

**SECONDARY AND CUMULATIVE IMPACT REPORT
NUTRIENT AND SEDIMENT ANALYSES**

CLAYTON BYPASS

**JOHNSTON AND WAKE COUNTY,
NORTH CAROLINA
(R-2552)**

PREPARED FOR:



**THE NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
RALEIGH, NORTH CAROLINA**

MARCH 2004

EXECUTIVE SUMMARY

Watershed analyses were performed on behalf of the N.C. Department of Transportation (DOT) for an area surrounding the proposed Clayton Bypass (Bypass) (R-2552) for Current Condition and two future scenarios that consider no project versus project development levels. The analyses conducted as part of this study include comparative modeling of current and future loadings for total nitrogen (TN), total phosphorus (TP), and sediment (both overland and in-stream transport) within the Study Area defined by watersheds draining to Swift Creek that are proposed to be crossed by the Bypass. The purpose of the study is to estimate the percentage difference in nutrient and sediment yield between the “with project” and “without project” scenarios. This study is required by the N.C. Division of Water Quality (DWQ) and the U.S. Fish and Wildlife Service (FWS) in an effort to address direct, indirect, and cumulative impacts for consideration during Section 404 permit review and Section 401 Water Quality Certification review. These analyses were completed using techniques that utilize the strengths of two different modeling approaches: 1) large-scale modeling on the entire Study Area using the Annualized Agricultural Non-Point Source (AnnAGNPS) model developed by the U.S. Department of Agriculture (USDA) coupled with 2) smaller-scale modeling of smaller sub-watersheds to provide data on 1) the effectiveness of Best Management Practices (BMPs) and 2) stream generated sediment. The more detailed modeling was performed using the Soil and Water Assessment Tool (SWAT) model developed by the USDA and a one-dimensional stream erosion and hydrodynamics model from the Center for Computational Hydrodynamics and Engineering (CCHE1D). The outputs from SWAT and CCHE1D were extrapolated for the entire Study Area.

Two future scenarios were evaluated including: 1) Year 2025 projected growth, without the Bypass and 2) Year 2025 projected growth, with the Bypass and proposed induced development specifically attributable to the Bypass. Existing (current) condition was evaluated to provide a baseline with similar model assumptions and parameters to facilitate a comparative analysis without verification from field data. Both future scenarios include reductions resulting from current and possible BMPs including Phase I and Phase II storm water controls (ponds) and Neuse River Riparian Buffers.

Study Area boundaries were defined through group consensus of the modeling team, the land-use consultant, N.C. Department of Transportation (DOT), and DWQ. All land-use coverage used in modeling the Study Area was provided by URS Corporation. Land-use data were provided in digital format and integrated into the water quality models using ArcView software for analyses.

By Year 2025, modeling of land use derived from predicted growth indicates that the Bypass and associated induced development will result in an increase of 5.1-percent in TN, 0.2-percent in TP, and 2-percent in total sediment. These analyses have been performed to support a comparative evaluation of pollutant yields, and actual pollutant loads are expected to be different than reported in this study.

TABLE OF CONTENTS

Executive Summary	i
1.0 Introduction	1
2.0 Methods	4
2.1 Study Area Definition	4
2.2 Land-use Generation	4
2.2.1 Current Condition	5
2.2.2 Year 2025 Predicted Condition: Scenarios 1 and 2	5
2.2.3 Land-use Controls	6
3.0 Model Comparisons and Descriptions	7
3.1 AnnAGNPS Model	7
3.2 CCHE1D In-Stream HydroDynamics	9
3.3 SWAT Model	9
4.0 Results and Discussion	10
4.1 Current Condition	10
4.2 Scenario 1 (without bypass)	10
4.3 Scenario 2	11
4.4 Land-use Controls	13
5.0 Summary	14
VI. References	16

FIGURES

Figure 1. Study Area Location	Appendix A
Figure 2. Modeling Boundaries for AnnAGNPS, SWAT, and CCHE1D	Appendix A
Figure 3. Land Use for Three Modeled Scenarios	Appendix A
Figure 4. Study Area Hypsography and Streams Generated from a 10-meter Digital Elevation Model (DEM)	Appendix A
Figure 5. AnnAGNPS Cell Network	Appendix A
Figures 6A-C. Watershed Pollutant Yields for Total Nitrogen, Total Total Phosphorus, and Total Sediment	Appendix A
Figures 7A-C. Pollutant Yield Changes Resulting from Development for Total Nitrogen, Total Phosphorus, and Total Sediment for 3 Modeled Scenarios	Appendix A

TABLES

Table 1. Federal and State designations of rare species with documented populations within the Study Area	2
Table 2. Corresponding land-use categories used in AnnAGNPS and SWAT	5
Table 3. Annual Watershed Pollutant Yields for the Study Area	12

**NUTRIENT AND SEDIMENT ANALYSES
CLAYTON BYPASS (R-2552)
WAKE AND JOHNSTON COUNTIES, NORTH CAROLINA**

1.0 INTRODUCTION

EcoScience Corporation (ESC) has been retained by the N.C. Department of Transportation (DOT) to perform watershed-based change analyses for nutrient and sediment yields within the vicinity of the proposed Clayton Bypass (the Bypass) in Johnston County, North Carolina (**Figure 1, Appendix A**). The 92.5-square mile region of study (hereafter referred to as the "Study Area") is composed of all watersheds draining to Swift Creek that are proposed to be crossed by the Bypass. The proposed alignment of the Bypass extends from the intersection of US 70 and US 70-Bypass westward to a proposed interchange with I-40. The 9-mile corridor is proposed as a multi-lane, divided, controlled-access facility on new location. Additional interchanges are planned at SR 1560 (JJ Ranch Road) and NC 42. The Bypass will relieve traffic congestion, improve commuting time, and generate improved access to employment centers like Raleigh, Durham, and the Research Triangle Park (RTP) for rural areas located in eastern Johnston County. However, streams within the vicinity of the Bypass contain populations of an aquatic species listed as Endangered and several species identified as Federal Species of Concern (FSC). These rare species receive consideration under the Endangered Species Act, and may be threatened by water quality degradation. The purpose of this study is to address the water quality implications of the Bypass and associated future development. In addition, the study provides regulatory agencies with supporting documentation to determine whether additional Best Management Practices (BMPs) may be required in order to protect regional water quality and maintain the integrity of existing federally protected aquatic species populations. These nutrient and sediment analyses provide a watershed-scale evaluation of potential water quality changes resulting from induced secondary and cumulative development associated with the Bypass.

This effort has been requested by the N.C. Division of Water Quality (DWQ) as part of the review process for issuance of Section 401 Water Quality Certification. In addition, the U.S. Fish and Wildlife Service (FWS) is interested in these analyses in order to comment on the potential for the Bypass to affect the federally Endangered dwarf wedge mussel (*Alasmodonta heterodon*), as well as the four Federal Species of Concern (FSC) listed species and seven state listed species with known occurrences within the Study Area (**Table 1**).

Currently, individual segments of streams within the region are primarily degraded by excessive sedimentation and nutrients, with fecal coliform being a secondary cause for concern (DWQ 2002). Named streams within the Study Area (Cooper Branch, Little Creek, Mahler's Creek, Neal Branch, Reedy Branch, Swift Creek, and White Oak Creek) have all been assigned the Best Usage Classifications of **C NSW**. The designation **C** denotes those "waters protected for secondary recreation, fishing, wildlife, fish and aquatic life propagation and survival, agriculture and other uses suitable for Class C." The supplemental designation Nutrient Sensitive Water (**NSW**) is intended "for waters needing additional nutrient management due to their being subject to excessive growth of microscopic or macroscopic vegetation. In general, management strategies for point and non-point source pollution control require no increase in nutrients over background levels." It should be noted that Little Creek is currently listed as "Impaired" and has

Table 1. Federal and State designations of rare species with documented populations within the Study Area.

COMMON NAME	SCIENTIFIC NAME	STATE ₁ STATUS	FEDERAL ₂ STATUS
Dwarf wedgemussel	<i>Alasmidonta heterodon</i>	E	LE
Yellow lance	<i>Elliptio lanceolata</i>	E	FSC
Atlantic pigtoe	<i>Fusconaia masoni</i>	E	FSC
Green floater	<i>Lasmigona subviridis</i>	E	FSC
Carolina least trillium	<i>Trillium pusillum var pusillum</i>	E	FSC
Pinewoods shiner	<i>Lythrurus matutinus</i>	SR	FSC
Triangle floater	<i>Alasmidonta undulata</i>	T	-----
Roanoke slabshell	<i>Elliptio roanokensis</i>	T	-----
Eastern lampmussel	<i>Lampsilis radiata radiata</i>	T	-----
Squawfoot	<i>Strophitus undulatus</i>	T	-----
Cape Fear spike	<i>Elliptio marsupiobesa</i>	SC	-----
Carolina madtom - Neuse river population	<i>Noturus furiosus pop 1</i>	SC	-----
Notched rainbow	<i>Villosa constricta</i>	SC	-----

¹Federal Status: LE=Listed Endangered, FSC= Federal Species of Concern

²State Status: E=Endangered, T=Threatened, SC=Special Concern, SR=Significantly Rare (Amoroso 2002; LeGrand and Hall 2001)

Source: N.C. Natural Heritage Program

recently been placed on the State's 303(d) list requiring development of special management plans to project Total Maximum Daily Loads (TMDLs) for pollutants. However, this effort has not been completed for the Little Creek watershed. It is expected that any water quality impairment in Little Creek has been due to urban expansion within the watershed resulting in increased stormwater runoff, increases in flooding, and introduction of other pollutants. Stream degradation and subsequent aquatic habitat loss have also occurred. Because there is a high correlation between sediment and nutrient concentrations (DWQ 2002), an evaluation of these contaminants is a valid indicator of impacts to water quality.

Results of the nutrient and sediment analyses will be used to quantify percentage increases between two future scenarios: 1) projected growth without the Bypass and 2) projected growth with the Bypass and development induced by the project. Analyses of current (Year 2003) condition was conducted to provide a baseline for comparison that uses similar assumptions as the future scenarios. Both future scenarios were modeled with consideration for constraints resulting from current and anticipated BMPs such as Neuse River riparian buffers and stormwater ponds resulting from Phase I and II Stormwater Controls.

In order to estimate loading-rate changes for each scenario, long-term, time-series measurements of stream flow, total suspended solids (TSS), and nutrient concentrations for various stream stages in the growing and non-growing seasons would be required. A detailed field study is prohibitive for the current effort due to the large size of the Study Area (92.5 square miles); therefore, predictive modeling efforts have been employed to determine future nutrient- and sediment-yield trends.

Currently, very few models compute non-point source nutrient and sediment loads. The Annualized Agricultural Non-Point Source (AnnAGNPS) model and Soil and Water Assessment Tool (SWAT) models were used simultaneously as duplicative, complimentary modeling

approaches. AnnAGNPS was created and released by the USDA (2001). AnnAGNPS has been shown to be an effective model for estimating pollutant loading in urban and urbanizing watersheds (Choi and Blood 1999). Also, AnnAGNPS has been designed so that it can be incorporated with other water quality models. The overland pollutant loading predicted by AnnAGNPS was integrated with the Center for Computational Hydroscience and Engineering, One Dimensional model (CCHE1D; Viera and Wu 2002) to determine in-stream hydrodynamics for four named stream sub-watershed areas within the Study Area.

SWAT was created and released by the USDA (Arnold and Allen 1992; Srinivasan and Arnold 1994). SWAT is capable of predicting the influence of land cover and land uses on sediment, water, and chemical yields from ungauged stream basins. SWAT also contains integrated sub-routines to predict stream channel erosion and stream transported sediment. Additionally, SWAT is capable of modeling the water quality protection benefits of BMPs such as riparian buffers and sediment ponds. Through using these two separate modeling approaches, it is possible to predict pollutant loading patterns across different scales, and to provide a means of cross checking data output from each model in the absence of verifiable field data.

Cooperation and coordination with a variety of groups and individuals was necessary for completion of this study. All study protocols were reviewed by DWQ prior to initiation of the models.

2.0 METHODS

This study was heavily dependent on accurate portrayal of available data from a number of sources utilized for quantitative analyses. Methods and sources of utilized data are described in four primary categories: Study Area Definition, Land-use Development, Nutrient and Sediment Analyses, and In-Stream Hydrodynamic Modeling.

2.1 STUDY AREA DEFINITION

The Study Area is defined by all watersheds draining to Swift Creek that are proposed to be crossed by the Bypass. The Study Area boundary was selected by consensus of personnel from DOT, DWQ, ESC, and URS Corporation. This boundary was digitized into a Geographical Information Systems (GIS) database by using 14-digit hydrologic unit boundaries created by the N.C. Center for Geographic Information and Analysis (CGIA). The approximate Study Area also defined the limits for land-use generation for the three modeled scenarios. The Study Area boundary was further refined through use of Light Detection and Ranging (LIDAR)-based elevation data (FMP 2000) with a reported vertical accuracy of 25 centimeters. The refined 92.5-square mile boundary has been used for all water quality modeling associated with this study (**Figure 2, Appendix A**).

The Study Area incorporates all of 14-digit hydrologic units (030202011100-30, -40, -50, -60, and -70) likely to be crossed by the Bypass. The limits of the Study Area are delineated to the north and east by the drainage divide between Swift Creek and the Neuse River, to the south by the drainage divide between Swift and Middle Creeks, and to the west by the drainage divide between the Swift Creek catchment above and below the Lake Benson dam. Portions of the Towns of Clayton, Garner, and Smithfield are within the Study Area. Additionally, portions of major roads such as I-40, US 70, US 70 Bypass, NC 50, and NC 42 occur within the Study Area providing the major infrastructure for commutes within the boundary.

Additional modeling was performed using higher resolution data on several sub-watersheds within the Study Area. **Figure 2 (Appendix A)** depicts the boundaries of these sub-watersheds, which were modeled using SWAT and CCHE1D to predict correction factors for AnnAGNPS output resulting from the benefit of BMPs and the increased yield of stream generated sediment. These sub-watersheds were selected for more detailed modeling efforts by DWQ due to their habitat significance for aquatic populations of interest to regulatory agencies. Additionally, the Swift Creek Mitigation Site, which is the compensatory mitigation project to offset unavoidable jurisdictional area impacts from the Bypass, is contained within the upper SWAT modeled boundary. The water quality benefit of preserving the Mitigation Site compared to its development without preservation was not considered in this study.

2.2 LAND-USE GENERATION

Twelve land-use categories are utilized by AnnAGNPS and SWAT models. The 12 categories are defined by the amount of impervious area and vegetation cover within a tax parcel unit (**Table 2**). It should be noted that there are nomenclatural differences between AnnAGNPS and SWAT; however, Table 2 depicts corresponding land-use categories utilized by these models. All land-use information was digitized and provided to ESC by URS Corporation (2004) in ArcView 3.x shapefile format. Within the subroutines of AnnAGNPS and SWAT, variables, including cover type, percent impervious surface, and runoff curve numbers, were assigned to

each land-use category and applied to the parcels within that category. Figures depicting land use for all scenarios are provided in **Figure 3 (Appendix A)**.

Table 2. Corresponding land-use categories used in AnnAGNPS and SWAT. Study Area land use was categorized using tax parcels as land-use units.

AnnAGNPS Land-use Category	SWAT Land-use Category
COMM: Business, Commercial, 85% impervious	UCOM: Commercial
CROPLAND: Fallow, Row Crops, Small Grain	SOYB: Soybean
HOUSE20: Housing, 1-acre lots, 20% impervious	URLD: Residential, Low Density
HOUSE25: Housing, 0.5-acre lots, 25% impervious	URML: Residential, Med/Low Density
HOUSE30: Housing, 0.3-acre lots, 30% impervious	URML: Residential, Med/Low Density
HOUSE38: Housing, 0.25-acre lots, 38% impervious	URMD: Residential, Medium Density
HOUSE65: Housing, 0.125-acre lots, 65% impervious	URHD: Residential, High Density
INDUST: Business, Industrial, 72% Impervious	UIDU: Industrial
PASTURE: Pasture, Grassland, or Range	PAST: Pasture
WATER: Lakes, Ponds, Reservoirs	Ponds have been inserted as a separate feature, not a land-use category
WOODG: Woods-Grass Combination	FRSE: Forest-Evergreen
WOODS: Woodland or Forest	FRST: Forest-Mixed

2.2.1 Current Condition

For both future scenarios, Current Condition serves as the baseline against which future land-use scenarios were developed. In addition to land-use mapping, Year 1998 U.S. Geological Survey (USGS) (National Aerial Photography Program [NAPP]) color infra-red digital aerial photography, Year 1999 Wake County color aerial photography, Year 2000 Johnston County color aerial photography, and Year 1993 DOT black-and-white aerial photography were used to generate figures, and as sources of reference for selecting appropriate model parameters for specific land uses. N.C. Floodplain Mapping Program (FMP) LIDAR data were used to generate landscape surface features for this study. Several resolutions of Digital Elevation Models (DEM) were created from the LIDAR data. The availability of these data sets allowed for the flexibility to use the appropriate resolution in relation to size for each area modeled. Data obtained from the N.C. Center for Geographic Information and Analysis (CGIA) for inclusion into the mapping database include Study Area hydrology (Neuse River basin), county lines, and 14-digit hydrologic unit boundaries for inclusion in the mapping database. Digital data obtained from the DOT include roadway networks and the alignment for the Bypass (R-2552). For clarity in mapping, each land-use category was color coded.

2.2.2 Year 2025 Predicted Condition: Scenarios 1 and 2

New development within the Study Area was projected to Year 2025 without (Scenario 1) and with (Scenario 2) the Bypass. Scenarios 1 and 2 are based upon estimated secondary and cumulative growth. These estimates were generated based on the following assumptions (URS 2004).

1. *The Study Area will likely experience considerable development regardless of the project.*
2. *Growth generated by the project will mainly be limited to new interchange catchment areas within the Study Area. However, the region south and east of the Study Area may also experience development pressure due to increased accessibility to regional employment centers*

New development in both future scenarios is dominated by the low-density residential category in previously rural areas of forest and cropland. Increases in the commercial and industrial categories are centered along major transportation corridors for both scenarios.

Scenario 1 predicts that 14.6-percent (13.5 square miles) of area will be converted from currently non-developed to developed land-use categories. Scenario 2 predicts that an additional 5.1-percent (4.7 square miles) of currently non-developed area will be converted to developed land-use categories. In summary, by the Year 2025 and without the project, the Study Area is anticipated to be subjected to an increase of 14.6-percent (13.5 square miles) of development relative to the Current Condition, while, by the Year 2025 and with the project, the Study Area is anticipated to be subjected to an increase of 19.7-percent (18.2 square miles) of development relative to Current Condition.

2.2.3 Land-use Controls

For Current Condition, if the existing land-use category of a parcel is 1) forested and adjacent to a stream or 2) water, then the parcel has been modeled considering the benefit of riparian buffers or a pond. For Scenarios 1 and 2, both structural and non-structural BMPs (storm water detention basins and riparian buffers) are considered by SWAT. 50-foot riparian buffers are preserved adjacent to streams on all land depicted as non-developed in Current Condition but characterized by development in Scenario 1 or 2. Storm water ponds have been applied to land use in future scenarios for all new development of 1.0 acre or more as required by Phase II storm water regulations (EPA 1999, DWQ 2001). To identify intermittent stream reaches for receipt of riparian buffers, the stream network generated by the AnnAGNPS model was used to find the specific drainages predicted to support an intermittent stream. The AnnAGNPS model derived the stream network by interpolation of the USGS 30-meter DEM data (see **Section 3.0**). Once the drainage had been identified, the CGIA stream hydrology layer for the Neuse River Basin was manually updated using GIS to include the intermittent channels to the extent indicated by the AnnAGNPS stream network. Data sources involved include Neuse River basin hydrology from CGIA, 30-meter DEM data created by ESC using FMP LIDAR data, URS land-use data, and several digital mapping products in GIS that were described in Section 2.2.1. These computer generated land-use controls were compared against the original data layers for quality control.

3.0 MODEL COMPARISONS AND DESCRIPTIONS

The AnnAGNPS model is the most flexible of the three models used in this study, and was deemed to be the most successful at providing overland pollutant loads over a large scale. The Study Area was modeled with AnnAGNPS using 30-meter resolution data to generate pollutant yields from surface run-off for the entire modeled area. Drawbacks of AnnAGNPS are that the model cannot easily predict the benefit of BMPs, cannot consider groundwater influences, and does not adequately consider stream erosion and stream-generated sediment loading.

While SWAT and CCHE1D are better at predicting BMP efficiencies and stream generated sediment, they are not practicable for modeling the required detail at the Study Area scale. Instead, these models were used on several sub-watersheds to generate correction factors for the AnnAGNPS output. SWAT and CCHE1D model runs were performed using 10-meter resolution data, and provided both information on the effectiveness of BMPs and an improved prediction of stream-generated sediment. SWAT was run using with- and without-BMP scenarios to provide a correction factor for the benefit of BMPs within the Study Area. AnnAGNPS data were imported into CCHE1D to predict the percent increase in total sediment yield from stream-generated sediment.

3.1 ANNAGNPS MODEL

AnnAGNPS is a continuous simulation, surface run-off, pollutant loading, computer model. AnnAGNPS is capable of predicting run-off, sediment yield by particle size-class, and nutrient loadings for TN and TP (USDA 2001, Bosch *et al.* 1998). The mathematical processes utilized within AnnAGNPS include weather generation, run-off volumes from precipitation, peak run-off from major storm events, erosion, and sediment delivery. The AnnAGNPS model predicts surface-generated pollutant loadings and routes the pollutants through stream reaches. The model does not predict in-stream erosion and channel evolution.

The AnnAGNPS model recreates daily weather for an established period, using either simulated weather data or actual measured climate data. Since actual climate data are available from regional weather stations, real daily climate observations were used for weather rather than internal weather generation processes of the AnnAGNPS model. Weather data from 2002 were used for these analyses since the 47.36 inches of annual rainfall for that year were close to the 30-year average of 46.77 inches reported for the region by the N.C. State Climate Office.

Remaining processes are generated internally within AnnAGNPS. Runoff volumes from precipitation are derived from the Soil Conservation Service (SCS) curve number method. This is a simple, efficient, and widely used method for determining the approximate amount of runoff from a rainfall event in a particular area. Although the method is designed for a single storm event, AnnAGNPS integrates this process with weather input and performs the method on each individual storm event that occurs within the modeled year. The curve number is assigned based upon the hydrologic soil group, land-use type, treatment method, and hydrologic condition of an area. A specific curve number is assigned to each land-use category and used by AnnAGNPS to determine the run-off that enters the stream network.

Technical Release 55 (TR-55) is a process developed by the SCS that estimates runoff and peak discharges in small watersheds. While TR-55 is designed for use in urban and urbanizing

watersheds, the procedures can be utilized on any small watershed with sufficient climate and landscape data.

Soil loss equations that utilize slope and land use as inputs have been available since the 1930s. These equations were modified through the addition of a rainfall parameter by the USDA in 1965 into the Universal Soil Loss Equation (USLE). Further improvements have been made to update USLE into the Revised USLE (RUSLE). RUSLE has the same basic formula as USLE, but with several improvements including new and revised isoerodent maps, a time-varying approach for soil erodability, an approach for evaluating land cover management, a new equation to reflect slope length and steepness, and new conservation-practice values (MSU 2002). A further derivative of RUSLE, Hydro-geomorphic USLE (HUSLE) is also used by AnnAGNPS to simulate overland soil loss and transport to ephemeral channels and stream networks (USDA-ARS 2000).

Input files required to run AnnAGNPS sub-routines include DEM, climate, soil, and land use data. To generate the required input files for AnnAGNPS, DEM data are utilized to generate Study Area topography. AnnAGNPS integrates another model, TOPographic PArameteriZation (TOPAZ; Martz and Garbrecht 1995), which uses DEM elevation values to generate watershed boundaries and then determines the direction of flow for each location within the landscape. The threshold for generation of a stream can be set within the model, and, for the purposes of this study, a watershed size of approximately 12-18 acres was determined to be sufficient for intermittent stream formation. This threshold is based on DWQ research that correlates watershed size to the formation of intermittent streams in the North Carolina Piedmont region (Smith, unpublished). **Figure 4 (Appendix A)** depicts the resulting landscape topography and stream network. AGFLOW, a sub-routine of AnnAGNPS, uses the TOPAZ output to generate a network of micro-watershed cells based upon landscape position hydrology, and hypsography (**Figure 5, Appendix A**). Stream locations generated by the model were compared to the CGIA Neuse hydrology layer and USGS topographic mapping for quality control (**Figure 5 Inset, Appendix A**). Once completed, the AGFLOW output is imported into an AnnAGNPS/ArcView interface allowing the user to intersect GIS-based input data to the AGFLOW cells. Data assigned to cells include soils and land use. Soils data were generated through the State Soil Geographic (STATSGO) program, which generates an AnnAGNPS-compliant version of soil identification and properties. Land-use data were then integrated into this database. Once soils and land use have been intersected to the AGFLOW cell network, the input files are used in the AnnAGNPS input editor.

The AnnAGNPS input editor is used to assign general parameters and data to each soil group and land-use category within the AGFLOW cell network. SCS curve numbers and Manning's N values are assigned to each land-use category, and RUSLE criteria (such as root mass, cover variation, rainfall height from canopy vegetation to soil surface, and surface residue cover) are assigned as well. Weather observations were added as a final input, and AnnAGNPS simulates every day within a one-year period. Weather, run-off, and transport of pollutants are all simulated. Results are predicted and can be interpreted for each cell, for groups of cells, or for entire watersheds. ArcView files of output were created so that pollutant export could be overlain and compared to land-use changes for different scenarios using GIS.

3.2 CCHE1D IN-STREAM HYDRODYNAMICS

The CCHE1D modeling system was designed to simulate unsteady flows and sediment transport processes in channel networks. CCHE1D simulates bed aggradation and degradation, bed material composition (hydraulic sorting and armoring), bank erosion, and the resulting channel morphologic changes under unsteady flow conditions. CCHE1D is a general, one-dimensional model, which is particularly effective in the estimation of long-term sediment loads and morphologic changes in channel networks (Viera and Wu 2002).

The channel network defined in CCHEID is generated with the use of TOPAZ directional flow output. The network is defined in terms of stream confluences (nodes), reaches, and watersheds. River bed and bank sediment properties are considered part of the cross-sectional data. CCHE1D accepts AnnAGNPS overland sediment flow data in watersheds to be used as boundary conditions for the CCHE1D channel simulations. The AnnAGNPS input specifies peak flow, time-to-peak, storm duration, and sediment rates entering channel reaches at network nodes. Outputs are in-stream hydrodynamics within four selected stream sub-watersheds.

3.3 SWAT MODEL

Along with AnnAGNPS, SWAT is also a continuous simulation, surface run-off, pollutant loading, computer model. SWAT is capable of predicting run-off, sediment yield by particle size-class, and nutrient loadings for TN and TP (Arnold and Allen 1992; Srinivasan. and Arnold 1994). The mathematical processes utilized within SWAT include weather generation, run-off volumes from precipitation, erosion, and sediment delivery. The SWAT model predicts both surface generated pollutant loadings as well as in-stream erosion and channel evolution.

The SWAT model generates input files using many of the same equations and processes as AnnAGNPS. Processes and input shared between the two models include the SCS curve number method, some of the soil loss equations, DEM data, climate data (Year 2002), soil data, and land use. Differences between the internal processes utilized by the models include runoff and peak discharge predictions, and a modified soil loss equation. Runoff and peak discharges are predicted in SWAT using the Modified Rational Method (MODRAT), which was developed by the Los Angeles County Department of Public Works. The MODRAT model is imbedded within SWAT and is used to compute hydrographs and runoff rates from any storm that can be represented by a rainfall mass curve. A further derivative of USLE, Modified USLE (MUSLE) is also used by SWAT to predict sediment yields from individual storm events and has been modified to improve sediment runoff predictions (USDA 2000).

4.0 RESULTS AND DISCUSSION

Loading rates of TN, TP, and TS (referred to cumulatively as “pollutants”) vary as land-use patterns change within the Study Area. In both future scenarios, regardless of the Bypass, increased coverage by impervious surfaces resulted in increases of pollutant yields. These results are expected as increased urbanization occurs over time. Higher pollutant export potential is anticipated as currently undeveloped parcels convert to residential, commercial, and industrial categories. Nutrient export loads from forest and pasture lands are significantly less than export from commercial and industrial parcels (Dodd *et al.* 1992, Hunt and Lucas 2003).

Predicted in-stream sediment rates are higher than overland export rates in this study. In-stream loadings account for 60-percent of the predicted sediment export from the watershed. This is not unexpected in that accelerated stream bank erosion has been found to be a major cause of non-point source pollution associated with increased sediment supply (Rosgen 2002). Bank collapse, bed erosion, and fluvial entrainment, contribute to stream sediment loads.

4.1 CURRENT CONDITION

An analysis of Current Condition was necessary to establish baseline parameters for development of future scenarios. Changes in land-use patterns were particularly relevant for use in the AnnAGNPS model due to the direct correlation between land use and nutrient/sediment loading. The results of the modeling effort indicate that 67.4 metric tons of TN (2.8 kilograms/hectare [kg/ha]), 116.6 metric tons of TP (4.9 kg/ha), and 38,200.9 metric tons (1.2 kg/ha) of sediment are currently being exported from the Study Area (Table 3; **Figures 6A-6C, Appendix A**). These values are in line with published results. Based on the Simple Method proposed by Hunt and Lucas (2003), export values of 0.9 kg/ha for TN and 6.9 kg/ha for TP will be realized from a sample watershed in the Study Area. Loading rates for TN in the Neuse River have been projected at 5.4 lbs/ac (DWQ 1999). This higher value in the Neuse River is attributed to an abundance of agricultural land in the area with resulting high nutrient-export coefficients. No comparative values for sediment export are available.

Currently, the highest pollutant loading rates within the Study Area occur at areas with a high prevalence of low density residential areas (House20) located within the Little Creek watershed. The House20 land use category represents 35.7-percent of the total land use within the Little Creek watershed, which is a higher proportion than the 22.7-percent that the category represents of the entire Study Area. The high run-off volumes and large peak flows transported across impervious areas into adjacent, natural areas result in elevated overland sediment erosion that contains attached nitrogen and phosphorus. Developed areas, which currently contain a mixture of impervious and pervious land use within individual parcels, comprise 45 percent (41.2 square miles) of the Study Area. Current Condition reflects land use features that occur in the Study Area at present; regional storm water controls and full riparian buffer compliance required by current and future regulations are not fully implemented as in future scenarios.

4.2 SCENARIO 1 (WITHOUT BYPASS)

Study Area land use is projected to change considerably by Year 2025, even without additional growth associated with the Bypass. By Year 2025, non-Bypass related ambient growth is expected to result in increases of 9.2 square miles of residential and 4.3 square miles of non-

residential (industrial and commercial) land uses. Residential growth will be scattered and located primarily in a watershed for an unnamed tributary to Swift Creek located in between White Oak and Little Creeks, while commercial and industrial growth will be concentrated along the NC 42 corridor and along US 70. Pollutant export in Year 2025 will increase in response to increased development. Increases of 30.9-percent in exported TN, 5.0-percent in exported TP, and 31.9-percent in total sediment will result from the 13.5 square miles of predicted additional growth relative to Current Condition (Table 3, **Figures 7A-7C, Appendix A**).

4.3 SCENARIO 2

Bypass construction and associated new development will be dominated by residential growth. The improved access to rural areas previously subject to unreasonable commute times is expected to stimulate residential growth, as well as the industry, commerce, and improved transportation infrastructure necessary to support the new residential development. Land use changes implemented in this scenario include all development predicted in Scenario 1 as well as increases of 1.7 square mile of residential growth and 2.2 square miles of non-residential growth. All induced growth in this scenario is considered to be attributable to the Bypass. Residential growth will predominantly be located in unincorporated areas of Wake and Johnston Counties that may receive water and sewer utilities by Year 2025. Commercial and industrial growth is anticipated to occur adjacent to the Bypass and be focused at interchanges and major arterial roadways.

Scenario 2 results in pollutant export increases of 5.1-percent in exported TN, 0.2-percent in exported TP, and 2.0-percent in total sediment from Scenario 1 (Table 3, **Figures 7A-7C, Appendix A**).

Table 3. Exported annual yields of pollutants from the Study Area. All numbers are reasonable yields for use in comparative analyses, but should not be interpreted as an estimate of actual Study Area yields. All mass units are in metric tons. Percent change in pollutant yields are color coded to assist in percent change interpretation. The percent change of each pollutant has a unique color, with TN depicted in red, TP depicted in blue, overland sediment depicted in purple, and stream sediment depicted in green.

Scenario	TN (Tons)	TP (Tons)	Overland		Stream		Overland		Stream		Overland		Stream	
			Sediment (Tons)	Change (Tons)	Sediment (Tons)	Change (Tons)	Sediment (Tons)	Change (Tons)	Sediment (Tons)	Change (Tons)	Sediment (Tons)	Change (Tons)	Sediment (Tons)	Change (Tons)
Existing	67.40	116.60	15279.90	22921.00	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Future No Bypass	88.20	122.40	20149.30	30225.60	20.80	30.86%	5.80	4.97%	4869.40	7304.60	31.87%	Over Existing		
Future Bypass	92.80	122.60	20551.50	30828.90	25.40	37.69%	6.00	5.15%	5271.60	7907.90	34.50%	Over Existing		

*Sediment has been divided into two distinct source categories.

4.4 LAND-USE CONTROLS

Study Area land-use controls are currently mandated by regulation including Neuse River Riparian Buffer rules and Phase I storm water controls. By Year 2025, municipalities within the Study Area may be subject to Phase II stormwater requirements. Modeled land-use controls contribute to the protection of water quality and minimize water quality degradation as the Study Area develops. It is well known that site-specific runoff impacts can largely be managed through land-use restrictions, controls over the amount of allowable impervious surface thresholds, implementation of riparian buffers, utilization of storm water catchment facilities (basins and treatment wetlands), and effective use of other structural BMPs (silt fencing, grassy swales, bioretention areas, *etc.*) during and after construction.

Benefits associated with land-use restrictions imposed by current stream buffer regulations are fully considered in these analyses. No development was considered within riparian stream buffers.

Efficiencies associated with sediment and nutrient removal by storm water ponds and riparian buffers are quantified in these analyses within two modeled sub-watersheds using SWAT. The benefits of such measures were observed to be within published ranges through micro-watershed specific analyses, but are inconclusive on a Study Area scale due to the large amount of development without BMP protection. An evaluation of individual micro-watershed sediment loading processed by BMPs indicates that efficiencies of 89-percent for total sediment are realized within SWAT. The reduction efficiencies of nutrients appear to be inconclusive, due to the fact that SWAT predicts stormwater ponds to primarily store water and sediment, and nutrient particles that had been bound to sediment are being erroneously released. Modeled BMPs predict reductions in Study Area stream volumes and velocities, but have not prevented failures in stream banks within quickly urbanizing watersheds.

5.0 SUMMARY

- Nutrient and sediment analyses were performed for a Study Area inclusive of watersheds proposed to be impacted by the Clayton Bypass (R-2552) in Wake and Johnston Counties, North Carolina. The purpose of the study is to estimate the percentage difference between “without project” and “with project”, Scenarios 1 and 2, respectively. These analyses are required by the N.C. Division of Water Quality and U.S. Fish and Wildlife Service to evaluate potential water quality impacts associated with future growth in the Study Area with and without the Bypass.
- The 59,212-acre (92.5-square mile) Study Area is based upon watershed boundaries that drain to Swift Creek that are likely to be impacted by Bypass and Bypass-related development. Swift Creek contains multiple populations of sensitive aquatic organisms that are of interest to federal and state regulatory agencies.
- Predicted future land uses were estimated for both Scenarios 1 and 2 in Year 2025. In Scenario 1, the Study Area is anticipated to be subjected to an increase of 14.6-percent (13.5 square miles) of development relative to the Current Condition, while, in Scenario 2, the Study Area is anticipated to be subjected to an increase of 19.7-percent (18.2 square miles) of development relative to Current Condition. Use of Best Management Practices, such as riparian buffers and storm water detention ponds were considered in both future scenarios. Twelve distinct land-use categories were generated and provided by URS Corporation.
- The Annualized Agricultural Non-Point Source (AnnAGNPS) pollutant model was used to predict annual pollutant yields exported from the Study Area for each future scenario. Correction factors for AnnAGNPS output were generated for BMPs and stream generated sediment using Soil and Water Assessment Tool (SWAT) and the Center for Computational Hydroscience and Engineering 1-Dimensional (CCHE1D) models. Stream-generated sediment has been estimated to be responsible for 60-percent of the total sediment yield. BMP efficiencies have been realized on sediment loads on the micro-watershed scale. BMP efficiency results are inconclusive for total Study Area pollutant yields, which is likely due to the large amount of existing development within the Study Area that is not treated by modeled BMPs.
- Predicted pollutant yields follow increase as impervious area increases. These trends are further supported in scientific literature (Dodd *et al.* 1992, Hunt and Lucas 2003). Low-density residential land-use categories are responsible for the largest increases in predicted pollutant yields in all modeled scenarios.
- Modeling for Scenario 1, predicted increases over Current Condition are 30.9-percent exported TN, 5.0-percent in exported TP, and 31.9-percent in exported total sediment.
- Modeling for Scenario 2, the proposed Bypass and induced Bypass-related development were added to the projected development from Scenario 1 to determine potential pollutant yields attributable to the Bypass. Modeled results showed an increase of 5.1-percent exported TN, 0.2-percent in exported TP, and 2.0-percent in exported total sediment, which suggests that a small increase in pollutant loading is attributable to the Bypass.

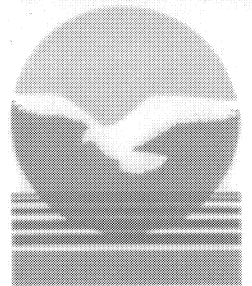
- AnnAGNPS, SWAT, and CCHE1D have demonstrated an ability to predict reasonable estimates of nutrient and sediment export loadings when compared to other published results (Dodd *et. al* 1992; Hunt and Lucas 2003). Additionally, loadings have been predicted to be reduced when reduction efficiencies of BMPs are considered.

VI. REFERENCES

- Amoroso, J.L. 2002. Natural Heritage Program List of the Rare Plant Species of North Carolina. North Carolina Natural Heritage Program, Division of Parks and Recreation, N.C. Department of Environment, Health and Natural Resources, Raleigh. 85 pp.
- Arnold, J.G. and Allen P.M. 1992. A Comprehensive surface-groundwater flow model. J. Hydrol. 142:47-69.
- Bosch, D., F. Theurer, R. Bingner, G. Felton, and I. Chaubey. 1998. Evaluation of the AnnAGNPS Water Quality Model. ASAE Paper No. 98-2195, St. Joseph, Michigan. 12 pp.
- Choi, K. S. and E. Blood. 1999. Modeling Developed Coastal Watersheds with the Agricultural Non-Point Source Model. Journal of the American Water Resources Association. Vol. 35, No. 2: pp. 233-244.
- Division of Water Quality (DWQ). 2001. North Carolina Municipal NPDES Phase II Stormwater Program Strategy. N.C. Department of Environment and Natural Resources, Stormwater and General Permits Unit, Raleigh, North Carolina.
- Division of Water Quality (DWQ). 2002. Neuse River Basinwide Water Quality Management Plan. N.C. Department of Environment and Natural Resources, Water Quality Section, Raleigh, NC.
- Division of Water Quality (DWQ). 1999. Total Maximum Daily Load for Total Nitrogen to the Neuse River Estuary, North Carolina. N.C. Department of Environment and Natural Resources, Water Quality Section, Raleigh, NC.
- Dodd, R.C., G. McMahon, and S. Stichter. 1992. Watershed Planning in the Albemarle-Pamlico Estuarine System: Annual Average Nutrient Budgets. North Carolina
- Environmental Protection Agency (EPA). 1999. Storm Water Phase II Proposed Rule. Fact Sheet 1. United States Environmental Protection Agency, Office of Water.
- Floodplain Mapping Program (FMP). 2000. Neuse River Basin Light Detection and Ranging Data: Bare Earth Resolution. Website citation: www.ncfloodmaps.com
- Hunt, B. and A. Lucas. 2003. Development of a Nutrient Export Model for New Developments and Establishment of BMP Removal Rates for Stormwater BMPs in the Tar-Pamlico River Basin. Biological and Agricultural Engineering, North Carolina State University. For the North Carolina Department of Environmental and Natural Resources, Tar-Pamlico Stormwater Group.
- LeGrand, H.E., Jr. and S.P. Hall. 2001. Natural Heritage Program List of the Rare Animal Species of North Carolina. North Carolina Natural Heritage Program, Division of Parks and Recreation, N.C. Department of Environment, Health and Natural Resources, Raleigh. 67 pp.

- Martz, L.W. and J. Garbrecht. 1995. Automated recognition of valley lines and drainage networks from grid digital elevation models: a review and a new method – Comment. *Journal of Hydrology* 167: 393-396.
- Michigan State University (MSU). 2002. RUSLE- Online Soil Erosion Assessment Tool. Website citation. URL-- <http://www.iwr.msu.edu/rusle/about.htm>
- Rosgen, D.L. 2002. A practical method of computing streambank erosion rate. *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, Vol. 2, pp. II - 9-15, March 25-29, 2001, Reno, NV
- Smith, S.D. (Unpublished). Investigation of Piedmont stream origins in the Neuse River Basin, North Carolina. MS Thesis, North Carolina State University, Raleigh, North Carolina.
- Srinivasan, R. and J.G. Arnold. 1994. Integration of a Basin-Scale Water Quality Model with GIS. *Water Resources Bulletin*. Vol. 30, No. 3., June 1994. Pgs. 453-462.
- United States Department of Agriculture (USDA). 2001. AnnAGNPS website. <http://msa.ars.usda.gov/ms/oxford/nsi/AGNPS.html>
- United States Department of Agriculture (USDA). 2000. Soil and Water Assessment Tool Users Manual. Website citation <http://www.epa.gov/waterscience/basins/b3docs/swat2000/>
- United States Department of Agriculture, Agriculture Research Service (USDA-ARS). 2000. AnnAGNPS: Estimating Sediment Yield by Particle Size for Sheet and Rill Erosion. *Federal Interagency Sedimentation Conference Proceedings*. Website citation. URL-- http://www.nps.ars.usda.gov/publications/publications.htm?SEQ_NO_115=116713
- Viera, Dalmo A. and Weiming Wu. 2002. CCHE1D Version 3.0-Model Capabilities and Applications. National Center for Computational Hydroscience and Engineering. University of Mississippi. NCCHE-TR-2002-05. 18 pages
- URS Corporation. 2004. Clayton Bypass: Indirect and Cumulative Effects Assessment. Submitted to North Carolina Department of Transportation.

Appendix A
Figures



Prepared For:



NCDOT

Project:

Nutrient and
Sediment Analyses

Clayton Bypass (R-2552)
Johnston and Wake County,
North Carolina

Figure Name

Study Area Location

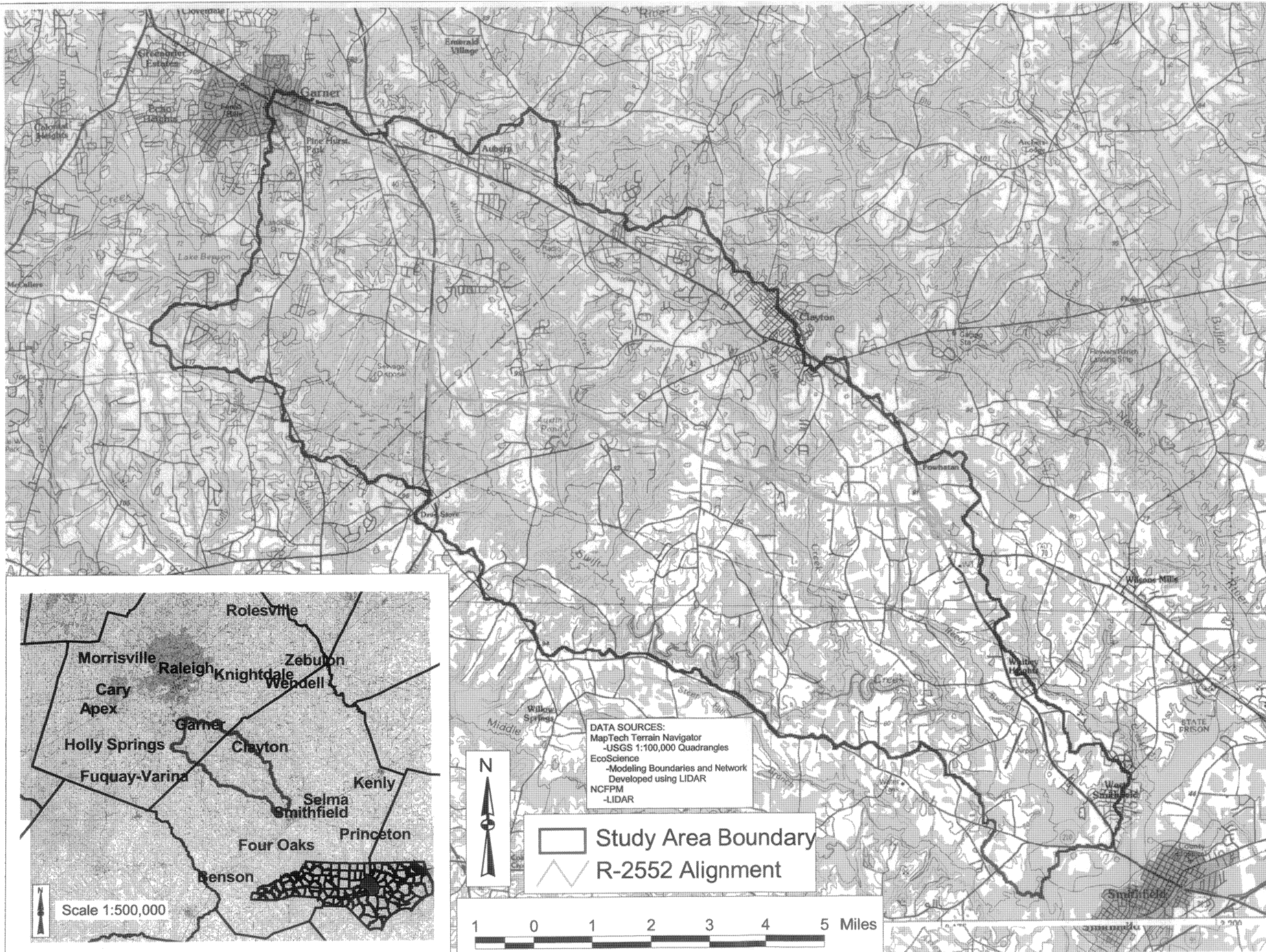
Drawn By:	Date:
MTC	March 2004

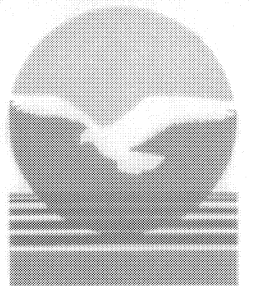
Chkd By:	Project No:
APS	02-113.40

SCALE:
AS SHOWN

FIGURE

1





EcoScience

Prepared For:



NCDOT

Project:

Nutrient and
Sediment Analyses

Clayton Bypass (R-2552)
Johnston and Wake County,
North Carolina

Figure Name

Modeling Boundaries

Drawn By:
MTC

Date:
March 2004

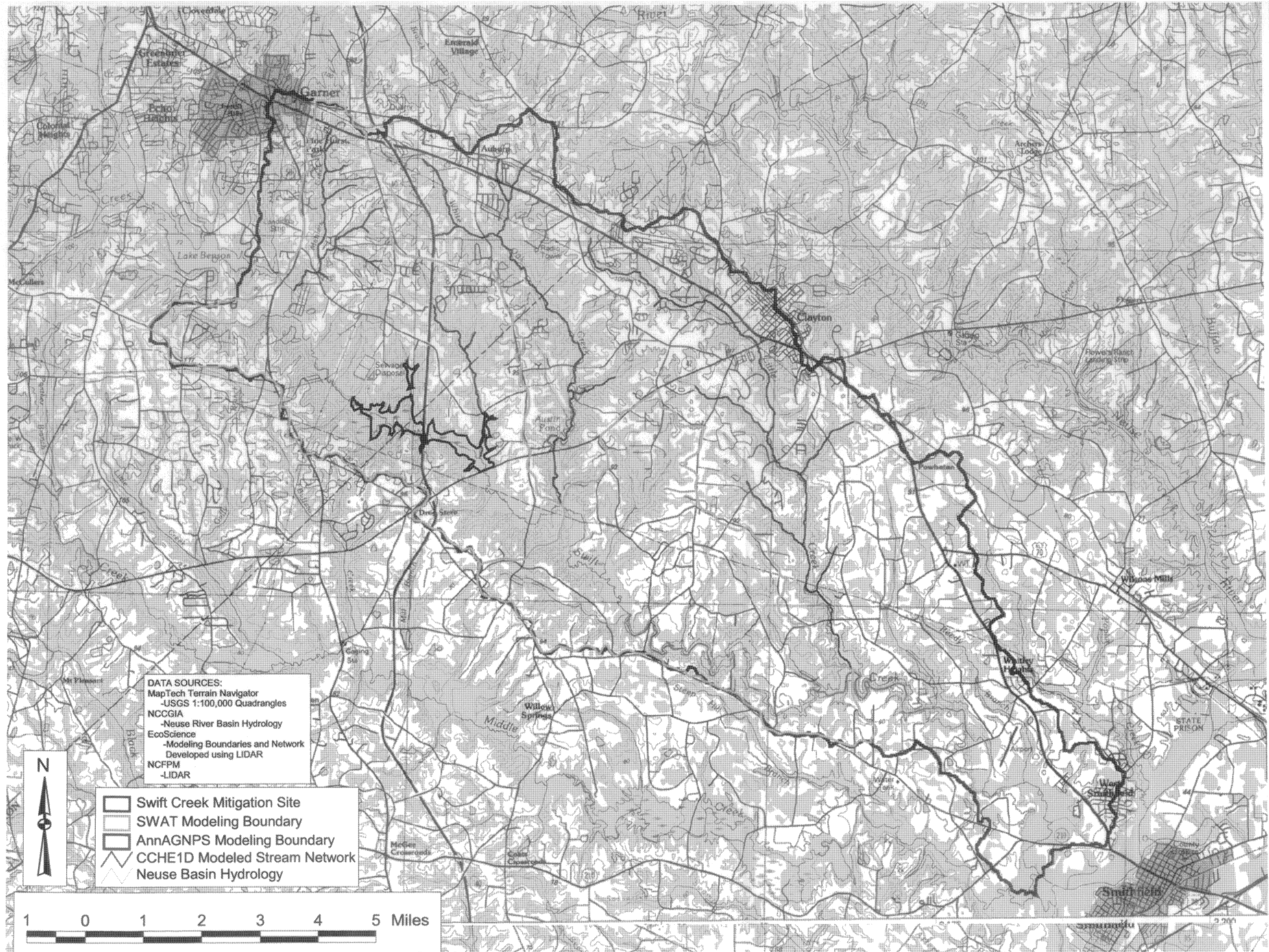
Chkd By:
APS

Project No:
02-113.40

SCALE:
1:100,000

FIGURE

2

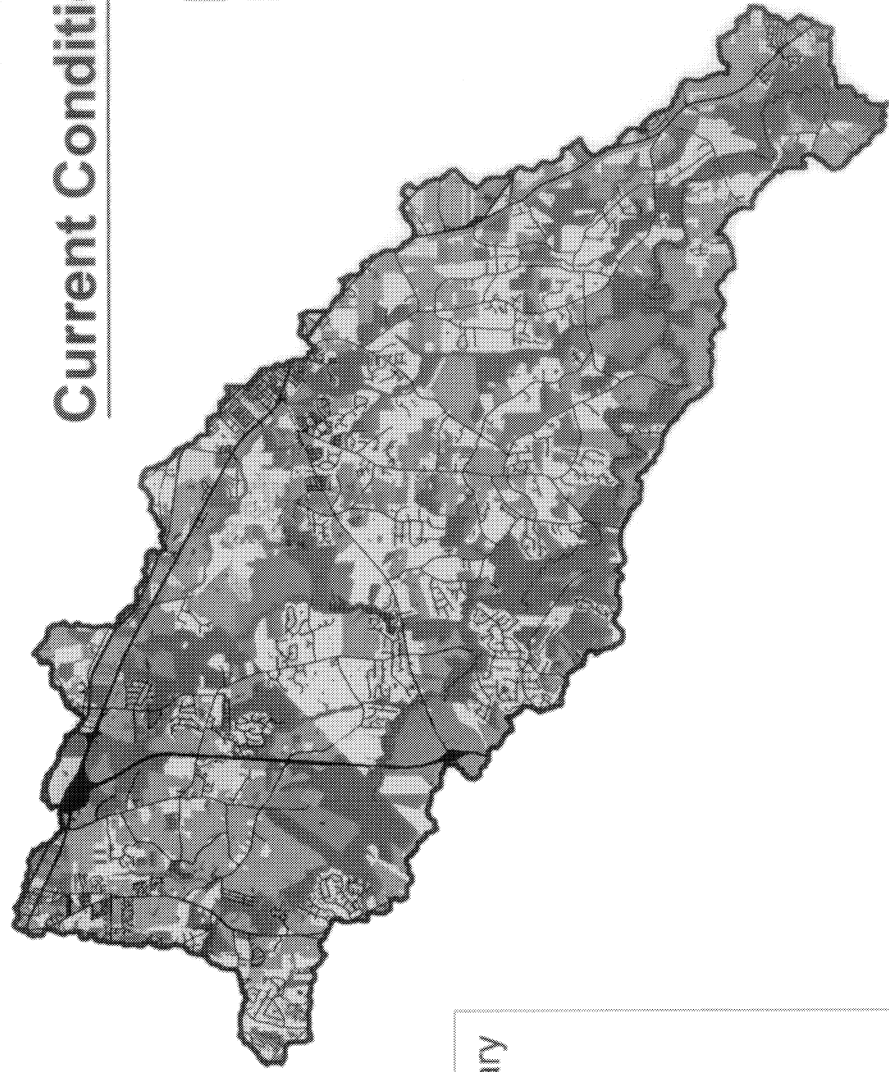


DATA SOURCES:
MapTech Terrain Navigator
-USGS 1:100,000 Quadrangles
NCCGIA
-Neuse River Basin Hydrology
EcoScience
-Modeling Boundaries and Network
Developed using LIDAR
NCFPM
-LIDAR

- Swift Creek Mitigation Site
- SWAT Modeling Boundary
- AnnAGNPS Modeling Boundary
- CCHE1D Modeled Stream Network
- Neuse Basin Hydrology

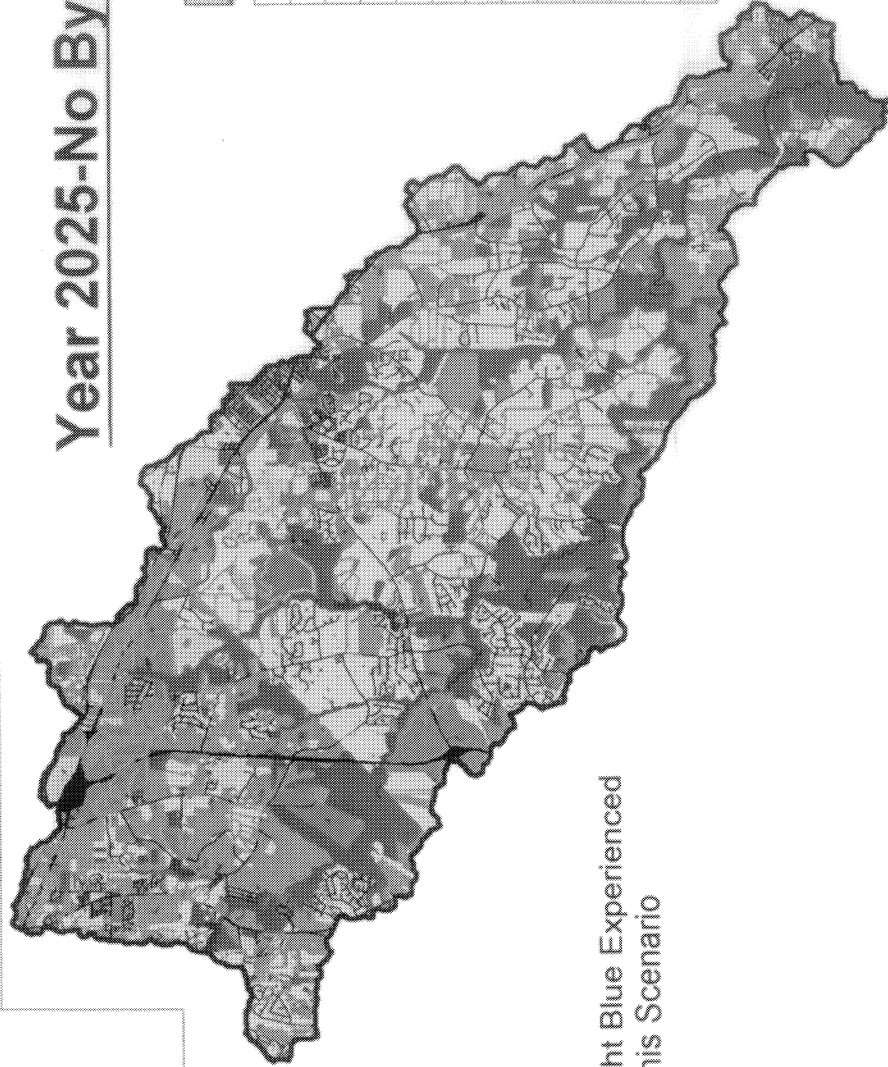
1 0 1 2 3 4 5 Miles

Current Condition



Land Use	Hectareage	Proportion
COMM	2752.50	4.65
CROPLAND	13174.14	22.24
HOUSE20	13464.02	22.73
HOUSE25	3640.44	6.15
HOUSE30	1004.18	1.70
HOUSE38	545.32	0.92
HOUSE65	455.86	0.77
INDUST	1095.91	1.85
PASTURE	507.11	0.86
ROAD	3427.32	5.79
WATER	695.08	1.17
WOODG	3705.63	6.26
WOODS	14756.16	24.92

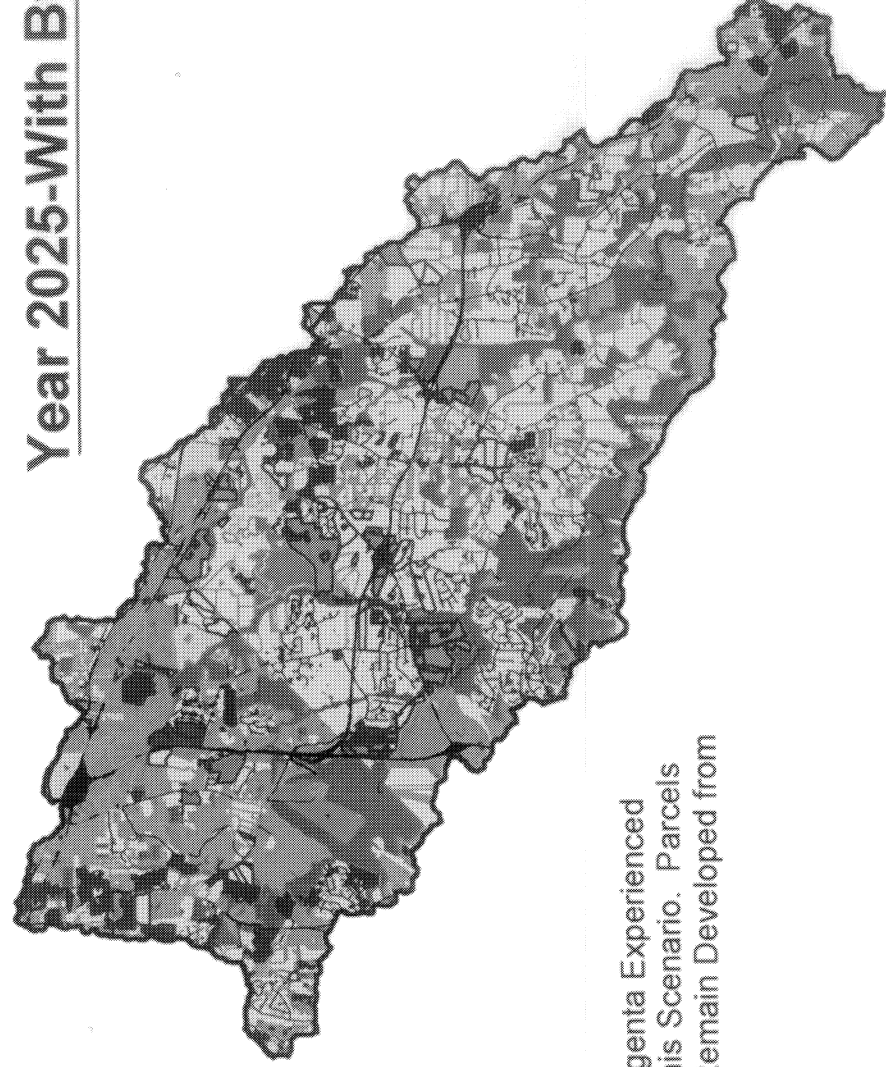
Year 2025-No Bypass



Land use	Hectareage	Proportion
COMM	4819.37	8.14
CROPLAND	9500.52	16.04
HOUSE20	18331.35	30.95
HOUSE25	3780.02	6.38
HOUSE30	1250.92	2.11
HOUSE38	1108.28	1.87
HOUSE65	499.43	0.84
INDUST	1783.07	3.01
PASTURE	489.50	0.83
ROAD	3435.79	5.80
WATER	695.08	1.17
WOODG	528.23	0.89
WOODS	13002.09	21.95

Parcels Outlined in Light Blue Experienced New Development in this Scenario

Year 2025-With Bypass



Land use	Hectareage	Proportion
COMM	6168.84	10.42
CROPLAND	7757.47	13.10
HOUSE20	19315.91	32.61
HOUSE25	3795.98	6.41
HOUSE30	993.40	1.68
HOUSE38	1114.34	1.88
HOUSE65	834.86	1.41
INDUST	1822.87	3.08
PASTURE	289.75	0.49
ROAD	3953.62	6.68
WATER	667.87	1.13
WOODG	687.99	1.16
WOODS	11826.55	19.97

Parcels Outlined in Magenta Experienced New Development in this Scenario. Parcels outlined in Light Blue Remain Developed from the Last Scenario



EcoScience

Land Use for Three Modeled Scenarios

Nutrient and
Sediment Analyses
Clayton Bypass (R-2552)
Johnston and Wake County, North Carolina

Drawn By:

MTC

Date:

March 2004

Chkd By:

APS

Project No:

02-113.40

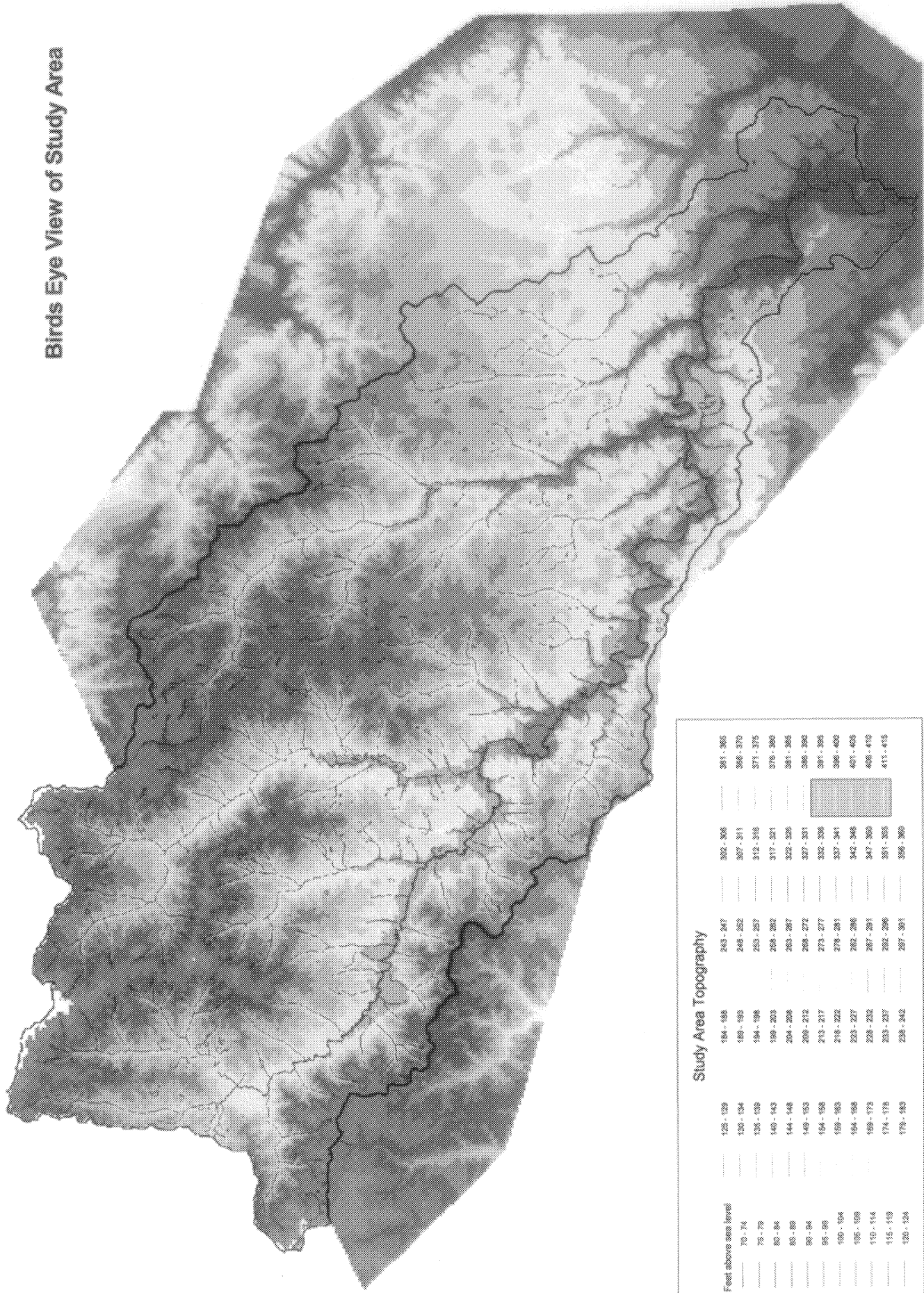
SCALE:

Not Scaled

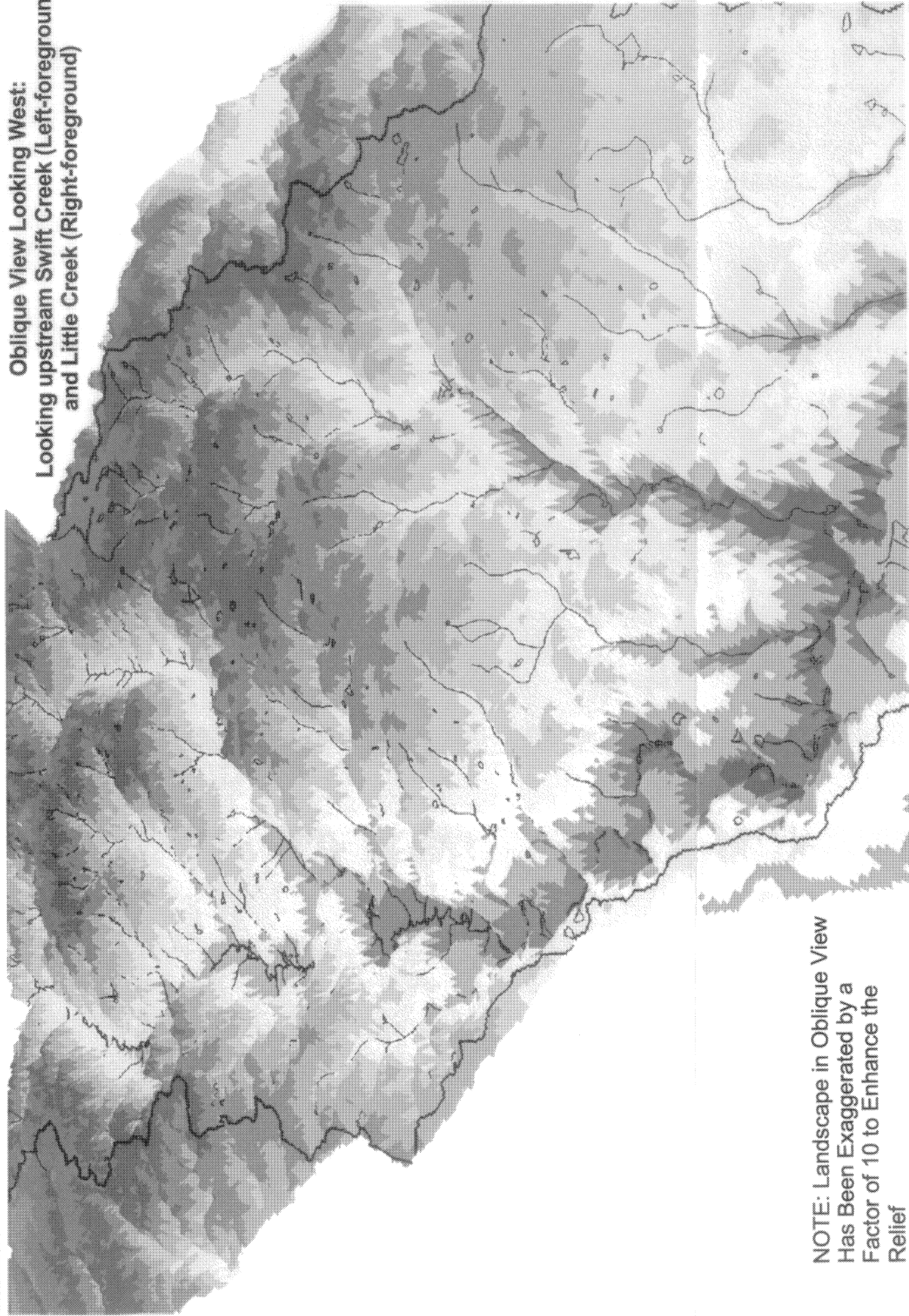
FIGURE

3

Birds Eye View of Study Area



Oblique View Looking West:
Looking upstream Swift Creek (Left-foreground)
and Little Creek (Right-foreground)



NOTE: Landscape in Oblique View
Has Been Exaggerated by a
Factor of 10 to Enhance the
Relief



EcoScience

Digital Elevation Model with Stream Network

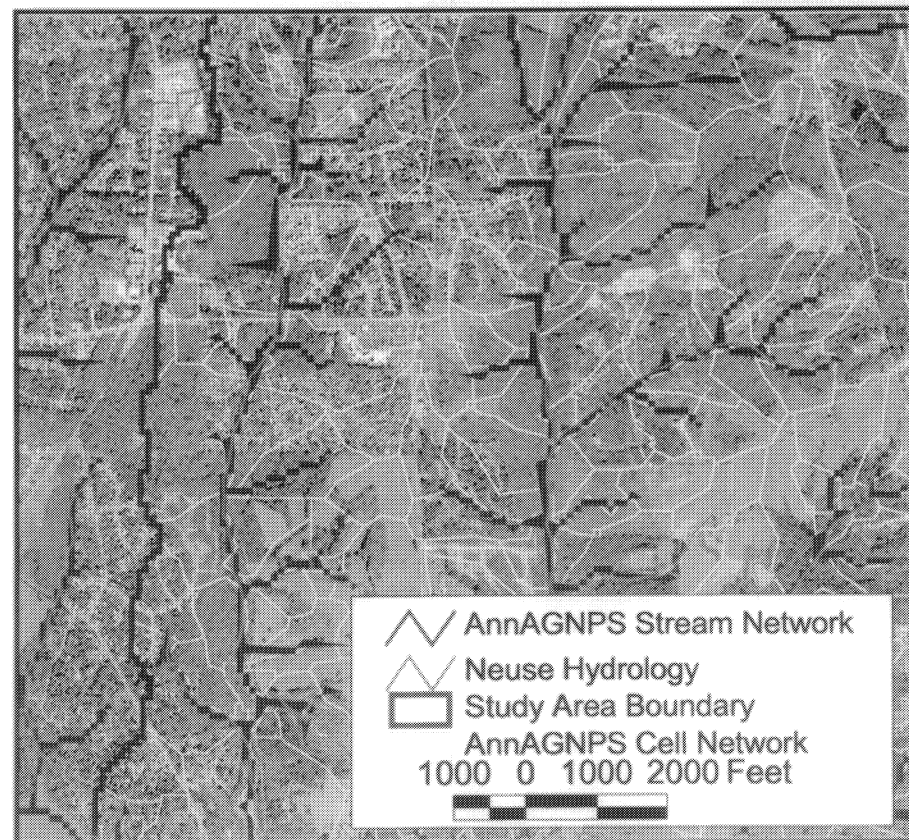
Drawn By:	Date:
MTC	March 2004
Chkd By:	Project No:
APS	02-113.40
SCALE:	FIGURE
NO SCALE	4

Nutrient and
Sediment Analyses
Clayton Bypass (R-2552)
Johnston and Wake County, North Carolina

DATA SOURCES:
 Wake County
 -Year 1999 real color aerial photos
 Johnston County
 -Year 2000 real color aerial photos
 EcoScience
 -Modeling Boundaries and Network
 Developed using LIDAR
 CGIA
 -Neuse River Hydrology
 NCFPM
 -LIDAR

SEE INSET

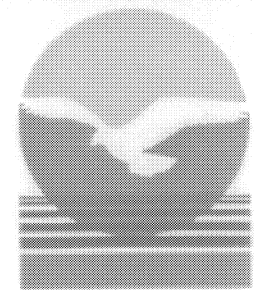
INSET: AnnAGNPS generated streams versus
 CGIA Neuse River Basin hydrology



Neuse Hydrology
 Study Area Boundary
 AnnAGNPS Cell Network



1 0 1 2 3 4 5 Miles



EcoScience

Prepared For:



NCDOT

Project:

Nutrient and
 Sediment Analyses

Clayton Bypass (R-2552)
 Johnston and Wake County,
 North Carolina

Figure Name

**AnnAGNPS Cell
 Boundaries with
 DEM-Generated
 Stream Network**

Drawn By:
 MTC

Date:
 March 2004

Chkd By:
 APS

Project No:
 02-113.40

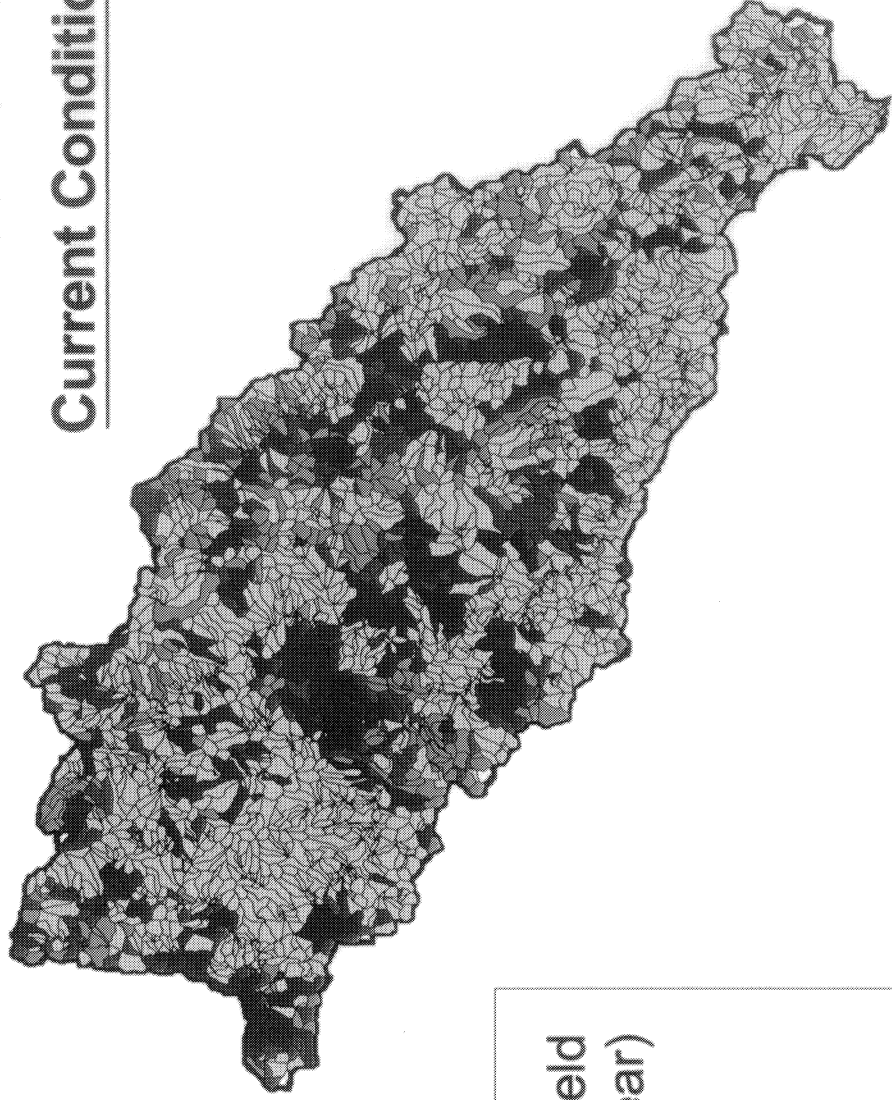
SCALE:

AS SHOWN

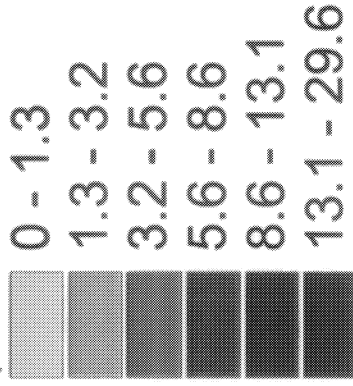
FIGURE

5

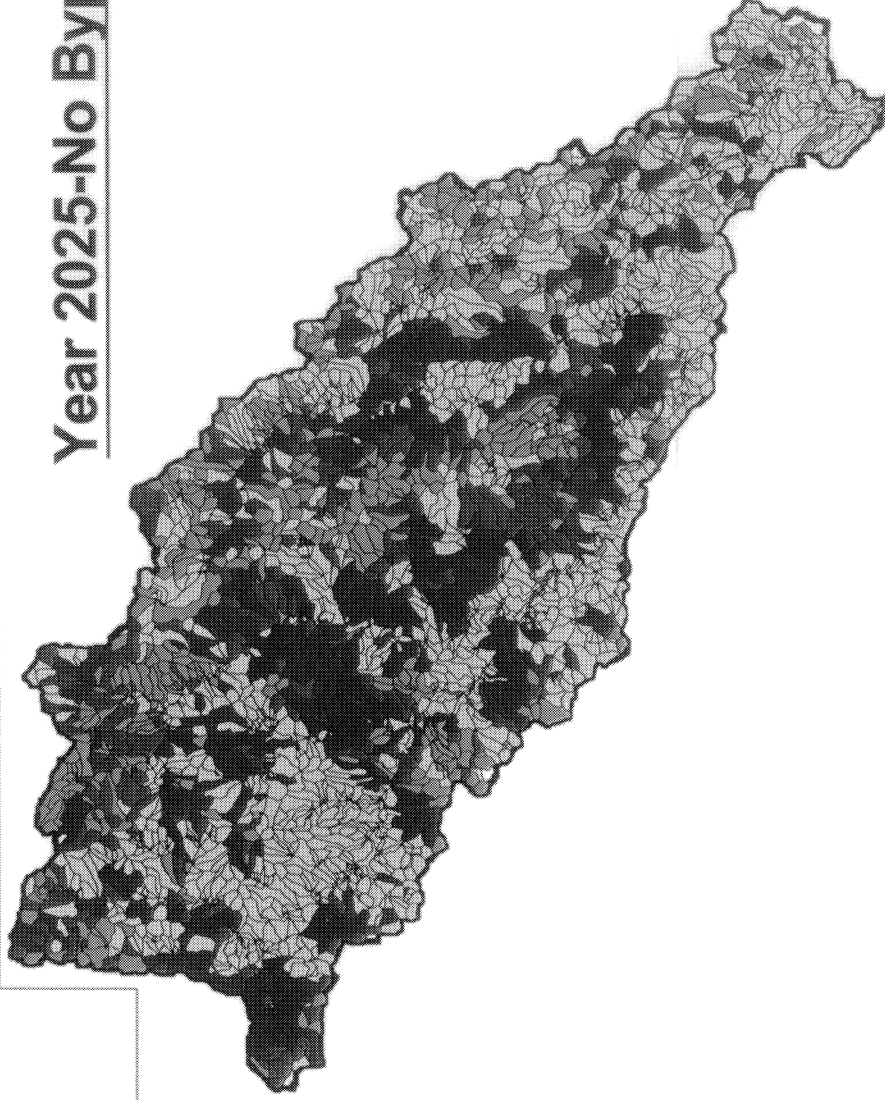
Current Condition



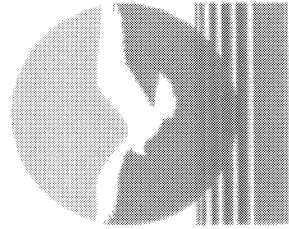
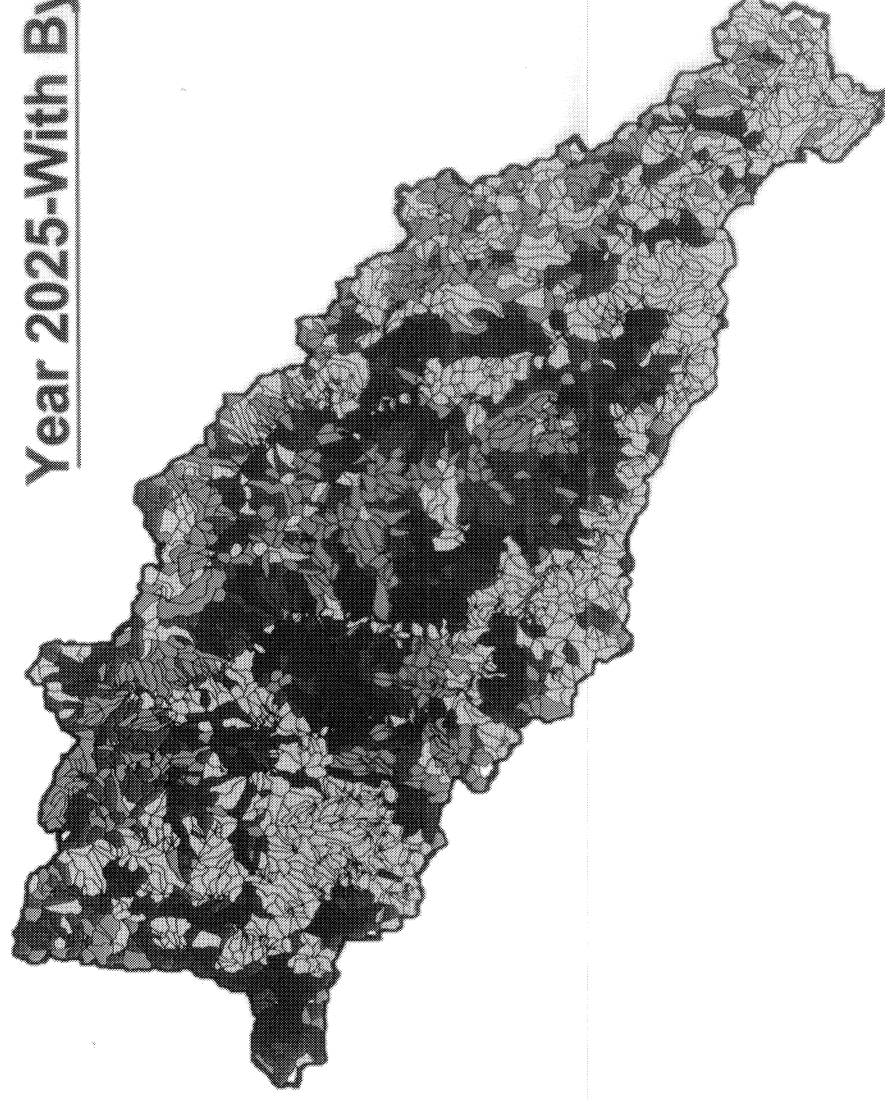
Total Nitrogen Yield
(Pounds/Acre/Year)



Year 2025-No Bypass



Year 2025-With Bypass



EcoScience

Total Nitrogen Yield for
Three Modeled Scenarios

Nutrient and
Sediment Analyses
Clayton Bypass (R-2552)
Johnston and Wake County, North Carolina

Drawn By:

MTC

Date:

March 2004

Chkd By:

APS

Project No:

02-113.40

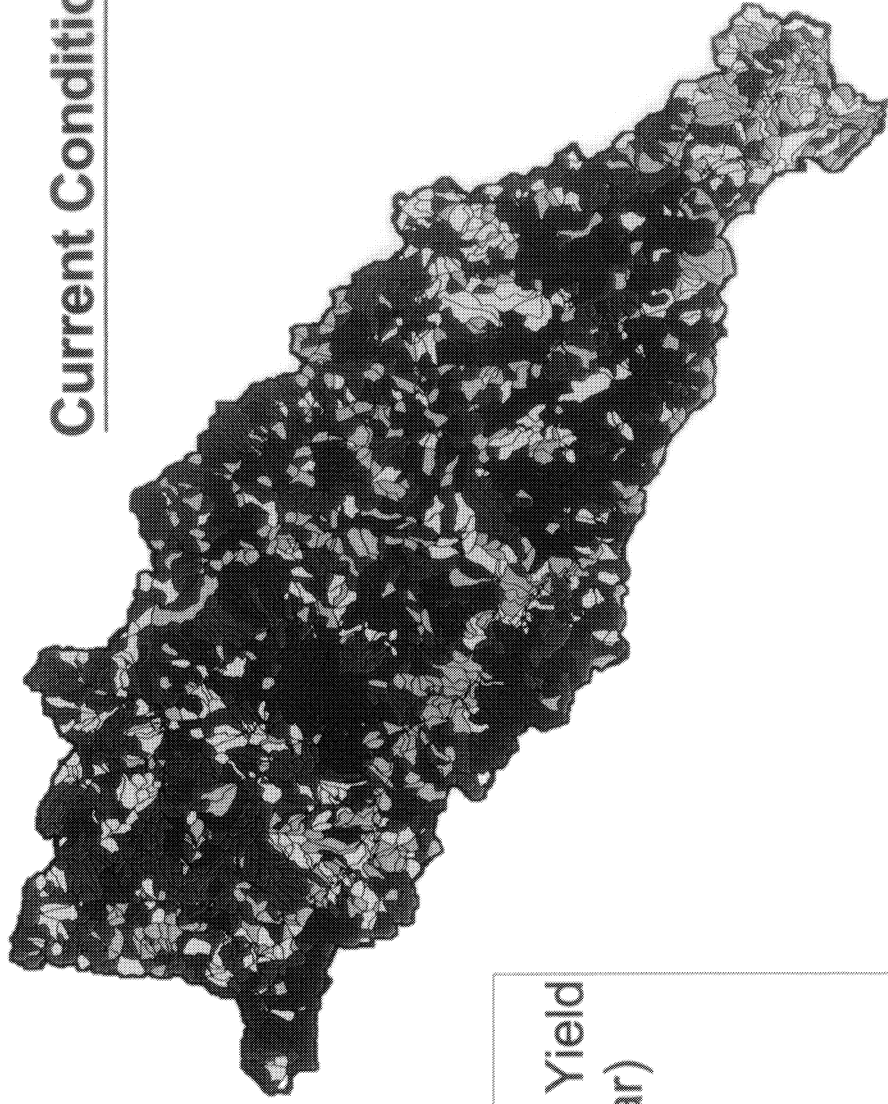
SCALE:

Not Scaled

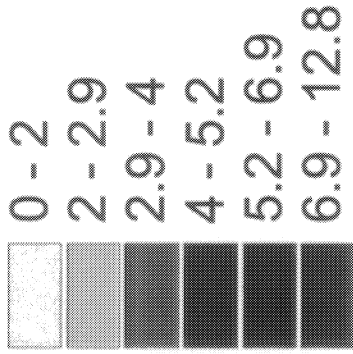
FIGURE

6A

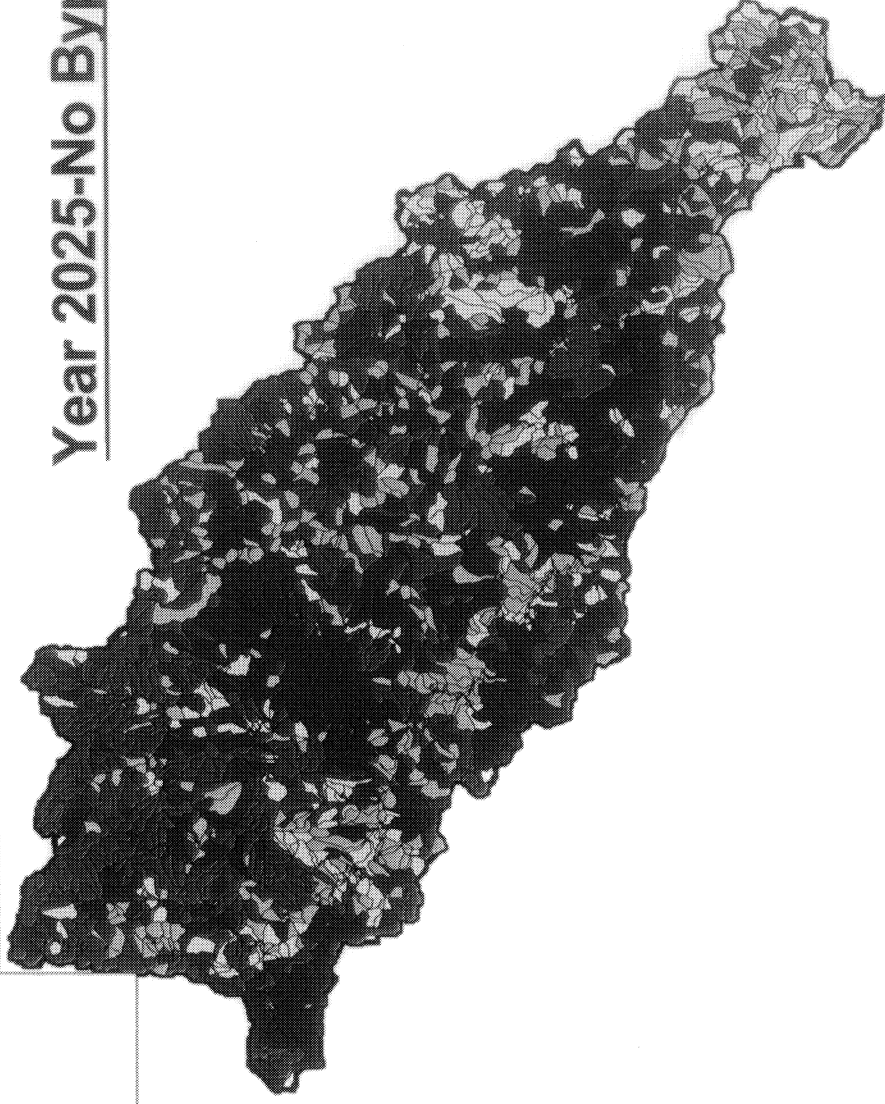
Current Condition



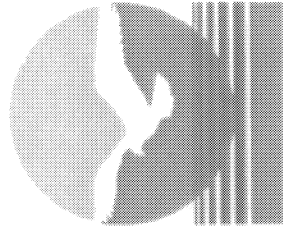
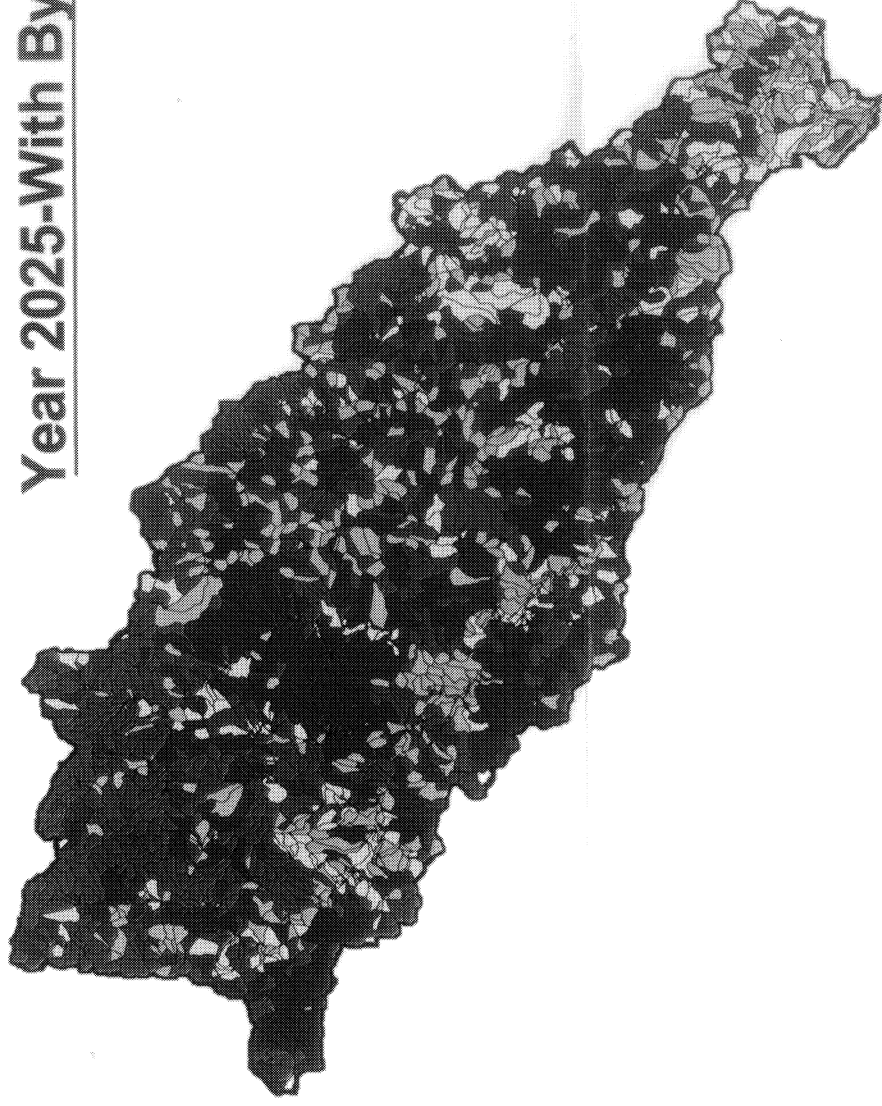
Total Phosphorus Yield
(Pounds/Acre/Year)



Year 2025-No Bypass



Year 2025-With Bypass



Total Phosphorus Yield for
Three Modeled Scenarios

Nutrient and
Sediment Analyses
Clayton Bypass (R-2552)
Johnston and Wake County, North Carolina

Drawn By:

MTC

Date:

March 2004

Chkd By:

APS

Project No:

02-113.40

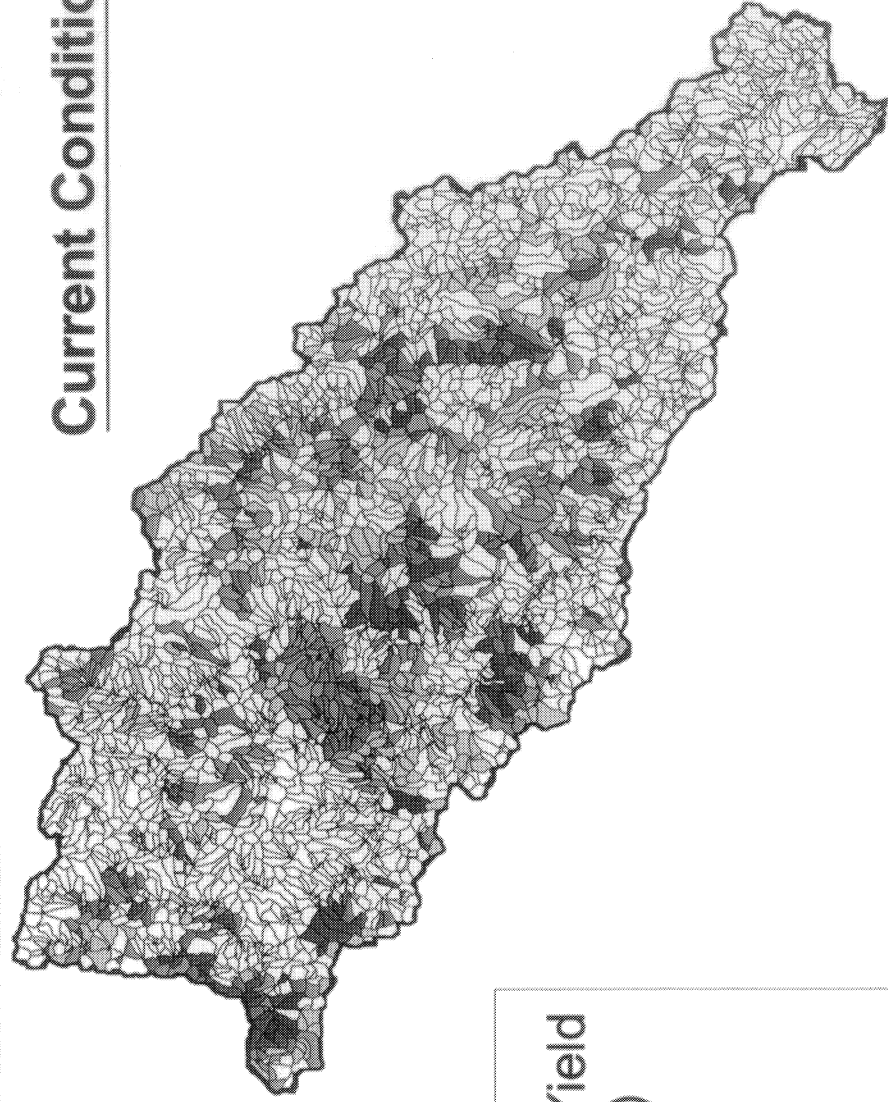
SCALE:

Not Scaled

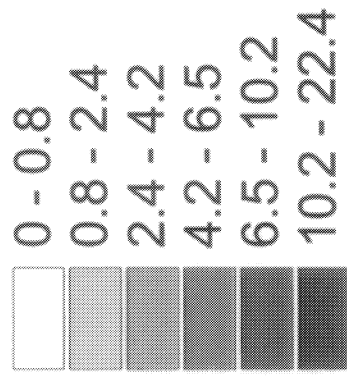
FIGURE

6B

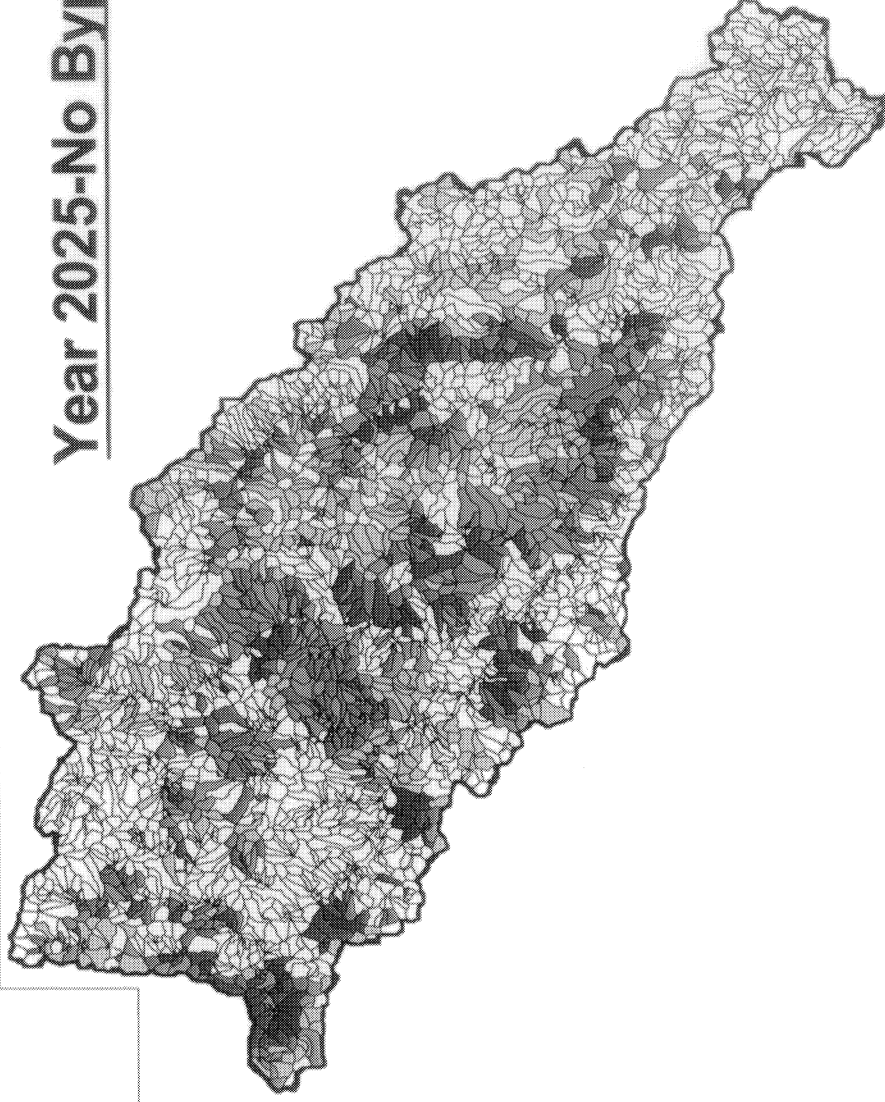
Current Condition



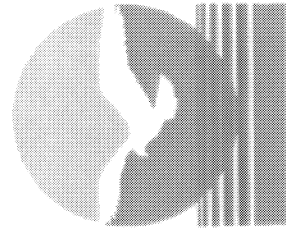
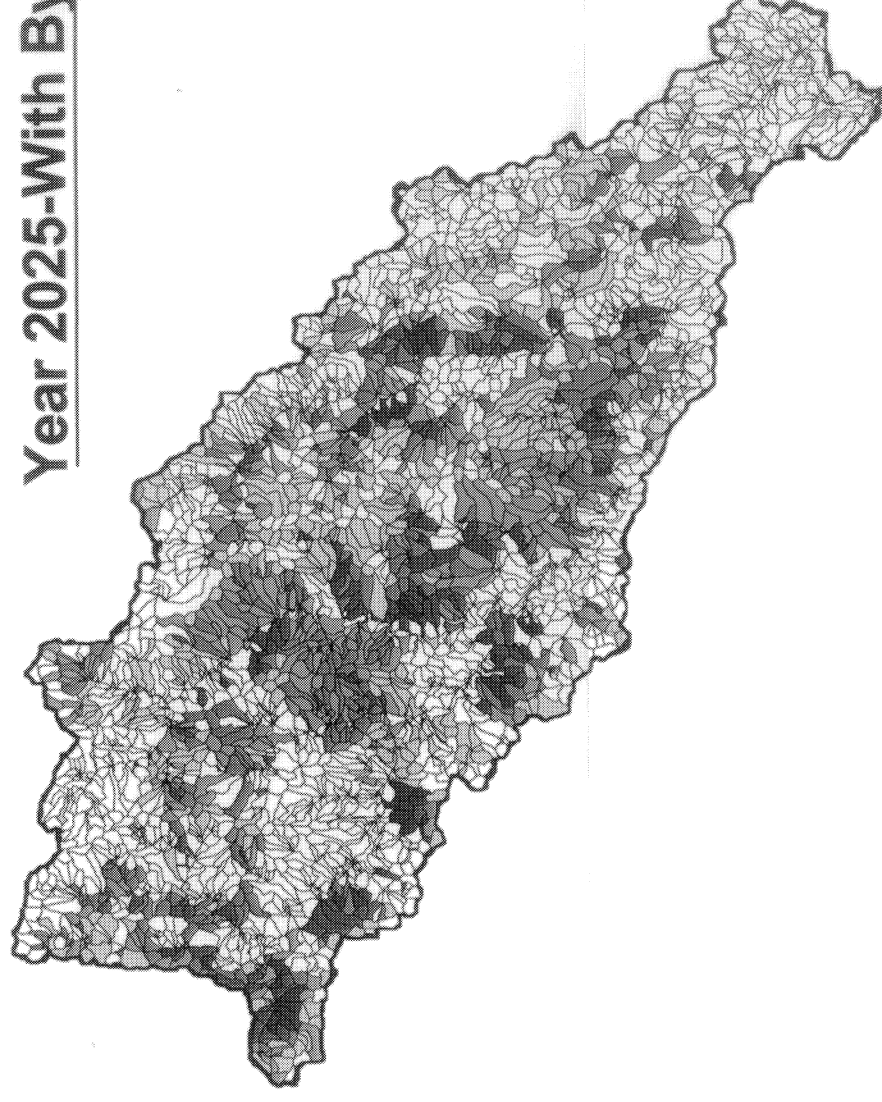
Total Sediment Yield
(Tons/Acre/Year)



Year 2025-No Bypass



Year 2025-With Bypass



EcoScience

Total Sediment Yield for
Three Modeled Scenarios

Nutrient and
Sediment Analyses
Clayton Bypass (R-2552)
Johnston and Wake County, North Carolina

Drawn By:
MTC

Date:
March 2004

Chkd By:
APS

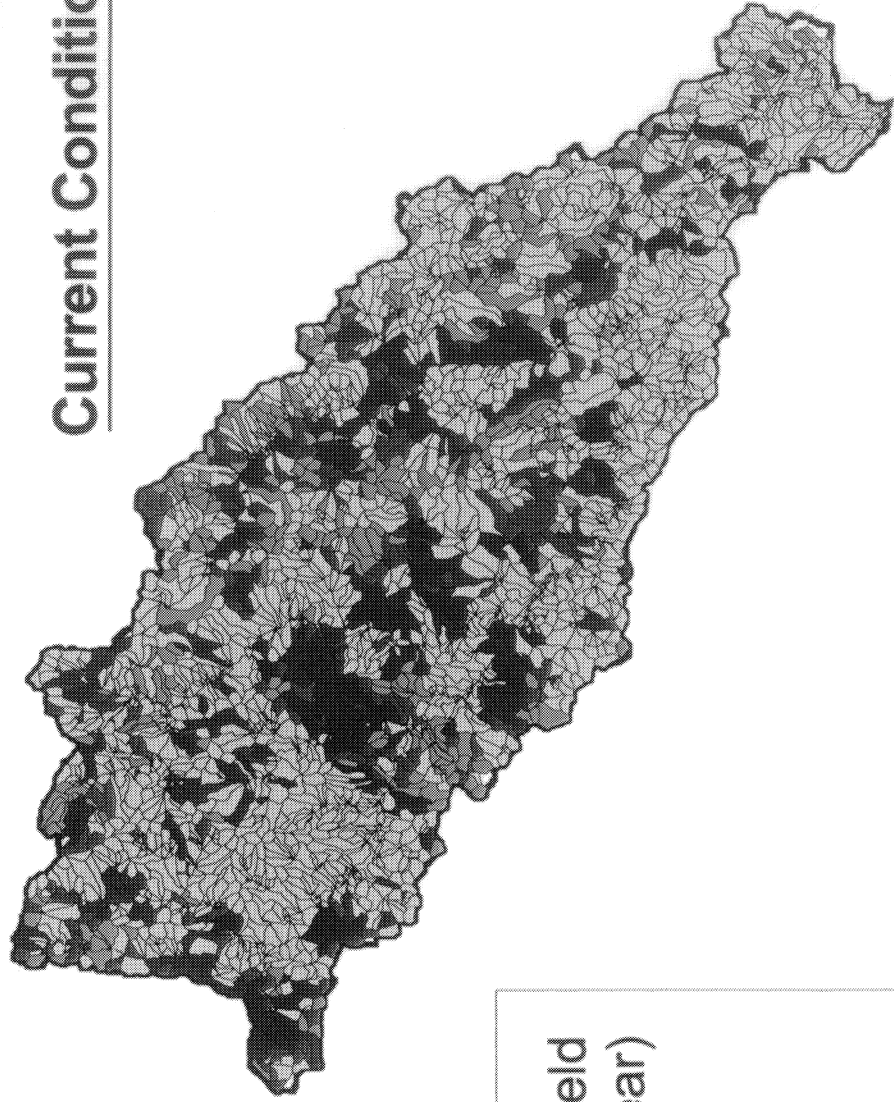
Project No:
02-113.40

SCALE:
Not Scaled

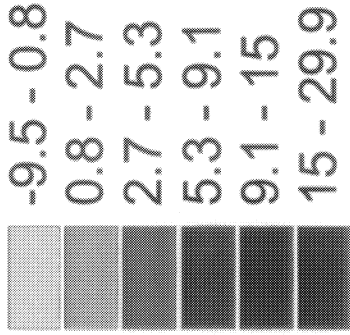
FIGURE

6C

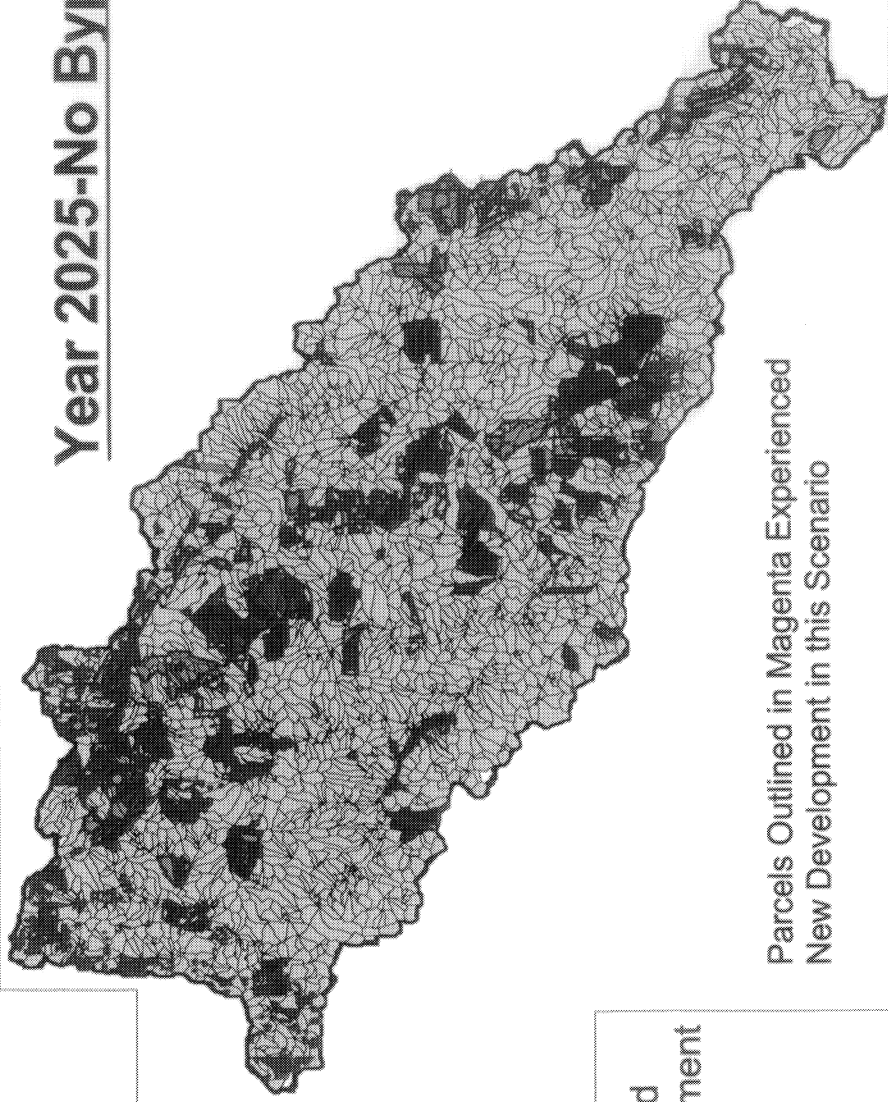
Current Condition



Total Nitrogen Yield
(Pounds/Acre/Year)

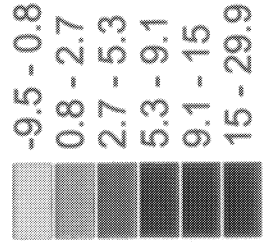


Year 2025-No Bypass

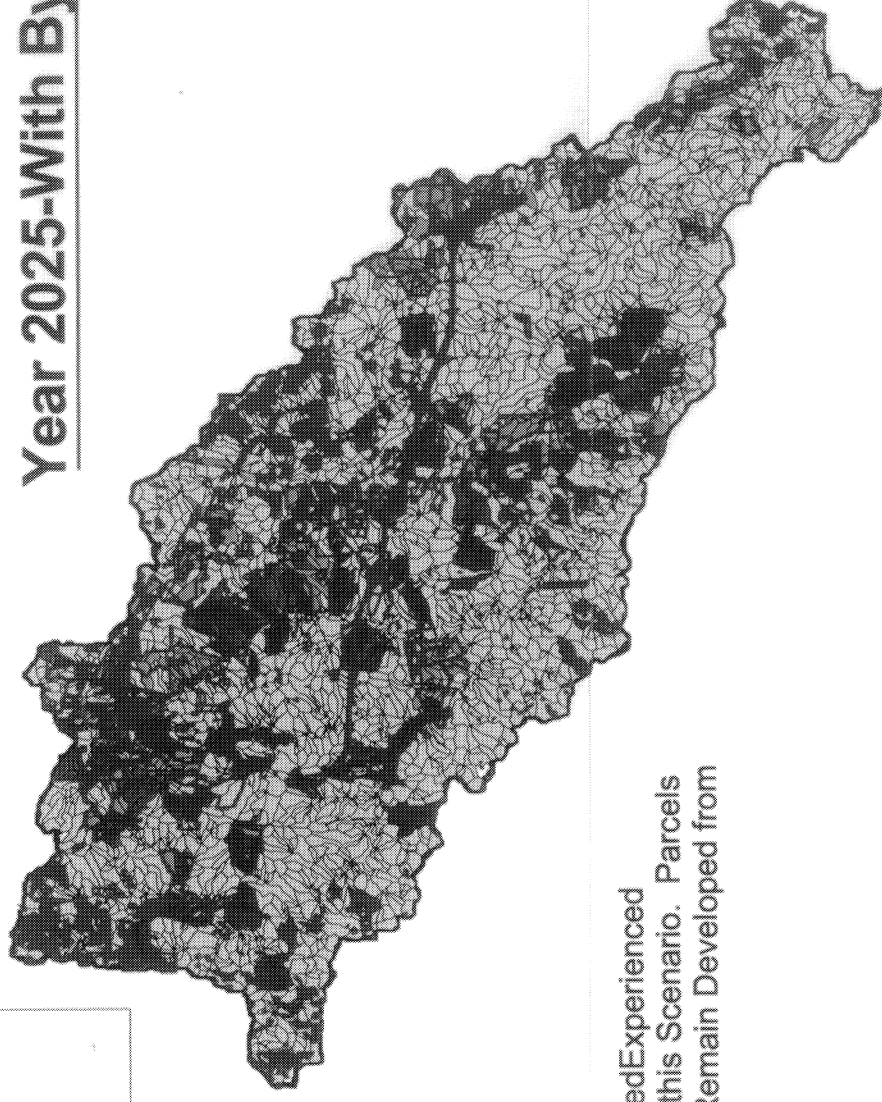


Parcels Outlined in Magenta Experienced
New Development in this Scenario

Change in Nitrogen Yield
Resulting from Development
(Pounds/Acre/Year)



Year 2025-With Bypass



Parcels Outlined in Red Experienced
New Development in this Scenario. Parcels
outlined in Magenta Remain Developed from
the Last Scenario



EcoScience

Change in Nitrogen Yield
Resulting from Development
for Three Modeled Scenarios

Nutrient and

Sediment Analyses

Clayton Bypass (R-2552)

Johnston and Wake County, North Carolina

Drawn By:

MTC

Date:

March 2004

Chkd By:

APS

Project No:

02-113.40

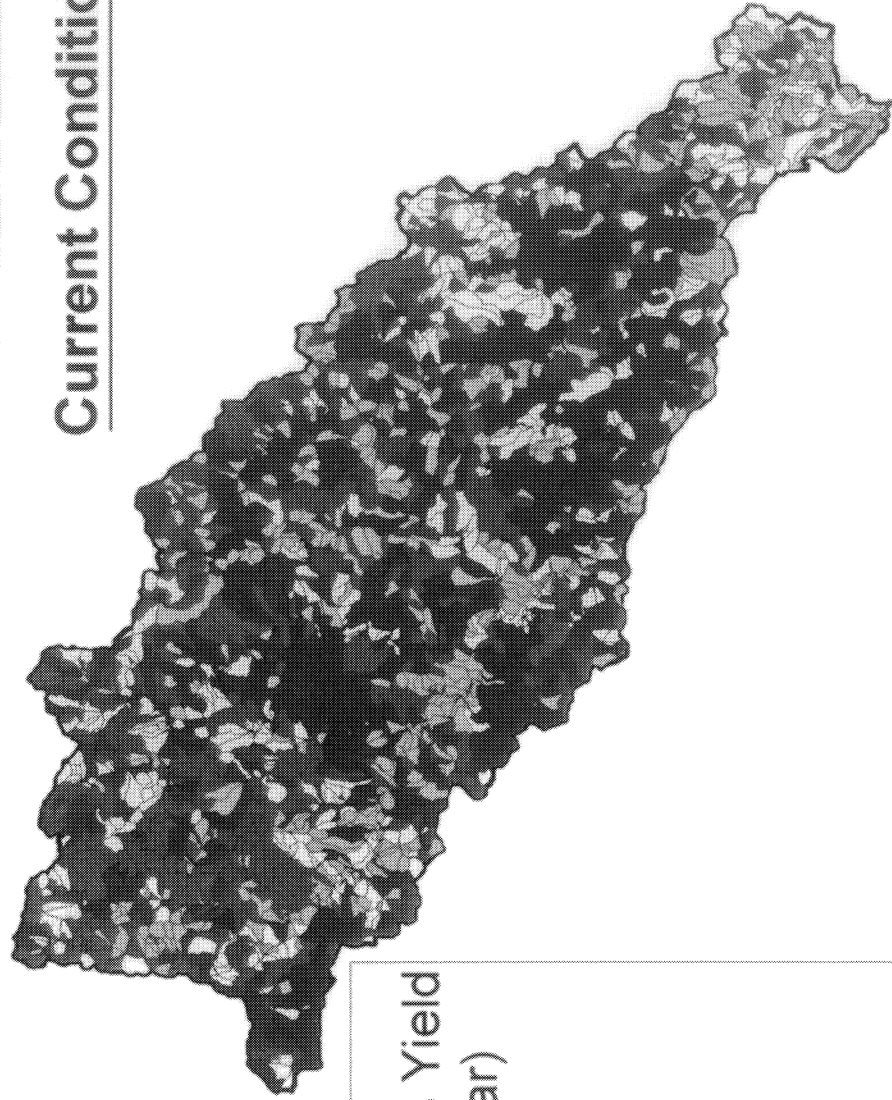
SCALE:

Not Scaled

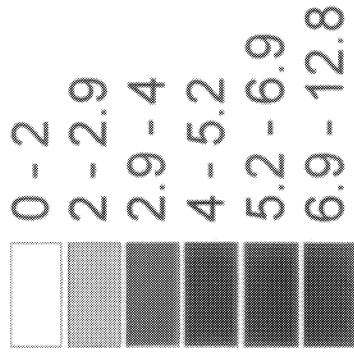
FIGURE

7A

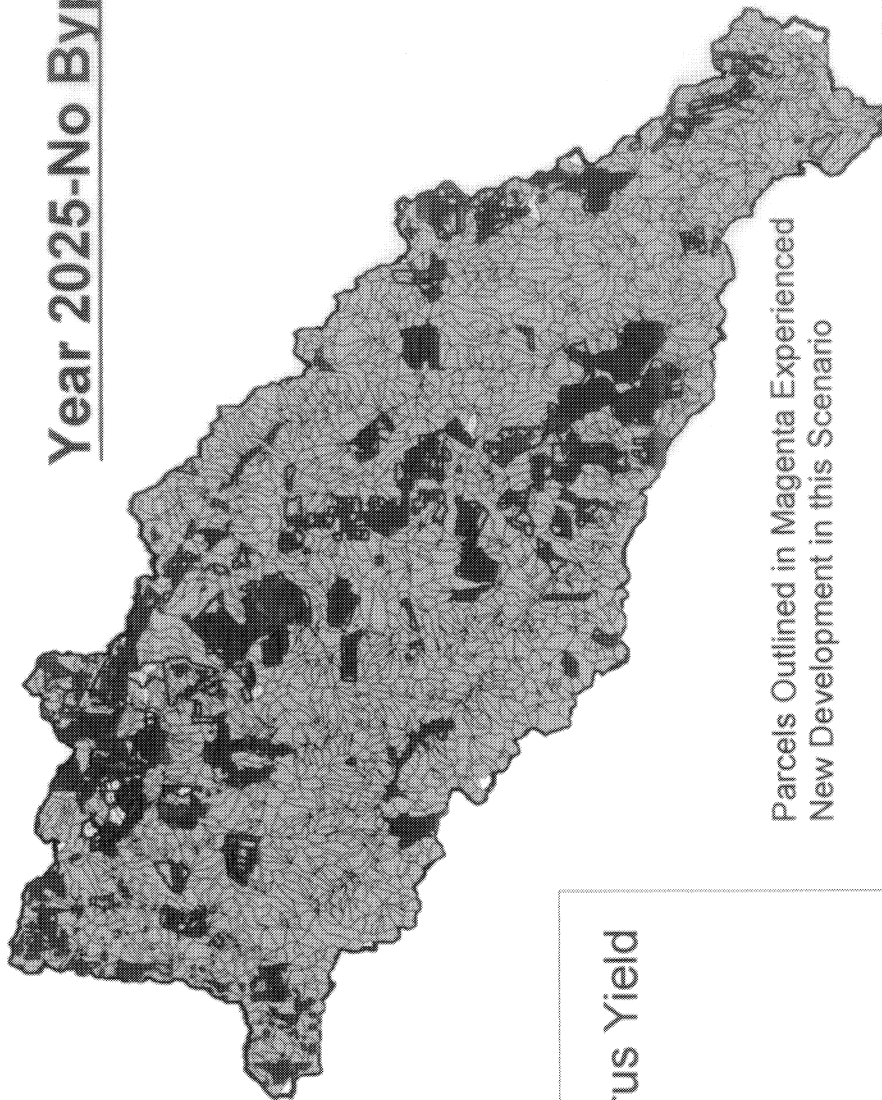
Current Condition



Total Phosphorus Yield
(Pounds/Acre/Year)

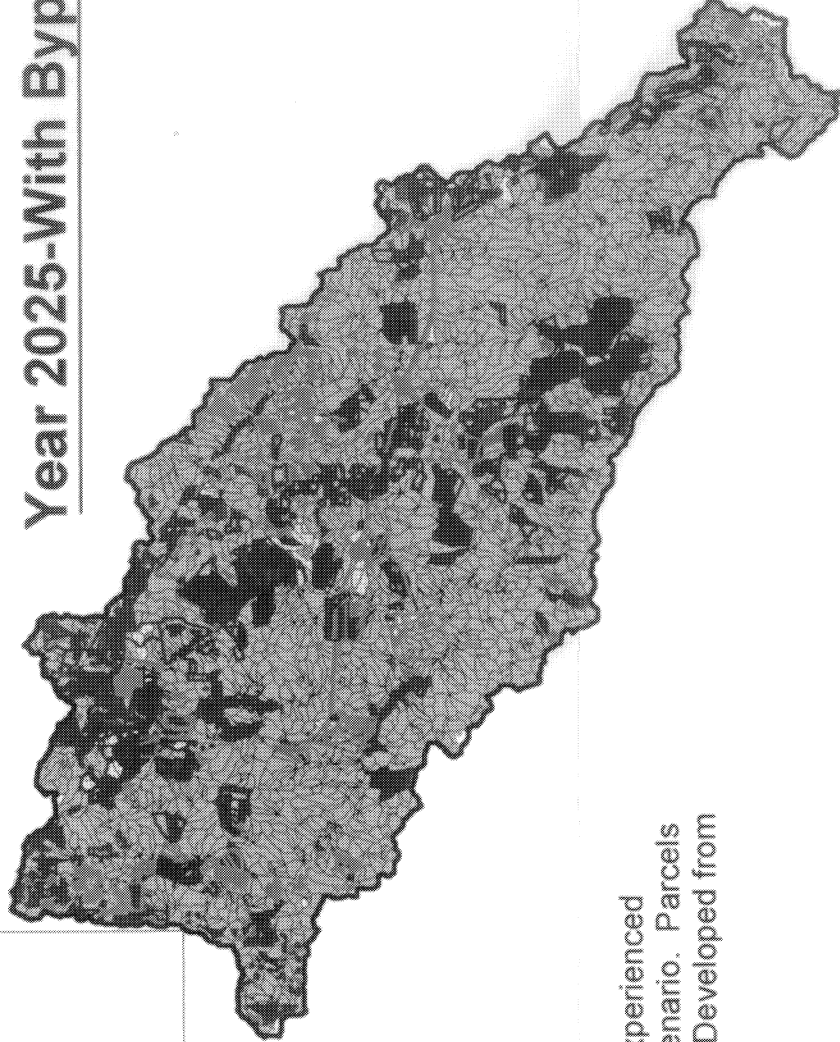


Year 2025-No Bypass



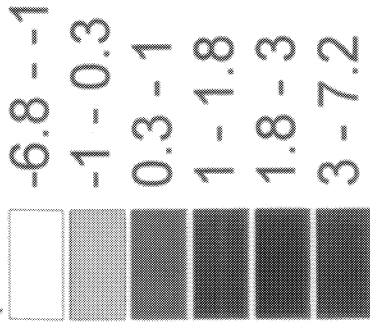
Parcels Outlined in Magenta Experienced
New Development in this Scenario

Year 2025-With Bypass



Parcels Outlined in Green Experienced
New Development in this Scenario. Parcels
outlined in Magenta Remain Developed from
the Last Scenario

Change in Phosphorus Yield
(Pounds/Acre/Year)



EcoScience

Change in Phosphorus Yield
Resulting from Development
for Three Modeled Scenarios

Nutrient and

Sediment Analyses

Clayton Bypass (R-2552)

Johnston and Wake County, North Carolina

Drawn By:

MTC

Date:

March 2004

Chkd By:

APS

Project No:

02-113.40

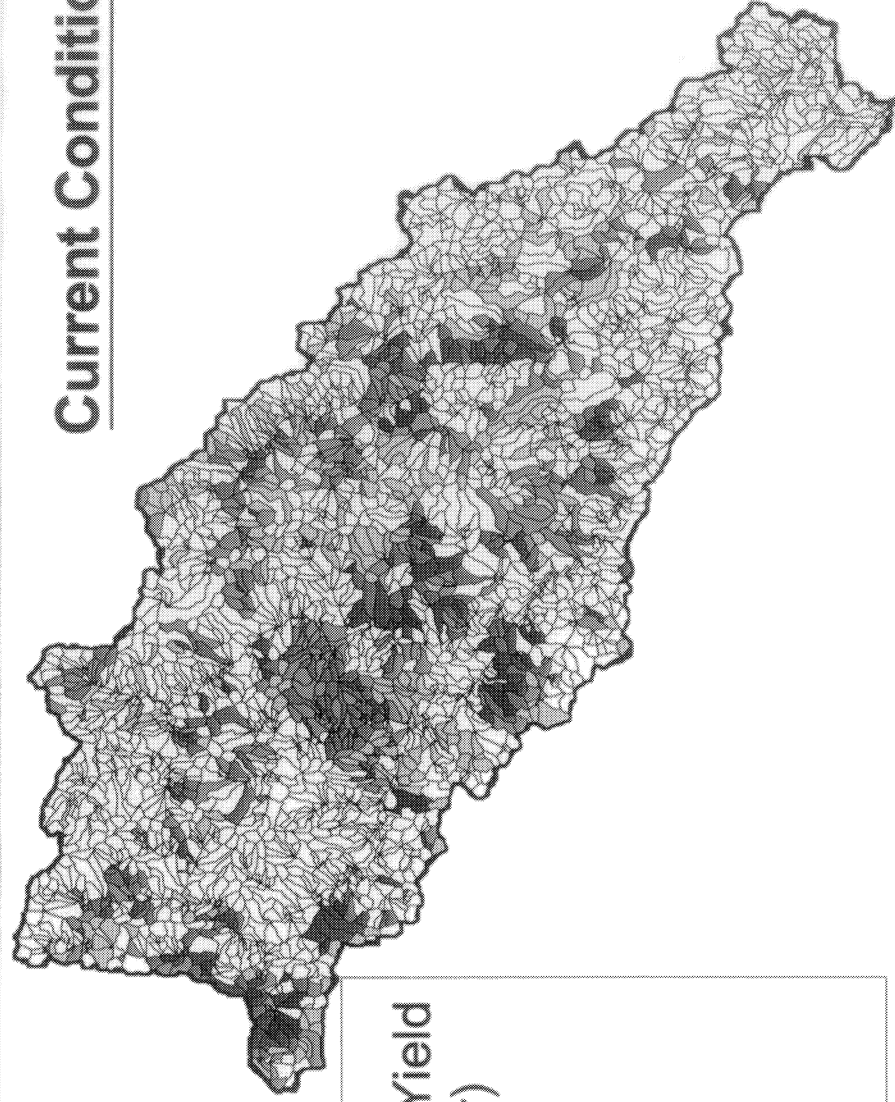
SCALE:

Not Scaled

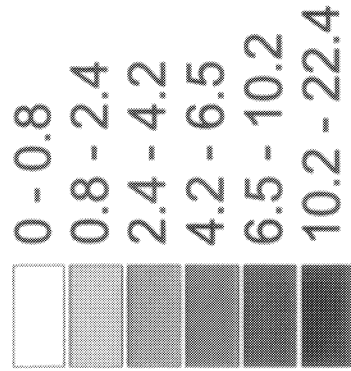
FIGURE

7B

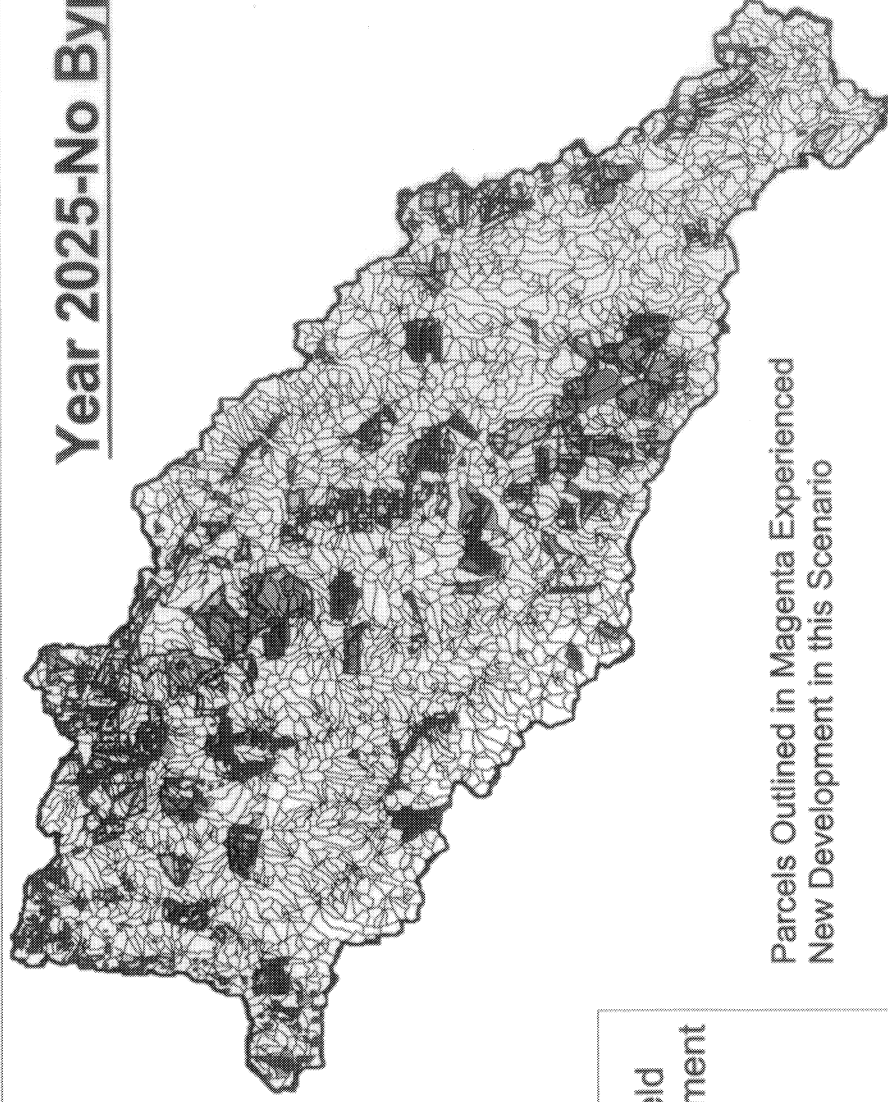
Current Condition



Total Sediment Yield
(Tons/Acre/Year)

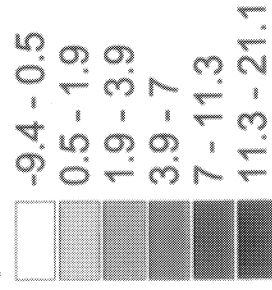


Year 2025-No Bypass

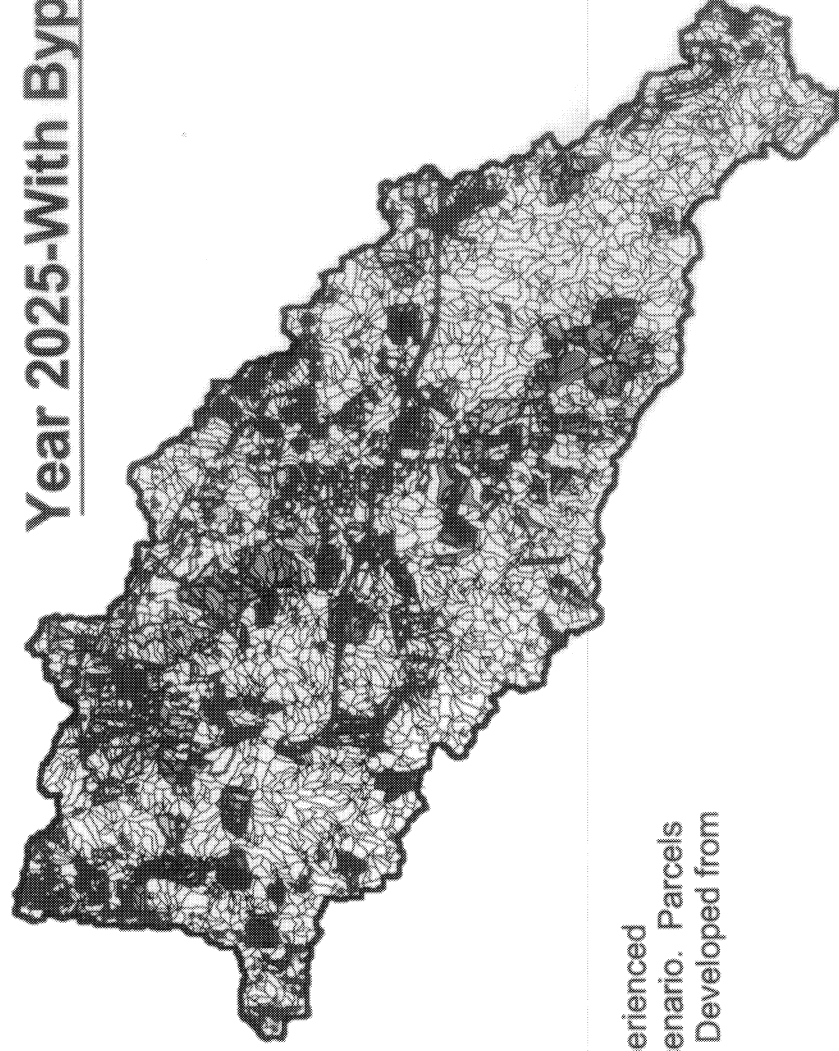


Parcels Outlined in Magenta Experienced
New Development in this Scenario

Change in Sediment Yield
Resulting from Development
(Pounds/Acre/Year)



Year 2025-With Bypass



Parcels Outlined in Red Experienced
New Development in this Scenario. Parcels
outlined in Magenta Remain Developed from
the Last Scenario



EcoScience

Change in Sediment Yield
Resulting from Development
for Three Modeled Scenarios
Nutrient and
Sediment Analyses
Clayton Bypass (R-2552)
Johnston and Wake County, North Carolina

Drawn By:
MTC

Date:
March 2004

Chkd By:
APS

Project No:
02-113.40

SCALE:
Not Scaled

FIGURE

7C