TECHNICAL MEMORANDUM #1:
Tar River Flow Study – Final Study Plan

To:
Greenville Utilities Commission
Tar River Flow Study Technical Advisory Group

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1. Introduction

The State of North Carolina typically limits water withdrawals to no more than twenty percent of the 7Q10 flow unless a flow study is conducted that determines additional withdrawals are acceptable. Greenville Utilities Commission's (GUC) water treatment plant (WTP) is permitted to withdraw 22.5 million gallons per day (mgd) from the Tar River for public water supply and is one of the few tidally influenced public water supply intakes in North Carolina. Because of this tidal influence, the State allowed GUC's permitted capacity to exceed twenty percent of the 7Q10 flow. When approving the permit that established GUC's 22.5 mgd withdrawal allocation, the Division of Water Resources noted that any future plant expansion requests would have to be accompanied by a flow study of the Tar River.

GUC has initiated this planning study to evaluate the issues associated with future flow conditions and a range of water withdrawals. GUC does not intend to request a permit for a water treatment plant expansion as a part of this instream flow study. The intent of this study is to develop an agency approved approach for evaluating the Tar River's instream flow needs. The study will develop models and methods to assess water quality, water quantity, and habitat conditions over a range of flow and metrological conditions. GUC has proactively initiated this Tar River Flow Study to understand the instream flow needs of the river and the amount of water available to support long-term water supply and capital improvements planning. Groundwater withdrawal reductions mandated by the Central Coastal Plain Capacity Use Area (CCPCUA) Rules, recent droughts, encroachment of saltwater, and increasing regional water supply needs have further emphasized the need for a better understanding of water availability in the Tar River.

GUC is investigating the capacity of the Tar River to support additional future water withdrawal under various flow conditions, particularly low flows. This investigation is not associated with a specific proposed water withdrawal amount at this time. However, the study will be valuable for identifying the flow ranges within which additional withdrawals are supported while maintaining beneficial habitat and water quality conditions in the lower Tar River. The ultimate goal of the study is to provide a sound basis for planning and to establish the scientific basis for GUC's future water withdrawal permit applications.

This Study Plan presents background information about the river, the study goals and objectives, and describes the proposed approach, study elements, and many technical details. GUC is committed to a broadly collaborative study process, involving federal and state resource and regulatory agencies in a Technical Advisory Group (TAG). The primary objective of this Study Plan is to serve as a basis for discussion and agreement during scoping with government agency participants on the issues, study design, Study Area, data collection, and methods of analysis.

1.1 Scoping Phase, Study Plan, and Technical Advisory Group

The Tar River Flow Study scoping is a collaborative process involving GUC, the consultant team, and the resource and regulatory agencies constituting the TAG. The process involves periodic interactive meetings with TAG participants, during which information will be exchanged so that TAG members can reach a consensus regarding key elements of the study including the scope, design, and methods to be used for the Tar River Flow Study.

The TAG is responsible for evaluating and commenting on the proposed study design and methods and will be consulted on methods development, analysis, and data interpretation throughout the duration of the study. Coordination meetings, the study plan, and technical memoranda are the primary tools for communicating and commenting on proposed approaches, methods, and analyses. Periodic meetings will be held with the TAG to provide a forum for open communication on the scoping process, study execution, and evaluation of the study results. The consultant team will summarize meetings and document decisions and outcomes for each meeting. Meeting summaries will be distributed to the TAG for review and comment, and will be placed on the project web site.

Elements of the Tar River Flow Study that continue to be refined in collaboration with the TAG include the following:

- Study goals and objectives
- Geographic boundaries and important time periods for modeling and assessment
- Data collection and analysis methods
- Baseline river hydrology
- Hydrologic, habitat, and hydrodynamic modeling approaches and model requirements
- Representative and important species and resources for the assessment
- Water quality parameters, species habitat indices, and appropriate biological criteria for modeling and assessment
- Study sites
- Scenarios for analysis of potential habitat and water quality effects resulting from increased water withdrawals
- Identification of maximum withdrawal amount

This Final Study Plan provides the framework for the entire Tar River Flow Study, though some elements of study site selection, biological criteria, and modeling details will be decided and documented separately in Technical Memorandums after final publication of the Study Plan.

1.2 Study Goals and Objectives

GUC has initiated the flow study for the Tar River to better understand instream flow issues and the amount of water seasonally available to support long-term water management projects. These include possible future expansion of the water treatment plant and conveyance system and additional interbasin transfers necessary to meet CCPCUA requirements and GUC's existing and future water agreements.

The main goals of the Tar River Flow Study are to:

- Quantify the amount of Tar River water, or withdrawal rate, available for future water supply.
- Identify environmental constraints to future withdrawals.

- Provide the analysis and documentation needed to support future permit applications for expansion of GUC's WTP.
- Address the movement of the fresh-saltwater interface and the potential impact to GUC's water supply and management operations.
- Allow GUC to respond to a wide range of water management issues in the basin.

The Tar River Flow Study objectives are to:

- Identify the capacity of the Tar River to provide drinking water for GUC customers while still supporting other critical instream water uses.
- Provide a method for quantifying the relationship between flow, instream habitat, and aquatic resources.
- Identify the potential habitat and water quality constraints on flow withdrawals.
- Develop potential flow management strategies to balance water availability and protection of aquatic resources in the Tar Basin.
- Characterize risk to public water supply associated with upstream movement of the freshwater/saltwater interface, especially under critical drought periods.

The following sections provide a brief overview of some of the factors and circumstances providing the impetus and need for this study, as well as how the findings of this study will fit into the context of GUC's water supply plans and programs.

1.3 Coastal North Carolina Water Management

The Tar River Flow Study is, in part, a direct result of the need to reduce groundwater use in coastal North Carolina, and to use surface waters, such as the Tar River, as an alternative source to groundwater. Groundwater is the primary water source in the central coastal plain of North Carolina, comprising 67 percent (64 mgd) of the total publicly supplied water (95 mgd) in 1997 (Waters et al., 2003). In the late 1990s, concern over declining groundwater levels, decreasing well yield, and saltwater intrusion into these aquifers prompted the Environmental Management Commission (EMC) to designate the CCPCUA, illustrated in Figure 1-1.

In order to reverse declining water levels and saltwater intrusion in the important Cretaceous aquifers, the EMC passed rules in 2002 for groundwater use in the fifteen-county CCPCUA. The CCPCUA rules mandated a reduction in groundwater withdrawals to decrease use of the Cretaceous aquifers in coastal North Carolina to sustainable levels. The rules target up to a 75 percent reduction in annual groundwater withdrawals by 2018. These rules have created the need for increased reliance on surface water sources, such as the Neuse River, Tar River, Contentnea Creek, and Northeast Cape Fear River, as well as the development of alternative water management strategies. According to Waters et al. (2003), the most promising water supply alternatives are aggressive water conservation, development of under-used or alternate aquifers and rivers, and regionalized water supply systems. Progress to date among suppliers has included the investigation of alternative groundwater sources, formation of regional entities to make use of surface water sources, and greater reliance upon interconnection and purchase agreements (DWR, 2004).

Unlike the surficial unconfined aquifers, Cretaceous aquifers are deep confined aquifers that are not directly connected with the Tar River. Groundwater contributions from surficial aquifers, however, do supply a considerable portion of the Tar River's baseflow within the Study Area. O'Driscoll et al. (2008) found that groundwater from the shallow water table aquifer contributes about 60 percent of the Tar River's baseflow. O'Driscoll et al. (2008) also noted that "groundwater flux into and out of the channel varied between the north and south sides of the river" as well as over time and distance with most river reaches gaining groundwater and others losing groundwater.

1.4 Recent Drought and River Conditions

Recent droughts have placed additional pressures on water resources in the Tar-Pamlico Basin. Two of the most significant droughts on record have occurred in the past decade. During the droughts of 1998 to 2002 (Weaver, 2005) and 2007, recorded stream flows reached record low levels and greatly concerned surface water suppliers. Rocky Mount reduced minimum release in 2007 and flows in the Tar River downstream of the reservoir went below 40 cubic feet per second (cfs). The reduced reservoir releases were the result of very low storage remaining in the reservoir due to a gaging error that caused their release protocol to function incorrectly. Tables and figures in Section 2.7 provide average annual and median monthly Tar River Flows at Greenville for flow comparisons and context for withdrawal quantities.

Climate cycles and possible long-term climate change also have the potential to increase variability in precipitation and runoff, and may pose a significant long-term risk to North Carolina's water resources, particularly along the coast. Investigators have suggested that the State of North Carolina may expect drier summers, when water is needed the most, and wetter winters, when water needs are lower (USGCRP, 2004). Riggs et al. (2008), suggest that Coastal North Carolina will see increased storm damage, higher flood levels and sea level rise and associated additional saltwater encroachment (Riggs et al., 2008). Drought conditions can also affect how far saltwater moves upstream in the Tar River. GUC has been closely monitoring the location of saline water in the river and in 2007, saltwater moved upstream to within ten miles of the GUC WTP intake.

The TAG requested that climate change be considered in the scoping of the Tar River Flow Study. Discussions related to climate change have been held with the TAG including recognition of possible increased drought conditions and sea level rise. GUC has agreed that this issue will be addressed in the future when there is additional consensus on the extent of the issue and the State has developed a policy. Addressing climate change through modeling is not within the scope of the current study, and accurate and accepted estimates of climate change on which those analyses would rely have yet to be developed. It is noteworthy that a recently published article in the Journal of the American Meteorological Society (Seager et al., 2009) demonstrates that droughts in the Southeast U.S. in recent decades are no more severe than those in the historical record. Seager et al. (2009) also indicate that the predictive skill of climate models to simulate future precipitation and evaporation patterns in the Southeast is low, especially during the summer.

1.5 GUC Water Use and Interbasin Transfers (IBT)

GUC's WTP (Figure 1-2) is permitted to withdraw 22.5 mgd from the Tar River for public water supply and one of the few tidally influenced public water supply intake in North Carolina. Currently, GUC's annual average daily water use is approximately 10 to 11 mgd with peak withdrawal rates of about 16 mgd. Typical of many municipal water intakes, GUC's intake is a run-of-river withdrawal with limited water storage capacity, and so could be vulnerable to saltwater intrusion.

In addition to providing for the needs of its service area, GUC serves as a regional water supplier and currently provides additional water to the Towns of Farmville, Winterville, Bethel, Stokes, and communities in Greene County. GUC's ability to supply water to Winterville, Farmville, and Greene County is contingent upon obtaining an Interbasin Transfer (IBT) Certificate. An Environmental Assessment (EA) was completed to evaluate potential effects on the Tar River and the receiving basins (Neuse River and Contentnea Creek) associated with the proposed IBT (ARCADIS, 2007). The draft IBT Petition was submitted to the EMC in May 2009. The IBT Certificate was issued in the fall of 2010.

1.6 Water Supply Planning and Management

GUC is proactively planning for long-term water supply and drought management. This planning has resulted in the development of water conservation measures that include three water conservation stages based on river level and salt wedge location. GUC is also conducting several studies that may provide options for improving their ability to continue to provide reliable public water supply during drought conditions. The use of water in existing sand mine borrow pits to supplement flows in the Tar River during critical periods is also being evaluated.

In order to reduce the likelihood of Tar River water levels falling below the existing intake levels, and to provide backup intake structures if the existing intake pipes were to become inoperable, GUC is installing an additional water intake structure just downstream of the existing WTP intake (Brown and Caldwell, 2008). The new intake structures will be at a greater river depth than the existing intake and will provide GUC redundancy and flexibility in water withdrawal location. Another study underway by GUC is an evaluation of the use of a portable and temporary, submerged, saltwater intrusion barrier to prevent saline water at the bottom of the river from moving further upstream and potentially reaching the existing WTP intake under extreme low-flow conditions. The results of the Tar River Flow Study will be useful for this evaluation; the modeling completed in the Tar River Flow Study will provide a better estimate of the potential for upstream saltwater intrusion under critical low-flow periods. Model results will predict the potential location of the saltwater wedge, and identify conditions when the barrier may be needed.

Aquifer storage and recovery (ASR) is also a potentially important component of the overall water supply management scheme being studied and implemented by GUC. ASR is the use of a well for the injection of potable water into an aquifer where it is stored until it is withdrawn for use. When implemented, GUC's ASR program will inject treated drinking water into the Black Creek and Upper Cape Fear aquifers for storage during times of excess supply. This water will be recovered later to help meet peak demands when river flows are typically low. GUC has received an underground injection control (UIC) permit from the State of North Carolina.

2. Background and Current Conditions

The Tar River Basin covers approximately 5,500 square miles and is the fourth largest basin in North Carolina (Figure 1-1). Only four basins including the Tar Basin lie entirely within the State's boundaries. The Tar River originates in north central North Carolina in Person, Granville and Vance counties and flows southeasterly until it reaches estuarine waters near Washington and becomes the Pamlico River Estuary (DWQ 2004).

The upstream portion of the river from its headwaters downstream to the City of Washington is the Tar River. Downstream from the City of Washington, the Pamlico River is a tidal estuary that flows into the Pamlico Sound. Most of the Tar River is fresh water with some transitional estuarine waters, whereas the Pamlico River is entirely estuarine. Major tributaries of the lower Tar River include Chicod Creek, Grindle Creek, and Tranters Creek (Figure 1-2). The transition from Pamlico River Estuary to Pamlico Sound occurs near the junction of the Pungo and Pamlico Rivers.

2.1 Water Quality in the Lower Tar River Basin and Pamlico River Estuary

2.1.1 Water Quality Monitoring Results and Waterbody Impairments

Water quality is monitored at a number of locations in the lower Tar River Basin and in the Pamlico River by either the DWQ or the Tar Pamlico Basin Association (TPBA) (Table 2-1). Table 2-1 also identifies the water quality classification of each location and whether any water quality parameters significantly violated water quality standards in the period from 2003 through 2007 (DWQ, 2008). The DWQ stations are monitored monthly for field parameters (temperature, DO, pH, and conductivity), fecal coliform, turbidity, and nutrients (ammonia, nitrite plus nitrate, total Kjeldahl nitrogen, and total phosphorus). Total suspended solids (TSS) and metals are monitored quarterly. Metals sampling has been suspended by DWQ since 2007. The TPBA stations are sampled twice monthly for field parameters and monthly for nutrients, turbidity, TSS, and fecal coliform. TSS is not measured at the two TPBA Flat Swamp Stations. GUC collects field parameters, turbidity, and salinity at multiple depths when monitoring the location of the freshwater/saltwater interface.

The DWQ considers water quality in the Tar River at Greenville to be "good" and "supporting" downstream of Greenville (DWQ, 2004). Despite drought conditions in 2007, none of the water quality samples collected by DWQ or the TPBA from 2003 through 2007 on the mainstem of the Tar River at US 264 bypass upstream of Greenville violated state standards. Data for the Tar River at Grimesland, about 10 miles downstream of the Tar River at US 264, indicate that dissolved oxygen (DO) measurements fell below the water quality standard for a single measurement, 4 mg/l, two percent of the time and pH fell below 6 salinity units (SU) two percent of the time. Fecal coliform levels in the Tar River at Grimesland exceeded 400 colonies per 100 ml in five percent of the samples.

For the Pamlico River Estuary at the NC 17 Bridge at Washington, six percent of the DO samples fell below 5 mg/l (saltwater DO standard), 16 percent of pH measurements were below 6.8 SU, zero percent of the pH readings were above 8.6 SU. Also at the NC 17 Bridge, eight percent of the chlorophyll a data were greater than 40 µg/l and one percent of the turbidity data were greater than 25 NTU. None of these measurements, except the low pH values on the Pamlico River at Washington, were significant enough for DWQ to classify the waterbody as impaired.

Table 2-1: Water Quality Monitoring Locations and Statistically Significant Water Quality Standards Violations in the Lower Tar and Pamlico Rivers 2003 to 2007

Organization	Station ID	Site Name	Stream Classification*	Date Established	Statistically Significant Water Quality Standard Violations (2003 – 2007 Data)**
Lower Tar Basin					
DWQ	O6200000	Tar R. at NC 222 NR Falkland	WS-IV NSW	10/10/1973	
DWQ	O6205000	Conetoe Ck at SR 1409 NR Bethel	C NSW	8/1/1984	32% of pH (<6 SU) and 42% of DO samples (<4 mg/l)
DWQ	O6240000	Tar R. at US 264 Bypass NR Greenville	WS-IV NSW	11/16/2005	
DWQ	O6450000	Chicod Ck at SR 1760 NR Simpson	C NSW	8/1/1984	
DWQ	O6500000	Tat R. at SR 1565 NR Grimesland	B NSW	7/5/1968	
TPBA	O6700000	Grindle Ck at SR 1427 near Bethel	C NSW	3/1/2007	
TPBA	O6798000	Grindle Ck at US 264 at Pactolus	C NSW	3/1/2007	
TPBA	O7000000	Flat Swamp at SR 1159 (Third St) at Robersonville	C SW NSW	3/1/2007	
TPBA	O7100000	Flat Swamp at SR 1157 NR Robersonville	C SW NSW	3/1/2007	
DWQ	O7300000	Tranters CK at SR 1403 NR Washington	C Sw NSW	10/10/1973	

Table 2-1: Water Quality Monitoring Locations and Statistically Significant Water Quality Standards Violations in the Lower Tar and Pamlico Rivers 2003 to 2007

Organization	Station ID	Site Name	Stream Classification*	Date Established	Statistically Significant Water Quality Standard Violations (2003 – 2007 Data)**
Pamlico River Estuary					
DWQ	O7650000	Pamlico R. at US 17 at Washington	SC NSW	7/6/1968	16% of pH samples (<6.8 SU)
DWQ	O7680000	Pamlico R. at CM 16 NR Whichard Beach	SB NSW	3/7/1992	17% chlorophyll *a* (>40 ug/l) and 14% pH (<6.8 SU) values
DWQ	O7710000	Chocowinity Bay Above Silas Ck NR Whichard Beach	SC NSW	3/7/1992	31% chlorophyll *a* (>40 ug/l)
DWQ	O787000C	Pamlico R. at Mouth of Broad Ck NR Bunyon Mid Channel	SB NSW	6/13/1974	21% chlorophyll *a* (>40 ug/l) and 10% pH (<6.8 SU) values
DWQ	O787000N	Pamlico R. at Mouth of Broad Ck NR Bunyon N Shore	SB NSW	6/14/1989	
DWQ	O787000S	Pamlico R. at Mouth of Broad Ck NR Bunyon N Shore	SB NSW	5/18/1999	
DWQ	O8495000	Bath Ck at NC 92 NR Bath	SB NSW	2/14/1974	21% chlorophyll *a* (>40 ug/l) and 10% pH (>8.5 SU) values
DWQ	O8498000	Pamlico R. at CM 5 NR Core Point	SB NSW	5/31/1989	23% chlorophyll *a* (>40 ug/l)
DWQ	O865000C	Pamlico R. at CM 4 NR Gum Point Mid Channel	SB NSW	5/18/1999	20% chlorophyll *a* (>40 ug/l)
DWQ	O865000N	Pamlico R. at CM 4 NR Gum Point N Shore	SB NSW	5/18/1999	

Table 2-1: Water Quality Monitoring Locations and Statistically Significant Water Quality Standards Violations in the Lower Tar and Pamlico Rivers 2003 to 2007

Organization	Station ID	Site Name	Stream Classification*	Date Established	Statistically Significant Water Quality Standard Violations (2003 – 2007 Data)**
DWQ	O865000S	Pamlico R. at CM 4 NR Gum Point S Shore	SB NSW	5/18/1999	
DWQ	O9059000	Pamlico R. at Hickory PT NR South Ck	SA HQW NSW	8/10/1977	
DWQ	O9755000	Van Swamp at NC 32 NR Hoke	C Sw NSW	8/1/1984	75% pH (<4.3 SU) values
DWQ	O982500C	Pamlico R. Between Mouths of Pungo R. and Goose Ck Mid Channel	SA HQW NSW	5/18/1999	
DWQ	O982500N	Pamlico R. Between Mouths of Pungo R. and Goose Ck N Shore	SA HQW NSW	5/18/1999	
DWQ	O982500S	Pamlico R. Between Mouths of Pungo R. and Goose Ck S Shore	SA HQW NSW	5/18/1999	

** C = Freshwaters protected for secondary recreation, fishing, and aquatic life, SC = Saltwaters protected for secondary recreation, fishing and aquatic life, B = Freshwaters protected for primary recreation which includes swimming and all Class C uses, SB = Saltwaters protected for primary recreation which includes swimming and all SC uses, NSW = Nutrient Sensitive Waters, Sw = Swamp Waters, SA = Suitable for commercial shellfishing and all other tidal saltwater uses, HQW = High Quality Waters which are rated as excellent based on biological and physical/chemical characteristics*

***Statistically Significant Water Quality Standards Violations as determined by DWQ in Tar-Pamlico River Basin Ambient Monitoring Report June 2008. Standards exceedances are considered significant if there is 95% or greater confidence that a standard has been violated by 10% or more samples.*

Table 2-2 identifies the waterbodies within the Study Area that are listed on North Carolina's 2008 Draft 303(d) list of impaired waterbodies. The most common reasons for impairment of these waters are when more than ten percent of the monitoring results violate water quality standards, or biological monitoring data indicates a negatively affected benthic or fish population. A segment of the mainstem, approximately 13 miles long, beginning at GUC's WTP intake is currently impaired for fish consumption due to elevated concentrations of mercury in fish tissue.

Table 2-2: Draft 2008 303(d) Impaired Waterbody List for Lower Tar and Pamlico River Basins

Waterbody	Impairment Segment (Assessment Unit)	Impaired Use and Parameter of Interest	303(d) Listing Year
Lower Tar Basin			
Tar River	From GUC WTP Intake to point 1.2 miles downstream of Broad Run	Fish Consumption: Mercury in Fish Tissue	2006
Chicod Creek	From Source to Tar River	Aquatic Life: Benthic sampling indicates impaired biologic health	1998
Hendricks Creek	Source to Tar River	Aquatic Life: Benthic sampling indicates impaired biologic health	2008
Cokey Swamp	Source to Dickson Branch	Aquatic Life: Benthic sampling indicates impaired biologic health	2006
Bynum's Mill Branch	Source to Town Creek	Aquatic Life: Benthic sampling indicates impaired biologic health	2006
Conetoe Creek	Source to 1350 meters north of NC 42 (two assessment units)	Aquatic Life: Benthic sampling indicates impaired biologic health	1998
Conetoe Creek	From Crisp Creek to Pitt County SR 1404	Aquatic Life: Standards Violation Low pH	2008
Ballahack Canal	Source to Conetoe Creek	Aquatic Life: Benthic sampling indicates impaired biologic health	2006
Greens Mill Run	Source to Tar River	Aquatic Life: Benthic sampling indicates impaired biologic health	2008
Pamlico River Estuary			
Pamlico River Estuary	G11	chlorophyll *a*	1996

Table 2-2: Draft 2008 303(d) Impaired Waterbody List for Lower Tar and Pamlico River Basins

Waterbody	Impairment Segment (Assessment Unit)	Impaired Use and Parameter of Interest	303(d) Listing Year
Pamlico River (Upper Segment)	From NC 17 Bridge to line 0.75 miles downstream of Runyon Creek and 0.5 miles downstream of Rodman Creek	Aquatic Life and Recreation: Standards Violation Low pH and Elevated Enterococcus	2008
Pamlico River (Upper Segment)	From the line 0.75 miles downstream of Runyon Creek and 0.5 mile downstream of Rodman Creek to 0.65 miles downstream of Chocowinity Bay.	Aquatic Life: Standards Violation Low pH	2008
Pamlico River (Blounts Bay Segment)	From 0.65 miles downstream of Chocowinity Bay to line at east mouth of Blounts Bay	Aquatic Life: Standards Violation chlorophyll *a*	2008
Pamlico River (Pamlico Bath Segment)	From line at east mouth of Blounts Bay to west mouth of Durham Creek	Aquatic Life: Standards Violation chlorophyll *a*	2008
Pamlico River (Middle Segment)	From west mouth of Durham Creek to line from Huddy Creek to Saint Claire Creek	Aquatic Life: Standards Violation chlorophyll *a*	2008

2.1.2 Relationship Between Inflows and Pamlico River Estuary Water Quality

The Pamlico River Estuary is considered impaired for chlorophyll *a* and DO and a Total Maximum Daily Load (TMDL) was approved for total nitrogen and total phosphorus in 1995. Although nutrient inputs to the estuary have decreased significantly over the last decade, the estuary still experiences episodes of low DO (DWQ, 2003; DWQ, 2004) and a recent nutrient trend analysis indicates that nutrient concentrations are increasing (DWQ, 2009).

In 2003, DWQ conducted an analysis of water quality data for the Tar River at Grimesland to look for trends in nutrient loading from 1991 through 2002. The DWQ used a nonparametric statistical analysis, the seasonal Kendall's test, to identify trends in nutrient loading. After removing the variability in nutrient concentrations associated with flow, DWQ found that there was an 18 percent reduction in total nitrogen and a 33 percent reduction in total phosphorus concentrations at the Grimesland station from 1991 to 2002 (DWQ, 2003). In 2009, DWQ repeated this analysis for 1997 to 2008 data at the same station. This analysis indicated that there was a 17 percent increase in total nitrogen and a 22 percent increase in median total phosphorus (DWQ, 2009). The Pamlico River Estuary has continued to have problems with summertime fish kills. The number of reported fish kills peaked in 2001 at 23 with significantly fewer fish kills observed since then (eight in 2002, six in 2003, two in 2004, one in 2005, one in 2006 linked to high water temperatures and bottom hypoxia, and zero in 2007). The number of fish kill events increased in 2008. According to DWQ's 2008 Fish Kill Monitoring Report:

> Salinity and DO profiles of the Pamlico River in early August [2008] reveal an infusion of high salinities, water column stratification, and an apparent drop in DO levels at the

> location of the...kill. Conditions such as these have been repeatedly documented prior to and during many events in the Neuse and Tar/Pamlico estuaries (DWQ 2008b).

Nutrient delivery and flows influence estuarine production. Certain inflow levels and meteorological conditions produce the development of stratification in the estuary and the occurrence of low DO levels particularly in the bottom layer of the water column next to the sediments. Relationships among bottom-water DO, vertical stratification, and the factors responsible for stratification and destratification in this shallow, low tidal-energy estuary were studied using a 15-year set of biweekly measurements (Stanley and Nixon, 1992). Stanley and Nixon (1992) found that:

> Hypoxia develops only when there is both vertical water-column stratification and warm water temperatures (≥ 15°C). In July 1991, 75 percent of the DO readings were < 5 mg/l and one-third were < 1 mg/l. Severe hypoxia occurred more frequently in the upper half of the estuary than near the mouth. Both the time series data and correlation analysis indicated that stratification events and DO levels are tightly coupled with variations in freshwater discharge and wind stress. Stratification can form or disappear in a matter of hours, and episodes lasting from one to several days seem to be common. Estimated summertime respiration rates in the water and sediments were sufficient to produce hypoxia if the water was mixed only every 6 to 12 days (Stanley and Nixon, 1992).

Stanley and Nixon saw no trend toward lower bottom water DO in the Pamlico River Estuary over the 15 years of data that their study evaluated. Lin et al. (2008) found a similar relationship between estuary stratification and low DO levels. East Carolina University (ECU) and the United States Geological Survey (USGS) conducted a 7-year water quality study on the Pamlico River system. ECU collected water quality data bi-weekly at eight stations from 1997 to 2003. The USGS collected continuous water quality data at three stations between 1999 and 2003. Analyses of the DO, salinity, temperature, and nutrient data were published by Lin et al. (2008). Lin et al. (2008) used the water quality data collected by ECU and USGS to associate estuary stratification levels and water quality conditions with patterns of freshwater discharge and wind mixing events. Strong salinity stratification appears to be associated with higher freshwater inflows and fewer wind mixing events. The greater nutrient loading and strong salinity stratification that occur during high discharge years is associated with higher average chlorophyll *a* concentrations. Chlorophyll *a* concentrations were significantly lower and DO concentrations higher in years with low inflows.

Hypoxic conditions were observed mostly in the upper to middle Pamlico estuary, but the frequency of hypoxic events varied between years. During June to October 1997–1999 bottom water hypoxia (DO < 2 mg/l) was found in 8.7 percent of the observations. By contrast, during June to October in 2001 through 2003, 37.9 percent of the total measurements had DO concentrations less than 2 mg/l. The more frequent and/or prolonged hypoxic conditions during 2001 to 2003 were closely associated with stronger salinity stratification and greater loadings of nutrient and particulate matter (Lin et al. 2008).

2.2 Hydrology of the Tar River

The Tar River system is largely unregulated; total reservoir storage in the basin equals only a small percentage of the annual flow of the river. The drainage area of the Tar River gage at Tarboro (Gage No. 02083500) is 2,186 square miles. The drainage area of the Tar River at Greenville (Gage No. 02084000) is 2,660 square miles. Historic flows in the Tar River were recently evaluated and characterized in detail by ENTRIX (2008) as a part of GUC's recent application for an interbasin transfer (ARCADIS, 2008). A hydrologic model was developed for the lower Tar River to predict river flows under current and future water usage scenarios. The relationship between available flow records for the Tar River at Greenville and the Tar River at Tarboro was estimated using hydrologic and statistical methods. The analysis was based on available USGS flow records from the Tar River at Tarboro and the Tar River at Greenville (USGS, NWIS). The flow record at the Tar River at Tarboro gage provides a long-term record (1931 to 2007) of hydrologic conditions in the river, representing the majority of the entire drainage area of the basin. The flow records at Tarboro are also the best available data for predicting downstream flows at Greenville, where a more limited period of record is available (1997 to 2007). Monthly and annual flow exceedance values at the USGS gage at Greenville, based on the hydrologic modeling, are provided in Appendix A.

2.3 Tar River Water Management and Previous Instream Flow Studies

There have been no comprehensive studies of the instream flow or freshwater inflow needs of the Tar-Pamlico River or Pamlico Sound. Flow management in the Tar-Pamlico River Basin to date has been accomplished largely on a case-by-case basis in response to proposed projects, National Pollutant Discharge Elimination System (NPDES) permits, stipulation of flows under the NC Dam Safety Act, and one habitat-based instream flow study in the Upper Tar River near Louisburg. With the exception of coordination of permits near the City of Rocky Mount for water supply and assimilative capacity, there are no basinwide or stream segment-specific flow requirements.

2.3.1 Tar River at Louisburg

In 1995, Division of Water Resources (DWR) completed a flow study in the Tar River in conjunction with a proposal by the Town of Louisburg to increase their withdrawal from the Tar River from 2 mgd to 3 mgd. The study evaluated stream flows and aquatic habitat in the Tar River at a site just upstream of the Louisburg wastewater treatment plant (WWTP) discharge and downstream of Fox Creek using a series of models and procedures referred to as the Instream Flow Incremental Methodology (IFIM). The analysis involved habitat mapping, hydraulic measurements and modeling, habitat preferences for aquatic species including redbreast sunfish, creek chub, and the Tar River spinymussel, flow time series and habitat time series. When the simulated physical conditions were merged with habitat preferences, the result was a habitat versus flow relationship for the life stages of each species.

The habitat versus flow relationship was merged with stream flows to yield a record of the habitat available over time for each species. This habitat record was analyzed to determine target amounts of habitat, which should be maintained to prevent significant effects and to compare different project scenarios to the pre-project baseline conditions. The pre-project flow record was modified to generate different project flow and habitat scenarios. The first scenario involved a constant withdrawal of 3 mgd "skimmed" from the pre-project flow record without any restrictions. Two other alternatives were examined, including one alternative with an 11.5 cfs (or 7.5 mgd) minimum flow requirement.

A review of the effect of the 3 mgd withdrawal scenario on the habitat index for the life stages of all species indicated that the greatest effects were on habitat available for the Tar River spinymussel. DWR therefore limited the evaluation of other scenarios to this species. A constant, unrestricted withdrawal of

2 mgd was modeled to evaluate the habitat effects under the existing maximum intake capacity. A third scenario, referred to as "Alternative #1," was also modeled. This involved a constant withdrawal of 2 mgd, with additional withdrawals up to a total of 3 mgd permitted as long as a minimum flow of 11.5 cfs was maintained below the intake. The largest effect was a 10 percent loss in habitat occurring during July and September under two scenarios. Because of the relatively small difference in withdrawal, and the infrequent occurrence of such low flows, both alternatives had virtually the same effect on downstream flows and habitat; however, Alternative #1 ensured that the 7Q10 flow for assimilation of the WWTP discharge was maintained.

In conjunction with a 3 mgd withdrawal, agencies requested that flow between 9.0 and 11.5 cfs be maintained at the stream gage just downstream of Highway 401. The Town of Louisburg later decided not to pursue the expanded water withdrawal (Jim Mead, personal communication, 2007).

2.4 Tar River at Rocky Mount

Water resource developments on the Tar River near Rocky Mount include two dams, two water withdrawals, and one wastewater treatment plant. The Tar River Reservoir, a 1,860-acre reservoir on the Tar River, southwest of Rocky Mount, was completed in 1971, and is used for municipal water supply, fishing, recreation, and other uses. Just downstream is the Rocky Mount Mills Dam, an unlicensed hydropower facility. The Town of Rocky Mount also has a water intake in the small reservoir formed by the Rocky Mount Mills Dam. Rocky Mount’s WWTP discharge to the river is approximately 6.3 river miles downstream of the Mill Dam.

In the NC Dam Safety Act permit for the Tar River Reservoir Dam, there is a requirement for a continuous downstream flow release (or minimum flow) of 80 cfs (DLR, 1999). The 80 cfs minimum flow was based on flow rates needed to maintain assimilative capacity in the river for the Rocky Mount WWTP discharge with some excess for future growth (Jim Mead, personal communication, 2007). During 1999, very low flow occurred in the Tar River and negotiations between Rocky Mount and DENR resulted in protocols that allowed Rocky Mount to reduce the minimum flow down to 60 cfs with certain conditions. A reservoir management strategy and model were developed that identified different water conservation measures and drought stages. The reservoir model identified when to initiate each drought stage based on the amount of water in the reservoir and the probability that water levels will drop below specified heights.

The following operating conditions for Rocky Mount’s Tar River Reservoir were made permanent in 2002:

- Stage I conditions involve a reduction in the minimum release from 80 to 75 cfs.
- Stage II conditions (when the reservoir elevation is at or below 120 feet) allow a reduction from 75 to 70 cfs.
- Stage III conditions (the reservoir operations model indicates for two consecutive weeks that the reservoir elevation will decrease to 115 feet or lower) allow a reduction from 70 to 60 cfs. Stage III requires Rocky Mount to impose mandatory water conservation measures.
- In addition to the minimum flow release requirements, the reservoir level must be managed so that it does not fluctuate by more than one vertical foot between April 15

and May 15 of each year. This management measure was put in place to protect favorable fish spawning conditions.

- Winter reservoir drawdowns are allowed under current management conditions.

In 1993, the City of Rocky Mount was given permission to allow the minimum release to go to 65 cfs and in 1995, the minimum release requirement returned to 80 cfs. In 1999, Rocky Mount was allowed to decrease reservoir releases to 60 cfs; and a 2002 letter from the Division of Land Resources (DLR) reaffirmed the operating Stages (reservoir management Stages I through III) approved in 1999. Due to drought conditions later in 2002, Rocky Mount was allowed to adopt a minimum release of 50 cfs at the reservoir, but had to maintain 60 cfs at the WWTP discharge location downstream of Rocky Mount Mills Dam. In 2007, reservoir releases below 50 cfs occurred as a result of the very low storage remaining in the Tar River reservoir. This low storage volume was due to a gaging error that caused the Rocky Mount reservoir model release protocol to function incorrectly.

Rocky Mount Mills Dam, under the NC Dam Safety Act, has a continuous, instantaneous minimum flow requirement of 60 cfs in the natural channel directly below the dam, the “bypass reach” (DLR, 2003). The dam is also required to have a calibrated staff gage on the dam crest or in the bypassed reach to monitor the flow requirement.

The Rocky Mount WWTP discharge requirements are based on a minimum river flow of 60 cfs. The WWTP permit conditions are based on the 60 cfs minimum release. DWQ may use the minimum release rather than the 7Q10 for assimilative capacity determinations.

2.5 Influence of Tar River Reservoir Operations on Tar River Flows

The normal and low flow releases from Rocky Mount’s Tar River Reservoir are reflected in the historical gage data. Reservoirs such as Rocky Mount’s often augment low flows in rivers because they store water from higher flow periods and release it over extended lower flow periods. Flow duration curves for the pre-reservoir period of record and post-reservoir period of record were developed and evaluated to determine if this effect was present in the Tar River at Greenville flow record (Figure 2-1). In this case, the Tar River Reservoir does not augment low flows observed at Greenville. It appears that the opposite is true; however, the difference in pre-reservoir low flows and post-reservoir low flows is limited. This small difference may be attributed to climatic or other natural differences between the two time periods and may be within the error of the regression model used to estimate much of the period of record for the Greenville gage.

2.6 Tidal Influences in the Lower Tar River

The lower Tar River is influenced by tides to a point upstream of the USGS gage at Greenville. The influence of tides on the Tar and Pamlico Rivers and their connection to the upper portion of Pamlico Sound will factor significantly into the design of the flow study. The amount of tidal influence is variable and depends on wind, tidal phase, and river flow (USGS, 2008; GMA, 2003). Tidal influence in the Tar River at Greenville is more pronounced during low-flow periods. Figure 2-2 illustrates the daily range in Tar River discharge levels at Greenville under different flow conditions and the greater relative influence of tides at low flow levels (average daily discharge of about 150 cfs). The tidal influence is greater when the daily average discharge is 150 cfs than 1,500 cfs or 15,000 cfs, (Figure 2-2). Instantaneous flow in the Tar River at Greenville ranges from negative 570 cfs to 656 cfs in a single day. During low flow periods, tidal fluctuations can significantly influence flow and aquatic habitat conditions. Tidal fluctuations will be considered in the flow study.

Monitoring conducted by GUC in 2002, 2007, and 2008 has demonstrated that the salt wedge moves further upstream during low flow conditions than during high flow conditions. Meteorological conditions, especially wind, also play an important role along with downstream flow volume in determining the location of the salt wedge. Wind strongly influences the magnitude of the tidal fluctuations in the lower Tar River and promotes mixing and circulation within the Pamlico River and the Pamlico Estuary. Pamlico Sound is a shallow estuarine system that is strongly influenced by wind-driven circulation and mixing (Lin et al., 2008; Stanley and Nixon, 1992).

Under certain common conditions, the tidal influence determines flow and habitat conditions in the lower Tar River. There are times when tidally-influenced flows in the river moving upstream and downstream past the Greenville gage are much greater than the net amount of flow being delivered from upstream. Groundwater Management Associates, Inc. (GMA) (2003) demonstrated that during low flow conditions (about 100 to 300 cfs), instantaneous flow measurements for the Tar River at Greenville varied by over 600 cfs or more during a single day in response to changing tides. Flow was negative (upstream) and positive (downstream) in response to tides, and were accompanied by a change in stage (water level) of about one foot or less. Although the net downstream flow was negative, the water level at Greenville did not substantially change (ENTRIX, 2008; GMA, 2003).

The GMA 2003 investigation, ENTRIX 2008, and ARCADIS 2008 reports, are the only available studies that directly address the hydrology of the Tar River, tidal influences on Tar River flow and stage at Greenville, and the potential effects of withdrawals. The GMA report characterized the magnitude of the tidal influences, the volume of freshwater in the tidal portion of the Tar River in 2002 during a period of very low flows, and average daily flow. The location of the salt wedge or brackish water boundary in the lower Tar River was used to calculate the size of the freshwater volume in the lower river. The potential effects of GUC WTP withdrawals were evaluated based on the freshwater volume of the lower river during low flow conditions.

GMA concluded that tidal influences are a major factor in affecting the hydrology of the Tar River at Greenville during low flow conditions. During periods of low flow, water levels at Greenville and the Pamlico River at Washington are very similar. The tidal oscillations were found to be much higher than net river flows under low flow conditions.

The GMA study also concluded that the river downstream of Greenville could be thought of as a large reservoir, which has the potential for holding over one billion gallons of water between the GUC intake and the brackish water boundary of the Pamlico River. GMA concluded that even if there were no flow in the Tar River, the City would have to pump for almost three days at the maximum permitted rate (22.5 mgd) to produce an upstream migration of the brackish water boundary equal to that which occurred naturally due to tides on a single day in August 2002. GMA calculated that with zero net downstream flow and at GUC's current peak pumping rate (then 16.4 mgd), it would take 62 days to deplete the freshwater in the Tar River downstream of the intake. The study was a simple examination of flows, stages, and volumes, but did not involve any predictive modeling that would allow the consideration of other factors such as weather and wind effects, other flow conditions, different withdrawal rates, or effects on water quality or ecological conditions. The ecological consequence of changes in the location of the salt wedge or changes in other water quality parameters was not considered in the GMA report.

2.7 Previous Hydrologic Analysis of GUC Withdrawals

Extensive hydrologic analyses were conducted by ENTRIX as part of the EA (ARCADIS, 2008) evaluating the potential effects of proposed interbasin transfers. To support the development of an EA for GUC's proposed transfer of water from the Tar River to the Neuse River Basin and the Contentnea Creek Basin, a spreadsheet based hydrologic model was developed for the lower Tar River to predict river flows under current and future water usage scenarios. This work is documented in the TM, "Analysis of Greenville Utilities Commission's Proposed Interbasin Transfer Withdrawals on Tar River Flows at Greenville, North Carolina", October 2007, revised April 2008 (ENTRIX, 2008).

The model was designed to evaluate the effect of GUC's proposed IBT withdrawals on current and future flows at Greenville. The model was based on available USGS flow records from the Tar River at Tarboro and the Tar River at Greenville (USGS NWIS, 2008). The relationship between available flow records for the Tar River at Greenville and the Tar River at Tarboro was estimated using hydrologic and statistical methods. This relationship was used to generate a long-term flow record at Greenville, which was then used in a spreadsheet model to estimate future flows at Greenville with and without the proposed IBT. The model quantifies the relative differences in flow associated with current and projected water usage and discharges. Tidal influences were not simulated in this model. Days may occur when the tidal influence creates a net downstream flow of zero or a net upstream flow ("negative" flow).

The model was used to evaluate resulting flow in the river at two locations. The first location was the USGS gage at Greenville, which is downstream of GUC's water treatment plant intake, but is upstream of GUC's WWTP discharge (Figure 2-3). The 7.7 mile portion of the Tar River between the WTP intake and the WWTP discharge is the reach that will have the lowest flows and is the reach of the Tar River most affected by future GUC withdrawals. This 7.7 mile area between the WTP withdrawal and WWTP discharge is proposed as the primary study area (Freshwater Tidal Segment) of the Tar River Flow Study.

The second location where flows were evaluated is the Tar River downstream of the GUC WWTP discharge (Figure 2-3). This reach downstream of the Greenville WWTP will also be affected by upstream water uses, but less so because the flows in that reach include the discharge from the WWTP. The flow in this reach goes to the Pamlico River and Pamlico Sound. Both reaches are tidally influenced, especially at low flow. An assessment of standard flow statistics needs to consider that daily tidal fluctuations at Greenville can be much greater than the net downstream flow of the Tar River arriving at Greenville.

The following scenarios were evaluated in the model at both locations:

- Current flows with No IBT.
- Current flows with 2030 Average Day IBT.
- Current flows with 2030 Maximum Withdrawal IBT.
- Predicted 2030 flows with No IBT.
- Predicted 2030 flows with 2030 Average Day IBT.
- Predicted 2030 flows with 2030 Maximum Withdrawal IBT.

Flow statistics for the Tar River were generated for each scenario at both river locations. In order to evaluate the seasonal flow fluctuations, the statistics were based on daily average flow by month. A range of flow statistics and comparisons were developed for each scenario in order to quantify and demonstrate the effect of the proposed IBT withdrawals on current and future conditions at both Tar River locations. The effects of projected growth and different IBT scenarios were evaluated by examining changes in these statistics. Finally, a discussion of the importance of the influence of tidal fluctuations on the Tar River at Greenville was provided to explain the potentially ameliorating effect of tides at Greenville on river flow estimated for GUC's proposed IBT.

Under some of the conditions where it was estimated that withdrawals and interbasin transfers have a small effect on net downstream river flow, tidal influences may be greater than the net amount of flow being delivered from upstream. The tidal influence during critically low periods may substantially ameliorate the effects of IBT withdrawals. The tidal influence at Greenville was cited by GMA (2003) as one factor that provides downstream aquatic habitat protection during low flows in the vicinity of Greenville. However, this conclusion will be examined in much greater detail in this study.

The year-to-year variability in Tar River flows is illustrated in Figure 2-4, which identifies the average annual flows for the period of record. Figure 2-5 identifies the range of flow percentiles observed in the Tar River at Greenville based on the modeled data (1931 to 2007). The median monthly flows for the period of record are represented by the 50 percent line (which means that the average monthly flow was at or below this flow 50 percent of the time). To provide context for flow comparisons and relative withdrawal quantities, Table 2-3 identifies the median annual and monthly flows for the Tar River at Greenville for the period of record (1931 to 2007). As is typical of North Carolina streams and rivers, flows are highest during winter and spring (median monthly flows range from about 1,700 cfs to 3,600 cfs) and lowest during summer and fall (median monthly flows range from about 600 cfs to 1,300 cfs). Flows less than 600 cfs can occur at any time of the year, but are far less frequent during December through April (less than 5 percent of the time) than during May through November (occurring about 5 – 50 percent of the time, depending on the month).

Table 2-3: Median Tar River Flows at Greenville (1931-2007)

Annual or Monthly Value	Median Flows at Greenville (cfs)
Annual	2,524
January	3,776
February	4,649
March	4,840
April	3,589
May	2,058
June	1,596
July	1,481
August	1,641
September	1,536
October	1,320
November	1,578
December	2,345

Monthly average and maximum withdrawals by GUC (based on 2005 records) are a relatively small portion of median daily flows in the Tar River (Figure 2-6). The maximum permitted GUC withdrawal ranges between approximately 0.6 percent and 4.2 percent of the mean monthly flows. However, during low flow conditions, these GUC withdrawals are a larger portion (up to almost 15 percent) of the total river flow (Figure 2-7). Figure 2-8 presents the monthly average and maximum GUC withdrawal amounts (based on 2005 records) expressed as a percentage of the summer 7Q10 flow (108 cfs). The average monthly GUC withdrawals range between 14 percent and 16 percent of the 7Q10 flow and the maximum monthly withdrawals range between 16 percent and 22 percent of the 7Q10 flow. These percentages will become larger in the future as flow withdrawals in the rest of the basin increase. It will be important for the Tar River Flow Study to address those portions of the flow regime that may be affected by proposed future withdrawals. The hydrologic analysis study, performed done in support of the EA for the IBT, provides additional flow statistics.

3. Technical Approach

This section of the study plan describes the general study area of the Tar River and defines analyses that will be conducted in individual study area segments. The technical approach to modeling and analyses is also described. Further details of the technical analyses and modeling are provided in subsequent sections.

This section also describes the link between the study objectives and the technical analyses. Specific analyses will be conducted based on the potential effects of GUC withdrawals and consumptive uses on the river's flow regime. The practicable scope of the analyses and the geographic extent of the Study Area and its segments are identified.

3.1 Study Area

The Tar River Flow Study includes four segments of the Tar River in the general vicinity of Greenville. These include the Freshwater Non-tidal, Tidal Freshwater, Estuarine Transition, and Pamlico River Estuary segments (Figure 3-1). These segments have dynamically changing boundaries. The boundaries are influenced by river discharge, tidal cycles, and meteorological conditions. Near Greenville, the river is freshwater, but within the Estuarine Transition Segment, salinity levels typically increase in a downstream direction to Washington. At Washington, the Tar River becomes the Pamlico River Estuary.

River flow, tidal cycles, and meteorological conditions (wind speed, direction, and barometric pressure) all affect the boundaries of these segments. Superimposed upon these changing boundaries are the GUC water infrastructure facilities, including the WTP and the WWTP. Together, the river tidal and salinity boundaries, and the infrastructure elements define the logical study segments (Figure 3-1). Table 3-1 describes the different segments, their characteristics, and the analyses that will be conducted in each.

Table 3-1: Tar River Flow Study Segments

Tar River Segment	Attributes and Approach
Tidal Freshwater Segment	Primary study area WTP to WWTP Subject to total GUC withdrawals Lowest net freshwater flows may occur in this segment due to withdrawals Habitat conditions influenced by tidal fluctuations, especially at low flows
Estuarine Transition Segment	Secondary study area. WWTP to Washington. Tidally dominated; fluctuating salinity levels and salt wedge location. Subject to consumptive use, not total withdrawals.
Pamlico River Estuary Segment	Tertiary study area Estuarine circulation dominated; freshwater inflows can be important Periodic summer bottom anoxia

3.2.1 Non-Tidal Freshwater Segment

This segment of the Tar River extends from the approximate upstream extent of tidal influence, upstream into the Tar River Basin. The upstream extent of tidal influence in the Tar River is variable. This boundary occurs under most conditions in the vicinity of the US 264 Bypass Bridge, approximately 1.75 miles upstream of the GUC WTP intake. Flow and water levels in this segment of the river are affected by river discharge, but are not measurably affected by withdrawals at the WTP. This assumption will be evaluated during the study using the hydrodynamic model.

A basin hydrologic model (Refer to Section 4, Tar River Basin Hydrologic Model) will be used to quantify the flows delivered to the Non-Tidal Freshwater Segment of the river. Since this segment of the river is not influenced by GUC withdrawals, no other habitat or water quality analyses are proposed.

3.2.2 Tidal Freshwater Segment

The Tidal Freshwater Segment extends from the GUC water intake located three miles upstream of the USGS gage in downtown Greenville to the WWTP discharge location approximately eight miles downstream of the water intake (Figure 3-1). This section of river experiences the effects of the total withdrawals made at the WTP. At the downstream end of this segment, the WWTP discharge, the majority of the water withdrawn at the WTP is returned to the river.

The downstream boundary of the Tidal Freshwater Segment of the river is highly variable. The boundary can vary from approximately ten miles downstream of the WTP to near Washington, depending on river flow. GUC monitors the saltwater boundary and during drought conditions in 2007, it moved as far upstream as 10 miles from the WTP intake. The WWTP discharge is the location at which the majority of the water withdrawn is returned to the river. Downstream of this point, the potential effects of GUC water withdrawals are limited to GUC's consumptive water use (e.g., withdrawals at the WTP minus discharges at the WWTP).

The Tidal Freshwater Segment is different from the upstream riverine habitat, primarily due to tidally induced physical processes, such as the increased residence time of the water, oscillating water levels, and reversing current velocities and directions (Schuchardt et al., 1993; Wagner and Austin, 1999). This eight-mile segment of the Tar River experiences the greatest quantity of flow depletion due to GUC withdrawals and may have the lowest rate of net downstream freshwater flow. The term "net downstream freshwater flow rate" is introduced at this point to address the fact that flow rates, due to tidal cycles in the Tidal Freshwater Segment (upstream-downstream tidal flux), can be greater than the rate of flow being delivered from the Non-Tidal Freshwater Segment of the river.

3.2.3 Transitional Estuarine Segment

The Transitional Estuarine Segment extends from the WWTP discharge, downstream to Washington where the Tar River becomes the Pamlico River. Based on water quality data collected by the State of North Carolina and GUC, this river segment is generally fresh water in its upper reaches and is progressively more brackish or saline with distance downstream to Washington. Salinity levels and the location of the salinity wedge are highly variable, depending on river flow, tidal cycles, and meteorological conditions (e.g., wind speed and direction, barometric pressure, etc.). This river segment is subject to consumptive use only (e.g., withdrawals at the WTP minus returns at the WWTP).

3.2.4 Pamlico River Segment

The City of Washington, North Carolina is generally regarded as the boundary between the Tar River and the estuarine Pamlico River. At this point, the Pamlico River contains higher salinity waters than the Tar River, except under very high river flow conditions. This section of the river is subject to consumptive use only (withdrawals at the WTP minus returns at the WWTP), WWTP discharges, and additional tributary flow. The effects of any proposed withdrawal or change in withdrawal by GUC on the hydrodynamics of the river in the Pamlico River Segment are greatly attenuated downstream of the NC 17 Bridge due to the influence of the tidal dynamics of Pamlico Sound.

3.2 Technical Approach

The technical approach to the Tar River Flow Study is driven largely by two of the study objectives:

- Quantify the relationship between river flows, instream habitat, and aquatic resources.
- Identify potential water quality and habitat constraints on flow withdrawals.

The remaining study objectives (identifying available capacity, developing flow management strategies, and characterizing risk during droughts) are also considered, but the basis for these objectives rely on a synthesis of the results of the technical analysis.

Instream habitat and potential constraints on flow withdrawals, as defined in this study, may include hydrodynamic conditions (e.g., river stage, depths, velocities, diffusion, and circulation), physical habitat structure, temperature and water quality conditions, and salinity regime. The Tar River Flow Study design primarily addresses the effects of flow rate manipulations, water withdrawals, but will also address the analysis of the effects of water withdrawal on water quality. However, this study will not address the detailed effects of future changes in WWTP discharge, its mixing zone, or provide a regulatory analysis for a plant expansion or discharge permit modification.

3.3 Study Components and Models

The major activities that will be conducted in each of the four segments within the Study Area are provided in Table 3-2. The Tar River Flow Study occurs within the context of a complex environmental setting (e.g., riverine-tidal-estuarine transition), so a number of hydrologic, hydrodynamic and biological approaches will be used address the issues and potential effects of greater water withdrawals.

All four segments of the Tar River will be addressed at various levels of detail, but the Tar River Flow Study will focus principally on the potential effects of total flow withdrawals in the Tidal Freshwater (WTP to WWTP) Segment and the potential effects of consumptive water use on the Estuarine Transition Segment.

In the Non-Tidal Freshwater Segment of the river, existing and future flows will be simulated using a basin hydrologic model, the Water Evaluation and Planning System (WEAP) Model and previous modeling and analysis of Tar River flows at Greenville (ENTRIX, 2008). WEAP is a comprehensive, straightforward basinwide water planning and management tool that supports water resources planning efforts (ENTRIX, 2009). The WEAP modeling will be set up for the Tar River Basin based on historical flow data sets. The model will be calibrated to enable simulation of existing and future inflow scenarios, so that flows arriving at the upper end of the Study Area (at the WTP) are quantifiable. These simulated flows and flow scenarios become the inputs for the modeling in the river segments downstream of the non-tidal to tidal boundary.

Table 3-2: Tar River Flow Study Technical Analysis Approach to Four Study Segments

Study Segment	Hydrologic Analysis	Habitat Modeling	Hydrodynamic Modeling of Salinity Regime	Model Selected Water Quality Constituents
Non-Tidal Freshwater	✓			
Tidal Freshwater (WTP to WWTP)		✓	✓	✓
Estuarine Transition (WWTP to Washington)			✓	✓
Pamlico River Estuary (Downstream of Washington)				✓

For the Tidal Freshwater Segment of the Tar River, the analysis will focus principally on:

- The potential effects of water withdrawals on the physical habitat of fish and other aquatic species (Habitat Modeling).
- The potential for encroachment of salinity under various low-flow regimes, withdrawal and metrological conditions (Hydrodynamic Modeling of Salinity Regime).
- Modeling of selected water quality constituents (Water Quality Modeling), such as temperature, and DO, will be completed to assess whether withdrawals during low-flow conditions would result in degradation of water quality and aquatic habitat, or violation of water quality standards.

The Environmental Fluid Dynamics Code (EDFC) hydrodynamic and water quality model will provide the platform to perform all of the necessary modeling and analysis of hydrodynamic conditions and water quality. The EFDC model is a state-of-the-art hydrodynamic and water quality model that has the ability to simulate aquatic system hydrodynamics and water quality in multiple dimensions (EPA, 2009a). The EFDC model will be the central model for all of the modeling analysis in the Tidal Freshwater, Estuarine Transition, and Pamlico River segments. Its hydrodynamic modeling results will provide inputs for the Habitat Model and the Water Quality Model. The EFDC model domain will extend from the GUC WTP downstream to the Pamlico River.

For the Estuarine Transition Segment of the Tar River, consumptive water uses are less likely to affect river habitat than tidal influences or the variable salinity regime. The analyses in this segment will focus on the hydrodynamic model results, potential effects on the salinity regime, and potential water quality effects. Hydrodynamic modeling of this segment of the river will also help in the understanding of how far and under what conditions the salt wedge (the front boundary between fresh and brackish water salinity zones) may migrate upstream in the lower Tar River.

In the Pamlico River Estuary Segment, the primary concern is whether consumptive use by GUC would result in any effects on water quality and attainment of water quality standards. The level of modeling and detail needed to address potential water quality issues is not yet known. The first logical step in this analysis is to determine the degree of modeling effort that is needed by performing initial model sensitivity analysis. This analysis will determine if water quality conditions are responsive to flow withdrawals of the magnitude being considered.

3.4 Range of Flows to be Considered (Indicators of Hydrologic Alteration – IHA)

Characterization of flows in the Tar River Basin and at Greenville was completed in advance of the Tar River Flow Study. The hydrology of the Tar River will be evaluated and modeled in the current study. Examination of the hydrologic data helps define the aspects of the Tar River flow regime over which GUC withdrawals and discharges may exert an influence – most likely low flow magnitude and low flow duration. It will also provide clarity for the elements of the flow regime that may remain unaffected (e.g., high flow magnitude and timing, etc.) by potential future withdrawals.

In the Draft Study Plan, it was proposed that traditional hydrologic analysis combined with an analysis with the Indicators of Hydrologic Alteration (IHA) could be used to identify the range of flow that would be affected by GUC withdrawals. The IHA is a software program used widely to provide useful information for managers to understand the hydrologic effects of human activities or trying to develop environmental flow recommendations (TNC, 2009). The IHA can be used to analyze hydrologic data available from either existing measurement points or model-generated data. It uses 32 different parameters, organized into five groups, to characterize annual and inter-annual hydrologic variation that provide information on some of the most ecologically significant features of flow regimes influencing aquatic, wetland, and riparian ecosystems (Richter et al., 1996 and 1997). This program has the ability to compare historical flows with present flows, regulated with unregulated flows, and offers a comparison of existing and future flows under different management scenarios.

Since the Draft Study Plan, these analyses have been completed and presented to the TAG. Table 3-3 summarizes the current and projected future basin consumptive uses and GUC withdrawals. These numbers are approximate and are for the purpose of evaluating the potential effects of cumulative withdrawals.

Table 3-3: Approximate Basin Withdrawals and Return Flows Including GUC for Demonstrative Purposes

Scenario	Year	GUC WTP (mgd)	Basin Withdrawals (mgd)	Basin Discharges (mgd)	Consumptive Use (mgd)	Consumptive Use (cfs)
1	2002	11.2	31	14	17	26
2	2030	22.5	52	24	27	42
3	2030	29	57	24	32	50
4	2048	32	64	28	36	55
5	[1]	40 [1]	72	28	44	68

[1] *Hypothetical increase for demonstrative purposes.*

Table 3-4 provides a summary of the results of the IHA analysis comparing the baseline period (2002) with future scenarios of approximate consumptive uses and GUC withdrawals. The results of the analysis suggest that the effects of future increases in water basin consumptive use and GUC withdrawals will be limited largely to the low-flow regime. The timing, magnitude, and frequency of moderate and high flows will not be affected by cumulative withdrawals, and many of the monthly median flows will be essentially unchanged by cumulative withdrawals. These results are expected because the magnitude of cumulative withdrawals is a very small proportion of river flows during most conditions.

The results of the IHA analysis provide some insights about the range of Tar River flows potentially affected by cumulative basin consumptive use and GUC withdrawals, and help to provide guidelines as to how the analyses might be focused. The Tar River system is largely unregulated; total reservoir storage in the basin equals only a small percentage of the annual flow of the river. Therefore, many of the natural attributes of flow regime in the Tar River, including high flows, high flow pulse timing and duration, monthly flow distributions, and other ecologically important elements of the flow regime are largely unaffected by water use in the basin. Further evaluations of these findings will be conducted through the modeling and analysis process described in this Final Study Plan.

Table 3-4: Result of Indicators of Hydrologic Analysis (IHA) for Baseline (2002) and Four Future Consumptive Use and GUC Withdrawal Scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Watershed area (sq mi)	2660	2660	2660	2660	2660
Mean annual flow (cfs)	2564	2544	2534	2525	2513
Mean flow/area (cfs/sq mi)	0.96	0.96	0.95	0.95	0.94
Annual C.V.	1.27	1.28	1.29	1.29	1.3
Flow predictability	0.35	0.35	0.34	0.34	0.33
Constancy/predictability	0.67	0.66	0.66	0.65	0.65
% of floods in 60d period	0.28	0.28	0.28	0.28	0.28
Flood-free season	0	0	0	0	0
Parameter Group #1					
October	100%	94%	92%	90%	88%
November	100%	97%	96%	95%	94%
December	100%	98%	98%	97%	96%
January	100%	99%	99%	99%	98%
February	100%	100%	99%	99%	99%
March	100%	99%	99%	99%	98%
April	100%	99%	99%	99%	98%
May	100%	99%	98%	98%	97%
June	100%	98%	97%	96%	95%
July	100%	97%	96%	94%	93%
August	100%	98%	97%	96%	94%
September	100%	96%	94%	92%	90%
Parameter Group #2					
1-day minimum	100%	88%	83%	79%	73%
3-day minimum	100%	87%	83%	78%	73%
7-day minimum	100%	88%	84%	79%	74%
30-day minimum	100%	94%	91%	88%	85%
90-day minimum	100%	98%	96%	95%	93%
1-day maximum	100%	100%	100%	100%	100%
3-day maximum	100%	100%	100%	100%	100%
7-day maximum	100%	100%	100%	100%	100%
30-day maximum	100%	100%	100%	99%	99%

Table 3-4: Result of Indicators of Hydrologic Analysis (IHA) for Baseline (2002) and Four Future Consumptive Use and GUC Withdrawal Scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
90-day maximum	100%	100%	99%	99%	99%
Number of zero days	0	0	0	0	0
Base flow index	100%	93%	89%	85%	81%
Parameter Group #3					
Date of minimum	100%	100%	100%	100%	100%
Date of maximum	100%	100%	100%	100%	100%
Parameter Group #4					
Low pulse count	100%	100%	100%	100%	100%
Low pulse duration	100%	100%	100%	96%	100%
High pulse count	100%	100%	100%	100%	100%
High pulse duration	100%	100%	100%	100%	100%
Low Pulse Threshold	100%	97%	95%	94%	92%
High Pulse Threshold	100%	99%	99%	98%	98%
Parameter Group #5					
Rise rate	100%	100%	100%	100%	100%
Fall rate	100%	100%	100%	100%	100%
Number of reversals	100%	101%	101%	101%	100%

3.5 Screening and Assessment of Water Quality Issues

An explicit part of the Tar River Flow scoping and study plan process will be the early screening of issues and their sensitivity to flow and freshwater inflow. In this study, the level of effort needed to model certain water quality issues, and to determine which water quality constituents might be sensitive to changes in flow of the magnitudes considered, have yet to be determined. In this sense, initial sensitivity analysis will be important to help define the important analysis to be completed, and to avoid spending effort on modeling the full range of possible water quality interactions. For example, in addressing potential effects on water quality in the Pamlico River Estuary Segment of the Study Area, an initial model sensitivity analysis will be performed based on previous modeling efforts (Xu et al., 2008) and screening with the EFDC model. If these analyses suggest that water quality changes are not responsive to flow withdrawals of the magnitude considered, then additional modeling will not be conducted.

4. Basin Hydrologic Analysis and Modeling

After discussions with the TAG, GUC, DWR, and the City of Rocky Mount, the Stockholm Environmental Institute's WEAP model has been selected to develop the Tar Flow Study Basin hydrologic model. A TM, Tar River Flow Study: Selection of Basin Hydrologic Model, is available that describes the model selection process. This model will be used along with previous hydrologic analysis and modeling.

The Tar River Flow Study requires an analysis of the basin projections of future flows arriving at Greenville on an annual, seasonal, and daily basis. These projections will account for river hydrology, future withdrawals upstream of Greenville, agricultural water use and other water management actions that may affect the amount of flow. The basin hydrologic model and its results will be a central part of the flow study and will provide information crucial to the other study elements, as well as information for GUC's water system planning and management and development of water conservation and drought management responses.

The WEAP model will provide a time series of flows within each study segment associated with various withdrawal scenarios. These time series will be used as inputs to the other models for the assessment of effects on water quality and aquatic habitat. The WEAP hydrologic model for the Tar River Basin will be developed, calibrated, and used to simulate existing and future flow regimes, including the effects of increased or seasonally modified withdrawals (e.g., simulated flow time-series for various operational and flow alternatives). The WEAP model will serve three basics functions.

1. Accurately simulates natural hydrological processes (e.g., rainfall, evapotranspiration and infiltration, runoff, water gains and losses from various sources, and performs water balancing within the system) to enable assessment of the availability of water within a catchment.
2. Simulate basic anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e., consumptive and non-consumptive water demands) to enable evaluation of the effects of human water use. The model must be capable of performing a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows.
3. The model will be run with changing rules, constraints, flow requirements, and other goals and objectives programmed within the system to simulate various operational schemes and management alternatives.

Subsequent discussions with the TAG will address other important details related to the hydrologic modeling effort such as basin water withdrawals and discharges, and consumptive use as well as modeling assumptions, approach, and results.

5. Hydrodynamic Modeling

This section describes the development of the hydrodynamic model for the Tar River Study Area. The hydrodynamic model will be central to all of the analyses described in Section 3 (Study Area and Technical Approach), because its simulations of riverine and estuarine circulation will be used in habitat, salinity, and water quality modeling.

The Tar River hydrodynamic model will be built as an extension of an existing model previously developed, calibrated, and used for hydrodynamic and water quality investigations of the Pamlico River Estuary. This existing model will be modified and expanded to include a larger model domain encompassing the Tidal Freshwater, and Transitional Estuarine study segments, and further calibrated and validated.

5.1 Overview

Coastal hydrodynamic models, generally two-dimensional (2-D) or three-dimensional (3-D) models, calculate the circulation of coastal water based on tides and wind, as well as the discharge from rivers. More specifically, the models calculate tidal stage, water velocities (speed and direction), and water levels for each cell within their computational model grid. The hydrodynamic models generally calculate salinity as well as water temperature, based on heat balance equations. These last two parameters are especially relevant for 3-D hydrodynamic calculations where density differences due to temperature and salinity can play an important role in the circulation of water. Such models may be used to simulate existing or historic conditions, and if calibrated and validated for a specific region, can predict future conditions.

The hydrodynamic model is the starting point in the analysis. The hydrodynamic model determines the water circulation, which in turn influences the transport and distribution of suspended materials and nutrients. The hydrodynamic model simulates the water level, velocity, temperature and salinity data that will be used in the habitat model to simulate habitat conditions and in the water quality model where they are used for calculating the advective transport of dissolved and suspended material. The temperature and salinity values are important in the simulation of many chemical and biological processes, as the rates for many of these processes are temperature and salinity dependent.

This same model structure and grid that is used for the hydrodynamic modeling will also used for the water quality and habitat models, and may be modified for specific purposes. Due to the importance of the model's representation of the physical structure of the Tar River and upper Pamlico Estuary, this section begins with a description of the existing model and the development of the expanded model configuration and grid.

5.2 Existing EDFC Model of the Pamlico River

The EFDC model is a public domain, multi-functional surface water modeling system, which includes hydrodynamic, sediment-contaminant, and eutrophication components. The model can be used to simulate aquatic systems in one, two, and three dimensions. It has evolved over the past two decades to become one of the most widely used and technically defensible hydrodynamic models in the world (EPA, 2009).

A coupled 3-D hydrodynamic and water quality EFDC model has been developed and tested for the Croatan-Roanoke-Albemarle-Pamlico-Core Sounds estuarine system. This model was used to analyze seasonal variation of water quality variables, and to predict the movement of the saltwater/freshwater interface (salt intrusion). The EFDC model also predicts the vertical stratification of DO and salinity under different river flow and wind conditions in the Pamlico River Estuary (Xu et al., 2008).

The EFDC model has been applied to several hydrodynamic and water quality numerical modeling studies in North Carolina by researchers at North Carolina State University (NCSU) in the Department of Marine, Earth, and Atmospheric Sciences (MEAS). Lin et al. (2007) applied a coupled 3-D hydrodynamic and water quality model (EFDC) to the Croatan-Roanoke-Albemarle-Pamlico-Core Sounds estuarine system (CAPE) to analyze seasonal variation in water quality parameters such as nitrite plus nitrate, total phosphate, chlorophyll *a*, and DO.

Xu et al. (2008) applied this model to investigate current circulation, salt intrusion, and vertical stratification under different river flow and wind conditions in the Pamlico River Estuary (PRE), the lower end of the Tar River Flow Study Area. The domain of the PRE model extends from Washington downstream to Pamlico Sound and includes the Pamlico River and its tributary, the Pungo River. The model was calibrated and verified against water level, temperature, and salinity measured during 2001 and 2003. Eight sensitivity tests were conducted with different river flow and wind conditions specified in the model. The EFDC model also predicts the vertical stratification of DO and salinity under different river flow and wind conditions in the Pamlico River Estuary (Xu et al., 2008).

A copy of the PRE application of the EDFC Model (the Pamlico River EDFC Model) has been obtained by ENTRIX and has been selected for use by the Tar River Flow Study. The models considered and the rational for the selection of the Pamlico River EDFC Model are described in a TM, Tar River Flow Study: Selection of Hydrodynamic and Water Quality Model.

5.3 Data Collection for Model Development

The existing Pamlico River Estuary application of the EDFC model will be modified and expanded to include a larger model domain encompassing the Tidal Freshwater, Estuarine Transition, and Pamlico River Estuary Segments of the Study Area. The following section describes the use of the existing model, collection of bathymetric, meteorological, discharge, and other boundary condition information and how it will be used for model development and calibration.

5.3.1 Hydrographic Data Collection

To extend the model domain upstream to GUC's WTP, additional hydrographic data will be collected to develop bathymetric maps. Sites for the hydrographic data collection will be from slightly upstream of the GUC WTP downstream to the NC 17 Bridge in Greenville. Due to differences in needed resolution of the hydrographic survey and data needs for the habitat modeling, surveys will be more intensive in the Tidal Freshwater Segment of the river.

5.3.2 Side Scan Sonar and Bathymetric Survey

A survey will be conducted from a shallow-draft survey vessel, positioned by a Trimble DSM 232 DGPS system operating with HYPACK hydrographic survey software. Initially, bathymetric survey lines will be run parallel to the course of the river. A minimum of two to three survey lines will be conducted in the upper 20 miles of the Study Area where the bank-to-bank widths range from 150 to 250 feet. Additional lines will be added at wider sections to keep the distance between survey lines at approximately 70 feet or less. From approximately Grimesland down to the NC 17 Bridge at Washington, additional survey lines will be added as needed to cover the width of the river at a minimum of 50 to 70 feet spacing. The bathymetry data will be collected with an Odom CV100 echo sounder and an Ocean Data Equipment Bathy 500 echo sounder operated simultaneously along two tracks separated by the length of the survey vessel and up to 15 feet across the beam of the survey vessel. Both survey grade echo sounders will utilize a 200 kHz three degree transducer to collect depth. Depth data will be collected at a minimum of 0.5 second intervals or approximately every two feet along the survey line at the expected survey speed of two to three knots.

The side scan sonar survey will be conducted along with the bathymetry data using a frequency between 900 to 1800 kHz depending on the frequency that provides the best detail of the bottom. The sonar records will be of sufficient detail to characterize and generally delineate the substrate types. Objects such as snags, logs, wrecks and other debris exposed above the river bottom will also be identifiable. Sonar investigations of side channels and branches of the Tar River will not be included. Sloughs positioned along the main channel course will be included if water depth and conditions permit boat access.

Each day, three sound velocity checks will be performed with a bar check. River water levels including tidal fluctuations will be monitored and recorded each survey day relative to nearest NAV 88 vertical datum in each river segment. River depths will be recorded with an expected vertical accuracy of ± 0.5 feet and a horizontal accuracy of a minimum ± 3 feet.

5.3.3 Hydrodynamic and Water Quality Data and Catalog

This task involves the assembly and analysis of existing data to support hydrodynamic and water quality model calibration, verification and application. The objective will be to develop a central data set to support the modeling project. Relevant water quality data will be compiled (location, river segment, date, parameter, collecting agency, etc.), focusing on applicability of existing data to the current modeling effort. Data sources are not limited to USGS, NOAA, National Weather Service (NWS), DWQ, and universities, particularly ECU, will be reviewed and analyzed. A central data set will be developed to support the modeling project.

5.4 Tar River EFDC Hydrodynamic Model Development

5.4.1 Hydrodynamic Model Configuration

Model configuration will include development of all input files required by the model for simulation of historical and projected future conditions of the system. Model configuration is typically the most time consuming portion of model development since it requires the assembly and analysis of large quantities of data into formats required by the model.

5.4.2 Model Grid Development and Bathymetric Interpolation

The EFDC hydrodynamic model operates by representing a water body by an assemblage of discrete volumetric cells. The model's horizontal grid defines the boundaries of these cells on a map projection. The EFDC model uses a boundary fitted curvilinear-orthogonal horizontal grid to represent shoreline and interior features of a water body. The model grid will be generated to resolve the shoreline and significant interior features such as navigational channels and islands. The grid will be optimized to balance tradeoffs between resolution and model run time.

The current PRE application of the EFDC model grid will be used for its portion of the model domain, and the bathymetric survey results will be used to generate the model grid upstream to the GUC WTP. Bathymetric information will be automatically interpolated to the grid and adjusted manually in critical areas as required. Additional data sources that may be used in this process include depth and diameter of the Tar River at various locations collected by GUC for depth studies; LiDAR data from North Carolina Floodplain Mapping Program; and detailed digital elevation model (DEM) data (1.5 m by 1.5 m) developed by USGS for their hydraulic modeling of areas around gage stations (Bales et al., 2007).

5.4.3 Open Boundary Conditions

Open boundary conditions at the ocean boundary and truncated open water interior boundaries are required for water surface elevation, salinity and temperature. The 15-minute surface elevation data near the mouth of PRE, and biweekly data of salinity and temperature from East Carolina University, will be specified as open boundary condition as established by the existing PRE application of the EFDC model.

5.4.4 Inflow Boundary Conditions

Freshwater inflow time series from point and distributed non-point inflows will be developed during the basin hydrologic analysis and basin model development. Point inflows include gaged tributaries and permitted discharges (USGS gage data and National Pollutant Discharge Elimination System (NPDES) permit records) and United States Environmental Protection Agency (EPA) records of the PCS Phosphate Mine (PCS) discharges. Non-point inflows will include runoff from un-gaged areas.

Estimated daily river discharge at the Tar River gage at Greenville will be used as the upstream inflow boundary condition. Flow records from the Chicod Creek gage at SR 1760 near Simpson will be used as one of the tributary inflows. For un-gaged major tributaries such as Grindle Creek and Tranters Creek, flow will be estimated from nearby gage station flow records and drainage area relationships.

5.4.5 Atmospheric Forcing Functions

Atmospheric forcing refers to forces that drive circulation in a particular waterbody, including tides, wind, atmospheric pressure, and solar radiation. Data on atmospheric forcing are required to represent wind driven circulation and to predict water temperature. Wind speed and solar radiation are also required by the water quality modeling component to predict re-aeration and primary production. Hourly wind data observed at the PCS station on the southern bank of the PRE will be used in the model. Hourly metrological data sets, including air pressure and temperature, relative humidity, rainfall, solar radiation, and cloud cover for the N.C. State Climate Office at Aurora Station will also be applied.

5.4.6 Preliminary Testing

The configured hydrodynamic model will be tested for stability and run-time performance prior to beginning calibration and verification. These tests will be primarily directed at identifying and correcting aspects of the grid resolution, boundary conditions, and forcing functions that can cause unrealistic model behavior or inhibit model performance.

5.4.7 Hydrodynamic Model Calibration and Verification Using Existing Data

Model calibration involves the adjustment of model spatial input data such as bathymetry and bottom roughness, boundary conditions, and forcing functions to achieve a best fit between model predictions and field observations over a specified period of time. Model verification involves using the calibrated model to simulate a different period of time and achieve a model predictive performance similar to that achieved over the calibration period.

The current PRE application of the EFDC model was calibrated and verified with observation data, including salinity and temperature at various locations along the Pamlico River and surface elevations at Washington Gage station, for year 2003 (a relatively wet year) and 2001 (a relatively dry year). The extended lower Tar River and Pamlico River model developed for this study will simulate the same periods, to confirm that model modifications have not violated earlier calibration and verifications.

5.4.8 Performance and Sensitivity Analysis

Performance of a simulation model requires quantitative substantiation of the model results, predictive ability, and sensitivity to model parameters. A variety of performance analysis measures such as time series error analysis, least squares harmonic analysis, regression analysis, and spectral analysis will be used to quantitatively evaluate and document the hydrodynamic model's performance in predicting water surface elevation, currents, salinity, and temperature. These performance measures will be compared with a sample of measures from other major estuarine modeling studies to document the quality of model calibration and verification.

6. Habitat Modeling

The availability of methods for establishing freshwater inflow requirements for estuaries lags behind those for establishing flow requirements in riverine ecosystems. Approaches to instream flow studies in tidally-influenced freshwater reaches and estuaries have borrowed heavily from free-flowing riverine methods, typically from habitat-based methods that integrate hydraulic and habitat modeling. Instream flow studies in tidal and estuarine systems have focused on salinity regimes and water quality issues as potentially more important drivers of habitat. Some of the common modifications for lower river tidal systems include:

- Modification of hydraulic and habitat modeling methods to accommodate tidal conditions.
- Hydrodynamic modeling to address coastal circulation and flow-salinity relationships and the potential effects of changes in flow regime on water quality.
- Development of various biological-habitat indices related to tidal systems and their salinity regimes. For the most part, these studies have been done in Texas and Florida, and various approaches have been used in different river systems.

This section describes how these approaches will be integrated and adapted for the Tar River Flow Study, how habitat will be defined in the Tar River Flow Study for each of the Study Area segments, and the modeling and criteria that will be used for the assessment of potential habitat changes due to water withdrawals and consumptive uses.

6.1 Modeling Approach

The approach to modeling in each Study Area segment is summarized in Table 6-1. Habitat will be defined differently in each segment based on the potential effects in that segment and the magnitude of withdrawals in that segment and the relative importance of physical habitat, salinity, and water quality.

Table 6-1: Habitat Modeling Approach for Each Segment of the Tar River Flow Study

Tar River Segment	Habitat Definition and Modeling Approach
Tidal Freshwater Segment	• Habitat in this segment of the river will be defined by the combination of physical habitat (depth, velocity, substrate, and cover), salinity regime, and water quality. • Habitat conditions may be influenced by tidal fluctuations, especially at low flows. • Physical habitat will be addressed by bathymetric, bottom type, and cover/structure mapping together with a GIS model that integrates hydrodynamic model results with habitat mapping in a GIS model to produce flow vs. habitat relationships. • Potential for salinity encroachment is very low, based on historical data, but the potential for this to occur will be addressed through sensitivity analysis using the hydrodynamic model. • Water quality model to assess whether withdrawals at the WTP have the potential to produce unsuitable habitat conditions or violations of water quality standards.

Table 6-1: Habitat Modeling Approach for Each Segment of the Tar River Flow Study

Tar River Segment	Habitat Definition and Modeling Approach
Estuarine Transition Segment	• Habitat in this segment of the river will be defined by salinity regime and water quality. • The hydrodynamic model will be used to address the greater potential for salinity encroachment associated with higher GUC consumptive water uses. • Also to be addressed are the potential effects of consumptive water use on the seasonal location and extent of salinity regimes and the amount of habitat area and volume in defined salinity zones. • Water quality model used to assess whether withdrawals at the WTP have the potential to result in unsuitable habitat conditions or violations of water quality standards.
Pamlico River Estuary Segment	• Habitat in this segment of the river will be defined by water quality conditions. • The potential effect of consumptive water use on water quality will be addressed through water quality modeling and sensitivity or screening analysis; this approach is based on varying inflow parameters under different water use and inflow scenarios, and observing water quality response. • This approach will be an extension of the approach used in Xu et al. (2008).

6.1.1 Scenario-Based Modeling

Approaches for evaluating riverine flow regimes often rely on the use of flow frequency analysis and flow time series data. In particular, one approach that is commonly used in North Carolina and elsewhere is "habitat frequency analysis." In this approach, historical flow time series are combined with habitat versus flow relationships to create habitat time series (Capra et al., 1995; Parasiewicz, 2008). These habitat time series represent the history of habitat events experienced in the past based on flows. The habitat time series are then divided into months and a habitat frequency analysis is developed, describing the levels of habitat typically experienced in the past and their frequency of occurrence by month or season.

Although flow time series and flow frequency analysis will be important in the basin hydrologic analysis, a time series approach to the habitat modeling will not be feasible in any of the study segments. This is largely due to the tidal conditions, which makes this approach conceptually challenging, due to the exceptional computational demands that it would create for the hydrodynamic and water quality models. For example, Xu et al. (2008) reported a model run time of one half day to run the PRE application of the EFDC model for one year for one scenario.

There are also other feasibility and data adequacy issues that limit the potential feasibility of long period time series analysis, such as availability of needed boundary condition data sets for parameters other than flow that extend for the same period of record. Even if the long-term boundary condition data were available, and the long run times could be accommodated, the resulting data sets would be massive and unwieldy for analysis.

A more appropriate approach for modeling systems when a hydrodynamic model and other linked water quality and habitat analyses are involved is the use of scenario-based modeling. Scenarios are defined by a set of conditions characteristic of the system being modeled (tidal range, inflows, wind conditions) with the values designed to cover the range of values experienced at some frequency. For example, in their study of the factors contributing to salinity stratification in the PRE, Xu et al. (2008) defined eight "scenarios" for investigative sensitivity analysis. Xu et al. created a base case and combinations of high and low inflows, wind direction (upriver, downriver, northeast, southwestward, remote wind) and specified tide and salinity settings, to address the relative effects of flow and wind conditions on salinity stratification, salinity intrusion, and general circulation and vertical diffusivity within the Pamlico River Estuarine Segment of the Study Area. Contrasting examination of these eight scenarios provided considerable insight into the behavior and dynamics of the Pamlico River estuary, as well as a good understanding of the relative importance of river discharge, wind direction, and other factors on the salinity regime.

The scenarios to be evaluated in the Tar River Flow Study will be developed with input from the TAG and will be documented in a subsequent technical memorandum.

6.2 Physical Habitat Modeling (Tidal Freshwater Segment)

Habitat in the Tidal Freshwater Segment of the river is defined by the combination of physical habitat (e.g., depth, velocity, substrate, and cover), salinity regime, and water quality. The primary steps in developing a physical habitat model of the Tidal Freshwater Segment of the Tar River will be as follows:

- Collect hydrographic and habitat data (e.g., channel bathymetry, substrate, structure).
- Complete habitat mapping and select representative study sites.
- Build a geo-referenced river habitat model and hydrodynamic model of the study sites with additional field data.
- Perform hydrodynamic modeling for study sites under different scenarios.
- Complete habitat modeling by combining hydrodynamic model simulation results with the habitat structural model in a GIS environment.
- Compute habitat values and relationships to flows for various scenarios.

6.2.1 Collect Hydrographic and Habitat Data

The procedures for collecting bathymetric data and side scan sonar data in the Tar River are fully described in Section 5, Hydrographic Data Collection. The resultant data will be used to create a geo-referenced GIS-based model of depths, bottom types, and structure/cover in the Tidal Freshwater Section of the river.

6.2.2 Habitat Data Collection and Site Selection

With the geo-referenced model, the general habitat types in the river will provide a characterization of the different habitats present and sufficient to address habitat changes along the length and width of the Study Area. The field survey will include confirmation of substrate and cover interpretations from side scan sonar results.

Once the habitat characterization is complete, potential representative study sites will be identified. The objective will be to select, in collaboration with representatives of the TAG, two study sites of sufficient length to characterize the habitats present in the Tidal Freshwater Segment. It is anticipated that one study site will be located between the GUC WTP and NC 13 and the other site will be located downstream of the USGS gage at Greenville (Figure 1-2) and upstream of the WWTP. The length, location, and intensity of habitat mapping and field checking are yet to be determined.

6.2.3 Hydrodynamic Model and Outputs

The EFDC hydrodynamic model that will be used for simulating tidal circulation, tidal height (stage), and velocities was described in Section 5. For the study sites selected, higher resolution areas will be developed within the overall EFDC model in order to create a more detailed computational model grid. This will allow hydraulic and habitat conditions to be modeled at a suitable level of detail. For each scenario, the hydrodynamic model will simulate the stage, depths and velocities within the model grid cells for the time period simulated. The hydraulic outputs of the model will be provided for each cell grid.

6.2.4 GIS Habitat Model

In this final step, the hydrodynamic model results and the habitat structure models will be combined. The depth and velocity results from EFDC model will be combined with substrate and cover attributes identified during the field mapping. The integration will be completed in a GIS database to allow the geo-referenced data to be assembled by grid cell, and to allow habitat values in each cell to be computed using habitat criteria to be described in Section 8. Once cell habitat values are computed, the habitat results can be displayed graphically on a map of the river as well as being summed together to produce traditional habitat versus flow relationships.

6.3 Salinity Regime Modeling (Estuarine Transition Segment)

The potential effects on habitat in this segment of the river due to GUC water use will be defined by salinity regime and water quality. The hydrodynamic model will be used to simulate flow-salinity relationships, the location of ecologically important salinity boundaries, and the potential salinity encroachment area. Analyses will include the spatial extent of salinity regimes and the amount of “habitat” area and volume in each defined salinity zones.

6.4 Water Quality Modeling/Screening (Tidal Freshwater Segment, Estuarine Transition Segment, and Pamlico River Estuary Segment)

The EFDC water quality model for the Tar River will be used to address water quality relationships and potential effects in the Estuarine Transition Segment and Pamlico River Estuary Segment due to GUC consumptive water uses. The primary purpose of the analysis will be to assess whether withdrawals at the WTP have the potential to result in unsuitable habitat conditions or violations of water quality standards for modeled constituents. Water quality modeling is described in more detail in Section 7.

7. Water Quality Modeling

In general, water quality models are designed to calculate the concentration and distribution of a constituent, property, or parameter in the surface waterbody being evaluated. Water quality modeling consists of simulating transport processes and constituent transformation processes. Simulation of transport is accomplished with hydrodynamic modeling (Section 6) including advection, diffusion, and dispersion. Transformation involves a quantification of sources and sinks to which a parameter is subjected, and may include physical, chemical, or biological processes.

This section briefly outlines the general approach to water quality modeling envisioned at this time. In contrast to the level of detail provided in other sections, the level of detail needed for water quality modeling, the parameters to be modeled, and the sensitivity of hydrodynamic characteristics of the Tar and Pamlico River Study Area have not yet been fully established. The final approach will be determined after the extension of the hydrodynamic model into the Tar River, and initial sensitivity analysis of withdrawals and consumptive uses. The modeling approach, evaluation of water quality constituents, and other aspects of the modeling process for the Tar River Flow Study will be developed with input from the TAG and will be documented separately.

7.1 Water Quality Model Development

The configuration of the water quality model will be based on the configuration of the hydrodynamic model. That is, it will share the same model grid, boundary conditions, forcing functions, and be dependent upon the hydrodynamic model results.

The first step in configuration of the water quality model is to select state variables, make decisions on the use of sediment flux sub-models, and estimate different reaction rate coefficients for variables. The goal is to choose a set of state variables that will achieve the level of modeling needed to meet the project objectives, and determine the model's predictive ability, consistent with the data requirements to define loads and to support model calibration and verification. A minimum set of state variables is needed to model specific parameters, such as DO. Decisions on sediment flux modeling, partitioning of state variables, and other model parameters will also be made at this point.

Time-varying open boundary conditions are required for all water quality model state variables. Time series of water quality open boundary conditions are typically developed using water quality monitoring data from stations nearest the open boundaries. It is expected that bi-weekly water quality data from ECU will be used (Section 5, Hydrodynamic Modeling), and then applied as open boundary conditions, equivalent to the current Pamlico EDFC Model. The boundary condition estimation procedure used for developing hydrodynamic open boundary conditions will be used, if necessary, for refining these boundary conditions during water quality model calibration.

Loads for permitted discharges will be developed using NPDES data provided by DWQ and EPA. Non-point source loads, including atmospheric deposition loads, will be estimated from the literature and other relevant local sources. Boundary condition loading will be developed from available water quality and gage discharge data.

Atmospheric forcing information, including wind speed and solar radiation, required by the water quality model component, will be provided from the hydrodynamic model simulation results, as will salinity and temperature.

The configured water quality model will be tested for correct linkage with the hydrodynamic model, stability, and runtime performance before beginning model calibration and verification. These tests will be primarily directed at identifying and correcting any aspects of the reaction parameter set, boundary conditions and loads that could result in instability and unrealistic model behavior.

7.2 Model Calibration and Verification

The water quality model with the expanded Tar River domain will be calibrated and verified with available water quality data. The water quality model calibration process will include the adjustment of model reaction parameters, boundary conditions, and loads to achieve a best fit between model predictions and field observations over a specified period of time. Model verification involves using the calibrated model to simulate a different period of time and achieve a model predictive performance similar to that achieved over the calibration period. Data sources include the bi-weekly sampling by ECU along Pamlico River, continuous data from the USGS, and additional data collected by DWQ along the Tar River.

A variety of performance analysis measures are available and will be used as appropriate. These include time series error analysis, least squares harmonic analysis, regression analysis, and spectral analysis to quantitatively evaluate and document the model's performance in predicting observable water quality state variables. These performance measures will be compared with a sample of measures from other major estuarine modeling studies to document the quality of calibration and verification. Sensitivity analysis is a methodology for determining the model's response to input parameters. The most sensitive parameters are those whose variation induces the greatest response and they correspond to the most uncertain parameters. Minimizing uncertainty will be achieved by demonstrating that model performance is insensitive to variation of uncertain parameters over their accepted ranges and provides additional documented support for the model application, and estimation.

8. Biological Data and Habitat Suitability Criteria

8.1 Aquatic Resource Information

Resident riverine aquatic species, estuarine dependent marine species, estuarine residents, and migratory species use habitats of the lower Tar River and Upper Pamlico system. Over two-thirds of all recreational fisheries and 90 percent of commercial fisheries in North Carolina are dependent on riverine estuaries like the Tar-Pamlico system (APNEP Science & Technical Advisory Committee, 2004). A number of important aquatic species and fisheries resources are present including state and federally designated species, habitats of ecological importance, anadromous fish populations (e.g., sturgeon, striped bass, and river herring), and estuarine-dependent marine species of recreational and commercial importance.

The Tar and Pamlico Rivers and their tributaries provide spawning habitat for a variety of fishes that migrate between saltwater and freshwater. These fish are ecologically, commercially, and recreationally important and have a substantial economic effect within the State of North Carolina, and include:

- Anadromous fish species, which live their adult lives in the ocean but move into freshwater streams to reproduce or spawn, such as hickory shad (*Alosa mediocris*), American shad (*Alosa sapidissima*), alewife (*Alosa psuedoharengus*), blueback herring (*Alosa aestivalis*), Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), and striped bass (*Morone saxatilis*).
- Catadromous species that live in freshwater and migrate to the ocean to spawn, such as American eel (*Anguilla rostrata*).
- A number of fish species that regularly migrate between saltwater and freshwater habitats (e.g., white perch, *Morone americanus*).

The aquatic habitats of the Tar Pamlico River and Upper Pamlico Estuary support significant aquatic resources. In 2000, the Tar-Pamlico River from the railroad bridge at Washington upstream to Rocky Mount Mills Dam was designated by the North Carolina Wildlife Resources Commission (WRC) as an Inland Primary Nursery Area (15A NCAC 10C.0503). Inland Primary Nursery Areas are inhabited by the embryonic, larval, or juvenile life stages of marine and estuarine fish and crustacean species due to favorable physical, chemical or biological factors (15A NCAC 10C.0502).

8.2 Available Aquatic Survey Data for the Tar River and Pamlico River Estuary

A number of agencies conduct regular sampling of the aquatic organisms present in the Tar River and Pamlico River Estuary. Researchers and students at ECU have conducted a number of surveys and studies in the Tar River Basin.

8.2.1 Tar River WRC Aquatic Survey Data

Annual spring surveys have been conducted by WRC for herring, shad, and striped bass since 1999 to assess anadromous fish spawning in the Tar River between the Rocky Mount Mills Dam and Tarboro.

Grindle and Chicod Creeks are also sampled for the presence of river herring. The numbers and species of fish spawning in these areas are documented annually (data obtained from Kirk Rundle WRC in 2008 and 2009).

In 2004 through 2005, WRC conducted a creel survey to assess the types and numbers of fish caught by anglers in the Tar River (WRC, 2005). The results indicated that most anglers in the Tar River are fishing for striped bass and largemouth bass. Sunfish species (e.g., bluegill, redear, pumpkinseed, and redbreast) and crappie are the game fish caught most often. In the spring of 2005 WRC, electrofishing in the Tar River, collected 1,423 striped bass including multiple size classes (WRC, 2005).

8.2.2 North Carolina Division of Marine Fisheries (DMF) Data

Annual trawls, juvenile trawls, and gill netting have been conducted by DMF to characterize the fish and benthic community in the Pamlico Estuary since 1978.

8.2.3 National Oceanic and Atmospheric Administration (NOAA) Studies

The overall objective of NOAA's Estuarine Living Marine Resources (ELMR) Program is to develop a database on the distribution, relative abundance, and life history characteristics of ecologically and economically important fish and invertebrates in the Nation's estuaries. The program focuses on 40 ecologically and commercially important estuarine species. In 1985, NOAA's ELMR program sampled extensively in Pamlico Sound and the Pamlico/Pungo Rivers (Nelson et al., 1991). NOAA typically characterizes the species present in three salinity zones: tidal fresh (0.0 to 0.5 ppt), mixing (0.5 to 25 ppt) and seawater (>25 ppt) and uses these zones when comparing estuary species composition. In the Pamlico Sound, the biologic community was characterized by five different salinity zones. No seawater zone (salinity >25 ppt) was found in the Pamlico or Pungo Rivers. The relative abundance of each species and life stage are provided by month (Nelson et al., 1991).

8.2.4 East Carolina University Data

Researchers at ECU have completed a number of relevant fisheries studies and reports. Some of the available data and reports include:

- Larval fish data for Tar River, Jones and Overton (2004), documents the habitat use by larval and juvenile fish as well as their community structure and spatial distribution;
- Habitat use of early *Alosa* species and striped bass in the lower Tar River; Masters Thesis, Eastern Carolina University (Smith, 2006).
- Coggins and Rulifson (2007), River Herring Surveys in the Tar River.
- Murauskas (2005), Patterns in Hickory Shad Spawning and Migration in Tar and Pamlico River. Masters Thesis, Eastern Carolina University.
- Salisbury (2008), Southern Flounder in the Tar-Pamlico River describes migration patterns and habitat use (Salisbury et al., 2008).

8.2.5 United States Geologic Survey (USGS) National Water Quality Assessment Program (NAWQA)

The Albemarle-Pamlico Drainage Study Unit (ALBE) National Water-Quality Assessment (NAWQA) project has been through a number of cycles including the initial surface water, groundwater and ecological data collection from 1991 to 1993, and groundwater and monthly surface water sampling from 1993 to 2001. A third cycle began in 2002 that focused on evaluating the influence of urbanization on the water quality and ecology of the area (Effects of Urbanization on Stream Ecosystems (EUSE)). This third cycle included nutrient source and delivery modeling (using Spatially Referenced Regressions on Watershed Attributes (SPARROW) modeling) and analysis of water quality in the Castle Hayne aquifer (Harned, 1994). No NAWQA fish data are available for locations within the Tar River Study Area, but data is available for three sites outside of the Study Area: Tar River at Tarboro, Tyson Creek near Faulkland, and Chicod Creek at SR 1760 near Simpson (http://nc.water.usgs.gov/albe/data/CycleI_ecology/ecology.html).

8.2.6 DWQ Data Benthic and Fish Sampling Data

DWQ conducts benthic and fish sampling in the Tar River Basin every five years and site ecological health is evaluated based on the North Carolina Index of Biotic Integrity (NCIBI) score determined for the site. The fish community sampling methods involve wading-based techniques, so non-wadeable and larger waterbodies are not monitored (DWQ, 2006a). The benthic community assessment methods allow for sampling larger systems from a boat with use of a petite ponar dredge (DWQ, 2006b).

Benthic and fish data are available for a number of Tar River tributaries (Table 8-1), but no fish data are available for the Tar River mainstem in the Study Area and fish community NCIBI rankings are not provided for the tributaries. According to DWQ's Standard Operating Procedure, Biological Monitoring, Stream Fish Community Assessment Program, 2006, the NCIBI for the Upper Coastal Plain, where our Study Area is located, is under revision (DWQ, 2006a).

Table 8-1: Fish and Benthic Macroinvertebrate Sampling Locations in the Lower Tar Basin Sampled by DWQ in 2007

Waterbody	Station	County	Fish/ Benthic	Level IV Ecoregion	Date	Observations	Bio-classification or NCIBI Rating*
Ballahack Canal	NC 42	Edgecombe	Fish	Southeastern Floodplains & Low Terraces	05/09/07	No darters or intolerant species, blue spotted sunfish in snags and rip/rap, BS and American eel 66% of fish	Not Rated
Ballahack Canal	NC 42	Edgecombe	Benthic	Southeastern Floodplains & Low Terraces	02/06/07	Very low habitat score and algal mats	Severe
Cokey Swamp	NC 43	Edgecombe	Benthic	Rolling Coastal Plain	02/08/07		Moderate

Table 8-1: Fish and Benthic Macroinvertebrate Sampling Locations in the Lower Tar Basin Sampled by DWQ in 2007

Waterbody	Station	County	Fish/ Benthic	Level IV Ecoregion	Date	Observations	Bio-classification or NCIBI Rating*
Cokey Swamp	SR 1135	Edgecombe	Fish	Rolling Coastal Plain	05/09/07	Eastern mosquitofish is 40% of fauna, 3 darter and 7 sunfish species	Not Rated
Conetoe Cr	SR 1510	Edgecombe	Fish	Mid-Atlantic Flatwoods	05/09/07	18 species present, 8 sunfish species, pirate perch and American eel common	Not Rated
Conetoe Cr	SR 1510	Edgecombe	Benthic	Mid-Atlantic Flatwoods	02/06/07		Moderate
Conetoe Cr	NC 42	Edgecombe	Benthic	Mid-Atlantic Flatwoods	02/06/07	5 mollusk taxa in 2002 and 1 in 2007	Moderate
Crisp Cr	SR 1527	Edgecombe	Fish	Mid-Atlantic Flatwoods	05/09/07	low fish abundance, 4 species of sunfish and American eel common, low % of tolerant fish	Not Rated
Crisp Cr	SR 1527	Edgecombe	Benthic	Mid-Atlantic Flatwoods	02/06/07		Moderate
Tyson Cr	SR 1255	Pitt	Fish	Rolling Coastal Plain	05/10/07	Good instream and riparian habitats, one intolerant species sawcheek darter, American eel 50% of fish	Not Rated
Otter Cr	SR 1614	Edgecombe	Benthic	Rolling Coastal Plain	02/07/07	Large number of mollusks	Moderate
Otter Cr	SR 1614	Edgecombe	Fish	Rolling Coastal Plain	04/02/97		Not Rated
Town Cr	NC 43	Edgecombe	Fish	Rolling Coastal Plain	08/28/97		Not Rated
Town Cr	SR 1601	Edgecombe	Benthic	Southeastern Floodplains & Low Terraces	06/27/07		Good
Chicod Cr	SR 1777	Pitt	Benthic	Mid-Atlantic Flatwoods	02/14/07		Natural
Grindle Cr	US 264	Pitt	Benthic	Mid-Atlantic Flatwoods	06/25/07		Good-Fair
Tranters Cr	SR 1552	Edgecombe	Benthic	Mid-Atlantic Flatwoods	02/13/07		Moderate

Table 8-1: Fish and Benthic Macroinvertebrate Sampling Locations in the Lower Tar Basin Sampled by DWQ in 2007

Waterbody	Station	County	Fish/ Benthic	Level IV Ecoregion	Date	Observations	Bio-classification or NCIBI Rating*
Flat Swamp	SR 1157	Martin	Benthic	Mid-Atlantic Flatwoods	02/13/07		Moderate
Horsepen Swamp	SR1001	Beaufort	Benthic	Mid-Atlantic Flatwoods	02/13/07		Moderate
Old Ford Swamp	US 17	Beaufort	Benthic	Mid-Atlantic Flatwoods	02/12/07		Moderate
Lathams Cr	SR 1410	Beaufort	Benthic	Mid-Atlantic Flatwoods	02/12/07		Natural
Beaverdam Swamp	SR 1523	Beaufort	Benthic	Mid-Atlantic Flatwoods	02/13/07		Moderate
Tar River	SR 1565 (Grimesland Bridge)	Pitt	Benthic	Mid-Atlantic Flatwoods	06/26/07		Good-Fair
Cannon Swamp	US 264	Pitt	Fish	Mid-Atlantic Floodplains & Low Terraces	05/10/07	Channelized and 0% canopy, abundant macrophytes. Productive, 82% tolerant species	Not Rated
Hardee Cr	NC 33	Pitt	Benthic	Mid-Atlantic Flatwoods	02/14/07		Natural
Juniper Swamp	SR 1766	Pitt	Fish	Mid-Atlantic Flatwoods	04/15/93		Not Rated
Parker Cr	NC 33	Pitt	Fish	Mid-Atlantic Floodplains & Low Terraces	05/10/07	American eel, redbreast sunfish and bluegill most abundant. Nine sunfish and four catfish species. Third highest catch rate of Tar Basin in 2007	Not Rated
Whichard Branch	SR 1521	Pitt	Fish	Mid-Atlantic Flatwoods	05/10/07		Not Rated
Whichard Branch	SR 1521	Pitt	Benthic	Mid-Atlantic Flatwoods	02/13/07		Moderate

8.3 Rare, Threatened, and Endangered Species Present in the Study Area

Existing databases on unique, endemic, and state or federally listed aquatic species within the Study Area have been obtained and summarized to serve as the basis for this and other project tasks. Species occurrence data were obtained from the Natural Heritage Program (NHP), Natural History Museum, and FWS. Species occurrence records from multiple agencies have been combined and mapped (Appendix B). The state and federally listed species that occur within the Tar River Flow Study Area are identified in Table 8-2. It is expected that WRC, DMF, and FWS will provide information and expert opinion regarding these species and will participate in the development of their habitat criteria.

A recent mussel survey conducted for GUC by John Alderman (Alderman, 2009) in the Tar River mainstem near the WTP intake found eight species of mussels, three species of which are listed as Threatened by the State of North Carolina (Table 8-3).

Table 8-2: State and Federally Listed Species Observed in the Tar River between GUC Water Treatment Plant Intake and Washington

Scientific Name	Common Name	Taxa	Federal Status	State Status	NOAA Fisheries Status
Vertebrates					
Trichechus manatus	West Indian manatee	Mammal	E	E	None
Acipenser oxyrhynchus	Atlantic sturgeon	Fish	T*	None	None
Ambloplites cavifrons	Roanoke bass	Fish	FSC	SR	None
Alosa pseudoharengus	Alewife	Fish	None	None	SOC
Alosa aestivalis	Blueback herring	Fish	None	None	SOC
Necturus lewisi	Neuse River waterdog	Amphibian	None	SC	None
Invertebrates					
Lampsilis cariosa	Yellow lampmussel	Mussel	FSC	E	None
Alasmidonta undulata	Triangle floater	Mussel	None	T	None
Leptodea ochracea	Tidewater mucket	Mussel	None	T	None
Lampsilis radiata	Eastern lampmussel	Mussel	None	T	None
Elliptio Roanokensis	Roanoke slabshell	Mussel	None	T	None
Oronectes carolinensis	NC spiny crayfish	Crayfish	None	SC	None
Baetisca obesa	Mayfly	Mayfly	None	SR	None

E = Endangered T = Threatened
T = NC Stock recommended for listing as Federally Threatened*
FSC = Federal Species of Concern
SR = State Rare, SC = State Species of Concern
SOC = National Oceanographic and Atmospheric Administration, Fisheries Division, Species of Concern

Table 8-3: April 2009 Mussel Survey in Tar River near GUC WTP Intake

Scientific Name	Common Name	Live Mussels	CPUE*	State Status	Federal Status
Elliptio roanokensis	Roanoke slabshell	10	2.22	T**	None
Lampsilis radiata radiata	Eastern lampmussel	2	0.44	T**	None
Leptodea ochracea	tidewater mucket	7	0.44	T**	None
Elliptio complanata	Eastern elliptio complex	163	36.22	None	None
Elliptio ictarina	variable spike complex	1	0.22	None	None
Elliptio congarea	Carolina slabshell	29	6.44	None	None
Elliptio cistellaeformis	box spike	85	ND	None	None
Corbicula fluminea	Asian clam	ND	ND	None	None

**CPUE = Catch per Unit Effort*
***T = Threatened*

8.4 Supplemental Mussel Surveys within the Freshwater Tidal Segment

The mainstem of the Tar River upstream of the Study Area is known to support a diverse freshwater mussel assemblage. Although habitat for rare and protected mussel species is presumably present, there is little recent collection information available for the Study Area other than the spring 2009 mussel survey near GUC's WTP intake (Alderman, 2009) and a few WRC surveys in the NHP database from the early 1980s.

A comprehensive freshwater mussel survey will be conducted as part of the Tar River Flow Study to provide updated and more detailed information as to which species are present and their relative abundance. Prior to conducting surveys field reconnaissance, aerial and topographical mapping, bathymetry and side scan sonar data will be used to assist in targeting survey locations. Mussel surveys will be conducted for three full days at a minimum of 15 sites within the Freshwater Tidal Segment of the Study Area.

A range of habitat types will be surveyed at each site. The amount of time spent at each survey location will be dependent on habitat quality and distribution across the river, with special attention to those that may support rare and/or listed State and Federal mussel species. Multiple sampling methods will be used including SCUBA based, visual surveys, glass bottom buckets, and tactile methods. Tactile methods will be employed particularly in the stream banks under submerged root mats.

Timed surveys will be conducted to provide catch per unit effort (CPUE) data. All species of freshwater bivalves will be identified, recorded and returned to the substrate. Representative photographs will be taken of each species and of the habitats where they are found. Habitat conditions for each site will be recorded and will include substrate types, water depth range, location in channel, and bank conditions. All individuals of species monitored by the NHP and WRC will be measured and checked for evidence of reproduction, and a representative sample of species that are not monitored will be processed in the same manner. The FWS and WRC will be contacted if any federally listed species are found.

8.5 Criteria for Habitat Modeling

In this portion of the study, we will use existing information and the results of fish and mussel surveys to develop the biological and habitat criteria that will represent the basic ecological requirements and habitat functions needed by freshwater and estuarine aquatic species and other flow-dependent habitats. These criteria may include defined suitability values of depth, velocity, substrate, and cover; salinity thresholds, criteria, or physical locations; and water quality standards. The development and use of these criteria is highly dependent upon their availability in the literature, knowledge of the ecology of the Tar-Pamlico system, and agreement with the TAG on their appropriate use.

Work under this task will include the compilation of available data and habitat approaches, assessing the applicability of the criteria to the Tar River, developing a proposed set of criteria to be used, and identifying any additional or supplementary data available through the TAG. The TAG will be provided with a summary of the available criteria and our recommendations. Comments and input will be solicited and used to develop a revised set of criteria and documented in a technical memorandum. The habitat criteria to be evaluated in the Tar River Flow Study will be developed with input from the TAG and will be separately documented. The final criteria will be used with habitat modeling to determine the effects of flow changes on the different habitats needed by Tar River aquatic species.

8.5.1 Habitat Suitability Criteria for Tidal Freshwater Habitat Modeling

A set of suitability criteria for depth, velocity, substrate, and cover will be established for species and/or functional groupings such as habitat-use groups or guilds, unique, endemic, and state or federal listed aquatic species, and selected life stages of anadromous species. These criteria will define optimal and suitable habitat for specific species or guilds. The development of biological and habitat criteria for the Tar River Flow Study will begin by compiling the selected species and habitat suitability criteria from published literature, previous studies, and available specialists with specific knowledge of key species. The results will be a set of habitat criteria (e.g., depth, velocity, substrate, cover) for selected species or habitat-use guilds that define optimal and suitable habitat for certain species and life stages. These habitat criteria will be used in physical habitat modeling.

Evaluation of available habitat criteria will specifically include the species of special interest, including yellow lampmussel, Atlantic sturgeon, Neuse River waterdog, and Roanoke bass. It is expected that the

DENR, NOAA fisheries, and FWS will provide information and expert opinion regarding these species and will participate in the development of their habitat criteria.

8.5.2 Criteria for Evaluating Salinity Regime in the Freshwater-Tidal Transitional Segment

It is broadly recognized and documented that the salinity regimes of estuarine systems are highly dependent upon the amount and timing of freshwater flows (Jassby, 1995; Alber, 2002; Estevez, 2002; Mattson, 2002; Montagna, 2008) and that salinity has been identified as a key water quality characteristic affecting species distribution and estuarine productivity (Longley et al., 1994; Flannery et al., 2002).

The approaches and criteria currently used to address salinity are variable among states and estuarine systems, and generally include monitoring and simulation of circulation and salinity patterns and assessment with biologically-defined salinity zones, salinity constraints, salinity refuges, and/or isohaline position (position of an isohaline boundary near known important habitat areas). Many of these criteria are river and estuary specific. Models are often used to predict changes in circulation and salinity for various inflow scenarios, and strong correlations are found between freshwater inflows and the salinity gradients in many estuaries. For example, desirable salinity regimes for different species are investigated through multivariate flow-salinity regressions as a function of inflow for multiple sites in Texas estuaries (Brandes et al., 2009).

Most often, these salinity criteria are based on long-term monitoring and the statistical characteristics of salinity within the estuary combined with known salinity preferences and tolerance limits of the target species. Long-term flow and salinity data sets and population levels of fish, invertebrates, and plants are used to set constraints and to develop statistical relationships between flow and salinity to establish these criteria.

While long-term research has been completed to support such studies in some estuaries in Florida, Texas, and California, the availability of such information is far more limited for North Carolina. The compilation of available biological data sets and flow records and meta-analysis has, with some limited exceptions, not yet been conducted. These analyses are well beyond the scope and time frame of this study, and may well take many years to be funded and accomplished.

However, the result of these available studies and the salinity criteria and guidelines that have been developed may be applicable with some modification, to the Tar River Flow Study. It is also possible that modeling approaches can be used to establish baseline conditions and sensitivity analysis can be used to define historical and existing conditions that would serve as a baseline for potential effects on salinity resulting from GUC’s consumptive water use.

As a part of the development of habitat criteria, an overview of potentially applicable salinity criteria and recommendations will be provided to the TAG for review and discussion.

8.5.3 Water Quality Criteria

There is a wide range of available water quality criteria that could be used to assess the results of the water quality modeling. These include state water quality standards and literature on the water quality tolerances of various organisms. As the water quality modeling is completed, these issues will be addressed with the TAG.

Existing information will be used to develop the biological and habitat criteria that will represent the basic ecological requirements and habitat functions needed by select aquatic species and other flow-dependent resources. The results will be a set of habitat criteria (e.g., depth, velocity, substrate, cover, temperature, salinity, and water quality parameters) for selected species or habitat-use guilds that define optimal and suitable habitat for certain species and life stages. These habitat criteria will be used in physical habitat modeling. Verification of, and agreement on, the habitat criteria developed may require expert consultation and literature research.

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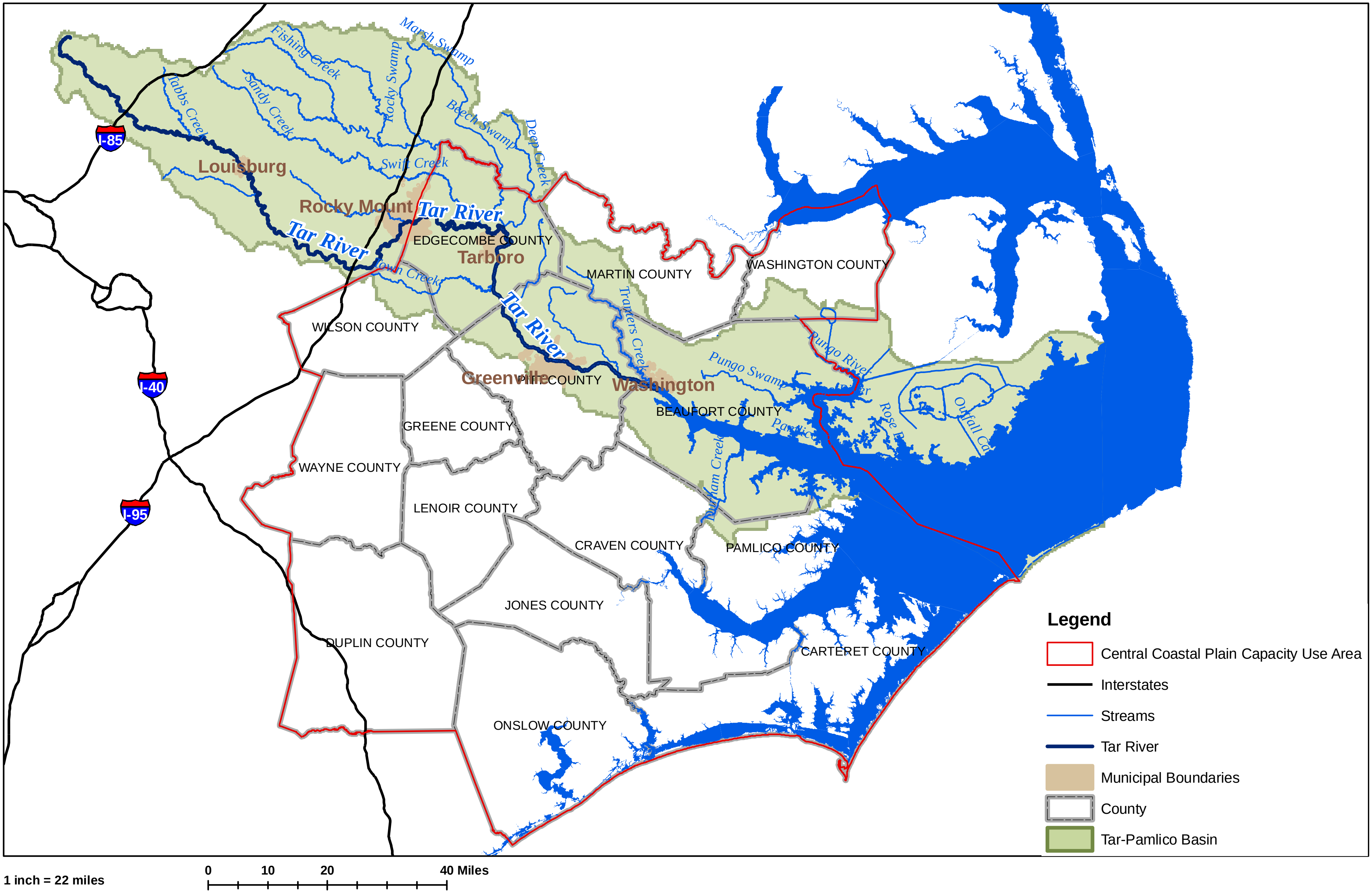

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Figure 1-1. Tar River Basin and Central Coastal Plain Capacity Use Area

Tar River Flow Study
Greenville Utilities Commission

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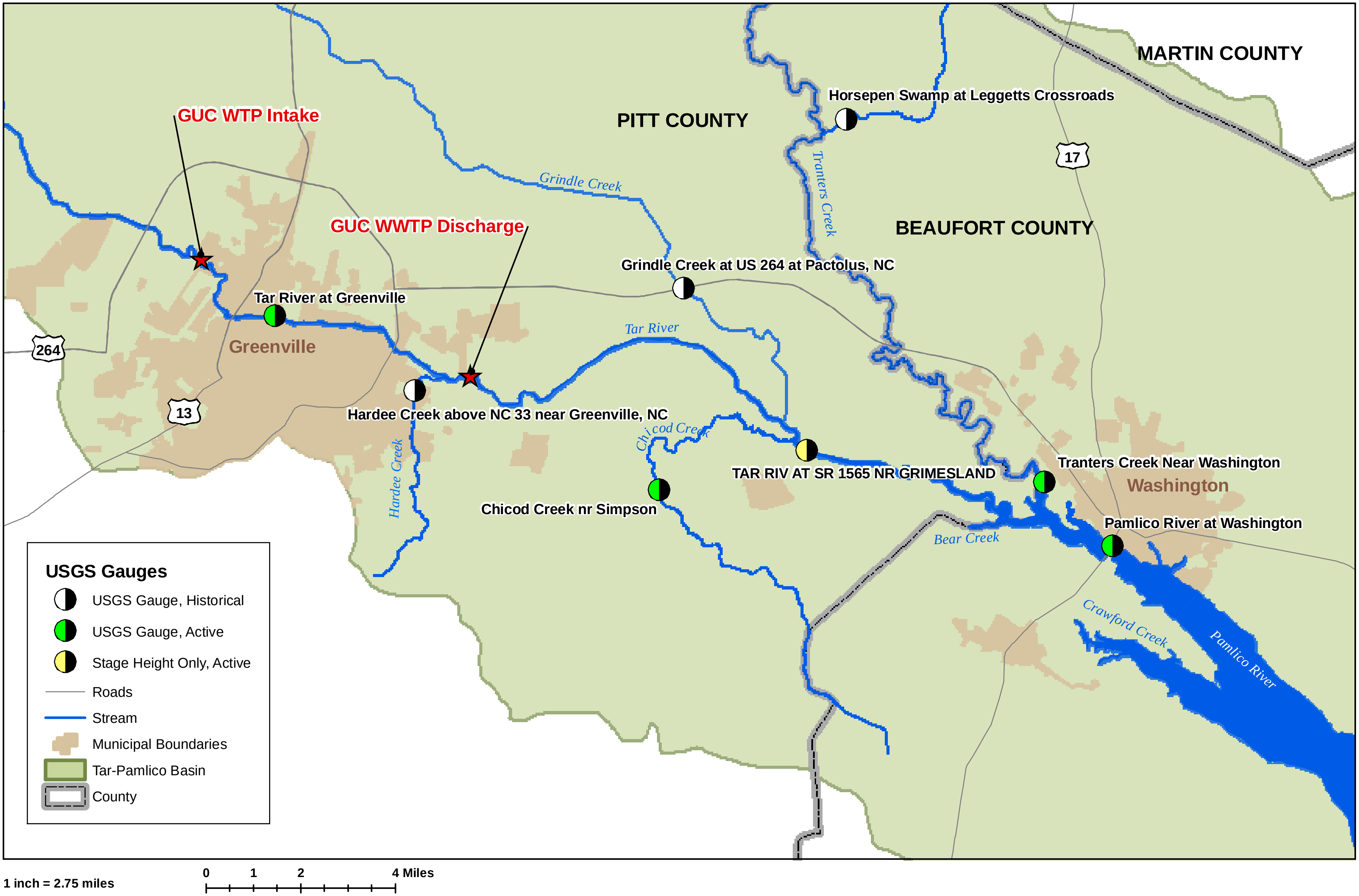

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Figure 1-2. General Study Area

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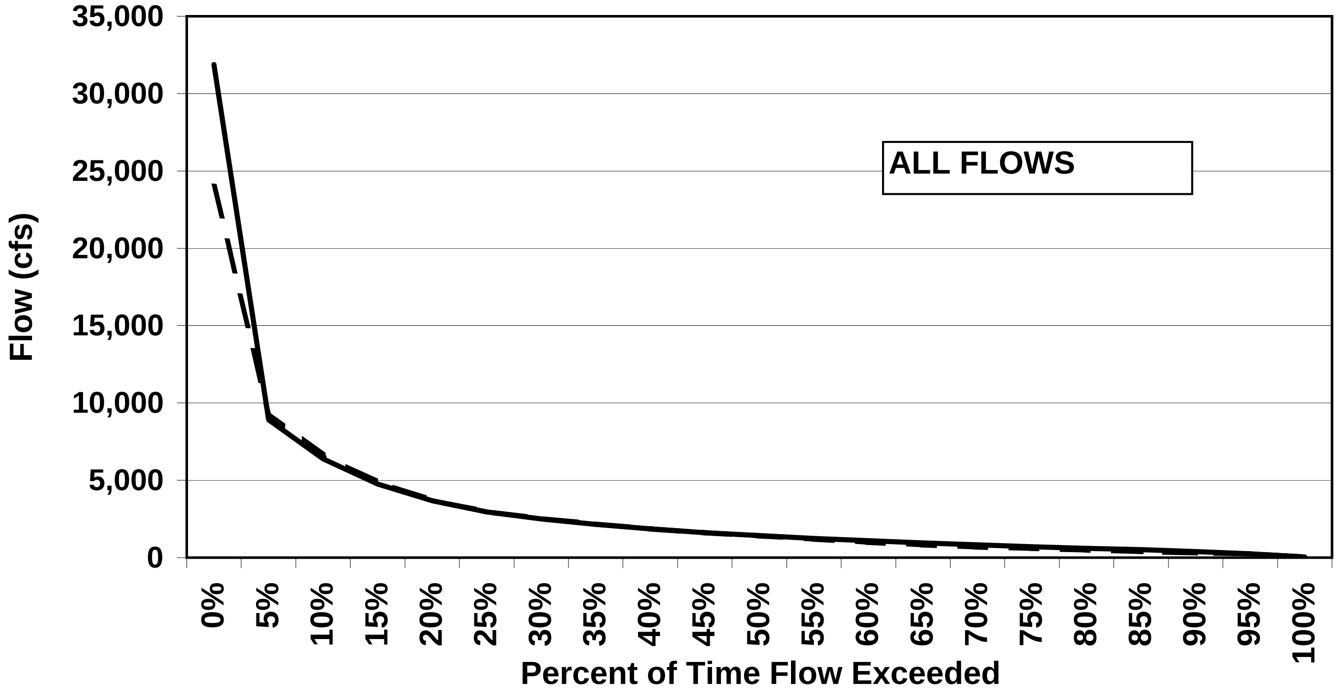
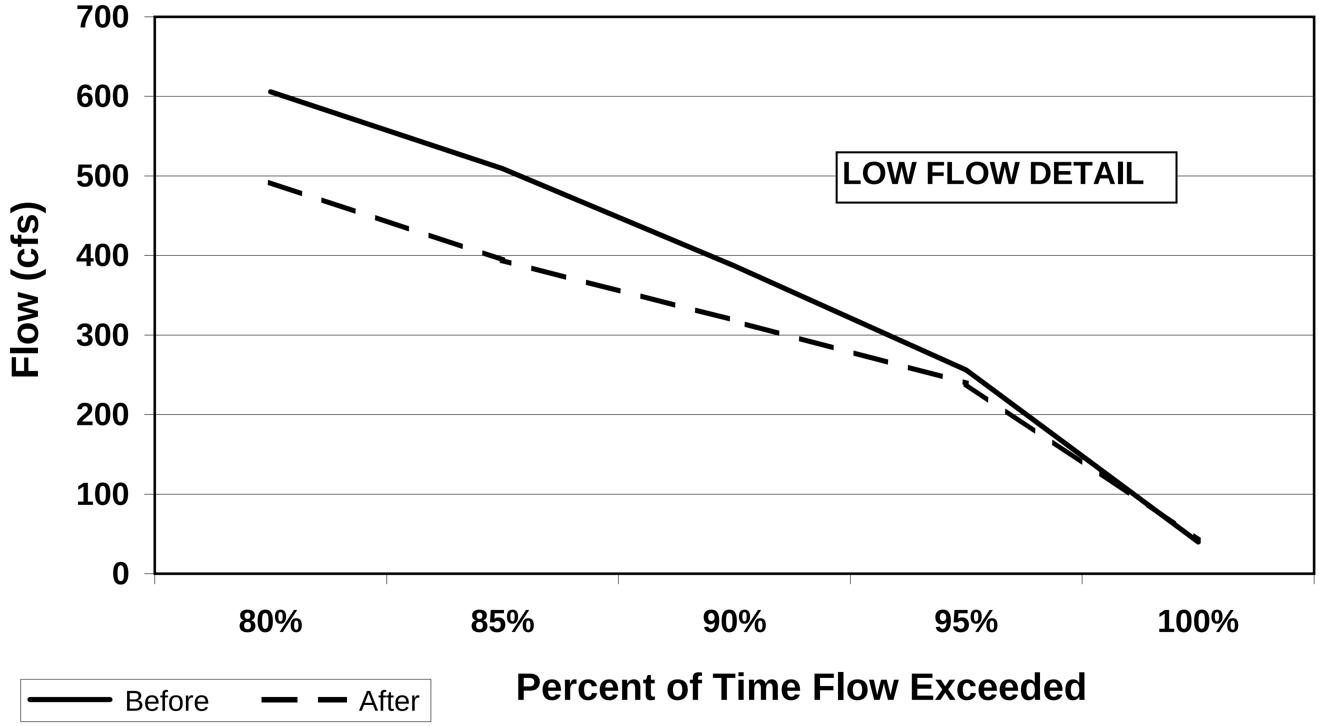
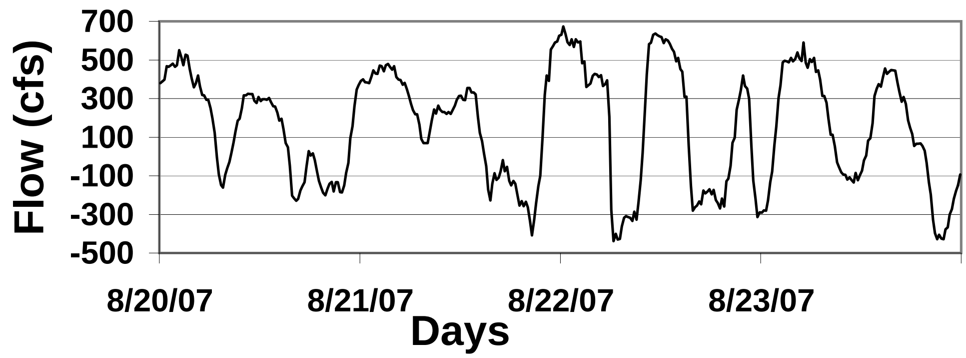


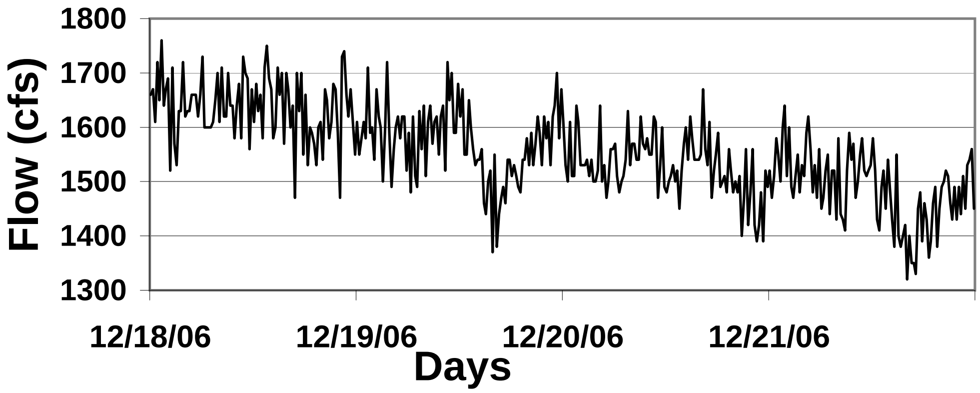


cfs = Cubic feet per second.

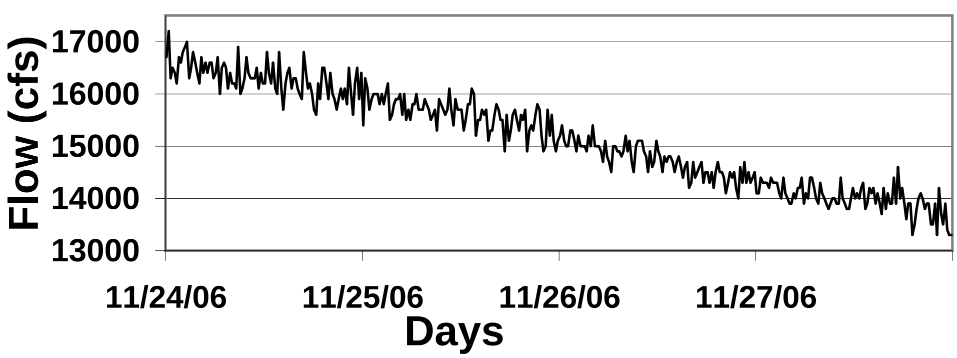
Figure 2-1. Flow Duration Curves Based on Average Annual Flow at Greenville Gage Station; Comparison of Generated Flow Record Before (1932-1968) and After [with] (1972-2006) Operation of the Rocky Mount Reservoir.



(a) Daily Average Flow of About 150 cfs



(b) Daily Average Flow of About 1,500 cfs



(c) Daily Average Flow About 15,000 cfs

Figure 2-2. Range of tidally-influenced flow oscillations in the Tar River at Greenville for three different ranges of average flow condition (a) 150 cfs (August 20-23, 2007), (b) 1,500 cfs (December 18-21, 2006), and (c) 15,000 cfs (November 24-27, 2006), fifteen minute flow data shown on graphs

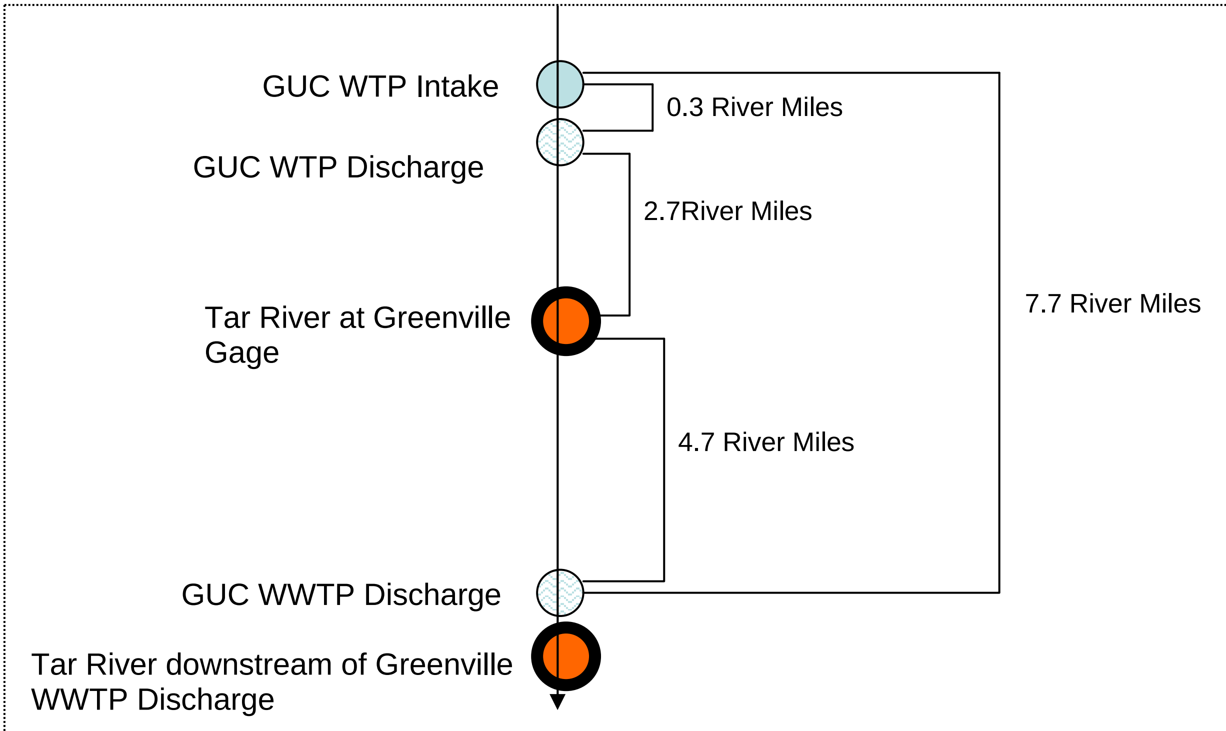


Figure 2-3. Schematic diagram of the Tar River in the vicinity of Greenville, NC showing the relative locations and approximate distances between withdrawal and discharge locations, USGS gage location, and hydrologic model output points

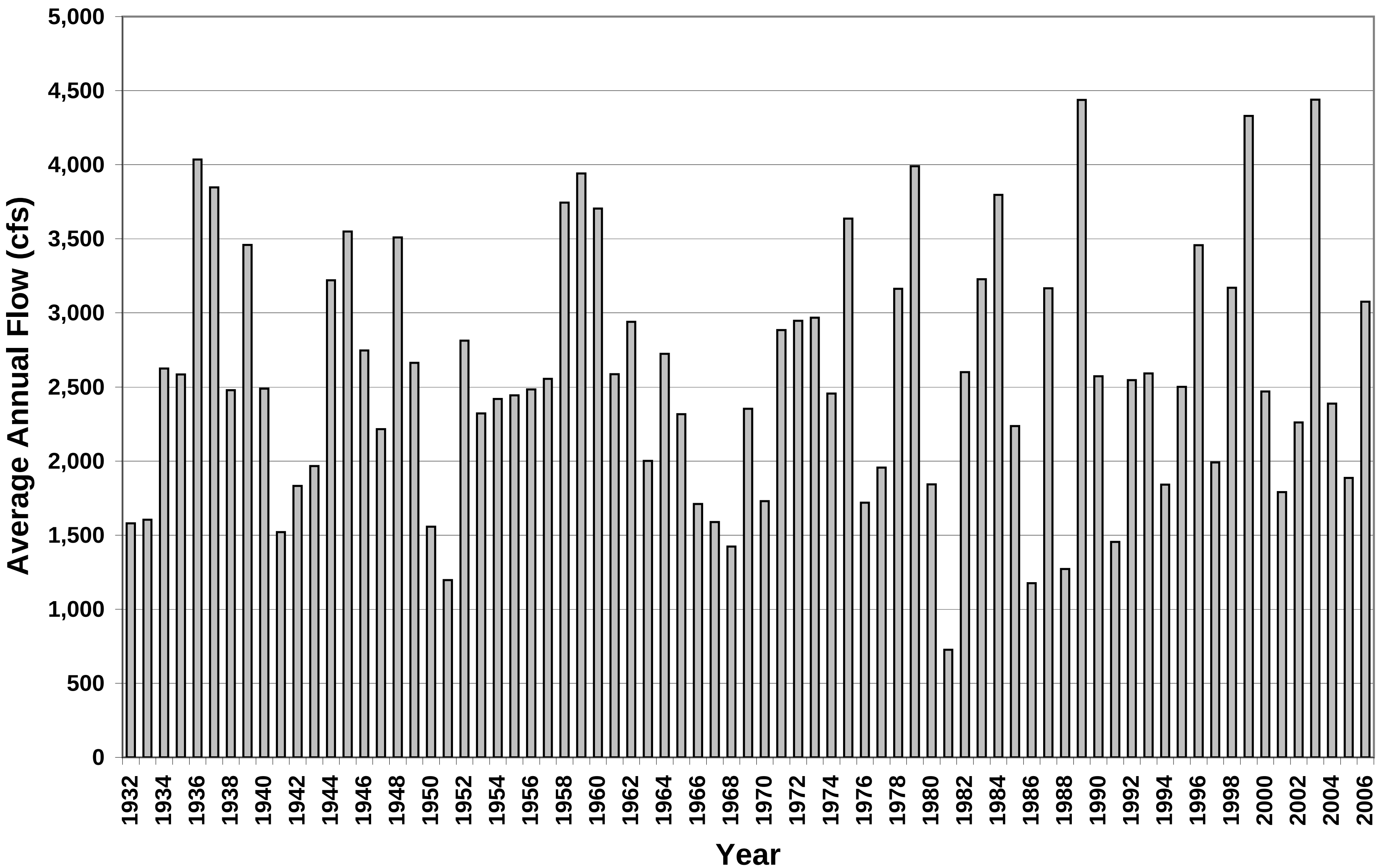
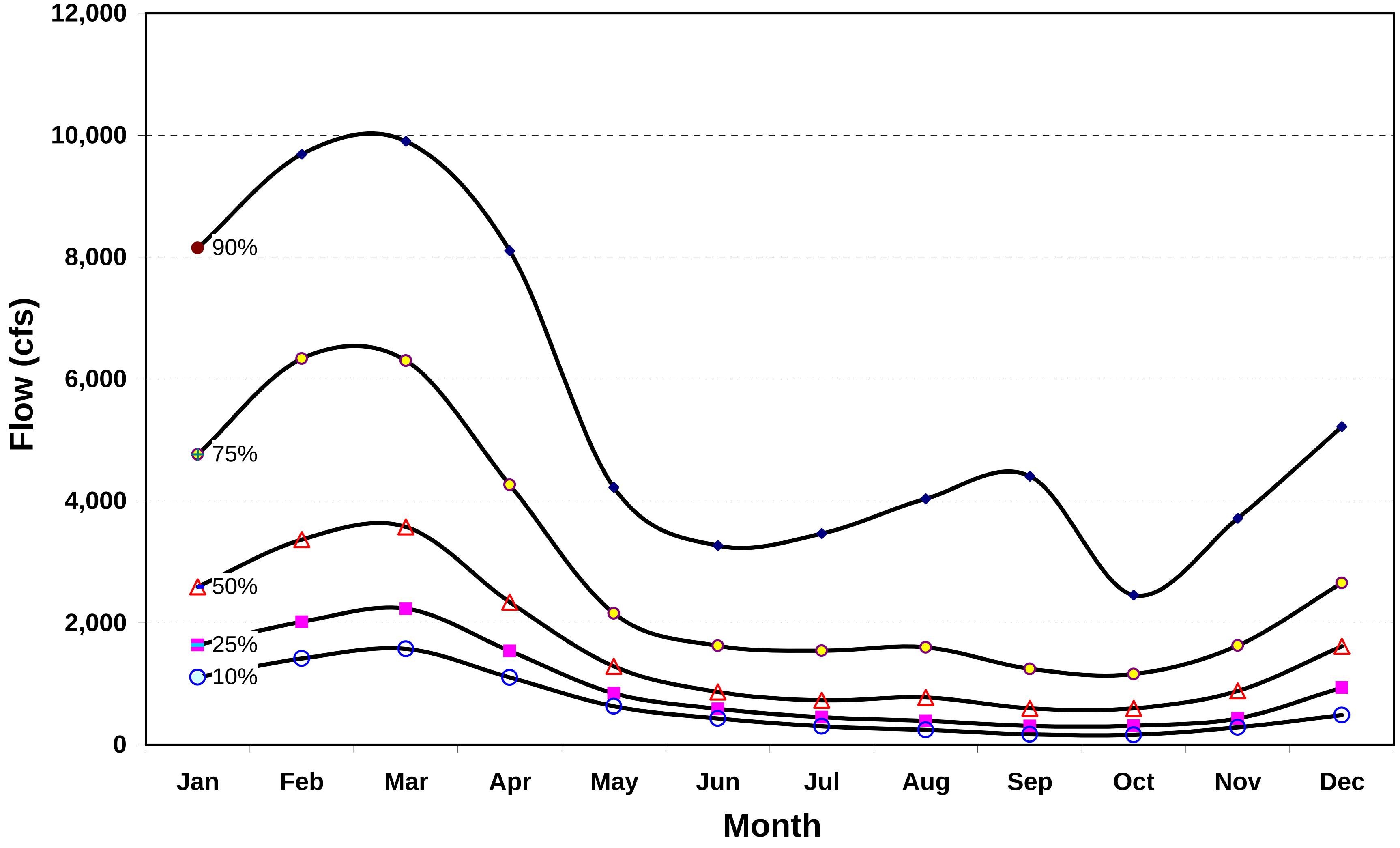


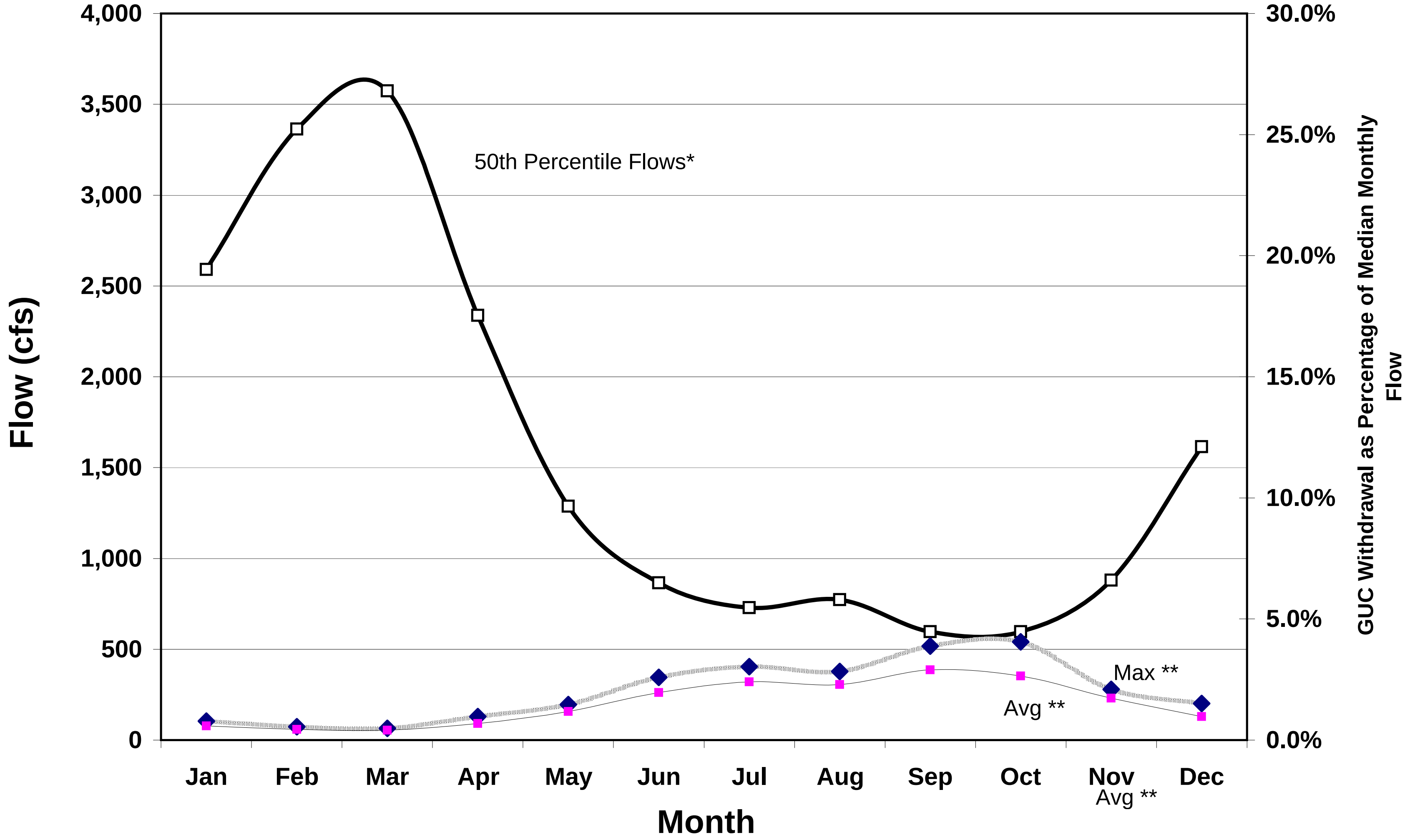
Figure 2-4. Average Annual Flows in the Tar River at Greenville based on Analysis of Historical Flow Records (1932-2006)



* Monthly median flows based on modeled data (1931 - 2007)

cfs - Cubic feet per second.

Figure 2-5. Flow Percentiles for Tar River at Greenville based on Modeled Data (1931-2007)



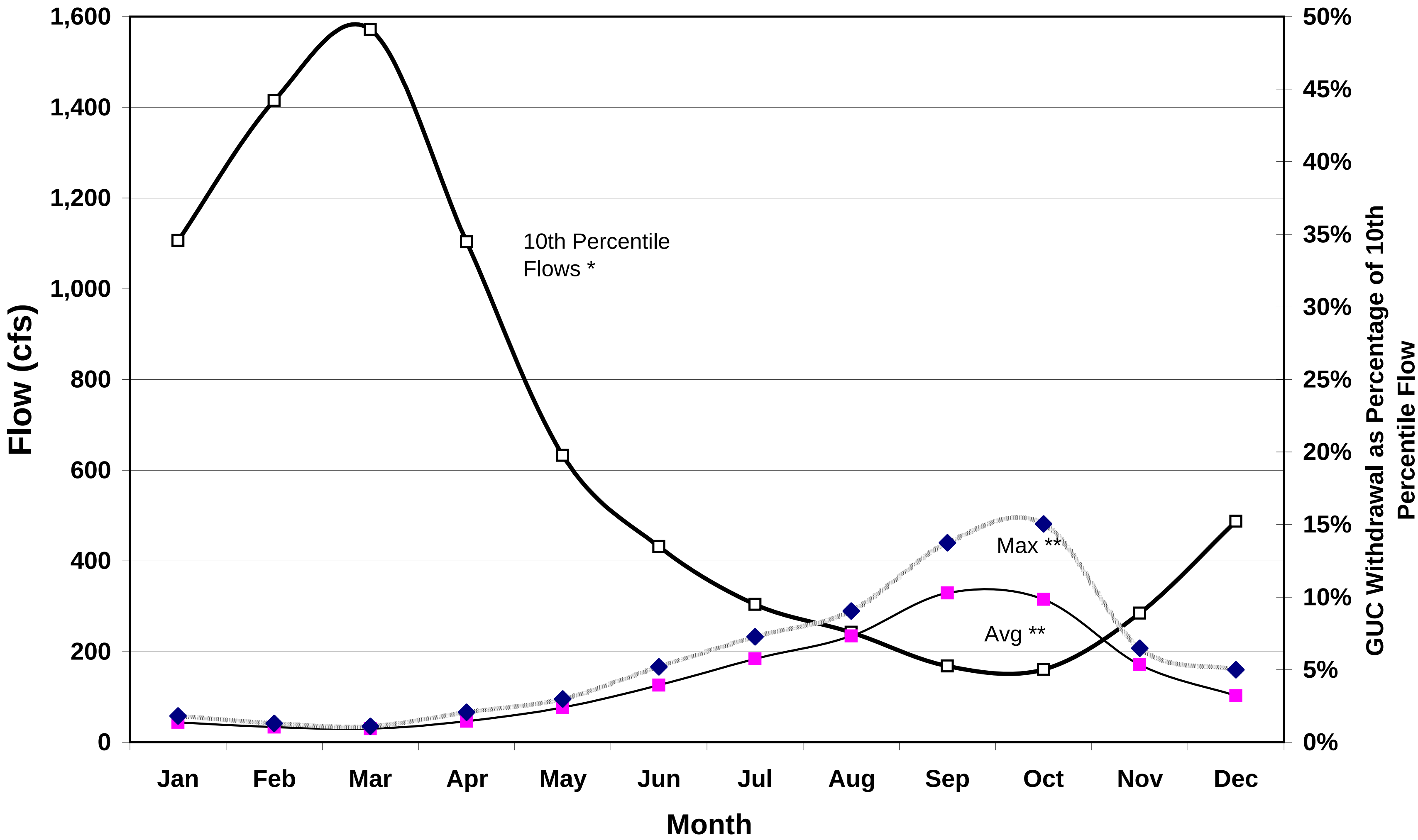
* Median monthly flow based on modeled data (1931 - 2007) for Tar River gage.

** Based on monthly average and maximum withdrawals for 2005.

cfs - Cubic feet per second.

GUC - Greenville Utilities Commission.

Figure 2-6. GUC Average and Maximum Withdrawals as a Percentage of the Median Tar River Flow



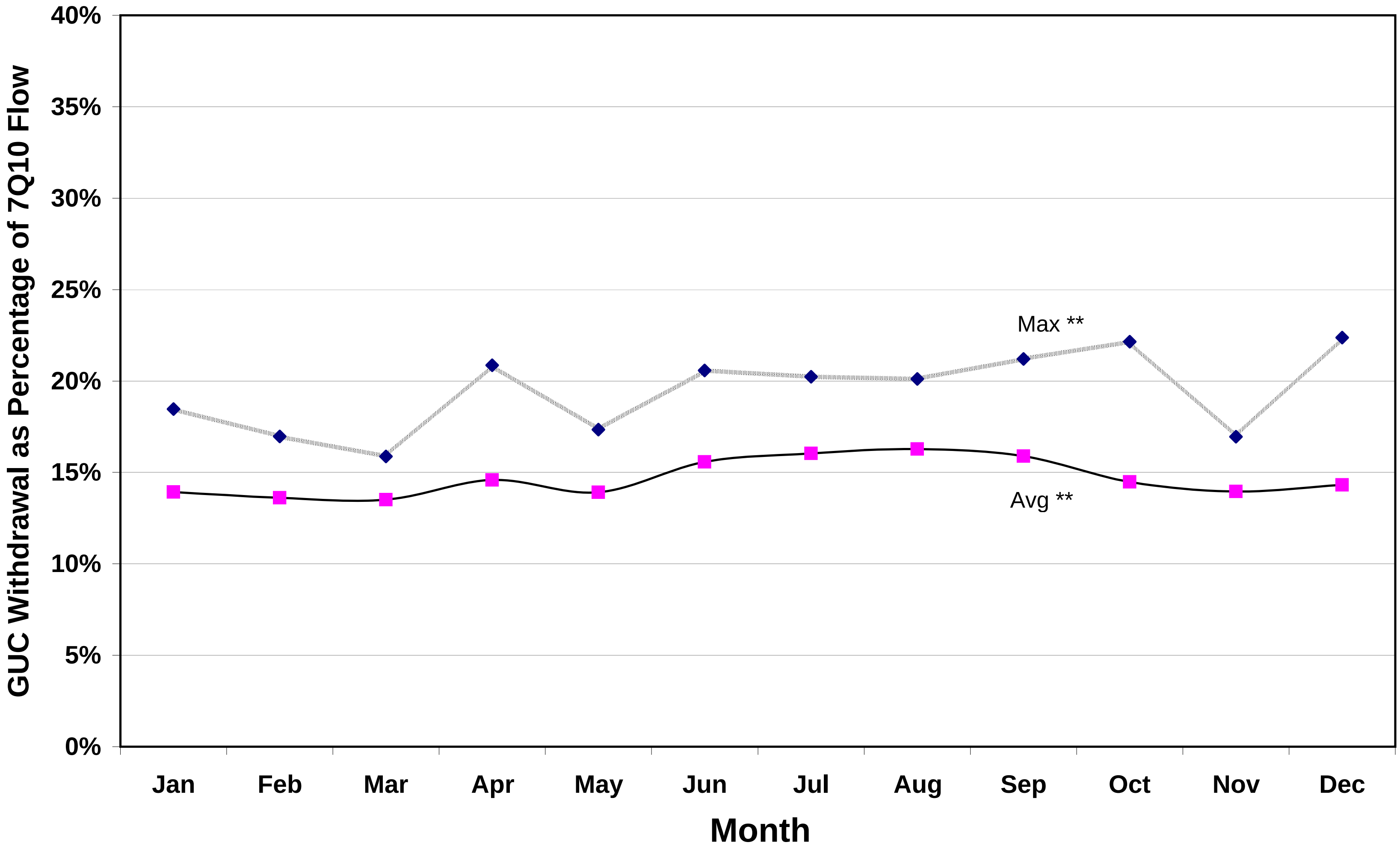
* Monthly 10th percentile flows based on modeled data (1931 - 2007)

** Based on monthly average and maximum withdrawals for 2005.

cfs - Cubic feet per second.

GUC - Greenville Utilities Commission.

Figure 2-7. GUC Withdrawals as a Percentage of the 10th Percentile Monthly Flows



* The summer 7Q10 flow is given as 108 cfs (GMA 2003).

** Based on monthly average and maximum withdrawals for 2005.

cfs - Cubic feet per second.

GUC - Greenville Utilities Commission.

Figure 2-8. Average and Maximum GUC Permitted Withdrawals as a Percentage of the 7Q10 Flow

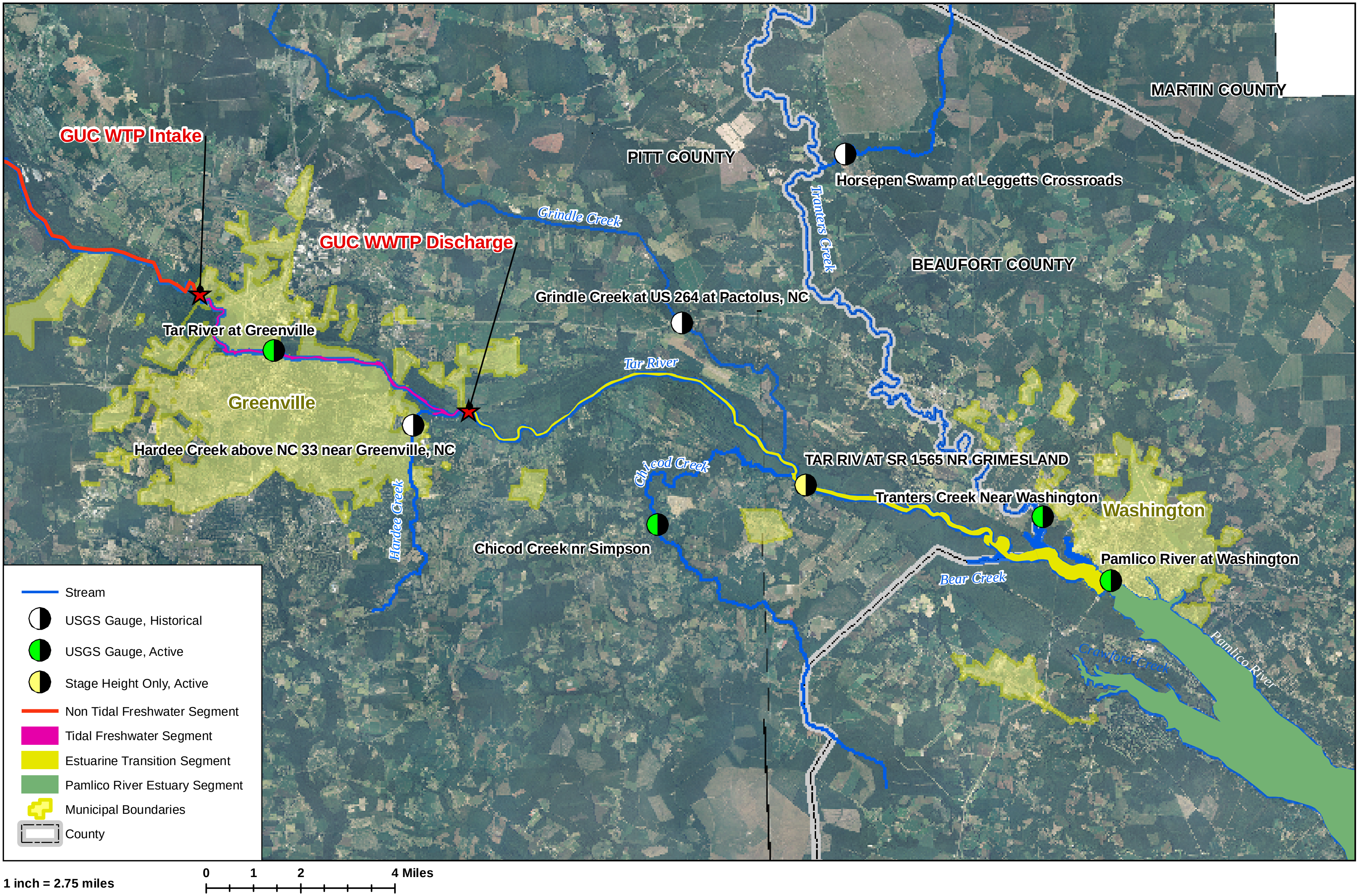


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Figure 3-1. Study Area Segments

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