build



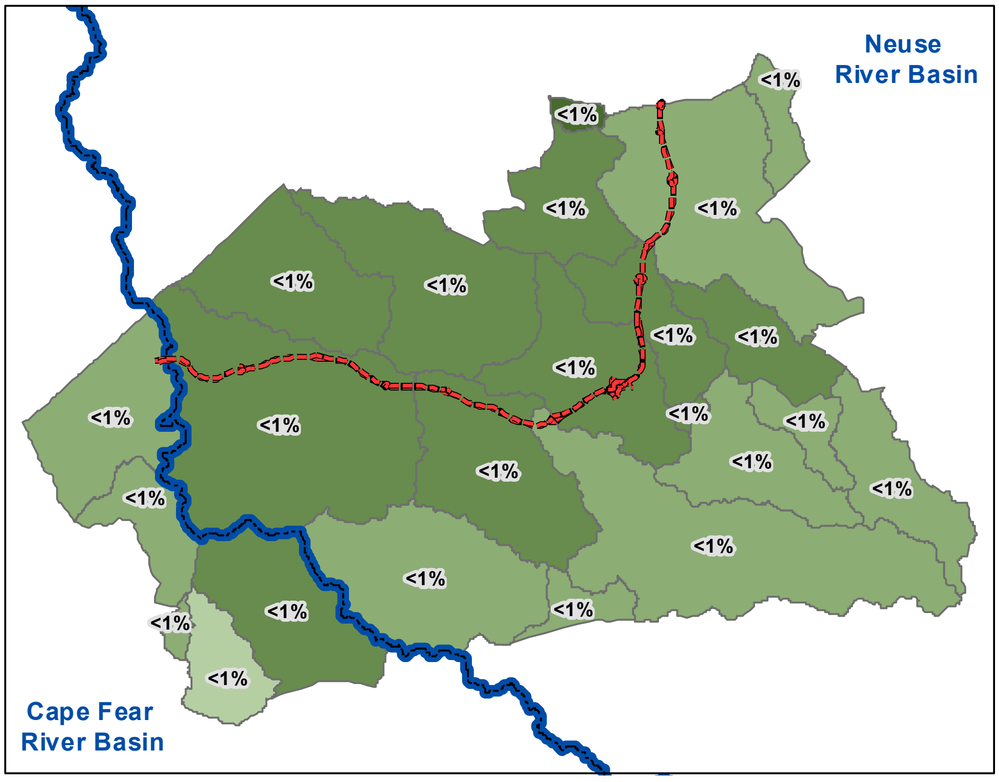
2040 Build (Model Run 1)

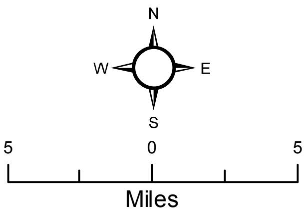
Percent Change - From 2040 No-Build to 2040 Build



2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build





Streamflow (cm) (Model Run 1)

- ▢ 24.24 - 25.47
- ▨ 25.48 - 26.55
- ▨ 26.56 - 27.82
- ▨ 27.83 - 29.58
- ■ 29.59 - 32.64

Legend

- Proposed 540
- River Basin Boundary

Streamflow (cm) (Model Run 2)

- ▢ 24.24 - 25.47
- ▨ 25.48 - 26.55
- ▨ 26.56 - 27.82
- ▨ 27.83 - 29.58
- ■ 29.59 - 32.64

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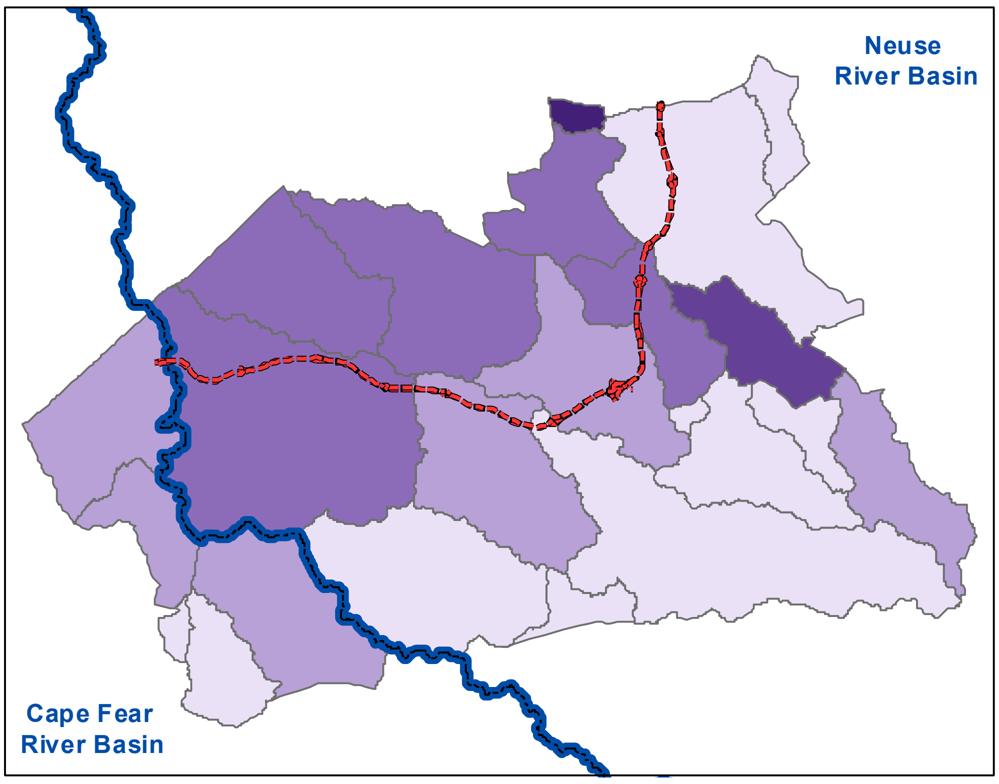
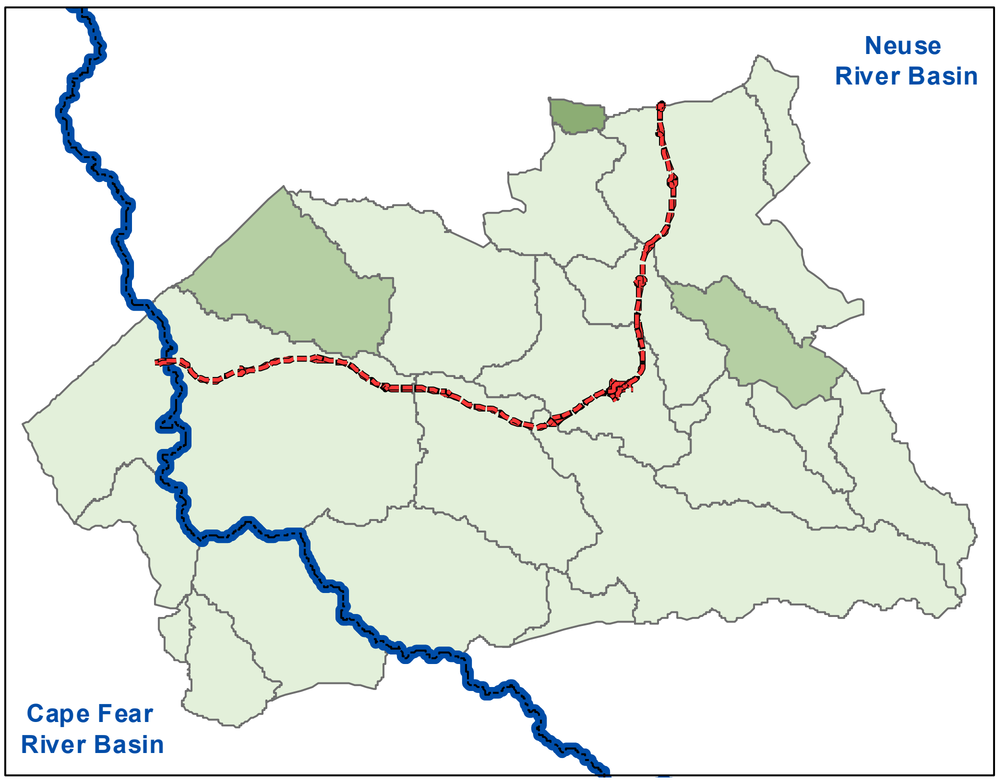
Complete 540 Water Quality
Runoff for Three Modeled Scenarios

2010 (Model Run 1)

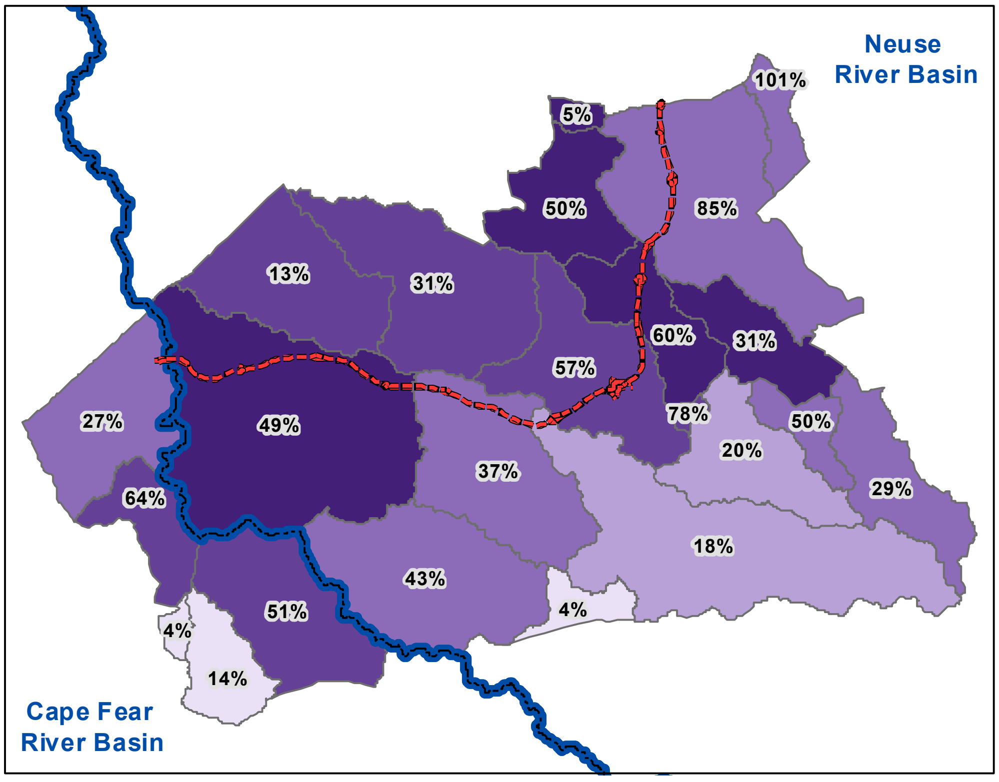


2010 (Model Run 2)



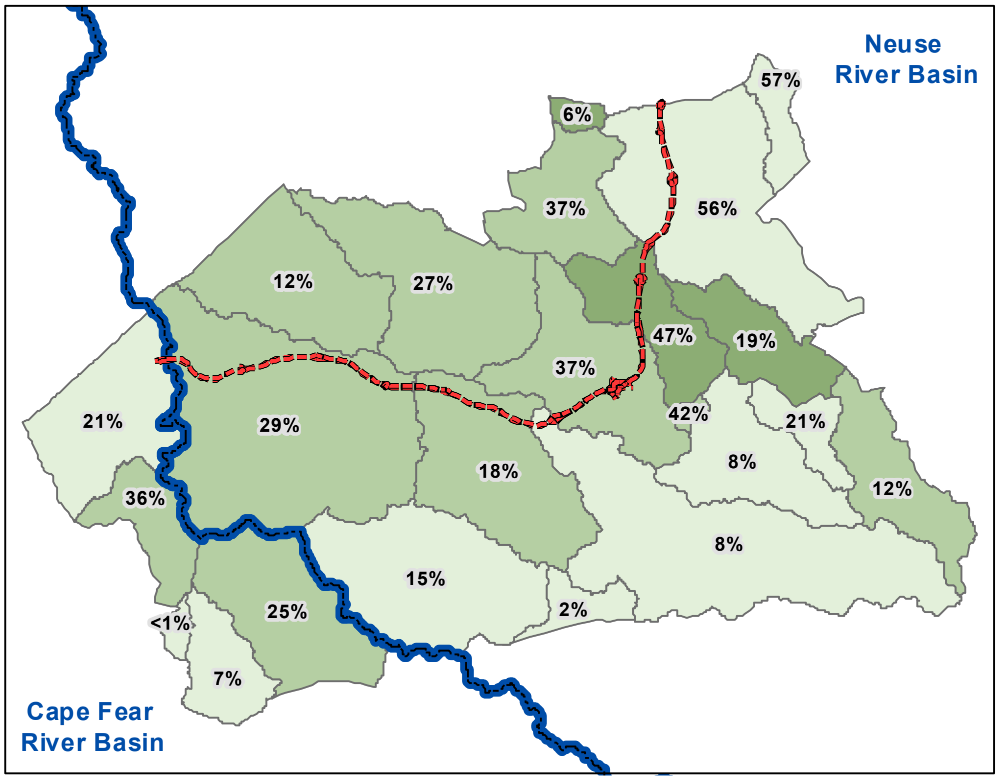
2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build



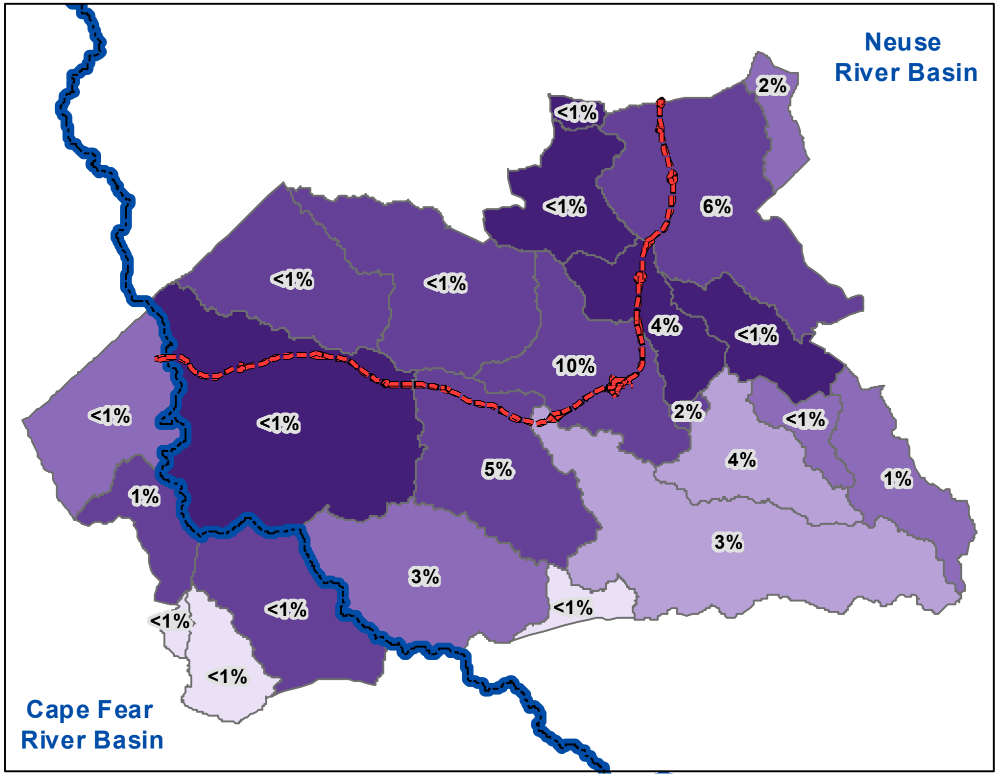
2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build



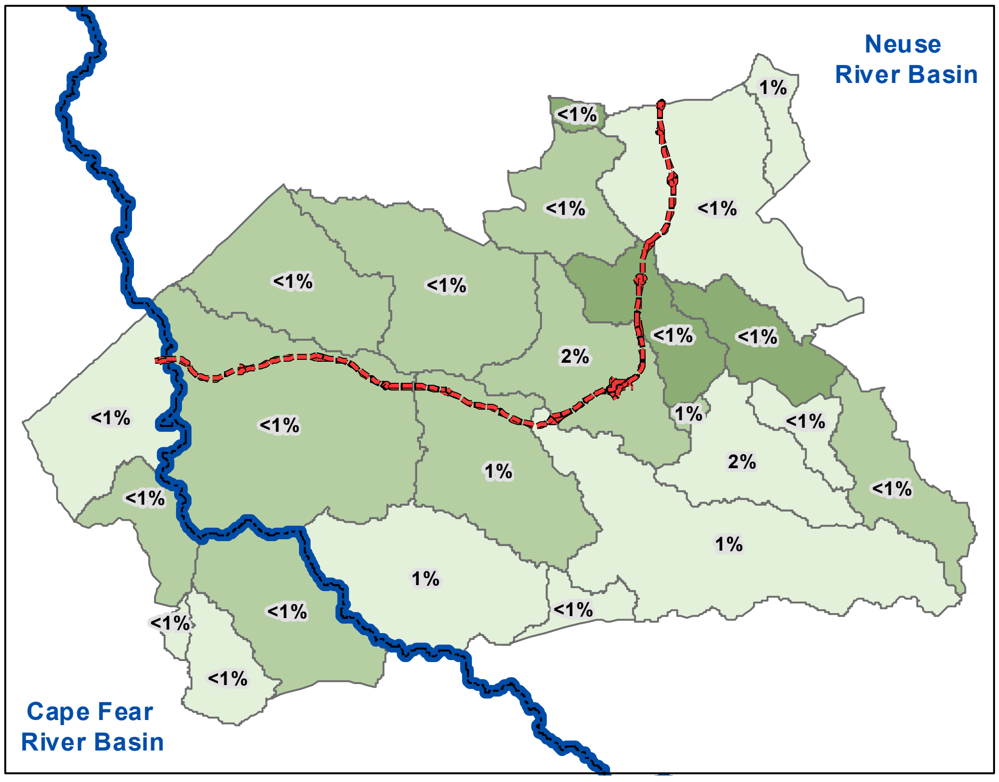
2040 Build (Model Run 1)

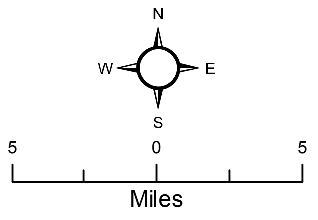
Percent Change - From 2040 No-Build to 2040 Build



2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build





Legend

Runoff (cm) (Model Run 1)

- ▨ 3.74 - 6.10
- ▨ 6.11 - 7.77
- ▨ 7.78 - 9.93
- ▨ 9.94 - 12.26
- ▨ 12.27 - 16.89

Proposed 540

River Basin Boundary

Runoff (cm) (Model Run 2)

- 🟩 3.74 - 6.10
- 🟩 6.11 - 7.77
- 🟩 7.78 - 9.93
- 🟩 9.94 - 12.26
- 🟩 12.27 - 16.89

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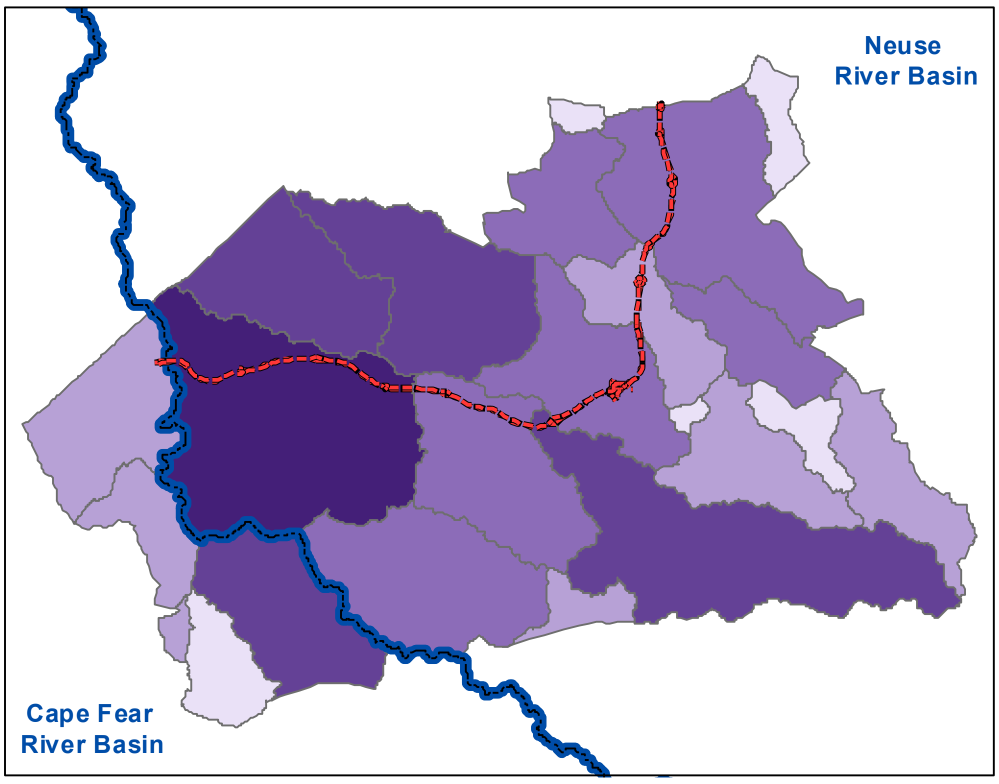
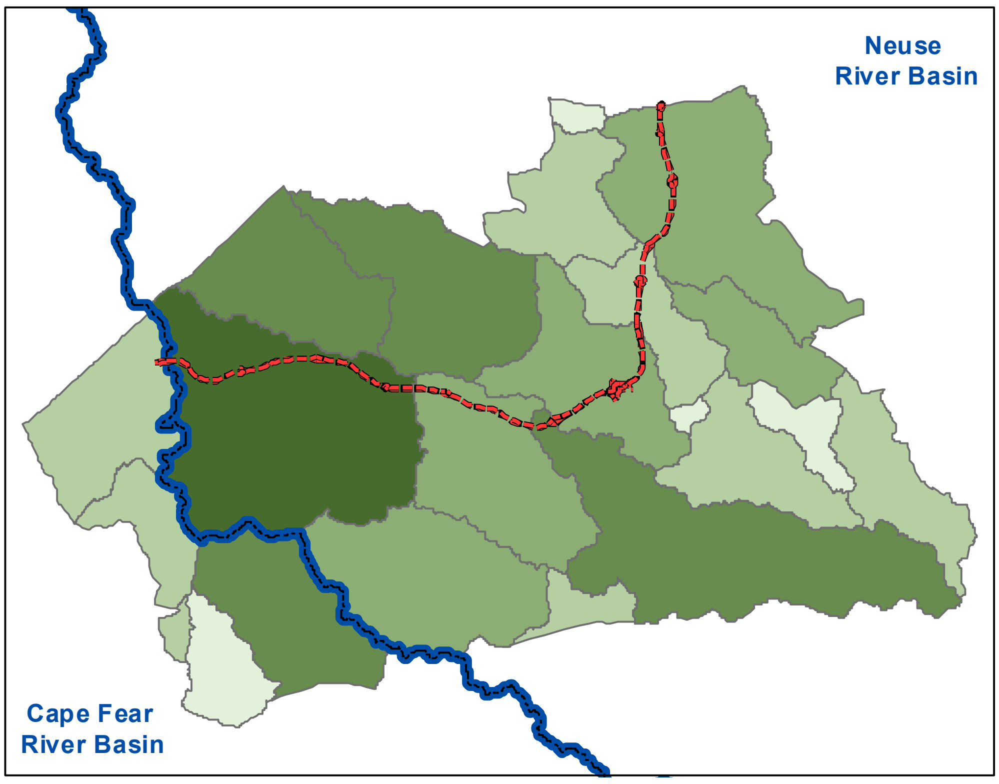
Complete 540 Water Quality

Annual Total Suspended Sediment (TSS) Loads for Three Modeled Scenarios

2010 (Model Run 1)

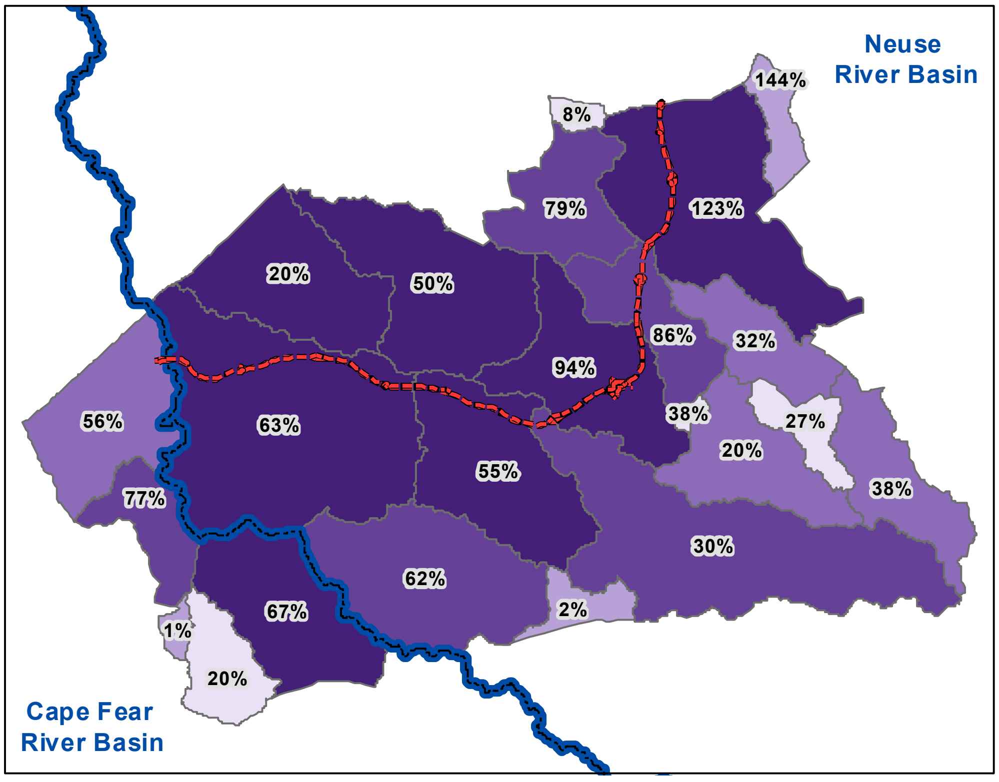


2010 (Model Run 2)



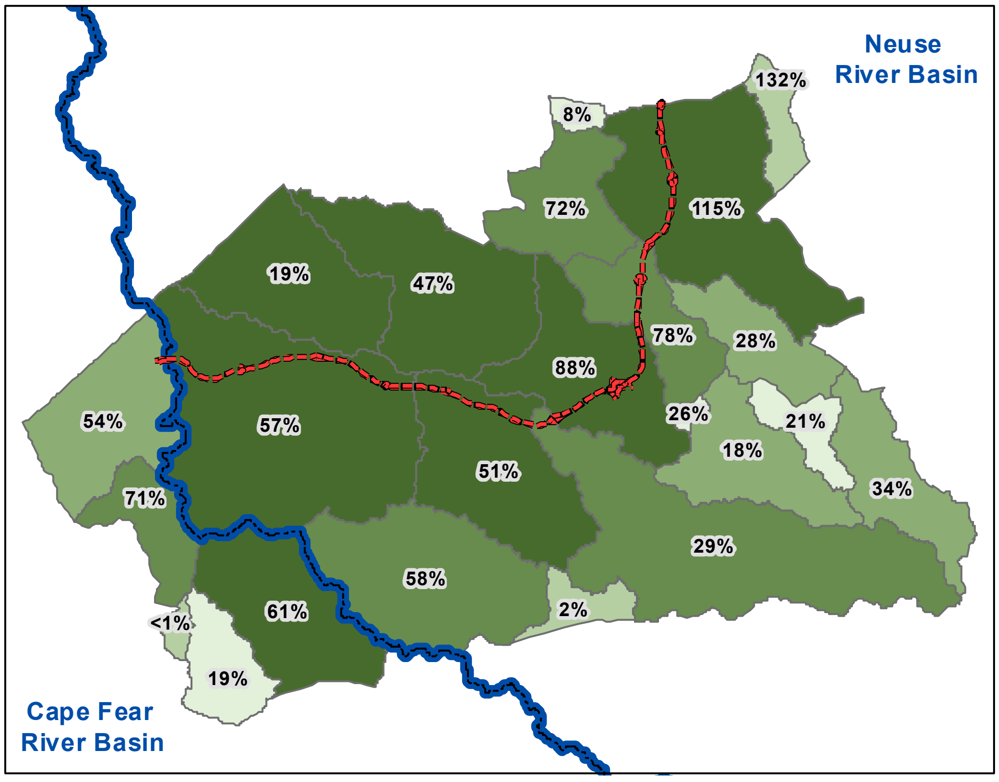
2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build



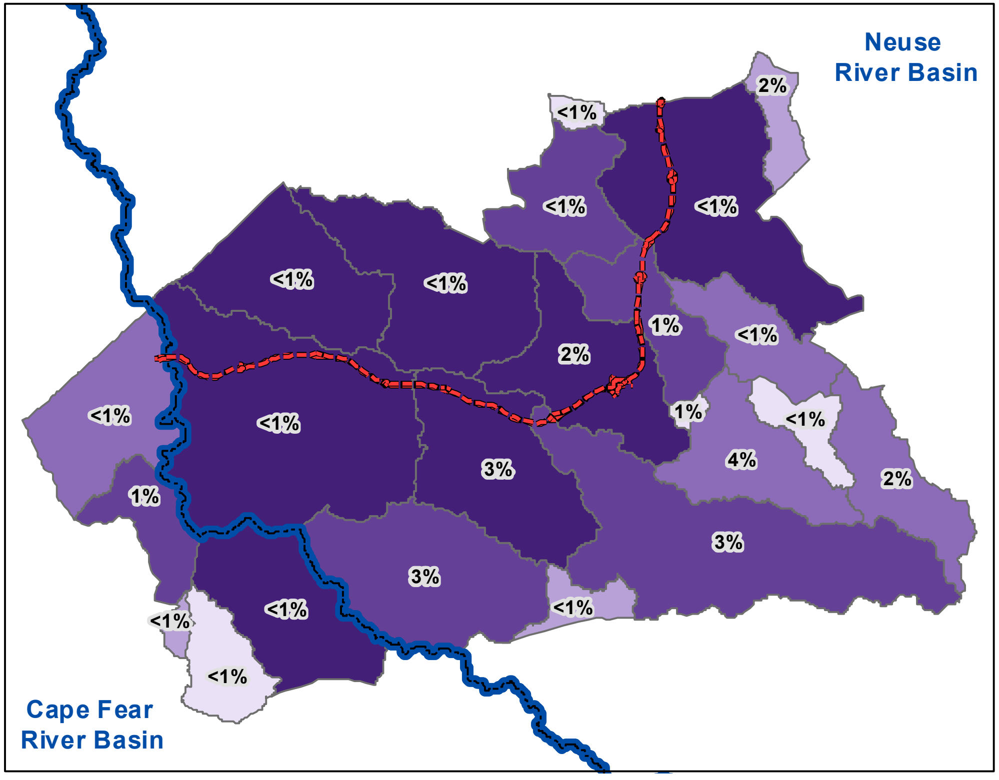
2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build



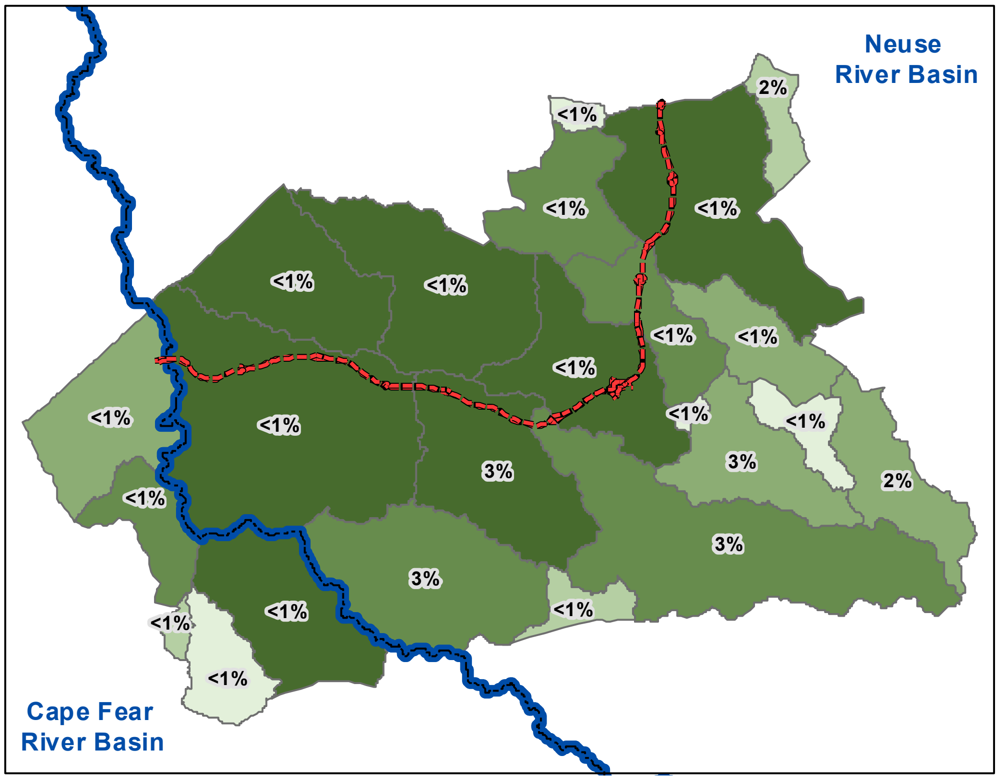
2040 Build (Model Run 1)

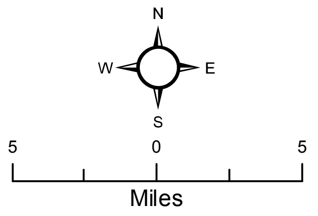
Percent Change - From 2040 No-Build to 2040 Build



2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build





TSS Loads (MT/yr/ac) (Model Run 1)

▢	0.07 - 0.14
▢	0.15 - 0.21
▢	0.22 - 0.32
▢	0.33 - 0.45
■	0.46 - 0.88

Legend

Proposed 540

River Basin Boundary

TSS Loads (MT/yr/ac) (Model Run 2)

▢	0.07 - 0.147
▢	0.15 - 0.21
▢	0.22 - 0.32
▢	0.33 - 0.45
■	0.46 - 0.88

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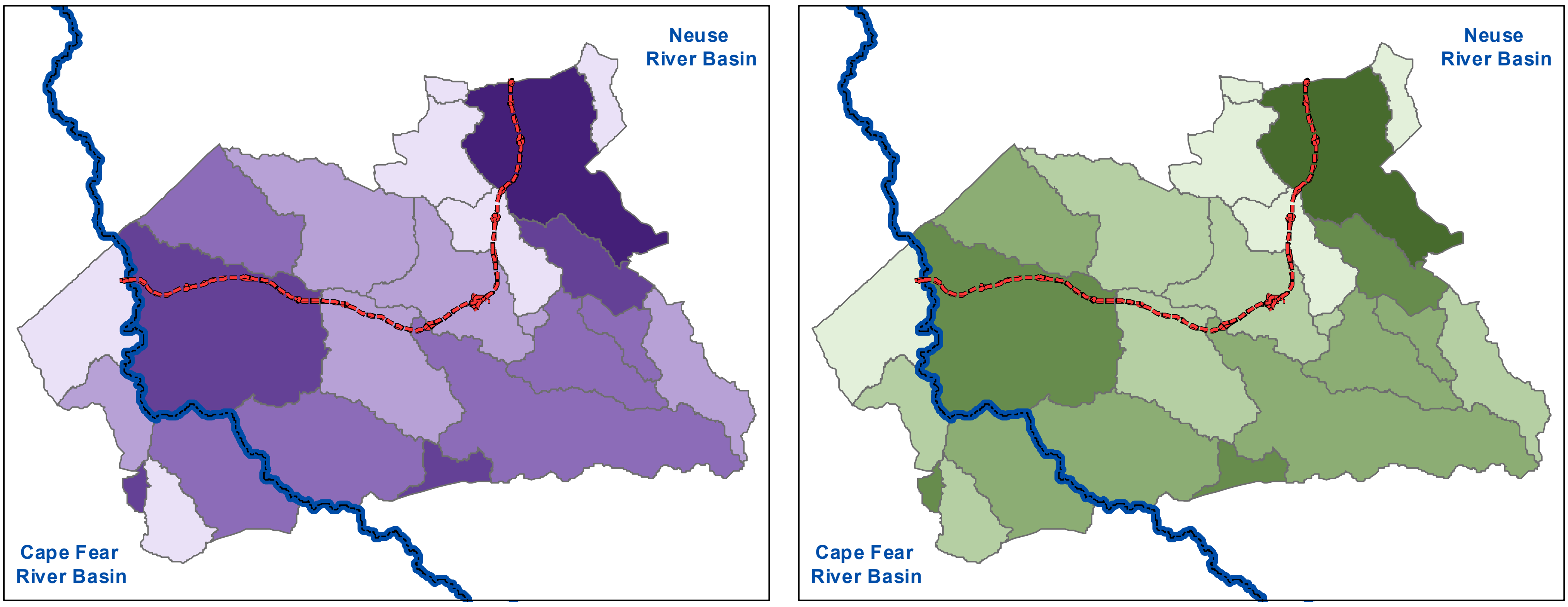
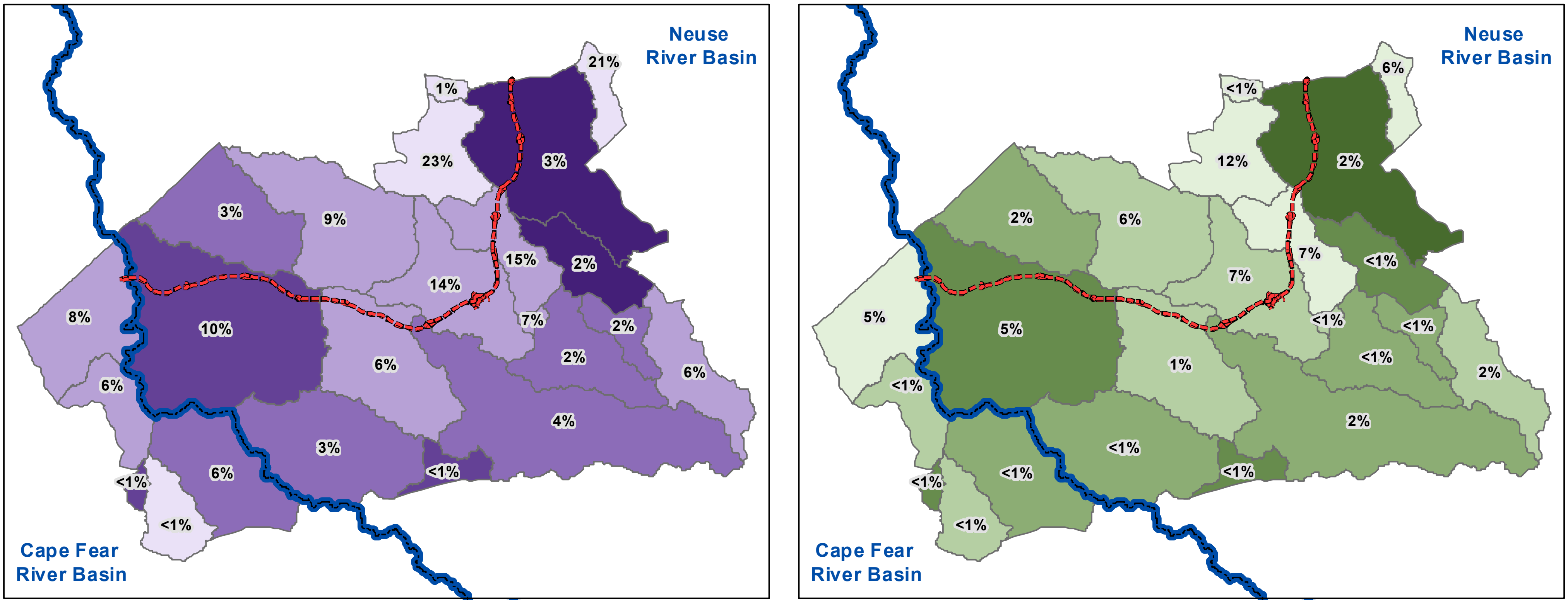
Complete 540 Water Quality
Total Nitrogen (TN) Loads for Three Modeled Scenarios



2010 (Model Run 1)

2010 (Model Run 2)

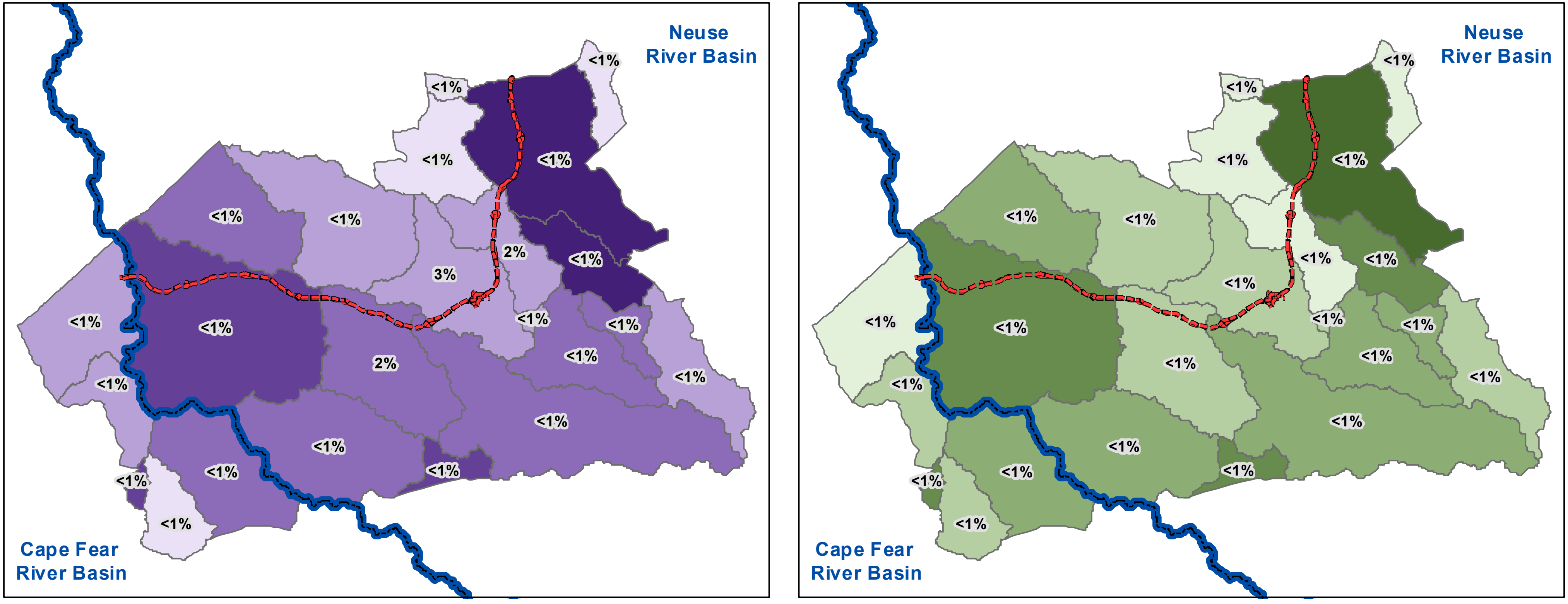


2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build

2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build

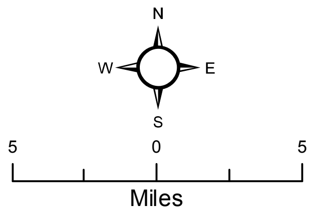


2040 Build (Model Run 1)

Percent Change - From 2040 No-Build to 2040 Build

2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build



TN Loads (kg/yr/ac) (Model Run 1)

▨	0.86 - 1.35
▨	1.36 - 1.74
▨	1.75 - 2.00
▨	2.01 - 2.91
▨	2.92 - 9.45

Legend

Proposed 540

River Basin Boundary

TN Loads (kg/yr/ac) (Model Run 2)

🟩	0.86 - 1.35
🟩	1.36 - 1.74
🟩	1.75 - 2.00
🟩	2.01 - 2.91
🟩	2.92 - 9.45

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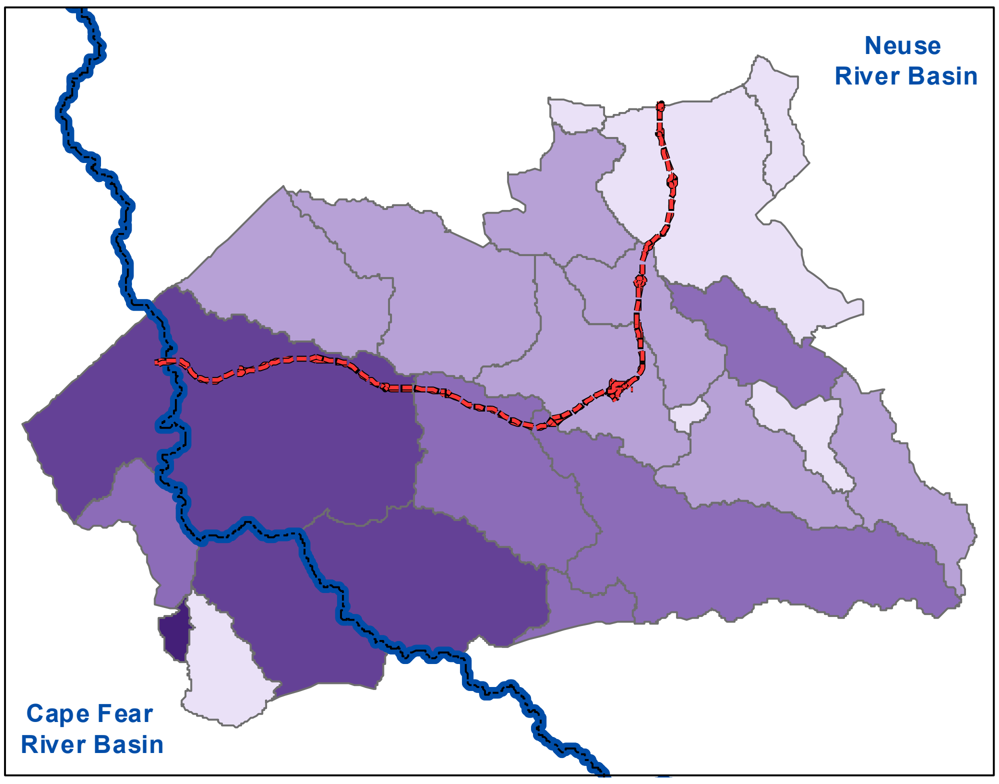
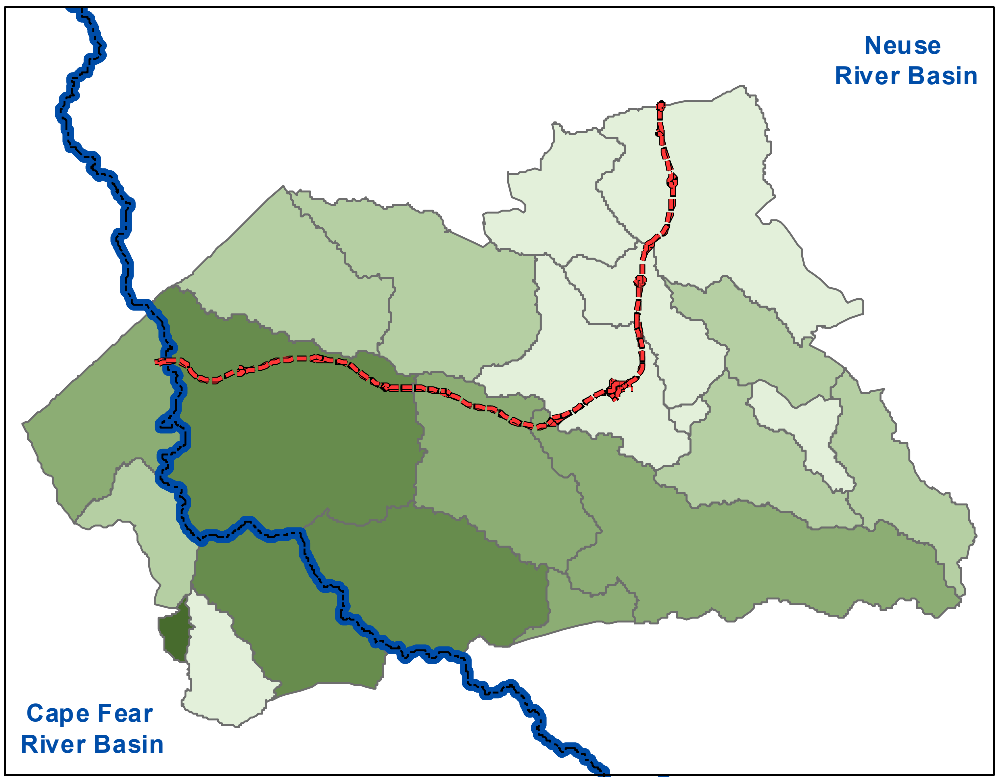
Complete 540 Water Quality
Total Phosphorus (TP) Loads for Three Modeled Scenarios

2010 (Model Run 1)

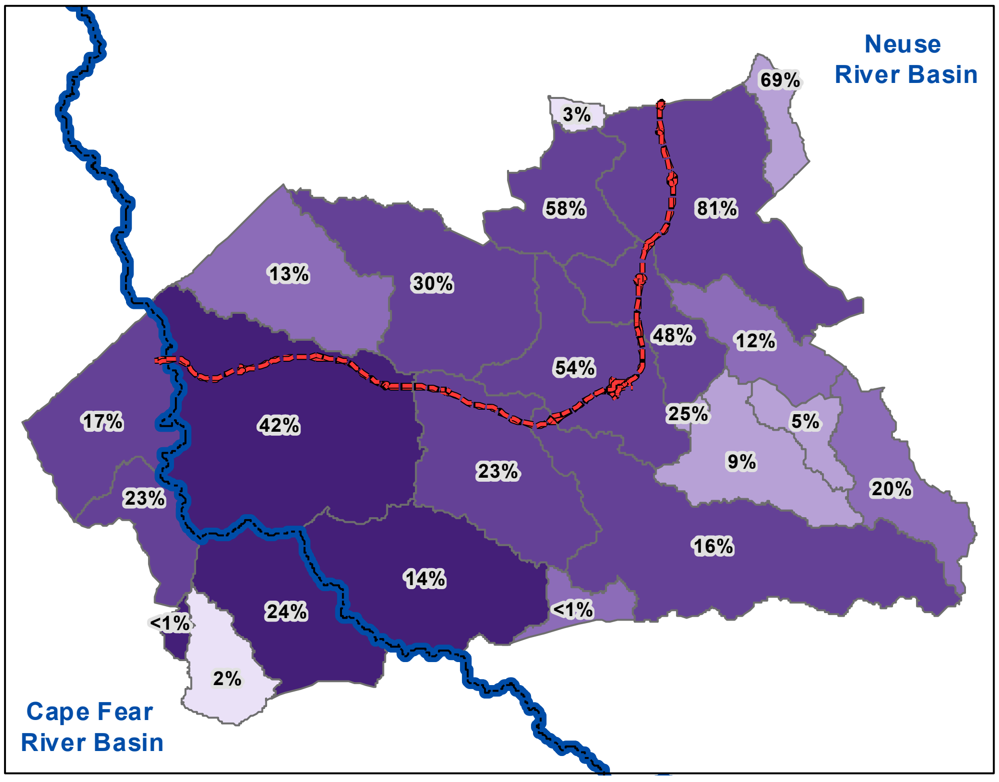


2010 (Model Run 2)



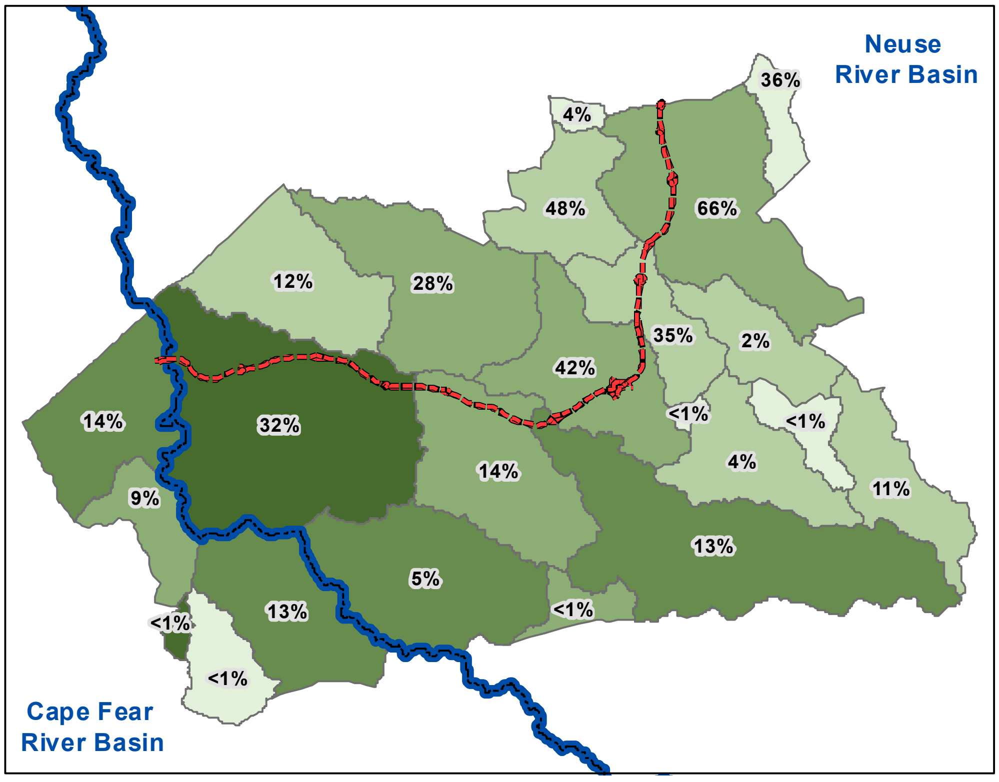
2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build



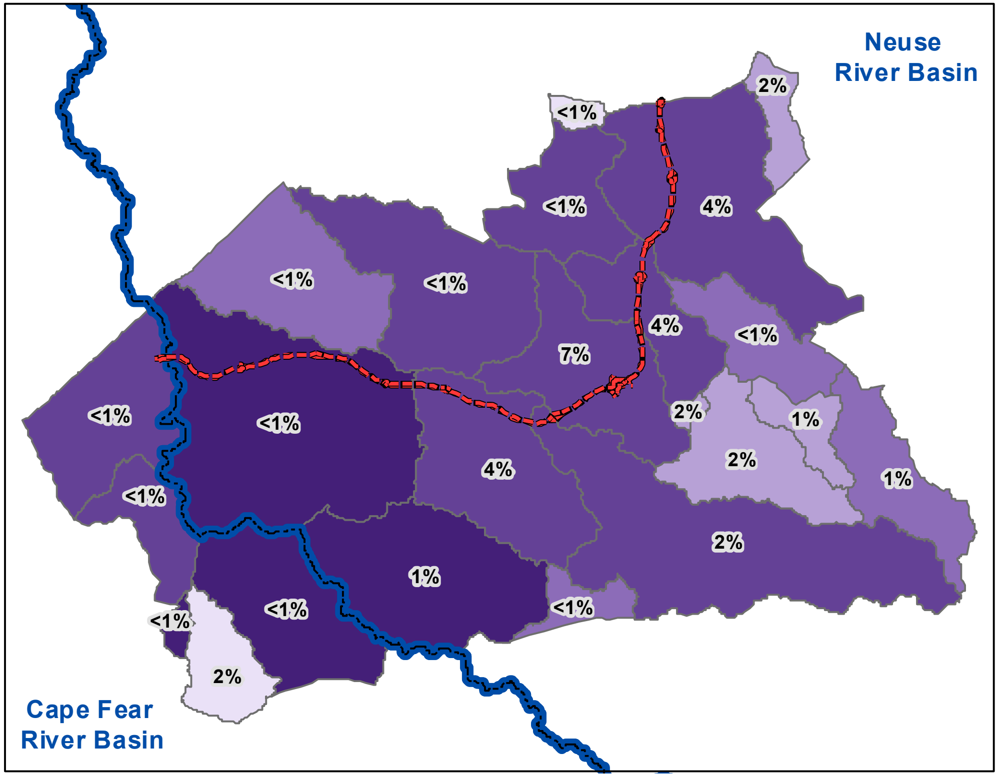
2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build



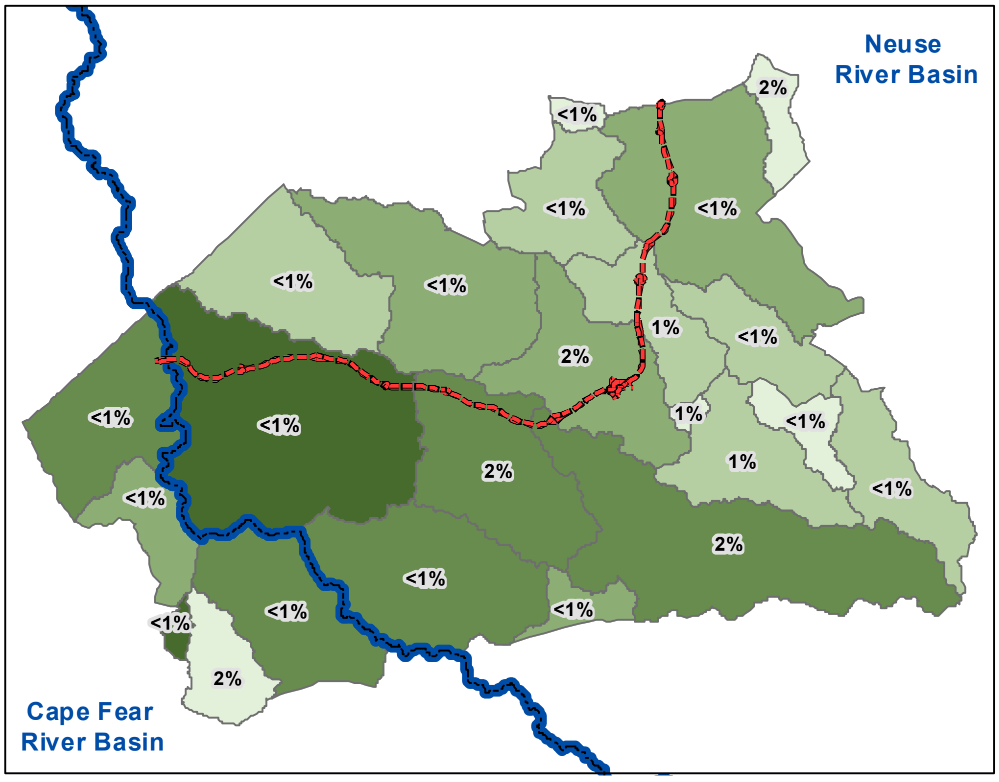
2040 Build (Model Run 1)

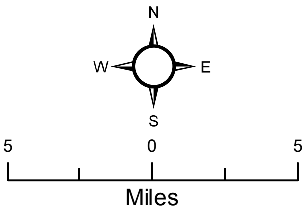
Percent Change - From 2040 No-Build to 2040 Build



2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build





TP Loads (kg/yr/ac) (Model Run 1)

▢	0.04 - 0.07
▢	0.08 - 0.09
▢	0.10 - 0.11
▢	0.12 - 0.14
■	0.15 - 0.18

Legend

Proposed 540

River Basin Boundary

TP Loads (kg/yr/ac) (Model Run 2)

▢	0.04 - 0.07
▢	0.08 - 0.09
▢	0.10 - 0.11
▢	0.12 - 0.14
■	0.14 - 0.18

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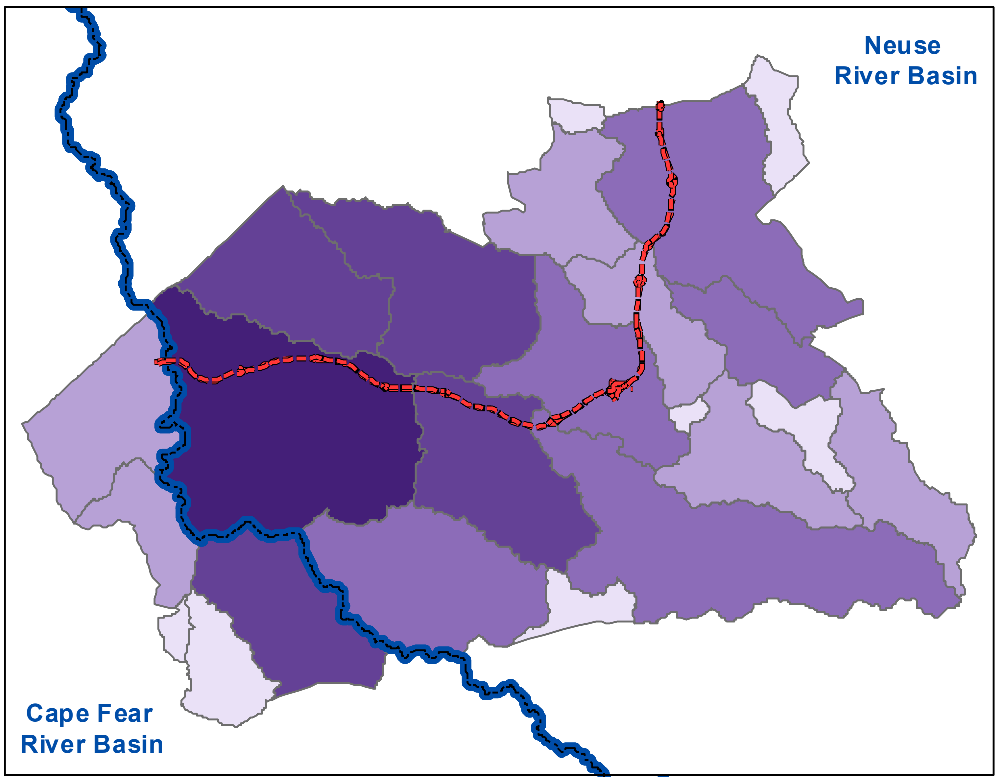
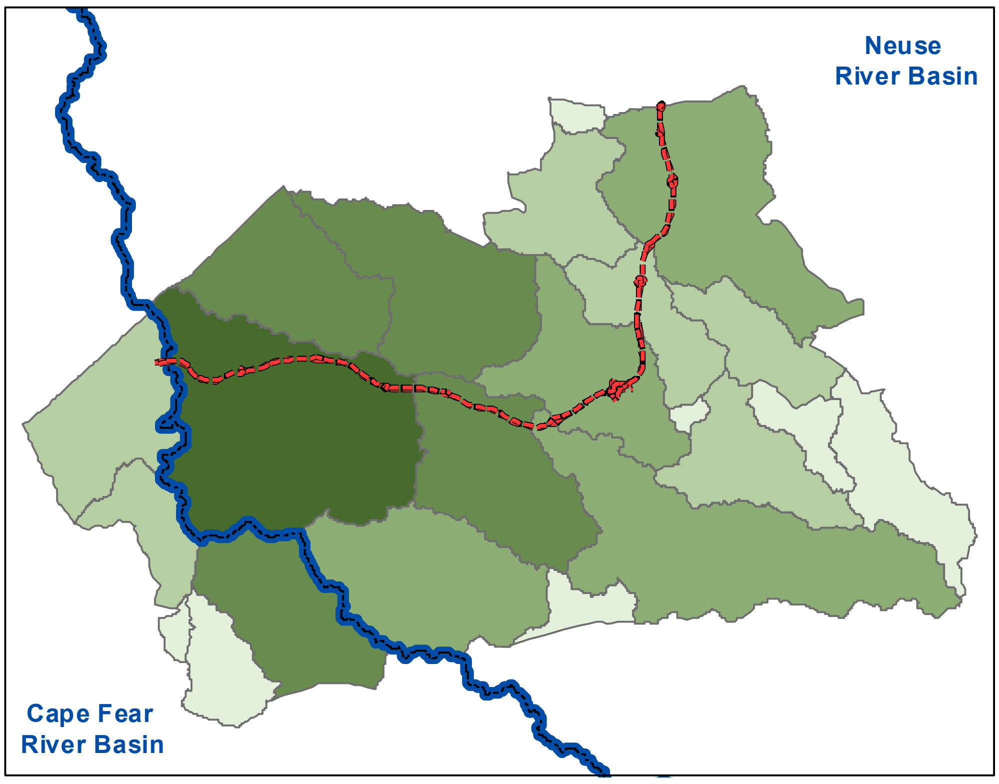
Complete 540 Water Quality
Copper (Cu) Loads for Three Modeled Scenarios

2010 (Model Run 1)

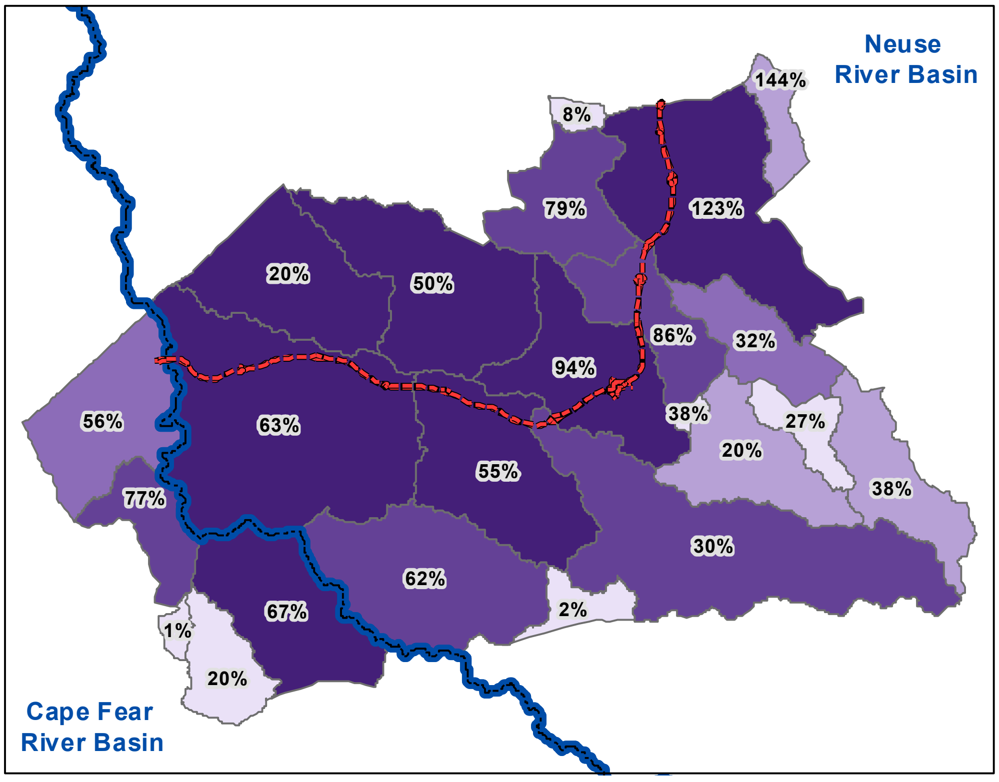


2010 (Model Run 2)



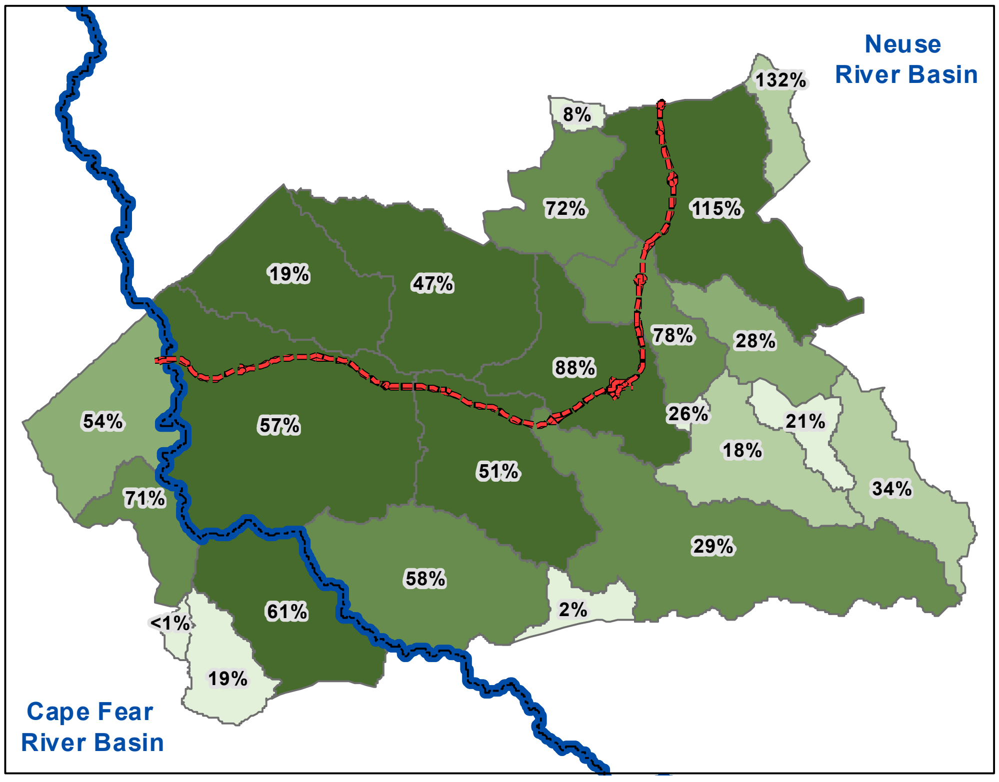
2040 No-Build (Model Run 1)

Percent Change - from 2010 to 2040 No-Build



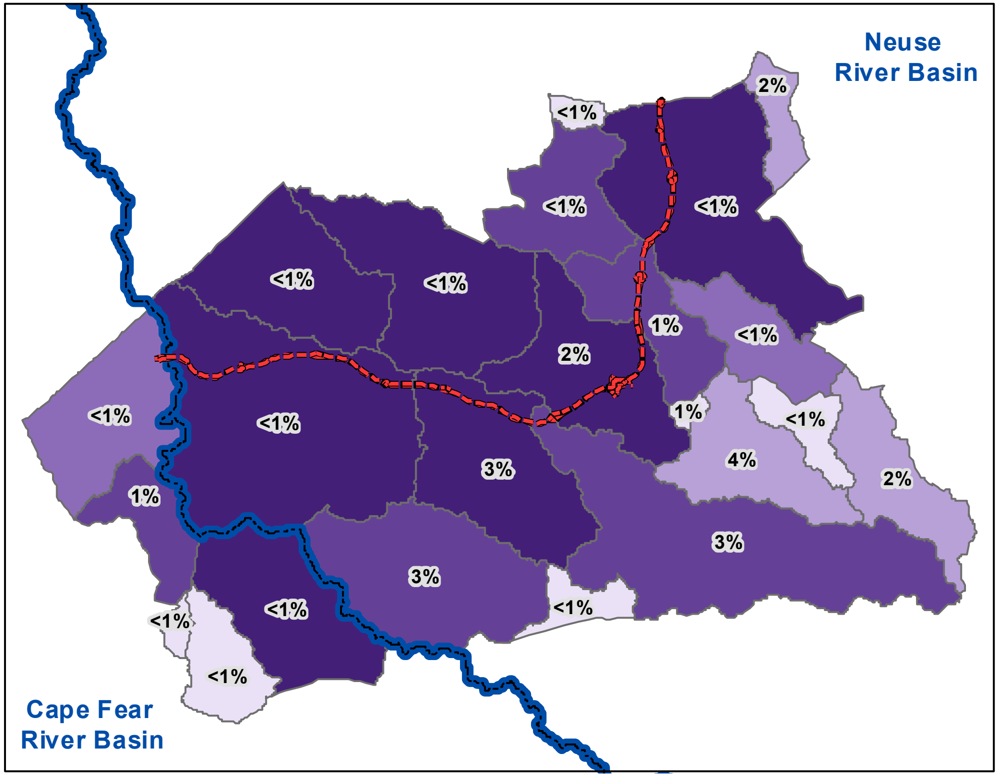
2040 No-Build (Model Run 2)

Percent Change - from 2010 to 2040 No-Build



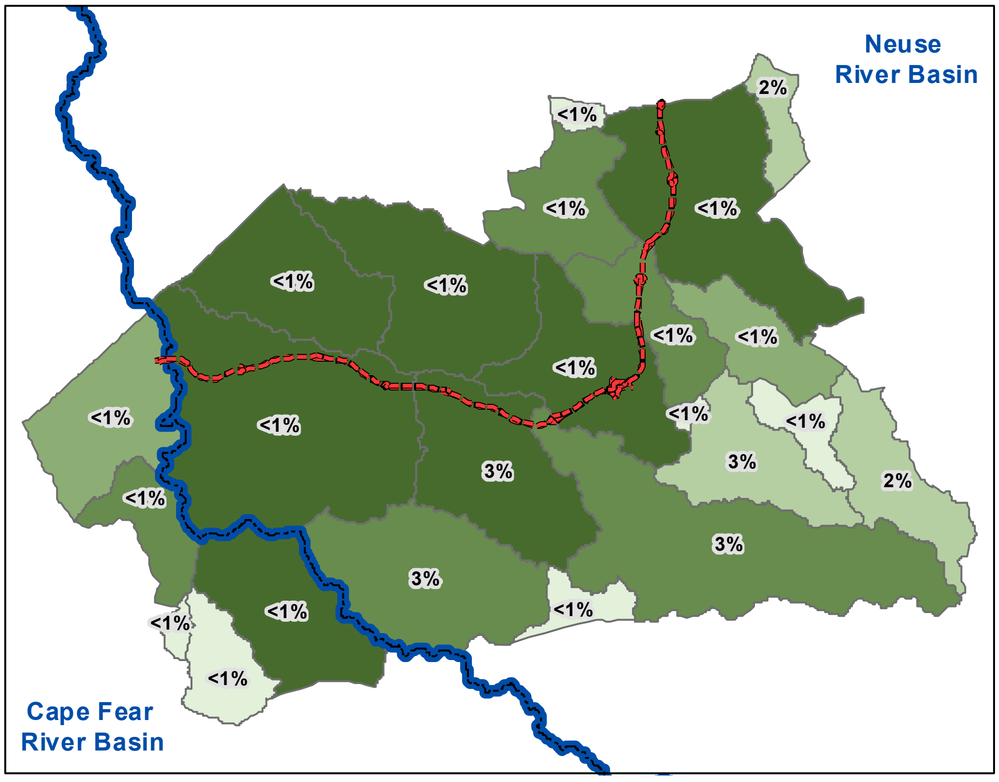
2040 Build (Model Run 1)

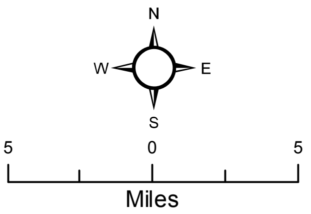
Percent Change - From 2040 No-Build to 2040 Build



2040 Build (Model Run 2)

Percent Change - From 2040 No-Build to 2040 Build





Cu Loads (g/yr/ac) (Model Run 1)

- 0.60 - 1.17
- 1.18 - 1.96
- 1.97 - 2.80
- 2.81 - 3.97
- 3.98 - 7.83

Legend

- Proposed 540
- River Basin Boundary

Cu Loads (g/yr/ac) (Model Run 2)

- 0.60 - 1.17
- 1.18 - 1.96
- 1.97 - 2.80
- 2.81 - 3.97
- 3.98 - 7.83

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Appendix B: Model Parameters and Notes

Parameter	Upper	Lower	Units	Group	Remarks
Recession coefficient (Model Run 1)	0.32	0.32	Unitless	3	Calibrated value. Modified from MAPSHED default to better reflect observed streamflows in the study area.
Recession coefficient (Model Run 2)	0.14	0.14	Unitless	3	Calibrated value. Modified from MAPSHED default to better reflect observed streamflows in the study area.
Seepage coefficient (Model Run 1)	0.56	0.56	Unitless	3	Calibrated value. Modified from MAPSHED default to better reflect observed streamflows in the study area.
Seepage coefficient (Model Run 1)	0.2	0.2	Unitless	3	Calibrated value. Modified from MAPSHED default to better reflect observed streamflows in the study area.
Sediment lateral erosion factor for streambank erosion	0.00649	0.00117	Unitless	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
Sediment adjustment factor	1	1	Unitless	1	Default constant supplied by MAPSHED.
Streams in agricultural areas	37.97	0	Km	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
Streams in agricultural areas with vegetated buffers	35.31	0	Km	3	Calculated. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Streams in urban areas	229.2	3.9	Km	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
Fraction of streams in urban areas with vegetated buffers	0.49	0.08	Unitless	3	Optional parameter with no default. Calculated in order to model BMPs. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Vegetated buffer strips BMP Nitrogen load efficiency	0.41	0.41	Unitless	3	Default constant supplied by MAPSHED.
Vegetated buffer strips BMP Phosphorus load efficiency	0.4	0.4	Unitless	3	Default constant supplied by MAPSHED.
Vegetated buffer strip width	22.99	15.14	m	3	Optional parameter with no default. Calculated in order to model BMPs. Varies by watershed based on stream GIS layer and calculated buffer intactness.
Vegetated buffer strips BMP sediment load efficiency	0.53	0.53	Unitless	3	Default constant supplied by MAPSHED.

Parameter	Upper	Lower	Units	Group	Remarks
Curve number for impervious fractions	98	92	Unitless	3	Calibrated value. Modified MAPSHED defaults by using area weighted curve numbers based on land use and soils to better reflect observed streamflows in the study area.
Curve number for pervious fractions	82	58	Unitless	3	Calibrated value. Modified MAPSHED defaults by using area weighted curve numbers based on land use and soils to better reflect observed streamflows in the study area.
Nitrogen accumulation on impervious surfaces	0.11	0.045	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Nitrogen accumulation on pervious surfaces	0.045	0.012	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Nitrogen dissolved fraction	0.33	0.28	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Phosphorus accumulation on impervious surfaces	0.0112	0.0045	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Phosphorus accumulation on pervious surfaces	0.0078	0.0016	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Phosphorus dissolved fraction	0.4	0.37	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Dissolved nitrogen runoff coefficient	2.9	0.012	mg/L	2	MAPSHED supplied default. Varies by land use and watershed based on input GIS layers.
Dissolved phosphorus runoff coefficient	0.1856	0.002	mg/L	2	MAPSHED supplied. Varies by land use and watershed based on input GIS layers including soil test phosphorus.
Manure nitrogen runoff coefficient	2.44	2.44	mg/L	1	Default constant supplied by MAPSHED.
Manure phosphorus runoff coefficient	0.38	0.38	mg/L	1	Default constant supplied by MAPSHED.
Groundwater nitrogen content	0.77	0.77	mg/L	1	Default constant provided by MAPSHED
Groundwater phosphorus content	0.01	0.01	mg/L	1	Default constant provided by MAPSHED
Tile drainage nitrogen content	15	15	mg/L	1	Default constant supplied by MAPSHED.

Parameter	Upper	Lower	Units	Group	Remarks
Tile drainage phosphorus content	0.1	0.1	mg/L	1	Default constant supplied by MAPSHED.
Per capita tank effluent – nitrogen	12	12	g/d	1	Default constant supplied by MAPSHED.
Per capita tank effluent – phosphorus	2.5	2.5	g/d	1	Default constant supplied by MAPSHED.
Growing season nitrogen uptake	1.6	1.6	g/d	1	Default constant supplied by MAPSHED.
Growing season phosphorus uptake	0.4	0.4	g/d	1	Default constant supplied by MAPSHED.
Sediment nitrogen content	2000	2000	mg/Kg	1	Default constant supplied by MAPSHED.
Sediment phosphorus content	562	562	mg/Kg	1	Default constant supplied by MAPSHED.
Percentage bank fraction for nitrogen	0.25	0.25	Unitless	1	Default constant supplied by MAPSHED.
Percentage bank fraction for phosphorus	0.25	0.25	Unitless	1	Default constant supplied by MAPSHED.
Septic system populations	268	268	people	2	MAPSHED supplied default.
Point source discharge	0	0	MGD	1	MAPSHED supplied default.
K = soil erodibility factor	0.248	0.17	Unitless	2	MAPSHED supplied default. Varies by land use and watershed based on input GIS layers.
LS = slope length factor * slope steepness factor	1.6	0.545	Unitless	2	MAPSHED supplied default. Varies by land use and watershed based on input GIS layers.
C = cover-management factor	0.42	0.001	Unitless	2	MAPSHED supplied default. Varies by land use based on input GIS layers.
P = support practice factor	0.45	0.1	Unitless	2	MAPSHED supplied default. Varies by land use and watershed based on input GIS layers.
Evapotranspiration (ET) cover coefficient	0.98	0.13	Unitless	3	Calibrated value. Modified from MAPSHED default to better reflect observed streamflows in the study area.
Daylight	14.4	9.6	hours	2	MAPSHED supplied. Varies by month.
Growing season	TRUE	FALSE	Boolean	3	Required parameter with no default. Used May - September growing season.

Parameter	Upper	Lower	Units	Group	Remarks
Erosion coefficient	0.28	0.18	Unitless	1	Default value provided by GWLF. Varies by month.
Stream extraction	0	0	cubic meters/ month	1	Default constant supplied by MAPSHED.
Ground extraction	0	0	cubic meters/ month	1	Default constant supplied by MAPSHED.
Initial unsaturated storage	10	10	cm	1	Default constant supplied by MAPSHED.
Initial saturated storage	0	0	cm	1	Default constant supplied by MAPSHED.
Unsaturated available water	18.403	10.68	cm	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
Initial snow	0	0	cm	1	Default constant supplied by MAPSHED.
Sediment delivery ratio	0.083	0.083	Unitless	2	MAPSHED supplied based on the watershed size.
Tile drain ratio	0.5	0.5	Unitless	1	Default constant supplied by MAPSHED.
Tile drain density	0	0	Unitless	1	Default constant supplied by MAPSHED.
TSS EMC	110	60	mg/L	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Open land nitrogen EMC	1.5	1.5	mg/L	1	Default constant supplied by MAPSHED.
Open land phosphorus EMC	0.12	0.12	mg/L	1	Default constant supplied by MAPSHED.
Ground water (subsurface) nitrogen	1	1	mg/L	1	Default constant supplied by MAPSHED.
Ground water (subsurface) phosphorus	0.01	0.01	mg/L	1	Default constant supplied by MAPSHED.
Soil nitrogen	50	50	ppm	1	Default constant supplied by MAPSHED.
Soil phosphorus	100	100	ppm	1	Default constant supplied by MAPSHED.
Lateral erosion factor for streambank erosion	0.00535	0.00299	Unitless	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
ET adjustment percentage	3.1	0.9	Unitless	3	Calibrated value. Modified from MAPSHED default to better reflect observed streamflows in the study area

Parameter	Upper	Lower	Units	Group	Remarks
Point source nitrogen loads	196997	0	Kg	3	Calculated based on NPDES data. Varies by watershed based on input GIS layers.
Point source phosphorus loads	868	0	Kg	3	Calculated based on NPDES data. Varies by watershed based on input GIS layers.
Combined sewer overflows - nitrogen	35	35	mg/L	1	Default constant supplied by MAPSHED.
Combined sewer overflows - phosphorus	10	10	mg/L	1	Default constant supplied by MAPSHED.
Critical rainfall	1	1	cm/day	1	Default constant supplied by MAPSHED.
Dissolved phosphorus runoff coefficient	0.752	0.002	mg/L	2	MAPSHED supplied. Varies by land use and watershed based on input GIS layers including soil test phosphorus.
High intensity urban nitrogen runoff coefficient	0.101	0.101	Kg/ha/d	1	Default constant supplied by MAPSHED.
Low intensity urban nitrogen runoff coefficient	0.12	0.12	Kg/ha/d	1	Default constant supplied by MAPSHED.
High intensity urban phosphorus runoff coefficient	0.011	0.011	Kg/ha/d	1	Default constant supplied by MAPSHED.
Low intensity urban phosphorus runoff coefficient	0.002	0.002	Kg/ha/d	1	Default constant supplied by MAPSHED.
Ground water nitrogen content	1	1	mg/L	1	Default constant provided by MAPSHED
Ground water phosphorus content	0.01	0.01	mg/L	1	Default constant provided by MAPSHED
Per capita tank effluent - nitrogen	12	12	g/d	1	Default constant supplied by MAPSHED.
Per capita tank effluent - phosphorus	2.5	2.5	g/d	1	Default constant supplied by MAPSHED.
Growing season Phosphorus uptake	2.5	2.5	g/d	1	Default constant supplied by MAPSHED.
Sediment nitrogen content	3000	3000	mg/Kg	1	Default constant supplied by MAPSHED.
Sediment phosphorus content	6143	474	mg/Kg	2	Default constant supplied by MAPSHED. Varies by watershed based on GIS including soil test phosphorus.

Parameter	Upper	Lower	Units	Group	Remarks
Septic system populations	4386	0	people	2	MAPSHED supplied default. Varies by watershed based on input GIS layers.
Point source nitrogen loads	6379.9	0	Kg	2	MAPSHED supplied default. Varies by watershed based on input GIS layers.
Point source phosphorus loads	652.3	0	Kg	2	MAPSHED supplied default. Varies by watershed based on input GIS layers.
Point source discharge	1.2	0	MGD	2	MAPSHED supplied default. Varies by watershed based on input GIS layers.
Curve number	91	59	Unitless	3	Modified MAPSHED defaults by using area weighted curve numbers based on land use and soils.
Vegetated buffer strips BMP Nitrogen load efficiency	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	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	0.9775	0.85	Unitless	3	Modified default value to fit NC standards from the NCDWQ stormwater manual.
Nitrogen accumulation on impervious surfaces	0.101	0.045	Kg/Ha/day	2	MAPSHED supplied. Varies by land use based on input GIS layers.
Point source nitrogen loads	196997	0	Kg	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
Point source phosphorus loads	868	0	Kg	2	MAPSHED supplied. Varies by watershed based on input GIS layers.
Point source discharge	0	0	MGD	2	MAPSHED supplied. Varies by watershed based on input GIS layers.